World Health Organization

Public health pesticide management

A course module

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Contents

Preface

This course was first developed in 2012 by the World Health Organization (WHO) in collaboration with the University of Cape Town (South Africa). The module was revised in 2015. The current version incorporates major revisions and updates of the course material.

The course module provides the students with the knowledge and skills for developing and implementing effective strategies to control disease vectors and domestic pests (e.g. integrated vector management), with emphasis on improved management of public health pesticides throughout their life cycle. Alternative methods and strategies for pest and vector control, their cost-effectiveness and their sustainability are discussed. Students will also examine the WHO strategies, policies and guidelines for using pesticides in public health.

Acknowledgements

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Dr Rajpal S. Yadav (WHO/NTD) reviewed and revised the document and, with Dr Raman Velayudhan (WHO/NTD), coordinated the production and formal publication of the course module.

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Abbreviations and acronyms

DALY	disability-adjusted life year
DDE	dichlorodiphenyldichloroethylene
DDT	dichlorodiphenyltrichloroethane
FAO	Food and Agriculture Organization of the United Nations
GVCR	Global Vector Control Response 2017–2030
IRS	indoor residual spraying
ITN	insecticide-treated net
kdr	knock-down resistance
LLIN	long-lasting insecticidal net
MDA	mass drug administration
NTD	neglected tropical disease
PBO	piperonyl butoxide
PPE	personal protective equipment
RDT	rapid diagnostic test
WHO	World Health Organization

Glossary

The definitions given below apply to the terms used in this manual. They may have other meanings in different contexts.

Adaptive management: systematic, iterative decision-making based on evidence for the efficacy of methods and strategies; decisions on efficient use of available resources (e.g. human, financial); and adaptation of decisions to prevailing conditions (e.g. ecological, insecticide susceptibility, epidemiological, socioeconomic).

Adulterated pesticide: a pesticide any component of which has been substituted wholly or in part, or any constituent of which has been wholly or in part abstracted, added or modified in quantity as compared with the regulatory specification on record.

Anthroponosis: a vector-borne infection that is carried predominantly in human hosts.

Behavioural resistance: adaptation of the behaviour of an insect population to avoid exposure to insecticides or insecticide-treated nets.

Capacity-building: development of essential physical infrastructure, financial resources and adequate human resources nationally and locally to manage integrated management strategies according to a situation analysis.

Communication for behavioural impact: a combination of information and education to achieve social mobilization; influenced by marketing principles used in the private sector to change consumer behaviour.

Control (of disease): reduction of disease incidence, prevalence, morbidity and/or mortality to a locally acceptable level as a result of deliberate efforts; continued interventions are required to maintain the reduction.

Counterfeit pesticide: a pesticide made by someone other than the manufacturer authorized or registered by a regulatory agency, such as by copying or imitating an original product without authority or right, with a view to deceive or defraud, and then marketing the copied or forged product as the original.

Dead-end host: a host that is not susceptible to infection, in which the disease agent cannot develop and reproduce.

Decision analysis model: used to assist risk managers and policy-makers in deciding on insecticide compounds for vector control; may involve several layers of decision-making and complex trade-offs when an insecticide reduces the risk of disease but increases the risk of adverse effects on human health and the environment.

Disability-adjusted life year (DALY): a measure of overall disease burden, expressed as the number of years lost due to ill health, disability or early death; introduced in the 1990s to compare overall health and life expectancy among countries; calculated for a disease or health condition as the sum of the years of life lost due to premature mortality in the population and the years lost due to disability resulting from the health condition or its consequences.

Ecosystem: a biological environment in which many species of organism live in an interrelated fashion.

Ectoparasite: a parasite that lives on the surface of a host and depends on that host to complete its life cycle (e.g. fleas).

Elimination (of disease): reduction of the incidence of clinical cases caused by a specific pathogen to zero or below a well-defined threshold as a public health problem (e.g. < 1 case/10 000 per year of visceral leishmaniasis) in a defined geographical area, with minimal risk of reintroduction, as a result of deliberate efforts (continued action to prevent re-establishment of pathogen transmission may be required).

Endophagy: tendency of insect vectors to blood-feed indoors.

Endophily: tendency of insect vectors to rest indoors; usually quantified as the proportion of insects resting indoors; used in assessing the effect of interventions, such as indoor residual spraying.

Enforcement: includes the investigation and legal actions necessary to ensure compliance with national pesticide regulations.

Entomological inoculation rate: rate of exposure of humans to infected vectors and thus of pathogen transmission; usually expressed as the number of infective bites received per person in 1 year; usually measured from the product of the abundance and the rate of infection of vectors.

Epidemiological assessment: analysis of a current disease situation and/or the burden it is causing, used by planners and risk managers in prioritizing allocation of resources to reduce disease risk.

Epidemiology: study of the distribution and determinants of health-related states or events in specified populations and application of the results to the control of health problems.

Eradication (of disease): permanent reduction to zero of the worldwide incidence of infection with a specific pathogen as a result of deliberate efforts, with no risk of reintroduction; intervention measures are no longer necessary once eradication has been achieved.

Evaluation: assessment of outcomes and impacts of a programme's interventions or activities, usually after a certain period.

Evidence-based decision-making: decision-making based on local surveillance data and on evidence for the effectiveness of interventions; implies that decisions are best made locally, in response to contextual information.

Exophagy: tendency of mosquitoes to blood-feed outdoors.

Exophily: tendency of mosquitoes to rest outdoors; usually quantified as the proportion of mosquitoes resting outdoors rather than indoors; used in estimating risk associated with outdoor transmission.

Fitness cost: implies that, when application of an insecticide is stopped, the resistant insect vectors are at a disadvantage and the susceptible ones will gradually take over ("revert") and dominate the population again.

Herd immunity: occurs when a large proportion of the community has become immune to infection with a virus, thus disrupting the propagation and spread of the disease it causes.

Importation risk: the risk that parasites are introduced into a country, for example by cross-border movement of people or by sea or air transport.

Incidence (of disease): the number of new cases of a disease within a given period, usually 1 year.

Indoor residual spraying (IRS): operational procedure and strategy for vector control involving spraying the interior surfaces of dwellings with a residual insecticide to kill or repel endophilic insect vectors (e.g. mosquitoes and sand flies).

Information, education and communication: intervention with a combination of mass media, group communication and interpersonal communication to change people's attitudes and behaviour.

Insecticide: a chemical product (natural or synthetic) that kills insects.

Insecticide resistance: property of insects to survive exposure to a standard dose of insecticide sometimes as a result of physiological or behavioural adaptation; a heritable characteristic that can circulate or spread in a vector population; development of resistance is inherent to the capacity of any species of living organism to adapt, or evolve, to changing circumstances.

Metabolic resistance: enhancement of particular enzyme systems in insects to accelerate degradation or metabolism of absorbed insecticides before they have a toxic effect on the insect.

Target-site resistance: resistance of insects to insecticides that are targeted to act at a specific receptor site in the insect's body, usually in the nervous system.

Insecticide-treated net (ITN): a mosquito net treated with an insecticide to repel, disable or kill insect vectors that come into contact with the netting while attempting to feed on human hosts or while resting on it after taking a blood meal.

Integrated vector management (IVM): a rational decision-making process to optimize use of resources for vector control, with the goal to improve the efficacy, cost-effectiveness, ecological soundness and sustainability of vector control and thus contribute significantly to the prevention and control of vector-borne diseases.

Judicious use of insecticides: sensible, well-informed insecticide application resulting from decisions about what, where, when and how to apply an insecticide.

Larval source management: management of water bodies or containers that are potential habitats of the immature stages of insect vectors (larvae and pupae) in order to kill them or prevent completion of their further development.

Larvicide: a substance used to kill mosquito larvae.

Malaria control: reduction of disease incidence, prevalence, morbidity or mortality to a locally acceptable level as a result of deliberate interventions, which may be required continually until elimination of the disease.

Mass drug administration (MDA): Distribution of medicines to the entire population of a given administrative setting (for instance, state, region, province, district, subdistrict or village), irrespective of the presence of symptoms or infection; however, exclusion criteria may apply. (In this document, the terms mass drug administration and preventive chemotherapy are used interchangeably).

Microhabitat: the smallest part of the environment that supports the development or reproduction of a vector.

Mixture: combination of two or more active ingredients in a single formulated insecticide product.

Monitoring: routine data collection and reporting to follow progress made in implementation of a programme or strategy.

Ovitrap: a device with a water-filled container in which females of *Aedes* or other mosquitoes can lay their eggs.

Pest: an organism that is considered to be injurious or unwanted to humans because it damages crops, affects domestic animals or invades people's domestic environment causing discomfort or disease.

Pesticide law: the core of pesticide legislation; issues in the law are regulated in further detail in pesticide regulations.

Pesticide legislation: laws or regulations introduced to regulate the manufacture, marketing, storage, labelling, packaging and use of pesticides with regard to quality, quantity and environmental effect.

Pesticide management: regulatory control, proper handling, supply, transport, storage, application and disposal of pesticides to minimize adverse environmental effects and human exposure.

Pesticide quality control: determination of the quantity of active ingredient(s), relevant impurities and other physical–chemical properties of an insecticide in suitable laboratory facilities.

Pesticide registration: authorization by a responsible national government authority of the sale and use of a pesticide after evaluation that comprehensive scientific data demonstrate that the product is effective for its intended purposes and does not pose an unacceptable risk to human or animal health or to the environment.

Pesticide regulatory control: process of pesticide registration, legislation and enforcement of legislation by a national authority.

Premises index (or **house index):** percentage of inspected premises found to have containers with larvae or pupae of *Aedes* species.

Prevalence (of disease): percentage of the population found to be infected or positive in tests for a disease at any one time.

Public health pesticides: collective term for all pesticides used in public health, which include vector control pesticides, household products (e.g. mosquito coils, foggers, aerosols, rodent pellets or baits, garden pest control products), pesticides applied directly to humans (e.g. for control of lice or scabies or as repellents) and professional pest management pesticide products (e.g. for fumigation).

Residual insecticide: insecticide that persists for several days to several weeks.

Rinsate: contaminated water generated after washing of spray equipment and pesticide containers.

Spray utility: recommended surface or area covered by a given amount of active ingredient. Public health pesticides are separated into those with low spray utility (i.e. high recommended dosage) and those with high spray utility (low recommended dosage).

Standard spray coverage: the surface covered by a given amount of insecticide, such as for a single application of IRS, assuming that operations comply with internationally recommended application rates; allows comparisons of insecticide active ingredients and types of intervention.

Stratification: a method of classification of disease-endemic areas, usually administrative units such as districts, by their epidemiological and ecological characteristics; used to guide allocation of resources.

Subsidiarity: an organizing principle that matters should be dealt with by the smallest, lowest or least centralized competent authority; hence, the central authority performs only those tasks that cannot be performed effectively at a more immediate or local level.

Substandard pesticide: a pesticide the physical or chemical properties of which do not meet the minimum quality standard.

Substitution principle: notion that if risks to the environment and human health can be reduced by replacing a chemical substance or product either by another substance or by some non-chemical technology, this should be done. A decision on any such substitution should be based on the best available evidence.

Total homestead environment approach: an approach that incorporates all possible ways in which people can be exposed to DDT in their sprayed home environment, comprising levels in the air and in indoor dust and also the outdoor environment.

Transmission (of disease): immediate transfer of a disease agent from a reservoir host to a susceptible host by a vector, by direct dermal or spread of droplets.

Unit of authority: one central authority with responsibility for regulatory control of all pesticides, including agricultural and public health pesticides, and their legislation.

Vector incrimination: determination of the role of a species as a vector of disease pathogens.

Vector susceptibility: the extent to which a mosquito population is susceptible (i.e. not resistant) to insecticides.

Vectorial capacity: a measure of the ability of a vector population to transmit a disease agent; defined as the expected number of infectious bites by all mosquitoes that bite a single person on a single day.

Vector: a living organism that can transmit a disease pathogen from one host to another, either between humans or from animals to humans (e.g. mosquitoes, sand flies, snails, triatomine bugs).

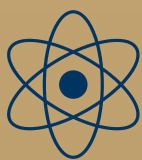
Zoonotic disease: a disease that affects animals (mammals, birds, reptiles) and is only occasionally or accidentally transmitted to humans by vectors.

Note: Each section of this course is preceded by a box of icons for studying the course materials

This icon indicates that there is a presentation recommended to be listened to or a video to be watched:

This icon indicates that there is a document or section recommended for reading:

This icon indicates where students should pause to consider the question:



This icon indicates that students are recommended to take a relevant online course:

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1

Basics of vector-borne disease control

Contents

Learning objectives

By the end of this section, students should be able to:

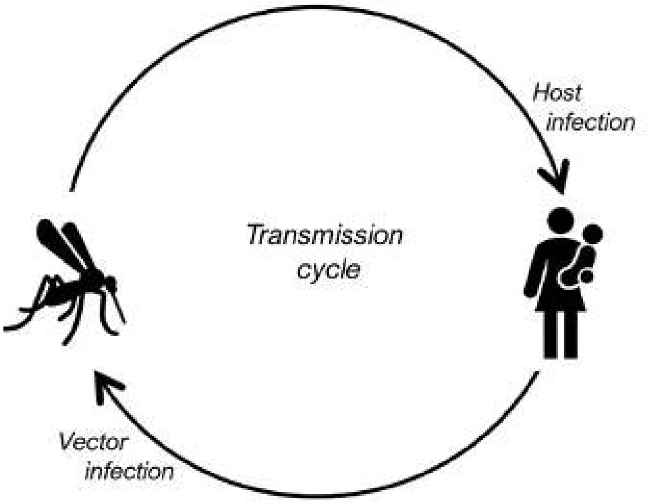
- describe the common vector-borne diseases and the burden of disease they cause;
- demonstrate understanding of the essential components of disease epidemiology and disease transmission cycles; and
- critically evaluate the role of disease control strategies and health systems, and identify those appropriate in their context.

1.1 The burden of vector-borne diseases

1.1.1 Vector-borne diseases

Vector-borne diseases are diseases that circulate between vertebrate hosts and vectors (Fig. 1.1). A vector is an organism that transmits the disease agent (pathogen or parasite) from one host to another. The pathogens or parasites that cause the diseases can be bacteria, viruses, fungi, protozoa or nematodes. Most pathogens undergo part of their development inside the vector organism, which may be an insect or snail, before they pass the pathogens on to the main host, such as reptiles, birds and mammals, including humans. Consequently, the vector plays a key role in the development cycle of the pathogen: without the vector, there is no vector-borne disease. Therefore, disease control programme managers must know which vectors are causing which diseases in their countries.

Fig. 1.1. Transmission cycle of pathogens that cause vector-borne diseases



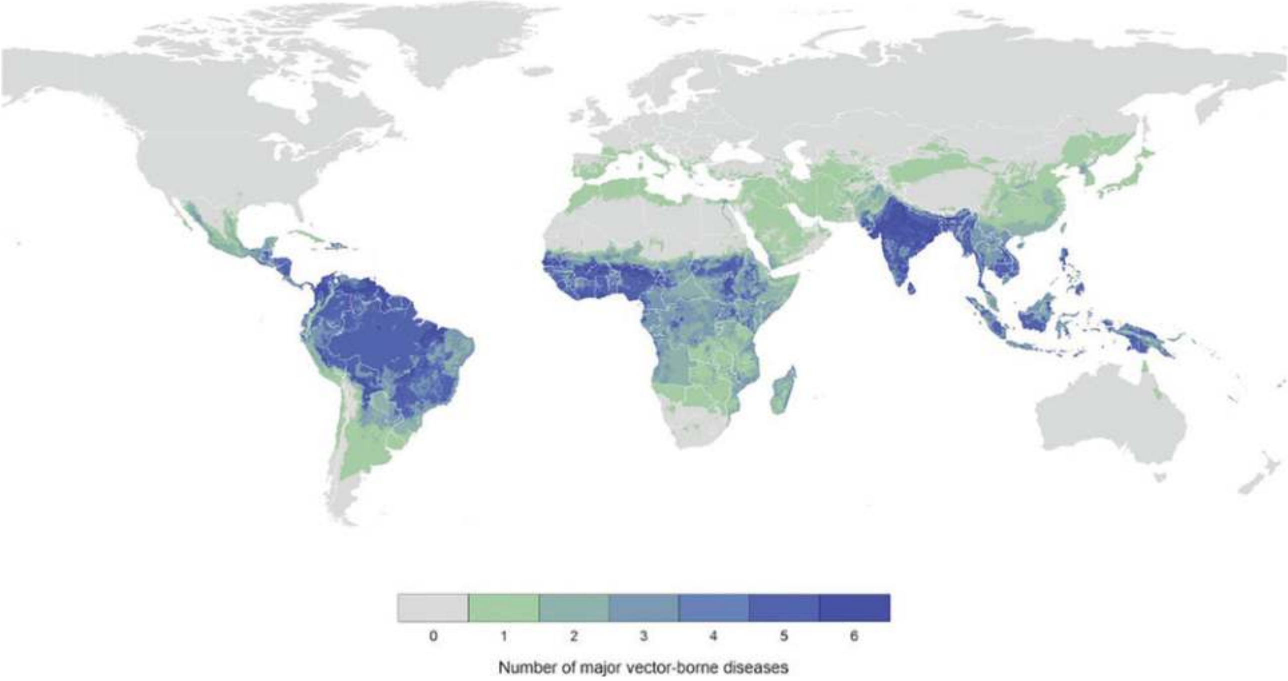
A number of pathogens of vector-borne diseases are specific to humans, and some pathogens share human and animal hosts. The major vector-borne diseases that affect humans in different countries, listed alphabetically, are:

- African trypanosomiasis
- arboviral diseases (dengue fever, chikungunya, Zika virus disease, Japanese encephalitis, yellow fever);
- Chagas disease;

— leishmaniases (visceral and cutaneous; and a third, less common form, mucocutaneous);
— lymphatic filariasis;
— malaria;
— onchocerciasis;
— schistosomiasis; and
— trachoma.

In many situations, several vector-borne diseases co-exist in the same environment, imposing a heavy burden on human populations, particularly in developing countries in tropical and subtropical zones. Fig. 1.2 shows that populations in large parts of western and eastern Africa, Latin America and South and South-East Asia are at risk of up to six major vector-borne diseases.

Fig. 1.2. Combined global distribution of seven major vector-borne diseases: malaria, lymphatic filariasis, leishmaniases, dengue, Japanese encephalitis, yellow fever, and Chagas disease



Source: Golding et al. *(1)*. Reproduced under the Creative Commons Attribution 4.0 International License (https://creativecommons.org/licenses/by/4.0/).

Colours indicate the number of vector-borne diseases that pose a risk.

1.1.2 Influence of poverty

Most, if not all, vector-borne diseases are associated with poverty. The poorest sections of society are subsistence farmers and those living in unplanned, unsafe urbanized environments, with very limited income and often little education. The poor are commonly exposed to one or more vector-borne diseases, and the relation between poverty and disease appears to be self-enforcing: disease leads to poverty because it costs money to seek treatment and causes loss of school days and workdays; in turn, the poverty that diseases bring creates conditions suitable for the transmission and prevalence of vector-borne disease. For example, poor housing and sanitation are favoured by vector mosquitoes and domestic pests, and lack of clean water for washing and hygiene also increases the risk of certain vector-borne diseases. This intimate relationship between vector-borne disease and poverty has been referred to as “the poverty trap” *(2)*.

Contemporary methods for the control of vector-borne diseases consist mainly of reducing human–vector contact and medication; the domestic conditions that favour disease transmission (e.g. housing, hygiene, safe water supply and storage) are rarely addressed in disease control programmes or by the relevant ministries. It should be noted that malaria disappeared from parts of Europe after improvement of living conditions, before the transmission cycle was known *(3)*.

Not all vector-borne diseases are associated with poverty. Some diseases, such as dengue and chikungunya fever, are common in urban environments and in the more affluent sectors of society, because the mosquito vectors of these diseases prefer to breed in human systems for water storage, such as containers, water tanks and cisterns and in plastic cups and bottles.

1.1.3 Types of disease burden

Vector-borne diseases are a major constraint to development, particularly in tropical and sub-tropical regions, where environmental conditions are suitable for the persistence of these diseases and their vectors. Vector-borne diseases not only cause human suffering due to illness and death but are also a leading cause of socioeconomic underdevelopment and poverty. They should therefore be a high priority in public policy and resource allocation from national budgets and donor assistance.

The heavy burden imposed by vector-borne diseases, particularly on poor and vulnerable groups, has recently become more widely recognized, and clear targets have been set for the control or elimination of diseases such as malaria, visceral leishmaniasis and lymphatic filariasis. An important basis for this increased recognition has been quantification of the disease burden. When progress can be measured, use of resources for disease control can be justified. Expression of the amount of suffering due to each vector-borne disease in quantifiable terms therefore provides justification for greater investment by countries, donors and funding agencies in strategies to reduce the disease burden. Measurement of the burden is also essential for ensuring political support for controlling vector-borne diseases.

1.1.4 Quantifying the burden

The type and amount of suffering, or burden, are different for each disease. Malaria causes severe morbidity and death, particularly among young children and pregnant women, and causes frequent illness in people due to repeated infections, even when they have acquired partial immunity. The worm parasites of lymphatic filariasis cause chronic morbidity. Thus, this disease does not kill but leaves patients with serious outgrowths of lymphoedema and hydrocoele throughout their lives, resulting in life-long physical disability and psychosocial and socioeconomic effects.

In order to provide a quantitative measure of the human burden of disease, the metric disability-adjusted life years (DALYs) was developed. The DALY expresses the sum of years of life and years of productive life potentially lost due to premature mortality. DALYs are calculated by taking the sum of years of life lost (YLL) plus years lived with a disability (YLD), as follows:

DALY = YLL + YLD

1 DALY = 1 year of healthy life lost.

One criticism of the DALY metric is that it is a "summary statistic" and thus obscures details and provides insufficient direction for prioritizing resource allocation for disease-specific control *(4)*. Moreover, for most diseases, it has been difficult to obtain reliable recent data, particularly from developing countries and from conflict zones, where the prevalence of vector-borne diseases is generally highest. For example, it has been difficult to attribute cause of death reliably to malaria, as other, unidentified health conditions might have caused or made a major contribution to the death. There is, however, no other universally applicable and acceptable measure of disease burden or consistent estimates of the burden in different geographical areas with different risk factors, that can be used to evaluate the impact of disease control programmes.

Despite the limitations of the DALY metric, much recent progress has been made in measuring it. Current estimates of the burden of vector-borne diseases (Table 1.1) clearly indicate the magnitude of the problem and have made a major contribution to mobilization of national and international resources to control or eliminate the diseases. The DALY is thus an important measure for decision-makers and managers for quantifying the disease burden in order to mitigate risk.

Table 1.1. Estimated global burden of vector-borne diseases

Disease	Annual no. of cases[a]	Annual no. of deaths	DALYs
Malaria	241 000 000	627 000	45 000 000
Dengue and chikungunya	112 000 000	40 000	NA
Leishmaniases	291 038	491	770 000
Chagas disease	6 500 000	10 000	NA
Schistosomiasis	236 000 000	24 000	2 500 000
Lymphatic filariasis	51 400 000	NA	1 600 000
Onchocerciasis	21 000 000	NA	1 300 000
Human African trypanosomiasis	1116	NA	NA

Sources: WHO *(5, 6)*, Kyu *(7)*.

DALYs: disability-adjusted life years; NA: not available.

[a] For lymphatic filariasis: people infected; for onchocerciasis: number of cases; for schistosomiasis: population who required mass drug administration.

Vector-borne diseases not only cause direct human suffering but also pose an economic burden. Poor health or disability results in reduced productivity, such as reduced agricultural output or profits, and absenteeism from school. In Kenya, primary school students were reported to miss 11% of school days per year because of malaria *(8)*. Moreover, poor health of family members affects the unpaid work and productivity of women as family caregivers. The economic impact of disease is difficult to quantify, and only a few detailed studies have been conducted. The available data indicate, however, that vector-borne diseases have a substantial economic impact, particularly when the seasonal peak in disease, typically during the rainy season, coincides with the peak in agricultural activities, such as planting or harvesting.

An analysis of the impact of malaria showed that countries with more cases of malaria generally had lower rates of economic growth. The growth of income per capita during the period 1965–1990 was only 0.4% per year for countries in which a high proportion of the population lived in regions of *Plasmodium falciparum* malaria transmission, whereas malaria-free countries had an average growth of 2.3% – five times higher *(9)*. Limited information is available on the economic impact of other vector-borne diseases. Dengue causes an economic burden of approximately US$ 30 million in India alone, mainly due to costs in the private health sector. Dengue is more prevalent globally in some years than in others. The cost of lost productivity due to lymphatic filariasis globally is an estimated US$ 1.3 billion, although this disease is gradually being eliminated in countries. Similarly, trachoma, a disease that causes blindness, results in an estimated loss in productivity of US$ 2.9 billion annually *(10)*.

Reports of the economic impact of a disease will encourage donors and governments to invest in prevention and control, which will reduce the cost of health care and the cost to the welfare system due to loss of work and will increase productivity and result in better schooling.

1.1.5 Cost of interventions

The cost of an intervention should be evaluated in terms of the amount of the burden averted by the intervention, as a measure of cost-effectiveness. For some diseases, such as those caused by nematode worms, effective drugs are available at very low cost, resulting in a high cost–effectiveness ratio, while the cost of some other interventions or combinations of interventions is considerably higher. The ultimate criterion for implementing an intervention should be whether the cost is justified by the reduced burden and the gain in health. Often, however, reliable, up-to-date data on the burden of a disease are not available and, too often, decisions are made without adequate evidence of their cost-effectiveness. The evidence for making decisions should be strengthened.

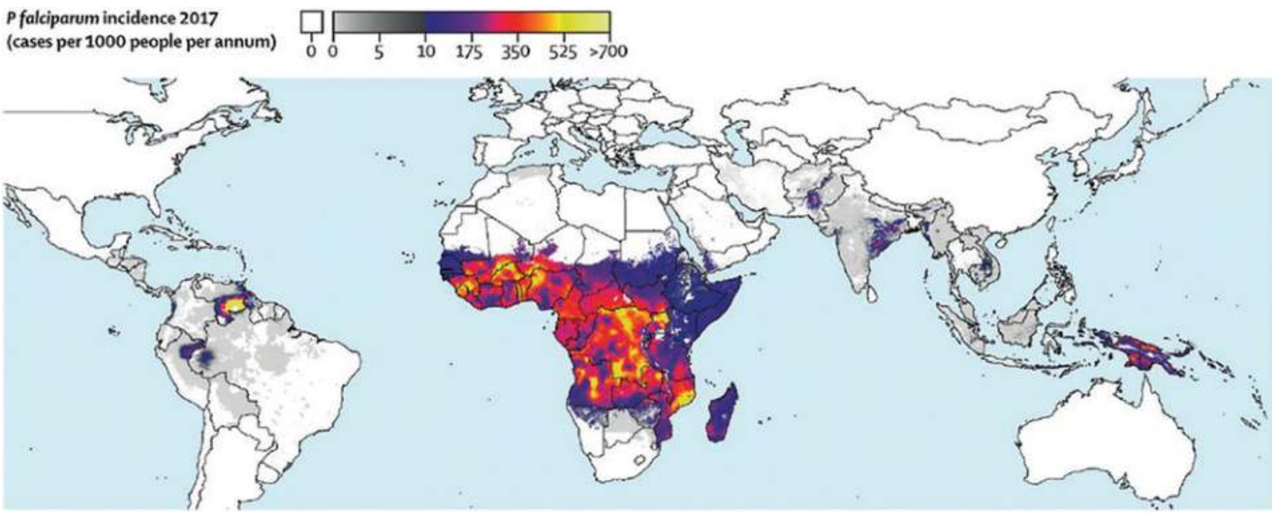
The cost-effectiveness of interventions is generally much lower for treatment than for prevention. Medical treatment is restricted to people with diagnosed illness who have presented themselves to a health worker (also for preventive medication), while preventive interventions such as vector control are used to cover entire communities at risk to prevent them from becoming ill. As prevention is always better than treatment of disease, risk managers should be able to explain succinctly why a preventive intervention is necessary, such as in a policy brief for policy-makers and government finance officials. Prevention is better than treatment not only for individuals but also for communities, as a person who becomes ill can infect other people close to them. When disease is prevented in one person, it is also prevented in others.

1.1.6 Brief descriptions of diseases

Below, each major vector-borne disease is described briefly. The geographical distribution of the diseases has been reported *(11)*. Their transmission cycles are discussed in section 1.3.

Malaria is caused by protozoans of the genus *Plasmodium*. Humans are affected by five species: *P. falciparum*, *P. vivax*, *P. ovale*, *P. malariae* and *P. knowlesi*. *P. falciparum* is found worldwide in tropical and sub-tropical areas and causes more deaths than any other *Plasmodium* species (Fig. 1.3). The other species can cause serious morbidity locally and are sometimes fatal.

Fig. 1.3. Spatial distribution of the incidence of malaria due to *Plasmodium falciparum*, 2017



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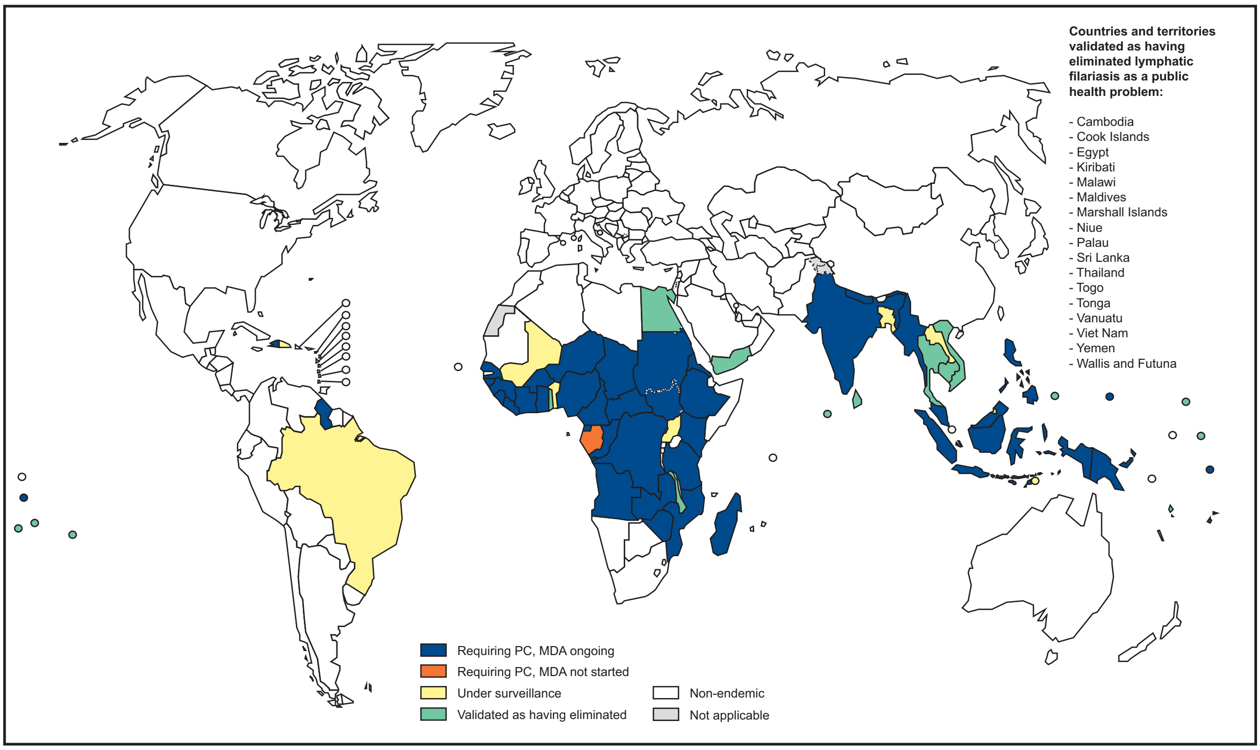
Plasmodia are transmitted by *Anopheles* mosquitoes. Part of the development phase of plasmodia, the so-called asexual phase, takes place inside the human host, while the other, the sexual phase, occurs only inside the mosquito vector, during which sporozoites are produced. The sporozoites migrate to the salivary glands of the mosquito, from where they can be transmitted with saliva through a mosquito bite to infect the human host. Preventing contact of humans with infectious mosquitoes helps interrupt transmission of the parasite.

The burden of malaria is much higher than that of other vector-borne diseases because it is widespread, causes high rates of infant mortality and frequently affects large numbers of people, thus reducing workforce output and productivity. Malaria is entirely preventable and curable with the use of effective interventions and treatment.

Lymphatic filariasis is caused by the parasitic nematodes *Wuchereria bancrofti*, *Brugia malayi* and *B. timori*, which are transmitted to humans by mosquitoes. After malaria, it is the vector-borne disease responsible for the highest human burden, because it causes life-long morbidity. Inside the human host, the nematodes move through the bloodstream to the lymph vessels and produce huge numbers of larvae, called microfilariae. The worms cause swelling of body parts and the development of scar tissue. About 120 million people are infected globally, and an estimated 40 million have advanced clinical manifestations, including approximately 15 million with stigmatizing, disabling clinical manifestations in the form of lymphoedema ("elephantiasis") and 25 million men with urogenital swelling, mainly scrotal hydrocoele *(13)*. Transmission of microfilariae can be interrupted by delivery of medicines to entire populations at risk, through an intervention known as mass drug administration (MDA) (Fig. 1.4).

Fig. 1.4. Distribution of lymphatic filariasis and status of mass drug administration in endemic countries, 2021

Distribution of lymphatic filariasis and status of mass drug administration, 2021



The boundaries and names shown and the designations used on this map do not imply the expression of any opinion whatsoever on the part of the World Health Organization concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. Dotted lines on maps represent approximate border lines for which there may not yet be full agreement.

Data Source: World Health Organization
Map Production: Control of Neglected Tropical Diseases (NTD)
World Health Organization

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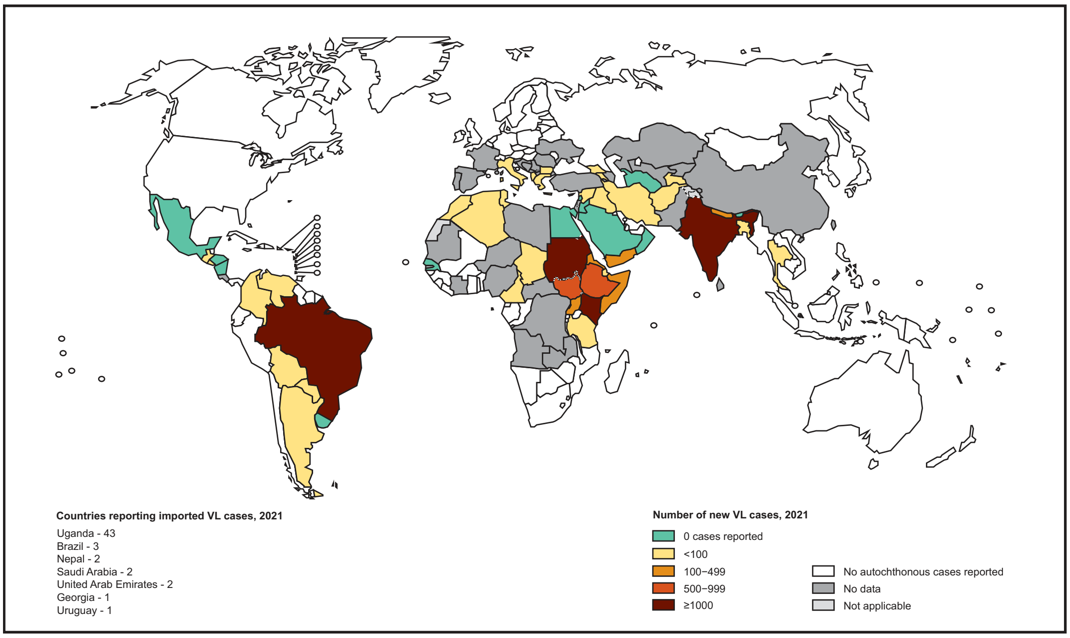
Leishmaniases are caused by protozoan parasites of the genus *Leishmania* and are distributed throughout Africa, South America, Asia and southern Europe. Two main clinical manifestations are seen: visceral leishmaniasis and cutaneous leishmaniasis (Figs 1.5 and 1.6). A third, less common form, mucocutaneous leishmaniasis, occurs in South America. Leishmaniases have been largely neglected in the past but appear to be of much greater public health importance than previously assumed. The *Leishmania* parasites occur in animal species, and humans are considered to be only accidental hosts. *Leishmania* parasites are transmitted by sand flies, which are small blood-feeding insects associated with dry environments, which feed predominantly on wild animals, particularly rodents. Human infection is due to about 21 of the 30 sand fly species that infect mammals. Some forms of the disease are difficult to treat, while others heal spontaneously, providing lifelong protection. Other forms can result in severe mutilation. Prevention of transmission is therefore essential.

Fig. 1.5. Endemicity of visceral leishmaniasis worldwide, 2021

Status of endemicity of visceral leishmaniasis worldwide, 2021

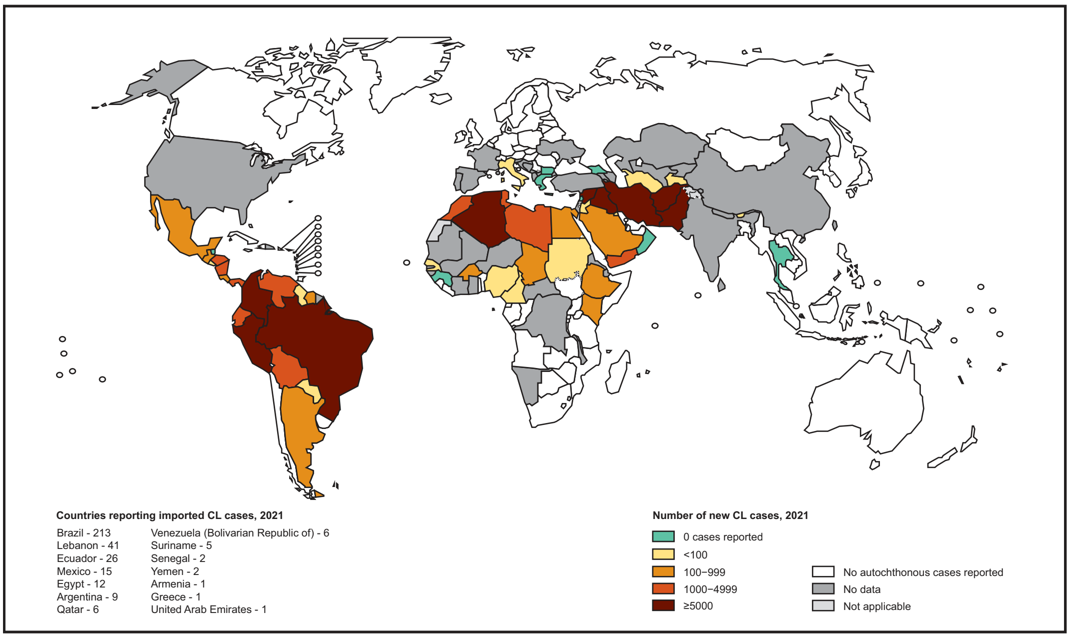


Data Source: World Health Organization
Map Production: Control of Neglected Tropical Diseases (NTD)
World Health Organization

World Health Organization

Fig. 1.6. Endemicity of cutaneous leishmaniasis worldwide, 2021

Status of endemicity of cutaneous leishmaniasis worldwide, 2021



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Map Production: Control of Neglected Tropical Diseases (NTD)
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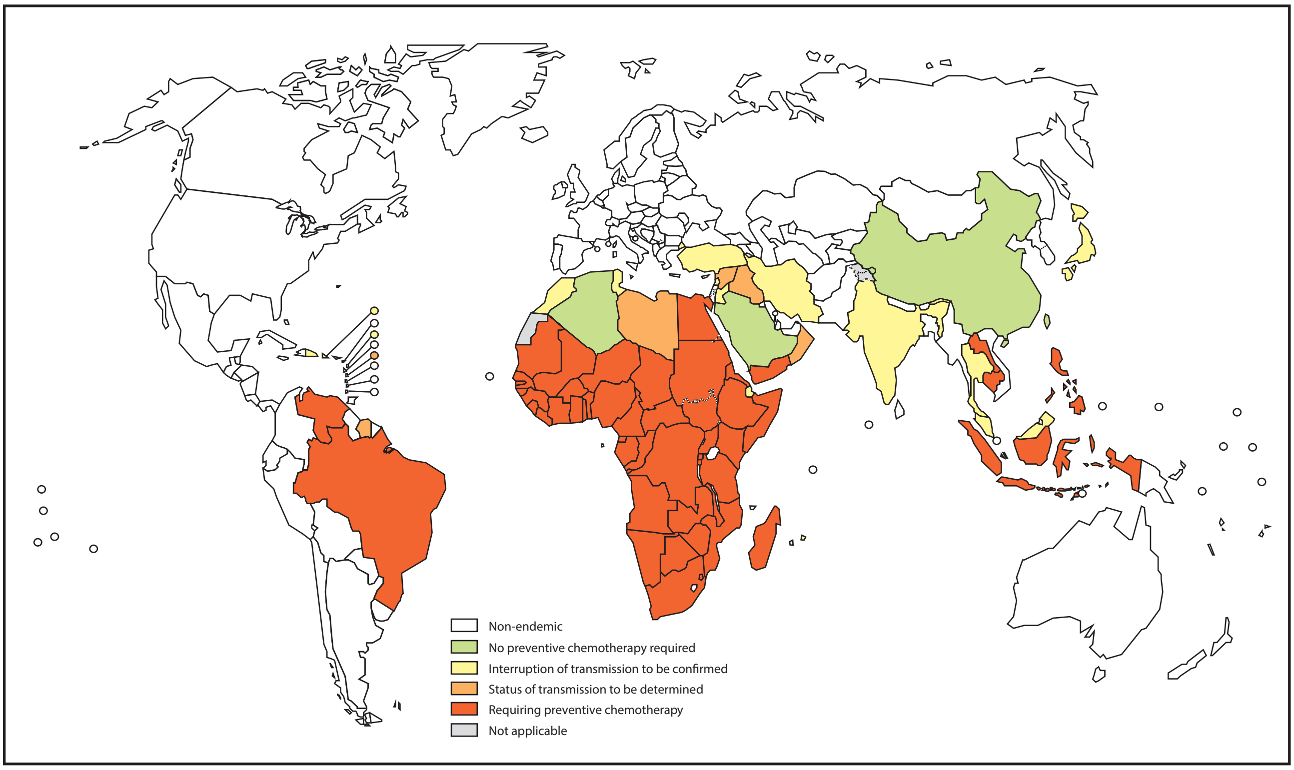
Schistosomiasis, also known as bilharzia, is a widely distributed vector-borne disease caused by small nematode parasites, or schistosomes (Fig. 1.7). Unlike other vector-borne diseases, which are caused by direct transmission of parasites from biting insects to humans, the schistosomes pass through a snail, which acts as an "intermediate host" and releases a small free-swimming stage called "cercaria" into the water. The cercariae penetrate the skin of people in contact with infected water, for example when bathing or standing in water to wash clothes or play. Schoolchildren who play in infected water are at particular risk. After infection, the parasite migrates to the intestines or kidneys, where it produces millions of eggs, which are released with the urine or faeces. Upon contact with water, the eggs emerge and the schistosomes infect the intermediate snail hosts. Schistosomiasis does not cause mortality but causes chronic morbidity. The drug praziquantel is effective against the disease and is widely used in control programmes.

Fig. 1.7. Endemicity of schistosomiasis, 2021

Status of schistosomiasis endemic countries, 2021



Data Source: World Health Organization
Map Production: Control of Neglected Tropical Diseases (NTD)
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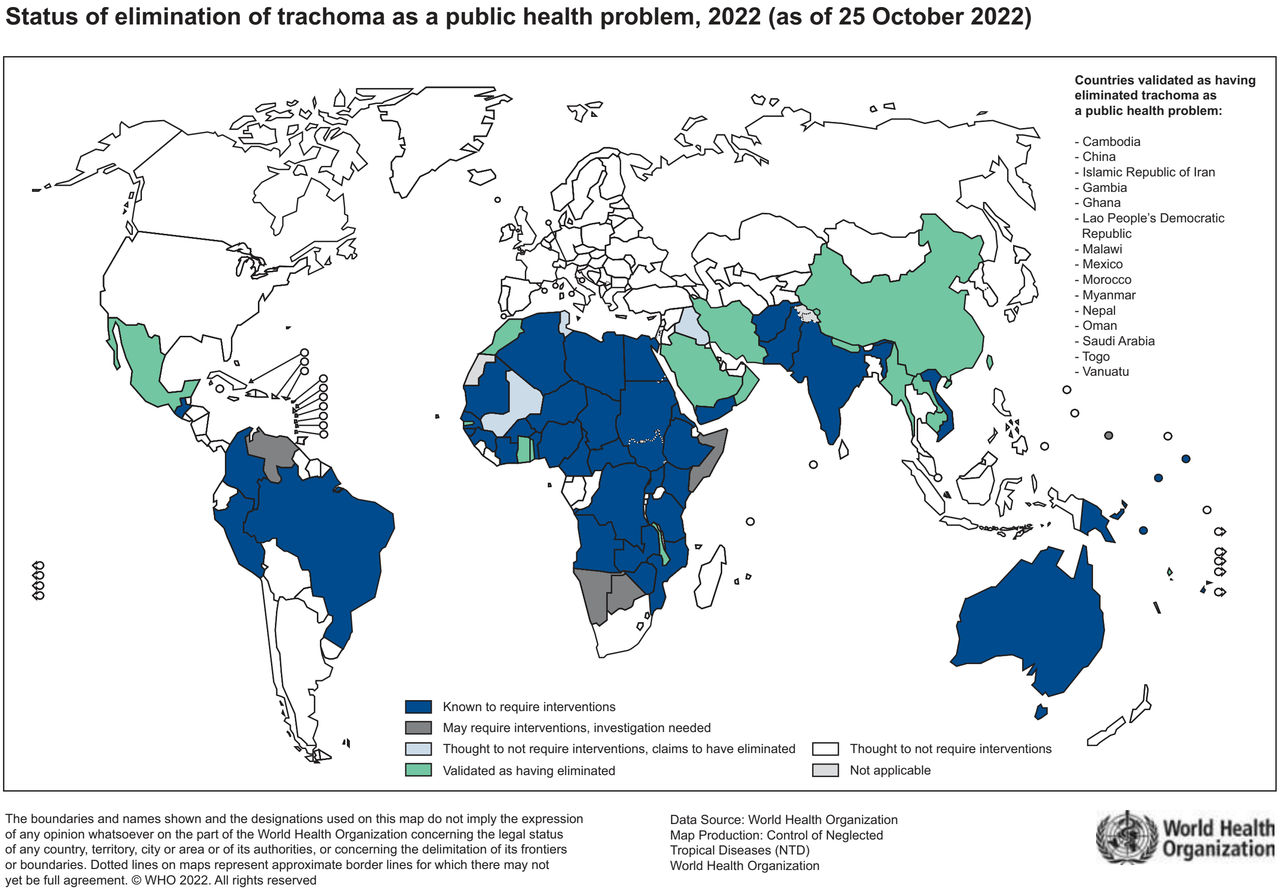
Human African trypanosomiasis, "sleeping sickness", is caused by protozoan parasites of the genus *Trypanosoma*. The parasites develop in tsetse flies, *Glossina* spp., and the infectious parasite stages are transmitted during biting of human hosts in the saliva of the flies. The parasites reproduce in the human host, causing severe illness with episodes of high fever. If left untreated, patients lose consciousness and eventually die. The current number of cases is estimated at 50 000–70 000. Although this is lower than the number due to other vector-borne diseases, the severity of illness has a large local socioeconomic impact *(14)*. The parasites are passed by tsetse flies to domestic and wild animals. The flies can be effectively controlled through the use of odour-baited traps.

Trachoma is an ocular disease caused by bacteria that are transmitted mechanically on the feet of filth flies to the human eye. Infection is facilitated by rubbing an eye with deposited bacteria. Antibiotics are an effective treatment. Trachoma is endemic mainly in Africa and the Middle East but also in parts of Latin America, Asia and the Pacific *(15)* (Fig. 1.8). Personal hygiene and fly control are important components of the disease control strategy: SAFE *(16,17)*.

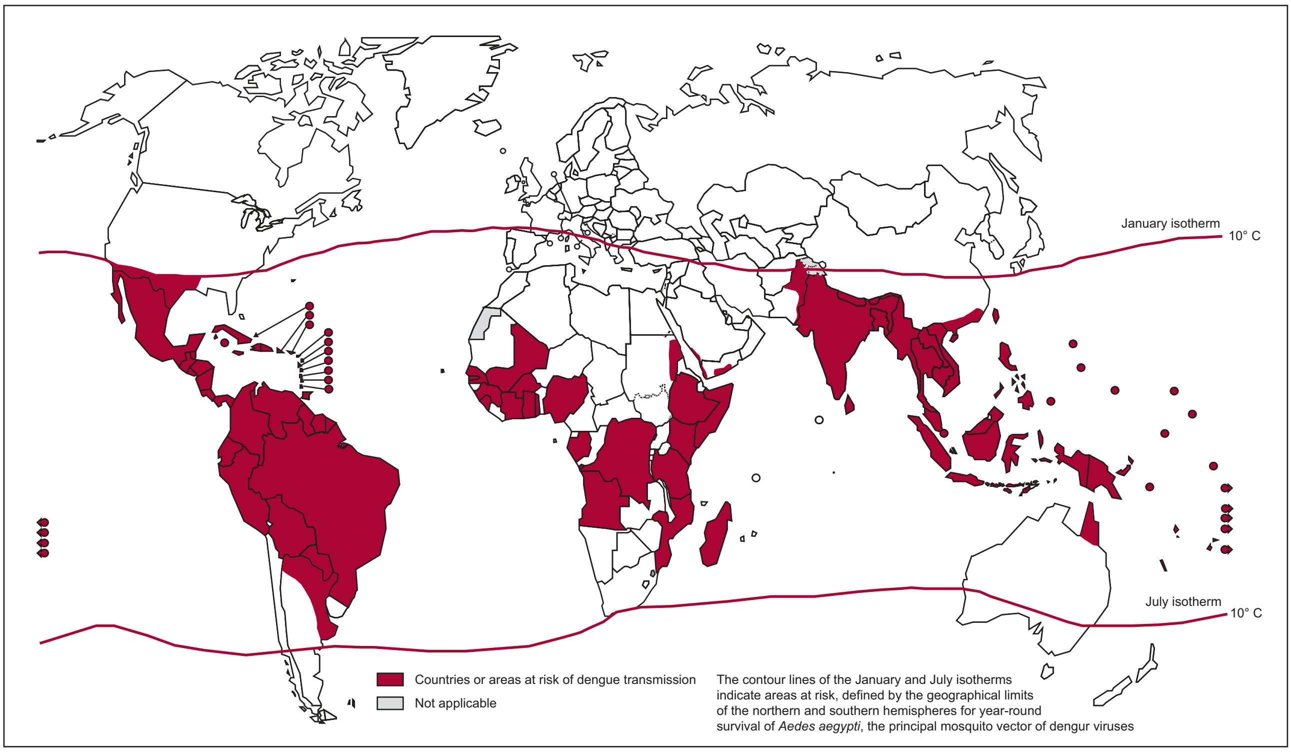
Fig. 1.8. Status of elimination of trachoma as a public health problem, 2022



Dengue and **chikungunya** are emerging vector-borne diseases with an expanding geographical range (Fig. 1.9). Dengue is caused by a complex of four arboviruses and is transmitted by *Ae. aegypti* mosquitoes; in many areas, however, *Ae. albopictus* is also responsible for transmission. The virus affects only humans and not animals. Infection with one type of arbovirus is not life-threatening, but, when a patient is subsequently infected by another type, severe disease with occasional fatality may follow, resulting in "severe dengue". As there are no effective drugs or vaccines against dengue, chikungunya or Zika virus, disease control depends mainly on reducing human–vector contact and management of cases for optimal recovery. The vector breeds in small water-filled containers, such as coconut husks, gutters, cups and old tyres, and is associated with urban and peri-urban environments. Rain fills the containers, creating aquatic breeding sites for the mosquito larvae and pupae. The vector also breeds in water reservoirs, indoors and outdoors. The breeding ecology of this vector is therefore quite different from that of most species of malaria vector.

Fig. 1.9. Distribution of countries and areas at risk of dengue transmission, 2012

Distribution of countries or areas at risk of dengue transmission, worldwide, 2012



The boundaries and names shown and the designations used on this map do not imply the expression of any opinion whatsoever on the part of the World Health Organization concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. Dotted lines on maps represent approximate border lines for which there may not yet be full agreement.

Data Source: World Health Organization
Map Production: Control of Neglected Tropical Diseases (NTD)
World Health Organization

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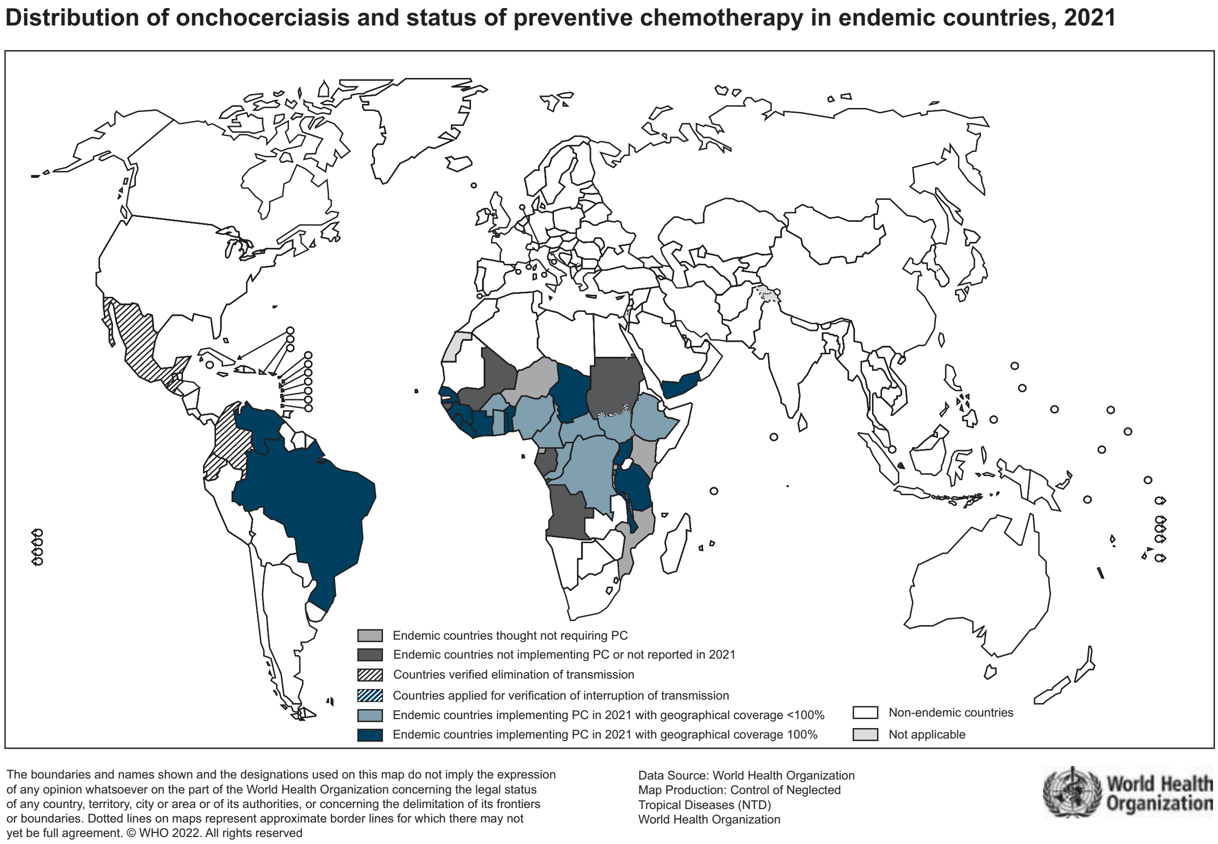
Chagas disease is a complex, life-threatening disease endemic in South America that is caused by the protozoan parasite *Trypanosoma cruzi*. The parasites are transmitted by triatomid bugs, which commonly live inside houses. Chagas disease has been controlled mainly by spraying the indoor walls and ceilings of houses with residual insecticides.

Onchocerciasis, "river blindness", is caused by the nematode *Onchocerca volvulus*. The worms are transmitted between human hosts by blackflies *(Simulium* spp.), and the disease is associated with fast-flowing streams, where the vectors breed. The global distribution of onchocerciasis is presented in Fig. 1.10. The blackflies deposit their egg masses on aquatic plants, and their larval and pupal stages live in clusters. The emerging adult flies feed on human blood. The nematodes cause skin irritation, and migrating stages damage eye tissue, causing blindness. Onchocerciasis is controlled by administration of ivermectin drugs to entire populations at risk and by larviciding vector breeding habitats.

Fig. 1.10. Distribution of onchocerciasis and status of preventive chemotherapy in endemic countries, 2021



1.2 Basics of disease epidemiology

1.2.1 General concepts

Epidemiology is the study of how often diseases occur in certain groups of people and why. It addresses the causes, effects, patterns and distribution of disease in human populations.

Vector-borne diseases have three components: the parasite or pathogen, the vector, and the host. In addition to interactions between parasite and host, a vector is necessary to transmit the parasite between hosts; without a vector, the parasite species cannot thrive. A common misunderstanding is that vectors transmit disease. This is incorrect. Vectors only transmit pathogens or disease agents, which subsequently cause infection by invading host tissue, leading to disease. Not all transmitted pathogens, however, cause disease in a host, because only some of the pathogens survive or escape the body's defence system. The efficiency of transmission differs considerably for different diseases, malaria transmission being much more efficient (a few transmitted parasites can cause disease) than that of lymphatic filariasis (many parasites have to be transmitted before they cause the disease in the human host). Hosts become infectious when the pathogens they carry are transmitted by vectors to other hosts.

The vectors of most vector-borne diseases are blood-sucking insects, such as ticks and other organisms that depend for their reproduction on ingestion of blood from human or animal hosts. A vector must take at least two separate blood meals to be able to transmit a disease agent from one host to another. The first blood meal is necessary for the vector to become infected (i.e. receive the pathogen or parasite) and the second to become infective and transmit the disease agents. Transmission can occur only with sufficient time between the first and second blood meal, because it takes time for the vector to become infective (literally: to become sick from the pathogen) and transmit the pathogen to the human host.

Some vectors do not have direct contact with the human host but are so-called "intermediate hosts". This is the role of freshwater snails in transmission of schistosomiasis. Strictly speaking, these are not vectors, because they do not themselves deliver the pathogens to the human host. Nevertheless, schistosomiasis is considered to be a vector-borne disease.

Other vectors contribute to mechanical transmission of disease pathogens, such as flies that transmit the agent that causes trachoma. Mechanical transmission consists of a simple "hand-over" of a pathogen, for example from a fly to a human. Hence, parasite stages do not develop inside the body of the vector, and the fly can immediately transfer the pathogen it has picked up.

1.2.2 Prevalence and incidence

Terms often used in disease epidemiology are the prevalence and the incidence of disease. The two must be distinguished, as their correct use is important in risk management. The "prevalence" of disease is the percentage of the population that has been found to be infected or to have a disease at a specific time. This could be established for example by taking finger-prick samples from the human population in a targeted area to assess the prevalence of malaria at a certain time. Some people with parasites may have been infected some time previously, whereas others may have acquired the disease more recently. All cases represent the average prevalence rate at that time. For example, if a survey is conducted in a sample of 10 000 people and 100 of those in the sample have malaria parasites, the prevalence is 1%.

The "incidence" of disease is the number of new cases of the disease within a given time, usually 1 year. For example, during the past year, 50 cases of malaria were recorded in a population of 1000 people, resulting in an incidence rate of 5% per year. The incidence rate is most easily measured by counting all the people who attended a health facility and were found to have the disease. The numbers of cases are recorded and reported to provide an indication of the incidence rate. A problem with this measure is that not all people with a disease report to a health facility, as some consult traditional healers or do not seek medical care. Underreporting of cases of disease results in underestimation of the incidence rate.

Explain the difference between prevalence and incidence in your own words.

A disease is said to be "endemic" in a population or area when it is always present or it reappears during specific transmission seasons each year. In endemic areas, people may have acquired immunity or partial immunity to the disease. An "epidemic" is occasional occurrence of large numbers of cases, usually in areas where people have no immunity or have lost their (partial) immunity and have thus become vulnerable to infection.

1.2.3 The vector

The "vector" is the carrier of a disease agent from host to host. A vector must live long enough for the disease agent to develop and/or reproduce inside it. For example, the females of many species of *Anopheles* mosquito do not live long enough for the malaria parasite to infect, develop and reproduce inside their bodies. In such cases, the mosquito cannot be a vector of the pathogen. Only female mosquitoes take blood meals, because the blood is required for their egg development; male mosquitoes do not take blood meals and do not contribute to pathogen transmission. Female mosquitoes go through several cycles of blood-feeding and egg laying. Once infected by a malaria parasite, they remain infected throughout their lifespan. The females of only some mosquito species live long enough, and these are the most effective and dangerous vectors of malaria. Consequently, when the age of female mosquitoes is reduced, for example by extremely hot weather or by premature death due to contact with insecticides, malaria parasites can no longer be transmitted, and the prevalence of disease is suppressed. Vector biology, ecology and control are discussed in detail in section 2.

Consider this: Why do malaria mosquitoes become more dangerous as they get older?

1.2.4 Mechanical transmission

Some diseases, like blindness due to trachoma and gastrointestinal diseases, are transmitted mechanically, usually by filth flies or house flies. The disease agents stick to the mouthparts or legs of the flies and are transported from host to host. Unlike in most other vector-borne diseases, the disease agent does not develop or reproduce within the fly and is thus not "amplified" in the fly vector. Hence, mechanical vectors are not essential to the development of the agent or pathogen. Mechanical transmission can be sustained only when there are many vectors in frequent contact with the host.

Bedbugs, cockroaches, scabies and lice are examples of other insects that can transmit disease pathogens mechanically.

1.2.5 Partial immunity

An important factor in the epidemiology of most diseases is that the hosts may acquire immunity or partial immunity against the pathogens. In "partial immunity", the host is still susceptible to infection but the disease symptoms are mild or absent. A person with partial immunity to the agent of malaria, for instance, may have no symptoms, but the agent can still develop and reproduce and still be able to infect others. Such a case is known as "asymptomatic" (no symptoms). Hosts that do not show symptoms are usually not detected or treated, but they contribute to the reservoir of the disease agent and are a source of infection.

A host that is completely immune to the disease agent does not support development or reproduction of the agent and will therefore not become infectious or contribute to transmission to other hosts. Partial or complete immunity may last a few months (in the case of malaria), a few years (in the case of dengue) or longer. Risk managers should be aware of the immune status of a human population, as this is critical to defining the risk and pattern of epidemics and of newly emerging diseases in the area. Where people lack immunity, an epidemic can cause severe suffering.

1.2.6 Vulnerable groups

Not all sections of society are equally vulnerable to infection and morbidity. Some diseases may begin mildly but become more severe as an infected person ages, as in the case of some diseases caused by worm parasites, notably lymphatic filariasis. Other diseases, like malaria and gastrointestinal diseases (e.g. diarrhoea), are a particular risk for children, either because they are most vulnerable or because their habits put them at high risk of contamination or infection. In areas in which malaria is highly endemic, young children are at particular risk of attacks of severe malaria because they have had no or only a few previous attacks and they have not yet developed partial immunity against the malaria parasite. Pregnant women are also particularly affected by malaria infection because they lose their acquired immunity against malaria and become vulnerable to certain complications and risks to their unborn child. Visitors from malaria-free areas are vulnerable to malaria when they enter an endemic area. Moreover, people with diseases such as HIV/AIDS that reduce their immune response are more vulnerable to diseases such as malaria.

Not only does the vulnerability of different sections of society to diseases differ, but mosquito vectors of disease do not blood-feed equally and have a preference for feeding on certain people, who experience more nuisance from mosquito bites than others. The differential biting behaviour of vector mosquitoes can result in efficient transmission of disease pathogens. Certain ethnic groups and groups that are isolated or impoverished may be more vulnerable than others to vector-borne diseases. The reasons may include the proximity of their houses to the breeding environment of disease vectors, such as contaminated water bodies, irrigated agricultural lands and forested habitats. Impoverished and malnourished groups may be less resilient to infection, resulting in increased morbidity. When isolated groups have little or no access to medical services, an infection could remain untreated for much longer than for people who live closer to a town or health facility.

Risk managers should identify the most vulnerable sections and groups of society in terms of transmission of the pathogens of each disease and in terms of their access to diagnostic and curative health services. These groups should be the primary targets for disease control interventions and prevention.

1.2.7 Climatic and geographical factors

The geographical distribution, seasonality and transmission intensity of vector-borne diseases depend on a number of environmental factors. The transmission of most insect-transmitted diseases peaks during the rainy season, when the conditions for breeding and survival are optimal and when human contact with the vectors or with contaminated water is highest. Conversely, fly-transmitted diseases, like trachoma and gastrointestinal diseases, may be a particular problem in the dry season when there may be insufficient water for personal hygiene.

Vector density depends on the presence of suitable breeding habitats. People who live close to such habitats, such as a river or irrigation scheme, are generally at higher risk of infection than those living further away. Most species of mosquito vector generally thrive best at lower altitude, whereas people who live higher, with a lower ambient temperature, may be infected less frequently. Temperature is critical for development of disease inside the vector and for its survival. The parasites and vectors thrive only within a certain range of temperature. For example, malaria parasites can develop inside mosquitoes only in sufficiently warm environments and will not survive when the temperature becomes too high.

1.2.8 Climatic and environmental changes

Global climate change is seen as a potential threat to human health because of changes in local temperature, humidity, rainfall and wind, which can render local environments suitable to new disease vectors and disease pathogens. Environments may also become unsuitable for vector-borne diseases, for example when temperatures are extremely high or water bodies dry out. Any change in the severity or distribution of a disease like malaria may result in an epidemic, because people in areas with no history of the disease have no immunity to it and are readily affected. Vector-borne diseases that are considered to be particularly sensitive to climate change, in alphabetical order, are dengue, lymphatic filariasis, malaria and schistosomiasis. The direct effects of warming may promote dengue transmission and reduce the suitability of regions of Africa for malaria, thus shifting the burden from malaria to dengue *(18)*.

There has been considerable debate among scientists about whether global climate change will increase the burden of vector-borne diseases at global scale *(19,20)*. It is generally considered that higher global temperatures will increase mosquito populations and increase the rate at which mosquitoes bite humans. Despite the rising temperatures experienced in the past century, however, the prevalence of malaria has actually decreased, due mainly to control interventions, the effects of which by far outweigh those of global climate change *(21)*.

The effects of other environmental changes on the severity and distribution of vector-borne diseases should not be underestimated. In particular, local urbanization, land degradation, intensification of agriculture, deforestation and globalization can influence the conditions of breeding and transmission of disease vectors and pathogens. Hence, an increase in malaria incidence locally may be thought to be caused by climate change but may actually be associated with changes made by humans to their local environment.

Modelled projections for the risk of dengue fever in Europe indicate that it will increase with increasing climate change, particularly in the coastal areas of the Mediterranean and Adriatic seas *(22,23)*.

1.2.9 Socioeconomic status and educational level

Human behaviour, attitudes and socioeconomic status are highly relevant to the risk of contracting a vector-borne disease. Housing conditions are critical to the risk, as poor housing generally attracts vectors for entry, resting and blood-feeding. Improved houses have fewer entry points and fewer crevices in the walls and ceilings for mosquitoes or triatomine bugs to hide. Breeding of vectors is favoured, for example, by the proximity of livestock, the presence of water containers and poor water drainage and sanitation facilities.

A higher educational level is usually associated with more appropriate human behaviour with regard to personal protection, risk reduction and seeking treatment. A higher educational level can thus reduce the incidence of disease.

Consider this: When socioeconomic status increases, the incidence of vector-borne diseases generally decreases. Explain why this is so.

1.2.10 People’s movements

The movement of people is also critical to the spread of vector-borne diseases. People living in the hills but working in a valley could import a disease from the valley into their home environment. Migrant workers may not show disease symptoms but can be carriers of disease agents and could thus introduce disease pathogens into new areas where people lack immunity. Identification of the vulnerable sections of society and of people’s movements is essential for planning disease control. Movement of people may also introduce bedbugs, scabies and lice into new areas.

1.2.11 Epidemiological study

The three means for acquiring information on the incidence or prevalence of a disease in a population are:

- from records at point-of-care health facilities (e.g. registry books in clinics and hospitals);
- by studying a population to collect data on prevalence or incidence (moderately expensive); or
- continuous demographic surveillance, covering every individual in the entire population of a certain study area (very costly).

Statistical records have some critical shortcomings, because clinics and hospitals record the numbers of cases that have been reported; however, not all cases are reported to health-care institutions. Many deaths due to malaria occur at home *(24)* and are not registered, and the causes of many deaths are not identified to determine whether the death was caused by a vector-borne disease.

Surveillance of disease helps to identify the geographical areas and times or seasons at which the disease risk is highest for effective, efficient planning of vector-borne disease control programmes. Surveillance is also required to evaluate whether programmes have reduced the disease prevalence below that at baseline.

1.3 Disease transmission cycles

1.3.1 Reservoir

In all vector-borne diseases, the pathogens or disease agents pass from the host via the vector to another host. This cycle keeps the disease circulating within the host population, unless the transmission cycle can somehow be interrupted. Understanding the transmission cycle is therefore essential for designing an effective disease control strategy.

The host population is generally the reservoir of the disease pathogen or parasite. Some pathogens can exist only in a human reservoir, while others can thrive in either a human reservoir or an animal host (including mammals and birds), which may complicate interruption of transmission. Some pathogens can persist within a human host for long periods, even when there are no vectors or new infections. Eventually, however, interruption of transmission will lead to gradual disappearance of the pathogen in the host population. This process can take some time. In order to accelerate it, infected or asymptomatic hosts can sometimes be treated with effective drugs to remove the parasite reservoir.

1.3.2 Anthroponosis and zoonosis

"Anthroponosis" is a vector-borne infection that is carried predominantly in human hosts. Malaria and dengue are anthroponotic diseases that affect only humans and have no animal hosts (although one type of malaria parasite, *Plasmodium knowlesi*, is found in both primates and humans). These diseases are most efficiently transmitted in places where the vectors have a strong preference for feeding on humans, not on animals, and where vector breeding sites are close to human domestic habitats.

A "zoonosis" is a disease that affects animals (mammals, birds, reptiles) and is only occasionally or accidentally transmitted to humans. Leishmaniases and trypanosomiasis could be considered zoonotic in the sense that they occur in animals and only accidentally in humans. In some areas, however, leishmaniasis is transmitted from human to human. Zoonotic diseases are difficult to contain because the parasite reservoir is in animal hosts, including in wild animals, birds and reptiles *(25,26)*.

1.3.3 Dead-end hosts

Dead-end hosts are not susceptible to infection, and the disease agent cannot develop or reproduce. Humans can be dead-end hosts. The malaria parasite cannot develop in domestic animals (cattle, goats), although certain malaria vectors, such as the mosquito *An. arabiensis*, readily feed on animals such as cattle. Therefore, keeping animals close to human habitations could divert the vectors to these dead-end hosts and thus contribute to malaria control. This strategy is referred to as “zooprophylaxis”, or animal protection (see section 2.4.1). Risk managers should consider whether dead-end animal hosts could be used to reduce risk of human infection.

Consider this. How could dead-end hosts contribute to disease control?

1.3.4 Off-season transmission

In tropical regions, transmission of the pathogens of vector-borne diseases is generally most intense during the rainy season. In areas with prolonged dry seasons, vector populations decrease during the dry season, and transmission may stop or be maintained at very low rates. Knowing where vectors hide and survive during dry spells can be vital to disease control. For example, water tanks that are maintained for household or agricultural use during the dry season can extend the period of malaria transmission throughout the dry season. Simple environmental methods, such as use of larvivorous fish or covers or lids, can help to suppress breeding during a dry season and break the transmission cycle.

1.3.5 Vector incrimination

Managers of a vector-borne disease control programme must know the principal vectors that are responsible for local transmission of the disease agents. Failure to identify the principal vectors could result in selection of inappropriate vector control methods, wastage of resources and an insufficient impact on disease occurrence. In vector incrimination, proof is sought that an organism (e.g. mosquito) is responsible for transmission of disease pathogens. The incrimination starts with field-collection of potential vectors to determine whether they are infected and, possibly, whether the pathogens are present in the salivary glands or mouthparts that come into contact with humans. The rate of human biting by the potential vectors should then be studied to compare their rates of human contact *(27)*.

For example, in a study in a traditionally dry-zone village in Sri Lanka, 14 species of *Anopheles* were found. As the relative contributions of the individual species to transmission of malaria were unclear, the population densities and seasonal trends of each species were studied. Parasite infection was detected in seven of the species, and the rate of infectiousness and the rate of feeding on humans were measured. The mean number of infective vectors was then calculated as a measure of transmission potential. Although *An. culicifacies* was fifth in abundance, it represented most of the infective vectors of malaria. *An. vagus* which was much more common but had a stronger preference for feeding on animals, was a distant second, and *An. peditaeniatus* ranked third *(28)*.

Table 1.2 lists the general groups of vectors for the main vector-borne diseases. The species that is the principal vector varies widely between regions and even within countries.

Table 1.2. Main vector-borne diseases, their vectors and their geographical distribution

Disease	Vectors	Geographical distribution
Malaria	*Anopheles* mosquitoes	Tropics, sub-tropics
Lymphatic filariasis	*Culex* spp., *Anopheles* spp., *Culex* spp., *Aedes* spp., *Mansonia* spp. mosquitoes	Tropics
Leishmaniases	Sand flies (Psychodidae)	Tropics, sub-tropics
Schistosomiasis	Freshwater snails (*Bulinus*, *Biomphalaria* and *Oncomelania* spp.) act as intermediate host.	Tropics, sub-tropics
Human African trypanosomiasis	Tsetse flies (*Glossina* spp.)	Africa
Trachoma	Filth flies (*Musca sorbens, M. domestica*)	Tropics, sub-tropics
Dengue	*Ae. aegypti* and *Ae. albopictus* mosquitoes	Tropics, sub-tropics
Chagas disease	Triatomine bugs (*Triatoma* and *Rhodnius* spp.)	South America
Onchocerciasis	Blackflies (*Simulium* spp.)	Africa, South America

1.3.6 Interrupting the disease cycle

The disease cycle can be interrupted by attacking either the reservoir of the disease agent or the vector and its contact with humans. In most cases, the pathogen is attacked on both fronts. The reservoir of disease is the place in which the infectious agent survives. In zoonotic diseases, the reservoir is an animal host. The reservoir of malaria is infected people, some of whom show symptoms, while others do not.

Before the development of effective drugs and chemical insecticides in the 19th and early 20th centuries, control of vector-borne diseases consisted largely of environmental management of vector breeding sites. When effective insecticides became available, vector control with insecticides such as DDT successfully interrupted the cycles of malaria and dengue in several countries during the 1950s and 1960s.

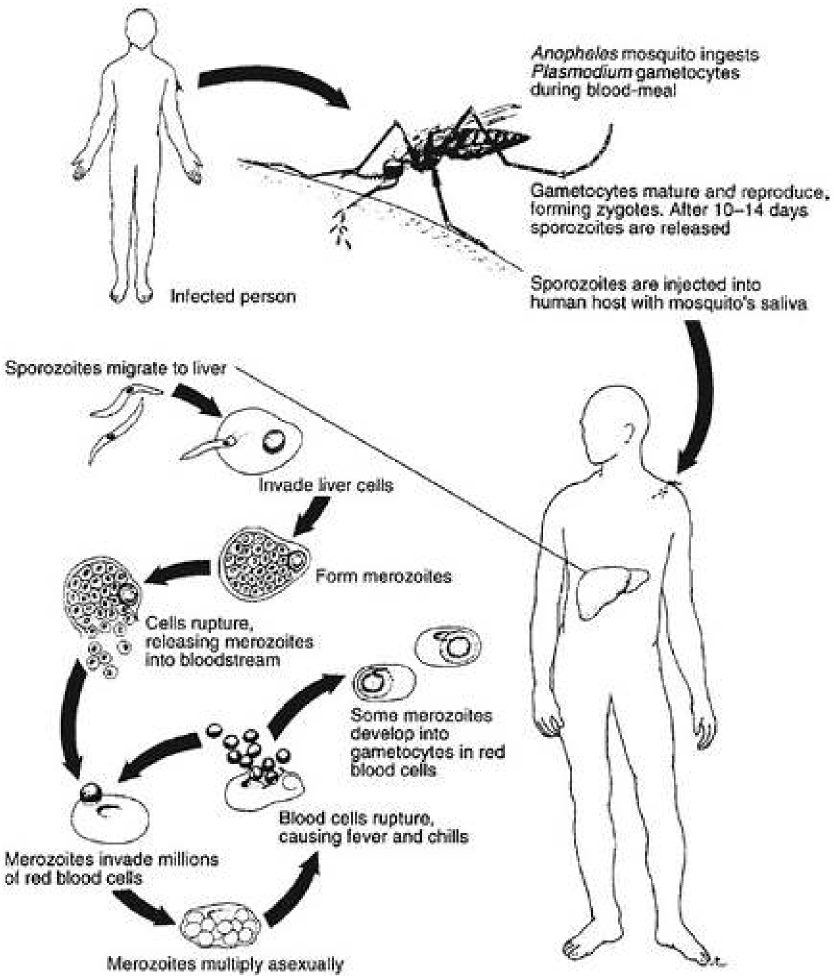
Generally, transmission is interrupted effectively by use of a combination of methods. In malaria control, vector control and treatment are combined, while control of dengue and chikungunya still depends solely on vector control because there are no effective drugs or vaccines. Control of lymphatic filariasis relies on MDA, although it has recently become clear that complementary interventions are necessary to interrupt the cycle and eliminate the disease *(29)*.

For vector-borne diseases in which the reservoir is mainly animals, elimination with treatment will be difficult, unless the hosts are domestic animals that can all be treated. When wild animals contribute to the reservoir of the disease agent, disease control should centre on the vector and on preventing contact with infested areas.

Boxes 1.1–1.4 illustrate the disease cycles of the four most important vector-borne diseases.

Box 1.1. Life cycle of *Plasmodium* parasites that cause malaria

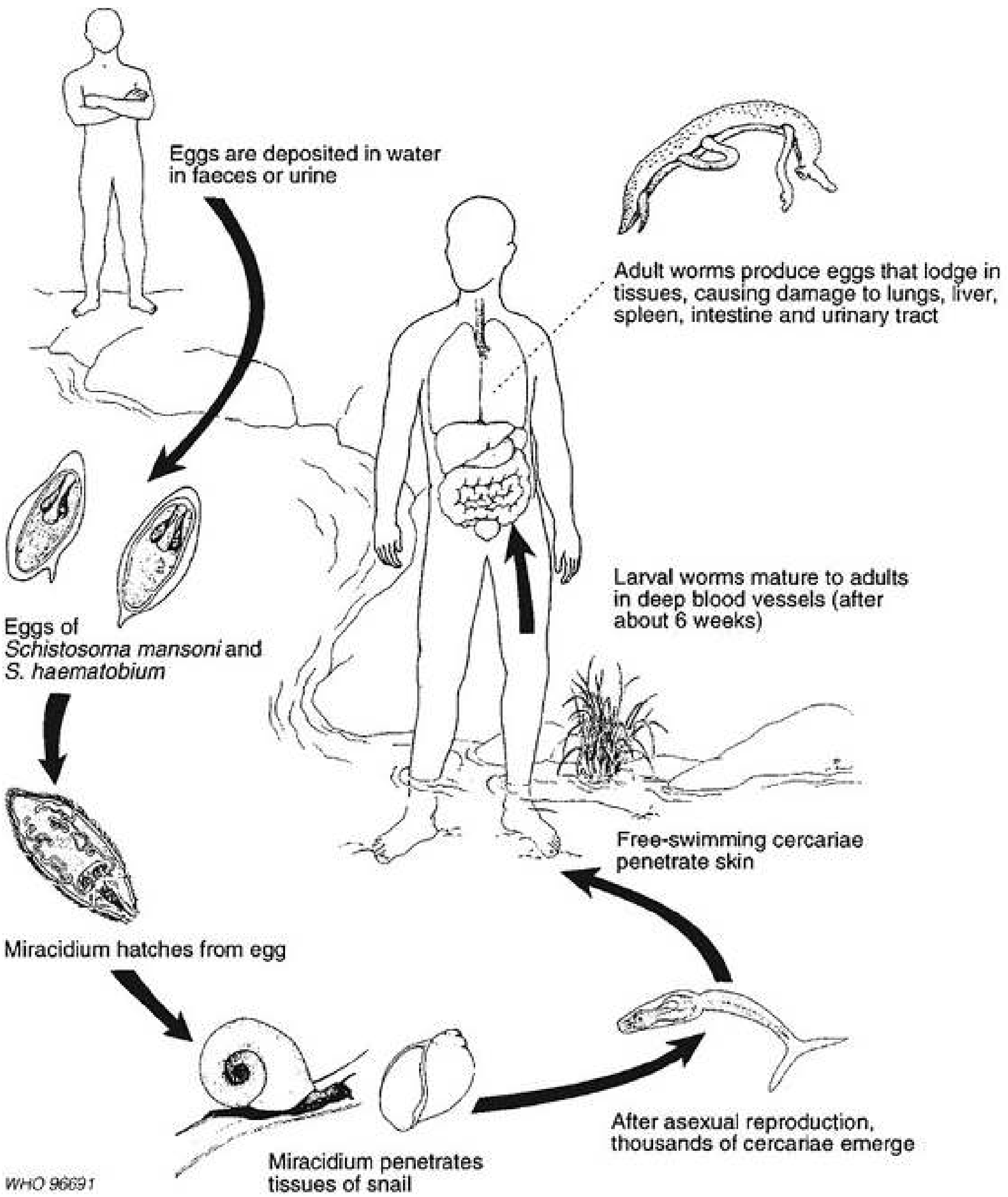
The plasmodia parasites that cause malaria enter the human body via the bite of an *Anopheles* mosquito. The parasites migrate via the bloodstream to the liver, where they multiply. After a number of days, a parasite stage, merozoites, are released into the bloodstream and invade the red blood cells, where they multiply. Some of the merozoites develop into gametocytes, the sexual stage of the parasite, when they are infectious and can be picked up by blood-feeding mosquitos. Once inside the mosquito gut, the gametocytes reproduce, and yet another stage, the sporozoites, emerge. The sporozoites move to the mosquito's salivary glands and are thus able to infect another person when the mosquito bites. Inside the new host, the sporozoites migrate to the liver, which closes the life cycle. The disease cycle can be interrupted at any stage. Medication targets the parasite stages inside the human host, while vector control targets the transmission of the vector to humans. The two strategies are being promoted as an integrated approach to the control of malaria.



Source: Rozendaal et al. *(30)*.

Box 1.2. Life cycle of schistosomes and the role of snails as intermediate hosts

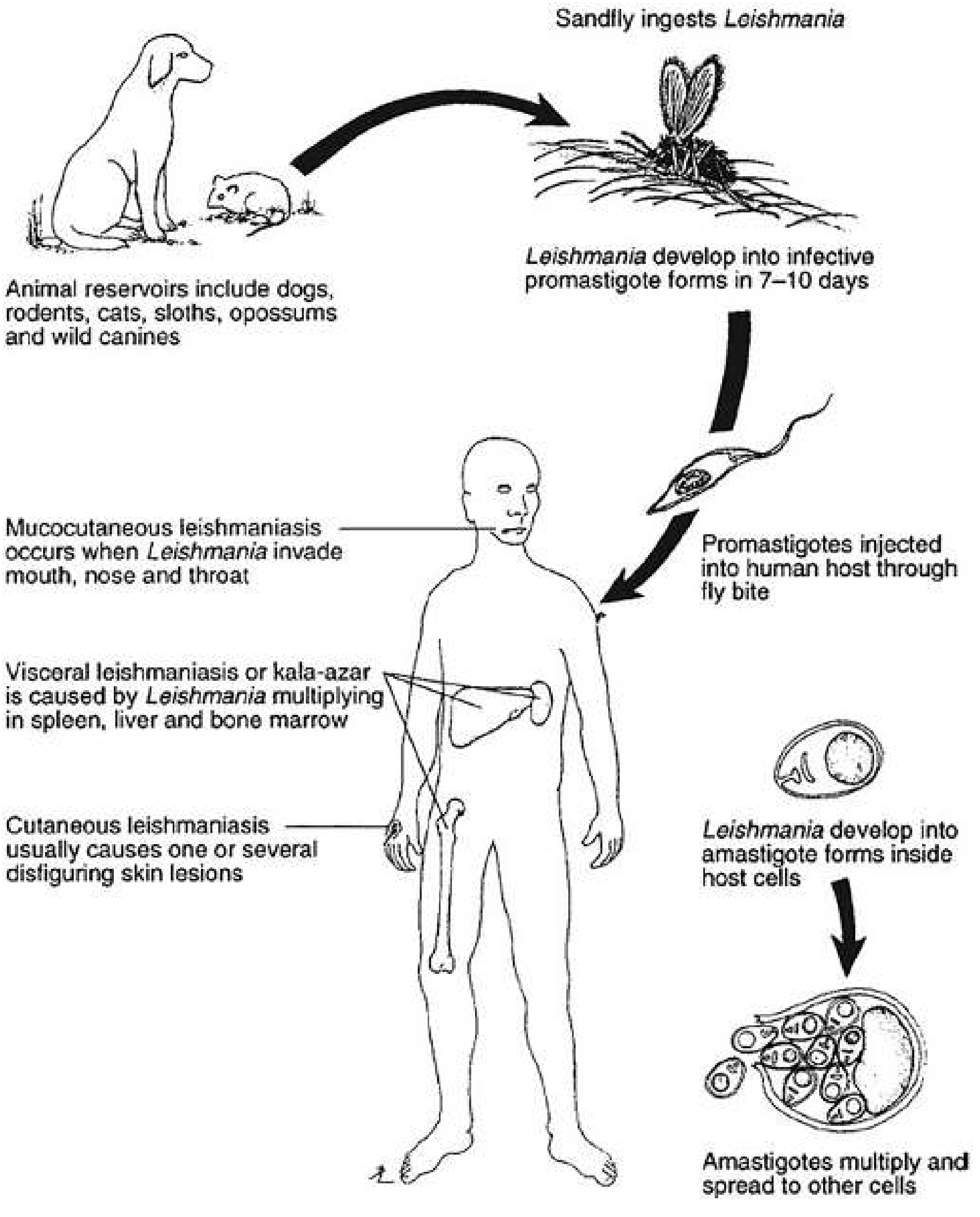
The eggs of schistosome parasites enter water bodies in the faeces or urine of humans. In water, the parasite larva, miracidium, emerges and swims in search of a suitable snail host. The miracidium lives less than 1 day, during which it must locate a snail host and penetrate its body. Inside the snail, the miracidium undergoes asexual reproduction, resulting in numerous stages known as cercariae. The cercariae emerge from the snail host and enter the water in search of a human host, which they must find within 2 days; they then penetrate the skin and enter the bloodstream. In the blood vessels, the cercariae develop into adult worms that mate and produce eggs. The male and female worms fuse and remain joined for years inside the human body. The eggs are released with human excreta, and the cycle is closed. The disease cycle is interrupted by provision of the anthelminthic drug praziquantel, which also kills several other nematode infections. As frequent reinfection may occur, regular medication may be required. Another strategy is to control transmission by removing the snail hosts or the habitats in which they thrive.



Source: Rozendaal et al. *(30)*.

Box 1.3. **Disease cycle of leishmaniases**

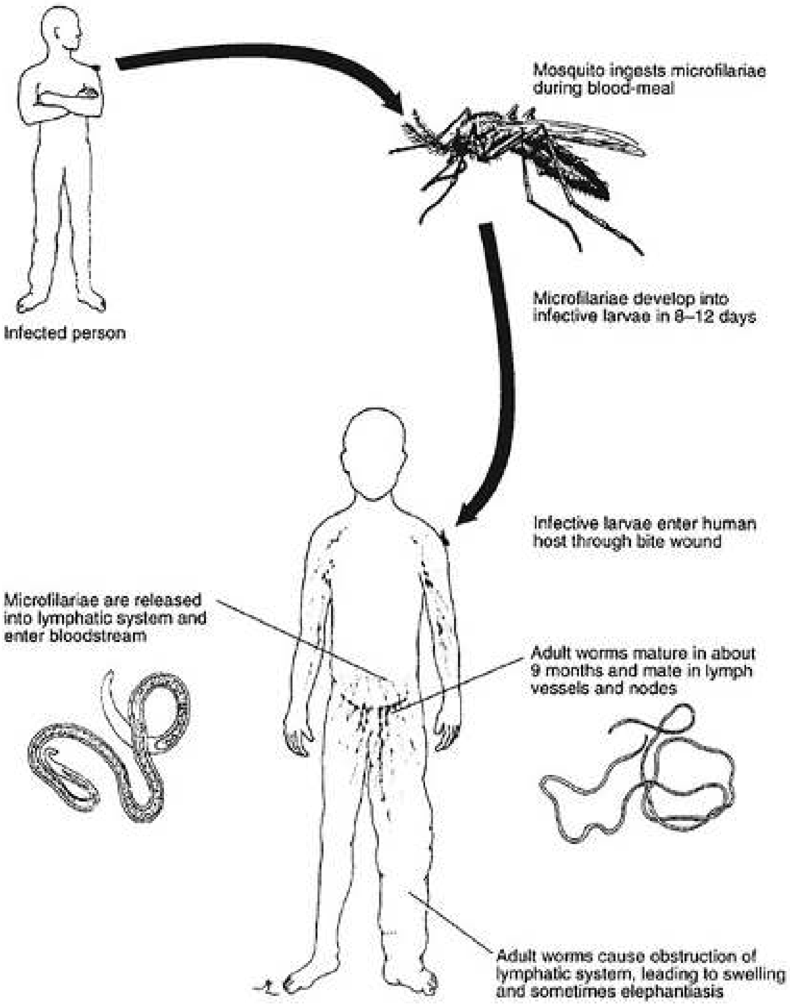
Leishmania parasites are transmitted to humans by small sand fly vectors, most of which have fed on small mammals. The parasite develops into infective stages within the vector, which becomes infective after 7–10 days. The parasites affect host organs according to the different forms of the disease.



Source: Rozendaal et al. *(30)*.

Box 1.4. **Disease cycle of lymphatic filariasis**

Mosquitoes of several genera can pick up microfilariae of lymphatic filariasis in their blood meals. After several days, the mosquitoes become infective, and the parasite stages can enter a human through a mosquito bite. The tiny worms migrate to the lymph nodes and develop into adult worms, some of which are very large, in the lymph vessels, where they can survive for many years. In the lymph vessels. they produce embryos called microfilariae, which circulate in the bloodstream and are picked up by biting mosquitos *(30)*. Anthelmintic drugs used for elimination of the disease kill the microfilariae but not the adult worms, which, after some time, can resume reproduction. Thus, use of drugs alone may not be sufficient to eliminate this disease, and vector control is required *(31)*.



Source: Rozendaal et al. *(30)*.

1.4 Control tools and strategies

1.4.1 Tools

A number of tools are available for the control of vector-borne diseases, and risk managers should familiarize themselves with them. Administration of prophylactic drugs protects particularly vulnerable sections of society and temporary visitors to a disease-endemic area or country. For example, prophylaxis is used to protect pregnant women from malaria, as malaria can be fatal to women and their unborn children, particularly during a first pregnancy. Prophylaxis is, however, generally too costly to administer to entire populations at risk over extended periods. Moreover, large-scale use of some drugs could accelerate the development of resistance to them in parasites, rendering the drugs ineffective after a certain time.

Development of universally applicable vaccines against malaria is difficult, because the parasites and pathogens change constantly *(32)*. Recent pilot studies in Ghana, Kenya and Malawi have indicated that the first vaccine against malaria, the RTS,S vaccine, provides partial protection to young children. Among children aged 5–17 months, the vaccine prevented 39% of cases of malaria and 29% cases of severe malaria. These benefits were additional to those due to use of long-lasting insecticidal nets (LLIN), prompt diagnosis and effective antimalarial treatment, as reported by WHO. In October 2021, WHO recommended the RTS,S vaccine for children at risk. The only vaccine available against other vector-borne diseases is that against yellow fever.

Case management requires accurate diagnosis and effective treatment. Medication is the most common tool used to manage a number of vector-borne diseases. For some diseases, such as malaria and schistosomiasis, curative drugs are available at low cost. It is important that treatment be given only to the people in whom the disease has been correctly diagnosed. If not, effective drugs are used unnecessarily, wasting resources and increasing the risk of resistance against the drugs. Rapid diagnostic test (RDT) kits are available to assist in diagnosis of malaria from a finger-prick blood sample by trained health workers in villages and do not require expensive microscopic equipment. The tests prevent wastage of malaria drugs, which are administered only if the test result is positive. In some studies, RDT kits have been found to be more accurate than microscopy *(33)*. Regulation and quality control of RDT kits are nevertheless urgently required *(34)*.

Anthelminthic drugs are used in the control of various vector-borne diseases caused by small worms, or nematodes. These include lymphatic filariasis, onchocerciasis, hookworm and several other diseases. The drugs kill the worm larvae, microfilariae, that periodically circulate in the blood. Not all infected people have microfilariae in their blood, and adult worms are not generally killed by these drugs. The drugs, which help reduce transmission, are so cheap that they can be administered to entire populations (MDA).

Vector control and personal protection reduce the contact between humans and vectors but do not reduce vector abundance. They are generally of major importance in the control of any vector-borne disease because they provide prevention against infection rather than treatment to cure an infection. Vector control and personal protection are discussed in more detail in section 2.

Cost-effectiveness, the cost of averting a certain amount of the burden of a disease, is a measure used for comparing tools for disease control. Anthelmintic drugs are highly cost-effective in the control of diseases like lymphatic filariasis, onchocerciasis and hookworm due to their low cost and their high effectiveness in killing worm larvae. Preventive methods such as vector control are generally more costly but provide protection against contracting an infection. Preventive measures are particularly important for protecting vulnerable groups such as young children.

1.4.2 Disease-specific strategies

Strategies for controlling vector-borne diseases have a component of case management, including diagnosis and treatment, and a component of vector control, and the proportion of each differs for each vector-borne disease control programme.

Malaria control is two-pronged, attacking the disease on both fronts by relying on diagnosis, treatment and vector control with LLIN and IRS *(35)*. Prophylaxis is administered to pregnant women, who are at particular risk of malaria.

The strategy for lymphatic filariasis control has until recently been MDA *(13)*, with little or no role for vector control; however, increased attention is being given to vector control *(31)*.

The control of dengue and chikungunya depends on vector control and personal protection, such as involving communities in the removal of vector breeding sites in and around people's houses *(36)*. There are no effective drugs or vaccines against dengue and chikungunya.

Control of Chagas disease is based mainly on residual spraying of insecticides to control the triatomid vectors *(37)*.

The strategy for control of onchocerciasis in past decades was vector control through aerial application of chemical larvicides to kill the larvae of *Simulium* spp. blackflies in streams and rivers in order to interrupt transmission of the microfilarial worms *(38)*. This strategy has, however, been considered too expensive to maintain for a sufficient number of years to remove a reservoir of adult worms from a human population. Therefore, the strategy has shifted to MDA of the anthelminthic ivermectin, which kills the small microfilarial worms but not the adult worms *(39)*.

1.4.3 Integrated disease control

Most vector-borne diseases are too complex to be controlled effectively by a single intervention. Reliance solely on drugs or insecticides as "silver bullets" to control or eliminate a disease may result in failure, because they may not sufficiently suppress disease prevalence and could exert intense pressure on the disease agents or vectors to develop resistance to the drugs or insecticides. Therefore, integrated approaches to disease control are often preferable or essential to ensure and sustain effective control and elimination. In integrated strategies, the disease is attacked on several fronts, with greater impact (discussed in sections 3 and 4). In integrated strategies, the effects of interventions are complementary.

The factors that determine the burden of vector-borne disease, the determinants, include the disease agent, the vector, the human host as well as the environment and socioeconomic and climatic conditions. For an integrated disease control approach to be effective, risk managers must identify and understand all the relevant determinants.

Human determinants are people's practices and attitudes, their domestic conditions, such as housing and hygiene, their proximity to vector breeding habitats, their movements, their vulnerability, their nutritional status and their access to effective medication.

Environmental determinants include the type of ecosystem, use of land, such as for agriculture or urban development, alternative hosts of the disease agents and climatic conditions.

Vector-borne disease control programmes usually concentrate on the *parasite* and the *vector*. If human and environmental determinants are ignored, however, people will continue to be at risk of infection, and the vectors will continue to proliferate in the environment.

Emerging vector-borne diseases, such as chikungunya, dengue, rickettsia, Lyme disease and West Nile virus are increasing risks for countries in Europe and North America *(40,41)*.

1.4.4 Multi-disease approaches

Vector-borne disease control has commonly been implemented in programmes segregated for each disease, each with its own objectives, targets, methods and staff, with very little interaction or collaboration. This is changing, as knowledge about the interactions and synergistic effects between disease-specific programmes increases. The most obvious examples are the diseases transmitted by worms, or nematodes, such as onchocerciasis, lymphatic filariasis and hookworm. Most of the drugs used to control the worm larvae, microfilariae, circulating in the bloodstream, affect all nematode worms and can be used to control more than one disease, depending on the dosage. As the geographical distribution of nematode infections overlaps substantially, communities may be at risk of (or infected by) several worms. Hence, administration of effective drugs can control more than one type of worm.

Another multi-disease approach is integration of strategies to control malaria and lymphatic filariasis, and WHO has published a position statement on integration of the control of these two diseases *(42)*. Although the two are caused by different groups of disease agents – malaria by protozoa and filariasis by nematodes – they are similar in several ways. Particularly in sub-Saharan Africa and parts of the Pacific, the parasites of the two diseases are transmitted by the same *Anopheles* mosquitoes. Therefore, vector control of one disease may result in a decrease in the prevalence of the other *(43)*.

The advantages of integration of disease-specific programmes are clear. Integration can ensure efficient use of resources by planning and evaluating programmes together and sharing technical expertise and infrastructure. Integration can also increase the impact on disease. Integration can, however, introduce logistical and organizational difficulties *(44)*.

1.4.5 The One Health approach

A further step is integration of health services for humans and for domestic animals *(45)*, which have usually been strictly separated, the former in the health sector and the latter in the agriculture sector. The health of humans and their livestock is, however, often closely connected. Particularly in pastoralist societies, people are affected by the health condition of their livestock, and insect vectors can transmit zoonotic diseases from animals to humans (Fig. 1.11). Examples are Rift Valley fever and rabies.

Fig. 1.11. Example of One Health in East Africa

Source: photo courtesy of H. van den Berg.

Sleeping sickness is being controlled by mass treatment of the cattle reservoir with chemotherapy and insecticidal treatment to control tsetse fly populations, which also reduces tick populations *(27)*.

In certain situations, especially in isolated areas, application of the One Health concept can strengthen health systems and increase the efficiency of operations in both disciplines. For example, combining human and animal vaccination campaigns can increase access to public health services in hard-to-reach pastoralist communities *(27,46)*.

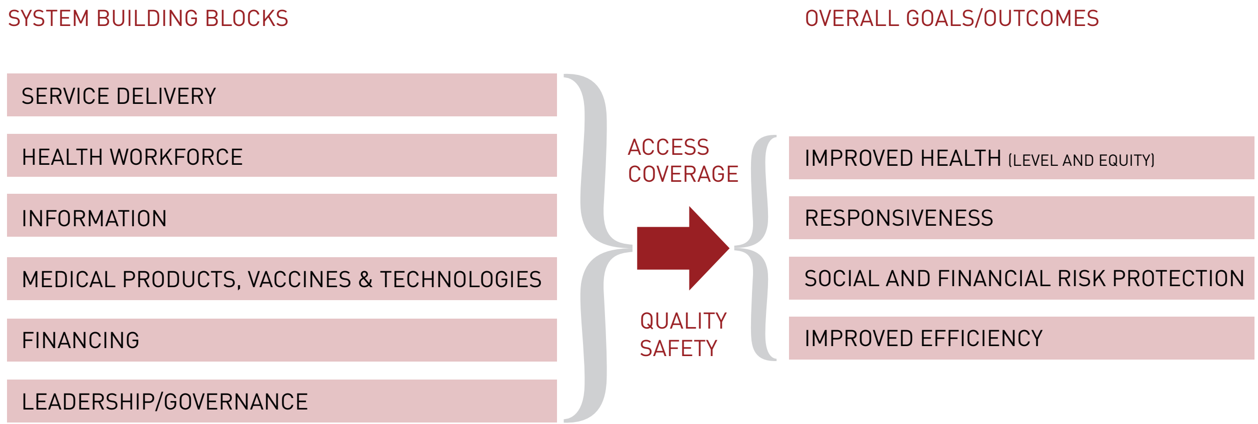
1.5 Health systems and vertical programmes

1.5.1 Health systems

A health system comprises all organizations, institutions and resources for improving health. Thus, the health system consists not only of institutions such as clinics and hospitals but also private-sector partners, special programmes, community health workers and others in communities who participate actively in health actions. The most obvious function of a health system is the services it provides for the diagnosis and treatment of disease and the promotion and maintenance of health. Health services with adequate resources ensure the delivery of health interventions. To be effective, health services must have the necessary financial resources, supply chain, equipment, ambulances and skilled staff and volunteers to ensure adequate coverage and the quality of services and to be accessible by the general public. Moreover, effective health services require good organization and management, for example to prevent stock-outs of medications and other supplies during peak disease seasons.

Vector-borne disease control depends on a functioning health system, particularly for diagnosis and treatment, case management, planning and implementation of preventive measures, and detection and containment of epidemics. It has been reported that several factors in a health system, such as delivery of routine services and hospital capacity, are strongly correlated with reductions in malaria burden *(47)*. This suggests that strengthening health systems can help to reduce the burden of vector-borne diseases. In most disease-endemic countries, however, health systems are weak, and it is critical that the interventions for vector-borne disease control be simple and straightforward in order that they be adopted by the health system. Box 1.5 illustrates the desirable attributes of a functioning health system.

Box 1.5. **WHO's health system framework**



The six building blocks of a health system and the aims and desirable attributes are as follows.

1. Good **health services** are those that **deliver** effective, safe, high-quality personal and non-personal health interventions to those who need them, when and where they are needed, with minimum waste of resources.
2. A well-performing **health workforce** works in ways that are responsive, fair and efficient to achieve the best health outcomes possible with the available resources and circumstances; that is, with sufficient numbers and mix of staff, fairly distributed, who are competent, responsive and productive.
3. A well-functioning **health information system** ensures the production, analysis, dissemination and use of reliable, timely information on health determinants, health system performance and health status.
4. A well-functioning health system ensures equitable access to essential **medical products, vaccines and technologies** of assured quality, safety, efficacy and cost-effectiveness and their scientifically sound, cost-effective use.
5. A good **health financing** system raises adequate funds for health in ways that ensure that people receive the necessary services and are protected from financial catastrophe or impoverishment associated with having to pay for them.
6. **Leadership and governance** involve ensuring strategic policy frameworks combined with effective oversight, coalition building, appropriate regulations and incentives, attention to system design and accountability.

Source: WHO *(48)*.

1.5.2 Decentralized health services

In most disease-endemic countries, reform in the health sector has resulted in decentralization of decision-making and resource allocation to districts or the equivalent. Hence, responsibility for planning, budgeting and implementation of health functions is transferred from the central government to districts. The central ministry limits its role to policy, guidance and technical support and leaves the provision of health services mainly to district health offices and community services.

Decentralization is effective only when the necessary skills, competence and resources are firmly established in the district and services are delivered locally. Front-line health workers need not be specialists but should be versatile in order to perform multi-purpose tasks. Local health units are, however, commonly understaffed and under-resourced, and a frequent problem in vector-borne disease control is that the sufficient technical and programmatic skills and resources that were established at national level are insufficient at district level and often inexistent at other levels. In many countries endemic for vector-borne diseases, vector control specialists or entomologists are present only at national and not at district or provincial level. Vector-borne disease control has therefore suffered from decentralization in many endemic countries, and capacity-building for vector-borne disease control is required.

1.5.3 Vertical programmes

Most programmes for vector-borne disease control are still implemented as vertical programmes, whereby they are directed and executed mainly by a special service, with its own staff and resources.

Vertical programmes, such as IRS for malaria control, require considerable technical and logistical input and are thus not generally performed by a decentralized health system. Vertical programmes often operate in parallel to an established health system and its general health services. Many vertical programmes are not sustainable because they depend on external funding, and their technical staff may be discontinued after the external support is terminated, leading to loss of expertise. In contrast, horizontal programmes operate within the health system, making use of the established institutions and their health staff.

Global programmes to eliminate malaria, lymphatic filariasis, onchocerciasis and trachoma are implemented vertically, because their goal of zero incidence is global, not national or local. Examples of the goals and strategies of the global programmes on malaria and lymphatic filariasis are shown in Table 1.3, which shows that the two strategies have a number of commonalities. It has therefore been suggested that the activities of the two programmes be coordinated *(43,49)*.

Table 1.3. Comparison of the global programmes for malaria and lymphatic filariasis

	Global Malaria Programme	Global Programme to Eliminate Lymphatic Filariasis
Vision	A world free from the burden of malaria	A world free of lymphatic filariasis
Goal	To eradicate malaria worldwide by reducing the global incidence to zero through progressive elimination in endemic countries	To eliminate lymphatic filariasis as a public-health problem by 2020
Aim	Strengthen health systems in endemic countries	Strengthen health systems in endemic countries
Strategy	Prevention through vector control (to reach all people considered to be at risk with insecticide-treated mosquito nets or IRS)	Prevention through MDA delivered to everyone living in endemic areas
	Morbidity management through early laboratory-based diagnosis of all suspected cases and effective treatment of all confirmed cases	Morbidity management and disability prevention

Source: WHO *(42)*.

The strategies for delivery and use of interventions in the programmes for control of lymphatic filariasis, onchocerciasis and soil-transmitted helminthiases are comparable, and management and implementation of these programmes could also be integrated.

Some programmes that are implemented vertically, such as for malaria control and elimination, have adequate resources, whereas programmes for dengue generally have inadequate resources and are implemented by municipalities or district health offices. A malaria control programme could therefore strengthen dengue control services by integrating operations and sharing expertise and training.

The US President's Malaria Initiative, launched in 2005, extends the US Government programme to reduce the burden of malaria and help to reduce poverty on the African continent. Its goals are to reduce mortality in high-burden countries, reduce morbidity in those with a high or moderate burden and reduce transmission to achieve elimination in low-burden countries. The Initiative collaborates with the national malaria control programme in each country to build local capacity and strengthen their health systems. Only proven, cost-effective interventions are used to control malaria: insecticide-treated nets (ITNs), IRS with insecticides, intermittent preventive treatment for pregnant women and prompt administration of artemisinin-based combination therapy for diagnosed cases of malaria. Countries are assisted in increasing access to these interventions.

1.5.4 Vertical versus horizontal approaches

In 1965, Gonzalez *(50)* described the dilemma between vertical and horizontal approaches in health measures.

> There are two apparently conflicting approaches to which countries should give careful consideration. The first, generally known as the "horizontal approach", seeks to attack the overall health problems on a wide front and on a long-term basis through the creation of a system of permanent institutions commonly known as "general health services". The second, or "vertical approach", calls for solution to a given health problem by means of single-purpose machinery. For the latter type of programme, the term "mass campaign" has become widely accepted. More authorities are becoming aware that many campaigns for the eradication of diseases will have only temporary effects if they are not followed by the establishment of permanent health services in those areas, to deal with day-to-day work in the control and prevention of disease and the promotion of health.

The message was that the vertical and horizontal approaches should not be seen as incompatible but should be combined in various ways, as each approach has its advantages and disadvantages *(51)*. One advantage of vertical programmes is that they are focused on specific health issues, have clear targets and resources, and have technical expertise. The advantage of horizontal programmes is that they contribute directly to strengthening health systems and may therefore result in broader health outcomes. Unlike vertical programmes, general health services are flexible, and can thus address changing disease situations, and are permanently embedded in districts and villages *(52)*.

1.5.5 Health system integration

Integration of vector-borne disease control into health systems implies close coordination or assimilation of activities into multi-purpose health services. Hence, vector control is not conducted in isolation but is part of general health services.

Disease elimination programmes are often vertical programmes because they have a restricted time horizon, are intensive (e.g. campaigns) and are specific (one disease of concern). Concern has been raised that vertical programmes not only bypass the health system, rather than strengthening it, but can even undermine it, by drawing away human resources and removing incentive structures. After a vertical programme has ended, it may have weakened the health system and reduced its expertise and human resources.

The case has, however, been made repeatedly that, once an elimination programme has achieved pre-elimination levels of disease prevalence, it should gradually be taken over by health systems and community workers for detection of the last cases and achievement and maintenance of elimination. The role of a vertical elimination programme is therefore to mobilize an "attack phase" for a limited time in order to reduce disease levels substantially, but, when a certain prevalence is reached, the vertical programme would retreat and the health system step in. A full-fledged attack phase could not be implemented by an established health system with multi-purpose services but requires a short-term, specialized programme and massive campaigns.

The contrast between vertical and horizontal approaches is likely to be less marked for programmes to reduce disease burden rather than eliminate a disease, and these programmes are more likely to be integrated in health systems throughout their implementation.

The success of a number of vector-borne disease control programmes, particularly those for neglected tropical diseases (NTDs) such as lymphatic filariasis, schistosomiasis, onchocerciasis and trachoma, has depended heavily on how well the strategies were integrated into health systems.

Project assignment 1

Outline the situation of vector-borne diseases in your country. Present the outline in the form of a matrix:

- In the first column, list the vector-borne diseases. Include emerging diseases and those that are occasionally introduced and/or locally transmitted.
- In the second column, indicate for each disease its epidemiological status (endemic, highly endemic, epidemic, emerging, risk of introduction) and whether the trend is increasing, decreasing or constant.
- In the third column, indicate the sections of society that are most vulnerable to the disease.
- In the fourth column, provide the most recent data on incidence and/or prevalence rate of each disease.

Also, identify any critical gaps in information and the type of activity that would be necessary to fill those gaps.

References

1. Golding N, Wilson AL, Moyes CL, Cano J, Pigott DM, Velayudhan R et al. Integrating vector control across diseases. BMC Med. 2015;13(1):249. doi:10.1186/s12916-015-0491-4.
2. Hotez PJ, Fenwick A, Savioli L, Molyneux DH. Rescuing the bottom billion through control of neglected tropical diseases. Lancet. 2009;373:1570–5. doi:10.1016/S0140-6736(09)60233-6.
3. Swellengrebel NH, de Buck A. Malaria in the Netherlands. Amsterdam: Scheltema & Holkema Ltd; 1938 (https://www.worldcat.org/formats-editions/1601407).
4. Sayers BM, Fliedner TM. The critique of DALYs: a counter-reply. Bull World Health Organ. 1997;75(4): 383–4 (https://iris.who.int/handle/10665/264250?show=full).
5. Ending the neglect to attain the Sustainable Development Goals: a road map for neglected tropical diseases 2021–2030. Geneva: World Health Organization; 2020 (https://iris.who.int/handle/10665/338565).
6. World malaria report 2021. Geneva: World Health Organization; 2021 (https://iris.who.int/handle/10665/350147).
7. Kyu HH, Abate D, Abate KH, Abay SM, Abbafati C, Abbasi N et al. Global, regional, and national disability-adjusted life-years (DALYs) for 359 diseases and injuries and healthy life expectancy (HALE) for 195 countries and territories, 1990–2017: a systematic analysis for the Global Burden of Disease Study 2017. Lancet. 2018;392(10159):1859–922. doi:10.1016/S0140-6736(18)32335-3.
8. Sachs J, Malaney P. The economic and social burden of malaria. Nature. 2002;415:680–685. doi:10.1038/415680a.
9. Gallup JL, Sachs JD. The economic burden of malaria. Am J Trop Med Hyg. 2001;64(1,2S):85–96. doi:10.4269/ajtmh.2001.64.85.
10. Working to overcome the global impact of neglected tropical diseases. Geneva: World Health Organization; 2010 (https://iris.who.int/handle/10665/44778).

11. Working to overcome the global impact of neglected tropical diseases. Update 2011. Geneva: World Health Organization; 2011 (https://iris.who.int/handle/10665/44778).

12. Weiss DJ, Lucas TC, Nguyen M, Nandi AK, Bisanzio D, Battle KE et al. Mapping the global prevalence, incidence, and mortality of *Plasmodium falciparum*, 2000–17: a spatial and temporal modelling study. Lancet. 2019;394(10195):322–31. doi:10.1016/S0140-6736(19)31097-9.

13. Progress report 2000–2009 and strategic plan 2010–2020 of the global programme to eliminate lymphatic filariasis: halfway towards eliminating lymphatic filariasis. Geneva: World Health Organization; 2010 (https://iris.who.int/handle/10665/44473).

14. Brun R, Blum J, Chappuis F, Burri C. Human African trypanosomiasis. Lancet. 2010;375(9709): 148–59. doi:10.1016/S0140-6736(09)60829-1.

15. Polack S, Brooker S, Kuper H, Mariotti S, Mabey D, Foster A. Mapping the global distribution of trachoma. Bull World Health Organ. 2005;83(12):913–9 (https://iris.who.int/handle/10665/269540).

16. Wright HR, Turner A, Taylor HR. Trachoma. Lancet. 2008;371(9628):1945. doi:10.1016/S0140-6736(08)60836-3.

17. Emerson PM, Lindsay SW, Alexander N, Bah M, Dibba SM, Faal HB et al. Role of flies and provision of latrines in trachoma control: cluster-randomised controlled trial. Lancet. 2004;363(9415):1093–8. doi:10.1016/S0140-6736(04)15891-1.

18. Mordecai EA, Ryan SJ, Caldwell JM, Shah MM, LaBeaud AD. Climate change could shift disease burden from malaria to arboviruses in Africa. Lancet Planet Health. 2020;4(9):e416–23. doi:10.1016/S2542-5196(20)30178-9.

19. Chaves LF, Koenraadt CJM. Climate change and highland malaria: fresh air for a hot debate. Q Rev Biol. 2010;85(1):27–55. doi:10.1086/650284.

20. Fouque F, Reeder JC. Impact of past and on-going changes on climate and weather on vector-borne diseases transmission: a look at the evidence. Infect Dis Poverty. 2019;8(1):1–9. doi:10.1186/s40249-019-0565-1.

21. Gething PW, Smith DL, Patil AP, Tatem AJ, Snow RW, Hay SI. Climate change and the global malaria recession. Nature. 2010;465(7296):342–5. doi:10.1038/nature09098.

22. Bouzid M, Colón-González FJ, Lung T, Lake IR, Hunter PR. Climate change and the emergence of vector-borne diseases in Europe: case study of dengue fever. BMC Public Health. 2014;14(1):781. doi:10.1186/1471-2458-14-781.

23. Semenza JC, Suk JE. Vector-borne diseases and climate change: a European perspective. FEMS Microbiol Lett. 2018;365(2):fnx244. doi:10.1093/femsle/fnx244.

24. Amexo M, Tolhurst R, Barnish G, Bates I. Malaria misdiagnosis: effects on the poor and vulnerable. Lancet. 2004;364(9448):1896–8. doi:10.1016/S0140-6736(04)17446-1.

25. Coker R, Rushton J, Mounier-Jack S, Karimuribo E, Lutumba P, Kambarage D et al. Towards a conceptual framework to support one-health research for policy on emerging zoonoses. Lancet Infect Dis. 2011;11(4):326–31. doi:10.1016/S1473-3099(10)70312-1.

26. Molyneux DM, Hallaj Z, Keusch GT, McManus DP, Ngowi H, Cleaveland S et al. Zoonoses and marginalised infectious diseases of poverty: Where do we stand? Parasit Vectors. 2011;4(106):1–19. doi:10.1186/1756-3305-4-106.

27. Beier JC. Vector incrimination and entomological inoculation rates. In: Doolan DL, editor. Malaria methods and protocols. Totowa (NJ): Humana Press; 2002;3–11. doi:10.1385/1-59259-271-6:01.

28. Handbook for integrated vector management. Geneva: World Health Organization; 2012 (https://iris.who.int/handle/10665/44768).

29. Lymphatic filariasis: practical entomology. A handbook for national lymphatic filariasis elimination programmes. Geneva: World Health Organization; 2013 (https://iris.who.int/handle/10665/87989).

30. Rozendaal JA. Vector control: methods for use by individuals and communities. Geneva: World Health Organization; 1997 (https://iris.who.int/handle/10665/41968).

31. Bockarie MJ, Pedersen EM, White GB, Michael E. Role of vector control in the global program to eliminate lymphatic filariasis. Annu Rev Entomol. 2009;54:469–87. doi:10.1146/annurev.ento.54.110807.090626.

32. Hill AVS. Vaccines against malaria. Phil Trans R Soc B Biol Sci. 2011;366(1579):2806–14. doi:10.1098/rstb.2011.0091.

33. Kahama-Maro J, D'Acremont V, Mtasiwa D, Genton B, Lengeler C. Low quality of routine microscopy for malaria at different levels of the health system in Dar es Salaam. Malar J. 2011;10(1):332. doi:10.1186/1475-2875-10-332.

34. Albertini A, Djalle D, Faye B, Gamboa D, Luchavez J, Mationg M et al. Preliminary enquiry into the availability, price and quality of malaria rapid diagnostic tests in the private health sector of six malaria-endemic countries. Trop Med Int Health. 2012;17:147–52. doi:j.1365-3156.2011.02904.x.

35. World malaria report 2011. Geneva: World Health Organization; 2011 (https://iris.who.int/handle/10665/44792).

36. World Health Organization, Special Programme for Research and Training in Tropical Diseases Dengue: guidelines for diagnosis, treatment, prevention and control. Geneva: World Health Organization; 2009 (https://iris.who.int/handle/10665/44188).

37. Yamagata Y, Nakagawa J. Control of Chagas disease. Adv Parasitol. 2006;61:129–65. doi:10.1016/S0065-308X(05)61004-4.

38. Davies JB. Sixty years of onchocerciasis vector control: A chronological summary with comments on eradication, reinvasion, and insecticide resistance. Annu Rev Entomol. 1994;39(1):23–45. doi:10.1146/annurev.en.39.010194.000323.

39. Hodgkin C, Molyneux DH, Abiose A, Philippon B, Reich MR, Remme JH et al. The future of onchocerciasis control in Africa. PLoS Negl Trop Dis. 2007;1(1):e74. doi:10.1371/journal.pntd.0000074.

40. Vorou R, Papavassiliou V, Tsiodras S. Emerging zoonoses and vector-borne infections affecting humans in Europe. Epidemiol Infect. 2007;135(8):1231–47. doi:10.1017/S0950268807008527.

41. Gratz NG. Emerging and resurging vector-borne diseases. Annu Rev Entomol. 1999;33:51–75. doi:10.1146/annurev.ento.44.1.51.

42. WHO position statement on integrated vector management to control malaria and lymphatic filariasis. Wkly Epidemiol Rec. 2011;86(13):121–7 (https://iris.who.int/handle/10665/70817).

43. van den Berg H, Kelly-Hope LA, Lindsay SW. Malaria and lymphatic filariasis: the case for integrated vector management. Lancet Infect Dis. 2013;13(1):89–94. doi:10.1016/S1473-3099(12)70148-2.

44. Suwonkerd W, Vryheid R, Suwannachote N. Progress of partial intrgration of malaria control with other vector borne diseases control in northern Thailand. Southeast Asian J Trop Med Public Health. 2010;41(6):1297–305 (https://www.tm.mahidol.ac.th/seameo/2010-41-6/03-J08-019.pdf).

45. Rock M, Buntain BJ, Hatfield JM, Hallgrímsson B. Animal–human connections. Soc Sci Med. 2009;68(6):991–5. doi:10.1016/j.socscimed.2008.12.04.

46. Singer BH, De Castro MC. Bridges to sustainable tropical health. Proc Natl Acad Sci U S A. 2007;104(41):16038. doi:10.1073/pnas.0700900104.

47. Sahu M, Tediosi F, Noor AM, Aponte JJ, Fink G. Health systems and global progress towards malaria elimination, 2000–2016. Malar J. 2020;19(1):1–12. doi.:10.1186/s12936-020-03208-6.

48. Everybody business: strengthening health systems to improve health outcomes. WHO's framework for action. Geneva: World Health Organization; 2007 (https://iris.who.int/handle/10665/43918).

49. Molyneux DH, Nantulya VM. Linking disease control programmes in rural Africa: a pro-poor strategy to reach Abuja targets and millennium development goals. BMJ. 2004;328:1129–32. doi:10.1136/bmj.328.7448.1129.

50. Gonzalez CL. Mass campaigns and general health services (Public Health Papers 29). Geneva: World Health Organization; 1965 (https://iris.who.int/handle/10665/40470).

51. Mills A. Mass campaigns versus general health services: What have we learnt in 40 fyears about vertical versus horizontal approaches? Bull World Health Organ. 2005;83(4):315–6 (https://iris.who.int/handle/10665/269382).

52. Gyapong JO, Gyapong M, Yellu N, Anakwah K, Amofah G, Bockarie M et al. Integration of control of neglected tropical diseases into health-care systems: challenges and opportunities. Lancet. 2010;375(9709):160–5. doi:10.1016/S0140-6736(09)61249-6.

Recommended reading

Alonso P, Noor AM. The global fight against malaria is at crossroads. Lancet. 2017;390:2532–4. doi:10.1016/S0140-6736(17)33080-5.

Barnett R. Case histories: Schistosomiasis. Lancet. 2018 392:2431. doi:10.1016/S0140-6736(18)33008-3.

Castro MC, ME Wilson, DE Bloom. Disease and economic burdens of dengue. Lancet Infect Dis. 2017;17:e70–8. doi:0.1016/S1473-3099(16)30545-X.

Deribe K, Bakajika DK, Zoure HMG, Gyapong JO, Molyneux DH, Rebollo MP. African regional progress and status of the programme to eliminate lymphatic filariasis: 2000–2020. Int Health. 2020,13:S22–7. doi:10.1093/inthealth/ihaa058.

Gyapong JO, M Gyapong, N Yellu, K Anakwah, G Amofah, M Bockarie et al. Integration of control of neglected tropical diseases into health-care systems: challenges and opportunities. Lancet. 2010;375:160–5. doi:10.1016/S0140-6736(09)61249-6.

Hotez PJ. Ten global "hotspots" for the neglected tropical diseases. PLoS Negl Trop Dis. 2014;8:e2496. doi:10.1371/journal.pntd.0002496).

Mitra AK, Mawson AR. Neglected tropical diseases: epidemiology and global burden. Trop Med Infect Dis. 2017;2(3):36 (https://www.mdpi.com/2414-6366/2/3/36).

WHO. A global brief on vector-borne diseases - Section 2. Geneva: World Health Organization; 2014 (https://iris.who.int/handle/10665/111008).

WHO. World malaria report 2020 – Chapter 11. 20 years of global progress and challenges Geneva: World Health Organization; 2020 (https://iris.who.int/handle/10665/337660).

WHO. Ending the neglect to attain the Sustainable Development Goals: a road map for neglected tropical diseases 2021–2030. Geneva: World Health Organization; 2020 (https://iris.who.int/handle/10665/338565).

2

Vector biology, ecology and control

Contents

Learning objectives

By the end of this course, students should be able to:

- demonstrate understanding of vector biology, behaviour and ecology and their significance for the transmission of disease pathogens, as a basis for selecting vector control interventions;
- describe options for vector control intervention for each type of vector; and
- describe the role of participation in vector control.

2.1 Vectors and their life cycles

Knowledge about a vector's life cycle is essential for planning effective vector control interventions, as they should target the stage of the life cycle at which the vectors are most vulnerable or easiest to attack. This section provides risk managers with essential information for understanding vectors and their life cycles.

2.1.1 Identification

Very few species of insects and snails can transmit human pathogens. Identification of which insect species are responsible for transmission of disease agents and which are harmless is a basic requirement for vector control and surveillance. Recognition of the main groups of vectors is simple and can be learnt by any non-specialist; however, differentiation of species of vectors is more difficult and requires specialist entomologists.

Vectors of disease pathogens include mosquitoes, filth flies, tsetse flies, sand flies, blackflies, reduviid bugs ("assassin bugs") and freshwater snails (Table 2.1). Certain genera in each of these groups include the vector species. Some species within a genus can act as vectors and certain cannot. For example, the mosquito genus *Aedes* contains many species, but only two are known to be effective vectors of the dengue virus.

Table 2.1. Types of vectors and the disease agents they can transmit

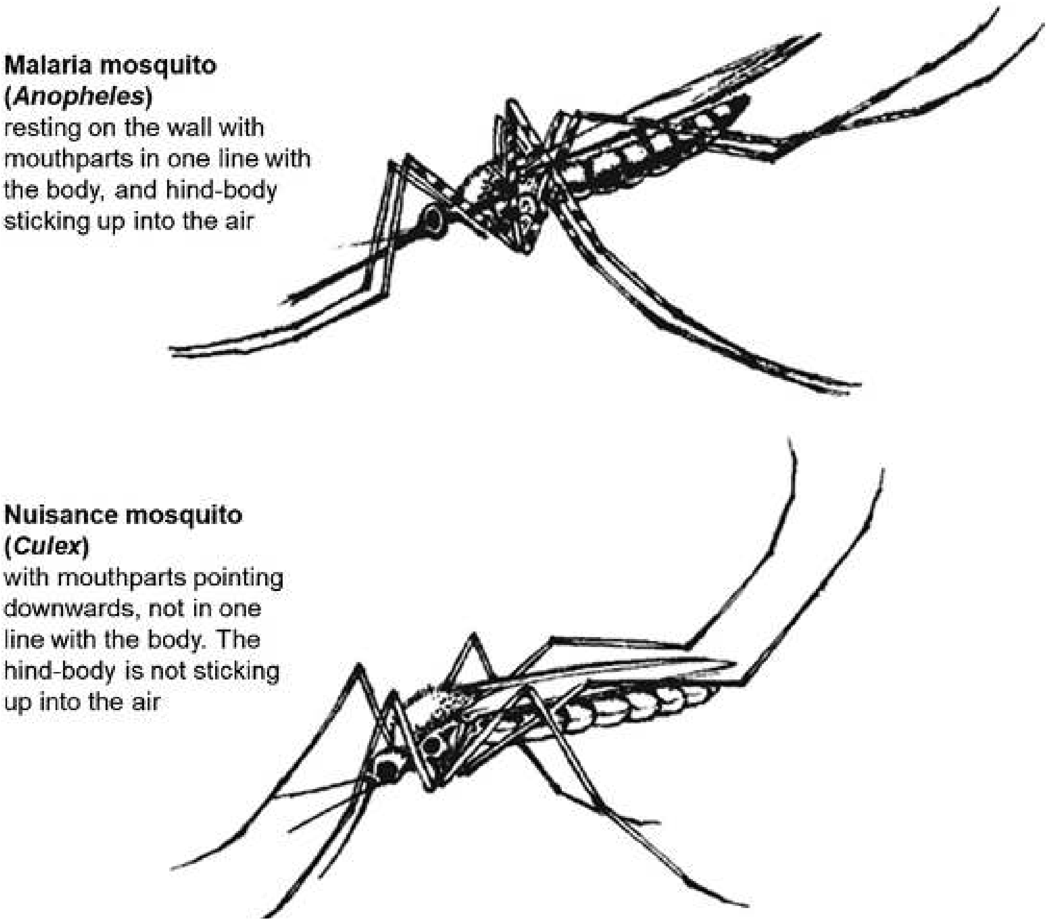
Vector	Disease
Anopheles mosquitoes	Malaria, lymphatic filariasis
Culex mosquitoes	Lymphatic filariasis, several viral diseases
Aedes mosquitoes	Dengue, other viral diseases (chikungunya, Zika virus disease, yellow fever), lymphatic filariasis
Filth flies (*Musca sorbens; M. domestica*)	Trachoma, gastrointestinal diseases
Tsetse flies (*Glossina* spp.)	Human African trypanosomiasis
Sand flies (*Phlebotomus* spp.; *Lutzomyia* spp.)	Leishmaniases
Blackflies (*Simulium* spp.)	Onchocerciasis
Triatomine bugs	Chagas disease
Freshwater snails	Schistosomiasis

2.1.2 Mosquitoes

Mosquitoes belong to the order Diptera, two-winged insects. There are a few thousand species of mosquitoes worldwide, but only a small number can transmit disease agents between humans. Some mosquitoes are not vectors but are a nuisance because of their biting. In this section, we focus on disease-transmitting mosquitoes. The nuisance caused by mosquitoes and other household pests is generally not considered to be a public health problem, even though the burden (e.g. by *Aedes* mosquitoes) can be considerable.

The mosquitoes that most commonly act as vectors belong to the genera *Anopheles*, *Aedes*, *Culex* and, less commonly, *Mansonia*. It is relatively easy to distinguish an *Anopheles* from a *Culex* or *Aedes* mosquito (Fig. 2.1) with a little practice. *Anopheles* can be recognized by their typical resting positions on different surfaces, because their mouthparts are in line with the body, while the hind-body sticks up in the air. *Culex* mosquitoes rest on walls with their mouthparts pointing downwards, not in line with the body, and the hind-body sticks up in the air less than for *Anopheles*.

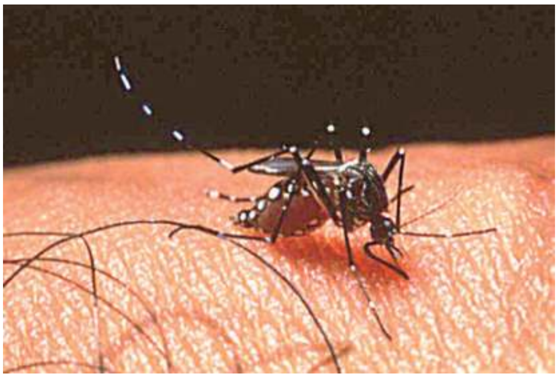
Fig. 2.1. Distinguishing between *Anopheles* and *Culex* mosquitoes



Source: adapted from Rozendaal *(1)*.

Further, the most common *Aedes* species are easily recognized by white-striped markings on their antennae and legs (Fig. 2.2).

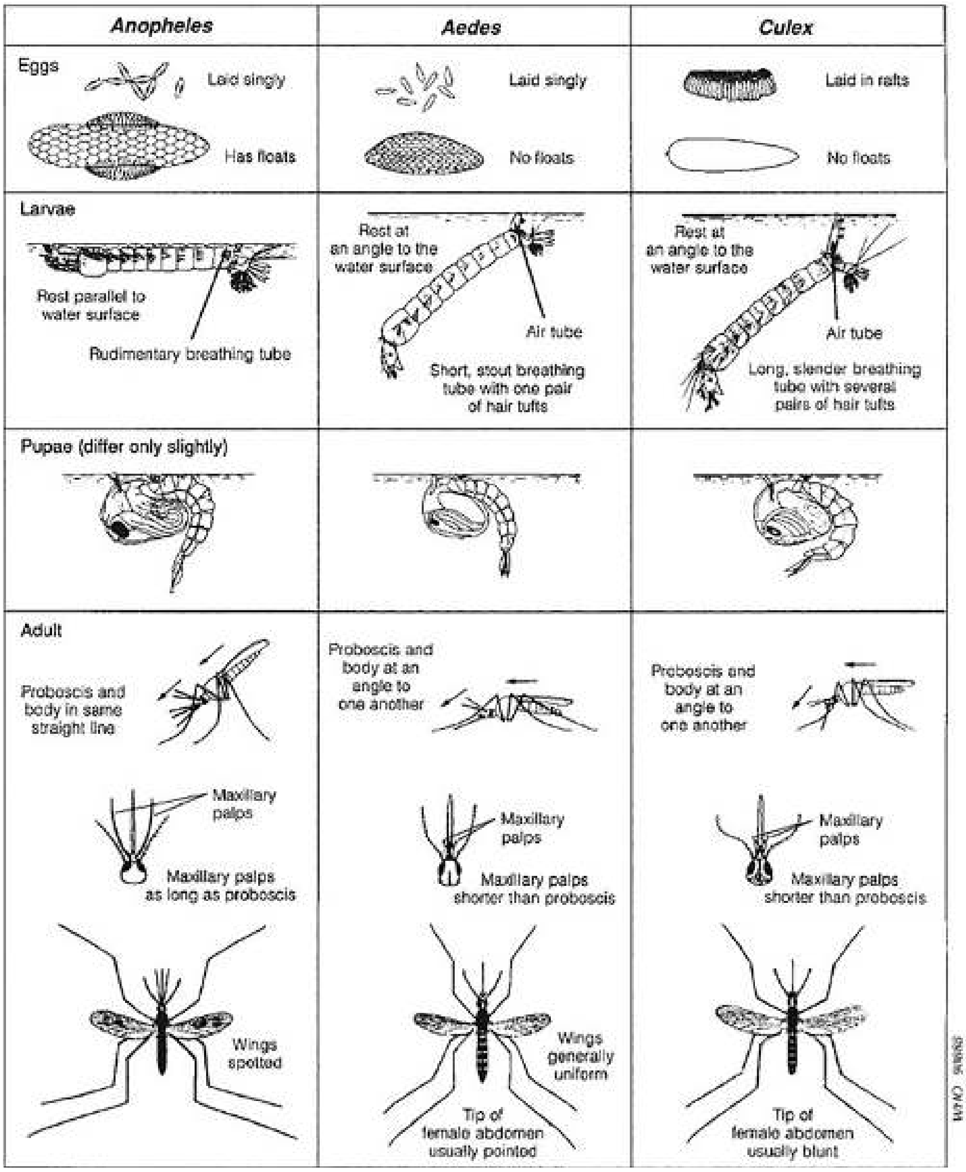
Fig. 2.2. *Aedes aegypti* with distinctive markings on the thorax and legs



Source: photo courtesy of S. Stammers, WHO/TDR.

In their larval stage, *Culex* and *Aedes* larvae show active behaviour, with wiggling or zigzag movements, whereas *Anopheles* larvae are less active and rest in a horizontal position on the water surface (Fig. 2.3).

Fig. 2.3. Simple characteristics for differentiating *Anopheles*, *Aedes* and *Culex* mosquitoes



Source: Rozendaal *(1)*.

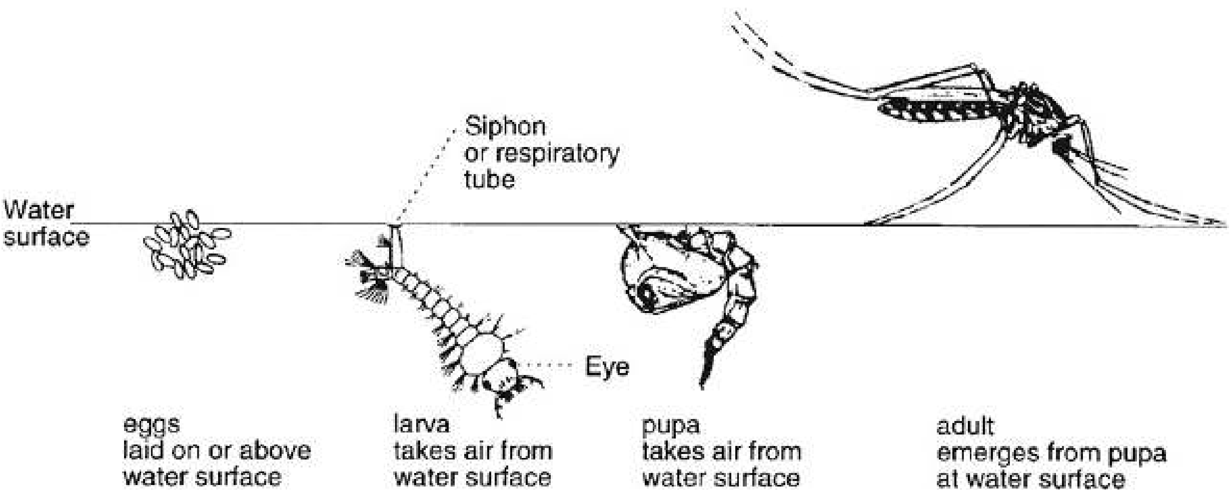
These mosquito genera have similar life cycles. Their tiny, elongated eggs are laid singly or, in the case of *Culex* species, in batches in or near water bodies. Some species lay their eggs on a humid substrate, not on standing water, and the eggs hatch only after the site is flooded, for example by heavy rain. Most mosquitoes, however, deposit their eggs on the surface of water bodies.

The larvae emerge as aquatic stages that develop near the water surface, feeding on microscopically suspended food particles (algae and other organisms). The mouthparts of mosquito larvae rotate rapidly, producing a water current from which the mouthparts filter out the food particles. They are therefore known as “filter feeders”. The larvae breathe through air tubes on their abdomen while resting upside down on the water. The larvae pupate in the water. The pupae can still move actively but stay close to the water surface.

Upon emergence, the adult mosquito flies off and mates, usually within several days. Adult males feed on plant sugar sources, such as nectar, but not on blood. Females also use sugar sources from plants but have to obtain a blood meal in order to produce eggs. After a blood meal, the female mosquito with her abdomen engorged with human blood rests on walls or in crevices for 2–3 days, during which the eggs grow. After the eggs have grown inside the ovaries, the female searches for suitable water bodies and deposits the eggs. The females then start another cycle of blood-feeding, egg development and egg deposition. Repetition of these cycles is essential in the epidemiology of disease, because repeated contact with human hosts allows the disease pathogens to be picked up by a mosquito and to be transmitted through subsequent bites to other humans.

The entire life cycle of mosquitoes, through the four stages of egg, larva, pupa and adult, is relatively short (Fig. 2.4). It takes only 1–5 weeks to develop from egg to adult, depending on the species and on factors such as temperature. Development is generally faster at higher temperatures, and therefore mosquito populations can develop more rapidly in the lowlands than at higher altitudes, where temperatures are lower.

Fig. 2.4. Life cycle of a mosquito



Source: Rozendaal *(1)*.

Male mosquitoes are shorter-lived than females. The females of the most effective vectors of disease pathogens can complete several egg development cycles, the number being directly related to the risk of disease transmission. The older the female mosquito (the more cycles it has completed), the higher the risk that it has taken a blood meal from an infected host and, thus, has become infective. The pathogens of disease take some time to develop and/or reproduce inside the mosquito’s body. Mosquitoes that are short-lived are therefore unable to act as effective vectors of disease pathogens.

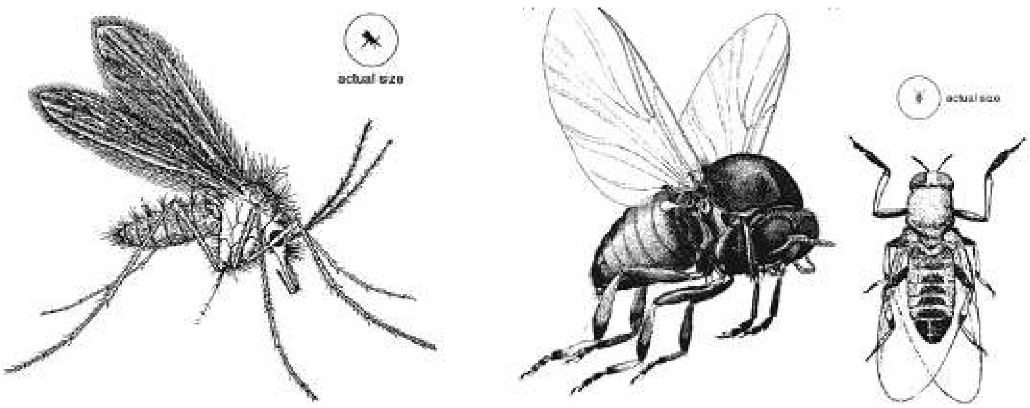
2.1.3 Sand flies

Sand flies, the vectors responsible for transmitting visceral and cutaneous leishmaniases, lay their eggs in soil that is rich in dead organic matter, such as in animal burrows, among tree roots, near animal excreta or in termite mounds. The larvae feed on organic matter. Sand flies therefore thrive well in the presence of domestic animals, with dung available for larval development and animal hosts available for blood-feeding by adult females (Fig. 2.5). The life cycle is completed within 1–4 months.

2.1.4 Blackflies

Blackflies are small (1.5–4 mm long) insects of the genus *Simulium* (Fig. 2.5), some of which act as vectors of onchocerciasis parasites in Africa and Latin America. Blackflies cause painful bites and can be a major nuisance when they appear in large numbers. Females lay their eggs on vegetation in fast-flowing streams or rivers, and the emerging larvae attach themselves to submerged rocks or plants. The pupae also remain attached to vegetation. Upon emergence, the adult leaves the water.

Fig. 2.5. Sand fly (left), blackfly (right)



Source: Rozendaal *(1)*.

2.1.5 Filth flies

Filth flies (*Musca sorbens*) and the related house fly (*Musca domestica*) are closely associated with humans and animals. Both can transmit trachoma blindness and various gastrointestinal diseases by mechanical transmission of pathogens with their legs and mouthparts. Filth flies are particularly effective vectors of the trachoma pathogens. The eggs are typically laid in manure and rubbish and take 1–5 weeks to develop into adult flies. A few hours after the eggs have been laid, white maggots emerge and start feeding on the organic matter. Pupation takes place in soil or dry places. The flies may live from 2 weeks to as long as a few months.

2.1.6 Tsetse flies

Tsetse flies, the vector of human African trypanosomiasis, are species in the genus *Glossina*. They are approximately 6–15 mm long, with pointed mouthparts (Fig. 2.6). The females do not lay eggs but the egg develops and emerges inside the female uterus. Once the larva has fully developed, it is deposited on to soil in a shaded spot, where it burrows itself to pupate. Females deposit a new larva at a minimum interval of 10 days.

2.1.7 Triatomine bugs

Triatomine bugs, the vectors of Chagas disease, are about 2 cm long and live in and around houses (Fig. 2.6). They are the vectors of the pathogens that cause Chagas disease, which is endemic mainly in South America. The bugs have a relatively long life cycle of 4–24 months, usually with one or two cycles per year. The feeding behaviour and habitats of the larvae, or nymphs, are similar to those of the adults, but only the adults have wings.

Fig. 2.6. Tsetse fly (left) and triatomid bug (right)

Source: photos courtesy of Fisher (left) and FG Revilla (right); WHO Photo Library.

2.1.8 Freshwater snails

Freshwater snails of the family Planorbidae are intermediate hosts of the small parasitic worms that cause schistosomiasis (Fig. 2.7). The most common intermediate hosts are aquatic snails, which live only in water, and amphibious snails, which live partly on land. Aquatic snails are intermediate hosts only in South-East Asia. They have both male and female organs, and single specimens can invade and reproduce in new places. The eggs are laid in batches, from which the young snails emerge and become adult after 4–7 weeks. The amphibious snails are of two sexes. Freshwater snails are strictly speaking not vectors but intermediate hosts, because they do not actively transmit the pathogen to humans but simply release the free-swimming stage, cercariae, into water. The cercariae enter a human host by penetrating skin in contact with infected water.

> The vectors of which diseases require water bodies in which to breed?

Fig. 2.7. Breeding site for *Bulinus* snails in Mali (left); *Bulinus* spp. snails (right)

Source: photo courtesy of H. van den Berg.

2.2 Vector behaviour

A vector's behaviour, its feeding preferences, its association with human habitations and its activity patterns are important aspects to consider in selecting vector control interventions. The behaviour of groups of vectors and even species in the same genus may differ widely.

2.2.1 Mosquitoes

A number of aspects of mosquito behaviour are important in relation to their role as vectors of human disease pathogens, including the time of biting, their preference to feed or rest indoors or outdoors and their preference to feed on human hosts or animal hosts. It is also important to determine whether the mosquitoes have changed their behaviour as a result of vector control, thus reducing the effectiveness of the intervention. The behaviour of mosquitoes that risk managers should understand are described below.

Diurnal or nocturnal. Diurnal behaviour refers to that of female mosquitoes that blood-feed during the day. The best example is *Aedes* species, "tiger mosquitoes", which are small, have characteristic black-and-white rings around their legs, and bite mainly in the morning and late afternoon. Most *Anopheles* and *Culex* species prefer to bite during the evening and night, around dusk or dawn or around midnight. *Cx. quinquefasciatus* is a very common species that is a nuisance at night due to its characteristic humming sound and itchy bites. In general, night-biting mosquitoes are easier to control than day-biting mosquitoes because they can be targeted by interventions indoors at a fixed location where people sleep (e.g. bed nets, wall spraying), whereas during the day people move around and can be bitten by day-biting mosquitoes outdoors. Vector control interventions used to target the indoor environment or to protect people during sleep are therefore generally effective against night-biting mosquitoes but not against day-biting, which may occur outdoors.

Consider this: Why are day-time biting mosquitoes more difficult to control with interventions than night-time biting mosquitoes?

Endophagy or exophagy. Some mosquitoes prefer to bite indoors (endophagy), while others bite mainly outdoors (exophagy). Indoor-biting mosquitoes are good targets for vector control interventions such as bed nets and IRS when they are active at night. Outdoor biting is more difficult to control because it can occur anywhere. Some *Anopheles* species bite strictly indoors, while others feed partly outdoors. The outdoor-biting fraction of the mosquito population is difficult to control if a programme relies on ITN and IRS. *Aedes* species feed both indoors and outdoors.

Endophily or exophily. Not only the place of biting but also the place of resting is important for vector control. After blood-feeding, female rest for several days to digest the blood and develop eggs. Some mosquitoes bite indoors (Fig. 2.8) or inside cattle sheds, and, after biting, the engorged females rest on walls or ceilings in the same room (endophily). This resting behaviour is important because IRS specifically targets indoor-resting insects. Some mosquitoes bite indoors but, after feeding, fly outside, in a "hit-and-run" strategy. Other mosquitoes bite mainly outdoors (exophily).

Fig. 2.8. Sampling of *Anopheles* mosquitoes resting in corners and crevices indoors during the day

Sources: photos courtesy of H. van den Berg (left); and ICMR-National Institute of Malaria Research, Nadiad, India (right).

Consider this: If IRS kills a mosquito only after it has fed and is resting on a sprayed wall, explain how IRS helps control malaria.

Anthropophily or zoophily. Mosquito vectors also differ in their host preference. Some species feed exclusively or mainly on animals, including domestic animals (zoophily), while others prefer to feed on humans (anthopophily). The most dangerous vectors are those that feed exclusively on humans, because they facilitate efficient transmission of disease agents from person to person. Mosquito vectors that feed partly on animals are less efficient, especially when the animal hosts are so-called "dead-end" hosts that do not support development and reproduction of the disease agents.

Behavioural resistance. Mosquitoes may change their biting behaviour as a consequence of vector control interventions. For example, some *Anopheles* species have changed from biting at midnight to biting during the early evening. There have also been reports of shifts from indoor to outdoor biting and resting behaviour in areas of intensive use of ITNs or IRS *(2,3)*. Such behavioural changes could reduce the effectiveness of malaria control. Reports from West Africa indicate a change in the behaviour of the highly efficient malaria vector *An. funestus*, from night-biting to day-biting after the introduction and distribution of ITNs *(4)*. In the absence of animals, the mainly zoophilic *An. culicifacies* species was found to feed on humans in a riverine village in India *(5)*.

Explain how a behavioural change in the vector population can reduce the effectiveness of ITNs.

2.2.2 Sand flies

Sand flies are weak fliers, with a limited range. During the day, sand flies take refuge in rock crevices, dense vegetation or indoors. Females of many species feed and rest outdoors. Only the species that feed and rest indoors are targets for vector control through IRS. Control of outdoor-resting anthropophagic and zoophilic sand fly vectors is therefore a major challenge. Sand flies commonly feed on animals, and humans are often infected by infectious animals. Sand flies can be collected by aspirators and light traps.

2.2.3 Blackflies

Simulium species blood-feed mainly outdoors during the day and feed on animals as well as humans. Only the females blood-feed; both sexes feed on plant sugars. Adult flies disperse mainly along rivers. Although in tropical Africa the species *S. damnosum* appears to be the main vector, several other species of Simuliidae are good vectors. The flies become infective 6–8 days after infection. Infectious nematodes escape from a blackfly during a blood meal. Females deposit their eggs in masses on sticks or plants in fast-flowing, clean water and also in turbulent water near rapids or sluice gates, where sufficient oxygen is available for the larvae to develop. Larvae cluster and are tightly attached. The pupae develop in the water, and the emerging adults search for blood from animals or humans.

2.2.4 Filth flies

Filth flies and house flies feed on food remains, rubbish, solid organic waste, sweat and excreta from animals and humans, but require the presence of water. The flies are active only during the day and live near their food sources. Fly control is essential for controlling trachoma and fly-transmitted intestinal diseases.

2.2.5 Tsetse flies

Tsetse flies spend most of their time resting in the shade, on tree trunks or twigs in forested areas close to the ground, often in the vicinity of animal hosts. The flies spend short periods searching for hosts. Both males and females feed on blood. Most sub-species prefer to feed on animals, but some are opportunistic, switching to any host that is available, including humans who enter their habitat. Control of trypanosomiasis appears to be most effective when it consists of controlling the tsetse vectors. This was originally done by clearing bush or eradicating wild animals. In the 1950s, the insecticides DDT and dieldrin became widely used for tsetse fly control; they were later replaced by an organophosphate and synthetic pyrethroids. More recently, tsetse flies have been controlled with tiny targets containing deltamethrin and odour-baited traps, which are low-cost, sustainable methods of vector control *(6)*.

2.2.6 Triatomine bugs

Some species of triatomine bugs are closely associated with the living spaces of humans and domestic animals. The bugs feed on wildlife and humans and frequently inhabit cracks and ceilings in dwellings. The species that act as vectors of Chagas disease are active and bite at night. They rest during the day, often hidden inside crevices in walls, inside beds or in thatched or wooden roofs. The bugs also rest just outside houses or in animal shelters.

2.2.7 Invasive species and emerging diseases

The two mosquito species that have spread most successfully around the world are *Ae. aegypti* and the *Cx. pipiens* complex *(7)*. These mosquitoes survived and bred on board sailing ships in past centuries, breeding in open containers filled with fresh water on board these ships. Small populations were introduced into new countries upon arrival. *Anopheles* species also spread in sailing ships, leading to the introduction of malaria in new areas, such as Brazil *(8)*. *An. stephensi* has recently invaded new territories in the Horn of Africa and in Sri Lanka *(9,10)*.

Review: Benedict MQ, Levine RS, Hawley WA, Lounibos LP. Spread of the tiger: global risk of invasion by the mosquito *Aedes albopictus*. Vector Borne Zoonotic Dis. 2007;7(1):76–85. doi:10.1089/vbz.2006.0562. *(11)*

The conditions for breeding on board ships are uncommon today, as fresh water is safely stored in closed containers, and mosquitoes do not breed in salty water. The most invasive mosquito species is now *Ae. albopictus*, the tiger mosquito *(11)*, a known vector of dengue, chikungunya and several other arboviral diseases. This species has adapted to survive long periods of drought, because its eggs can enter diapause, a stage of hibernation, and emerge upon contact with water. This species is notorious for its exploitation of used car tyres with accumulated water, which is a reliable breeding habitat. Even during drought, the female mosquitoes deposit their eggs in dry tyres, and the eggs emerge in contact with water after rain *(12)*. International trade in used tyres shipped to countries for re-use or re-threading has resulted in inadvertent importation and global distribution of tiger mosquito eggs into many new countries *(13)*. Importation of certain plants and plant parts (e.g. "lucky bamboo") has also facilitated importation of *Ae. albopictus (14)*.

Consider this: Why is *Ae. albopictus* (the tiger mosquito) such a successful invasive species?

Disinsection of aircraft and ship cargo with aerosol sprays and residual treatments and quarantine on the importation of plant products or plant parts can reduce the risk of introduction of live mosquitoes or their eggs into new countries or areas. The WHO guidelines on aircraft disinsection have recently been updated *(15)*. This is still considered to be effective in reducing the risk of introduction of insects into a country *(16)*, but there are limited data on its effectiveness. Furthermore, frequent exposure to insecticides could increase the risk of aircraft crew for poisoning *(17)*. Individual mosquitoes carried inside airplanes are less likely to establish themselves successfully in the country of arrival, while small colonies of *Ae. Albopictus* can be introduced (in the egg stage) in used tyres. There have been calls to restrict or even ban exportation of used tyres to reduce the risk of spread of tiger mosquitoes.

2.3 Ecology and ecosystems

Vectors have two major requirements to survive and reproduce: suitable habitats for breeding that allow them to proliferate, and appropriate sources for feeding on human or animal hosts, sometimes supplemented with plant materials (e.g. nectar). The requirements of each type of vector result in intricate interactions with their environment in selecting microhabitats and ecosystems suited for their development and reproduction. Understanding the ecology of individual vector species and the association of several vectors with particular ecosystems is vital to designing appropriate methods for vector control.

A distinction is made between the "microhabitat", the smallest part of the environment that supports development or reproduction of a vector, and the ecosystems that constitute a biological environment in which many species of organisms live in an interrelated fashion.

2.3.1 Microhabitats

Vectors have particular requirements for their development. Mosquito vectors, such as some *Anopheles* species, search for clear, sunlit water bodies with suitable nutrients and often do not lay their eggs if they detect the presence of predatory insects or spiders. Some species can develop in car tracks or hoof prints filled with water during rains. Other *Anopheles* species prefer shaded water bodies, streaming water or brackish water. It is thus important to know the preferred habitat of the principal vector for larval control. Some species of *Culex*, including those that are vectors of human disease agents, develop in highly polluted water, even in pit latrines, and can become numerous in urban or village environments where sanitation and drainage are poor. Polluted water bodies cannot produce the vectors of malaria, which require clear water.

One of the most common species of *Aedes* mosquitoes, *Ae. aegypti*, is the vector of several viral diseases, including dengue and yellow fever, and commonly occupies small water containers in the human environment, such as flowerpots, vases, coconut husks, plastic bottles and used car tyres. Other *Aedes* species prefer to breed in the leaf axils of certain plants, which contain standing water, holes in trees and small tanks filled with water.

A simple comparison of the characteristics of the preferred breeding habitats of *Anopheles*, *Culex* and *Aedes* mosquitoes is presented in Table 2.2. Important characteristics are the type and size of a water body, whether it is temporary or permanent, flowing or stagnant, clear or turbid, sunlit or shaded, deep or shallow, and whether it contains predators that can feed on mosquito eggs or larvae. Locally important vectors must be understood so that their breeding sites can be characterized to target larval control.

Table 2.2. Characteristics of common breeding sites for three mosquito genera

Characteristic	*Aedes*	*Culex*	*Anopheles*
Type of water body	Plastic containers, tyres, holes in trees, leaf axils, puddles, rockpools	Blocked drains, puddles, shaded pools	Rooftops, sunlit pools, hoof prints, seepage pools
Permanent or temporary	Temporary	Mainly temporary	Mainly temporary
Large or small	Small	Small, large	Small, large
Flowing or stagnant	Stagnant	Stagnant, mildly flowing	Stagnant, mildly flowing
Clear or turbid	Clear, turbid	Turbid	Clear
Sunlit or shady	Shady	Shady	Sunlit
Deep or shallow	Shallow	Shallow	Shallow
Predators (fish, insects)	Rarely found in the presence of predators	Rarely found in the presence of predators	Rarely found in the presence of predators

Source: WHO *(18)*.

Blackfly vectors of onchocerciasis parasites prefer streams and rivers, which provide the conditions for their larval development. In contrast, sand flies do not require water bodies for larval development but prefer rich organic soil and plant roots that provide food for their larval stages. Tsetse flies are associated with shaded forested savannah landscapes. Houseflies, filth flies and triatomine bugs are closely associated with the peri-domestic environment and domestic animals. Snail vectors of schistosomes have their own aquatic habitats, with plant species on which they feed.

Predation plays an important role in suppressing the populations of most vector species. The developmental stages (egg, larvae and pupae) of most vectors are vulnerable to attack by predatory insects, spiders or small fish, and these predators are beneficial organisms that should be conserved. A problem associated with the use of insecticides to kill vectors (e.g. in larviciding) is that they can also destroy many of the predators that usually feed on the vectors when left undisturbed. When, after spraying, insect vectors and predators are decimated, vectors can re-colonize relatively quickly, while most predators recover only slowly, giving the vectors an advantage. Current WHO guidelines include prevention of contamination of drinking-water and protection of fish and crustaceans *(19)*; however, guidance on the protection of arthropod predators in permanent or semi-permanent aquatic habitats should be developed further. Certain bacterial insecticides, particularly *Bacillus thuringiensis israelensis* (discussed in section 2.4), are highly specific, killing only mosquitoes and not adversely affecting beneficial organisms such as spider predators, bugs or aquatic beetles.

2.3.2 Ecosystems

Many different ecosystems can be distinguished, each with its own conditions for vector breeding and, consequently, each harbouring its own complex of vector species and disease pathogens that they may transmit. The differences have important implications for disease control programmes *(20)*. Ecosystems are categorized as: urban, savannah, irrigated agriculture, smallholder farming, riverine, plantations, coastal, forest and forest fringe. Each ecosystem has unique disease settings or vector species. For example, in irrigated rice ecosystems, the vector species and diseases are different from those in tropical forests in the same region. Malaria could be prevalent in both ecosystems but is probably transmitted by different vector species with their own microhabitats.

Urban ecosystems are characterized by high human density, many vector shelters, solid waste, contaminated surface water (preferred for breeding by *Cx. quinquefasciatus*) and small-scale vegetable gardening. Poor urban environments (e.g. slums and shanty towns) are characterized by poor sanitation, no or inconsistent rubbish removal and poorly constructed houses, conditions that are favourable to one or more disease vectors. High human density enables efficient person-to-person transmission, even for vectors that are weak flyers. A number of vectors have adapted to characteristic urban conditions. Flies and other pests feed on solid waste and excreta. *Aedes* mosquitoes, which can transmit various disease viruses, use artificial containers and rubbish filled with water as breeding sites. *Culex* mosquitoes breed in large numbers in polluted or contaminated water resulting from poor sanitation and drainage, including in pit latrines. Malaria is not generally considered to be an urban disease, but in many situations in tropical cities malaria is a problem. Irrigated vegetable gardens in a city's perimeter can provide the clean water habitats preferred by *Anopheles* mosquitoes, the vectors of malaria parasites. In cities in South Asia, the malaria vector *An. stephensi* has adapted to breeding inside water tanks in or near people's houses. Bedbugs are a problem associated with high population density and are a pest in major cities in developing countries and an increasing problem in European cities *(21)*. The issue of urbanization is addressed in section 6.

Savannah ecosystems are characterized by seasonal changes in rainfall, hot temperatures and temporary water bodies that serve as breeding habitats for mosquito vectors. These ecosystems harbour highly efficient vectors of malaria and the vectors of several other diseases, including tsetse flies. Moreover, human settlements in these ecosystems can attract filth flies, sand flies and snails that are vectors for a number of disease pathogens. Seasonal rainfall usually results in a peak in transmission of disease.

In irrigated agricultural ecosystems, unlike rain-fed agriculture, water is available for prolonged periods, which favours the breeding of various vectors. Irrigation can bring water and crop cultivation to areas that were previously arid or semi-arid. Some of the most common are irrigated rice systems, particularly in Asia, where rice is grown in flooded conditions (Fig. 2.9). Irrigation not only creates new conditions for vectors (mosquitoes, snails) to breed but also extends the period during which these vectors can proliferate; areas with three crops of rice per year, for instance, provide breeding conditions almost continuously. Other examples of irrigated crops are cotton, sugar cane and vegetables. Canal irrigation comprises a system of canals, shallow ditches and seepage pools. Overhead irrigation can create puddles of standing water. All these water bodies provide suitable breeding sites for various vector species. During development of a rice crop, the conditions for vector breeding change from flooded and fully sunlit to more shaded conditions as the rice plants grow. Some mosquitoes prefer the sunlit conditions and are thus likely to be common in the early rice season, while others prefer the shadier conditions of the maturing crop. Snails that act as intermediate hosts of schistosomiasis parasites may be common in irrigation canals, feeding on the aquatic plants. After harvesting of rice, puddles of standing water usually remain in the fields for some time, providing new breeding opportunities for mosquito vectors.

Fig. 2.9. Irrigated rice ecosystems, with breeding of *An. culicifacies* in Sri Lanka

Source: photos courtesy of H. van den Berg.

Smallholder farming ecosystems are usually non-irrigated agricultural environments with subsistence farming and small human settlements but no public services. Under these conditions, which are generally accompanied by poor education, low income, and lack of water and sanitary facilities, poverty is widespread, creating conditions that are favourable to a number of disease vectors. Lack of access to health services results in late or no treatment of infections and no preventive interventions such as ITNs. Poor housing conditions and the presence of domestic animals and dogs in the peri-domestic environment also favour the establishment of vector populations and contact between animal and human hosts. Vectors associated with these ecosystems include mosquitoes, flies and sand flies.

Fig. 2.10. A typical riverine breeding habitat for the blackfly vector of *Onchocerca volvulus*, the parasite that causes onchocerciasis

Source: photo courtesy of D. Baldry (WHO/TDR).

Riverine ecosystems are the environments in the vicinity of rivers and streams. Clean running water provides a suitable habitat for blackfly vectors (*Simulium* species) of onchocerciasis (Fig. 2.10). Some species of *Anopheles*, including the vectors of malaria parasites, are adapted to breeding in small streams, while others breed in the pools created in riverbeds during the dry season. In certain areas of South-East Asia, the risk of contracting malaria is greatest near forest streams on hillsides, because they are the habitat of the principal local vector. Some species of tsetse flies prefer to breed in riverbeds and riverine forests and can transmit trypanosomes between animals and humans.

Plantation ecosystems, especially in humid tropical zones, commonly harbour effective vectors of disease pathogens. Examples are rubber and oil palm plantations in South-East Asia, which provide breeding conditions for some species of *Anopheles*, which transmit malaria parasites. Hence, plantation workers are at risk of the disease. In West Africa, tsetse flies can take shelter in the shaded conditions provided by cocoa plantations, and epidemics of human African trypanosomiasis may occur. Sugar cane plantations with overhead irrigation can create water pools in which *Anopheles* or *Culex* mosquitoes can breed.

Coastal ecosystems include estuaries, coastal marshes, lagoons and mangrove forests, all of which are the habitats of various vectors of human disease agents. In Africa, Asia and Latin America, certain species of *Anopheles* mosquitoes have adapted to breeding in the brackish water found in coastal marches and estuaries. In large river deltas, agriculture is practised on annually flooded plains. These conditions support the vector breeding and pathogen transmission of malaria and schistosomiasis.

Forest and forest fringe ecosystems areas can support various vector species, but the size of vector populations depends on the presence and abundance of human or animal hosts. In the absence of hosts in a deserted area, the mosquito vectors cannot thrive because of lack of the blood meals they require for egg development. Forest clearing for mining, logging or moving cultivation of crops can create new vector breeding sites as well as human hosts, which can result in serious outbreaks of diseases such as malaria and Chagas disease, especially where the human hosts have no or limited immunity to the disease pathogens. In Latin America, the sand fly vectors of *Leishmania* parasites dwell in rainforest ecosystems, adapted to conditions of dark shade and high humidity.

2.4 Vector control options

Vector control refers to all interventions or activities for **reducing the populations** of vectors and/or **reducing human contact** with vectors. Vector control is a major component of the prevention and control of most vector-borne diseases. For some vector-borne diseases (e.g. dengue, chikungunya), there are no effective drugs or vaccines, and, thus, the vector itself is the target for control. Vector control, when properly planned and implemented, can reduce or interrupt the transmission of disease pathogens.

A number of options or methods of vector control are available *(1)*. The methods can be divided into four categories: environmental, mechanical, biological and chemical. It should be noted that chemical methods are mentioned last, even though, in practice, they are most often those selected and used in vector control programmes.

The approach of integrated vector management (IVM; discussed in detail in sections 3 and 4), is modelled on the successful example of integrated pest management in agriculture. In these approaches, insecticide application is considered the method of last resort, after all non-chemical methods have been considered or attempted. For example, in the case of mosquitoes, it may be easier to control the larvae than the adults because the larvae are confined to water bodies, particularly when the breeding sites are few, focal and findable *(22)*. Thus, a method such as removal of water bodies that serve as mosquito breeding sites, called "source reduction", could be a primary consideration.

Guiding questions to be asked by risk managers when selecting vector control methods:

- Has the method proven to be effective?
- Is the method likely to be effective under local circumstances?
- Is the method in line with current government policies?
- What are the costs involved in terms of materials, protective equipment, staff salaries and supervision?
- What is the optimal timing and frequency of the vector control method?
- Does the vector control method pose any risk to the health of applicators and residents?
- What are the risks to the environment and non-target organisms?
- If insecticides are used, is there evidence that local vector populations are susceptible to the selected insecticides?
- What role should communities or other end-users play in compliance or active involvement in planning, implementation and evaluation?
- Is logistics support available for implementation of the method?

Review:

- Guidelines for malaria vector control. Geneva: World Health Organization; 2019 (https://iris.who.int/handle/10665/310862).
- Malaria entomology and vector control. Guide for tutors – Guide for participants.Geneva: World Health Organization; 2013 (https://iris.who.int/handle/10665/85890).

2.4.1 Environmental methods

Environmental management is the manipulation or modification of environmental factors to reduce the survival and reproduction of vectors and to reduce contact between vectors and humans or domestic animals. Environmental management was once the mainstay of vector-borne disease control, before effective drugs and insecticides became available for diseases such as malaria and lymphatic filariasis. The potential of larval source management, which is any measure used to target the immature, aquatic stages of the mosquito (the larvae and pupae), has recently been reconsidered. It includes both environmental methods and larviciding (use of biological or chemical insecticides). The results of a systematic review on mosquito larval source management for controlling malaria *(23)* showed that, in Africa and Asia, this is a useful policy option for malaria control, with ITNs and IRS, as it reduces malaria morbidity in both urban and rural areas when a sufficient proportion of larval habitats is targeted. The conclusion was that further research is necessary to determine whether larval source management is appropriate or feasible in parts of rural Africa where larval habitats are more extensive.

WHO has published an operational manual for the use of larval source management as a supplementary measure for malaria vector control *(22)*.

What is larval source management?
Malaria is transmitted by female mosquitoes of the Anopheles genus (anophelines). The life cycle of the mosquito has four stages: egg, larva, pupa and adult, the first three of which are aquatic. Larval source management consists of management of aquatic habitats (water bodies) that are potential larval habitats for mosquitoes, in order to prevent completion of development of the immature stages (22). The four types of larval source management are:
- habitat modification: a permanent alteration to the environment, e.g. land reclamation;
- habitat manipulation: a recurrent activity, e.g. flushing of streams;
- larviciding: regular application of biological or chemical insecticides to water bodies; and
- biological control: introduction of natural predators into water bodies.

Environmental management can contribute substantially to malaria control by making temporary or long-term changes to the vector habitat. The most common methods are source reduction, environmental manipulation, irrigation management and design, the proximity of livestock and waste management. The elements of each with which risk managers should be familiar are described below.

Habitat modification**:** Habitat modification is a permanent alteration to the environment, such as land reclamation of water bodies for the elimination of vector breeding sites by drainage, land levelling, filling or covering. Habitat modification is highly relevant to mosquito control because mosquitoes require suitable water bodies to deposit their eggs. Draining and filling are most straightforward in areas where water bodies are made by human beings, e.g. in cities. As sources for vector proliferation may be available in people's domestic sphere, the participation of communities in source reduction is essential for widespread effectiveness.

House flies and filth flies can be prevented from proliferating by improving environmental sanitation and hygiene, for example by reducing fly breeding sites, protecting food items from contact with flies, personal hygiene and removal of sources that attract flies *(1)*.

Habitat manipulation**:** Habitat manipulation refers to recurrent elimination of breeding of disease vectors, such as flushing of streams. Habitat manipulation can include improvement or management of water bodies or impounding water; clearance of aquatic vegetation when this is used for larval development by local vectors; and providing shade or sunlight for water bodies to prevent breeding by vectors that prefer sunlit or shady conditions *(24)*. Streams or canals can be flushed by sudden release of impounded water upstream or by improving or straightening river banks *(25)*. Snail intermediate hosts of schistosomiasis are also vulnerable to changes in their habitat, such as through seepage control, stream canalization, proper drainage, vegetation removal, ponding and adapted agricultural practices.

Irrigation management and design: Various vectors of the agents of malaria, lymphatic filariasis and schistosomiasis proliferate in irrigated agricultural areas and their water delivery structures. In particular, irrigated rice, with its flooded conditions and wide areas, can contribute substantially to vector numbers and malaria transmission. The influence of irrigated agriculture on malaria prevalence remains, however, unresolved in most cases *(26)*. Irrigation may increase vector breeding but also increases farmers' income and thus the quality of their housing and living conditions; and these factors may compensate each other. Mosquito vectors that breed in irrigated crops are potentially controlled by a combination of environmental methods, such as land levelling, bounding and intermittent irrigation. Intermittent irrigation also increases rice production, as rice plants develop better with occasional drainage of surface water *(27)*. During development of new irrigation systems or dams, precautions must be taken to prevent vector breeding or human–vector contact. Hence, health impact assessments should be conducted at the design stage to avoid health risks.

The development and management of water resources determine the prevalence of schistosomiasis. For example, in the Senegal river basin, construction of major dams enabled the creation of new irrigation canals, extension of irrigated rice fields but also suitable habitats for the snail that is the intermediate host of schistosomiasis. This led to a high prevalence of the disease *(28)*. Water development projects should therefore include strategies to mitigate negative effects of water management.

Proximity of livestock: Certain vectors are attracted more to domestic animals than to humans. For disease pathogens such as malaria parasites that do not develop and reproduce in animal hosts, so-called "dead-end hosts", these hosts could be used as an attractant. This method, of luring vectors and their disease pathogens away from human hosts, is called zooprophylaxis *(29)* and is applicable to vectors that strongly prefer feeding on animals rather than humans.

Waste management: Solid waste provides breeding opportunities for filth flies and houseflies, while polluted water is suitable for breeding of *Culex* mosquitoes, which can contribute to transmission of lymphatic filariasis. Solid waste can be managed by creating dung heaps and storing, collecting and disposing of rubbish. Improved sanitation, drainage and construction and improvement of latrines and toilets are essential for suppressing the populations of these vectors.

2.4.2 Mechanical methods

House improvement: Vectors may be much more numerous in some houses than in others. The mosquitoes, flies and triatomine bugs that are associated with human dwellings prefer to hide in crevices and holes in walls, thatched roofs and wooden structures that give shelter and protect against desiccation. Improvement of housing is important for limiting the presence of vectors indoors and thus reducing human–vector contact (Fig. 2.11). Houses can be improved, for example by plastering walls and ceilings, filling crevices and holes and screening the eaves and windows of houses and sleeping quarters.

Fig. 2.11. House improvement: community members closing eaves and screening windows in Malawi

Source: photo courtesy of H. van den Berg.

Housing design has recently improved in sub-Saharan Africa and perhaps in other regions. Traditional building materials such as metal for roofs and cemented walls have been partly replaced with modern materials, and eaves have been closed. This has been associated with lower vector densities and a lower prevalence of malaria. Moreover, existing housing can be improved by window screens and closing eaves to keep the vectors out while maintaining ventilation. Communities are important in improving their housing *(30)*, and a number of studies indicate the importance of house improvement in malaria control *(31)*. A review of two trials of housing modifications to prevent malaria showed some evidence that screening may reduce malaria transmission and infection in people living in the house *(32)*. Four more trials may soon provide further evidence of the benefits of house improvement. Most such studies have addressed malaria control; however, house improvement can also have an impact on arboviral diseases that are transmitted by *Aedes* mosquitoes (dengue, chikungunya, Zika), especially as these mosquitoes live and breed inside or around people's houses.

Polystyrene beads: Spreading a thin layer of expanded polystyrene beads on the surface of small, confined water bodies prevents mosquitoes from depositing eggs and suffocates mosquito larvae (Fig. 2.12). Polystyrene beads have been used in the control of lymphatic filariasis and malaria in areas where vector breeding was more or less confined to burrow pits, pit latrines, wells and small water tanks *(33)*. The use of polystyrene, however, raises concern about environmental pollution.

Fig. 2.12. A layer of polystyrene beads prevents mosquito larvae from reaching the water surface to breathe.

Source: photo courtesy of Rajpal S. Yadav, ICMR-National Institute of Malaria Research, Nadiad, India.

Mineral oil: Application of mineral oil to water bodies is common for vector control in many countries. Its effectiveness in terms of protection against transmission is doubtful, but it may provide temporary relief from the nuisance of mosquitoes *(34)*. Addition of mineral oils to aquatic ecosystems can be harmful and can pollute drinking-water. The use of engine oil or kerosene to treat water bodies should be discouraged, because of risks to the environment and human and animal health.

2.4.3 Biological methods

Conservation of natural enemies: Natural enemies of vector species include the predatory insects, spiders and fish that occur in water bodies where vectors breed. Mosquito larvae are particularly vulnerable organisms; they have few defence mechanisms and stand little chance against aquatic predators and are unable to flee. Predators are especially common in large, permanent habitats such as marshes, rivers, lakes and permanent ponds and may also be abundant in irrigated environments, such as rice fields *(35)*.

Conservation or enhancement of natural enemies can be promoted by the introduction of insects, crustaceans or fish. The use of insecticides in water bodies, especially those with broad-spectrum action against a wide range of organisms, however, kills most predator species. After spraying, the predators recover only slowly, whereas some vector species, particularly mosquitoes, recolonize more efficiently, giving them a head-start in recently sprayed water bodies *(35)*. Thus, although larvicides control aquatic vector stages, they may also decimate populations of natural enemies, unless highly specific larvicides are used. The destruction of natural enemies increases dependence on insecticides.

The pupal stage of tsetse flies are attacked by a variety of vertebrate and invertebrate predators, although the adults manage to escape most of the predation pressure.

The intermediate snail hosts of schistosomiasis have a number of natural enemies *(36)*; however, it is considered unlikely that indigenous predators will be able to control the snail populations. Several attempts have been made to introduce exotic predator species, such as Chinese grass carp, but such introduction carries its own risk, and the snails can hide from predators inside aquatic vegetation.

***Fish*:** Fish have been used for the control of larval stages of insects, including mosquitoes, for almost two centuries. Various studies have reported the effect of fish in reducing the larval densities of mosquito species of the genera *Anopheles* and *Culex,* and a few also showed an impact on malaria *(37,38)*. Most of the studies, however, had poor experimental design.

A systematic review on the efficacy of larvivorous fish in preventing malaria transmission concluded that "reliable research is insufficient to show whether introducing larvivorous fish reduces malaria transmission or the density of adult anopheline mosquito populations" *(39)*.

Weak evidence suggests that introducing large stocks of fish into localized water bodies, such as wells and domestic water sources, rice field plots and water canals, reduces the density or presence of immature anopheline mosquitoes. It is unknown whether introduction of fish alone or with other vector control measures will benefit health. Furthermore, the effect of introduced fish species on native fish and other non-target species should be studied.

Biological larvicides: *B. thuringiensis israelensis* and *B. sphaericus* produce toxins that kill mosquito larvae when ingested. Formulations of these bacteria have been used as biological larvicides to treat water bodies in order to reduce vector proliferation *(40)*. The toxins are specific to mosquitoes and do not affect beneficial natural enemies. *B. thuringiensis israelensis* is increasingly being used to control mosquito nuisance and vectors, and three formulations have been recommended for larval control within the WHO Pesticide Evaluation Scheme.

Review: Mutero CM, Okoyo C, Girma M, Mwangangi J, Kibe L, Ng'ang'a P et al. Evaluating the impact of larviciding with Bti and community education and mobilization as supplementary integrated vector management interventions for malaria control in Kenya and Ethiopia. Malar J. 2020;19:390. doi:10.1186/s12936-020-03464-6.

Fungi: Fungi that are pathogenic to insects could play a role in mosquito vector control *(41)*, although further study is required. Fungi have shown promising results in trials in controlling adult *Anopheles* mosquitoes when sprayed on surfaces inside houses to kill mosquitoes that are resting after a blood meal. Fungi might also be used to control *Aedes* species.

Botanicals: In many traditions, local plants and leaves are burnt to repel mosquitoes and prevent biting. Repellent plants can also be potted or planted near or in houses to help reduce vector–human contact *(42)*. Repellents are widely availability and can be a useful complement to mainstay methods of vector control. Botanical products, particularly neem oil, are occasionally used as larvicides, and some studies have investigated the potential of other botanicals. Recently, neem chippings were shown to be a good tool for malaria larval control under field conditions *(43)*. Plant products that are highly toxic to humans should not be used.

2.4.4 Chemical methods

Insecticide-treated nets*:* ITNs are the mainstay of vector control against malaria (Fig. 2.13). They also offer protection against day-biting *Aedes* vectors in some situations (e.g. in hospitals) and against sand fly vectors and *Culex* mosquitoes. Moreover, when ITNs are hung indoors during the day, they can also reduce the abundance of daytime active *Aedes* mosquitoes, which include the vectors of dengue and chikungunya. The nets offer a physical barrier, protecting people under the net against night-biting mosquitoes. The insecticide incorporated in the net fabric enhances the protective effect by killing, repelling or irritating mosquitoes resting on the net. Hence, even when nets are wearing out and have holes through which mosquitoes could enter, the insecticide may still have an effect. The mass killing effect of the insecticides in the nets may be more important than the mechanical barrier in reducing transmission *(44)*.

Fig. 2.13. Storage of ITNs in a district health office ready to be distributed

Source: photo courtesy of H. van den Berg.

The effectiveness of ITNs in controlling malaria has convincingly been demonstrated in various epidemiological situations, from epidemic to highly endemic settings *(45)*. Extended use of ITNs has been associated with major decreases in malaria prevalence and transmission *(46)*. The vectors have, however, developed widespread resistance to the pyrethroids used in ITNs. ITNs continue to provide protection against malaria transmission *(47)*, but at a reduced rate. To address the increasing problem of pyrethroid resistance, WHO has tested and approved new net products based on chemical synergists or a second insecticide class, in addition to pyrethroids. Three classes of ITN are distinguished: pyrethroid-only nets (LLIN and conventionally treated nets), pyrethroid–piperonyl butoxide (PBO, synergist) nets, and dual-insecticide nets (with addition of a pyrrole or a juvenile hormone mimic) *(48)*. Conventionally treated nets must be re-treated with insecticide regularly by the users, while LLIN are intended to retain their efficacy for 3 years.

In a systematic review, it was shown that ITNs used to prevent malaria may also prevent other, co-endemic diseases, notably cutaneous leishmaniasis, dengue and Japanese encephalitis *(49)*.

Other insecticide-treated materials include hammocks and curtains. Treated hammocks are being promoted in parts of South-East Asia where the main malaria vector is *An. dirus*, a forest-dwelling, early-biting, outdoor-biting species that feeds on people resting in hammocks in the evening before going indoors. Resting in hammocks was identified as an important risk factor in malaria transmission, which obstructs elimination of malaria *(50)*. Ensuring the compliance of people with use of insecticide-treated hammocks remains a challenge.

Impregnated curtains have been used successfully to control malaria and dengue, and their use has reduced the mortality of young children from all causes in Burkina Faso *(51)*. Window curtains and domestic water container covers treated with insecticide have been shown to reduce the density of dengue vectors effectively and may reduce the prevalence of dengue *(52)*.

An issue for risk managers is disposal of insecticidal nets. Millions of polyethylene nets have been distributed annually during the past decade, and millions more will be distributed in coming years. The materials, with residual content of insecticides, will eventually be disposed of as waste and pollute the environment. Some effort has been made to collect old nets, but communities have been reluctant to return them because they value old nets. It may be possible to collect old nets when new nets are distributed to replace them. In 2014, WHO published recommendations for the sound management of old long-lasting bed nets *(53)*. When collection is possible, WHO recommended that old nets containing insecticide residues be incinerated at high temperature or be buried. Plans made for disposal of used nets have not yet been implemented. Old nets should not be collected if they are still being used for protection, and WHO considers that recycling of old ITNs is impractical and not cost-effective.

Indoor residual spraying: Spraying of walls and ceilings inside houses and sleeping quarters with residual insecticides is a proven, commonly used method in the control of malaria, Chagas disease and leishmaniases (Fig. 2.14). It affects malaria not only by killing the vector but by shortening the average lifespan of adult female mosquitoes to below the level necessary for the infectious stages of the parasite.

Fig. 2.14. Operators wearing personal protective equipment apply insecticide to indoor surfaces of houses

Source: photos courtesy of N. Garnage (WHO Photo Library) (left); Rajpal S. Yadav/WHO (right).

IRS has been extensively used for the control of visceral leishmaniasis in some countries, although evidence for its efficacy in reducing the incidence of the disease is limited. In Morocco, IRS with the pyrethroid α-cypermethrin reduced the incidence of cutaneous leishmaniasis *(54)*.

IRS is effective only in areas where the vectors prefer to rest indoors on sprayed walls after taking a blood-meal. Vector populations can adapt to IRS by feeding and/or resting outdoors, reducing their contact with the insecticide on sprayed walls. Nine compounds in four insecticide classes have been prequalified for use in IRS by WHO, which include several new compounds not formerly available for public health. The problem of insecticide resistance is discussed in section 5, and WHO prequalification of insecticides and larvicides is discussed in section 7.

Insecticides are used to kill insects; however, insecticides can also have irritant and repellent effects, depending on the product and active ingredient. An irritant effect refers to irritation of an insect on contact with a treated surface, which it then quickly leaves, having received only a sub-lethal dose of insecticide. These insects may live on and reproduce, although they may live less long than unexposed insects and contribute less to disease transmission. The other possible effect of insecticides is their repellency. In this case, insects do not make contact with the insecticide but perceive it from a certain distance. The insects are not killed. Repellent and irritant effects can contribute to reducing transmission, although their effects are less drastic than killing. In the Americas, DDT sprayed indoors repelled malaria mosquitoes to such an extent that they entered sprayed houses less often than unsprayed houses *(55)*.

Insecticidal treatment of habitats: Larvicides applied to water bodies to control mosquito vector breeding can be effective in controlling vectors in places where vector breeding sites are focal and accessible. Malaria eradication in north-eastern Brazil was achieved mainly with larvicides, with elimination of malaria and its *Anopheles* vector *(8)*. WHO has prequalified eight larvicides: temephos, a commonly used organophosphate, and three insect growth regulators, two bacterial larvicides, a spinosyn and a mechanical barrier product. Temephos is classified as slightly hazardous (hazard class III), but insect growth regulators are less toxic, and bacterial larvicides are not toxic to non-target organisms. When insecticides are used for larviciding, their potential adverse effects on aquatic ecosystems should be considered. Used engine oil has been spread on small, confined pools to suffocate mosquito larvae; however, in warm climates, the oil layer can evaporate within days. Insect growth regulators are highly specific and have shown their efficacy in some settings; however, they are considered too costly for large-scale use.

A systematic review of the effectiveness of larviciding in preventing malaria transmission *(56)* showed that larviciding of larval habitats covering less than 1 km^2 may reduce malaria transmission; however, the effect on large aquatic habitats is unclear. The bacterial larvicide *B. thuringiensis israelensis* shows particularly good potential in larval control. In a large-scale study in Burkina Faso, application of the bacteria to water bodies reduced the populations of adult malaria vectors by 70% *(57)*. Less information is available on the effect of larviciding on diseases other than malaria. Most studies of larviciding for *Aedes*-borne diseases have included other methods, notably environmental management (e.g., source reduction) and space spraying, and it is often difficult to ascribe the results to one method.

Consider this: What are the advantages and disadvantages of mosquito larval control?

Insecticide-treated targets: In certain settings, treatment of targets such as animals with insecticides can effectively control vectors. In a study in Pakistan, treatment of livestock with a pyrethroid insecticide reduced the vector populations and malaria incidence *(58)*.

Chemical repellents and attractants: Chemical and plant-based repellents are widely available and could supplement mainstay methods such as ITNs in reducing vector–human contact, if widely adopted by a community. Insect repellents can complement use of bed nets in malaria control *(59)*, although this method is not effective in all situations. Combining repellents and attractants in domestic environments could improve protection. Tsetse flies are controlled by the use of odour-baited traps, a low-cost, sustainable method of vector control *(60)*. Repellents were found to be highly acceptable in a study in the United Republic of Tanzania; however, use of repellents as a complement to bed nets for protection from mosquito bites in the early evening and outdoors will require longer-lasting, cheaper products than those currently available *(61)*.

A systematic review of studies on topical repellents against malaria indicated that, although topical repellents can provide individual protection against mosquitoes, they do not convincingly provide effective protection against malaria *(62)*. The studies showed substantial heterogeneity, however. In a trial in the Mekong sub-region, mass distribution of highly effective topical repellents did not decrease the prevalence of malaria, because community members did not comply with daily use and used the repellents inappropriately *(63)*.

Spatial repellents are volatile chemicals that prevent biting by mosquitoes in the space in which they are applied. Spatial repellents could reduce vector–human contact and thus prevent transmission. A randomized control trial of the effect of spatial repellents in Indonesia indicated that transfluthrin prevented malaria infection *(64)*, but more evidence is required to confirm this finding. Further trials are under way in Kenya and Mali, as results from more than one country are necessary as a basis for a global policy.

2.4.5 Options per disease

A vector control method could be effective against more than one disease (Table 2.3). For example, insecticide-treated or untreated nets protect against Japanese encephalitis, filariasis and malaria in areas where these diseases occur together. Consequently, in areas where there is more than one vector-borne disease, selection and use of vector control methods must be carefully planned to achieve an optimal impact on locally prevalent diseases.

Review:

- Konradsen F, van der Hoek W, Amerasinghe FP, Mutero C, Boelee E. Engineering and malaria control: learning from the past 100 years. Acta Trop. 2004;89: 99–108. doi:10.1016/j.actatropica.2003.09.013.
- Bowman LR, Donegan S, McCall PJ. Is dengue vector control deficient in effectiveness or evidence? Systematic review and meta-analysis. PLoS Negl Trop Dis. 2016;10(3):e0004551. doi:10.1371/journal.pntd.0004551.

Table 2.3. Methods used to control vector-borne diseases

Category	Vector control method	Chagas disease	Dengue	Human African trypanosomiasis	Japanese encephalitis	Leishmaniasis	Lymphatic filariasis	Malaria	Onchocerciasis	Schistosomiasis	Trachoma
Environmental	Source reduction		+		+		+	+			
	Habitat manipulation						+	+		+	
	Irrigation management and design				+			+	+	+	
	Proximity of livestock				+			+			+
	Waste management						+				+
Mechanical	House improvement	+			+	+		+			
	Removal trapping		+	+		+					
	Polystyrene beads						+				
Biological	Natural enemy conservation		+		+			+		+	
	Biological larvicides		+		+		+	+	+		
	Fungi										
	Botanicals		+					+			

Chemical	Insecticide-treated nets	+			+	+	+	+	
	Indoor residual spraying	+				+		+	
	Insecticidal treatment of habitats		+	+			+	+	+
	Insecticide-treated targets			+					
	Biorational methods[a]		+					+	
	Repellents					+	+	+	

[a]Biorational methods are those in which the pesticides used have low toxicity to non-target organisms.

Source: adapted from WHO *(65)*.

2.5 Collaboration and stakeholder participation

Vector control has traditionally been the responsibility of the health sector, which has managed and coordinated national programmes in most countries, including IRS, mass distribution of ITNs, awareness-raising, promotion, social marketing, procurement and distribution. Implementation of vector control methods should not, however, be confined to health programmes but involve other sectors. Partners such as communities, schools, the private sector and public sectors such as agriculture, construction and local government also have important roles in planning and implementing vector control and personal protection. Programmes in other sectors could inadvertently create conditions suitable for vector breeding or for transmission of disease pathogens. For example, construction may create standing water, which provides a breeding habitat for malaria or dengue. Other sectors should therefore actively participate in measures for the prevention and control of disease vectors. Likewise, communities must participate in reducing the risk for vector-borne disease in domestic and agricultural environments and participate actively, such as in environmental management and house improvement, to increase the effectiveness and sustainability of vector control.

2.5.1 Beyond the health sector

Agriculture and irrigation

Agricultural activities, irrigation systems and animal husbandry all have a major influence on the spread of vector-borne diseases. Crop cultivation with overhead or canal irrigation creates large-scale aquatic environments that are suited for mosquito vectors and snail hosts of the pathogens of diseases such as malaria, lymphatic filariasis and schistosomiasis. Animal husbandry can increase the risk of zoonotic diseases or vector-borne diseases that share animal and human hosts, such as leishmaniases and human African trypanosomiasis. Animals can also serve as dead-end hosts. Animal hoofprints create ideal breeding sites for malaria vectors during the rainy season when they fill up with water. Moreover, animal dung deposited in the environment of humans supports populations of filth flies and houseflies, which are mechanical vectors of trachoma blindness and gastrointestinal diseases. Adequate consideration should therefore be paid to agriculture–health interactions through active collaboration between the two sectors.

Dams

In Tigray, Ethiopia, a micro-dam was associated with the creation of larval habitats in seepage at the dam base, leaking irrigation canals, pools that formed along the beds of streams from the dam and man-made pools. This resulted in higher numbers of malaria vectors in a nearby village *(66)*.

Public works, city planning

Activities like public rubbish collection by a city council office or district council office directly influence the control of breeding sites for dengue vectors. Used car tyres and other items that are preferred breeding sites for these vectors should be recognized by local authorities. Clogged sewers produce large number of *Cx. quinquefasciatus* mosquitoes that cause a major public health nuisance in urban areas (Fig. 2.15).

Fig. 2.15. A neglected sewer as a potential mosquito breeding habitat, India

Source: photo courtesy of Rajpal S. Yadav, ICMR-National Institute of Malaria Research, Nadiad, India.

Rural development programmes and construction projects may also inadvertently create breeding sites for vectors. Sanitation, drainage and prevention of risks during construction should be designed to reduce the risk of vector-borne diseases. Road construction, for example, commonly results in temporary pools of water at roadsides, which encourage proliferation of vectors and spread of the malaria parasite. House construction standards should include consideration of the factors that prevent mosquito vectors from entering or resting in houses and other structures.

2.5.2 Intersectoral collaboration

Ministries of the environment and the tourism sector have roles in preventing vector breeding and vector–human contact in areas or wastelands surrounding towns and roads and in the vicinity of beach resorts. The private sector and civil society organizations can participate in vector control, for example by providing sprayers for IRS programmes or by assisting in bed net distribution campaigns.

All the risks of vector breeding and vector–human contact are largely preventable when adequate consideration is given to health. Most sectors other than health do not consider the health risks of their activities. Sectors should therefore collaborate in designing solutions, streamlining interventions and forming long-term preventive strategies. Other sectors might have to adopt new policies to make their programmes compatible with vector-borne disease control. Their policies should receive committed financing through budgetary allocation for vector control in programmes and, where applicable, sanctions to enforce compliance.

Establishing collaboration between health and other sectors is not simple. WHO has published a framework for planning a multisectoral approach to the prevention and control of vector-borne diseases *(67)*. Each sector has its own mandate, and crossing sectoral boundaries may require agreement at inter-ministerial level. High-level intersectoral support is therefore essential. Generally, there are fewer obstacles to collaboration at lower levels of administration, e.g. the district, where sectors are often less separated, and representatives meet each other more regularly. Partnerships should be formed in districts and lower levels of administration, with representatives from public sectors and civil society. A shared vision should be developed and the goals, scope of work and roles of each partner agreed upon. Section 3.3 elaborates on the institutional and organizational aspects of intersectoral collaboration.

Preparation and training are necessary to introduce sectoral partners to new roles. Generally, they require basic knowledge of the local vectors and diseases, where vectors breed, the vector life cycles and how disease risk could be reduced. The vector control unit of the health system should coordinate and facilitate partnerships with other sectors, and other public sectors and civil society organizations should assume responsibility for implementing certain interventions or actions. Box 2.1 provides an example of collaboration between organizations responsible for irrigation and for health.

Box 2.1. **Irrigation–health collaboration**

In the Huruluwewa tank watershed in north-eastern Sri Lanka, which is an ancient tank cascade irrigation system for rice and slash-and-burn agriculture, the Yan-Oya stream served as a feeder canal to the large water reservoir. Approximately 3000 people, mainly subsistence farmers, were living within 3 km of the stream. Field studies showed that *An. culicifacies* was the principal vector of malaria, which was locally prevalent. A larval survey showed that this vector species bred predominantly in flowing streams in streambed pools, after the water level in the stream had decreased and created pools on its perimeter, with a relation between the depth of the stream and the intensity of vector breeding: when the depth decreased below 20 cm, the number of larvae caught in samples was drastically increased. It was observed that a sudden release of impounded water from an upper reservoir could flush the stream and remove mosquito larvae from the pools, and “stream flushing” was institutionalized and used by the irrigation authority in collaboration with health officials.

Source: Konradsen et al. *(25)*.

2.5.3 Involvement of nongovernmental organizations

Civil society organizations, including international and local nongovernmental organizations, can play important roles in various aspects of vector control. They can mobilize funds for vector control, for example through revolving funds or by attracting donor support, and facilitate establishment of community associations and organizations for vector control. They can make in-kind contributions to vector control by communities and civil society organizations, for example by improving sanitation, drainage or housing to reduce vector breeding.

Another approach is to add vector control and disease prevention as a component of general development projects by nongovernmental organizations and other agencies. For example, projects with agricultural objectives or income generation and microfinance could benefit from an added component of health, especially when diseases such as malaria are a major obstacle to development. This can create win–win situations for community development.

2.5.4 Community participation

Community participation is central to effective vector control interventions. The simplest form of participation is compliance with interventions; a more advanced form is active involvement in planning and implementing vector control activities. Communities should use interventions such as IRS appropriately and comply with instructions for use and maintenance of ITNs. Communities should also participate actively in environmental sanitation, by removing vector breeding sites, clearing rubbish, improving hygiene and housing and reducing contact with vectors. For example, source reduction, the removal of sources of vector breeding such as water-filled containers, is effective only with the participation of communities or clean-up drives, as many places for breeding of mosquito and fly vectors of disease pathogens are within the peri-domestic environment.

Aedes mosquitoes, which are responsible for transmitting the viruses that cause dengue and other diseases, breed in and around people's houses in small containers (vases, rubbish and roof gutters) filled with water. Dengue control requires advocacy to change people's behaviour and to promote early treatment in the event of symptoms of dengue. Public services cannot control people's domestic environment or clear people's roof gutters to control dengue vectors, and this should be the responsibility of households. Dengue control programmes therefore depend largely on community participation, through clean-up drives, environmental sanitation and disposal of containers and waste *(68)*. Community participation in dengue vector control could substantially reduce the risk of dengue. Studies have shown that community and integrated control of *Ae. aegypti* significantly reduced vector density and convincingly reduced dengue transmission *(69,70)*. Box 2.2 provides an example of community participation in the control of Chagas disease.

Box 2.2 Community participation in control of Chagas disease in Argentina

The National Chagas Service was established in 1962 to control Chagas disease. The approach was largely based on the successful example of malaria control programmes, with a vertical, top–down structure of planning and operations based on IRS with insecticides. The programme had a strong impact on the seroprevalence of the disease but did not achieve full coverage of interventions in all districts. Consequently, the disease was not eliminated. When health services became decentralized during the 1980s, and budgets for vertical programmes were drastically cut, the programme for Chagas disease control could not be maintained.

In 1992, a new strategy was launched, adapted to the decentralized health services by encouraging community participation and use of appropriate technology. Community leaders and villagers were trained in surveillance of disease cases and in control of the triatomid vectors. After 12 years, the cost-effectiveness of three strategies was evaluated: a "horizontal" community strategy, a "mixed" strategy of a vertical attack phase followed by horizontal surveillance, and a "vertical" strategy.

The costs of the horizontal and mixed strategies were considerably lower than those of the vertical strategy, and cost-effectiveness was highest for the horizontal, followed by the mixed strategy. The mixed strategy was, however, preferred because it averted more human disease cases than the fully horizontal strategy and was the best strategy for elimination of the disease. Hence, when funding for vertical programmes for vector control of Chagas disease is reduced, community participation provides a viable addition in the longer term.

Source: Vazquez-Prokopec et al. *(72)*.

Farmers may also participate in preventing vector breeding in agricultural fields, depending on the local vector species and their breeding habits, especially in irrigated fields. Farmers can be trained to improve cultivation of rice crops while learning about prevention of vector proliferation in these environments *(71)*.

Section 3.4 elaborates on communication strategies for communities and community empowerment.

Project assignment 2

Review the list of diseases in your country in project assignment 1, and construct a new matrix.

- In the first column: Identify the main species of vector for each disease.
- In the second column: For each disease, determine the major types of ecosystem with which disease transmission is associated (e.g. coastal, riverine, savannah, urban, forest, agriculture, high altitude, plantations) and the micro-habitats for breeding of each vector (e.g. type and characteristics of water bodies).
- In the third column: Determine the time of biting by the vector (or time of transmission, e.g. day, evening, night), where biting occurs (e.g. indoors, outdoors, cattle sheds), whether the vectors rest indoors or outdoors (when applicable) and the hosts attacked by the vector (e.g. humans, domestic animals, wild animals, birds).
- In the fourth column: For each disease, indicate the vector control methods currently being used.

Reflect on your vector assessment, identify gaps in knowledge, and propose priorities for further study.

References

1. Rozendaal JA. Vector control: methods for use by individuals and communities. Geneva: World Health Organization; 1997 (https://iris.who.int/handle/10665/41968).

2. Russell TL, Govella NJ, Salumi Aziz S, Drakeley CJ, Kachur SP, Killeen GF. Increased proportions of outdoor feeding among residual malaria vector populations following increased use of insecticide-treated nets in rural Tanzania. Malar J. 2011;10:80. doi:10.1186/1475-2875-10-80.

3. Kreppel K, Viana M, Main B, Johnson P, Govella N, Lee Y et al. Emergence of behavioural avoidance strategies of malaria vectors in areas of high LLIN coverage in Tanzania. Sci Rep. 2020;10(1):1–11. doi:10.1038/s41598-020-71187-4.

4. Sougoufara S, Diédhiou SM, Doucouré S, Diagne N, Sembène PM, Harry M et al. Biting by *Anopheles funestus* in broad daylight after use of long-lasting insecticidal nets: a new challenge to malaria elimination. Malar J. 2014;13:125. doi: 10.1186/1475-2875-13-125.

5. Bhatt R, Srivastava H, Yadav R. Dynamics of *Anopheles culicifacies*-transmitted malaria in the absence of effective zooprophylaxis in a riverine settlement in Gujarat, India. Curr Sci. 2008;95(1):82–7 (https://www.currentscience.ac.in/Volumes/95/01/0082.pdf).

6. Control and surveillance of African trypanosomiasis: report of a WHO Expert Committee. Geneva: World Health Organization; 1998 (https://iris.who.int/handle/10665/95732).

7. Calder L, Laird M. Mosquito travelers, arbovirus vectors and the used tire trade. Travel Med Int. 1994;12:3–12.

8. Killeen GF, Fillinger U, Kiche I, Gouagna LC, Knols BGF. Eradication of *Anopheles gambiae* from Brazil: lessons for malaria control in Africa? Lancet Infect Dis. 2002;2:618–27. doi:10.1016/s1473-3099(02)00397-3.

9. Takken W, Lindsay S. Increased threat of urban malaria from *Anopheles stephensi* mosquitoes, Africa. Emerg Infecti Dis. 2019;25(7):1431. doi:10.3201/eid2507.190301.

10. Dharmasiri AGG, Perera AY, Harishchandra J, Herath H, Aravindan K, Jayasooriya HTR, et al. First record of *Anopheles stephensi* in Sri Lanka: a potential challenge for prevention of malaria reintroduction. Malar J. 2017;16(1):326. doi:10.1186/s12936-017-1977-7.

11. Benedict MQ, Levine RS, Hawley WA, Philip Lounibos L. Spread of the tiger: global risk of invasion by the mosquito *Aedes albopictus*. Vector Borne Zoonotic Dis. 2007;7(1):76–85. doi:10.1089/vbz.2006.0562.

12. Hawley WA. The biology of *Aedes albopictus*. J Am Mosq Control Assoc. 1988;4:1-40 (https://pubmed.ncbi.nlm.nih.gov/3068349/).

13. Reiter P. *Aedes albopictus* and the world trade in used tires, 1988–1995: The shape of things to come? J Am Mosq Control Assoc. 1998;14(1):83–94 (https://pubmed.ncbi.nlm.nih.gov/9599329/).

14. Hofhuis A, Reimerink J, Reusken C, Scholte EJ, Boer A, Takken W et al. The hidden passenger of lucky bamboo: Do imported *Aedes albopictus* mosquitoes cause dengue virus transmission in the Netherlands? Vector-borne Zoonotic Dis. 2009;9(2):217–20. doi:10.1089/vbz.2008.0071.

15. WHO aircraft disinsection methods and procedures. Geneva: World Health Organization; 2021 (https://iris.who.int/handle/10665/339863).

16. Gratz NG, Steffen R, Cocksedge W. Why aircraft disinsection? Bull World Health Organ. 2002;78(8):995–1004 (http://apps.who.int/iris/handle/10665/268195).

17. Sutton PM, Vergara X, Beckman J, Nicas M, Das R. Pesticide illness among flight attendants due to aircraft disinsection. Am J Ind Med. 2007;50:345–56. doi:10.1002/ajim.20452.

18. Core structure for training curricula on integrated vector management. Geneva: World Health Organization; 2012 (https://iris.who.int/handle/10665/44765).

19. Pesticides and their application for the control of vectors and pests of public health importance. Geneva: World Health Organization; 2006 (https://iris.who.int/handle/10665/69223).

20. Schapira A, Boutsika K. Malaria ecotypes and stratification. Adv Parasitol. 2012;78:97–167. doi:10.1016/B978-0-12-394303-3.00001-3.

21. Reinhardt K, Siva-Jothy MT. Biology of the bed bugs (Cimicidae). Annu Rev Entomol. 2007;52:351–74. doi:10.1146/annurev.ento.52.040306.133913.

22. Larval source management: a supplementary measure for malaria vector control: an operational manual. Geneva: World Health Organization; 2013 (https://iris.who.int/handle/10665/85379).

23. Tusting LS, Thwing J, Sinclair D, Fillinger U, Gimnig J, Bonner KE et al. Mosquito larval source management for controlling malaria. Cochrane Database Syst Rev. 2013;8:008923. doi:10.1002/14651858.CD008923.pub2.

24. Imbahale SS, Mweresa CK, Takken W, Mukabana WR. Development of environmental tools for anopheline larval control. Parasit Vectors. 2011;4(1):130. doi:10.1186/1756-3305-4-130.

25. Konradsen F, Matsuno Y, Amerasinghe FP, Amerasinghe PH, van der Hoek W. *Anopheles culicifacies* breeding in Sri Lanka and for control through water management. Acta Trop. 1998;71:131–8. doi:10.1016/s0001-706x(98)00060-6.

26. Ijumba JN, Lindsay SW. Impact of irrigation on malaria in Africa: paddies paradox: a review. Med Vet Entomol. 2001;15:1–11. doi:10.1046/j.1365-2915.2001.00279.x.

27. Keiser J, Utzinger J, Singer BH. The potential of intermittent irrigation for increasing rice yields, lowering water consumption, reducing methane emissions, and controlling malaria in African rice fields. J Am Mosquito Control Associ. 2002;18:329–40 (https://pubmed.ncbi.nlm.nih.gov/12542191/).

28. Southgate V. Schistosomiasis in the Senegal River Basin: before and after the construction of the dams at Diama, Senegal and Manantali, Mali and future prospects. J Helminthol. 1997;71(2):125–32. doi:10.1017/s0022149x00015790.

29. Tirados I, Gibson G, Young S, Torr SJ. Are herders protected by their herds? An experimental analysis of zooprophylaxis against the malaria vector *Anopheles arabiensis*. Malar J. 2011;10(1):68. doi:10.1186/1475-2875-10-68.

30. van den Berg H, van Vugt M, Kabaghe AN, Nkalapa M, Kaotcha R, Truwah Z et al. Community-based malaria control in southern Malawi: a description of experimental interventions of community workshops, house improvement and larval source management. Malar J. 2018;17(1):266. doi:10.1186/s12936-018-2415-1.

31. Tusting LS, Ippolito MM, Willey BA, Kleinschmidt I, Dorsey G, Gosling RD et al. The evidence for improving housing to reduce malaria: a systematic review and meta-analysis. Malar J. 2015;14:209. doi:10.1186/s12936-015-0724-1.

32. Furnival-Adams J, Olanga EA, Napier M, Garner P. House modifications for preventing malaria. Cochrane Database Syst Rev. 2021;1:013398. doi:10.1002/14651858.CD013398.pub2.

33. Curtis CF, Malecela-Lazaro M, Reuben R, Maxwell CA. Use of floating layers of polystyrene beads to control populations of the filaria vector *Culex quinquefasciatus*. Ann Trop Med Parasitol. 2002;96:S97–104. doi:10.1179/000349802125002446.

34. Malaria vector control and personal protection. Report of a WHO study group (WHO Tech. Rep. Ser. No. 936). Geneva: World Health Organization; 2006 (https://iris.who.int/handle/10665/43425).

35. Settle WH, Ariawan H, Astuti ET, Cahyana W, Hakim AL, Hindayana D et al. Managing tropical rice pests through conservation of generalist natural enemies and alternative prey. Ecology. 1996;77:1975–88. doi:10.2307/2265694.

36. Madsen H. Biological methods for the control of freshwater snails. Parasitol Today. 1990;6(7): 237–41. doi:10.1016/0169-4758(90)90204-h.

37. Yadav RS, Haq S. Role of fishes in vector-borne disease control in Southeast Asia. In: Nath K, Sharma V, editors. Water and sanitation in the new millennium. New Delhi: Springer; 2017:163–83. doi:10.1007/978-81-322-3745-7_14.

38. Use of fish for mosquito control. Cairo: World Health Organization Regional Office for the Eastern Mediterranean; 2003 (https://iris.who.int/handle/10665/116355).

39. Walshe DP, Garner P, Abdel-Hameed Adeel AA, Pyke GH, Burkot TR. Larvivorous fish for preventing malaria transmission. Cochrane Library. 2013;12:008090. doi:10.1002/14651858.CD008090.pub3.

40. Fillinger U, Lindsay SW. Suppression of exposure to malaria vectors by an order of magnitude using microbial larvicides in rural Kenya. Trop Med Int Health. 2006;11(11):1629–42. doi:10.1111/j.1365-3156.2006.01733.x.

41. Scholte EJ, Knols BGJ, Samson RA, Takken W. Entomopathogenic fungi for mosquito control: a review. J Insect Sci. 2004;4:19. doi:10.1093/jis/4.1.19.

42. Seyoum A, Kabiru EW, Lwande W, Killeen GF, Hassanali A, Knols BGJ. Repellency of live potted plants against *Anopheles gambiae* from human baits in semi-field experimental huts. Am J Trop Med Hyg. 2002;67(2):191–5. doi:10.4269/ajtmh.2002.67.191.

43. Imbahale SS, Mukabana WR. Efficacy of neem chippings for mosquito larval control under field conditions. BMC Ecol. 2015;15(1):8. doi:10.1186/s12898-015-0041-0.

44. Killeen GF. Control of malaria vectors and management of insecticide resistance through universal coverage with next-generation insecticide-treated nets. Lancet. 2020;395(10233):1394–400. doi:10.1016/S0140-6736(20)30745-5.

45. Lengeler C. Insecticide treated bednets and curtains for malaria control. Cochrane Library. 1998;3: 1–54. doi:10.1002/14651858.CD000363.pub2

46. Bhatt S, Weiss DJ, Cameron E, Bisanzio D, Mappin B, Dalrymple U et al. The effect of malaria control on *Plasmodium falciparum* in Africa between 2000 and 2015. Nature. 2015;526(7572):207–11. doi:10.1038/nature15535.

47. Kleinschmidt I, Bradley J, Knox TB, Mnzava AP, Kafy HT, Mbogo C et al. Implications of insecticide resistance for malaria vector control with long-lasting insecticidal nets: a WHO-coordinated, prospective, international, observational cohort study. Lancet Infect Dis. 2018;18(6):640–9. doi:10.1016/S1473-3099(18)30172-5.

48. Guidelines for malaria vector control. Geneva: World Health Organization; 2019 (https://iris.who.int/handle/10665/310862).

49. Wilson AL, Dhiman RC, Kitron U, Scott TW, van den Berg H, Lindsay SW. Benefit of insecticide-treated nets, curtains and screening on vector borne diseases, excluding malaria: a systematic review and meta-analysis. PLoS Negl Trop Dis. 2014;8(10):e3228. doi:10.1371/journal.pntd.0003228.

50. Thang ND, Erhart A, Speybroeck N, Xa NX, Thanh NN, Van Ky P et al. Long-lasting insecticidal hammocks for controlling forest malaria: a community-based trial in a rural area of central Vietnam. PLoS One. 2009;4(10):e7369. doi:10.1371/journal.pone.0007369.

51. Habluetzel A, Diallo DA, Esposito F, Lamizana L, Pagnoni F, Lengeler C et al. Do insecticide-treated curtains reduce all-cause child mortality in Burkina Faso? Trop Med Int Health. 1997;2:855–62. doi:10.1046/j.1365-3156.1997.d01-413.x.

52. Kroeger A, Lenhart A, Ochoa M, Villegas E, Levy M, Alexander N et al. Effective control of dengue vectors with curtains and water container covers treated with insecticide in Mexico and Venezuela: cluster randomised trials. BMJ. 2006;332(7552):1247–52. doi:10.1136/bmj.332.7552.1247.

53. WHO recommendations on the sound management of old long-lasting insecticidal nets. Geneva: World Health Organization; 2014 (https://iris.who.int/handle/10665/338356).

54. Faraj C, Adlaoui EB, Ouahabi S, Elkohli M, Elrhazi M, Laqraa L et al. Field evaluation of alphacypermethrin in indoor residual spraying for leishmaniasis control in an endemic area, northern Morocco. Parasites Vectors. 2013;6(1):354. doi:10.1186/1756-3305-6-354.

55. Roberts DR, Andre RG. Insecticide resistance issues in vector-borne disease control. Am Jo Trop Med Hygi. 1994;50(6-Suppl):21–34. doi:10.4269/ajtmh.1994.50.21.

56. Choi L, Majambere S, Wilson AL. Larviciding to prevent malaria transmission. Cochrane Database Syst Rev. 2019;(8):012736. doi:10.1002/14651858.CD012736.pub2.

57. Dambach P, Baernighausen T, Traoré I, Ouedraogo S, Sié A, Sauerborn R et al. Reduction of malaria vector mosquitoes in a large-scale intervention trial in rural Burkina Faso using Bti based larval source management. Malar J. 2019;18(1):1–9. doi:10.1186/s12936-019-2951-3.

58. Rowland M, Durrani N, Kenward M, Mohammed N, Urahman H, Hewitt S. Control of malaria in Pakistan by applying deltamethrin insecticide to cattle: a community-randomised trial. Lancet. 2001;357: 1837–41. doi:10.1016/S0140-6736(00)04955-2.

59. Hill N, Lenglet A, Arnez AM, Carneiro I. Plant based insect repellent and insecticide treated bed nets to protect against malaria in areas of early evening biting vectors: double blind randomised placebo controlled clinical trial in the Bolivian Amazon. BMJ. 2007;335:1023. doi:10.1136/bmj.39356.574641.55.

60. Takken W, Oladunmade MA, Dengwat L, Feldmann HU, Onah JA, Tenabe SO et al. The eradication of *Glossina palpalis palpalis* (Robineau-Desvoidy) (Diptera:Glossinidae) using traps, insecticide-impregnated targets and the sterile insect technique in central Nigeria. Bull Entomol Res. 1986;76: 275–86. doi:10.1017/S0007485300014747.

61. Sangoro O, Kelly AH, Mtali S, Moore SJ. Feasibility of repellent use in a context of increasing outdoor transmission: a qualitative study in rural Tanzania. Malar J. 2014;13(1):347. doi:10.1186/1475-2875-13-347.

62. Wilson AL, Chen-Hussey V, Logan JG, Lindsay SW. Are topical insect repellents effective against malaria in endemic populations? A systematic review and meta-analysis. Malar J. 2014;13(1): 446. doi:10.1186/1475-2875-13-446.

63. Sluydts V, Durnez L, Heng S, Gryseels C, Canier L, Kim S et al. Efficacy of topical mosquito repellent (picaridin) plus long-lasting insecticidal nets versus long-lasting insecticidal nets alone for control of malaria: a cluster randomised controlled trial. Lancet Infect Dis. 2016;16(10):1169–77. doi:10.1016/S1473-3099(16)30148-7.

64. Syafruddin D, Asih PB, Rozi IE, Permana DH, Nur Hidayati AP, Syahrani L et al. Efficacy of a spatial repellent for control of malaria in Indonesia: a cluster-randomized controlled trial. Am J Trop Med Hyg. 2020;103(1):344–58. doi:10.4269/ajtmh.19-0554.

65. Handbook for integrated vector management. Geneva: World Health Organization; 2012 (https://iris.who.int/handle/10665/44768).

66. Yohannes M, Haile M, Ghebreyesus TA, Witten KH, Getachew A, Byass P et al. Can source reduction of mosquito larval habitat reduce malaria transmission in Tigray, Ethiopia? Trop Med Int Health. 2005;10(12):1274–85. doi:10.1111/j.1365-3156.2005.01512.x.

67. Multisectoral approach to the prevention and control of vector-borne diseases: a conceptual framework. Geneva: World Health Organization; 2020 (https://iris.who.int/handle/10665/331861).

68. Vanlerberghe V, Toledo ME, Rodríguez M, Gómez D, Baly A, Benítez JR et al. Community involvement in dengue vector control: cluster randomised trial. BMJ. 2009;338:b1959. doi:10.1136/bmj.b1959.

69. Toledo ME, Rodriguez A, Valdés L, Carrión R, Cabrera G, Banderas D et al. Evidence on impact of community-based environmental management on dengue transmission in Santiago de Cuba. Trop Med Int Health. 2011;16(6):744–7. doi:10.1111/j.1365-3156.2011.02762.x.

70. Kay B, Vu SN. New strategy against *Aedes aegypti* in Vietnam. Lancet. 2005;365(9459):613–7. doi:10.1016/S0140-6736(05)17913-6.

71. Evaluation of the integrated pest and vector management (IPVM) project in Sri Lanka. New Delhi: World Health Organization Regional Office for South-East Asia; 2006 (https://iris.who.int/handle/10665/205031).

72. Vazquez-Prokopec GM, Spillmann C, Zaidenberg M, Kitron U, Gürtler RE. Cost-effectiveness of Chagas disease vector control strategies in northwestern Argentina. PLoS Negl Trop Dis. 2009;3(1):e363. doi:10.1371/journal.pntd.0000363.

Recommended reading

Bowman LR, Donegan S, McCall PJ. Is dengue vector control deficient in effectiveness or evidence?: Systematic review and meta-analysis. PLoS Negl Trop Dis. 2016;10(3):e0004551. doi:10.1371/journal.pntd.0004551.

Mutero CM, Okoyo C, Girma M, Mwangangi J, Kibe L, Ng'ang'a P et al. Evaluating the impact of larviciding with Bti and community education and mobilization as supplementary integrated vector management interventions for malaria control in Kenya and Ethiopia. Malar J. 2020;19:390. doi:10.1186/s12936-020-03464-6.

Rozendaal JA. Vector control: methods for use by individuals and communities. Geneva: World Health Organization; 1997:Chapters 1, 2, 3 and 8 (https://iris.who.int/handle/10665/41968).

WHO. Malaria entomology and vector control. Guide for participants. Geneva: World Health Organization; 2013 (https://iris.who.int/handle/10665/85890).

Wilson AL, Courtenay O, Kelly-Hope LA, Scott TW, Takken W, Torr SJ et al. The importance of vector control for the control and elimination of vector-borne diseases. PLoS Negl Trop Dis. 2020;14(1):e0007831. doi:10.1371/journal.pntd.0007831.

3

Framework for integrated vector management

Contents

Public health pesticide management

Learning objectives

By the end of this course, students should be able to:

- identify the motives, guiding principles and key elements of integrated vector management (IVM) and their local significance;
- conduct a situational analysis of policy and institutional arrangements in relation to IVM; and
- demonstrate understanding of aspects of management, communication and capacity-building in relation to IVM.

3.1 The concept of integrated vector management

3.1.1 The role of vector control

The importance of the vector control component in vector-borne disease programmes has long been undervalued. Disease control programme managers usually have a medical background and often have no entomological expertise. They therefore often pay greater attention and allocate more resources to medical components, such as diagnosis, treatment, prophylaxis, case management and staff training, than to vector control. In many cases, a few entomologists are given limited resources for vector surveillance, monitoring, evaluation and operational research and are diverted to perform non-technical tasks. Programme managers should understand and appreciate the role of vector control in the prevention, control and elimination of vector-borne diseases. The role has recently become clear in malaria control, as, for example, more financing has been allocated for malaria vector control in sub-Saharan Africa, mainly because scaled-up use of ITNs and IRS led to sharp reductions in the number of malaria cases *(1)* (Box 3.1). Decreased ITN coverage, increasing insecticide resistance and disruption of vector control services by the coronavirus disease (COVID-19) pandemic have, however, recently resulted in intermittent increases in the numbers of malaria cases *(2)*.

Box 3.1. **The contribution of vector control interventions to malaria control**

Since 2000, malaria control campaigns have ensured high coverage of interventions across sub-Saharan Africa. The three interventions commonly used are ITNs, IRS and prompt treatment of clinical cases with artemisinin-based combination therapy. The first two are core vector control interventions, while therapy is a medical intervention.

A systematic analysis was conducted with a large database of the results of field surveys on the effects of changing intervention coverage between 2000 and 2015. The analysis allowed attribution of the numbers of malaria cases averted to each of the three interventions. The study addressed the malaria parasite species *P. falciparum*, the dominant malaria parasite species in Africa, which causes the most debilitating cases of malaria.

The number of clinical cases of *P. falciparum* malaria fell by 40% between 2000 and 2015, and it was estimated that the interventions had averted as many as 663 million clinical cases during the study period. ITNs were by far the largest contributor, accounting for 68% of averted malaria cases. Artemisinin-based combination therapy averted 22% of cases, and IRS (used mainly in southern Africa) for 10% of averted cases. Vector control (ITNs plus IRS) was responsible for 78% of averted cases.

Source: Bhatt et al. *(1)*.

Other NTD vector-borne disease programmes have not generally benefitted similarly, as accurate data on the potential role of vector control in the prevention and control are lacking, even though there is evidence of a major role of vector control in the control of onchocerciasis and Chagas disease. In the Onchocerciasis Control Programme in West Africa, larvicide applications over large areas to control the blackfly vectors of river blindness at the edges of rivers and streams and distribution of ivermectin resulted in major reductions in the rate of transmission of the parasites *(3)*. In the Southern Cone Initiative for the control of Chagas disease in Latin America, intensive vector control with insecticides to kill the triatomine vectors reduced disease incidence *(4)*. Wilson et al. *(5)* has reported other stories of the success of vector control.

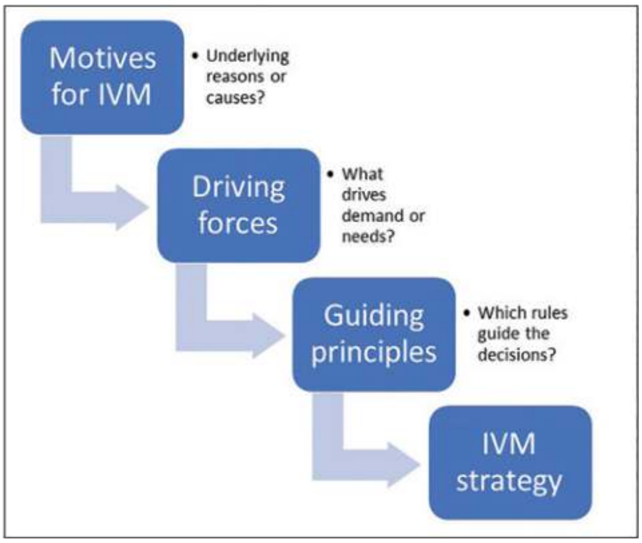
Most programmes for the control or elimination of lymphatic filariasis, schistosomiasis and leishmaniases have relied on a medical component, with diagnosis and treatment. Programmes for the elimination of lymphatic filariasis are based on MDA, although vector control could play an important role in eliminating the disease *(6)*. Programmes for control of schistosomiasis and leishmaniases have also made limited use of vector control or personal protection, although there are exceptions, such as use of IRS in South Asia, which has resulted in a significant reduction in the prevalence of visceral leishmaniasis *(7)*. For diseases such as dengue and chikungunya, which are transmitted by *Aedes* mosquitoes, there is no treatment or vaccine available, and vector control is the only control option.

Townson H, Nathan MB, Zaim M, Guillet P, Manga L, Bos R et al. Exploiting the potential of vector control for disease prevention. Bull World Health Organ. 2005;83:942–7 (https://iris.who.int/handle/10665/269548) *(8)*.
Global vector control response 2017–2030. Geneva: World Health Organization; 2017 (https://iris.who.int/handle/10665/259002) *(9)*.

Vector control should be effective, efficient and sustainable in order to interrupt pathogen transmission. To be effective, vector control must be adapted to the behaviour and ecology of local vectors (see section 2). To be efficient and sustainable, vector control must be targeted only where necessary and become part of established public health systems. Lack of planning and adaptation of vector control operations will inevitably result in wasting resources and suboptimal effects on the disease burden.

This section addresses the underlying reasons or motives for IVM, the driving forces that support it and the guiding principles, which lead to a strategy on IVM (Fig. 3.1).

Fig. 3.1. The IVM concept



3.1.2 Motives for IVM

Several factors determine effective, efficient vector control. The vector control services in many countries are static and outdated and have not changed in decades. Such programmes are unable to adapt to changing circumstances or have not adopted newly recommended products or interventions. The world is, however, changing.

- Urbanization changes the conditions for disease, some becoming more important and others less important.
- Modernization is influencing housing and other conditions, which in turn affect the risk of contact with disease vectors and transmission of disease pathogens.
- Environmental degradation can profoundly influence the breeding and survival of disease vectors and their proximity to people's homes.
- Population displacement is an increasing problem in some regions, exposing families to new environments, cramped living conditions and major risks of vector-borne disease outbreaks.
- Climate change is affecting geographical regions differently, changing the conditions for vector breeding and transmission.
- The success of global programmes for disease elimination also results in change, to which a national programme must adapt. Where malaria has been recently eliminated, malaria vector control units should adapt from malaria control to prevention of reintroduction.
- Emerging diseases introduce new risks, to which national programmes should adapt. Examples are the recent spread of dengue, chikungunya and West Nile viruses into new regions and countries. Global travel and global trade have increased the distribution of emerging vector-borne diseases and the introduction of vectors into new areas.

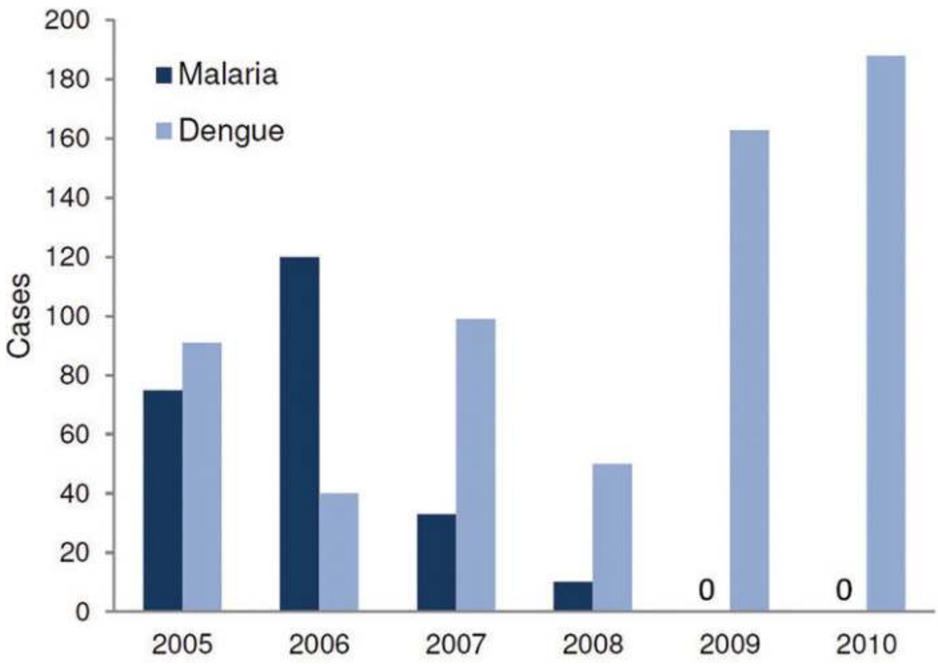
Many countries lack adequate capacity and entomological expertise to adapt their decisions on vector control, and the vector control interventions or strategies used are often not optimal for local conditions. Important information on which decisions should be based includes the behaviour of vectors, seasonal fluctuations and people's attitudes. Vector control should be adapted constantly to changing circumstances.

Resistance of vector populations to the insecticides used in vector control interventions is increasing in many regions. As vector control interventions such as IRS and ITNs increase, increasing pressure is placed on vectors to develop resistance (see section 4). Resistance to insecticides could compromise the efficacy of insecticidal interventions and even result in failure of control, although this is not always the case *(10)*. Vectors can also develop behavioural resistance, such as changing their biting behaviour from night to day *(11)*.

Many countries have fragmented entomological capacity that is available in one programme (e.g. for malaria) but not for another (e.g. dengue). There has been little sharing of entomological expertise or laboratory facilities between disease-specific programme, which is a problem, as entomological capacity is scarce in most endemic countries. Furthermore, opportunities for greater efficiency and cost savings are missed. Some diseases that co-exist in the same area could potentially be controlled by the same interventions or strategies *(12)*. For example, in Mati City, Philippines, malaria was being eliminated while the prevalence of dengue was increasing (Fig. 3.2). The municipal health department therefore established a malaria–dengue task force, in which the expertise and human resources for malaria vector control were shifted from malaria to dengue vector control, and the expertise in malaria vector control was not lost.

The activities of other public and private sectors and of communities can have unintended consequences for vector breeding and vector-borne disease control. For example, irrigated agriculture can support vector proliferation *(14)*, and communities may be rearing mosquito vectors in their backyards without realizing it *(15)*. These unintended effects hinder work to control vector-borne disease.

Fig. 3.2. Pattern of incidence of malaria and dengue in Mati City, Philippines



Source: van den Berg et al. *(13)*. Reproduced under the Creative Commons Attribution 2.0 International License (https://creativecommons.org/licenses/by/2.0/).

Community compliance and adoption of vector control and personal protection measures has often been poor. In general, health sector programmes have not been able to involve communities adequately in prevention and control of vector-borne diseases.

Major shortcomings have been encountered in managing the life-cycle of pesticides, such as urban trade in substandard, poorly labelled, highly toxic pesticide products that are currently available to the public and accumulation of obsolete pesticide stocks for public health.

3.1.3 Driving forces for IVM

In the face of these complex problems, which are the motives for IVM, a number of factors can be identified that drive the demand for IVM ("driving forces"). The first is global resolutions and treaties that call for IVM. The Stockholm Convention on Persistent Organic Pollutants *(16)* and World Health Assembly resolution WHA50.13 on promotion of chemical safety, with special attention to persistent organic pollutants *(17)* both call on countries to develop sustainable strategies for vector control to reduce their reliance on insecticides. IVM fills that need.

Several global programmes address the elimination of malaria, lymphatic filariasis and leishmaniases, with greater emphasis on an efficient system of vector control. The programmes rely in part on the continued effectiveness of vector control. The target for investment in malaria includes 64% for vector control, and that for NTDs is 60% *(18,19)*, indicating that the role of vector control is being recognized.

Lessons learnt from agriculture on the cost-effectiveness and sustainability of integrated pest management also support IVM and indicate avenues to be followed *(20)*.

It is widely recognized that there is a small arsenal of insecticide options for vector control. In view of the increasing problem of insecticide resistance in disease vectors (especially in vectors of malaria and dengue), it is urgent to reduce current reliance on those few insecticides and develop alternative strategies for vector control.

To improve the efficacy, cost-effectiveness, ecological soundness and sustainability of vector control, a different approach is needed: one that is adaptable, based on local evidence and integrative and inclusive.

3.1.4 Guiding principles of IVM

IVM is defined as "a rational decision-making process for the optimal use of resources for vector control" *(21)*. The goal of IVM is to improve the efficacy, cost-effectiveness, ecological soundness and sustainability of vector control *(22)* and thus make a significant contribution to the prevention and control of vector-borne diseases. The four guiding principles for implementation of IVM are adaptive management, inclusiveness, protection of human health and the environment, and subsidiarity (decentralization).

Adaptive management

Adaptive management, an accepted term in natural resource management, applies equally to the control of vector-borne diseases. It implies systematic, iterative decision-making based on the available evidence on methods and strategies (what works and what does not work). Decisions are also made about efficient use of available resources (e.g. human, financial). The decisions are then adapted to the prevailing conditions (e.g. ecological, insecticide susceptibility, epidemiological, socioeconomic conditions). Feedback obtained through surveillance, monitoring and evaluation is essential in the adaptive management approach, so that the iterative process of decision-making is improved over time.

Inclusiveness

Inclusiveness implies collaboration and participation in IVM. The effectiveness of control is due not only to the health sector but to collaboration and participation within the health sector, with other public and private sectors and with communities.

Protection of human health and the environment

The main aim of IVM is to improve the control of vector-borne diseases and to reduce the burden of disease. A specific guiding principle of IVM is also to consider the environmental soundness and human safety of methods selected for vector control. This includes the notion that chemical insecticides should be used only as a last resort. Initially, this notion appears to conflict with reality, as insecticides are currently the mainstay of vector control. Nevertheless, alternative methods, when feasible, cost-effective and acceptable, should be given priority over the use of chemicals. This consideration will highlight the shortage of alternative methods or the paucity of information about their cost-effectiveness and can be expected to promote operational research on alternative methods of control. Environmental management for source reduction, in particular, should be promoted, as it could provide sustainable solutions for vector control by removing the source of the vector.

Subsidiarity (decentralization)

Subsidiarity is an organizing principle whereby matters are handled by the smallest, lowest or least centralized competent authority. The central authority performs only those tasks that cannot be performed effectively at a more immediate or local level.

Decentralization promotes planning, implementation and evaluation of vector control at the most local level. This is a departure from top–down, centrally planned vector control programmes. Bottom–up planning and implementation can be more responsive, flexible, precise and accountable. For example, locally elected representatives are better informed about the needs and complaints of their constituents.

3.1.5 Key elements of an IVM strategy

IVM promotes the use of various interventions, alone or in combination, selected on the basis of local knowledge about the vectors, diseases and disease determinants. IVM addresses vector-borne diseases in an integrated manner, because some vectors are responsible for several diseases, and some interventions are effective against several vectors. If properly implemented, an IVM strategy will reduce the pressure imposed by insecticides to select for insecticide resistance.

Conceptualization of IVM was influenced by developments in integrated pest management in agriculture, in which insecticide application is the method of last resort *(24)*. The measures taken by sectors outside the health sector can have major influences on vector populations and disease burden. The IVM approach promotes collaboration and regulation of actions among sectors and among sections within the health sector.

Five elements of an IVM strategy were identified in the global strategic framework for IVM *(23)* (Table 3.1), which should be supported by national legislation and regulation.

Table 3.1. Key elements of an IVM strategy

Element	Description
Advocacy, social mobilization and legislation	Promotion and embedding of IVM principles in the development policies of all relevant agencies, organizations and civil society; establishment or strengthening of regulatory and legislative controls for public health; empowerment of communities
Collaboration within the health sector and with other sectors	Consideration of all options for collaboration within and between public and private sectors; application of the principles of subsidiarity in planning and decision-making; strengthening channels of communication among policy-makers, vector-borne disease control programme managers and other IVM partners
Integrated approach	Ensuring rational use of resources in a multi-disease control approach; integration of non-chemical and chemical vector control methods; integration with other disease control measures
Evidence-based decision-making	Adaptation of strategies and interventions to local ecology, epidemiology and resources, guided by operational research and routinely monitored and evaluated
Capacity-building	Development of the essential physical infrastructure, financial resources and adequate human resources at national and local levels to manage IVM strategies according to a situation analysis

Source: WHO *(23)*.

The first element, advocacy, social mobilization and legislation, refers to promotion and communication of the IVM concept to make it acceptable to national policy-makers and to communities in order to achieve the required compliance and participation. Advocacy is necessary both to emphasize the important role of vector control in vector-borne disease control and to stress the urgency of better, more efficient vector control.

Social mobilization is a key element in its own right. Although community participation and empowerment are essential for the adoption and effectiveness of interventions and for the sustainability of operations, they have been neglected in vertical disease control programmes. Only a few examples are available in which community participation substantially reduced the risks of dengue *(25,26)* and malaria *(27)*.

The second element refers to necessary collaboration among sectors to harmonize their actions for the prevention and control of vector-borne disease, while the third, the integrated approach, refers to combining vector control methods, where appropriate, for integrated control of several diseases, in contrast to approaches that rely on single methods for control of one disease.

The fourth element, evidence-based decision-making, is use of local data and evidence in making decisions to ensure the effectiveness of interventions, indicating that decisions are best made locally, in response to contextual information. The fifth, capacity-building, consists of strengthening infrastructure and human resources for effective implementation of IVM. As expertise in vector control and medical entomology is inadequate in most disease-endemic countries, this is a high priority in the IVM strategy.

Aspects that are not unique to IVM but apply to any new development programme or strategy are advocacy and capacity-building. Aspects essential for IVM are evidence-based decision-making, adopting a multi-disease approach, combining interventions where appropriate and involving other sectors and communities. IVM can therefore be defined in terms of aims, means and processes. The aims are to improve the efficacy, cost-effectiveness, ecological soundness and sustainability of vector control. The means are increasing the emphasis on local evidence, adopting a multi-disease approach, and combining vector control interventions when appropriate. The processes used are integration within the health sector, collaboration among sectors and participation of communities.

Although there appears to be broad support for the IVM concept, the element of increasing integration and coordination are likely to be criticized by those who claim that vertical, centrally planned programmes are most effective for a large reduction in the burden of malaria in particular, within a relatively short time. Transformation of the vector control system might be perceived as too complex for countries or programmes. Others might question the use of several vector control methods, where applicable, claiming that only the most cost-effective intervention should be selected. The IVM approach requires changing a system internally, which will cost time and resources.

List the pros and cons of the IVM approach in comparison with vertical, centrally planned disease control programmes.

Which approach do you favour? Explain why.

IVM requires solving problems on the basis of field observations, data, surveillance and situation analyses to plan action. Strategies in which one set of interventions is used over large geographical areas, without selecting interventions adapted to local conditions, usually result in waste of resources and suboptimal effects on disease prevalence, as every situation is distinct and complex. The more closely a strategy is adapted to the local context, the more effective and efficient it will be. This problem-solving approach, discussed in detail in section 4, requires the necessary skills and capacity for surveillance, analysis and adaptive management at several administrative levels. The smaller the area to be addressed in a situation analysis, the more detailed and accurate the data and the more effective the actions; this will require planning, logistics and capacity.

In an IVM strategy, skills and capacity are required at national, district and even village level. Problem-solving skills will be useful not only for IVM but, once established in districts and villages, will also be useful in other areas of health services and may increase the efficiency of the health system.

3.2 Policy development

An IVM approach will require organizational and institutional changes, establishment of intersectoral collaboration and a more active role of communities, supported by national policies and a public health regulatory and legislative framework. An early step in developing an IVM strategy is therefore to identify the policies that are necessary or to conduct a policy review. Policy is developed by identifying the problems, analysing existing policy and then formulating, implementing and evaluating adapted policies and policy instruments to achieve the government's goals and objectives in relation to IVM *(28)*.

3.2.1 Situation analysis

Situation analysis is the first step in developing a policy. WHO has published guidelines for vector control needs assessment *(29)*, which include a section on situation analysis. It is essential to understand the prevailing disease epidemiology and vector control services in the country and to identify any problems or hurdles in implementation and to analyse the policy environment. Only then can the situation be systematically improved through policy development.

A valid, acceptable policy is achieved only if there is wide representation of participants in policy development. They may include politicians, bureaucrats, technical experts and civil society. Politicians make decisions on policy change in a sector or institution. Bureaucrats know how government structures and institutions function and how they could be used to establish an IVM strategy in the health sector and collaborate with other sectors. Technical experts provide knowledge and expertise about vector-borne disease control. Civil society organizations represent communities and voice their interests and concerns.

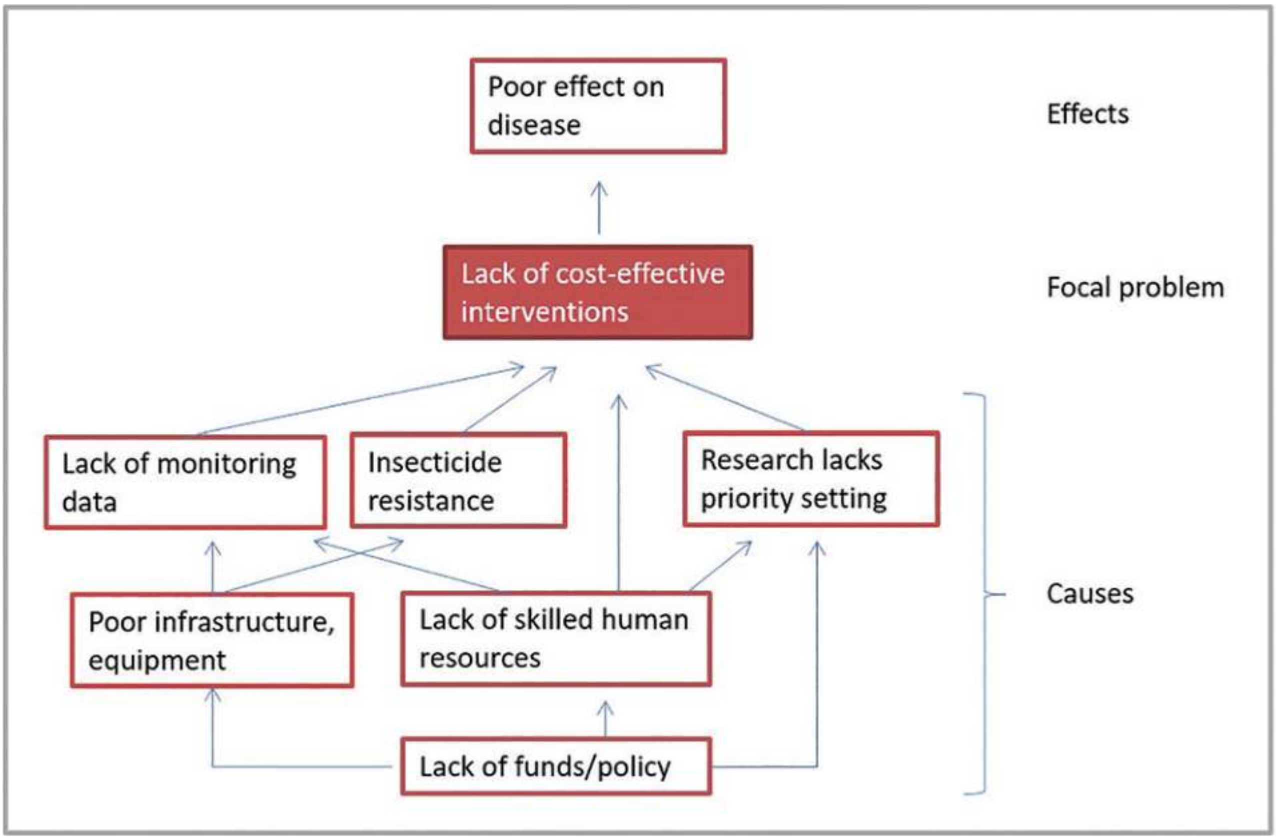
The problems and constraints in the vector control system must be analysed to identify the priorities to be addressed. The problem analysis detects the constraints to exploiting the full potential of vector control in the country, such as sufficient funding of vector control for one disease but not for another; inadequate human resources with appropriate training; no laboratory facilities; no collaboration with stakeholders outside the health sector and communities; or no cost-effective tools. Questions could draw attention to issues that are not currently considered problems but could reduce the potential of vector control (see Table 3.2). Common problems are lack of capacity for evidence-based decision-making; static, compartmentalized disease control programmes; lack of involvement of other sectors and communities; and resistance to insecticides.

Table 3.2. Identify the problems in vector control in your country

Question	Situation in your country
Is capacity for decision-making on vector control adequate, and could it adapt decisions to local conditions?	
Is insecticide resistance considered a problem in vector control, or, is the level of resistance being monitored?	
Do vector-borne disease control programmes focus on specific diseases?	
Are stakeholders in other sectors sufficiently aware of the need for vector control and prevention?	
Are communities adequately involved in the prevention and control of vector-borne diseases?	
Are there any other problems related to vector control in your country?	

After identifying the constraints, cause–effect relationships could be established. For example, if no cost-effective tools are available for the control of a particular vector, the cause should be identified: Have the tools not been studied? Have vectors developed resistance to the insecticides? Are there inadequate skilled human resources? (Fig. 3.3) The problems identified provide the starting point for policy development.

Fig. 3.3. Example of a "problem tree" indicating a focal problem, its causes and effects

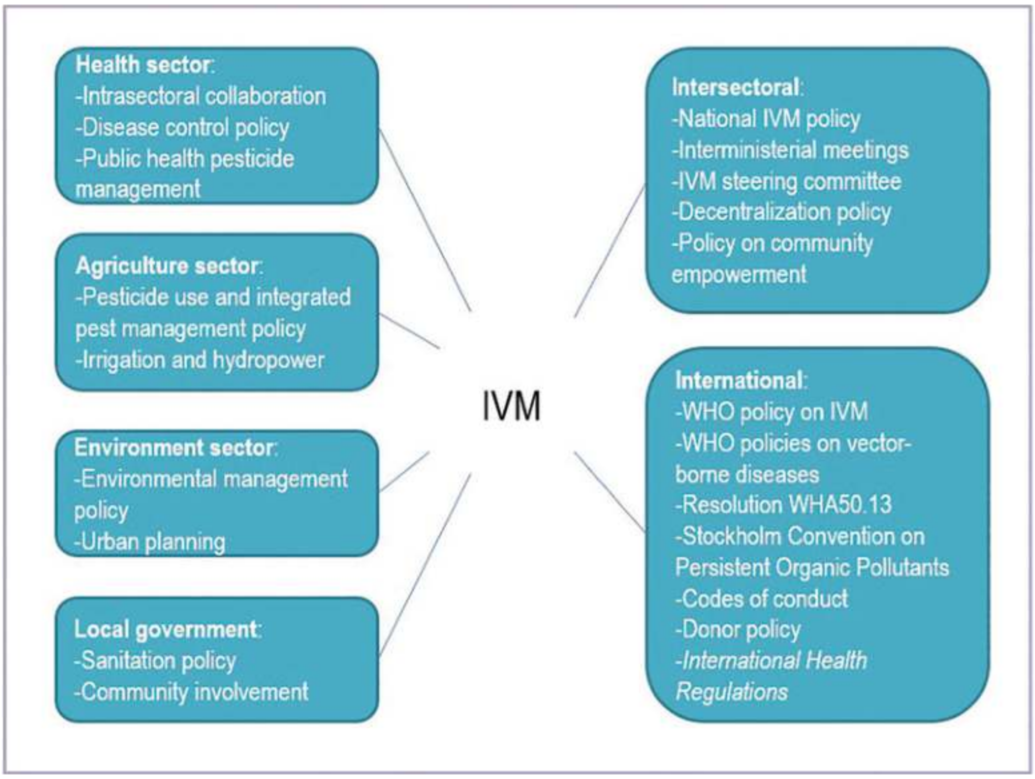


Source: visual courtesy of H. van den Berg.

The current policy environment is then analysed to determine whether policies should be changed (Fig. 3.4). Policies may be insufficient, inconsistent or absent. For example, agriculture policies may be inconsistent with health policies when they result in conditions that favour vector breeding. Irrigation projects or dam construction projects can increase the risk of diseases such as malaria and schistosomiasis that could be avoided or limited if consideration is given to reducing opportunities for vector breeding or reducing the risk of contracting disease pathogens *(14)*. Policies on the environment, local government and construction may also affect health. For example, a policy to avoid "wastelands", private properties in an urban area that remain unoccupied and neglected, can help to reduce the breeding opportunities for dengue vectors. Wastelands generate rubbish and refuse, which provide breeding habitats for *Aedes* mosquitoes.

Fig. 3.4 presents the policy environment, with examples of policies relevant to the health sector and relevant programmes, policies and programmes in other sectors that could affect the incidence of vector-borne diseases, intersectoral policies and international policies.

Fig. 3.4. Policy environment for integrated vector control



Source: WHO *(30)*.

Policies can be divided into those that adversely affect vector-borne disease control, those that are neutral and those in favour. Most of the issues identified in problem analysis are due to gaps or inconsistencies in policies. Gaps and shortcomings in the policy environment are used as a basis for finding solutions, by amendment or creation of policies to support IVM.

3.2.2 Policy formulation

The aim of a policy should be to improve vector control or reduce the burden of vector-borne disease. The objectives of each policy related to IVM should be specified (Table 3.3). For example, the objective of a policy for an integrated approach would be to achieve efficient, effective control of several diseases.

Policies should be implemented with existing or new policy instruments, which are the tools that a government has to ensure leadership of the IVM strategy. Examples of policy instruments are listed in Table 3.3, and Table 3.4 lists policy instruments that facilitate, instruct and which are market-based and legislative. To ensure that effective policy instruments are available, they should be identified pre-emptively.

Table 3.3. Example of a policy framework for IVM

Element	Policy objective	Policy instruments
Advocacy, social mobilization and legislation	Effective legislation and regulation in place	Legislation, regulation on pesticide management Legislation, regulation on environmental management
	Communities empowered to participate in vector control	Support for community-based services Community awareness, education programmes Support for decentralization in decision-making Incentives programmes

Table 3.3. (Continued)

Element	Policy objective	Policy instruments
Collaboration within the health sector and with other sectors	Collaboration achieved within the health sector	Government position statement on IVM Instruct on collaboration among health divisions Review of job descriptions Facilitate a vector control needs assessment
	Collaboration achieved between sectors	Government position statement on IVM Establish intersectoral IVM committee Facilitate inter-ministerial meetings Instruct sectors on health Impact assessment
Integrated approach	Efficient, effective control of several diseases achieved	Provide instructions on collaboration among health divisions Allocation for monitoring and evaluation
	Effective, ecologically sound combinations of methods used	Legislation, regulation on pesticide management Legislation, regulation on environmental management Allocation and strategic direction for research
Evidence-based decision-making	Strong, updated evidence base used in making decisions	Allocation for capacity-building and career paths Support for decentralized decision-making Allocation for surveillance systems Allocation and strategic direction for research
Capacity-building	National and local capacity on IVM strengthened	Allocation for capacity-building and career paths Support for decentralized decision-making

Source: WHO *(30)*.

IVM has a broad scope, with five key elements, and a policy framework can be useful in policy formulation. An example of a policy framework on IVM is given in Table 3.4. For each of the key elements, specific policy objectives are formulated, and, for each objective, suitable policy instruments are proposed for implementation.

Table 3.4. Examples of policy instruments related to IVM

Type	Policy instruments
Instructive	Allocation for capacity-building and career paths Instruction in collaboration among health divisions Instruction for each sector on health impact assessment Review of job descriptions Allocation for monitoring, evaluation and surveillance Allocation and strategic direction for research
Facilitative	Government position statement on IVM Establishment of inter-sectoral IVM committee Facilitation of inter-ministerial meetings Facilitation of a vector control needs assessment Facilitation of decentralized decision-making Support for community-based services Community awareness and education programmes Incentives for community participation
Market-based Legislative	Subsidies, tariffs or taxes on vector control products Legislation and regulation on pesticide management Legislation and regulation on environmental management

A logical first step is to develop a general national policy on IVM (Box 3.2) and then, under this umbrella policy, more specific policies, e.g. on supportive research, mandates and career paths. A newly developed policy must be compatible with existing public policies.

Box 3.2. Example of national policy development on IVM

In 2002, the Government of Zambia adopted a new national malaria treatment and control policy, with IVM as a strategic approach to vector control. Implementation of the policy began in 2003. A new national malaria strategic plan (2006–2011) was developed, with the following components: policy; coordination of partnerships; equity and increased access to malaria control interventions; strengthening the health system to scale up preventive interventions; monitoring and evaluation of an evidence-based, cost-effective package of interventions; and strong collaboration of various public and private agencies that affect vector breeding, such as agriculture and urban development, including local authorities and engagement of communities with strengthened education, information and communication.

The country had a suitable legal and regulatory policy framework that provided the basis for delivery of IVM, including the Public Health Act (Chapter 295) and Acts for mosquito extermination (CAP 312). After systematic review of all the Acts for consistency with the new IVM policy, it has been implemented, resulting in better control of malaria. The policy addresses only one disease: malaria. Integration with other disease control programmes is now necessary.

Source: Chanda et al. *(31)*.

Alternative policy options should also be considered, with their likely effects and impact in the long term. The advantages of each option should be considered by hypothesizing the effects in scenarios with and without the new policy. Public policy must be endorsed at a high level in order to be implemented.

Practice in analysing policy scenarios

Imagine a situation in which your government is considering a new policy to facilitate collaboration among sectors at all levels in relation to vector control. Now, consider the current scenario without and with intersectoral collaboration and coordination on vector control.

1. List all the positive aspects of each scenario (e.g. cost, effectiveness, sustainability, feasibility, coordination, central control, decentralization, community acceptance and participation).
2. Now, list all the negative aspects of each scenario.
3. Balance the negative and positive aspects for each scenario.
4. Select the best scenario.

Questions:

- Which is the preferred policy option, and why?
- What important data are lacking? Could they be obtained, or will there be data gaps?
- Which stakeholders should ideally participate in policy-making? Why is their participation important?

Sande S, Zimba M, NyasVisvo D, Mukuzunga M, Kooma E, Mberikuashe J et al. Getting ready for integrated vector management for improved disease prevention in Zimbabwe: a focus on key policy issues to consider. Malar J. 2019;18:322. doi:10.1186/s12936-019-2965-x. *(32)*

3.2.3 Policy implementation

Policy is implemented with selected policy instruments, which provide strategic guidance and direction to the overall IVM strategy. The IVM approach encourages bottom-up planning and decision-making on vector control in response to local conditions and not top–down decision-making. Hence, the IVM policy should not stipulate actual vector control strategies or interventions but ensure the means and processes for implementation of IVM by local stakeholders.

A policy that supports a bottom–up approach includes one or more of the following: capacity-building for decision-making in districts and villages; capacity-building for decentralized surveillance, monitoring and evaluation; a policy for integration within the health system; and revision of job descriptions. Policies that encourage a top–down, centralized approach to vector control are national guidelines and standards, national capacity-building for decision-making and surveillance, national planning of operations and centralized monitoring and evaluation. The two approaches do not necessarily conflict with each other, as certain aspects will continue to be directed centrally, even in the context of a decentralized programme.

Policy implementation requires setting time frames and identifying milestones or clear achievements. Roles and accountability in policy implementation must be defined. Use of the policy instruments should be monitored and their effect in achieving the objectives evaluated *(33)* to identify gaps and weaknesses and take corrective measures. The outcome indicators for monitoring and evaluation are discussed in section 4.5.

3.3 Institutional and organizational aspects of IVM

3.3.1 Institutions and organizations

An institution is an organization founded for a specific purpose (e.g. social, professional or educational). Organizations consist of groups of people with a common set of objectives. Formal organizations have their own budgets and staff, such as government ministries, departments and civil society organizations. People may also be organized more informally, for example in farmers' or religious organizations and as ethnic groups.

The policies, systems and processes used by organizations to achieve their objectives are known as "institutional arrangements". An IVM strategy is implemented not by the health sector alone but with other public and private sectors and civil society organizations. Therefore, effective implementation of IVM requires agreement among them with regard to institutional arrangements. For example, a district health office and a district agricultural office operating in the same area may be pursuing a common strategy for reducing the risk of transmission of schistosomiasis and of malaria while optimizing agricultural productivity with irrigated agriculture. The two sectors must therefore be able to collaborate at district, village and field levels, and differences in sectoral priorities, organizational structures, operating procedures and staff requirements should be overcome to ensure effective collaboration. Discrepancies or inconsistencies in the policies of different organizations should be identified in a joint analysis by risk managers from both sectors.

In general, sectors or divisions often work more or less in isolation. Although such separation works well most of the time, it hinders effective implementation of vector-borne disease control. Vector control crosses the boundaries of divisions and sectors. Two sectors might, for example, have conflicting objectives and policies in relation to water use, irrigation or construction standards, one sector making agricultural production or efficient construction a priority and the other addressing prevention of vector breeding. Incompatible standards or rules can limit collaboration between two sectors; for example, lack of rules or standards on vector proliferation or environmental sanitation in one sector would conflict with the objectives of the health sector *(30)*.

Coordination and collaboration among sectors and with research institutes can be improved by identifying constraints and opportunities with respect to vector control and by initiating joint planning, collaboration and policy reform. Intersectoral coordination helps sectors to develop common goals and to resolve inconsistencies in relation to vector control. As each sector has its own responsibilities, coordination will not be spontaneous but requires policy support and a coordinator who facilitates cross-sectoral coordination of vector control, who is usually a health sector specialist in technical and operational aspects of vector control.

3.3.2 Organization and management

The aim of the IVM approach is to make vector control more efficient, cost-effective, ecologically sound and sustainable. This may require substantial changes in the organization and management of vector control. IVM should not be seen as a separate programme but rather as a strategy for strengthening the health system. National funding for current health systems could thus also benefit implementation of IVM if effectively coordinated and managed. Although IVM would strengthen health systems, it would add a mandate for redirection of funds and more time and work on vector-related activities for health staff in districts and villages.

IVM may require re-orientation of disease control programmes according to the IVM principles. The new approach calls for more emphasis on evidence-based decision-making, better integration of programmes and more collaboration and participation, resulting in new roles, responsibilities, job descriptions and organizational linkages.

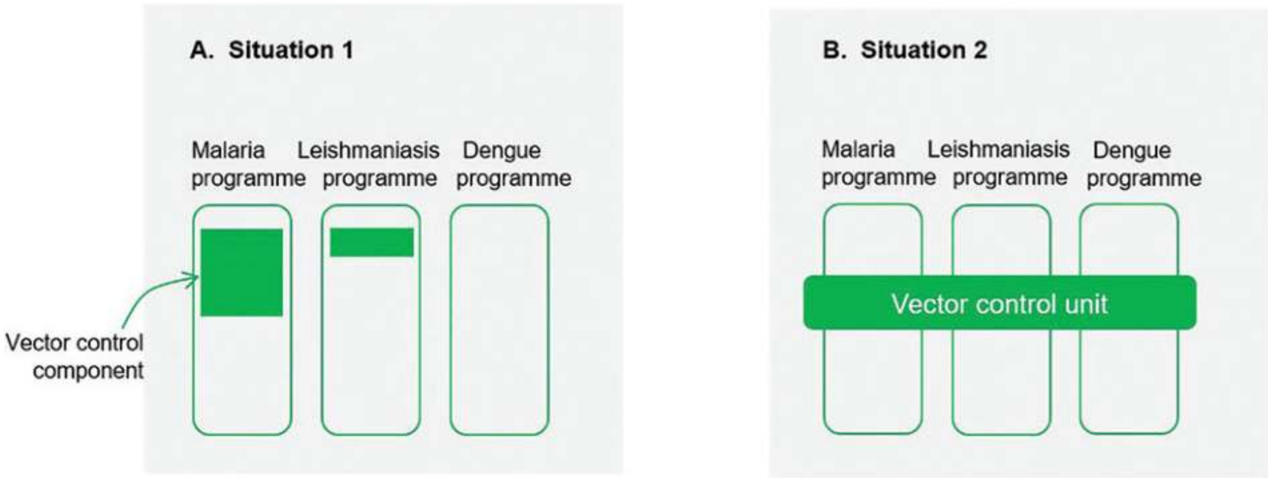
The aim of IVM as a management approach is to make better use of:
- institutions and people,
- the ways in which they operate and collaborate and
- the techniques and knowledge required.

Better management of these elements should result in more efficient, effective use of resources and competence.

In the health sector, which in most countries leads IVM, vector-borne disease control often consists of separate programmes for single diseases. Entomological capacity may be available for a malaria programme but weak or absent for a programme on leishmaniases or dengue (Fig. 3.5). Although sharing of entomological capacity among programmes has been uncommon, some countries have established a vector control unit with a mandate to participate in several programmes, to ensure efficient, shared use of scarce entomological capacity.

A unit for coordinating vector control will ensure sharing of information on all vector control activities and harmonization of the work of each partner. This will avoid duplication of work and reduce waste of resources. Entomology laboratories and equipment such as for monitoring insecticide resistance could be used for the vectors of several diseases. A central unit for vector control should not, however, oppose the bottom–up approach of IVM, such as making decisions on operations that could better be made at a lower administrative level. Rather, it should have an overall view of the control of all vector-borne diseases and thus avoid duplication and ensure greater efficiency of programmes.

Fig. 3.5. **Organization of vector control as separate vector control units within each programme and as one vector control unit with a mandate to work with each programme**



In IVM, bottom–up decision-making and the subsidiarity principle have important implications for the organization and management of vector control. The advantages of bottom–up rather than top–down decision-making are that the decisions are more responsive to local needs or demands, more flexible in responding to local changes, more precise and more directly accountable (e.g. by contact with local leaders or decision-makers).

Health reforms have resulted in decentralization of decision-making and resource allocation. In decentralized health systems, the responsibility for planning, budgeting and implementing rests with the district or equivalent unit of administration. Decentralized health systems thus provide suitable conditions for implementation of IVM (Box 3.3). A major challenge in decentralized decision-making is that the necessary skills and capacity, including for vector control, are often still inadequate at district level. Therefore, an IVM strategy with capacity for bottom–up decision-making can contribute to strengthening decentralized health systems.

Box 3.3. **Decentralization of malaria control**

An analysis of case studies in four countries suggested that decentralization can potentially benefit malaria control *(34)*. For example, in Brazil, decentralization of the malaria control programme from central level to municipalities resulted in local ownership and facilitated the development of local capacity for malaria control. Specialists at national level remained responsible for setting standards, procuring drugs and insecticides and providing technical support. Three years later, the rate of morbidity with malaria had decreased by 60%.

IVM can involve integration of disease-specific vector control programmes and surveillance services within a decentralized health system. Embedding IVM in local health systems requires new skills and capacities for analysis and decision-making. Each district or health unit need not have its own medical entomologist, which would be unrealistic in most settings. Health sector reform in some countries, however, may mean that a team of specialist medical entomologists is available neither nationally or at decentralized levels. Establishment of IVM at district level requires that district health staff and rural health workers have the necessary technical, operational and managerial competence for active implementation and coordination of the strategy. This requires development of human resources by training and supervision *(35)*.

The new links, partnerships and community participation in IVM can be important new assets, enabling local health systems to extend their reach and improve community compliance. Vector control activities in villages could be used to deliver other community health services, making more efficient use of resources. Use of existing infrastructure and community structures, such as involving local health staff and community health workers, increases the operational sustainability of vector control (Box 3.4). It helps to ensure that vector control can continue after the end of external donor-funded programmes if the competence and job descriptions of health staff and rural health workers are revised according to the principles of IVM. Vector control should receive regular allocations from local budgets.

Box 3.4. **Using existing infrastructure for dengue control**

In the Philippines, as in many other countries, national and international support for dengue control is limited, despite the escalating problem. In Mati City, temporary support for dengue control had been provided by a private mining company operating in the area; however, in 2011, this financial support was coming to an end. In response, the city health authorities took measures to integrate dengue vector control into the health infrastructure.

The first measure was training of "health emergency response" teams in each village in dengue prevention and adjustment of their job descriptions to include these activities, including organizing weekly clean-up drives and monthly vector larval surveillance. The teams had been present in each village since an epidemic on severe acute respiratory syndrome. The second measure was to create a disease surveillance unit to coordinate weekly reporting of cases of all notifiable diseases, including dengue and other vector-borne diseases, at the city's two hospitals and all 26 *barangay* health centres. These two measures led the city to provide a budget for the detection and control of dengue *(36)*.

Vertical programmes, such as IRS programmes for malaria control, are based on a top–down planning model (see section 1.5). These programmes can operate within decentralized health systems as long as they involve local leaders and local representatives in planning and decision-making and are flexible, so that the programme can be adapted to local data or local preferences.

3.3.3 Intersectoral collaboration

Sectors such as agriculture, local government, environment, plantations, construction and tourism have important roles in the prevention of vector-borne diseases. Their programmes and activities, e.g. on irrigation in agriculture, influence when and where vectors of disease pathogens breed. Formal collaboration between the health and other public sectors is therefore important to increase the participation of those sectors in vector control. Production sectors often have more resources than the health sector, and they could therefore make significant contributions to vector control or transmission reduction.

Intersectoral coordination of an IVM strategy should be initiated from the top, by establishing a national inter-ministerial steering committee on IVM. Risk managers can encourage formation of such a committee by raising awareness about its importance in policy briefs and other reports. The committee, which should include representation of the pesticides board and other relevant groups, could provide oversight, assign partners, coordinate resource mobilization and review and adjust policies, strategies and work plans for IVM. This authoritative body could also set up technical working groups, such as for monitoring and evaluation. To be sustainable, the committee must be supported from the regular government budget and not depend on external financing.

Intersectoral collaboration is usually more straightforward in districts, where staff in different sectors meet regularly, and it is probably easier to establish partnerships on IVM. Partnerships should include civil society representation.

Before starting IVM activities, basic training in the principles of IVM and vector biology is required for all involved, including members of the intersectoral committee, to increase knowledge, skills and motivation for establishing partnerships. A partnership is formalized through a shared vision, common goals and objectives and defined roles in IVM. The partnerships should allow joint allocation of tasks such as vector control interventions, awareness campaigns, education and vector surveillance. They should ensure that their work is consistent and complementary. Technical support to local partnerships could be provided by occasional visits of national experts to districts or villages, for example, to give advice during planning or evaluation.

The main functions of an intersectoral steering committee on IVM are to:

- constitute and coordinate technical working groups, including on policy review, monitoring, evaluation and prioritization of operational research;
- assign roles and responsibilities to partners;
- coordinate mobilization of resources for intersectoral action;
- oversee implementation of the national IVM strategy and work plans; and
- use monitoring and special studies to review and adjust policies, strategies and work plans on IVM regularly.

According to a recent WHO survey, 51% of responding countries reported that they had a national task force for multisectoral engagement in vector control, such as an intersectoral task force (Carrington L., Global Malaria Programme, WHO, personal communication, 2022).

It is not known to what extent each task force is active and functional. Countries have found it difficult to establish and maintain a functioning intersectoral committee on IVM. For example, in Oman, attempts in 2007 and 2009 to establish a committee reportedly failed because senior decision-makers were not represented. In 2017, the committee was revived, with representation from relevant ministries and a technical task force. Oman experienced a dengue outbreak in 2018, during which the revived committee led collaboration among stakeholders and managed to secure funds from the Cabinet that resulted in a successful response to contain the outbreak.

Multisectoral approach to the prevention and control of vector-borne diseases: a conceptual framework. Geneva: World Health Organization; 2020 (https://iris.who.int/handle/10665/331861).

3.4 Communication

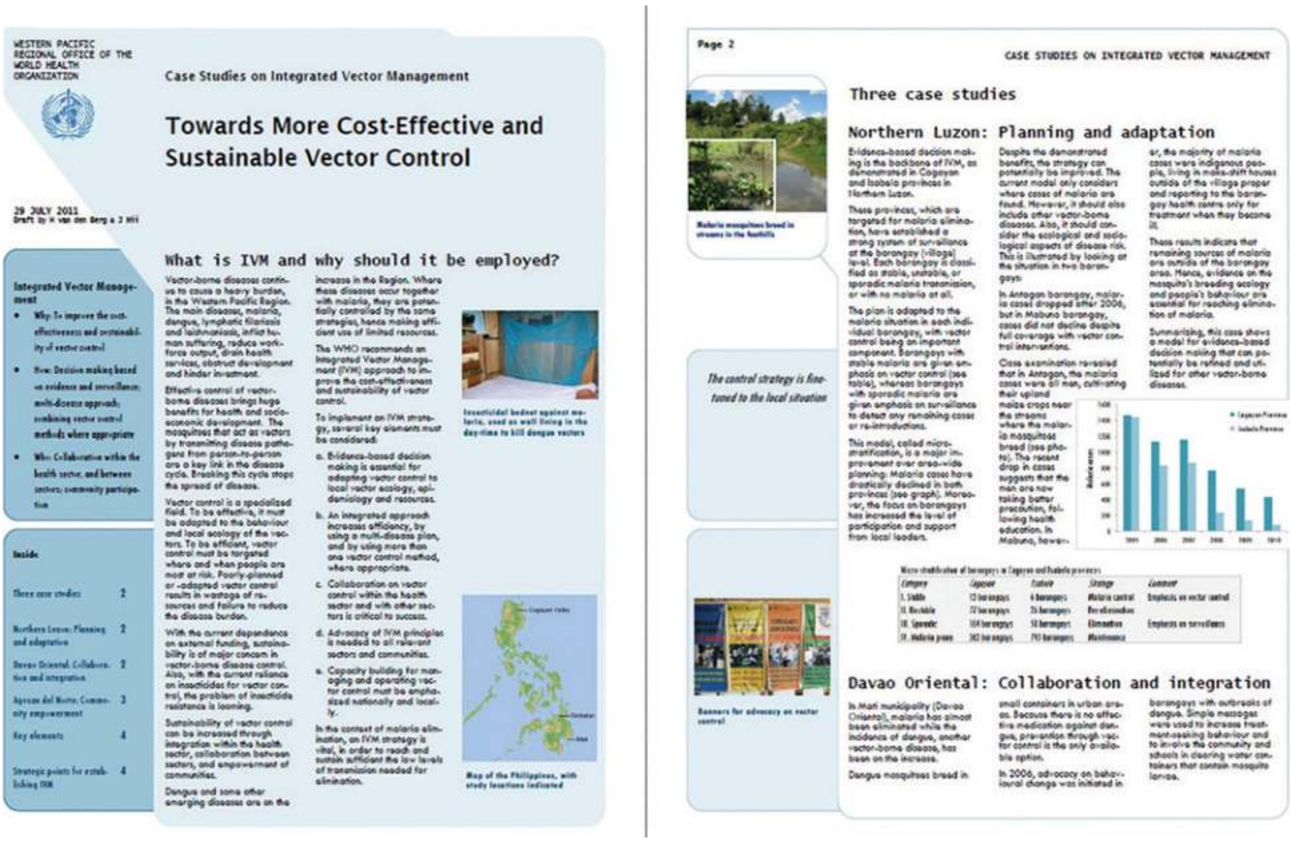
The principles, objectives and potential benefits of IVM must be communicated effectively for it to be adopted. Communication should be at two broad levels: to national policy-makers and decision-makers and to all who might be involved in implementing IVM-related activities in districts, villages and communities. Communication to national actors is through advocacy, while communication to those involved in operations is through training, education and awareness campaigns.

Advocacy on IVM can be initiated only when people in senior positions understand and are committed to IVM and have access to policy-makers and decision-makers. Sande et al. *(32)* presented a compelling case for advocacy on IVM to senior decision-makers in Zimbabwe. The activities involved in advocacy and communication depend on the phase of the IVM strategy (Table 3.5). During conceptualization of an IVM strategy, advocacy is required at ministerial and senior levels to leverage commitment in terms of policy, funding and research. During transition to and establishment of an IVM strategy, feedback will be required on the performance and impact of IVM to sustain support. Documentation of early successes plays a major role in leveraging continued support by demonstrating the feasibility and benefits of IVM and where adjustments to the strategy are required (Fig. 3.6).

Table 3.5. Framework for advocacy and communication, with examples of targets, tools and expected outcomes

Phase	Target audience	Tools	Expected outcomes
Conceptualization	Politicians, policy-makers, donors, researchers	Messages (e.g. "What is IVM", "How will IVM improve the situation") Examples from other countries	Political commitment, institutional restructuring, revised research agenda, funding
Transition and consolidation	Politicians, policy-makers, donors, researchers	Successful results, including local examples	Sustained support, expansion
	General public	Media Information, education and communication Communication for behavioural change Farmers' field schools	Awareness, behavioural change, empowerment

Fig. 3.6. Example of IVM advocacy leaflet for policy-makers and decision-makers



3.4.1 Advocacy to policy-makers

The purpose of advocacy on IVM is to convince political leaders and policy-makers of the importance of IVM (Box 3.5). The expected outcome is that IVM rises on the national agenda, policies are formulated to promote IVM, and guidance is given to public sectors, professionals and the general public.

Box 3.5. **Examples of advocacy on IVM**

A. What is IVM?

Basic concept:	*Answer:*
Evidence-based decision-making	Decisions made in accordance with data or information on the local conditions of diseases and disease transmission
Multi-disease approach	Vector control for all prevalent vector-borne diseases in one strategy
Integration of vector control interventions	All relevant vector control methods included in order to use supplementary effects
Involvement of other sectors	Other health divisions, sectors and communities involved in vector control.

B. How will IVM improve the situation?

In the absence of IVM, the following problems might be encountered:

- suboptimal choice or timing of interventions, no monitoring and waste of resources;
- no integration of vector control programmes for single diseases in the health system;
- vector control programme not optimally adapted to ecological and environmental conditions;
- other sectors and communities insufficiently aware of the consequences of their activities on vector-borne diseases; and
- resistance to insecticides an increasing problem in vector control.

IVM increases the efficacy, cost-effectiveness, ecological soundness and sustainability of vector control.

Source: WHO *(30)*.

To convince politicians and policy-makers of the value of IVM and re-orientation of existing programmes and structures according to the principles of IVM, the problems posed by the existing system of vector control should be pointed out and the benefits of IVM stressed in terms of increasing the efficiency and effectiveness of field operations. The importance of vector control in vector-borne disease control and the potential role of IVM in strengthening health systems and increasing the participation of communities should be emphasized.

Several tools can be used in advocacy: simple messages, policy briefs, documented examples from other countries and successful initial results.

As IVM may be considered a complex, intangible concept, messages on IVM should be clear. They should be based on information on the burden of vector-borne diseases (see section 1.1) and its economic consequences for workforce output and school attendance. IVM should not be advocated as a new programme but as a management tool for improving systems of vector control. It is a strategy based on evidence-based decision-making, a multi-disease approach, integration of vector control interventions and involvement of other sectors and communities.

After initial sensitization of policy-makers with simple, straightforward messages on IVM, policy briefs are a powerful, more structured advocacy tool. In a policy brief, statements are made on the problem, the issue at stake and the background, with a summary of the policy analysis, new policy options with their advantages and disadvantages and clear recommendations, with references.

Documented examples are another useful tool in advocacy, as they provide real examples and demonstrate the expected benefits. Successful examples of IVM *(36)* or of some components of IVM *(37–39)* are available, but documentation of new case studies on IVM is urgently required.

Another tool for advocacy is reporting of initial results obtained locally. Monitoring the initial results of an IVM strategy informs politicians about early benefits, which could convince them that the IVM strategy deserves continued support and can become policy.

3.4.2 Communication strategies for communities

IVM should also be communicated to communities, where most vector control activity take place. The role of communities in the prevention of vector-borne disease should not be underestimated *(40)*, as it is necessary to increase the uptake of preventive interventions for personal protection and vector control. The Roll Back Malaria action plan emphasizes a long-term commitment to community engagement.

Most types of vectors are associated with environments in which people live, and they develop and reproduce around houses. The choices of people on use of water containers, disposal of waste, personal hygiene, personal protection and others directly influence their risk of contracting vector-borne diseases. People influence their domestic environment, not the health sector, and communities can reduce the disease risk drastically if they know the importance of their behaviour and practices on the vectors and on disease transmission and if they are motivated or mobilized to improve their behaviour and practices.

In order to provide effective awareness-raising, behavioural change or education, the sociocultural barriers to participation or change in behaviour with respect to vector control must first be understood, for example by conducting surveys on the knowledge, attitudes and practices of people with regard to vector-borne diseases, vector control and personal protection. If people are asked to change practices of obvious cultural or economic importance, they will react negatively.

The major challenges in communication and education for targeted communities or the general public are raising awareness and motivating people to play active, beneficial roles in vector control. A number of methods have been used to communicate health messages. In this course, four methods are discussed, each with its own strengths and weaknesses: the media; information, education and communication; communication for behavioural impact; and farmers' field schools.

The media, such as newsprint and radio and television broadcasts, can be used to send simple messages to a wide audience and help create awareness about a specific aspect of IVM to the general public. Interesting examples of community involvement in IVM could be filmed and shown to motivate others *(41)*.

Interventions for "information, education and communication" involve a combination of mass media, group communication and interpersonal communication to change people's attitudes and behaviour *(42)*. The intervention is based on an analysis of behaviour, such as through surveys of knowledge, attitudes and practices in relation to the disease, its prevention and control. Several methods of communication can be used, such as radio broadcasts, magazines, leaflets, posters, newspaper articles, religious meetings, school education, community meetings, market meetings and health facility meetings. Such interventions have been shown to increase knowledge and change attitudes, although the effect on changing people's behaviour has been questioned. A focus on knowledge and skills by providing better access to information and services does not necessarily change people's behaviour.

The third approach, "communication for behavioural impact" also involves a combination of information and education to achieve social mobilization, based on marketing principles used in the private sector to change consumer behaviour. The approach has been used in the control of dengue (Box 3.6), lymphatic filariasis, malaria and several other infectious diseases to improve control of vector breeding sites and has been beneficial in a number of field situations. A trial on malaria control in Sudan showed that communication for behavioural impact increased awareness about malaria and increased use of ITNs *(43)*. Nevertheless, its use for public health purposes has been criticized by some as manipulative and political *(44)*. The approach starts with identification of desirable behaviour and barriers to adopting such behaviour, with development of a few behavioural objectives. A strategy is then developed to achieve those objectives. A combination of tools is used, as appropriate, including public relations, campaigns, advertising and interpersonal communication. Once the strategy is implemented, progress is monitored.

Box 3.6. **Communication for behavioural impact on dengue**

After a study of people's behaviour and attitudes, four desired types of behaviour on treatment seeking and vector breeding were identified for advocacy:

- attend a health facility if fever is not relieved after 2 days of medication;
- cover all water containers inside and outside at all times;
- clean all water containers before refilling, at least once a week; and
- cover or drill holes in used tyres to prevent water accumulation.

The trained community health workers then conducted health promotion and dengue vector surveillance in their villages each month and, during dengue outbreaks, every week (Fig. 3.7).

Fig. 3.7. Banners used as a tool in communication for behavioural impact to convey four messages in relation to dengue vector control in the Philippines

Photo: courtesy of H. van den Berg.

A fourth approach is farmers' field schools, in which educational methods and experiential learning are used to "empower" farmers to make better decisions *(45–47)* (Box 3.7). The method was developed by the Food and Agriculture Organization of the United Nations in Asia to educate farmers in integrated pest management. It involves a "learner-centred" approach, with "learning through discovery", and the teacher acts as facilitator by providing the conditions for learning. It includes the "learning cycle" model, with systematic observation and analysis of the local (i.e. farming) situation in order to understand general biological principles and to develop skill in decision-making. Subsequent evaluation of the results of decisions provides feedback.

Farmers' field schools help farmers to adapt their practices to local conditions in group learning; communication skills are learnt in group dynamics exercises. During a full crop cycle, farmers make observations about the agroecosystem, analyse and present their findings for group discussion, make decisions on management options and evaluate the effect of those decisions the following week (Fig. 3.8). These weekly learning cycles strengthen the analytical and decision-making skills of the participants. The farmers' field school model has been used in vector control *(30,48)* and has had various human, social, natural and financial impacts *(47)*.

Box 3.7. **Farmers' field school**

There is usually more experience with community participation and empowerment in the agricultural sector than in the health sector. In Sri Lanka, an agricultural farmer training programme using the farmers' field school approach had been conducted to improve production of irrigated rice and to reduce the reliance on and misuse of chemical insecticides for pest control. The schools resulted in important benefits in terms of increased production, reduced expenditure on insecticides and thus an increase in farmers' incomes.

The irrigated rice environments were the breeding habitat of the mosquito vectors of several locally prevalent diseases, namely malaria, Japanese encephalitis and lymphatic filariasis. Also, dengue vectors were breeding in the peri-domestic environment.

Coordination meetings between scientists, health officials and agricultural officials resulted in the development of methods and training curricula to educate rice farmers on aspects of vector management in the context of their agricultural environment. The farmer field school model thus incorporated agricultural and health components. The education was given through practical, field-based weekly sessions in the field to teach farmers the skills of observation, analysis and decision-making. Farmers also acquired communication skills and developed active farmers' groups.

As a result of the training, rice farmers became involved in the environmental management of vector populations in irrigated agriculture, using methods such as canal clearing, land levelling and intermittent irrigation to control mosquito breeding. Trainees also became more aware of the benefits of bed nets, and their use increased after the training.

Fig. 3.8. Participants in a farmers' field school

Photo: courtesy of H. van den Berg.

Sources: WHO *(48)*, Yasuoka et al. *(49,50)*.

Mutero CM, Mbogo C, Mwangangi J, Imbahale S, Kibe L, Orindi B et al. (2015) An assessment of participatory integrated vector management for malaria control in Kenya. Environ Health Perspect. 2015;123(11):1145–51. doi:10.1289/ehp.1408748. *(51)*

A comparison of the strengths and weaknesses of each method is shown in Table 3.6. Media and information, education and communication programmes may have wider coverage but may have less impact on people's behaviour. Communication for behavioural impact can affect people's behaviour but not equip them to make independent analyses and decisions on vector control. The farmers' field school model strengthens people's skills of observation, analysis and decision-making, without requiring long-term, targeted, intensive education. It is thus suitable in situations when decisions must be adapted to changing local conditions.

Table 3.6. Comparison of four tools for communicating behavioural change and social mobilization

Aspect	Media	Information, education and communication	Communication for behavioural impact	Farmers' field schools
Method	Broadcasting of messages	Needs assessment; development of strategy; use of mass media; group communication; interpersonal communication	Situation analysis; behavioural objectives; strategy with an optimal mix of actions	Weekly group sessions for observation and analysis of local ecosystems, decision-making and experimentation; group dynamic exercises
Application	Settings that require generally applicable messages	Settings that require generally applicable messages	Settings that require generally applicable messages	Complex settings in which locally adapted solutions are required
Strength	Low cost, wide coverage	Relatively low cost. rapid coverage, increases awareness	Sharp focus on outcomes, impact on behaviour and mobilization	Empowering effect, local adaptation, group building, prospects for inter-sectoral cooperation
Weakness	Limited impact on behaviour	Relatively limited impact on behaviour	Cost; human resources	Cost; human resources

3.4.3 Community empowerment

Awareness or changed behaviour do not mean that people are also empowered. With empowerment, people take control of their lives. In the context of vector control, empowerment is required in complex situations in which decisions have to be made locally in response to changing conditions. Empowerment of communities and community health workers on vector control also improves the prospect of sustainability of vector control, by making the work less dependent on external programmes and their resources. A challenge, however, is maintaining the motivation of empowered communities to continue their engagement in vector control activities. Examples from the Philippines and Malawi are shown in Boxes 3.8 and 3.9.

Box 3.8. **Empowerment for malaria control**

In the *barangay* (or village) of Simbalan, Philippines, recent malaria control interventions have resulted in a very low incidence of malaria. The village is in an isolated location in the mountains. Malaria control in the village has had strong local leadership, and, after substantial training and investment in malaria control by provincial and municipal health offices, the *barangay* and community leaders helped to mobilize local resources and voluntary services for vector control. Five local initiatives on malaria control have been established, with voluntary participation by villagers:

Local initiative	Malaria control component			
	Detection, diagnosis	Case treatment	Vector control	Health promotion
Barangay action committee	+	+	+	+
Anti-malaria brigades	+		+	+
Transport services	+	+		
House-to-house visits			+	+
School education programme			+	+

An action committee on malaria was established to plan and coordinate malaria control in the village. Under the auspices of this committee, an anti-malaria brigade of volunteers was formed in every outlying part of the village to conduct environmental management and various other activities. The local motorbike-taxi association provided transport services, usually for free, for example to transport patients, blood slides and reports. Regular house-to-house visits were carried out by "personal sellers", to promote and monitor the use and maintenance of LLINs by residents. Health education on malaria transmission and vector control was provided in schools.

Barangay authorities and the community were actively involved in planning, implementing and evaluating the malaria control actions, indicating local ownership of the programme. The village developed its own vision statement in order to be independent of external resources for malaria control, an indication of their commitment to sustain malaria control. The challenge is for local leaders to sustain the commitment to and activities for malaria control or elimination once the incidence has remained low or negligible for a long time.

Source: van den Berg et al. *(36)*.

Communities in the peri-domestic environment should be empowered to improve their situation by preventing disease and thus depend less on health services. It has been suggested that empowerment requires two conditions: means or enabling factors, such as opportunities, resources and capacity-building, and analysis and decision-making *(53)*. Because of its emphasis on observation, analysis and decision-making, the farmers' field school results in empowerment.

Box 3.9. **Potential roles of health animators and nongovernmental organizations**

In Chikwawa district, southern Malawi, an interesting collaboration was established between a malaria control project and a nongovernmental organization. The organization established so-called epicentres in selected localities, each with a catchment area, for community-driven initiation of local programmes, such as for agriculture, micro-financing, a food bank, literacy classes, nutrition and HIV. A building houses the programmes and serves as a meeting place for the community (Fig. 3.9). Malaria control has been attached to the epicentre as a community programme.

Health animators are volunteers, each selected from one village, who have been trained in malaria and its prevention and control. They have also learnt how to conduct village workshops in their localities, working in teams of two or three animators.

The annual curriculum consists of 26 sessions of village workshops every 2 weeks. Each session addresses a topic, ranging from the basics of malaria (signs, symptoms, diagnosis, treatment, vulnerable groups), vector ecology (behaviour, breeding), personal protection (bed net installation, maintenance, repair), to environmental determinants, participatory mapping and community action planning.

The village workshops have already been seen to have direct outcomes: villagers have improved their treatment-seeking behaviour; bed net use has improved; and community demand for good-quality health services has risen, leading to a positive response from the health system. Other interventions are house improvement and larval source management.

Source: van den Berg et al. *(52)*

Fig. 3.9. A community workshop in Malawi

Photo: courtesy of H. van den Berg.

1. What factors led to success in this example?
2. What are the challenges for replicating this example elsewhere?
3. What do you consider the benefits of linking malaria control with a nongovernmental organization that has a holistic strategy for community development?
4. What challenges do you foresee in this approach?

3.5 Capacity-building

The IVM strategy promotes evidence-based decision-making and integration of measures and programmes. The success of IVM depends largely on the human resource capacity and infrastructure in a country. The required capacity includes entomological expertise for vector surveillance, monitoring and planning of vector control interventions, with trained operational teams and the necessary infrastructure, such as entomology laboratories. Many disease-endemic countries have serious shortages of capacity at national, district and village levels.

3.5.1 Required competence

A number of types of competence are required for implementing an IVM strategy. Table 3.7 presents the core functions required for IVM and, for each function, the required competence.

Table 3.7. Functions and competence of partners in integrated vector management

Level	Core function	Competence
National, sub-national	Advocacy	Access, communication
	Setting of strategic direction and conduct overall evaluation	Planning and evaluation
	Advice on policy and institutional arrangements	Policy analysis
	Epidemiological and vector assessment, stratification	Technical knowledge
	Supervision of decentralized planning and implementation	Facilitation, technical knowledge
	Supervision of decentralized monitoring and evaluation	Facilitation, technical knowledge
	Supervision of decentralized organization and management	Facilitation and management
	Curriculum development and training of trainers	Training
	Coordination of emergency response	Technical knowledge, management
	Advice on research priorities	Technical knowledge
District, village	Advocacy	Access, communication
	Establishing inter-sectoral partnerships and networking	Access, communication
	Planning and implementing local IVM strategy	Analysis and decision-making
	Implementing health sector interventions	Operational skills
	Monitoring and evaluation	Technical skills
	Organization and management	Management
	Local vector surveillance	Technical skills
	Training, education and awareness raising	Training and communication

The core functions at national level are provision of strategic direction, coordination of evaluation, and advocacy to policy-makers. Other important functions are provision of advice, guidance and supervision to those involved at decentralized levels. The assumption is that an IVM strategy is not planned and managed from top to down but that it adheres to the principle of "subsidiarity" by promoting decision-making at lower levels of administration. The technical functions required at national level are epidemiological and vector assessment, operational research, emergency response and development of curricula on IVM. The types of competence required for these core functions are skills in facilitation, communication, coordination, strategic direction and technical aspects.

The core functions at local levels of administration are planning and implementation of strategies, monitoring and evaluation, organization and management, vector surveillance, and training and awareness-raising. These require training or retraining health staff and staff in other relevant sectors in analysis, decision-making, operations, technical aspects, management, training and communication. Skills for developing intersectoral partnerships, including with civil society organizations, should be developed. Most core functions require a problem-solving approach, for which analytical and decision-making skills are indispensable.

The development of human resources will benefit from a situation analysis of the existing types and levels of competence of the personnel to identify gaps and shortcomings that require specific training.

3.5.2 Training and infrastructure

National training curricula for IVM are developed in accordance with the prevalent requirements and local context, using the guidance provided by the WHO in the document *Core structure for training curricula on integrated vector management (35)*. Training curricula could be tailored to different target audiences, such as those in the health sector with a background in vector-borne disease control and those with no such background. Surveys of social and cultural perceptions among partners and communities can help to identify training requirements. Field-testing of training curricula is essential to ensure that they suit the target group.

A problem-solving approach is central to training courses, because the observations, analyses, decision-making and evaluation stimulate active learning in real-life situations and can empower those involved. A decentralized strategy such as IVM draws on human resources in districts and villages, which may result in large numbers of staff and volunteers. Therefore, training and human resources development should include as many people as practicably possible in relatively short courses. Courses to train trainers establish a cadre of trainers to provide in-service training to staff in the health and other sectors and to local authorities and community representatives, each with a specific curriculum.

Training in IVM could be added to formal education in primary and secondary schools and to the curricula of science, medical and engineering faculties in higher educational institutions. Establishment of a career track in vector control and public health entomology could encourage students to seek training and help ensure that graduates find jobs in their chosen profession.

An IVM strategy has several requirements for infrastructure, some of which may be present in the health or other sectors (e.g. entomological equipment in agriculture). The infrastructure includes entomology laboratories, insectaries, supplies, equipment, transport and communication technology.

A large problem in vector-borne disease control is the scarcity or lack of entomologists, who guide the surveillance, monitoring, evaluation and implementation of vector control *(54,55)*. Moreover, entomologists are necessary to address critical issues such as insecticide resistance, changes in vector populations and the elimination of disease *(56,57)*. The shortage is due partly to inadequate career opportunities for public health entomologists. Laboratory infrastructure for entomological surveillance is also in short supply *(58)*.

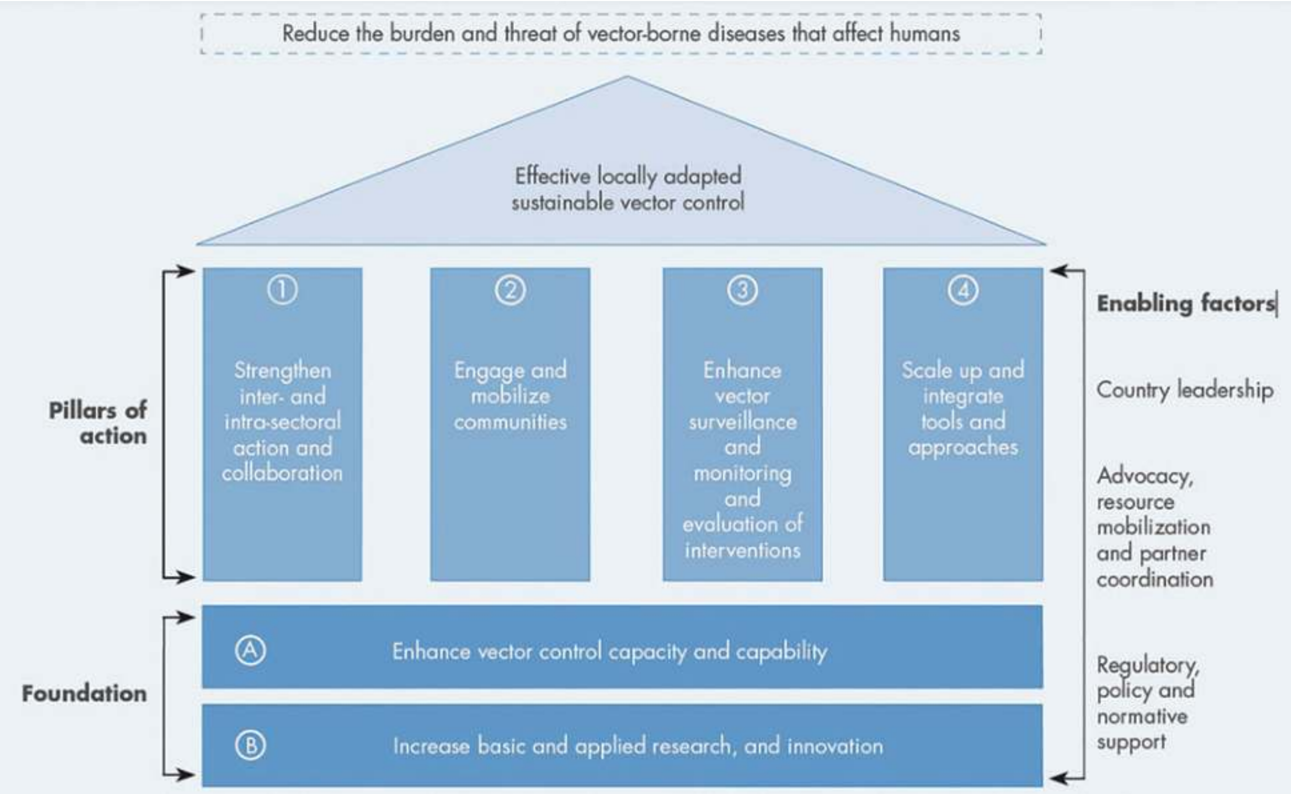
3.5.3 The global vector control response

Several years have passed since the IVM strategy was launched, in 2004, by WHO, with publication of the global strategic framework on IVM, followed by the IVM handbook in 2012. International policy support for IVM helped in the development of strategies in each region. The uptake of the IVM strategy was not, however, as intended at country level because of insufficient political buy-in for reorientation of vector-borne disease control programmes *(57)*. Some countries made good progress *(40,58)*, but others have been less successful due to difficulties in establishing intersectoral collaboration and severe shortages of entomological expertise *(59)*.

Meanwhile, the burden of vector-borne diseases continued, with previous advances made in malaria control stalled due to inadequate financing for vector control. Furthermore, surges occurred of several emerging diseases, including dengue, chikungunya, Zika virus and West Nile virus. Global disease vector control suffered because of poor financing and poor entomological capacity, and the full impact of vector control was not reached.

The Global Vector Control Response 2017–2030 (GVCR) was adopted by the World Health Assembly in 2017 in resolution WHA 70.16 *(9)* to reposition vector control as a key approach to prevent and eliminate vector-borne diseases. The GVCR was developed to advance the IVM concept by re-emphasizing its key elements in four pillars of action: strengthen inter- and intra-sectoral action and collaboration; engage and mobilize communities; enhance vector surveillance; and scale up and integrate tools and approaches (Fig. 3.10). These pillars are based on enhanced vector control capacity and more research and innovation. The pillars of action and their foundation are influenced by enabling factors, such as country leadership, advocacy and policy support.

Fig. 3.10. Framework of the global vector control response



Source: WHO *(9)*.

Can you identify the key elements of IVM in the framework of the global vector control response?

The GVCR defined milestones and targets (Table 3.8): to reduce mortality due to vector-borne diseases globally by 75% by 2030 relative to 2016; to reduce the incidence of cases of vector-borne diseases globally by 75% by 2030 relative to 2016; and to prevent epidemics of vector-borne diseases in all countries by 2030.

Table 3.8. Goals of the global vector control response

GOALS	MILESTONES	TARGETS	
	2020	2025	2030
Reduce mortality due to vector-borne diseases globally relative to 2016	By at least 30%	By at least 50%	**By at least 75%**
Reduce case incidence due to vector-borne diseases globally relative to 2016	By at least 25%	By at least 40%	**By at least 60%**
Prevent epidemics of vector-borne diseases[a]		In all countries without transmission in 2016	**In all countries**

[a] Rapid detection and curtailment of outbreaks to prevent spread beyond the country.

Source: WHO *(9)*.

Please comment on the feasibility, in your view, of the GVCR targets, and explain.

The GVCR proposed a number of priorities, including development of a national vector control strategic plan, an updated vector control needs assessment and national research agendas on vector control; establish an inter-ministerial task force on vector control; and strengthen national vector surveillance systems.

In 2020, WHO reported on progress in implementation of the GVCR *(60)*. Regional strategic plans had been developed in the WHO African, Americas, South-East Asia, European and Eastern Mediterranean regions, and various normative and capacity-building activities had been conducted in regions and countries. Progress was, however, lagging due to inadequate human and financial resources for implementation of the GVCR. In particular, a vector control needs assessment had been completed recently in only some countries. The assessment is considered an important first step in implementation of the response.

Project assignment 3

A. Policy and institutional framework

1. Identify the policies, laws and regulations in your country that support IVM. Consider those in the health sector and those in other sectors (e.g. agriculture, water resources, urban development, environment, local government).
2. Identify policies, laws and regulations that could conflict with the aims of IVM.
3. From the national policies identified above, briefly outline the major shortcomings of the current policy framework, and propose actions for resolving this problem.
4. Are there good examples of intersectoral collaboration in vector control in your country? If yes, which factors or activities contribute to collaboration? If no, what is necessary to establish collaboration?

B. Communication strategies

Review the diseases listed for your country in project assignment 1, and construct a new matrix.

1. First column: For each disease, identify the strategies currently used in your country for communication to the community.
2. Second column: For each disease, determine the current objectives for involving communities in the prevention and control of disease. (What does the programme want communities to contribute, e.g. compliance with a certain behaviour?)
3. Third column: Identify the main weaknesses in communication strategies, and propose improvements.

References

1. Bhatt S, Weiss DJ, Cameron E, Bisanzio D, Mappin B, Dalrymple U et al. The effect of malaria control on *Plasmodium falciparum* in Africa between 2000 and 2015. Nature. 2015;526(7572):207–11. doi:10.1038/nature15535.

2. World malaria report 2022. Geneva: World Health Organization; 2022 (https://iris.who.int/handle/10665/365169).

3. Hougard JM, Alley ES, Yaméogo L, Dadzie KY, Boatin BA. Eliminating onchocerciasis after 14 years of vector control: a proved strategy. J Infect Dis. 2001;184(4):497–503. doi:10.1086/322789.

4. Dias JCP. Southern Cone Initiative for the elimination of domestic populations of *Triatoma infestans* and the interruption of transfusion Chagas disease: historical aspects, present situation, and perspectives. Mem Inst Oswaldo Cruz. 2007;102:11–8. doi:10.1590/s0074-02762007005000092.

5. Wilson AL, Courtenay O, Kelly-Hope LA, Scott TW, Takken W, Torr SJ et al. The importance of vector control for the control and elimination of vector-borne diseases. PLoS Negl Trop Dis. 2020;14(1):e0007831. doi:10.1371/journal.pntd.0007831.

6. Lymphatic filariasis: practical entomology. A handbook for national lymphatic filariasis elimination programmes. Geneva: World Health Organization; 2013 (https://iris.who.int/handle/10665/87989).

7. Operational manual on leishmaniasis vector control, surveillance, monitoring and evaluation. Geneva: World Health Organization; 2023 (https://www.who.int/publications/i/item/9789240060340).

8. Townson H, Nathan MB, Zaim M, Guillet P, Manga L, Bos R et al. Exploiting the potential of vector control for disease prevention. Bull World Health Organ. 2005;83(12):942–7 (https://iris.who.int/handle/10665/269548).

9. Global vector control response 2017–2030. Geneva: World Health Organization; 2017 (https://iris.who.int/handle/10665/259205).

10. Kleinschmidt I, Bradley J, Knox TB, Mnzava AP, Kafy HT, Mbogo C et al. Implications of insecticide resistance for malaria vector control with long-lasting insecticidal nets: a WHO-coordinated, prospective, international, observational cohort study. Lancet Infect Dis. 2018;18(6):640–9. doi:10.1016/S1473-3099(18)30172-5.

11. Sougoufara S, Diédhiou SM, Doucouré S, Diagne N, Sembène PM, Harry M et al. Biting by *Anopheles funestus* in broad daylight after use of long-lasting insecticidal nets: a new challenge to malaria elimination. Malar J. 2014;13:125. doi:10.1186/1475-2875-13-125.

12. Pedersen EM, Mukoko DA. Impact of insecticide-treated materials on filaria transmission by the various species of vector mosquito in Africa. Ann Trop Med Parasitol. 2002;96(Suppl_2:S91–5. doi:10.1179/000349802125002437.

13. van den Berg H, Velayudhan R, Ebol A, Catbagan BHG, Turingan R, Tuso M et al. Operational efficiency and sustainability of vector control of malaria and dengue: descriptive case studies from the Philippines. Malar J. 2012;11(1):269. doi.:10.1186/1475-2875-11-269.

14. Keiser J, De Castro MC, Maltese MF, Bos R, Tanner M, Singer BH et al. Effect of irrigation and large dams on the burden of malaria on a global and regional scale. Am J Trop Med Hyg. 2005;72(4): 392–406 (https://pubmed.ncbi.nlm.nih.gov/15827275).

15. Gubler DJ, Clark GG. Community-based integrated control of *Aedes aegypti*: a brief overview of current programs. Am J Trop Med Hyg. 1994;50(6_Suppl):50–60. doi:10.4269/ajtmh.1994.50.50.

16. Stockholm Convention on Persistent Organic Pollutants, as amended in 2009. Text and annexes. Geneva: United Nations Environment Programme; 2010 (http://chm.pops.int/TheConvention/Overview/TextoftheConvention/tabid/2232/Default.aspx).

17. Fiftieth World Health Assembly, Geneva 12 May 1997. Promotion of chemical safety, with special attention to persistent organic pollutants. Geneva: World Health Organization; 1997 (https://apps.who.int/iris/bitstream/handle/10665/179736/WHA50_R13_eng.pdf).

18. The global malaria action plan. Geneva: Roll Back Malaria Partnership; 2008 (https://www.afro.who.int/sites/default/files/2017-06/Gmapfull.pdf).

19. Investing to overcome the global impact of neglected tropical diseases: third WHO report on neglected diseases. Geneva: World Health Organization; 2015 (https://iris.who.int/handle/10665/152781).

20. Thomas MB, Godfray HCJ, Read AF, van den Berg H, Tabashnik BE, van Lenteren JC et al. Lessons from agriculture for the sustainable management of malaria vectors. PLoS Med. 2012;9(7):e1001262. doi:10.1371/journal.pmed.1001262.

21. WHO position statement on integrated vector management. Geneva: World Health Organization; 2008 (https://iris.who.int/handle/10665/69745).

22. Working to overcome the global impact of neglected tropical diseases. Update 2011. Geneva: World Health Organization; 2011 (https://iris.who.int/handle/10665/44778).

23. Global strategic framework for integrated vector management. Geneva: World Health Organization; 2004 (https://iris.who.int/handle/10665/68624).

24. Kogan M. Integrated pest management theory and practice. Entomol Exp Appl. 1988;49:59–70. doi:10.1111/j.1570-7458.1988.tb02477.x.

25. Toledo ME, Rodriguez A, Valdés L, Carrión R, Cabrera G, Banderas D et al. Evidence on impact of community-based environmental management on dengue transmission in Santiago de Cuba. Trop Med Int Health. 2011;16(6):744–7. doi:10.1111/j.1365-3156.2011.02762.x.

26. Kittayapong P, Yoksan S, Chansang U, Chansang C, Bhumiratana A. Suppression of dengue transmission by application of integrated vector control strategies at sero-positive GIS-based foci. Am J Trop Med Hygi. 2008;78(1):70–6 (https://pubmed.ncbi.nlm.nih.gov/18187787).

27. Maheu-Giroux M, Castro MC. Impact of community-based larviciding on the prevalence of malaria infection in Dar es Salaam, Tanzania. PloS One. 2013;8(8):e71638. doi:10.1371/journal.pone.0071638.

28. Guidance on policy-making for integrated vector management. Geneva: World Health Orzanization; 2011 (https://iris.who.int/handle/10665/44766).

29. Framework for a national vector control needs assessment. Geneva: World Health Organization; 2017 (https://iris.who.int/handle/10665/259405).

30. Handbook for integrated vector management. Geneva: World Health Organization; 2012 (https://iris.who.int/handle/10665/44768).

31. Chanda E, Masaninga F, Coleman M, Sikaala C, Katebe C, MacDonald M et al. Integrated vector management: the Zambian experience. Malar J. 2008;7:164. doi:10.1186/1475-2875-7-164.

32. Sande S, Zimba M, Nyasvisvo D, Mukuzunga M, Kooma EH, Mberikunashe J et al. Getting ready for integrated vector management for improved disease prevention in Zimbabwe: a focus on key policy issues to consider. Malar J. 2019;18:322. doi:10.1186/s12936-019-2965-x.

33. Monitoring and evaluation indicators for integrated vector management. Geneva: World Health Organization; 2011 (https://iris.who.int/handle/10665/76504).

34. Barat LM. Four malaria success stories: how malaria burden was successfully reduced in Brazil, Eritrea, India, and Vietnam. Am J Trop Med Hyg. 2006;74(1):12–6 (https://pubmed.ncbi.nlm.nih.gov/16407339/).

35. Core structure for training curricula on integrated vector management. Geneva: World Health Organization; 2012 (https://iris.who.int/handle/10665/44765).

36. van den Berg H, Velayudhan R, Ebol A, Catbagan BHG, Turingan R, Tuso M et al. Operational efficiency and sustainability of vector control of malaria and dengue: descriptive case studies from the Philippines. Malar J. 2012;11(1):269. doi.org/10.1186/1475-2875-11-269.

37. Mukabana WR, Kannady K, Kiama GM, Ijumba JN, Mathenge EM, Kiche I et al. Ecologists can enable communities to implement malaria vector control in Africa. Malar J. 2006;5:9. doi:10.1186/1475-2875-5-9.

38. Fillinger U, Ndenga B, Andrew Githeko A, Lindsay SW. Integrated malaria vector control with microbial larvicides and insecticide-treated nets in western Kenya: a controlled trial. Bull World Health Organ. 2009;87:655–65. doi:10.2471/blt.08.055632.

39. Takken W, Snellen WB, Verhave JP, Knols BGJ, Atmosoedjono S. Environmental measures for malaria control in Indonesia – An historical review on species sanitation. Wageningen: Agricultural Research Papers 1990;90.7 (https://edepot.wur.nl/282643).

40 Mutero CM, Mbogo C, Mwangangi J, Imbahale S, Kibe L, Orindi B et al. An assessment of participatory integrated vector management for malaria control in Kenya. Environ Health Perspecti. 2015;123: 1145–51. doi:10.1289/ehp.1408748.

41. van Mele P. Zooming-in zooming-out: a novel method to scale up local local innovations and sustainable technologies. Int J Agric Sustainability. 2006;4:131–42. doi:10.1080/14735903.2006.9684796.

42. Information, education and communication: lessons from the past; perspectives for the future. Geneva: World Health Organization; 2001 (https://iris.who.int/handle/10665/67127).

43. Elmosaad YM, Elhadi M, Khan A, Malik EM, Mahmud I. Communication for behavioural impact in enhancing utilization of insecticide-treated bed nets among mothers of under-five children in rural North Sudan: an experimental study. Malar J. 2016;15:509. doi:10.1186/s12936-016-1551-8.

44. Banerji D. Reinventing mass communication: a World Health Organization tool for behavioral change to control disease. Int J Health Serv. 2004;34(1):15–24. doi:10.2190/DTX3-QJH1-XDQM-56JJ.

45. Pontius JC, Dilts DR, Bartlett A. Ten years of IPM training in Asia: from farmer field school to community IPM. Rome: Food and Agriculture Organization of the United Nations; 2002 (http://www.fao.org/docrep/005/ac834e/ac834e00.htm).

46. Braun A, Jiggins J, Roling N, van den Berg H, Snijders P. A global survey and review of farmer field school experiences. Wageningen: Endelea; 2006 (https://www.researchgate.net/publication/228343459_A_Global_Survey_and_Review_of_Farmer_Field_School_Experiences).

47. van den Berg H, Phillips S, Dicke M, Fredrix M. Impacts of farmer field schools in the human, social, natural and financial domain: A qualitative review. Food Security. 2020;12:1443–59 doi:10.1007/s12571-020-01046-7.

48. Evaluation of the integrated pest and vector management (IPVM) project in Sri Lanka. New Delhi: World Health Organization Regional Office for South-East Asia; 2006 (https://iris.who.int/handle/10665/205031).

49. Yasuoka J, Levins R, Mangione TW, Spielman A. community-based rice ecosystem management for suppressing vector anophelines in Sri Lanka. Trans R Soc Trop Med Hyg. 2006;100:995–1006. doi:10.1016/j.trstmh.2005.12.014.

50. Yasuoka J, Mangione TW, Spielman A, Levins R. Impact of education on knowledge, agricultural practices, and community actions for mosquito control and mosquito-borne disease prevention in rice ecosystems in Sri Lanka. Am J Trop Med Hyg. 2006;74:1034–42. doi:10.4269/ajtmh.2006.74.1034.

51. Mutero CM, Mbogo C, Mwangangi J, Imbahale S, Kibe L, Orindi B et al. An assessment of participatory integrated vector management for malaria control in Kenya. Environ Health Perspect. 2015;123(11):1145–51. doi:10.1289/ehp.1408748.

52. van den Berg H, van Vugt M, Kabaghe AN, Nkalapa M, Kaotcha R, Truwah Z et al. Community-based malaria control in southern Malawi: a description of experimental interventions of community workshops, house improvement and larval source management. Malar J 2018;17(1):266. doi:10.1186/s12936-018-2415-1.

53. Bartlett A. No more adoption rates! Looking for empowerment in agricultural development programmes. Dev Practice. 2008;18:524–38. doi:10.1080/09614520802181269.

54. Mnzava AP, Macdonald MB, Knox TB, Temu EA, Shiff CJ. Malaria vector control at crossroads: public health entomology and the drive to elimination. Trans R Soc Trop Med Hyg. 2014;108(9):550–4. doi:10.1093/trstmh/tru101.

55. Almeida APG, Fouque F, Launois P, Sousa CA, Silveira H. From the laboratory to the field: updating capacity building in medical entomology. Trends Parasitol. 2017;33(9):664–8. doi:10.1016/j.pt.2017.05.011.

56. Russell TL, Farlow R, Min M, Espino E, Mnzava A, Burkot TR. Capacity of national malaria control programmes to implement vector surveillance: a global analysis. Malar J. 2020;19(1):1–9. doi:10.1186/s12936-020-03493-1.

57. Alonso P, Engels D, Reeder J. Renewed push to strengthen vector control globally. Lancet. 2017;389(10086):2270–1. doi:10.1016/S0140-6736(17)31376-4.

58. Chanda E, Ameneshewa B, Mihreteab S, Berhane A, Zehaie A, Ghebrat Y et al. Consolidating strategic planning and operational frameworks for integrated vector management in Eritrea. Malar J. 2015;14(1):488. doi:10.1186/s12936-015-1022-7.

59. Chanda E, Ameneshewa B, Bagayoko M, Govere JM, Macdonald MB. Harnessing integrated vector management for enhanced disease prevention. Trends Parasitol. 2017;33(1):30–41. doi:10.1016/j.pt.2016.09.006.

60. Global vector control response: progress in planning and implementation. Geneva: World Health Organization; 2020 (https://iris.who.int/handle/10665/336658).

Recommended reading

Chanda E, Ameneshewa B, Bagayoko M, Govere JM, Macdonald. Harnessing integrated vector management for enhanced disease prevention. Trends Parasitol. 2017;33:30–41. doi:10.1016/j.pt.2016.09.006.

Golding N, Wilson AL, Moyes CL, Cano, J, Pigott DM, Velayudhan R et al. Integrating vector control across diseases. BMC Med. 2015;13:249. doi:10.1186/s12916-015-0491-4.

Handbook for integrated vector management. Geneva: World Health Organization; 2012:chapters 1, 2, 3, 5 and 6 (https://iris.who.int/handle/10665/44768).

4

Planning and implementing integrated vector management

Contents

Learning objectives

By the end of this course, students should be able to:

- demonstrate understanding of the requirements for evidence- and surveillance-based decision-making;
- describe planning and implementation of IVM; and
- list the main indicators for monitoring and evaluating IVM.

4.1 Assessment of disease burden

A prerequisite for effective vector-borne disease control is good understanding of the current disease situation. For this purpose, three parts of a situational analysis are required:

- an epidemiological assessment,
- a vector assessment and
- stratification.

All three parts are essential for developing a strategy and selecting targets for interventions. Leaving out one part will result in an incomplete assessment.

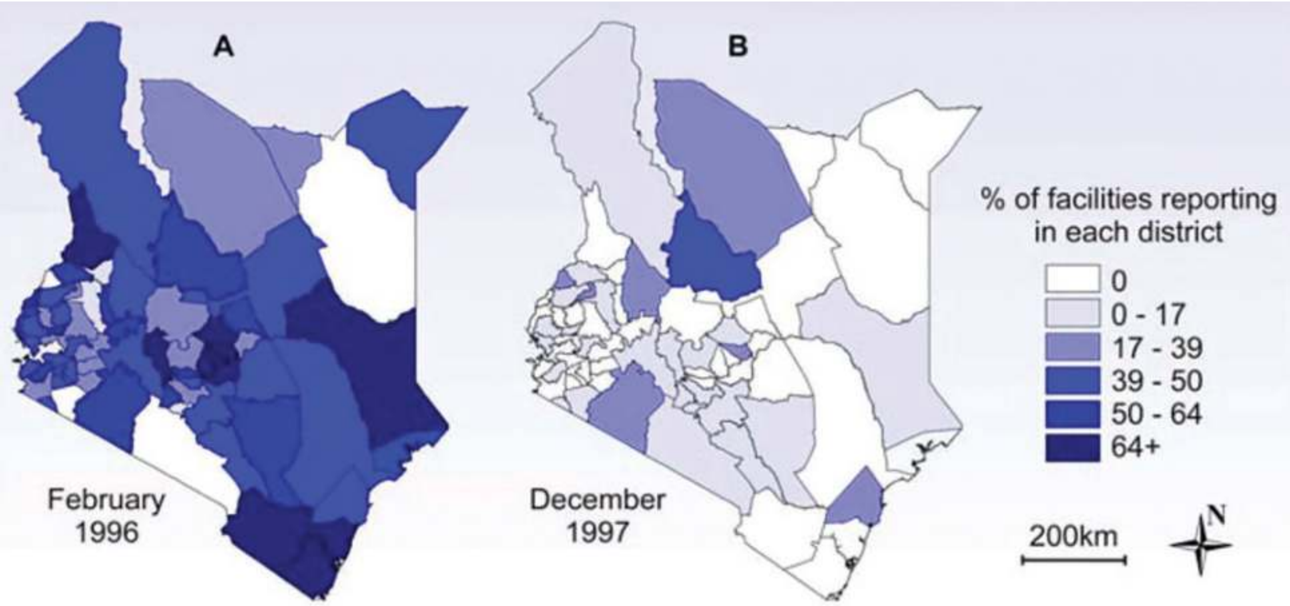
4.1.1 Epidemiological assessment

An epidemiological assessment is an analysis of the current disease situation and/or burden. It is used by planners and risk managers to prioritize allocation of resources and to prioritize each vector-borne disease in national budget allocations. For example, for an emerging disease such as dengue, with increasing numbers of cases being reported, annual data could be used to convince decision-makers and finance departments to increase allocations to contain this disease. Regular updates allow evaluation of the impact of an intervention strategy.

Possible measures of the burden of disease include incidence, prevalence, mortality, work days lost, school days lost and proportion of outpatients affected. The most appropriate measure depends on the disease. For a comprehensive epidemiological assessment, data are collected on all prevailing vector-borne diseases to identify areas in which two or more diseases coexist. Data on disease incidence can be collected by passive or active case detection. The data on incidence most commonly available are obtained passively, from reports of diagnoses at clinics and hospitals. Although these data give an indication of incidence, the rates are generally an underestimate, because not all patients report to health facilities *(1)*.

More and more countries have developed health management information systems to improve the quality and frequency of epidemiological assessment *(2)* by coordinating routine "passive" data on diagnoses, for instance to derive the test-positivity rate, and treatment, such as the number of patients treated, from health facilities, for analysis of district, provincial and national rates *(3)*. Ideally, all health facilities provide data each month for epidemiological assessment by area and by month. In reality, however, health information systems in many countries are weak (see e.g. Fig. 4.1).

Fig. 4.1. Proportions of government health facilities in each district (fourth administrative level) in Kenya that submit monthly reports on outpatient morbidity to the health management information system



A, the most complete (February 1996) and B, the least complete (December 1997) reporting during the 84-month study in January 1996–December 2002.

Source: Gething et al. *(3)*. Reproduced under the Creative Commons Attribution 4.0 International License (https://creativecommons.org/licenses/by/4.0/).

> What factors could result in a person with suspected malaria not receiving a diagnosis at a health facility?

A more accurate but much more costly method for estimating disease prevalence or incidence is active case detection. This requires dedicated resources to conduct surveillance by sampling a population for symptoms or evidence of disease parasites or infections (in blood samples) in target populations. Thus, people with symptoms but who do not report to a health clinic are included in the sample.

> Describe in your own words the difference between prevalence and incidence. (See sections 1.2.2)

Passive case detection and use of health management information systems are the most straightforward means for obtaining epidemiological data, although the outcomes should occasionally be verified by active case detection surveys, which will indicate the extent to which passive data have resulted in an underestimate of the actual disease burden.

4.1.2 Vector assessment

The methods and strategies for vector control should be based on knowledge of which species are the principal vectors of disease pathogens and understanding of their biology, ecology and behaviour.

Vector incrimination (see section 1.3.5) is the stage at which the role of the species as a vector of disease pathogens is determined. Vector incrimination requires entomologists to establish whether the species is associated with humans in a particular ecosystem, whether it makes frequent biting contact with humans and whether there is evidence that pathogens develop and reproduce inside the species. Although vector species are not uniformly distributed, most are strongly associated with a particular ecosystem, such as agricultural, urban, coastal, riverine or forest. An ecosystem analysis serves to identify the vector species most likely to be found in an ecosystem.

Vectorial capacity is a measure of the ability of a vector population to transmit the disease agent. It is defined as the expected number of infectious bites that will eventually arise from all the mosquitoes that bite a single person on a single day *(4)*. Hence, it is a measure of the rate at which future inoculations will arise from a currently infective case and is determined by the rate at which people are bitten, a preference to bite humans over animals and the expected life span of the female mosquitoes. Measurement of all these entomological components to calculate vectorial capacity is difficult, and the measurement of each introduces error *(5)*.

The entomological inoculation rate is a measure of the exposure of humans to infected vectors and thus the rate of pathogen transmission *(5)*. It is usually expressed as the number of infective bites received per person during 1 year and is most commonly measured as the product of the vector abundance (e.g. in standard mosquito traps indoors) and the rate of infection of the vectors.

Other aspects of vector assessment are the microhabitats selected by vectors for breeding and resting, the seasonal occurrence of vectors, host preference, time of activity and biting behaviour. The biting behaviour of mosquitoes, flies or triatomine bugs determines the vector control interventions used. Some mosquitoes feed outdoors, while others feed indoors. Thus, ITNs, repellents and house improvement are most effective against indoor-feeding vector species. The resting sites of flying vectors are also important targets for vector control interventions, such as use of residual insecticides. The preference of vectors for feeding on human rather than animal hosts should be ascertained.

A number of insecticides have been prequalified by the WHO for use in insect vector control *(6)*. The susceptibility of vectors to the insecticides used to control them must be monitored regularly to detect whether resistance has increased or spread in the vector population (see section 8.5). An updated, standardized WHO protocol is available for testing and monitoring the susceptibility of mosquitoes to insecticides *(7)*, which is based on the lethality of the insecticide when the insects are forced into contact with treated filter papers. Insecticide resistance must be detected early to prevent the spread of resistance genes within populations *(8)*. Various options are available for managing resistance, such as changing to an insecticide with a different mode of action, rotating insecticides and diversifying vector control methods to increase use of non-chemical methods *(8)*.

4.1.3 Stratification

The prevalence of vector-borne diseases is not distributed uniformly in a country or province. Certain zones or districts have higher endemicity or are at greater risk of outbreaks than others. Diseases such as malaria may be focal, with clear hotspots of transmission, particularly in the low-transmission or dry season *(9,10)*. “Stratification”, commonly used in disease control, consists of classifying disease-endemic areas by their epidemiological and ecological characteristics to guide the allocation of resources. It is usually conducted for an administrative unit, such as a district with a high or a medium incidence of disease or for the area served by one health facility. Administrative stratification is practical, because data on disease incidence are usually collected per district or equivalent unit, even if the incidence is not uniform within the area. Stratification per district can also guide the allocation of district budgets for disease control. Each stratum of disease endemicity may require a specific strategy for disease control, thus increasing the cost-effectiveness of operations. As each vector-borne disease has its own geographical distribution, more than one vector-borne disease could be prevalent, or co-endemic, in an area. Overlay maps can help in identifying areas in which diseases co-exist *(11,12)*.

In the above example, stratification is conducted according to disease incidence *(13)*. It can also be stratified according to factors that determine disease risk, such as ecological or climatic variables, in so-called “risk maps”. For example, data on ecosystem, vegetation cover and altitude can be used as a basis for planning disease control strategies when the association of vectors and diseases with each ecosystem or altitude is known. Risk maps show areas where populations are at risk of infection, but they do not show the incidence or prevalence of disease.

“Macro-stratification” by ecological zone can also be used, for example according to altitude or rainfall pattern *(13)*. Some countries, such as the Philippines, conduct “micro-stratification”, which is particularly relevant when a disease is being eliminated and last foci of transmission are being identified and targeted. Precise data on malaria incidence are collected by each village, each of which is categorized as stable, unstable, sporadic malaria or malaria-free *(14)*.

A unique strategy for malaria control, elimination or maintenance is then used in each village, with emphasis on vector control, diagnosis or case detection (Table 4.1). Micro-stratification is essential for identifying hotspots of transmission and for ensuring cost-effective use of resources, especially in pre-elimination.

Table 4.1 Example of micro-stratification of malaria epidemiology in the Philippines, with the village as the unit of stratification

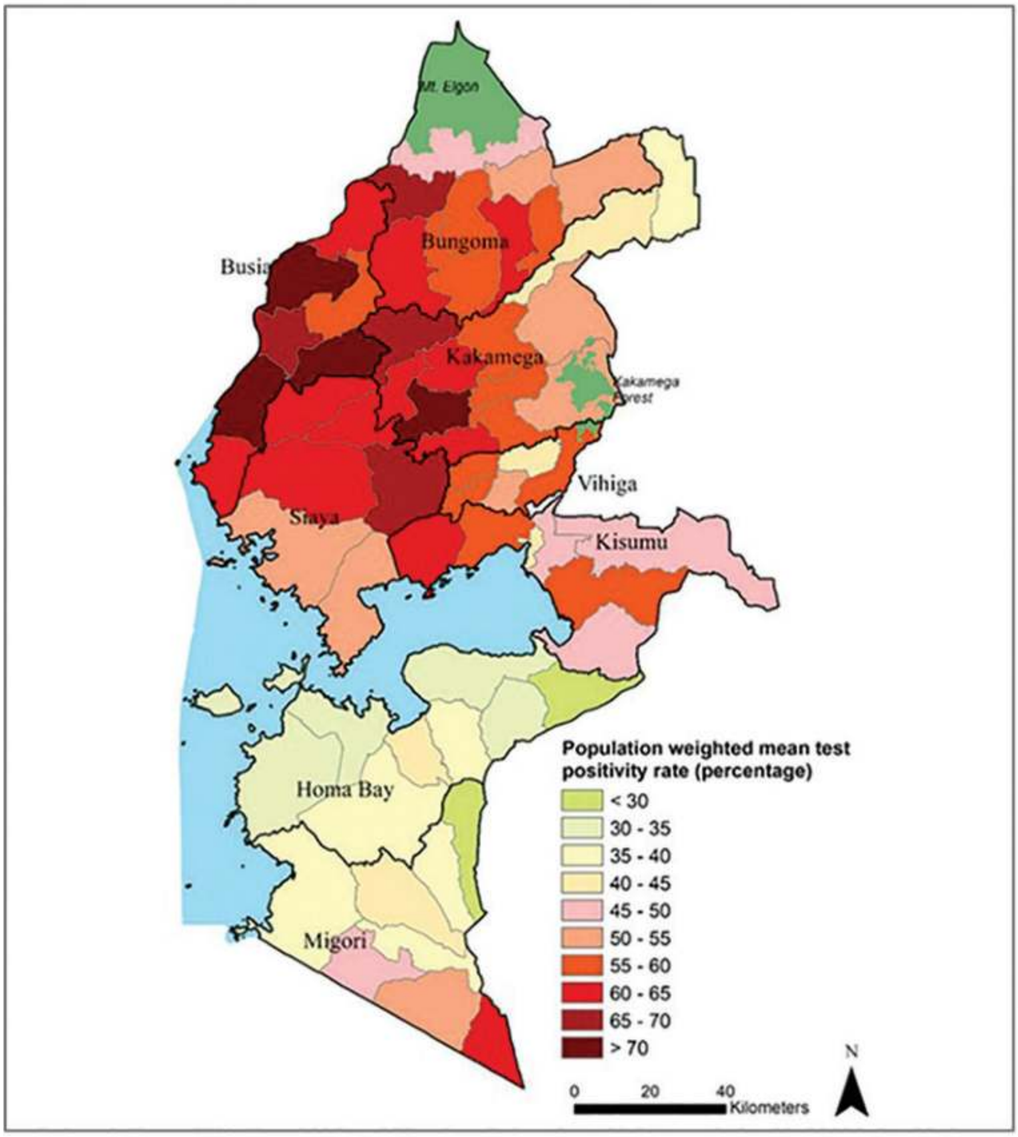
Item	Category			
	Stable transmission	Unstable transmission	Sporadic transmission	Malaria prone
Categorization criterion	Villages in which there have been ≥ 6 months of continuous transmission in the past 3 years	Villages in which there have been 2–5 months of continuous transmission in the past 3 years	Villages in which there has been at least one indigenous case in the past 3 years	Villages in which there have been no indigenous cases in the past 3 years
Goal	Malaria control	Pre-elimination	Elimination	Maintenance
Strategy	Passive case detection; rapid diagnostic testing	Active case detection; rapid diagnostic testing	Mass blood surveys	Case investigation
	Vector control coverage	Vector control coverage	Vector control coverage	
	Health promotion	Health promotion	Health promotion	Health promotion

Source: adapted from van den Berg et al. *(14)*.

Fig. 4.2 shows another example of micro-stratification; in this case, conducted to determine the malaria test-positivity rate among patients attending health facilities in western Kenya. These data are collected routinely at health facilities and could be used in programmes to improve targeting of interventions and malaria control methods to local conditions, especially when approaching pre-elimination of disease *(15)*.

Epidemiological assessment, vector assessment and stratification are thus three essential elements in analysing the disease situation. They provide baseline information for planners, programme managers and risk managers in making decisions about interventions and implementation strategies.

Fig. 4.2. Map of micro-stratification of malaria test-positivity rate in western Kenya



Source: Alegana et al. *(15)*. Reproduced under the Creative Commons Attribution 4.0 International License (https://creativecommons.org/licenses/by/4.0/).

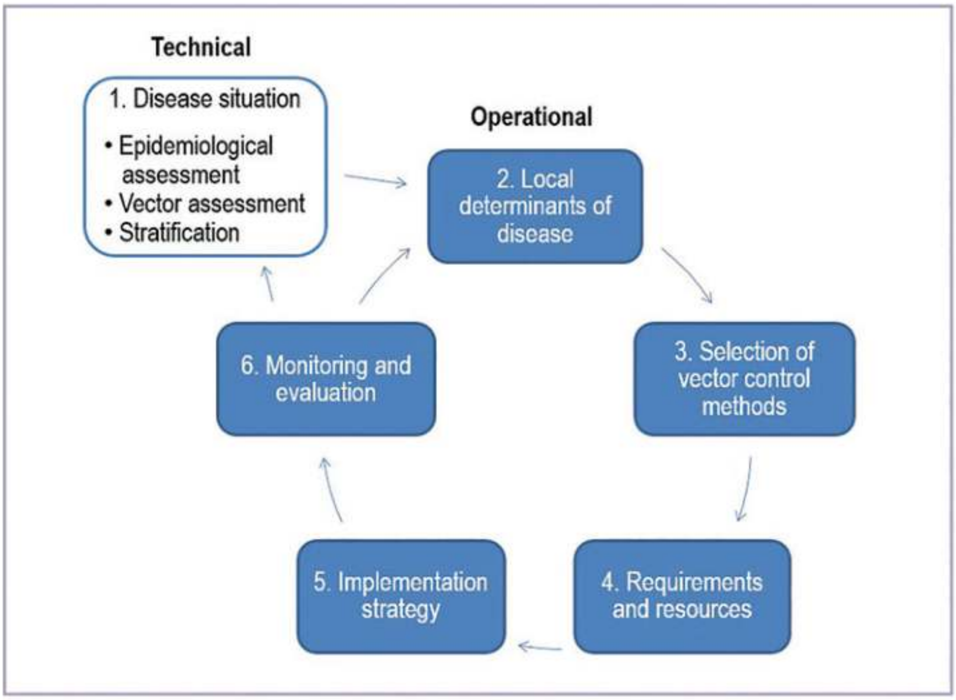
Consider whether malaria prevalence should be stratified by district or village in your country.

— Identify the advantages and disadvantages of each.

4.2 Determinants of disease

Assessment of the disease situation, discussed above, is a technical investigation that requires the expertise of epidemiologists and entomologists and other trained personnel. It provides important input for the operational steps in decision-making (Fig. 4.3), which are more appropriately conducted locally because they benefit from the participation and input of local stakeholders to ensure more precisely planned activities in response to local conditions.

Fig. 4.3. Decision-making in integrated vector management, with a technical component and operational steps



Source: WHO *(16)*.

A risk factor or a "determinant" of disease is a factor associated with increased or decreased risk of the disease. It is one of the underlying factors that determine whether a disease is likely to occur. Knowing all the important determinants of vector-borne disease is essential in an IVM strategy in order to prevent disease in the broadest sense by taking appropriate action to reduce the risks. Hence, attention to the determinants of disease during planning ensures a comprehensive approach to prevention.

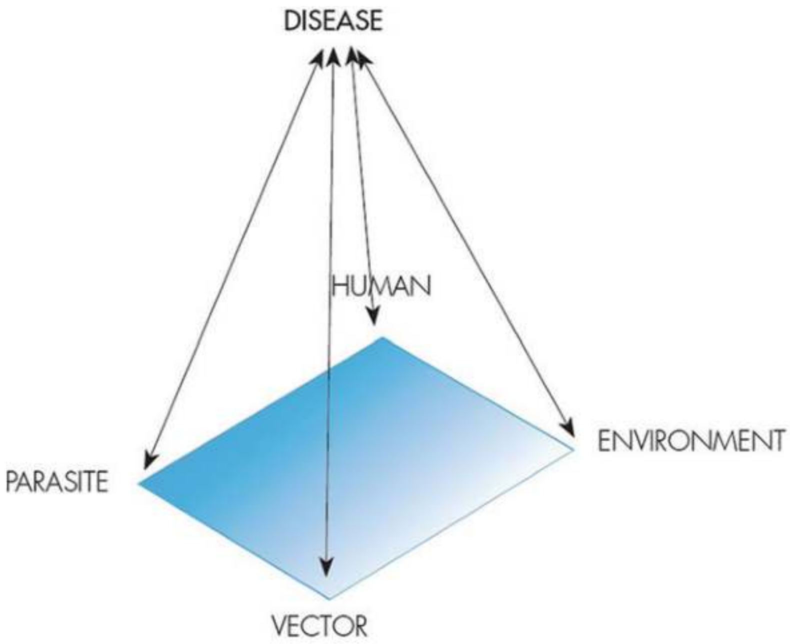
Chanda E, Masaninga F, Coleman M, Sikaala C, Katebe C, MacDonald M et al. Integrated vector management: the Zambian experience. Malar J. 2008;7:164. doi:10.1186/1475-2875-7-164 *(17)*.

4.2.1 Four categories of determinant

Four categories can be identified: those related to the parasite, to the vector, to human activities and to the environment (Fig. 4.4).

There are many **human determinants** of the risk of vector-borne disease, including people's attitudes, behaviour and socioeconomic conditions. For example, human concentrations in urban areas and also schools, markets and religious centres can increase the risk of transmission from person to person. Movement of people such as migrant workers, refugees and pastoralists can increase the risk of introduction or spread of disease.

Fig. 4.4. The four categories of determinants of vector-borne disease: human, environment, vector and parasite, with arrows indicating their relation to the disease



Source: WHO *(16)*.

Uneven distribution or differences in equity can create vulnerable groups, such as sub-populations living close to a vector breeding habitat or with poor access to health services. People's attitudes, behaviour and customs also have a major influence on the epidemiology of vector-borne diseases, such as compliance with interventions, including proper use of ITNs. Housing conditions and income affect the risk of contact with vectors (Table 4.2). The nutritional and immune status of people and their access to effective prophylactic drugs affect their risk of contracting disease and spreading the disease pathogens to others.

Table 4.2. Malaria risk in houses of good and poor construction in Sri Lanka

House type	Population	No. of cases of malaria	Malaria risk (incidence rate)
Well-constructed houses	838	424	0.50
Poorly built traditional houses	906	1155	1.27

Source: Gunawardena et al. *(18)*.

Monroe A, Olapeju B, Moore S, Hunter G, Merritt AP, Okumu F et al. Improving malaria control by understanding human behaviour. Bull World Health Organ. 2021;99(11): 837–9. doi:10.2471/BLT.20.285369 *(19)*.

Determinants related to the environment include weather, climate, altitude, local ecosystems and people's use of those ecosystems. For example, the way in which land is farmed, such as with irrigation, or used for construction will influence the risk of vector-borne diseases. In particular, the creation of bodies of standing water by human activities such as brickmaking, pit digging, field irrigation and road construction can cause proliferation of malaria vector species *(20,21)*. The peri-domestic environment is particularly important in this regard because the proximity of vector breeding sites to people's living environment increases the risk of transmission of disease pathogens *(22)*.

Several determinants are **related to the vector.** The species or sub-species of vector determines the efficiency of disease transmission, some species being minor vectors and others being the principal local vector of disease. Biting behaviour, a preference for feeding on humans, occurrence indoors or outdoors and their resting behaviour are important determinants on which a vector control strategy should be based. Most aspects of vector identification and behaviour require study by specialist entomologists. Therefore, cooperation with entomologists during planning is essential for IVM. Some countries do not have teams of specialist entomologists, even at national level, and training and career development in medical entomology and vector control are urgent priorities *(23,24)*. Regional collaboration among countries for capacity-building in vector control can help resolve the situation.

Determinants related to parasites and pathogens are those associated with the species or strains of disease pathogens that occur locally and factors such as their resistance to the available drugs. Identification of these factors requires technical assistance from epidemiologists.

In the past, vector-borne disease control programmes concentrated mainly of addressing the parasite and the vector, e.g. with drugs and insecticides, whereas the human and environmental determinants of disease were largely ignored. The attitudes and behaviour of people and environmental conditions must not, however, be overlooked. Some vector-borne diseases could be controlled by single interventions targeting the parasite *(25)* or the vector *(26)*. In most situations of endemic disease, however, more interventions are necessary to control and eliminate the disease. The disease is therefore attacked through all the determinants, including human and environmental determinants.

Arunachalam N, Tana S, Espino F, Kittayapong P, Abeyewickreme W, Wai KT et al. Eco-bio-social determinants of dengue vector breeding: a multicountry study in urban and periurban Asia. Bull World Health Organ. 2010;88:173–84. doi:10.2471/BLT.09.067892 *(27)*.

4.2.2 Spatial and temporal analysis

Participatory **mapping** of the determinants of disease is useful for planning IVM strategies for districts or villages. Mapping should be participatory, with indications of the locations of some major determinants of disease by several stakeholders to show where the risks of vector-borne diseases are highest. For example, concentrations of human activity (e.g. markets, villages), patterns of movement, roads, agricultural land use, forests, concentrations of domestic animals, and known vector breeding sites should be indicated on a map. The maps should also show the locations of service providers, such as health centres, municipal offices and community health workers. Hand-drawn maps provide a basis for selecting and targeting vector control interventions and preventive activities by IVM stakeholders. The stakeholders could include staff in sectors other than health, local authorities, farmers and civil society organizations. Mapping provides a spatial dimension to planning IVM (Fig. 4.5).

Fig. 4.5. Example of participatory mapping for planning an IVM strategy in a village

Source: WHO *(16)*.

A temporal analysis provides information on the times and seasons of disease risk as a basis for planning the timing of vector control. A participatory tool for a temporal analysis is a so-called "seasonal calendar", which consists of identifying and depicting the periods of the year in which the risk for vector-borne diseases is highest. A seasonal calendar could include the times of highest incidence of the diseases, the times of highest vector population densities or biting rates, the times of agricultural activities or other economic activities, and the times of migration (Fig. 4.6).

Fig. 4.6. Examples of participatory mapping and seasonal calendars on newsprint paper and drawn in sand prepared by pastoralists in Kilombero, United Republic of Tanzania

Source: photo courtesy of H. van den Berg.

Spatial and temporal analysis of the local situation results in clearer understanding of the places and times for targeting vector control. For example, sections of society that live near poorly drained areas or forests might be at greatest risk of contracting vector-borne diseases, depending on the locally prevalent disease pathogens and vectors. Communities with the poorest housing conditions, in which livestock are also kept, might be another high-risk group, requiring specially targeted preventive interventions to control disease.

Determinants of vector-borne diseases are tackled by various interventions, such as environmental management, sanitation, improved construction and design, house screening, agricultural practices, personal protection and behavioural change campaigns. Some of these interventions might be outside the mandate of the health sector and require collaboration with other sectors, such as agriculture, environment, construction and urban and rural development. Communities play a major role in addressing the determinants of disease that are in their domestic environment.

Select a district in your country with which you are most familiar:

- Prepare a seasonal calendar of factors that might influence the prevalence of vector-borne disease according to the examples above.
- What are the most critical periods of the year? Explain why.

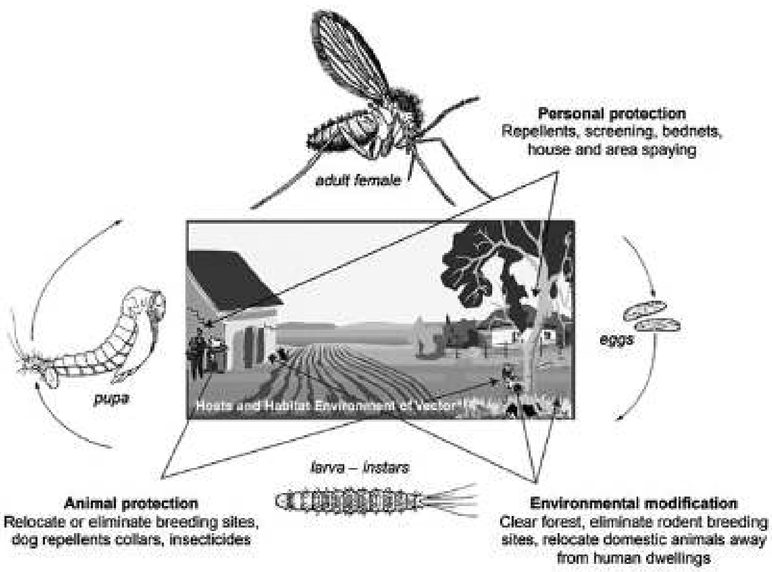
4.3 Implementation strategy

Fig. 4.3 showed the steps in planning IVM, from assessment of the disease situation to identification of the determinants of disease. The next steps are selection of appropriate vector control methods, assessment of the available resources and development of an implementation strategy.

4.3.1 Selection of vector control methods

There are a number of options for vector control and personal protection (see example in Fig. 4.7), which are discussed in section 2. Each method has its advantages and disadvantages, and, in developing an implementation strategy in IVM, the advantages and disadvantages of each should be evaluated with regard to the local context to decide on those that are most suitable. Criteria for selecting vector control methods include their effectiveness, human and environmental safety, risk for development of resistance, affordability, community participation and policy and logistical support.

Fig. 4.7. Example of vector control options for leishmaniases control



Source: WHO *(28)*.

Questions to consider when selecting a vector control method

- What is known about the effectiveness of the method in controlling the vector and reducing the disease burden?
- Does the method pose any risk to human health or the environment?
- Is there a risk of development of insecticide resistance?
- Is implementation of the method affordable with the available resources?
- Can communities be expected to comply or take part in implementing the vector control method? Is the method socially acceptable?
- Will there be logistical and policy support from a ministry or department for implementing the vector control method?

Some vector control methods are more effective than others for the vector development stage that is to be attacked. For example, ITNs against adult mosquitoes are considered to be highly effective in malaria control in various epidemiological situations, because they combine a physical barrier with the action of an insecticide, the sleeper acting as bait to attract mosquitoes *(29)*. IRS is also highly effective in killing adult mosquitoes, which contributes to reducing transmission. Source reduction (against vector larvae), environmental management (against vector larvae; snails) and use of repellents (against adult mosquitoes) are considered relatively less effective in controlling malaria, because it is relatively difficult to control larvae over a large area as not all breeding sites may be found. Repellents may reduce transmission but do not kill mosquitoes. Nevertheless, their effects will depend on the local context. Evidence on the behaviour of local vectors should be used in appraising the comparative effectiveness of interventions.

A number of criteria should thus be used in selecting the most appropriate methods of vector control. An example of use of criteria in selecting vector control methods for malaria control is shown in Table 4.3. The selected methods are listed in the last column. As selection is based on technical, managerial and social-cultural aspects, various stakeholders should participate in selection.

Risks to health and the environment and insecticide resistance are concerns in the use of insecticidal methods, especially when the insecticides are used to spray houses or outdoor environments.

The affordability of vector control interventions and operations and the compliance and participation of communities are important for the sustainability of vector control. Source reduction and environmental methods are generally cheap, locally appropriate and feasible with active participation of communities. IRS is a method that does not have these features because it requires resources and trained spray teams. Compliance is also determined by the social acceptance of a vector control method. In some countries or some sections of society, people may not accept nets because of high night temperatures, or they may refuse house spraying. House spraying with DDT leaves obvious stains on walls and furniture, which are generally not acceptable to people living in modern houses. For example, the malaria control programmes in South Africa and several neighbouring countries have been using pyrethroids for IRS in modern houses and DDT in traditional houses *(30)*.

In many countries, housing is gradually being upgraded to modern houses. What would be the implications for IRS programmes with DDT?

Logistical and policy support are important criteria for selecting a vector control method. Ministerial support is most likely for methods that are planned and/or implemented from top–down and have been proven to be effective. These include use of ITNs and IRS and also space spraying. These interventions are clearly visible means that can be used by a government for vector control. Interventions that must be

Table 4.3. Example of the use of criteria for selecting vector control methods against malaria

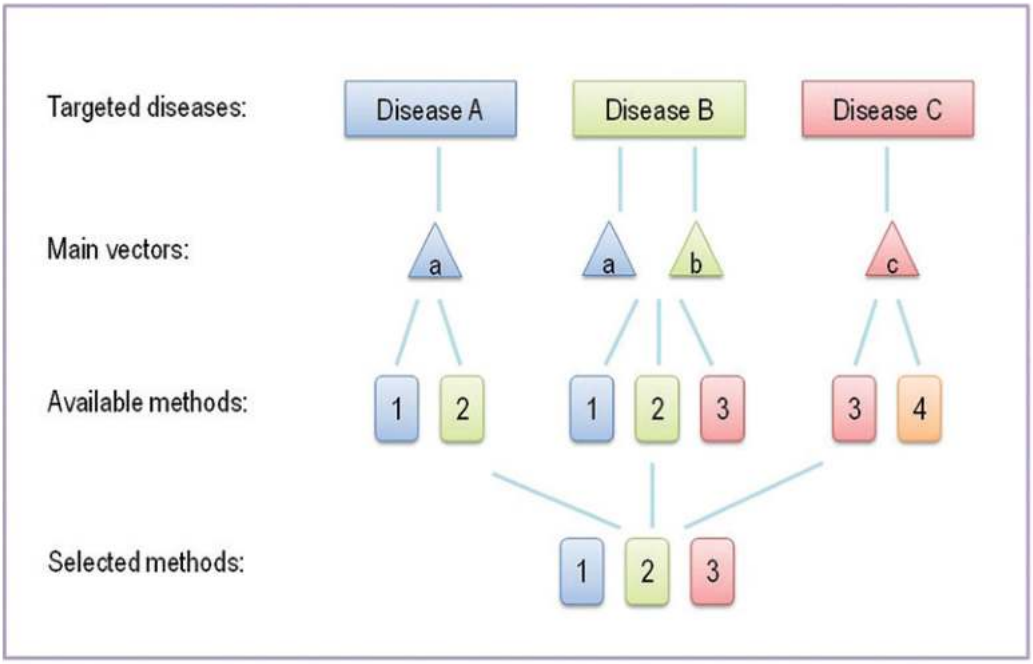
Category	Vector control method	Effectiveness	Safety	Risk of resistance	Community participation	Affordability	Logistic, policy support	Selected methods
Environmental	Source reduction	±	+		+	+		+
	Habitat manipulation	±	+		±	±		
	Irrigation management and design	±	+		+	±		
Mechanical	House improvement	+	+		+	–		+
Biological	Natural enemy conservation	±	+	+	+	+		
	Biological larvicides	±	+	+	+	–	±	
	Botanicals		±	+	+	+		
Chemical	Insecticide-treated bednets	++	±	–	+	–	+	+
	Indoor residual spraying	++	±	–	–	–	+	
	Insecticidal treatment of habitat		–	–	–	–		
	Chemical repellents	±	±			±		

Source: WHO *(16)*.

planned and implemented locally with the participation of other partners and communities (e.g. house improvement, larval source management), however, are less visible and are not readily supported in top–down planning. These "less tangible" methods, however, also deserve policy support by a government.

In many disease-endemic countries, human populations are commonly affected by or at risk of more than one vector-borne disease, and the selection of vector control methods should take this into account. Some vector control methods are effective against several vector-borne diseases; for example, distribution of ITNs provides protection against both malaria and lymphatic filariasis in all areas and regions in which the two diseases are transmitted by the same anopheline vectors. Fig. 4.8 shows a diagram of three local diseases with some common species of vector and suitable methods for each disease. Selection of vector control methods in this example includes consideration of the diseases and vector species targeted.

Fig. 4.8. Diagram for selection of vector control methods in an area with three co-existing vector-borne diseases, some of which have the same vector species



Source: WHO *(16)*.

In selecting vector control methods, an inventory should be made of the available financial, human and technical resources and of the resources necessary for implementing vector control. Local stakeholders could participate in preparing the inventory, each group with specific resources. Examples are use of agricultural resources in controlling vector breeding in crop irrigation systems and the participation of communities in source reduction.

4.3.2 Developing a strategy

Once vector control methods have been selected, a local IVM strategy can be formulated for how and when to use the methods. Stakeholder participation is crucial in developing the strategy, and the strategy should be updated regularly to adapt it to changing circumstances. The strategy should include expected milestones and targets, with timelines, which will provide the indicators for monitoring and evaluation (see section 4.5).

Questions to be asked in developing a vector control strategy

1. Which vector species should be targeted?
2. Which methods have been selected as the best or optimal options?
3. When should these methods be implemented?
4. Where should they be implemented?
5. What are the roles of different partners in implementation?
6. Who has overall responsibility?
7. Who monitors and evaluates the intervention?

The components of an implementation strategy are the vectors targeted, the timing of implementation, the areas of implementation, the entities involved, the entities responsible for implementation and external monitoring and evaluation. Table 4.4 gives an example of a situation in which three vector control methods were selected to control malaria and dengue.

Table 4.4. An IVM strategy for a hypothetical situation with targets to control the prevalence of malaria and dengue

Item	Vector control method			
	Source reduction	Management of wasteland, drains	Insecticide-treated nets	Irrigation management
Vectors targeted	*Aedes, Anopheles, Culex* spp.	*Aedes, Anopheles, Culex* spp.	*Anopheles, Culex* spp.	*Anopheles* spp.
When to implement	Year-round, but intensely during the rainy season	According to cropping season	Continuous	According to periods of rainfall; frequently
Where to implement	Residential areas, streets, markets, woodlands	High-risk areas, all wastelands and drains in the village	80% of houses within reach	≥ 70% of agricultural fields under irrigation in the village area
Role in implementation	Communities, local government, ministries of environment, community health workers, schools	Ministry of environment, local government, health workers, communities	Nongovernmental organizations, health officers	Farmers' association, extension officers, local government, community health workers
Responsibility	Health office	Local government	Health office	Agriculture office
Role in monitoring and evaluation	Local government	Health office	University	Health office

Vectors targeted: Some interventions are effective against several vector species and are particularly useful where several vector-borne diseases co-exist.

When to implement: A vector control method should be implemented when it is expected to achieve the maximal effect on the vector population or on disease incidence, such as at the onset of rains or at high vector population levels, taking into account the effective period or residual effect of the intervention. For example, larvicides have a short residual effect of 1–3 weeks, IRS can last for several months, and LLIN are expected to be effective for 3 years.

Where to implement: High coverage of the population with the intervention is desirable but is costly and increases the risk for development of resistance in the vector population to the insecticides used. Particularly vulnerable human populations or people living in hotspots of disease transmission, such as areas with poor access to public health services or in environments with a high risk of transmission, should be prioritized.

Role in implementation: The district health office usually plays a major role in activities such as health promotion, awareness-raising, social marketing or procurement and distribution of ITNs. Dedicated spray teams conduct IRS and larviciding. Other partners, such as communities, schools, the private sector and public sectors including agriculture, construction and local government, should also be involved in planning and implementing vector control, personal protection and health promotion. Community participation can be crucial in source reduction. Local governments could contribute by bulk waste collection, drainage and sanitation to control dengue, malaria and lymphatic filariasis. Ministries of the environment and agriculture could contribute by managing wastelands and irrigation systems. Farmers could contribute by using field crop management practices that do not result in standing water for prolonged periods.

Responsibility: Although several partners could be involved in implementing a vector control method such as irrigation management, one entity should assume responsibility overall. Use of ITNs has usually been the responsibility of the health sector; however, environmental management in agriculture, irrigation systems, construction sites, waterways and peri-urban areas could be the responsibility of another entity, such as a department of agriculture, irrigation and environment or the local government. The private sector may also be involved, particularly in special economic zones such as mining areas, plantations and protected areas visited by tourists.

Role in monitoring and evaluation: Activities or interventions should be monitored regularly and the effects evaluated to determine whether the expected milestones are being reached and whether an impact is being made (see section 4.5). Monitoring and evaluation should be conducted by an entity other than that responsible for implementation to ensure objectivity and accountability for vector control.

Barrera R, Harris A, Hemme RR, Felix G, Nazario N, Muñoz-Jordan JL et al. Citywide control of *Aedes aegypti* (Diptera: Culicidae) during the 2016 Zika epidemic by integrating community awareness, education, source reduction, larvicides, and mass mosquito trapping. J Med Entomol. 2019;561033–46. doi:10.1093/jme/tjz009 *(31)*.

4.4 Operational research

Evidence-based decision-making involves making decisions on interventions or operations on the basis of evidence from the field. Evidence-based decision-making is central to implementation of IVM in order to ensure the efficacy, cost-effectiveness, ecological soundness and sustainability of vector control. This requires that an evidence base for solving problems and for adapting programmes to local circumstances be available. Often, however, this is not or is insufficiently the case. Hence, operational research has an important role in IVM.

Operational research requires specific studies or analyses to generate new evidence for improving decisions. Research on the epidemiological or vector situation in an area can be considered operational research. Operational research addresses a priority problem in implementation of vector-borne disease control operations.

A prerequisite of effective operational research is a mechanism in the country to prioritize strategic areas that require research. This should avoid overlaps and gaps in research. Operational research should address priorities and provide practicable solutions to be disseminated to and used in programmes. For example, a technical working group that has been established to identify priorities for operational research should have representation of researchers, risk managers, programme managers and decision-makers to ensure that the topics being studied are directly relevant to the field situation.

Examples of common issues or problems for operational research:
- disease burden and seasonal incidence;
- knowledge about vector species, their biology, ecology and behaviour;
- the effectiveness of a new intervention method; and
- people's acceptance and compliance.

Regional collaboration and sharing of information among neighbouring countries, such as on insecticide resistance, can be instrumental in building an evidence base and conducting systematic reviews. Operational research does not necessarily result in better decisions on vector control. A common problem is **poor linkages** between researchers and programme managers or implementers, which result in irrelevant studies or impracticable solutions or in slow uptake of research outcomes or solutions developed at field level. Ultimately, operational research is valuable when the results are effectively communicated to those who use the solutions or methods.

What would be a priority for operational research in relation to vector control in your country?

4.4.1 Evidence base

Evidence-based decision-making depends directly on the evidence available. The "evidence base" is the body of evidence about a disease, its vectors and the interventions that could be used in a country. The information that constitutes an evidence base is usually scarce or not available in one place but scattered in several different sources, some undocumented, some in reports or published articles, some locally obtained, others obtained from abroad. In particular, little is known in most settings about the specific ecology, biology and behaviour of the vectors of disease and how best they could be controlled with cost-effective interventions. A collated evidence base from 100 years of research on *Anopheles* vectors in Nigeria has been produced *(32)*. Similar databases are required in other endemic countries or sub-regions.

Evidence on the cost-effectiveness of interventions is limited in most countries. Evaluation of cost-effectiveness requires large-scale trials covering entire human populations, with major financial, logistic and ethical requirements for the effectiveness and cost of the intervention. This is difficult to achieve. Moreover, the results of a study conducted in one country may not necessarily be applicable to another country where the conditions (e.g. vector, environment, housing conditions) may be different. Also, costs vary.

An alternative to studying the cost-effectiveness of interventions on disease outcomes is studying the factors or parameters that are likely to determine whether an intervention will be effective. For example, to determine whether IRS is likely to be effective locally, vector characteristics should be identified, such as indoor biting and resting behaviour of local vectors and whether people leave sprayed surfaces intact or repaint them. Studying simple factors that determine the effectiveness of interventions is relatively easy and straightforward, and therefore studies, observations or surveys could be conducted in various epidemiological and ecological settings. This type of evidence improves decision-making on vector control interventions *(33)*.

Monroe A, Olapeju B, Moore S, Hunter G, Merritt AP, Okumu F et al. Improving malaria control by understanding human behaviour. Bull World Health Organ. 2021;99:837–9. doi:10.2471/BLT.20.285369 *(19)*.

4.4.2 Vector surveillance

Systematic monitoring of the seasonality and abundance of vector populations, "vector surveillance", is the most basic, essential type of evidence required for deciding on vector control. The data generated by vector surveillance are used to select, time and target vector control interventions. Vector surveillance is also used to evaluate the effect of previous interventions on vector populations.

A number of methods are available, depending on the type and behaviour of the vector. Commonly used methods are suction tube collection, animal-baited traps, human landing catches, entry and exit traps, spray-sheet collection and laboratory techniques *(34)*. Other, indirect methods that could be used by non-specialists are surveys of biting during the previous day or night in communities, surveys of breeding sites and surveys of the cleanliness of the environment (e.g. for monitoring dengue vectors).

Vector surveillance could be conducted with the involvement of trained community representatives *(35)* (Fig. 4.9), which would require some training in vector biology, ecology, sampling and mapping and on-site supervisory visits.

Fig. 4.9. Examples of community-based malaria surveillance

Source: Mukabana et al. *(35)*. Figure reproduced under the Creative Commons Attribution 2.0 License (https://creativecommons.org/licenses/by/2.0/).

Left: Field training of Child and Family Programme community volunteers in sampling mosquito larvae and pupae in western Kenya.
Right: Community members mapping and characterizing mosquito breeding sites in Dar es Salaam, United Republic of Tanzania.

Methods have been suggested for rapid assessment of entomological and epidemiological parameters that could be used to estimate the risk of transmission within a few days *(36)*. Standardization of these methods would be useful for future entomological surveillance.

Observations at fixed locations, or sentinel sites (see section 8.5.3), can reduce natural variation in collected data. Vector surveillance should be the basis for decisions on vector control interventions. Therefore, the links between those involved in surveillance and those involved in planning vector control should be strong. It is important that vector surveillance be conducted regularly and consistently, including in periods of low vector density.

Mosquito surveillance

Consult the following weblinks, and click and watch three short videos on mosquito vector surveillance methods:

- Collection of mosquito larvae and pupae. https://www.youtube.com/watch?v=-z1Z4-alQHQ
- Hand collection of adult mosquitoes SD. https://www.youtube.com/watch?v=qc7uu52wtpw
- Spray sheet collection. https://www.youtube.com/watch?v=wcA9RFuYLpo

Which of these methods could be used for community-based surveillance?

As background material, read Chapter 8 in A toolkit for integrated vector management in sub-Saharan Africa. Geneva: World Health Organization; 2016 (https://iris.who.int/handle/10665/250267) *(12)*.

Vector surveillance is more advanced in malaria programmes than in programmes for other vector-borne disease control. A survey of national malaria control programmes in malaria-endemic countries in Africa and Asia showed, however, various weaknesses in vector surveillance *(37)*. In almost every country surveyed, the programme had inadequate capacity (e.g. of entomologists, laboratories and resources). Although most countries had the capacity to use ITNs and IRS, many reported that vector surveillance was not considered a priority. The vector surveillance component of other vector-borne disease control programmes (e.g. for dengue, leishmaniases) is expected to be particularly weak or absent.

If a malaria programme uses ITNs (distributed to communities) or IRS (deployed by spray teams visiting houses), in your opinion, should it conduct vector surveillance? For what reason(s)? Explain.

van den Berg H, Velayudhan R, Ebol A, Catbagan BHG, Turingan R, Tuso M et al. Operational efficiency and sustainability of vector control of malaria and dengue: descriptive case studies from the Philippines. Malar J. 2012;11:269. doi:10.1186/1475-2875-11-269 *(14)*.

4.5 Monitoring and evaluation

4.5.1 General concepts

Monitoring and evaluation have several purposes, to:
- guide planning and implementation of a strategy,
- assess its effectiveness,
- identify aspects of the strategy that should be improved and
- be accountable for the resources used.

Monitoring and evaluation thus provide feedback to managers involved in planning and implementing a strategy.

Monitoring and evaluation are two distinct activities. Monitoring refers to routine data collection and reporting to determine the progress made in implementing a programme or strategy. For example, monitoring is conducted to determine the use of inputs and activities (e.g. funds, materials, staff time, workshops, training courses, travel) and to determine whether the expected outputs are being achieved. Evaluation consists of assessment of the outcomes and impacts of the interventions or activities, usually after a certain period.

Combination of monitoring and evaluation into a functional system of data collection (i.e. routine observations on inputs, outcomes and impacts and dissemination of analysed results to managers and decision-makers) is used to establish the relations between a programme's interventions and its effects (outcomes, impacts). For example, lack of effect can be attributed to shortcomings in implementation, as a basis for corrective action or a change in the implementation strategy. A functioning system of monitoring and evaluation requires a set of strong indicators for objective, systematic measurement to monitor progress or impact.

Monitoring, evaluation and learning underscore the value of learning at programme level to improve the quality of interventions and to achieve the expected outputs, outcomes and impacts. For this, the collected data are used to reflect on what was found and to use the findings to improve the interventions in order to attain the impact targets.

IVM is a management strategy. It is not a typical disease-specific project or programme with its expected achievements and impacts. Consequently, monitoring and evaluation of IVM are not the same as for a regular project or programme. IVM is a strategy for re-orienting, or transforming, how vector control is structured and implemented. The purpose is to achieve greater efficacy, cost-effectiveness, ecological soundness and sustainability of vector control. Hence, the "transformation" of the system of vector control can be considered to be the "outcome" of the IVM strategy with its required inputs and processes. Improved efficacy, cost-effectiveness, ecological soundness and sustainability are the expected impacts of IVM.

New tools are necessary to measure the degree of "transformation" in how vector control is structured and implemented. Transformation is expected in all the major components of an IVM strategy, which are:
- policy,
- institutional arrangements,
- organization and management,
- planning and implementation,
- advocacy and social mobilization and
- capacity-building.

These components of IVM should be monitored. The process of transformation should be evaluated by measuring a small number of indicators of the expected outcomes. The indicators include indicators of process, outcome and impact.

Process and input indicators reflect the performance of a programme: whether the planned activities were adequately conducted in a timely manner or whether the inputs were sufficient. Outcome indicators show the desirable outcomes of the activities conducted, and impact indicators reflect the impact that can be attributed to a programme's outcomes.

Table 4.5 lists the potential outcome indicators of IVM, with their process indicators. Examples of outcome indicators are the existence of a national IVM policy, the number of personnel trained in vector control or the number of knowledge gaps that have been addressed by operational research. Outcome indicators should be formulated simply to ensure objective, systematic measurement and recording. All the outcome indicators are quantitative, either numerical (number, percentage) or logical (presence or absence) data. For example, the number of training courses or staff trained in IVM is a quantifiable indicator.

Table 4.5. Indicators of process and outcome for monitoring and evaluating progress in achieving each component of IVM, with the type of data

Category	Process indicator	Data type	Outcome indicator	Data type
Policy framework	Focal person for IVM identified	Logical	Existence of national policy on pesticide management	Logical
	Situation analysis completed	Logical		Logical
	Economic impact of vector-borne diseases assessed	Logical	Existence of national IVM policy	Logical
Institutional framework	Mandate and composition of national steering committee on IVM developed	Logical	National steering committee on IVM established	Logical
	Terms of reference for national coordinating unit on vector control developed	Logical	National coordinating unit on vector control established	Logical
Organization and management	Regular organization of meetings between programmes or sectors	Descriptive	Terms of reference, job descriptions and operating procedures of health sector programmes aligned with IVM policy	Descriptive
	Task force in place to align programmes with IVM policy	Descriptive	Terms of reference, job descriptions and operating procedures of major stakeholders aligned with IVM policy	Descriptive
	Work plans and budgets aligned with IVM policy	Descriptive		
Planning and implementation	Resources for implementing IVM costed and mobilized	Descriptive	National strategic and implementation plan on IVM developed	Logical
	Types of competence required for IVM identified; resources for capacity-building mobilized	Descriptive	Number (and proportion) of targeted personnel trained in programme planning, management and coordination; vector control; judicious use of pesticides; epidemiological and entomological assessment; and operational research	Numerical

Table 4.5. (Continued)

Category	Process indicator	Data type	Outcome indicator	Data type
Planning and implementation	Data management system reviewed and strengthened, comprising data collection, data dissemination, data interpretation, decision-making, and feedback mechanism	Descriptive	Regular epidemiological surveillance in place; number of vector-borne diseases covered	Descriptive
			Number of established sentinel sites for regular vector surveillance and monitoring of insecticide resistance; number of disease vectors covered	Numerical
			Influence of epidemiological and vector-related data on decision-making	Descriptive
	Institutions to conduct operational research identified; mechanism for setting research priorities and coordination of research established	Descriptive	Number (and proportion) of gaps in knowledge addressed by operational research	Numerical
			Number of operational research solutions used by programmes	Numerical
Advocacy and communication	Policy-makers, civil society and media engaged in advocacy on IVM; awareness campaigns and educational programmes conducted; case studies conducted and documented	Descriptive	Regular stakeholder meetings; number of sectors involved	Numerical
			Commitment of resources by major stakeholders	Descriptive
			Changes in knowledge, attitudes, practice and behaviour of communities in relation to vector control	Descriptive
			Number of community-driven activities on vector control per year	Numerical
Capacity-building	Curricula developed for each required competence; incorporation of IVM in school curricula initiated; plan for human resource development of major stakeholders adjusted to identified needs; institutions for training and for independent evaluation and certification identified	Descriptive	Certified training programmes established for IVM and sound management of pesticides	Descriptive
			Career structure for vector control developed or enhanced	Descriptive
			Infrastructure for IVM and sound management of pesticides developed or enhanced	Descriptive

Source: WHO *(16)*.

What would be an objective, quantifiable indicator of a change in the involvement of district health staff in vector control?

Process indicators provide more background to outcome indicators. A process indicator shows whether the procedures or activities conducted were appropriate to achieve the expected outcome. These indicators are often more descriptive and qualitative than outcome indicators. They describe the processes used and those that were not, which provides deeper understanding of the reasons for the observed outcomes or the lack thereof. Consequently, process indicators are a useful addition to outcome indicators in helping a country to achieve expected outcomes.

Assume that a country that has not yet developed a national IVM policy (i.e. outcome indicator) but has already made several steps in that direction.

— What process indicators would you propose to determine whether the country is on its way towards developing a national IVM policy?
— In what ways are process indicators helpful in monitoring and evaluation?

4.5.2 Impact indicators

The expected impacts of an IVM strategy are:

— a reduced risk of transmission,
— a reduced disease burden,
— more cost-effective operations and
— greater ecological soundness and sustainability.

Indicators of impact in these areas are proposed in Table 4.6. An output is the direct result of an activity or intervention, which may or may not result in an outcome, which in turn could have an impact. Hence, impact is the indirect result of the activity or intervention. Impacts are generally more difficult to measure than outcomes, the main challenge being reliable attribution of an observed impact to the intervention. Outcome indicators are monitored by recording progress over time, or a longitudinal change relative to the baseline situation. For example, if five people were trained in IVM at baseline, and, after 2 years, 20 people had been trained in IVM, progress has been made.

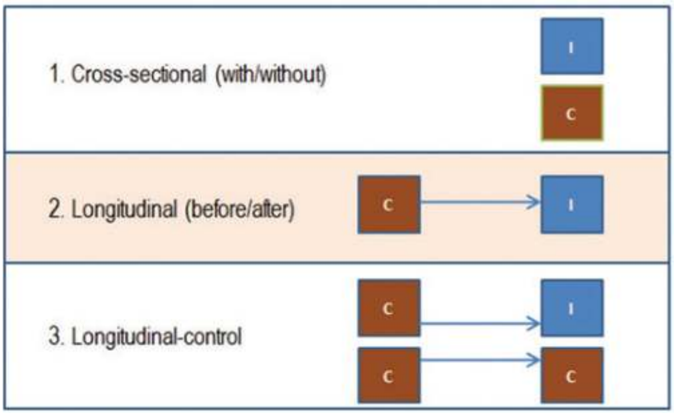
Table 4.6. Expected impacts and indicators of impact of IVM

Expected impact	Indicator
Reduced risk of transmission	Vector characteristics
Reduced disease burden	Prevalence and incidence rates of vector-borne disease
Cost-effectiveness	Cost per case of disease averted per year
Ecological soundness	Toxic units of insecticide used per case of disease averted per year
Organization and management	Strategy in place to ensure continued mobilization of resources for vector control

Source: WHO *(38)*.

A simple "longitudinal" comparison of the current situation with the baseline does not, however, suffice in the case of impact indicators, which often requires more precise study methods (Fig. 4.10). For instance, in measuring impact on vector populations, an expected impact is a decrease in vector populations as a result of implementation of the IVM strategy; however, vector populations are influenced not only by the IVM strategy but also by other factors in the environment, including weather patterns, environmental changes and the effects of development. A vector population might have increased during implementation of IVM if, during the same period, there was unusually high rainfall, creating favourable breeding sites for the vector. Other developmental projects and activities might have been conducted in the same area, influencing vector populations. These factors, known as "confounding" variables, should be considered, as they can obscure the effect due to the IVM intervention.

Fig. 4.10. Comparison of three study designs



Source: WHO *(39)*.

I: intervention; C: control.

Removing confounding variables in order to reliably attribute an observed impact to an intervention requires a "cross-sectional" design, in which the results for the treatment group (e.g. villages with an IVM strategy) and those for the control group (villages without an IVM strategy) are compared. In the cross-sectional design, however, villages selected as the "control group" may differ from those selected as "IVM villages", which might have been selected because of a high incidence of disease or poor housing. Hence, the two types of village are not comparable. Risk managers and researchers evaluating impact often find it difficult to decide on an experimental design in which the control and the IVM villages can be selected randomly, either because the programme has already been implemented in all areas, leaving no areas to serve as controls, or because it may be unethical purposely to leave communities with a disease burden but no proven interventions in order to serve as the control in a study.

To circumvent this problem, a longitudinal and cross-sectional comparison, sometimes called a "longitudinal control", is usually the best design for impact studies *(40)*. The treatment and control groups are compared both before and after the intervention to ensure that confounding variables and any differences between conditions in the two groups are filtered out.

4.5.3 Monitoring and evaluation system for IVM

In a functioning system of monitoring and evaluation of IVM, a central authority such as an intersectoral steering committee on IVM should assume general coordination and oversight. The committee could assign roles in monitoring and evaluation and mobilize the required resources.

What would be the implications of lack of central coordination for each of the following:
- Routine monitoring and evaluation?
- Methods and reliability of data collection?
- Comprehensiveness of data?
- Feedback of data to decision-makers at national, district and village levels?

The intersectoral steering committee could form a technical working group for monitoring and evaluation. The group could then establish the appropriate standards, procedures and guidelines and a mechanism for collecting, analysing and feeding back data. A plan for monitoring and evaluation should include indicators, with baselines and targets; the methods for collecting, processing, disseminating and using data; the resources required; and roles and responsibilities in monitoring and evaluation. Monitoring and evaluation should start before implementation of any activities in the field. A baseline must be established for monitoring progress; however, a common problem is establishment of a baseline after activities have been implemented. An important aspect of monitoring and evaluation is effective, timely dissemination and use of the collected data to improve decision-making on implementation at all levels.

Indicators must be studied through routine monitoring and record-keeping, with appropriate data collection methods, such as direct observations, reports, interviews or surveys. Studies of impact require systematic observations or use of surveillance systems to collect data on vectors, disease, cost and the environment.

For data dissemination, data should be processed and analysed and the results interpreted and presented in a form that is useful for programme managers and implementers in deciding how to improve their strategies. Dissemination to policy-makers helps them decide whether an investment in IVM has paid off. Results can be disseminated in forums such as seminars and workshops.

- Why should data from monitoring and evaluation of IVM be disseminated?
- Who should receive monitoring and evaluation data, at national, district and village levels?
- Who might have a conflict of interest in participating in monitoring and evaluation?
- Why and how should conflicts of interest be guarded against in monitoring and evaluation?

- What is the purpose of a baseline in monitoring and evaluation?
- What activities should be conducted to establish a baseline?

4.6 Importance of entomological expertise

Vector control is a specialized field. Public health entomologists and vector control specialists must thoroughly understand subjects such as insect taxonomy, biology, ecology, epidemiology, vector control, surveillance techniques and insecticide resistance monitoring. Entomologists require this knowledge to guide the control and vector surveillance in the right direction. In some countries, ITNs and IRS have been used in malaria control without entomological expertise to guide the operations or to conduct vector surveillance. Nets and spraying can be used without the guidance of entomologists; however, vector populations and the composition of vector species can adapt to interventions, such as developing resistance to the insecticides used. Vectors can also adapt, for example, by biting earlier in the evening, before people are asleep under a net. Vector species that were previously uncommon may become more dominant as a result of vector control interventions. The abundance of vector species is highly variable and determines when people are most at risk of disease transmission. The effectiveness of interventions may diminish as a consequence of these adaptations or changes in vector populations. Routine vector surveillance can detect changes in vector density, behaviour or susceptibility to insecticides, which can guide future decisions on vector control. Moreover, vector surveillance is essential when a country is at the stage of eliminating a disease such as malaria, when vector surveillance plays an important role in assessing the risk of remaining transmission.

In view of the crucial importance of entomological expertise in vector control and vector surveillance, it is unfortunate that there are shortages of public health entomologists, particularly in countries endemic for vector-borne disease *(24,41–43)*. Control of vector-borne diseases has long been considered a medical field, in which the role of entomologists was underappreciated. Consequently, most countries have insufficient training and capacity-building opportunities for entomologists, and their career opportunities are limited. Entomology laboratories play an important role by processing field samples, conducting operational studies and monitoring insecticide resistance *(37)*; however, there are few such facilities.

WHO recommends that countries that are endemic for vector-borne diseases conduct a needs assessment for vector control *(44)* to demonstrate the requirements for entomological expertise for vector control and vector surveillance as an important basis for strengthening them. Some programmes (e.g. malaria) have entomological capacity for one disease only, while others (e.g. lymphatic filariasis, dengue) may have no access to entomological expertise or infrastructure. It is therefore good practice to establish a vector control unit for several diseases, as it will increase efficient use of the expertise and the laboratory infrastructure. It will also contribute to the sustainability of entomological expertise, for example by ensuring continued services even after one disease has been eliminated.

- What could a country do to increase its pool of entomologists?
- How could career opportunities for entomologists be improved?

Project assignment 4

A. Determinants of disease
Select a vector-borne disease in your country. Prepare a matrix with three columns.

First column: List the determinants of disease, including the parasite, vector, humans and the environment. Highlight the determinants that you think contribute most to disease risk.
Second column: For each determinant, list the intervention(s) required to reduce disease risk.
Third column: For each determinant, list the partners who should be involved in implementing the intervention.

B. IVM implementation strategy
Review your assessments of the situation of vector-borne disease and vectors in your country (project assignments 1 and 2). From the assessments, identify the vector control methods necessary to tackle the diseases. (Some methods might be used against more than one disease.)
Outline an IVM strategy for your country in the form of a matrix, according to the example in Table 4.4.

C. Monitoring and evaluation of IVM
Identify the main indicators of IVM (among those mentioned in this section or additional indicators) that are most crucial in the context of your country for ensuring that the vector control system will result in substantial progress.
Point out how each of the indicators could be measured or verified objectively.

References

1. Rowe AK, Kachur SP, Yoon SS, Lynch M, Slutsker L, Steketee RW. Caution is required when using health facility-based data to evaluate the health impact of malaria control efforts in Africa. Malar J. 2009;8:209. doi:10.1186/1475-2875-8-209.
2. Developing health management information systems: a practical guide for developing countries. Geneva: World Health Organization; 2004 (https://iris.who.int/handle/10665/207050).
3. Gething PW, Noor AM, Gikandi PW, Ogara EAA, Hay SI, Nixon MS et al. Improving imperfect data from health management information systems in Africa using space–time geostatistics. PloS Med. 2006;3(6):e271. doi:10.1371/journal.pmed.0030271.
4. Smith DL, Smith TA, Hay SI. Measuring malaria for elimination. In: Feachem RGA, Phillips AA, Targett, GA, editors. Shrinking the malaria map: a prospectus on malaria elimination. San Francisco (CA): The Global Health Group, UCSF Global Health Sciences; 2009:108–26 (https://shrinkingthemalariamap.org/sites/default/files/resources/AProspectusonMalariaElimination.pdf).
5. Tusting LS, Bousema T, Smith DL, Drakeley C. Measuring changes in *Plasmodium falciparum* transmission: precision, accuracy and costs of metrics. Adv Parasitol. 2014;84:151–208. doi:10.1016/B978-0-12-800099-1.00003-X.
6. Vector control product prequalification. Geneva: World Health Organization; 2022 (https://extranet.who.int/prequal/vector-control-products).
7. Test procedures for insecticide resistance monitoring in malaria vector mosquitoes. Second edition. Geneva: World Health Organization; 2016 (https://iris.who.int/handle/10665/250677).
8. The technical basis for coordinated action against insecticide resistance: preserving the effectiveness of modern malaria vector control: meeting report. Geneva: World Health Organization; 2011 (https://iris.who.int/handle/10665/44526).
9. Bousema T, Griffin JT, Sauerwein RW, Smith DL, Churcher TS, Takken W et al. Hitting hotspots: spatial targeting of malaria for control and elimination. PLoS Med. 2012;9:e1001165. doi:10.1371/journal.pmed.1001165.
10. Carter R, Mendis KN, Roberts D. Spatial targeting of interventions against malaria. Bull World Health Organ. 2000;78:1401–11 (https://iris.who.int/handle/10665/268030).
11. Brooker S, Utzinger J. Integrated disease mapping in a polyparasitic world. Geospat Health. 2007;1(2):141–6. doi:10.4081/gh.2007.262.
12. A toolkit for integrated vector management in sub-Saharan Africa. Geneva: World Health Organization; 2016 (https://iris.who.int/handle/10665/250267).
13. Shiff C. Integrated approach to malaria control. Clin Microbiol Rev. 2002;15:278–93. doi:10.1128/CMR.15.2.278-293.2002.
14. van den Berg H, Velayudhan R, Ebol A, Catbagan BHG, Turingan R, Tuso M et al. Operational efficiency and sustainability of vector control of malaria and dengue: descriptive case studies from the Philippines. Malar J. 2012;11(1):269. doi.org/10.1186/1475-2875-11-269.
15. Alegana VA, Suiyanka L, Macharia PM, Ikahu-Muchangi G, Snow RW. Malaria micro-stratification using routine surveillance data in western Kenya. Malar J. 2021;20(1):1–9. doi:10.1186/s12936-020-03529-6.
16. Handbook for integrated vector management. Geneva: World Health Organization; 2012 (https://iris.who.int/handle/10665/44768).
17. Chanda E, Masaninga F, Coleman M, Sikaala C, Katebe C, MacDonald M et al. Integrated vector management: the Zambian experience. Malar J. 2008;7:164. doi:10.1186/1475-2875-7-164.

18. Gunawardena DM, Wickremasinghe AR, Muthuwatta L, Weerasingha S, Rajakaruna J, Senanayaka T et al. Malaria risk factors in an endemic region of Sri Lanka, and the impact and cost implications of risk factor-based interventions. Am J Trop Med Hyg. 1998;58(5):533–42. doi:10.4269/ajtmh.1998.58.533.

19. Monroe A, Olapeju B, Moore S, Hunter G, Merritt AP, Okumu F et al. Improving malaria control by understanding human behaviour. Bull World Health Organ. 2021;99(11):837–9. doi:10.2471/BLT.20.285369.

20. Erlanger TE, Keiser J, De Castro MC, Bos R, Singer BH, Tanner M et al. Effect of water resource development and management on lymphatic filariasis, and estimates of populations at risk. Am J Trop Med Hyg. 2005;73(3):523–3 (https://pubmed.ncbi.nlm.nih.gov/16172476).

21. Keiser J, Maltese MF, Erlanger TE, Bos R, Tanner M, Singer BH et al. Effect of irrigated rice agriculture on Japanese encephalitis, including challenges and opportunities for integrated vector management. Acta Trop. 2005;95(1):40–57. doi:10.1016/j.actatropica.2005.04.012.

22. Konradsen F, Amerasinghe P, Van der Hoek W, Amerasinghe F, Perera D, Piyaratne M. Strong association between house characteristics and malaria vectors in Sri Lanka. Am J Trop Med Hyg. 2003;68:177–81 (https://pubmed.ncbi.nlm.nih.gov/12641408).

23. Killeen GF, Knols BGJ, Fillinger U, Beier JC, Gouagna LC. Interdisciplinary malaria vector research and training for Africa. Trends Parasitol. 2002;18:433–4. doi:10.1016/s1471-4922(02)02367-x.

24. Mnzava AP, Macdonald MB, Knox TB, Temu EA, Shiff CJ. Malaria vector control at crossroads: public health entomology and the drive to elimination. Trans R Soc Trop Med Hyg. 2014;108(9):550–4. doi:10.1093/trstmh/tru101.

25. Ottesen EA, Hooper PJ, Bradley M, Biswas G. The global programme to eliminate lymphatic filariasis: health impact after 8 years. PLoS Negl Trop Dis. 2008;2:e317. doi:10.1371/journal.pntd.0000317.

26. Rowland M, Mahmood P, Iqbal J, Carneiro I, Chavasse D. Indoor residual spraying with alphacypermethrin controls malaria in Pakistan: a community-randomised trial. Trop Med Int Health. 2000;5(7):472–81. doi:10.1046/j.1365-3156.2000.00581.x.

27. Arunachalam N, Tana S, Espino F, Kittayapong P, Abeyewickreme W, Wai KT et al. Eco-bio-social determinants of dengue vector breeding: a multicountry study in urban and periurban Asia. Bull World Health Organ. 2010;88:173–84. doi:10.2471/BLT.09.067892.

28. Decision-making for the judicious use of insecticides. Facilitator's guide. Trial edition. Geneva: World Health Organization; 2004 (https://iris.who.int/handle/10665/68781).

29. Curtis CF, Jana-Karab B, Maxwell CA. Insecticide treated nets: impact on vector populations and relevance of initial intensity of transmission and pyrethroid resistance. Jo Vector Borne Dis. 2003;40: 1–8 (https://pubmed.ncbi.nlm.nih.gov/15119065).

30. Sharp BL, Kleinschmidt I, Streat E, Maharaj R, Barnes KI, Durrheim DN et al. Seven years of regional malaria control collaboration – Mozambique, South Africa, and Swaziland. Am J Trop Med Hyg. 2007;76(1):42–7 (https://pubmed.ncbi.nlm.nih.gov/17255227).

31. Barrera R, Harris A, Hemme RR, Felix G, Nazario N, Muñoz-Jordan JL et al. Citywide control of *Aedes aegypti* (Diptera: Culicidae) during the 2016 Zika epidemic by integrating community awareness, education, source reduction, larvicides, and mass mosquito trapping. J Med Entomol. 2019;56(4): 1033–46. doi:10.1093/jme/tjz009.

32. Okorie PN, McKenzie FE, Ademowo OG, Bockarie M, Kelly-Hope L. Nigeria *Anopheles* vector database: an overview of 100 years' research. PLoS One. 2011;6(12):e28347. doi:10.1371/journal.pone.0028347.

33. Ferguson HM, Dornhaus A, Beeche A, Borgemeister C, Gottlieb M, Mulla MS et al. Ecology: a prerequisite for malaria elimination and eradication. PloS Med. 2010;7:e1000303. doi:10.1371/journal.pmed.1000303.

34. Silver JB. Mosquito ecology. Field sampling methods. Dordrecht: Springer; 2008 (https://link.springer.com/book/10.1007/978-1-4020-6666-5).

35. Mukabana WR, Kannady K, Kiama GM, Ijumba JN, Mathenge EM, Kiche I et al. Ecologists can enable communities to implement malaria vector control in Africa. Malar J. 2006;5:9. doi:10.1186/1475-2875-5-9.

36. Billingsley PF, Charlwood JD, Knols BGJ. Rapid assessment of malaria risk using entomological techniques: taking an epidemiological snapshot. In: Takken W, Martens P, Bogers RJ, editors. Environmental change and malaria risk: global and local implications. Wageningen: Springer; 2005: 51–67 (https://library.wur.nl/ojs/index.php/frontis/article/view/960).

37. Russell TL, Farlow R, Min M, Espino E, Mnzava A, Burkot TR. Capacity of national malaria control programmes to implement vector surveillance: a global analysis. Malar J. 2020;19(1):1–9. doi:10.1186/s12936-020-03493-1.

38. Monitoring and evaluation indicators for integrated vector management. Geneva: World Health Organization; 2012 (https://iris.who.int/handle/10665/76504).

39. Core structure for training curricula on integrated vector management. Geneva: World Health Organization; 2012 (https://iris.who.int/handle/10665/44765).

40. van den Berg H, Takken W. Evaluation of integrated vector management. Trends Parasitol. 2009;25(2):71–6. doi:10.1016/j.pt.2008.11.005.

41. Almeida APG, Fouque F, Launois P, Sousa CA, Silveira H. From the laboratory to the field: updating capacity building in medical entomology. Trends Parasitol. 2017;33(9):664–8. doi:10.1016/j.pt.2017.05.011.

42. Horstick O, Runge-Ranzinger S, Nathan MB, Kroeger A. Dengue vector-control services: How do they work? A systematic literature review and country case studies. Trans R Soc Trop Med Hyg. 2010;104:379–86. doi:10.1016/j.trstmh.2009.07.027.

43. Wirth DF, Casamitjana N, Tanner M, Reich MR. Global action for training in malaria elimination. Malar J. 2018;17(1):1–4. doi:10.1186/s12936-018-2199-3.

44. Framework for a national vector control needs assessment. Geneva: World Health Organization; 2017 (https://iris.who.int/handle/10665/259405).

Recommended reading

Beier JC, Keating J, Githure JI, Macdonald MB, Impoinvil DE, Novak RJ. Integrated vector management for malaria control. Malar J. 2008;7(S4). doi:10.1186/1475-2875-7-S1-S4.

Handbook for integrated vector management. Geneva: World Health Organization; 2012:chapters 4,7 (https://iris.who.int/handle/10665/44768).

A toolkit for integrated vector management in sub-Saharan Africa. Geneva: World Health Organization; 2016:chapters 4, 8 (https://iris.who.int/handle/10665/250267).

5

Elimination of vector-borne diseases: the role of vector control

Contents

Learning objectives

By the end of this course, students should be able to:

- demonstrate understanding of the role of previous experience in the elimination of vector-borne disease, particularly malaria; and
- describe the contribution of vector control and transmission reduction to effective control, elimination and prevention of reintroduction of vector-borne diseases.

5.1 Elimination of malaria

5.1.1 History of malaria

In the early seventeenth century, long before malaria was recognized, Jesuit missionaries learnt from indigenous tribes in Peru about use of medicinal bark from a tree in treating fever. The medicine became known as quinine and was used for treatment of malaria. It is still one of the most effective drugs for treatment of complicated cases. A French surgeon recognized parasites in the blood of patients with malaria in 1880, but it was not until 1897 that Ronald Ross, working in India, observed that malaria parasites could be transmitted to humans by mosquitoes.

During construction of the Panama Canal in 1905–1910, many workers suffered from malaria and yellow fever. Under the leadership of William Gorgas, malaria was interrupted and yellow fever was eliminated locally with mosquito control methods such as environmental modification, fumigation with insecticides and medication *(1)*.

Entomologists in Indonesia and Malaysia developed methods of environmental management that provided substantial control of the principal vectors of malaria. They also investigated the breeding preferences of each vector species and tailored the control methods to each *(2,3)*. These methods, known as "species sanitation", included lining and paving canals, improving water control gates and drainage, mosquito-proofing houses and tanks, flushing streams, changing water salinity, and water level management.

Discovery of the insecticidal properties of DDT in 1939 marked the beginning of a new era of malaria control (Box 5.1). DDT was first used against malaria by the US Army during the Second World War *(4)*. After the War, DDT and several related insecticides (e.g. dieldrin and lindane), were used on a large scale, in public health but predominantly in agriculture. From the 1940s, an increasing number of countries adopted indoor spraying for vector control with DDT *(1)*. Once these programmes had shown that malaria transmission could be interrupted by use of DDT, the objective was gradually shifted from malaria control to malaria eradication. During the same period, new antimalarial drugs such as chloroquine became available. After intense advocacy, substantial international funding was committed, and, in 1955, the World Health Assembly adopted a resolution to launch a global malaria eradication programme.

DDT had a long residual effect and therefore had to be applied only once or twice a year to provide continuous protection, depending on the duration of the malaria transmission season. Interest in indoor spraying grew after George Macdonald showed by mathematical modelling that systematic killing of adult vectors strongly affected the epidemiology and transmission of disease and was better than other vector control methods, most of which targeted the larval stage of mosquitoes *(6)*. The mathematical model showed that DDT spraying reduced the average longevity of mosquitoes below the age necessary to become infective malaria parasites, which develop in mosquitoes over about 12 days before migrating to their salivary glands. In other words, only older female mosquitoes can transmit malaria parasites. During the 12 days, the female mosquitoes have to take three or four blood meals on human or animal hosts.

Each time females come into contact with sprayed surfaces during their visits to houses, they risk being killed and not living long enough to become infectious with malaria parasites.

Box 5.1 **Timeline of DDT discovery and use**

1939	Insecticidal properties of DDT discovered
1940	DDT first applied in agriculture for pest control
1944	DDT first used for malaria vector control to protect military personnel in Italy
1945	DDT first used for vector control in public health
1955	Global malaria eradication campaign launched
1962	"Silent Spring" by Rachel Carson alerted the public about environmental effects
1969	The global malaria eradication campaign ended
1972	DDT officially banned in the USA
Late 1990s	Negotiations on a global ban of DDT
2001	Stockholm Convention listed and classified DDT as "restricted for disease vector control"

Source: Sadasivaiah et al. *(5)*.

5.1.2 Lessons from the first global malaria eradication campaign

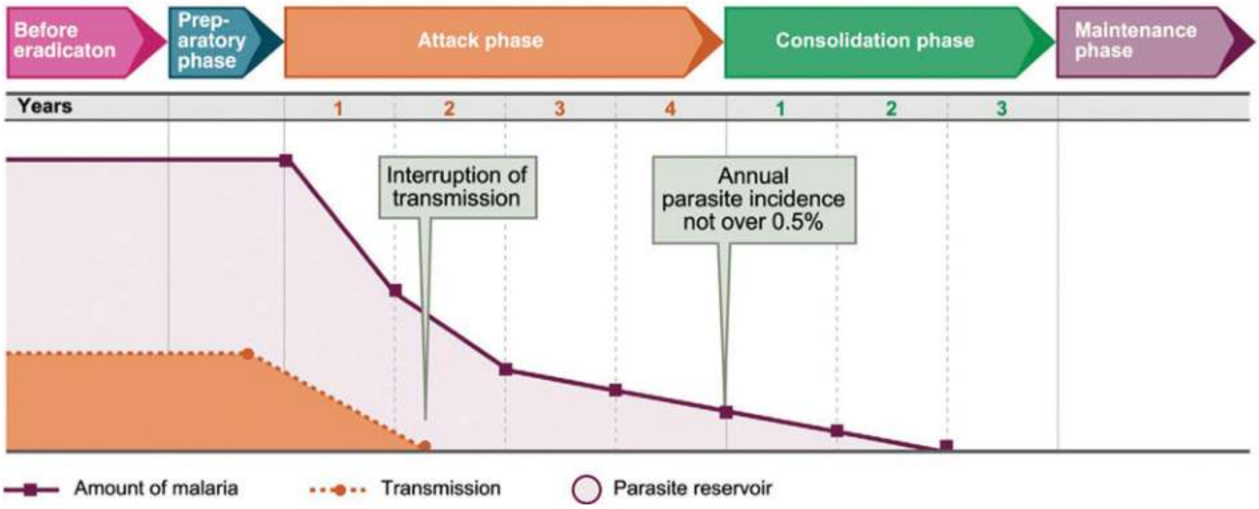
Macdonald's discovery fuelled the ambitious global malaria eradication campaign (1955–1969), which was adopted at the World Health Assembly in 1955. The aim was to eradicate malaria in all endemic countries. From the start, however, it was clear that it would be difficult to address the problems in sub-Saharan Africa, where there were highly efficient vectors and weak health infrastructure *(4)*. The objective in sub-Saharan Africa therefore was to control malaria while conducting pilot studies of local elimination in several countries. Because of disappointing results, however, elimination in Africa was not fully achieved *(7)*. Resistance to DDT, first noted in Greece in 1951, made it urgent to fully use this insecticide before it lost its effect.

In 1956, the WHO Expert Committee on Malaria *(4)* designed an eradication campaign, with preparatory, attack, consolidation and maintenance phases (Fig. 5.1).

During the attack phase, rapid reductions had to be achieved in malaria prevalence in populations, and transmission had to be interrupted before the onset of insecticide resistance. Eradication programmes concentrated on indoor spraying with residual insecticides, mainly DDT, and use of antimalarial drugs, combined with surveillance. Elimination consisted of successive steps of preparation, attack, consolidation and maintenance. The campaign to end malaria transmission and to eliminate the reservoir of infected cases had to be limited in time, as the cost of such massive operations could not be sustained for long, and continued application of DDT resulted in the development of resistance in the vector populations *(4)*. Elimination was therefore projected to take 4–5 years and the period of consolidation another 3 years.

Confidence in the campaign resulted in depreciation of the role of research and neglect of possible problems. As a result, the global campaign resulted in systematic reductions in the numbers and competence of malariologists, particularly entomologists. Field entomologists were no longer trained or considered necessary, as effective tools to achieve eradication (i.e. spraying with DDT) were considered to be already available. No technical needs were considered to be required – only operational needs. Also, the focus on insecticides for residual spraying reduced consideration of larval control and environmental management. With its programmatic approach, the campaign developed more or less in isolation from the general health systems of countries. Malaria elimination was a separate, standalone programme, mainly detached from health services.

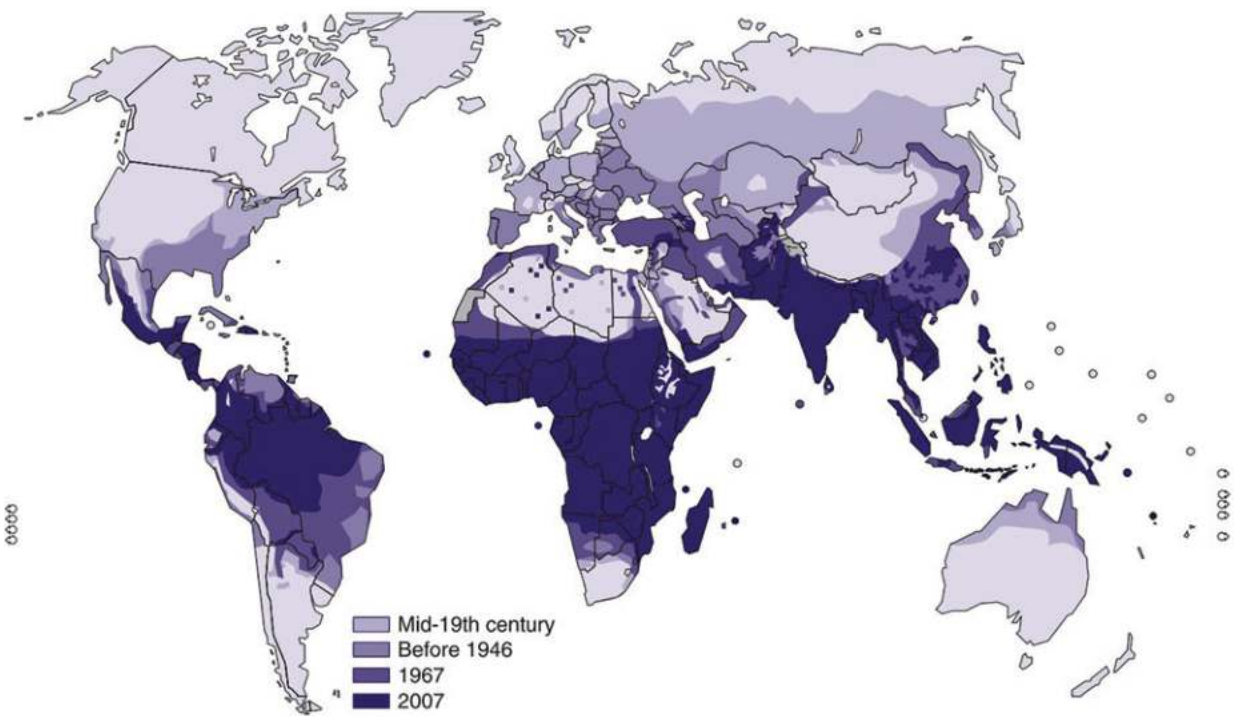
Fig. 5.1. Phases of the malaria eradication campaign established by WHO in 1963



Source: Najera et al. *(4)*. Reproduced under the Creative Commons Attribution 4.0 International License (https://creativecommons.org/licenses/by/4.0/).

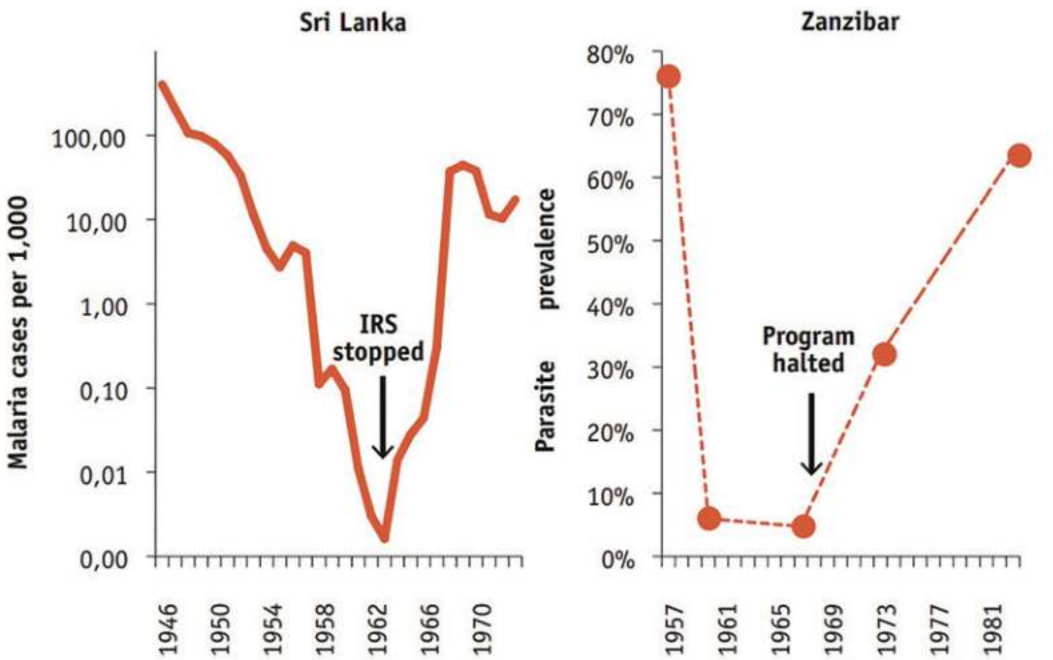
The global campaign resulted in a substantial reduction in the distribution of malaria (Fig. 5.2). The disease disappeared from many countries but could not be eliminated from others. There was limited progress in sub-Saharan Africa, where elimination programmes were never fully implemented *(4)*. In Sri Lanka, the malaria incidence was reduced to a few cases, but, after control lapsed and the human population lost their immunity, malaria rapidly resurged after the eradication campaign (Fig. 5.3). A similar resurgence was experienced in Zanzibar, United Republic of Tanzania.

Fig. 5.2. Areas at risk of malaria before the mid-nineteenth century, before 1946, in 1967 after the end of the global malaria eradication programme, and in 2007



Source: Mendis et al. *(8)*. © World Health Organization, all rights reserved.

Fig. 5.3. Examples from Sri Lanka and Zanzibar, where malaria control was stopped after very low levels of malaria transmission had been achieved, resulting in rapid resurgence



Source: WHO *(9)*.

Resistance of *Anopheles* vectors to DDT and other organochlorine insecticides became an increasing problem, as was funding for programmes, which resulted in failure of malaria elimination in several countries. The strong resistance of parasite to the antimalarial drug chloroquine was recognized only after the problem had spread.

As indicated earlier, elimination of malaria was never formally recommended in sub-Saharan Africa, where malaria was highly endemic and where, as a consequence of regular infection with malaria parasites, human populations developed a certain level of immunity against malaria. Lack of information on the immune response and the possible consequences for malaria resurgence were reported as the main reasons for not attempting full elimination in Africa *(10)*. Another reason was the presence of highly efficient malaria vectors in Africa, due to their strong preference for biting humans rather than animals and their longevity as adults, as older mosquitoes are more likely to be infective than younger ones. Hence, in sub-Saharan Africa, the malaria situation remained almost unchanged after the global eradication campaign, except in Mauritius, Réunion and South Africa. In the place of elimination programmes, pilot research projects were conducted in Africa.

The global eradication campaign was gradually abandoned after 1969, when it was recognized that malaria eradication was not feasible in all countries. Overall funding had decreased, and major financial resources were shifted from malaria eradication programmes to general health programmes.

In retrospect, a number of lessons can be learnt from the first malaria eradication campaign that are relevant for contemporary programmes to control or eliminate malaria *(4)*, with a renewed focus on malaria elimination in endemic countries and global eradication. The main lessons are *(11)*:

- Eradication strategies should address the most difficult places from the outset, to avoid failure before the strategy is launched.
- Eradication should not be promised too early, so that it can be used to mobilize resources and to avoid donor and political fatigue when goals are not reached on time.
- National malaria elimination strategies must be designed for each country context, with strong surveillance systems, and be flexible enough to adjust to short- and long-term changes.

— Research and development are critical until eradication is achieved, and even beyond, to limit a post-eradication risk of resurgence.
— The outcome of a second global malaria eradication programme will have profound implications, not only for malaria but also for other diseases being considered for eradication.

The design of the first campaign was not flexible enough to adapt the strategy to local conditions and was insufficiently integrated into health systems. In some countries, this was no obstacle to elimination, while other countries required more adaptive programmes rather than a one-size-fits-all.

Resurgence of malaria after periods of interrupted transmission resulted in epidemics, with many deaths in some areas because people had not been exposed to malaria parasites for some time and had thus lost their acquired immunity. Epidemiological surveillance was not conducted and health systems were not available after malaria had been eliminated; subsequent initiatives included strengthening of health systems and surveillance systems to sustain achievements in malaria control and elimination. Now, public health services and epidemiological surveillance are considered important conditions for the elimination of malaria.

Community participation was not a priority in the first malaria eradication campaign, which was based on centrally organized, vertical programmes in which communities were recipients, not active partners. The role of communities as active participants in malaria elimination programmes is being recognized increasingly, to ensure the acceptability of and compliance with interventions and to assist in detection of any remaining malaria cases in an elimination context.

Another lesson was that research is important in malaria control and elimination. The programmatic, one-size-fits-all approach to malaria eradication neglected changes in biological, ecological and sociocultural variables that influence the effectiveness of operations. Mosquito vectors developed resistance to DDT and changed their biting behaviour in response to the interventions used; malaria parasites developed resistance to drugs, but the lack of operational research capacity meant that this went unnoticed until it had spread and reduced the effectiveness of interventions. Also, insufficient attention was paid to identifying and overcoming ecological factors, such as the diversity of malaria vectors globally, each with its own ecology and behaviour.

Currently, capacity for entomological surveillance and monitoring insecticide resistance is still inadequate in many malaria-endemic countries *(12)*, and this should be a priority for risk managers (see section 4.5). Lack of coordination between operational and research programmes has also been noted.

The first global malaria eradication campaign is often considered a failure, because the goal of was not achieved. The successes of the campaign should not, however, be underestimated: over one billion people were no longer at risk of malaria, and the burden of malaria had been greatly reduced in many countries where the disease remained endemic. An important exception was sub-Saharan Africa, where countries did not benefit significantly from the campaign.

If you, as a pesticide risk manager, were asked to participate in designing a malaria elimination programme in your country, how would the lessons learnt from the past influence your plans regarding:
— vector control,
— the role of health systems,
— community participation and
— surveillance?

What would you do differently?

Najera JA, Gonzalez-Silva M, Alonso PL. Some lessons for the future from the global malaria eradication programme (1955–1969). PloS Med. 2011;8:e1000412. doi:10.1371/journal.pmed.1000412 *(4)*.

5.1.3 Control versus elimination

After the first global malaria eradication campaign, malaria remained prevalent in many countries, particularly in sub-Saharan Africa, where malaria elimination was not attempted, and the strategy of elimination was re-oriented after 1970 to malaria control with the available means to reduce malaria as a public health problem by reducing the numbers of malaria-related cases and deaths. Malaria control was conducted from the 1970s until today (although the aim of programmes in many countries is now elimination). Some countries have conducted vector control programmes successfully for two or three decades, while others have experienced difficulty in sustaining vector control operations because of the spread of insecticide resistance.

Malaria control and malaria elimination each has advantages and difficulties. The general view has been that elimination is possible in areas with low malaria endemicity and should be attempted. The main question is how to keep areas malaria-free after elimination.

In 1998, WHO launched the Roll Back Malaria initiative to increase malaria control in countries in order to reduce morbidity and mortality, with universal coverage and strengthening health systems. The initiative has increased national commitment to controlling malaria in most endemic countries. It has attracted major global financial resources and, recently, has achieved high coverage of interventions for populations at risk, particularly in sub-Saharan Africa, where populations have the greatest burden of malaria. The high level of malaria control that has been achieved in countries, including in those in Africa that are highly endemic, has led to renewed interest in the possibility of malaria elimination and eradication *(13)*.

Moonasar D, Morris N, Kleinschmidt I, Maharaj R, Raman J, Mayet NT et al. What will move malaria control to elimination in South Africa? S Afr Med J. 2013;103(10):801–6. doi:10.7196/samj.7445 *(14)*.

5.1.4 New call for eradication

After several decades of accepting the idea of malaria control, the malaria control community was woken up by a call for change, not from scientists or policy-makers but from the donor community. In 2007, the Bill & Melinda Gates Foundation announced the goal of malaria eradication. In response, WHO offered support for the elimination of malaria in countries where it is feasible. The terms “control”, “elimination” and “eradication” clearly differentiate the goals, “elimination” indicating a confined geographical area and “eradication” at global level *(15)*.

The initial targets for elimination were countries with low-to-moderate endemicity or unstable malaria, with occasional epidemics separated by periods without transmission. In the new strategy for elimination, control is increased until only a few cases per 1000 population are at risk per year *(16)*. At this stage, the situation is considered manageable, and the control programme can be reoriented towards a pre-elimination phase, which consist of systematic work towards full elimination by identifying and treating the last remaining cases, with or without malaria symptoms, by analysis of blood samples. When there are fewer than one case per 1000 population per year, cases occur more erratically and are concentrated in "hotspots". The start of the elimination phase is a change in strategy from overall coverage with interventions to detection, management of hotspots *(17)* and prevention of the introduction of cases *(18)*.

In countries that neighbour others with high malaria transmission or areas that are epidemic-prone, local transmission of malaria could be completely interrupted with strong political will and adequate financial and human resources. With the available tools for malaria control, however, it will be difficult if not impossible to interrupt transmission in highly endemic areas, especially in Africa, because of the biological properties of African vector species, their highly efficient biting habits, the long lives of female mosquitoes, and the development of insecticide resistance.

Once a country has had no locally acquired malaria cases for 3 consecutive years, it is certified by WHO as malaria-free *(8)*. Table 5.1 provides an overview of the countries that have become malaria-free since 1955. During the global malaria eradication programme in 1955–1969, 15 countries and one territory became malaria free. Another seven countries and one territory became malaria free during 1972–1987; however, no additional countries eliminated malaria in 1987–2007. Since 2007, 13 more countries have been certified malaria-free. It is noteworthy that re-establishment of malaria has so far been prevented in malaria-free countries.

Table 5.1. Certified elimination of malaria in countries by period

Period	Malaria elimination	Countries
1955–1972	15 countries and 1 territory	Bulgaria, Cyprus, Dominica, Grenada, Hungary, Italy, Jamaica, Netherlands (Kingdom of the), Poland, Romania, Saint Lucia, Spain, Taiwan (China), Trinidad and Tobago, USA, Venezuela (Bolivarian Republic of)
1972–1987	7 countries and 1 territory	Australia, Brunei, Cuba, Mauritius, Portugal, Réunion, Singapore, Yugoslavia (Bosnia Herzegovina, Croatia, Montenegro, North Macedonia and Serbia)
1987–2007	None	–
2007–2015	5 countries	Armenia, Maldives, Morocco, Turkmenistan, United Arab Emirates
2015–2021	8 countries	Algeria, Argentina, China, El Salvador, Kyrgyzstan, Paraguay, Sri Lanka, Uzbekistan

Sources: WHO *(19,20)*.

The initial aim of the Global Technical Strategy for Malaria 2016–2030 (Table 5.2) was to make 10 countries in which malaria was transmitted in 2015 malaria-free by 2020; however, this was not achieved. Another target was to make 20 more countries in which malaria was transmitted in 2015 malaria-free by 2025 and an additional 35 countries by 2030. Time will tell whether these targets were too ambitious. The strategy included a call for additional malaria control tools in order to achieve its targets, which will require further innovations and research, particularly for use in areas and population groups that are hard to reach with current interventions *(21)*.

Table 5.2. Framework of the Global Technical Strategy for Malaria 2016–2030

Pillar	Strategy
I	Ensure universal access to malaria prevention, diagnosis and treatment.
II	Accelerate work towards elimination and attainment of malaria-free status.
III	Transform malaria surveillance into a core intervention.
Supporting element I	Harness innovation and extend research.
Supporting element II	Strengthening the enabling environment.

Source: WHO *(21)*.

The Strategy was designed to eradicate about 90% of malaria in the world, with the ultimate goal of global malaria eradication *(11)*. Unfortunately, global progress in malaria control has levelled off, and no substantial gains have been made in reducing the incidence of malaria during the past 5 years *(20)*, and, in some countries with a high burden, the prevalence of malaria is increasing again. Therefore, some of the targets for 2020 have been missed. The COVID-19 pandemic has further hindered work to reduce malaria prevalence globally.

Despite these recent setbacks, WHO maintains its vision of global eradication of malaria *(11)*. Countries that have eliminated malaria but that border countries in which malaria is endemic may not be able to sustain elimination in the long term. Importation of cases from a neighbouring country will impose continually high costs on countries to prevent reintroduction of malaria. Furthermore, the continuing development of resistance to drugs and insecticides will complicate future malaria control in endemic countries.

The available tools and high coverage of interventions are expected to achieve malaria elimination in some but not all settings. In highly endemic areas and those with highly adaptive mosquitoes, new, additional interventions will be required. In Angola, the Democratic Republic of the Congo, Mozambique and Uganda, the local prevalence of malaria can exceed 70%. ITNs and IRS provide protection against night-time and indoor-biting mosquitoes, but some residual transmission may occur locally due to mosquitoes that bite outdoors or in the early evening. Several new vector control tools are being evaluated, but they will not be commercially available on a large scale for some time.

Another urgent requirement is strong leadership. In this regard, Zimbabwe is implementing a programme to build leadership and management capacity among district-level malaria leaders *(22)*. This initiative is reportedly resulting in greater productivity, coverage, quality, strengthened management and team performance.

Better surveillance data are necessary for decision-making, with targeted, tailored interventions based on stratification, incentives for staff, active community participation and increased involvement of the private sector, for example in ITN distribution.

5.1.5 Vector control for malaria elimination

Vector control has been the mainstay of the control of malaria, even before organochlorine insecticides such as DDT became available. Before the advent of DDT, malaria vector control was based largely on environmental management tailored to the breeding ecology of local vector species *(2)*. Use of an inorganic compound, Paris green (copper [II] acetoarsenite) as a larvicide in northeast Brazil in the 1930s eradicated an invasive malaria vector and simultaneously eliminated malaria *(23)*. These experiences provide valuable evidence that well-planned, well-targeted vector control can interrupt transmission of malaria.

Vector control with IRS was the main intervention in the first global malaria eradication campaign and was considered to be sufficient to achieve elimination. This method has been largely responsible for drastic reductions in malaria morbidity and mortality in many countries and for elimination of malaria in other countries, including much of South-East Asia. IRS campaigns also resulted in local elimination of populations of *An. funestus*, a highly efficient malaria vector which strongly prefers to feed on human hosts, from Kenya, Mauritius and parts of Uganda.

Although vector control had clear effects, after the first malaria eradication campaign, emphasis shifted to use of curative drugs for treatment of malaria, and prevention through vector control was no longer the backbone of malaria control. This was due partly to the serious shortage of trained medical entomologists to help design and evaluate vector control programmes.

This situation changed in the 1980s, when synthetic pyrethroids became available and were used to treat bed nets. The innovation of ITNs was accompanied by re-appreciation of the role of vector control (Fig. 5.4). Lindsay et al. *(24)* showed in 1991 that use of permethrin-impregnated bed nets reduced mosquito blood-feeding by 91% as compared with untreated nets.

The importance of malaria vector control is also clearly illustrated in a study that showed that the majority of malaria cases could be averted by the use of ITNs and IRS, while medication made a smaller contribution (see section 3.1).

Fig. 5.4. Use of an insecticide-treated net, Cambodia

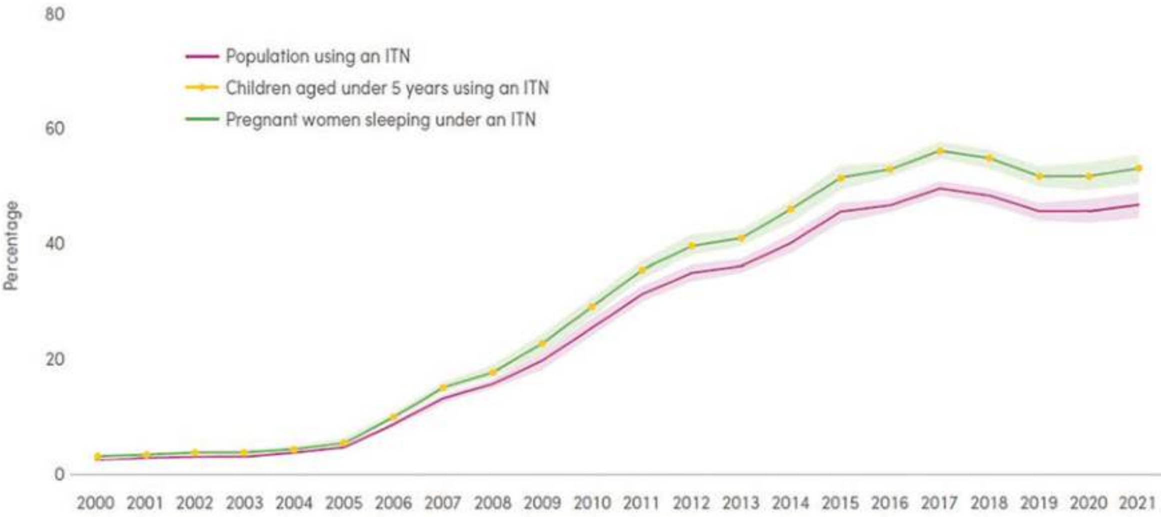
Source: photo courtesy of S. Hollyman (WHO Photo Library).

ITNs provide a physical barrier to night-biting mosquitoes, and the insecticide enhances the protective effect. ITNs have thus substantially reduced the rate of mortality from all causes among children in various epidemiological situations *(25)*. In highly endemic settings, their use reduced the risk of severe disease, particularly in infants and young children before they had acquired a certain level of natural immunity *(26)*.

At present, three classes of ITNs are distinguished: pyrethroid-only nets, pyrethroid–PBO (synergist) nets and dual-insecticide nets (with a pyrrole or a juvenile hormone mimic added to a pyrethroid) *(27)*. Conventionally treated nets must be re-treated regularly with the insecticide by the users; however, factory-made insecticidal nets are effective for longer.

Access to ITNs in sub-Saharan Africa decreased after 2017, which is a worrying trend (Fig. 5.5).

Fig. 5.5. Population-level use of ITNs in sub-Saharan Africa, 2000–2020



Source: WHO *(20)*.

Proper use and maintenance of ITNs is critical. Nets must be hung and washed properly and examined for damage by the edges of mats or a bed, and proper instructions must be given. Improper maintenance can also lead to rapid loss of insecticidal action. Communities should be educated in methods for hanging, proper use, maintenance and repair of nets and in the best practices for washing and drying them. People should also be made aware that the nets not only protect against the nuisance-biting of mosquitoes, which are often *Culex* mosquitoes that do not transmit malaria, but also protect them against malaria-transmitting mosquitoes, which are less readily noticed. Furthermore, *Culex* mosquitoes transmit lymphatic filariasis in certain countries. People should be told that the noisy mosquitoes that keep them awake at night are not those that transmit malaria, and nets should be used not only to remove nuisance. Community education on bed net use is often neglected in malaria control programmes.

ITNs that contain pyrethroids are generally considered "safe" for humans; however, a risk assessment showed that dermal and oral exposure to treated netting could be a cause of concern and should be closely monitored by regulatory decision-makers *(28)*. Children are at highest risk, due to extraction of the chemicals in saliva and because of their small body size relative to their body surface area.

Use of ITNs as fishing nets is a visible sign that they are being misused. See, for example, Fig. 5.6 from a study at Lake Victoria, Uganda *(29)*.

Fig. 5.6. Use of ITNs for fishing, Chikwawa, Malawi

Source: photo courtesy of H. van den Berg.

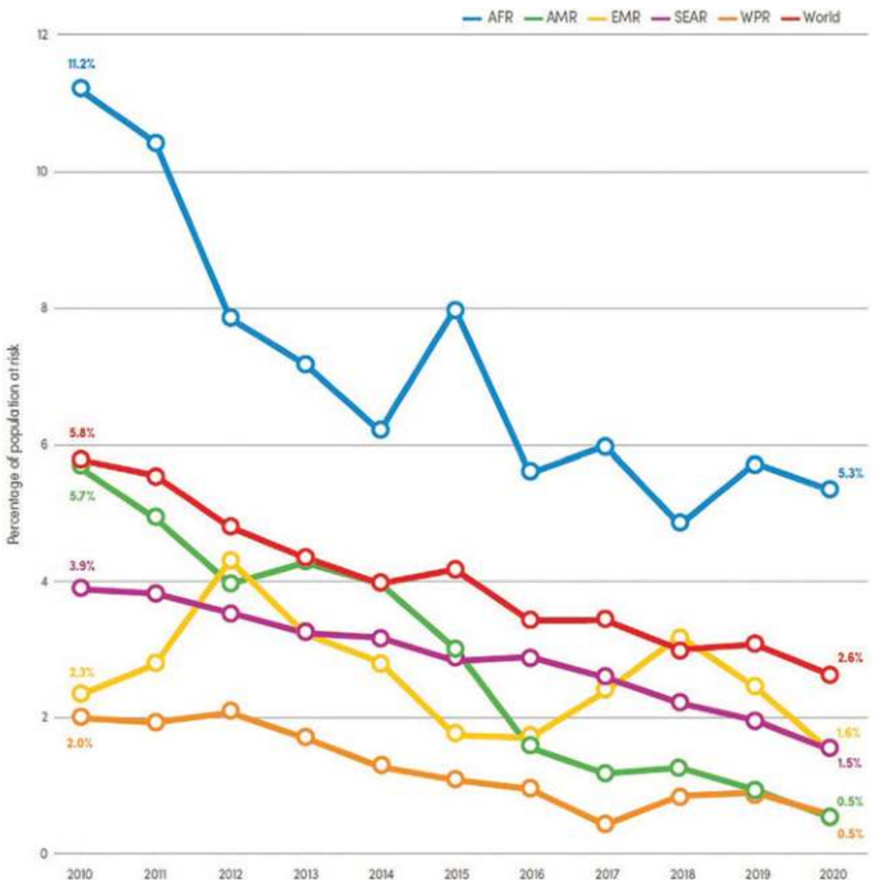
Another concern in mass distribution of ITNs is safe disposal of chemical residues (see section 2.4.4).

Peterson RKD, Barber LM, Schleier III JJ. Net risk: A risk assessment of long-lasting insecticide bed nets used for malaria management. Am J Trop Med Hyg. 2011;84(6):951–6. doi:10.4269/ajtmh.2011.11-0016) *(28)*.

Only a few countries, including India, Namibia and South Africa, have continued to use IRS since the first malaria eradication campaign; a number of other countries recently reintroduced IRS *(30)*. The insecticide sprayed onto walls and ceilings kills female mosquitoes only after they have fed and rest on sprayed surfaces to digest their blood meal. The strength of IRS is that it shortens the life span of adult female mosquitoes, reducing malaria transmission, because the parasite requires about 12 days to develop inside the vector *(31)*. Another strength of IRS, when conducted properly, is that it has a community-wide effect on the vector population within a short time. Indoor methods of vector control are effective, however, only in areas in which the principal vectors prefer to feed and rest indoors. In areas in which a proportion of vectors feed outdoors or in which mosquitoes have behavioural resistance (i.e. no longer rest indoors after feeding inside), other methods of vector control are required.

The proportion of people protected by IRS has been decreasing steadily in all WHO regions (Fig. 5.7). One reason for the decrease is the switch in some countries to more costly insecticides to avoid insecticide resistance, leading them to reduce the areas covered by IRS. Another reason is the increasing number of countries in which malaria is being or has been eliminated.

Fig. 5.7. Proportions of populations at risk protected by IRS, by WHO region, 2010–2020



Source: WHO *(20)*.

AFR: WHO African Region; AMR: WHO Region of the Americas; EMR: WHO Eastern Mediterranean Region; IRS: indoor residual spraying.

Non-chemical methods of vector control have also been shown to be effective in reducing transmission of and morbidity from malaria. Before the Second World War, malaria control was based primarily on environmental management to reduce vector breeding *(32)*, which substantially reduced the risk of malaria *(33)*. Several other non-chemical methods of malaria vector control have more recently been shown to be effective, including larval source management, recently recommended by WHO as a supplementary measure for malaria vector control where vector breeding sites are "few, fixed and findable" *(34)*. Anti-larval measures such as use of bacterial insecticides can improve malaria control by ITNs. House screening can contribute to prevention of malaria-related illness *(35)*. Therefore, combinations of vector control methods can improve control, reduce long-term exposure to pesticides and reduce environmental contamination by pesticides.

Vector control is essential in each phase of a malaria elimination programme *(36)*. Full coverage with proven vector control interventions is necessary to reduce the incidence of malaria quickly and substantially, by interrupting transmission. This may be feasible in areas where vectors feed and rest indoors but less so where some vectors feed outdoors.

In large parts of sub-Saharan Africa, parts of India, Pakistan and Sudan and the Mekong sub-region, people receive many infectious bites each year. In these high-transmission areas, transmission can be decreased to some extent by use of ITNs or IRS. In this setting, however, it may not be possible to eliminate malaria with the available tools, as the transmission that continues outdoors is more than sufficient to maintain the disease cycle without interrupting it *(37)*. If malaria is to be eliminated, there should be no options for transmission of the parasite. So-called "residual transmission" of malaria parasites through biting in the evening or outdoors is a problem for achieving elimination status. Additional vector control tools are required that specifically target outdoor biting (e.g. through use of repellents) or that reduce the vector population as a whole (e.g. targeting larvae or adult mosquitoes) *(38)*. These tools should be accessible and acceptable to the population at risk. Thus, an IVM strategy is necessary for achieving malaria elimination.

- Why is **outdoor biting** of vectors a concern for the design of a malaria elimination programme?
- What could be done to stop outdoor transmission of malaria?

After the incidence rate has decreased to only a few cases per 1000 population at risk per year, control programmes enter the pre-elimination phase. Vector control is reoriented from full coverage with interventions to targeted, responsive vector control, with resources focused on hotspots and emerging epidemics, with a strong epidemiological surveillance system. Isolated sections of society may have continued transmission, work temporarily in transmission zones (e.g. forests) or migrate from hotspots. These components of "residual transmission" must be recognized and be targeted with appropriate interventions.

When elimination is being approached, intensive surveillance is necessary to detect any introduced cases or emerging outbreaks, and vector control is targeted at the locations of new cases. This requires a rapid response, or a "fire-brigade" approach, for which the health services and surveillance system must be prepared, which is always the case.

Once elimination is achieved, the strategy concentrates on long-term prevention of reintroduction of malaria parasites through infected travellers or imported mosquitoes. This phase requires long-term improvements to discourage vector breeding and human–vector contact. The tools used in this phase should not be time-limited, because of the risk of resistance, but should have a preventive effect that can be sustained within an IVM strategy. Detection of introduced cases and emergency response to new outbreaks remain important during the maintenance phase.

In South Africa, major progress has been made in controlling malaria, some provinces having begun strategies of pre-elimination, elimination and prevention of reintroduction *(14)*. Nevertheless, major financial gaps remain for surveillance, vector control, health promotion and case management. The country should also re-orientate its strategy to a much more targeted approach to eliminate the remaining hotspots of transmission.

In Mauritius, the Government spent US$ 4.43 per capita per year during its second elimination campaign in 1982–1988. The country has since eliminated malaria and is currently spending US$ 2.06 per capita per year to prevent reintroduction of malaria *(39)*. Over one third of the costs are for screening passengers at airports and seaports. While 49% of cases missed in initial passenger screening are identified by case detection, some unidentified imported infections remain.

Enayati A, Lines J, Maharaj R, Hemingway J. Suppressing the vector. In: Feachem RGA, Phillips AA, Targett, GA, editors. Shrinking the malaria map: a prospectus on malaria elimination. San Francisco (CA): The Global Health Group, UCSF Global Health Sciences; 2009:143–54 (https://shrinkingthemalariamap.org/sites/default/files/resources/AProspectusonMalariaElimination.pdf) *(36)*.
Hemingway J. The role of vector control in stopping the transmission of malaria: threats and opportunities. Phil Trans R Soc B Biol Sci. 2014;369(1645):20130431. doi:10.1098/rstb.2013.0431 *(40)*.

5.1.6 Drug resistance

Long-term use of drugs in treating malaria cases has resulted in the emergence of resistance to first-line drugs, a threat to curative treatment. Resistance is due to selection pressure on the parasite when suspected cases are given antimalarial treatment. The more people who receive antimalarial treatment, the higher the risk of drug resistance. Resistance to most of the major classes of drugs is already widespread. The first-line approach in many countries is use of artemisinin-based combination therapy, although resistance to this combination has emerged in areas of South-East Asia, and resistance genes may have spread to other parts of the world. Partial resistance to artemisinin has emerged in East Africa *(20)*, and possible spread of artemisinin resistance in Africa should be considered a major disaster *(41)*. To reduce the spread of drug resistance, it is essential that drugs be given only after accurate diagnosis of malaria. A global plan has been developed for the containment of artemisinin resistance *(42)*.

The problem of drug resistance highlights the importance of implementing preventive strategies based on vector control., as vector control reduces the need for antimalarial treatment and thus the risk of drug resistance.

Use of drugs as prophylactics is recommended for travellers to at-risk areas. Intermittent preventive treatment is a form of prophylactic recommended by WHO for pregnant women living in areas of moderate or high transmission of *P. falciparum*, which prevents asymptomatic infections that go unnoticed but may affect the foetus *(43)*. Continuous use of prophylactics by the whole population is, however, not an option in endemic countries because of their side-effects, high cost and the risk of drug resistance.

5.2 Elimination of other vector-borne diseases

Elimination of other vector-borne diseases has received much less attention than elimination of malaria in programmes and in the literature *(44)*. In the past, local elimination of visceral leishmaniasis, yellow fever and lymphatic filariasis was considered to be a beneficial side-effect of the global malaria eradication programme.

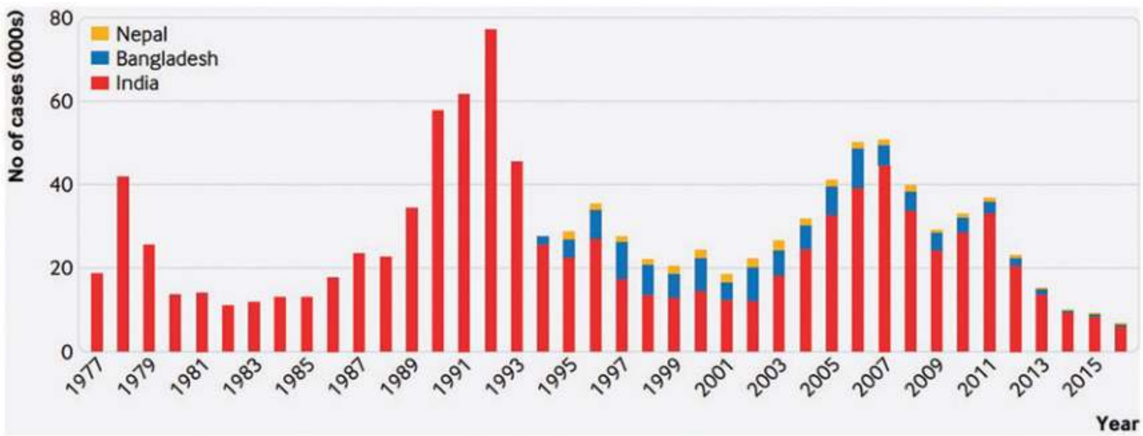
5.2.1 Visceral leishmaniasis

China provides an early example of a dedicated programme for the elimination of visceral leishmaniasis. The national programme was begun in 1951 with control interventions consisting of diagnosis and chemotherapy for patients; identification, isolation and disposal of infected dogs; and IRS for vector control. With massive, effective mobilization of the general public and health workers, the incidence of the disease was reduced from highly endemic in 1950 to eliminated as a public health problem in 1980 *(45)*.

In South Asia, visceral leishmaniasis caused devastating epidemics in the past. A single vector species, *Phlebotomus argentipes*, was responsible for transmission in Bangladesh, India and Nepal. The main intervention was IRS with DDT; however, the sand fly vector became fully resistant to it. In 2005, the three countries established regional collaboration, with support from WHO, to eliminate visceral leishmaniasis by reducing the incidence to such low levels that it would cease to be of public health importance by 2015 *(46,47)*. The programme was focused on a well-defined number of endemic districts in each country. The global elimination goal is now set for 2030 within the road map to eliminate NTDs.

Substantial progress has been made by introduction of pyrethroid IRS and better surveillance, case detection and treatment (Fig. 5.8). The disease has been eliminated from most districts, but transmission continues in others. Vector control with IRS in villages that had reported cases in the preceding 3 years is the main intervention; however, the effectiveness, logistics and acceptability of IRS have been problematic *(46)*. The deadline for elimination has been delayed several times. To address the challenges in vector control, further innovation in vector control is necessary to ensure elimination.

Fig. 5.8. Numbers of cases of visceral leishmaniasis (kala-azar) reported in Bangladesh, India and Nepal, 1977–2016



Source: Rijal et al. *(46)*. Reproduced under the Creative Commons Attribution 4.0 International License (https://creativecommons.org/licenses/by/4.0/).

5.2.2 Lymphatic filariasis

Vector control has achieved local elimination of lymphatic filariasis in certain settings. In some areas of the Pacific region and in Australia, the disease has been eliminated by vector control alone *(44)*. In contemporary work to eliminate lymphatic filariasis, the main intervention for stopping transmission is MDA of preventive chemotherapy.

In 2000, WHO launched the Global Programme to Eliminate Lymphatic Filariasis to eliminate the disease as a public health problem *(48)*. The programme had two main components: (i) stopping the spread of infection through large-scale annual preventive chemotherapy; and (ii) providing an essential package of care to reduce morbidity and suffering from lymphatic filariasis. The strategy for preventive chemotherapy involved annual or semi-annual MDA, and WHO reported in 2022 that, since 2000, 8.6 billion treatments had been delivered. This reduced transmission in many areas, and 692 million people no longer require preventive chemotherapy due to successful implementation of WHO strategies. In 2018, some 51 million people were still infected with lymphatic filariasis, a 74% decrease since 2000 *(49)*.

Seventeen countries and territories in Asia, the Pacific, the Middle East and one African country (Malawi) have achieved elimination of lymphatic filariasis as a public health problem. Five additional countries are under surveillance to demonstrate that elimination has been achieved. Preventive chemotherapy is still required, however, in 50 countries, and in 10 of the countries endemic areas are not yet covered with MDA *(49)*.

So far, vector control has played only a minor role in the elimination of lymphatic filariasis. WHO considers vector control a supportive strategy *(50)*. Examples are use of ITNs and IRS in areas in which the main vectors are *Anopheles* species. Vector control is expected to further reduce transmission during and after MDA. People must generally accumulate a large number of infective mosquito bites over a long period before they become infectious with lymphatic filariasis parasites *(51)*, indicating the potential role of vector control in eliminating the disease.

Lymphatic filariasis is transmitted by various genera of mosquitoes, namely *Anopheles, Culex, Mansonia, Ochlerotatus* and *Aedes*, each with its own characteristics and biting behaviour. The Global Programme could therefore not recommend a simple strategy for vector control that was applicable in all regions *(52)*. MDA was considered the most cost-effective method, as the addition of vector control more than doubled the costs *(53)*.

The strong reliance on MDA for reducing transmission has raised questions about the feasibility of achieving elimination in certain countries. Annual coverage of populations with MDA is often deficient, and addition of vector control could have been more effective for interrupting transmission *(54)*. Vector control is particularly promising in areas in which *Culex* or *Anopheles* is the main mosquito vector, as effective control tools are available. For example, ITNs are effective in reducing parasite transmission by *Anopheles* and *Culex (55)*, so that the ITNs that are distributed to control malaria also control lymphatic filariasis *(56)*. Floating layers of polystyrene beads are effective for larval control of *Culex* in confined aquatic habitats *(57)*. Supplementary vector control could therefore reduce the number of MDA treatment cycles required to interrupt parasite transmission *(54)*. Vector control is less promising in areas in which *Aedes* mosquitoes are the vectors of *Wuchereria bancrofti*.

Methods for the control of *Culex* spp. are environmental management and larviciding, especially in urban and semi-urban areas in which breeding habitats are well known and findable. Larvicides to which local *Culex* spp. are proven to be susceptible (e.g. bacterial larvicides, benzoylureas, juvenile hormone mimics, organophosphates, spinosyns) should be applied to the main *Culex* breeding habitats, with control by use of monomolecular film-producing products, for example. Space spraying is not recommended for routine control of *Cx. quinquefasciatus* or other *Culex* species. The insecticide options include a number of WHO-prequalified pyrethroids. Where *Culex* spp. are resistance to pyrethroids, a WHO-prequalified insecticide in a class with an unrelated mode of action should be used.

Bockarie MJ, Pedersen EM, White GB, Michael E. Role of vector control in the global program to eliminate lymphatic filariasis. Annu Rev Entomol. 2009;54:469–87. doi:10.1146/annurev.ento.54.110807.090626 *(54)*.

5.2.3 Arboviral diseases

Vector control has been the only option for the prevention and control of arboviral diseases such as dengue, chikungunya, Zika virus transmitted by *Aedes* mosquitoes and Japanese encephalitis transmitted by *Cx. tritaeniorhynchus*.

Dengue has been addressed mainly by control or local elimination of its mosquito vectors. Dengue control in the Caribbean and Central and South America in the 1950s and 1960s achieved a dramatic decrease in *Ae. aegypti* populations and major reductions in the prevalence of dengue *(58)*. The vector was presumed to have been eliminated from a large part of these areas in the early 1970s; however, both the vector and dengue have since returned.

An intensive vector control programme for dengue control in Singapore in the 1970s and 1980s also temporarily eliminated dengue, but, again, elimination was not sustained *(59)*. A similar situation was seen after a programme in Cuba in the 1980s and 1990s *(60)*.

More recently, in Viet Nam, *Mesocyclops*, predatory aquatic copepods, have been used as a biological control agent, applied by local communities. This resulted in local elimination of *Ae. aegypti* and eventually in elimination of dengue *(61)*.

Control should target both immature and adult vector populations, and more than one intervention should be used. Control programmes should also target places of work and study, in addition to residential areas, because of the daytime biting habit of the vectors. Environmental management is recommended to control dengue and other arboviral diseases, although more evidence of its epidemiological impact is necessary. Reduction of the sources of mosquito larvae, with active community support, should be the mainstay in controlling mosquito populations. In emergencies, to suppress an epidemic or to prevent an incipient outbreak of disease, WHO recommends use of indoor space spraying (fogging) with hand-held space spray applicators. This is more effective than outdoor space spraying, as vehicle-mounted sprayers may have little or no impact on disease transmission. Space spraying should not be used in routine vector control. Targeted IRS with pyrethroids at high coverage and to a high standard can be used as a preventive or reactive intervention, especially when the endophagic mosquito *Ae. aegypti* is the primary vector. Such interventions eliminated *Aedes* spp. from several countries in South America in a campaign against yellow fever in the 1960s to 1970s *(58)*. Personal protection with pyrethroid-containing ITNs should be promoted for young children and people who are older or unwell who may sleep during the day, and to protect inpatients in hospitals and special wards undergoing treatment for *Aedes*-borne diseases. WHO also recommends use of certain WHO-prequalified topical repellents for personal protection.

Several novel approaches to eliminating the vector or dengue are the sterile insect technique, other genetic methods and the use of *Wolbachia* bacteria, which infect *Ae. aegypti* mosquitoes and cause the vector to become less susceptible to dengue virus infection.

5.2.4 Chagas disease

Chagas disease originated in Latin America but has spread to other parts of the world. The disease has an acute and a chronic phase. If untreated, Chagas infection can be lifelong. In 1991, the governments of Argentina, Bolivia (Plurinational State of), Brazil, Chile, Paraguay, Peru and Uruguay entered a joint agreement, the Southern Cone Initiative, to control Chagas disease by eliminating its main vector *Triatoma infestans (62)*. The strategy consisted of interrupting transmission by domestic vector control and ensuring safe blood transfusion (as the parasite can be transmitted through blood). Vector control was conducted by IRS, house improvement and community education. Houses were improved by cementing mud walls and floors and replacing thatched roofs with corrugated iron.

The initiative was highly successful, resulting in rapid reductions in vector populations and a steep decrease in the rate of infection of children. Vectorial and transfusional transmission of Chagas disease parasites was first interrupted in Uruguay (1997), followed by Chile (1999) and Brazil (2006) and parts of Argentina, Bolivia (Plurinational State of) and Paraguay *(44,63)*. Transmission became negligible. Despite interruption of transmission, a considerable population of ageing people still suffer from the chronic, life-long phase of the disease *(64)*.

Control cannot be relaxed, because the vector is still present, albeit at a low level. Many wild mammal species host the parasite and could result in reinfection and resurgence of Chagas disease in South America. Moreover, other, secondary vectors living in forested habitats could adapt to the peri-domestic environment and invade houses *(62)*. These aspects of the disease complicate full elimination of Chagas disease in humans.

5.2.5 Onchocerciasis

Onchocerciasis is confined mainly to the African continent. The Onchocerciasis Control Programme implemented since 1974 in West Africa brought the disease to a good level of control by the use of aerial spraying of larvicides against blackfly vectors (*Simulium* spp.) along the edges of rivers *(65)*. Vector control was the only intervention used until 1989, when MDA of ivermectin was added as preventive chemotherapy. In 1995, the African Programme for Onchocerciasis Control was launched to tackle onchocerciasis in the countries not included in the Onchocerciasis Control Programme, and was based predominantly on MDA and much less on vector control. Both programmes radically reduced the prevalence of the disease and of the accompanying blindness to near-elimination. The African Programme for Onchocerciasis Control was stopped in 2015, and, in 2016, the Expanded Special Project for the Elimination of Neglected Tropical Diseases in Africa was begun, covering several NTDs with preventive chemotherapy. For example, onchocerciasis, lymphatic filariasis and *loa loa* are all caused by filarial worms and can be treated with some of the same types of chemotherapy.

Onchocerciasis also occurred in six countries in Latin America. In recent years, however, four countries in Latin America have been certified by WHO as free from onchocerciasis: Colombia (2013), Ecuador (2014), Mexico (2015) and Guatemala (2016). Elimination was achieved with preventive chemotherapy.

- Identify the differences in the elimination programmes for malaria, visceral leishmaniasis and lymphatic filariasis.
- Elimination of malaria has received much more support and funding than elimination of other vector-borne diseases. Can you explain this difference? Why did other diseases receive less?
- Identify the differences in the elimination programmes for malaria, visceral leishmaniasis and lymphatic filariasis.

Wilson AL, Courtenay O, Kelly-Hope LA, Scott TW, Takken W, Torr SJ et al. The importance of vector control for the control and elimination of vector-borne diseases. PLoS Negl Trop Dis. 2020;14:e0007831. doi:10.1371/journal.pntd.0007831 *(44)*.

5.3 Sustaining elimination

Perhaps the greatest challenge in sustaining elimination status for many years is maintaining political commitment, interest and operational budgets. In the past, health authorities have tended to underestimate potential disease resurgence after elimination and have underestimated the importance of continued investment and surveillance *(62)*. Some countries and territories that have eliminated a vector-borne disease continue to host populations of competent vector species. For example, Australia, France, Italy, Mauritius, Morocco, Réunion, Singapore and Sri Lanka have, in the recent or distant past, eliminated malaria; although the mosquitoes that transmit malaria parasite continue to breed and feed on human hosts, they are free of disease parasites. In these countries, there is a risk of reintroduction of malaria and of other vector-borne diseases transmitted by local populations of vector species.

5.3.1 Risk of reintroduction

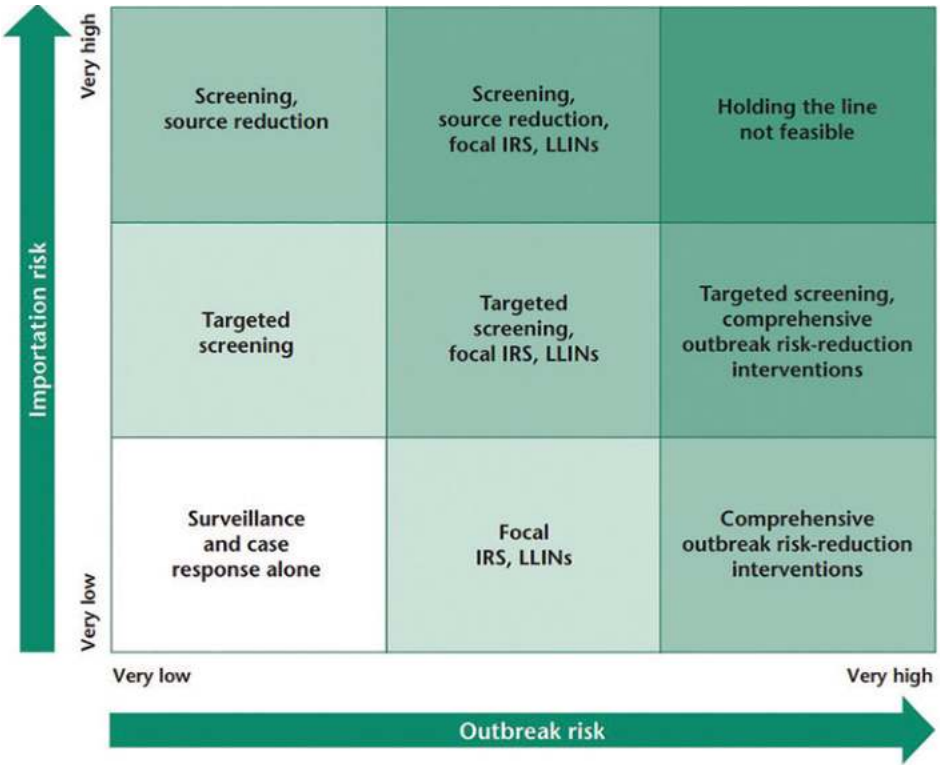
The risk of reintroduction of disease depends on the risk of importation and the risk of an outbreak *(66)* (Fig. 5.9). The combination of these two risks determines the likelihood that a vector-borne disease will return in a country. "Importation risk" is the risk that the parasites will be introduced into the country, for example by cross-border movements of people or by sea or air transport. Parasites are usually imported by human carriers. Infected vectors could also be introduced into countries in airplanes, and cases of so-called "airport malaria" and "airport dengue" have been reported at major airports in Australia and Europe; nevertheless, importation of infected vectors can be considered rare *(67)*. The occasional reports of airport malaria in countries that are malaria-free nevertheless demonstrate the risk of reintroduction of malaria. For example, in Tunisia, a country that has been malaria-free since the 1980s, four cases of malaria were recorded in the summer of 2013 among residents near the international airport and with no history of travel to a malarious country *(68)*. When infectious vectors arrive, they could transmit disease pathogens to people living in the vicinity of the port.

The second type of risk is outbreak risk. Once a disease parasite is introduced into a country, it could be transmitted from the infected case to other people. The outbreak risk thus depends on the vectorial capacity (i.e. the daily rate at which future inoculations arise from a currently infective case) of local anopheline populations (see section 4.1). Vectorial capacity depends on: the number of bites per person per day; whether the vectors feed only on humans or also on animals; and the life expectancy of the mosquito. Highly effective vector populations increase the chance that an introduced disease case will be transmitted locally and cause an outbreak. Prevention of reintroduction of disease thus depends on the levels of risk of importation and of an outbreak.

Countries with a high risk of importation are those with long, porous borders with endemic countries or with high volumes of migrants or refugees (such as in bordering countries in conflict zones). Countries with a high outbreak risk have efficient vector species and the conditions that favour vector proliferation and parasite transmission. Thus, any country in Africa that has eliminated malaria but still has the highly efficient vector species and a human population that continues to live in poverty has a high outbreak risk.

The same is true for vectors of dengue and of leishmaniases. Invasive vector species that are extending their geographical range increase the outbreak risk in newly invaded areas or regions. For example, *An. stephensi* is a malaria vector that has recently invaded countries in the Horn of Africa and Sri Lanka, and *Ae. albopictus* is a vector of arboviral diseases that has recently invaded parts of Europe.

Fig. 5.9. Examples of the feasibility and measures required to prevent reintroduction of malaria at various levels of outbreak risk and importation risk



IRS: indoor residual spraying; LLIN: long-lasting insecticidal nets.

Source: Cohen et al. *(69)*. Reproduced under the Creative Commons Attribution 4.0 International License (https://creativecommons.org/licenses/by/4.0/).

It is essential that, once a disease has been eliminated or has ceased to be a public health problem, the country maintain its political commitment to preventing reintroduction of the disease by managing the factors that determine importation risk and outbreak risk.

- In a post-elimination situation, what are the roles of insecticides and of non-chemical vector control methods in reducing importation risk?
- In a situation in which malaria has ceased to be a public health problem, how could risk-reduction measures be justified in national budget allocation?

5.3.2 Managing the risks

As an island state, Mauritius provides a good example of the management of importation risk. The country receives many travellers, who are screened at the airports and seaports of entry and placed under surveillance for 42 days, during which blood smears may be taken if they came from a malaria-endemic country *(39)*. Those who test positive for a malaria parasite are given treatment, and their condition is monitored. Mauritian nationals traveling to malarious countries are given free prophylaxis by the Government to prevent them from returning with *Plasmodium* infection.

Outbreak risk is managed by a strong system of surveillance and response and by preventive measures to suppress local vector populations. After elimination of malaria, humans lose their partial immunity to malaria. Thus, a person infected with *Plasmodium* will immediately show symptoms of the disease, facilitating rapid detection of new malaria cases. In people with partial immunity, infection might occur without clear disease symptoms, making detection of new incident cases more difficult.

To reduce outbreak risk, a large proportion of cases of fever should be screened for malaria. In Mauritius, any malaria case that is detected is thoroughly investigated to determine whether it resulted from local transmission or was imported. Cases of local transmission prompt a rapid response of active case detection, treatment, health promotion and intensive vector control of an area within a 500-m radius of the place of transmission *(39)*.

It is also important to ensure that the vectorial capacity (i.e. the daily rate at which future inoculations arise from a currently infective case) is maintained at a low level with the use of long-term measures that prevent vector breeding and by promoting better housing, screening and personal protection (e.g. use of untreated nets) to reduce mosquito biting.

Sri Lanka was certified malaria-free in 2016. The country developed a national plan to sustain its malaria-free status by preventing reintroduction *(70)*. The plan included screening passengers at points of entry for fever and providing prophylactic chemotherapy for citizens travelling to malaria-endemic countries. The country realigned its entomological surveillance and vector control activities to the new situation. The methods and strategy of entomological surveillance conducted during the elimination phase were subsequently adapted to the requirements of the post-elimination phase. The methods included routine reports from sentinel sites, proactive spot checks, larval surveys and reactive spot checks in response to a detected case. The frequency and intensity of each sampling method was reoriented to prevention of reintroduction. National guidelines for entomological surveillance were revised, and staff trained. Another adaptation was targeting of vector surveillance and control. During malaria elimination, vector control operations were targeted to where malaria cases had been detected. In the post-elimination phase, with no indigenous malaria cases and only occasional introduced cases, malaria risk (rather than malaria cases) were targeted. Risks were mapped with entomological data, historical case data and environmental data (e.g. vegetation, water). Vector control action is therefore used proactively in high-risk locations and at sites to which cases are imported or introduced. The country is planning to adapt its methods further for use in areas at moderate risk.

– What are the advantages of a regional strategy for disease elimination (among neighbouring countries) versus a national strategy (with no collaboration with neighbouring countries)?

5.3.3 Cost

The cases of Mauritius and Sri Lanka show that, after elimination, a country may still require investment in infrastructure and staff to sustain its elimination status. The costs are not necessarily lower than those for malaria control in a pre-elimination stage. Keeping malaria out of a country's borders is a policy decision that demands continuous commitment of resources. The risk of importation into Mauritius was considerably lower than that of Zanzibar, another island attempting to eliminate malaria. In Sri Lanka, the investment in activities to prevent reintroduction of malaria, including vector control, was reported to be acceptable because the cost of allowing a malaria resurgence to occur would be much higher *(71)*.

– Why is it more difficult to convince decision-makers to prevent an outbreak as compared with controlling an outbreak?

Malaria is not the only infectious disease that affects travelling human populations. Emerging diseases such as dengue, chikungunya and West Nile fever should also be kept out of a country's borders. To increase the efficiency and cost-effectiveness of measures to manage importation risk, a multi-disease approach is required to prevention, detection and response. Preventive programmes for individual vector-borne diseases may not be financially sustainable for countries, but, when the work, expertise and infrastructure are combined for other emerging diseases, the chances that such a system could be sustained will increase.

The costs of keeping malaria and other vector-borne diseases out of a country should be compared with the positive economic and development effects for a country that remains malaria-free, including on foreign investment, productivity, tourism and trade.

Project assignment 5

Using your assessments under project assignments 1 and 2, review the prospect of elimination of one vector-borne disease in your country by answering the questions below. Obtain additional information as required. If your country is not at risk of vector-borne diseases, use the example of a neighbouring country with malaria.

1. First, conduct macro-level stratification of disease risk, as discussed in module 4. Do this by obtaining estimates of the average incidence of the selected vector-borne disease in each administrative unit (e.g. district).
2. Define several categories of incidence, such as low, medium and high. Draw a map of the country, with administrative borders, indicating the categories of stratification.
3. Briefly outline the national plan for control, elimination or prevention of reintroduction of the selected vector-borne disease. Describe whether and how the strategies and interventions are adapted to different levels of disease risk in each area, or whether one strategy applies to the whole country.
4. Discuss the prospect of elimination (or prevention of reintroduction, if appropriate) of the vector-borne disease in your country.
5. Discuss whether development of insecticide resistance in your country can be expected to undermine disease elimination in the near future.

References

1. Nájera JA. Malaria control: achievements, problems and strategies. Parassitologia. 2001;43(1–2):1–89. PMID:11921521.

2. Takken W, Snellen WB, Verhave JP, Knols BGJ, Atmosoedjono S. Environmental measures for malaria control in Indonesia – An historical review on species sanitation (Wageningen Agricultural University Research Papers 90-7]1990]). Wageningen: Department of Entomology, Wageningen Agricultural University; 1990 (https://edepot.wur.nl/282643).

3. Bradley DJ. Watson, Swellengrebel and species sanitation: environmental and ecological aspects. Parassitologia. 1994;36(1–2):137 (https://pubmed.ncbi.nlm.nih.gov/7898951/).

4. Najera JA, Gonzalez-Silva M, Alonso PL. Some lessons for the future from the global malaria eradication programme (1955–1969). PloS Med. 2011;8:e1000412. doi:10.1371/journal.pmed.1000412.
5. Sadasivaiah S, Tozan Y, Breman JG. Dichlorodiphenyltrichloroethane (DDT) for indoor residual spraying in Africa: How can it be used for malaria control? Am J Trop Med Hyg. 2007;77(6_Suppl):249–63 (https://pubmed.ncbi.nlm.nih.gov/18165500/).
6. MacDonald G. Epidemiological basis of malaria control. Bull World Health Organ. 1956;15:613–26 (https://iris.who.int/handle/10665/265759).
7. Litsios S. Re-imagining the control of malaria in tropical Africa during the early years of the World Health Organization. Malar J. 2015;14(1):1–9. doi:10.1186/s12936-015-0700-9.
8. Mendis K, Rietveld A, Warsame M, Bosman A, Greenwood B, Wernsdorfer WH. From malaria control to eradication: the WHO perspective. Trop Med Int Health. 2009;14(7):802–9. doi:10.1111/j.1365-3156.2009.02287.x.
9. From malaria control to malaria elimination: a manual for elimination scenario planning. Geneva: World Health Organization; 2014 (https://iris.who.int/handle/10665/112485).
10. Bruce-Chwatt LJ. Lessons learned from applied field research activities in Africa during the malaria eradication era. Bull World Health Organ. 1984;62(Suppl):19–29 (https://iris.who.int/handle/10665/264947).
11. Malaria eradication: benefits, future scenarios and feasibility. Geneva: World Health Organization; 2020 (https://iris.who.int/handle/10665/326551).
12. Kelly-Hope L, Ranson H, Hemingway J. Lessons from the past: managing insecticide resistance in malaria control and eradication programmes. Lancet Infect Dis. 2008;8(6):387–9. doi:10.1016/S1473-3099(08)70045-8.
13. Greenwood BM. Control to elimination: implications for malaria research. Trends Parasitol. 2008;24(10):449–54. doi:10.1016/j.pt.2008.07.002.
14. Moonasar D, Morris N, Kleinschmidt I, Maharaj R, Raman J, Mayet NT et al. What will move malaria control to elimination in South Africa? S Afr Med J. 2013;103(10):801–6. doi:10.7196/samj.7445.
15. Sabot O, Cohen JM, Hsiang MS, Kahn JG, Basu S, Tang L et al. Costs and financial feasibility of malaria elimination. Lancet. 2010;376(9752):1604–15. doi:10.1016/S0140-6736(10)61355-4.
16. Sabot O, Tulloch J, Basu S, Dyckman W, Moonasar D, Moonen B. Getting to zero. In: Feachem RGA, Phillips AA, G.A. T, editors. Shrinking the malaria map: a prospectus on malaria elimination. San Francisco (CA): The Global Health Group, Global Health Sciences, University of California; 2009:19–39 (https://shrinkingthemalariamap.org/sites/default/files/resources/AProspectusonMalariaElimination.pdf).
17. Bousema T, Griffin JT, Sauerwein RW, Smith DL, Churcher TS, Takken W et al. Hitting hotspots: spatial targeting of malaria for control and elimination. PLoS Med. 2012;9:e1001165. doi:10.1371/journal.pmed.1001165.
18. Global malaria control and elimination: report of a technical review. Geneva: World Health Organization; 2008 (https://iris.who.int/handle/10665/43903).
19. Eliminating malaria. Geneva: World Health Organization; 2016 (https://iris.who.int/handle/10665/205565).
20. World malaria report 2021. Geneva: World Health Organization; 2021 (https://iris.who.int/handle/10665/350147).
21. Global technical strategy for malaria: 2016–2030, 2021 update. Geneva: World Health Organization; 2021 (https://iris.who.int/handle/10665/342995).

22. Feachem RG, Chen I, Akbari O, Bertozzi-Villa A, Bhatt S, Binka F et al. Malaria eradication within a generation: ambitious, achievable, and necessary. Lancet. 2019;394(10203):1056–112. doi:10.1016/S0140-6736(19)31139-0.

23. Killeen GF. Following in Soper's footsteps: northeast Brazil 63 years after eradication of *Anopheles gambiae*. Lancet Infect Dis. 2003;3(10):663–6. doi:10.1016/s1473-3099(03)00776-x.

24. Lindsay SW, Adiamah JH, Miller JE, Armstrong JRM. Pyrethroid-treated bednet effects on mosquitoes of the *Anopheles gambiae* complex in the Gambia. Med Vet Entomol. 1991;5: 477–83. doi:10.1111/j.1365-2915.1991.tb00576.x.

25. Lengeler C. Insecticide-treated bednets and curtains for preventing malaria. Cochrane Database Syst Rev. 2004;2:CD000363. doi:10.1002/14651858.CD000363.pub2.

26. Smith TA, Leuenberger R, Lengeler C. Child mortality and malaria transmission intensity in Africa. Trends Parasitol. 2001;17(3):145–9. doi:10.1016/s1471-4922(00)01814-6.

27. Guidelines for malaria vector control. Geneva: World Health Organization; 2019 (https://iris.who.int/handle/10665/310862).

28. Peterson RKD, Barber LM, Schleier III JJ. Net risk: A risk assessment of long-lasting insecticide bed nets used for malaria management. Am J Trop Med Hyg. 2011;84(6):951–6. doi:10.4269/ajtmh.2011.11-0016.

29. Minakawa N, Dida GO, Sonye GO, Futami K, Kaneko S. Unforeseen misuses of bed nets in fishing villages along Lake Victoria. Malar J. 2008;7(165):58. doi:10.1186/1475-2875-7-165.

30. Tangena JAA, Hendriks CM, Devine M, Tammaro M, Trett AE, Williams I et al. Indoor residual spraying for malaria control in sub-Saharan Africa 1997 to 2017: an adjusted retrospective analysis. Malar J. 2020;19(1):1–15. doi:10.1186/s12936-020-03216-6.

31. MacDonald G. The epidemiology and control of malaria. London: Oxford University Press; 1957 (https://www.cabdirect.org/cabdirect/abstract/19582900392).

32. Environmental management for vector control: Fourth Report of the WHO Expert Committee on Vector Biology and Control (WHO Technical Report Series, No. 649). Geneva: World Health Organization; 1980 (https://iris.who.int/handle/10665/41404).

33. Keiser J, Singer BH, Utzinger J. Reducing the burden of malaria in different eco-epidemiological settings with environmental management: a systematic review. Lancet Infect Dis. 2005;5(11): 695–708. doi:10.1016/S1473-3099(05)70268-1.

34. Larval source management: a supplementary measure for malaria vector control: an operational manual. Geneva: World Health Organization; 2013 (https://iris.who.int/handle/10665/85379).

35. Fox T, Furnival-Adams J, Chaplin M, Napier M, Olanga EA. House modifications for preventing malaria. Cochrane Database Syst Rev. 2022;10:CD013398. doi:10.1002/14651858.CD013398.pub4.

36. Enayati A, Lines J, Maharaj R, Hemingway J. Suppressing the vector. In: Feachem RGA, Phillips AA, Targett GA, editors. Shrinking the malaria map: a prospectus on malaria elimination. San Francisco (CA): The Global Health Group, Global Health Sciences, University of California; 2009:143–54 (https://shrinkingthemalariamap.org/sites/default/files/resources/AProspectusonMalariaElimination.pdf).

37. Russell TL, Govella NJ, Salumi Aziz S, Drakeley CJ, Kachur SP, Killeen GF. Increased proportions of outdoor feeding among residual malaria vector populations following increased use of insecticide-treated nets in rural Tanzania. Malar J. 2011;10:80. doi:10.1186/1475-2875-10-80.

38. Killeen GF, Moore SJ. Target product profiles for protecting against outdoor malaria transmission. Malar J. 2012;11(1):17. doi:10.1186/1475-2875-11-17.

39. Tatarsky A, Aboobakar S, Cohen JM, Gopee N, Bheecarry A, Moonasar D et al. Preventing the reintroduction of malaria in Mauritius: a programmatic and financial assessment. PLoS One. 2011;6(9):e23832. doi:10.1371/journal.pone.0023832.

40. Hemingway J. The role of vector control in stopping the transmission of malaria: threats and opportunities. Phil Trans R Soc B Biol Sci. 2014;369(1645):20130431. doi:10.1098/rstb.2013.0431.

41. Dondorp AM, Ringwald P, Krishna S, Kremsner PG, Bensch S, Hellgren O et al. Artemisinin resistance is a clear and present danger. Antimicrob Agents Chemother. 2013;57:914–23. doi:10.1016/j.pt.2013.05.005.

42. Global plan for artemisinin resistance containment. Geneva: World Health Organization; 2011 (https://iris.who.int/handle/10665/44482).

43. Technical expert group meeting on intermittent preventive treatment in pregnancy (IPTp), Geneva, 11–13 July 2007. Geneva: World Health Organization; 2007 (https://iris.who.int/handle/10665/43892).

44. Wilson AL, Courtenay O, Kelly-Hope LA, Scott TW, Takken W, Torr SJ et al. The importance of vector control for the control and elimination of vector-borne diseases. PLoS Negl Trop Dis. 2020;14(1):e0007831. doi:10.1371/journal.pntd.0007831.

45. Lun ZR, Wu MS, Chen YF, Wang JY, Zhou XN, Liao LF et al. Visceral leishmaniasis in China: an endemic disease under control. Clin Microbiol Rev. 2015;28(4):987–1004. doi:10.1128/CMR.00080-14.

46. Rijal S, Sundar S, Mondal D, Das P, Alvar J, Boelaert M. Eliminating visceral leishmaniasis in South Asia: the road ahead. BMJ. 2019;364:k5224. doi:10.1136/bmj.k5224.

47. Singh OP, Hasker E, Boelaert M, Sundar S. Elimination of visceral leishmaniasis on the Indian subcontinent. Lancet Infect Dis. 2016;16(12):e304–9. doi:10.1016/S1473-3099(16)30140-2.

48. Ichimori K, King JD, Engels D, Yajima A, Mikhailov A, Lammie P et al. Global programme to eliminate lymphatic filariasis: the processes underlying programme success. PLoS Negl Trop Dis. 2014;8(12):e3328. doi:10.1371/journal.pntd.0003328.

49. Lymphatic filariasis. Geneva: World Health Organization; 2022 (https://www.who.int/news-room/fact-sheets/detail/lymphatic-filariasis).

50. Lymphatic filariasis: practical entomology. A handbook for national lymphatic filariasis elimination programmes. Geneva: World Health Organization; 2013 (https://iris.who.int/handle/10665/87989).

51. Hairston NG, de Meillon B. On the inefficiency of transmission of *Wuchereria bancrofti* from mosquito to human host. Bull World Health Organ. 1968;38(6):935 (https://pubmed.ncbi.nlm.nih.gov/4235739/).

52. Ottesen EA. Lymphatic filariasis: treatment, control and elimination. Adv Parasitol. 2006;61:395–441. doi:10.1016/S0065-308X(05)61010-X.

53. Krishnamoorthy K, Rajendran R, Sunish I, Reuben R. Cost-effectiveness of the use of vector control and mass drug administration, separately or in combination, against lymphatic filariasis. Ann Trop Med Parasitol. 2002;96:S77–90. doi:10.1179/000349802125002428.

54. Bockarie MJ, Pedersen EM, White GB, Michael E. Role of vector control in the global program to eliminate lymphatic filariasis. Annu Rev Entomol. 2009;54:469–87. doi:10.1146/annurev.ento.54.110807.090626.

55. Pedersen EM, Mukoko DA. Impact of insecticide-treated materials on filaria transmission by the various species of vector mosquito in Africa. Ann Trop Med Parasitol. 2002;96(Suppl.2):S91–5. doi:10.1179/000349802125002437.

56. Kelly-Hope LA, Molyneux DH, Bockarie MJ. Can malaria vector control accelerate the interruption of lymphatic filariasis transmission in Africa; capturing a window of opportunity? Parasites Vectors. 2013;6(1):1–12. doi:10.1186/1756-3305-6-39.

57. Curtis C, Malecela-Lazaro M, Reuben R, Maxwell C. Use of floating layers of polystyrene beads to control populations of the filaria vector *Culex quinquefasciatus*. Ann Trop Med Parasitol. 2002;96: S97–104. doi:10.1179/00034980212500244.

58. Achee NL, Gould F, Perkins TA, Reiner Jr RC, Morrison AC, Ritchie SA et al. A critical assessment of vector control for dengue prevention. PLoS Negl Trop Dis. 2015;9(5):e0003655. doi:10.1371/journal.pntd.0003655.

59. Ooi EE, Goh KT, Gubler DJ. Dengue prevention and 35 years of vector control in Singapore. Emerg Infect Dis. 2006;12(6):887–93. doi:10.3201/10.3201/eid1206.051210.

60. Kourí G, Guzmán MG, Valdés L, Carbonel I, del Rosario D, Vazquez S et al. Reemergence of dengue in Cuba: a 1997 epidemic in Santiago de Cuba. Emerg Infect Dis. 1998;4(1):89. doi:10.3201/eid0401.980111.

61. Nam VS, Yen NT, Duc HM, Tu TC, Thang VT, Le NH et al. Community-based control of *Aedes aegypti* by using *Mesocyclops* in southern Vietnam. Am J Trop Med Hyg. 2012;86(5):850–9. doi:10.4269/ajtmh.2012.11-0466.

62. Massad E. The elimination of Chagas' disease from Brazil. Epidemiol Infect. 2008;136(9):1153–64. doi:10.1017/S0950268807009879.

63. Schofield CJ, Jannin J, Salvatella R. The future of Chagas disease control. Trends Parasitol. 2006;22(12):583–8. doi:10.1016/j.pt.2006.09.011.

64. Martins-Melo FR, Ramos Jr AN, Alencar CH, Heukelbach J. Prevalence of Chagas disease in Brazil: a systematic review and meta-analysis. Acta Trop. 2014;130:167–74. doi:10.1016/j.actatropica.2013.10.002.

65. Brattig N W, Cheke RA, Garms R. Onchocerciasis (river blindness)–more than a century of research and control. *Acta Tropica* 2021;*218:*105677.

66. Smith DL, Smith TA, Hay SI. Measuring malaria for elimination. In: Feachem RGA, Phillips AA, Targett GA, editors. Shrinking the malaria map: a prospectus on malaria elimination. San Francisco (CA): The Global Health Group, Global Health Sciences, University of California; 2009:108–25 (https://shrinkingthemalariamap.org/sites/default/files/resources/AProspectusonMalariaElimination.pdf).

67. Hutchinson RA, Bayoh MN, Lindsay SW. Risk of airport malaria in the UK. Eur Mosq Bull. 2005;19:12–3 (https://www.cabdirect.org/cabdirect/abstract/20053077076).

68. Siala E, Gamara D, Kallel K, Daaboub J, Zouiten F, Houzé S, et al. Airport malaria: report of four cases in Tunisia. Malar J. 2015;14(1):42. doi:101186/s12936-015-0566-x.

69. Cohen JM, Smith DL, Vallely A, Taleo G, Malefoasi G, Sabot O. Holding the line. In: Feachem RGA, Phillips AA, Targett GA, editors. Shrinking the malaria map: a prospectus on malaria elimination. San Francisco (CA): The Global Health Group, Global Health Sciences, University of California; 2009:40–60 (https://shrinkingthemalariamap.org/sites/default/files/resources/AProspectusonMalariaElimination.pdf).

70. van den Berg H, Manuweera G, Marasinghe M. Integrated vector management for control, elimination and prevention-of-reintroduction of malaria in Sri Lanka: a historical review. In: Koenraadt CJM, Spitzen J, Takken W, editors. Innovative strategies for vector control Progress in the global vector control response. Ecology and control of vector-borne diseases. Wageningen: Wageningen Academic Publishers; 2021. doi:10.3920/978-90-8686-895-7.

71. Shretta R, Baral R, Avanceña AL, Fox K, Dannoruwa AP, Jayanetti R et al. An investment case to prevent the reintroduction of malaria in Sri Lanka. Am J Trop Med Hyg. 2017;96(3):602–15. doi:10.4269/ajtmh.16-0209.

Recommended reading

Feachem RG, Chen I, Akbari O, Bertozzi-Villa A, Bhatt S, Binka F et al. Malaria eradication within a generation: ambitious, achievable, and necessary. Lancet, 2019;394:1056–112. doi: 10.1016/S0140-6736(19)31139-0 *(22)*.

Mnzava AP, Macdonald MB, Knox TB, Temu EA, Shiff CJ. Malaria vector control at crossroads: public health entomology and the drive to elimination. Trans R Soc Trop Med Hyg. 2014;108:550–4. doi:10.1093/trstmh/tru101.

Rijal S, Sundar S, Mondal D, Das P, Alvar J, Boelaert M. Eliminating visceral leishmaniasis in South Asia: the road ahead. BMJ. 2019;364:k5224. doi: 10.1136/bmj.k5224 *(46)*.

6

Control of vectors and pests in urban environments

Contents

Learning objectives

By the end of this module, students should be able to:

- describe and identify the major types of urban pests and strategies for their control; and
- give examples of urban vector control and critically comment on differences from vector control in rural contexts.

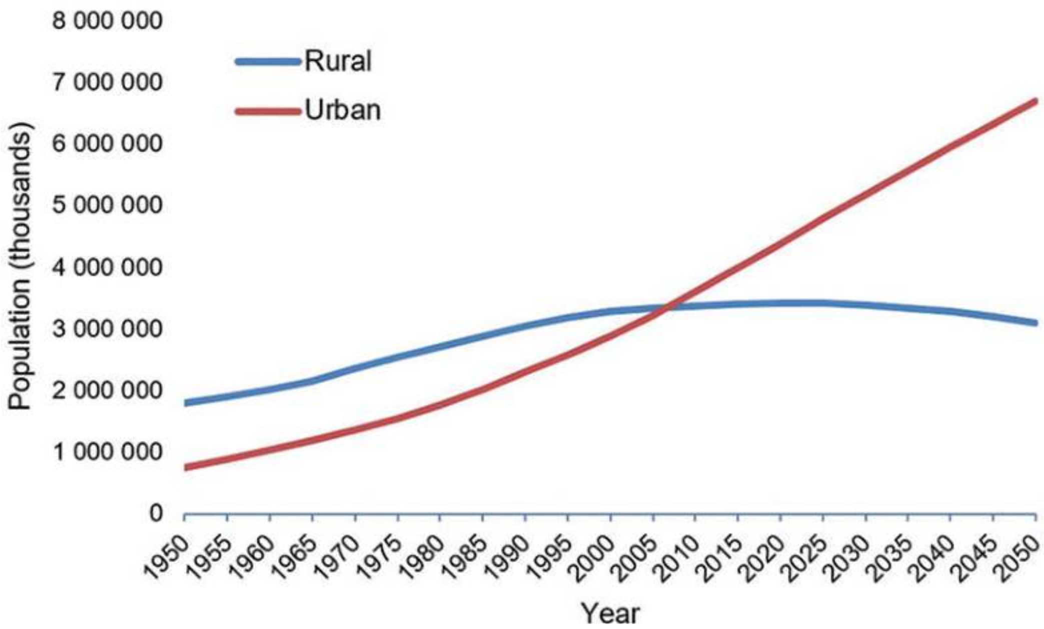
6.1 Urban vectors and pests

6.1.1 Urbanization

Urbanization is a well-recognized phenomenon throughout the developing world. In past decades, people left the countryside *en masse* for cities in search of work and settled permanently. The cities in most low- and middle-income countries could not accommodate the huge influx of people, and they often grew without adequate planning, leaving many people in poor living conditions and without drinking-water or sanitation *(1)*.

Urban areas are defined variously. National statistical offices apply their own definitions. Some use administrative boundaries, others population density and others the absence of activities such as agriculture. In less-developed regions, the total human population of urban areas is fast approaching that living in rural areas (Fig. 6.1), while, before 1985, the urban population was less than half that of rural areas. It has been estimated that the urban population in less-developed regions will continue to increase, while that in rural areas will gradually decrease. This striking trend indicates that the control of vector-borne disease in urban contexts should increasingly be emphasized in public health risk management.

Fig. 6.1. Population development and prognosis in urban and rural regions



Source: https://population.un.org/wup/Download/

Keiser J, Utzinger J, De Castro MC, Smith TA, Tanner M, Singer BH. Urbanization in sub-Saharan Africa and implication for malaria control. Am J Trop Med Hyg. 2004;71(Suppl):118–27 (https://pubmed.ncbi.nlm.nih.gov/15331827) *(2)*.

6.1.2 Urban characteristics

Urbanization changes the environment in several ways, some of which are positive and some negative. Urban environments create opportunities for pests and vectors to breed that are different from those in rural environments, often resulting in differences in the spectrum and epidemiology of vector-borne diseases (Table 6.1).

Table 6.1. Urban characteristics and their implications for vector-borne diseases

Urban (vs rural) characteristic	Implications for vector-borne diseases
Better socioeconomic conditions	Lower risk of morbidity
Better access to health services	Better health care
Close proximity of people	Efficient transmission from person-to-person
Increased mobility and movements	Efficient spread of disease
Artificial, human-made environment	Adapted vector breeding behaviour
Little diversity of breeding opportunities for vectors	Few but common vector species
Humans as the only common host	Efficient spread of disease; fewer zoonotic diseases

Sources: adapted from Lines et al. *(1)* and Knudsen & Sloof *(3)*.

Urban development programmes can improve living conditions over rural conditions, including better housing, water supply, drainage and sanitation, more income due to opportunities for education and jobs, and better access to public services. Nevertheless, pests such as rodents may remain a problem, despite good infrastructure and sanitation. Expansion of shanty towns and slums often results in rubbish accumulation, poor sanitation and hygiene, a poor water supply and poor drainage; these conditions are favourable for the breeding of vectors of several diseases. City dwellers may live close to health facilities, but the capacity of municipal health services may not keep pace with population growth in some cities.

The high concentrations of people in urban environments facilitates transmission of disease pathogens from person to person, thus promoting the spread of disease, including emerging diseases. In the urban context, vector species may have fewer opportunities than in rural areas to feed on wild and domestic animals. Thus, zoonotic diseases may be less common in the urban than in the rural context. Also, in urban areas, there are fewer animals that could serve as dead-end hosts; the hosts for biting mosquitoes are mainly humans, which could increase the spread of disease. Migration from urban to rural areas can expose people to each other's diseases, potentially leading to outbreaks. Visits of city dwellers to rural areas may expose them to malaria, resulting in morbidity.

Urbanization in Africa has generally resulted in improvements in a number of health indicators. Thus, the child mortality rate is lower, vaccine coverage is higher, bed net ownership is higher, and access to health facilities is better than in rural areas (Table 6.2).

Table 6.2. Health indicators in urban and rural environments in sub-Saharan Africa

Health indicator	Urban	Rural
Childhood mortality (deaths per 1000)	57.3	83.1
Nutritional status (maternal body mass index)	22.9	21.4
Vaccine coverage (% of children)	57.9	38.5
Average distance to health facility (km)	16	47.6
Households with insecticide-treated nets (%)	32.9	10.1

Source: Hay et al. *(4)*.

6.1.3 Urban pests

A pest is defined as any species, strain or biotype of plant, animal or pathogenic agent that is injurious to plants and plant products, materials or environments. They include vectors of parasites or pathogens of human and animal disease and animals that are a public health nuisance *(5)*. In public health, a pest is an organism considered to be injurious or unwanted to humans, causing discomfort or health problems because it invades people's domestic or work environment. A number of domestic pests have adapted well to the human environment and to human behaviour and are consequently a major urban problem *(6)*. Several categories of urban pests have been identified: cockroaches, fleas, human body lice, flies, bedbugs, house dust mites, rodents and mosquitoes (Table 6.3)

Table 6.3. Categories of common urban pests, with their public health importance

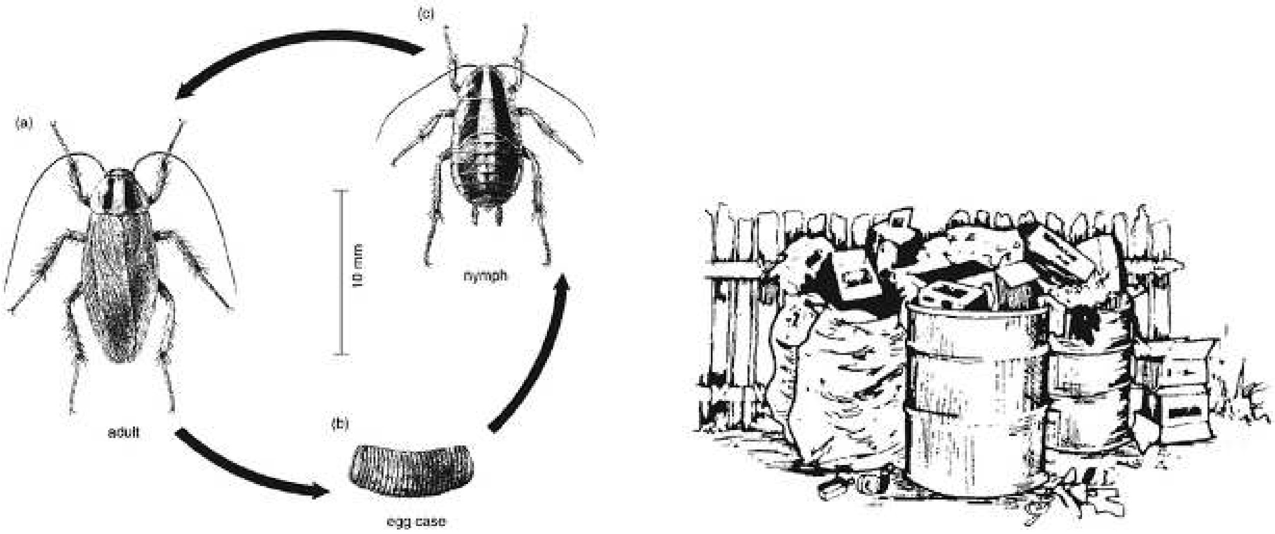
Pest	Public health effect
Cockroaches	Allergic reactions, asthma, food contamination, disease transmission, anxiety
Fleas	Skin irritation; vectors of bubonic plague and murine typhus
Human body lice	Itching and skin irritation; vector of typhus
Flies	Nuisance, food contamination, mechanical vectors of gastrointestinal and eye diseases
Mosquitoes	Nuisance; some species are vectors of disease pathogens
Bed bugs	Discomfort, skin reactions
House dust mites	Allergic reactions
Rodents	Nuisance, food spoilage; carrier and reservoir of zoonotic diseases

Sources: Adapted from Bonnefoy et al. *(6)* and Rozendaal *(7)*.

Cockroaches

Cockroaches are one of the most common and most objectionable house pests (Fig. 6.2). They are a source of anxiety and a health hazard for people living in infested homes. Health problems due to cockroaches include allergic reactions, infection with pathogenic organisms and contamination of food *(6)*. Cockroach infestation causes people to apply insecticides frequently in their home environment, resulting in exposure to pesticides and associated illness. Stigmatization associated with cockroaches also results in high pesticide use. "Street pesticides" and illegal pesticides are often used to control cockroaches, which are resistant to products registered for domestic use.

Fig. 6.2. Life cycle of the German cockroach (left), with breeding habitat (right)



Source: Rozendaal *(7)*.

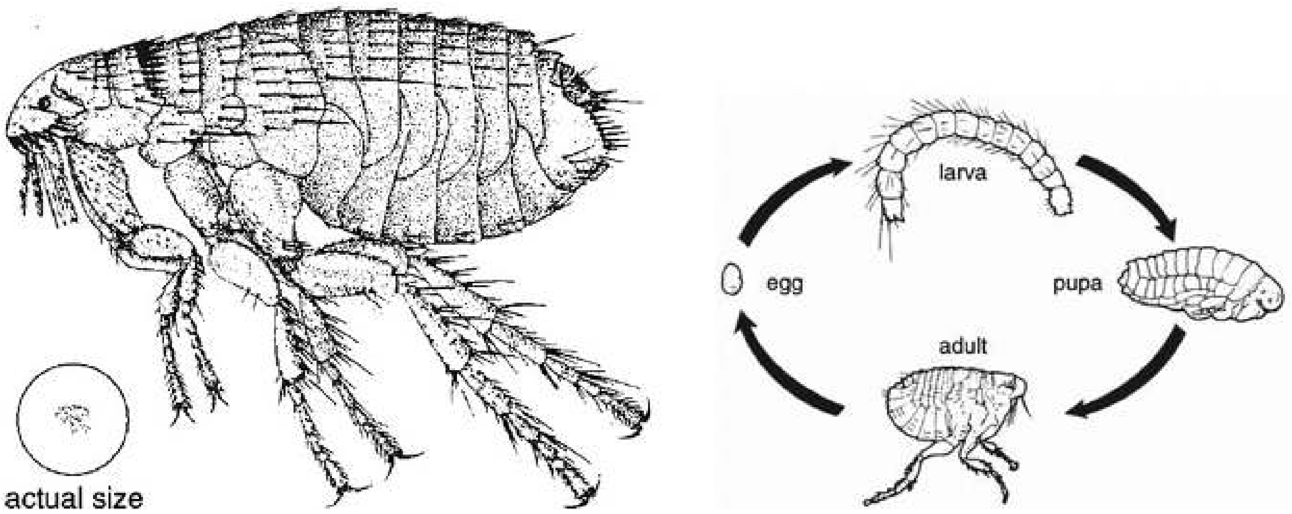
Cockroaches produce significant amounts of allergens in so-called "cockroach dust" *(6)*, which can remain active for 6 months or longer. Even low cockroach densities produce enough allergens to cause allergic reactions, and rigorous cleaning or suppression of cockroach density may not be sufficient to alleviate the problem.

Another public health concern is the role of cockroaches in food contamination and disease transmission. Cockroaches feed near human and animal waste and may therefore be vectors of human diseases. Cockroaches are often infested with microbial pathogens, particularly bacteria, including species of *Salmonella*, and also species of fungi, viruses, protozoa and helminths *(6)*. The most common species are the German cockroach, the American cockroach and the oriental cockroach *(6)*.

Fleas

Flea species of public health concern are rodent fleas (*Xenopsylla* spp.) and cat fleas (*Ctenocephalides* spp.) *(6)*. Adult fleas are 1–4 mm long and feed exclusively on blood. They are found mainly in the hair or fur of their host (Fig. 6.3). Fleas cannot fly but have long legs with which they can jump. Flea species are divided into host fleas and nest fleas according to their strategy for feeding. Host fleas hardly ever leave the acquired host that provides them with blood meals and shelter. Nest fleas live inside the nest of their host (e.g. rodents) and approach the host only to obtain a blood meal. Flea larvae do not feed directly on blood but on the excreta of adult fleas, which consist of partially digested host blood. Flea bites result in itching and skin irritation. Rodent fleas, most of which are nest fleas, are the vectors of serious zoonotic bacterial diseases, namely bubonic plague and murine typhus. Cat fleas are a common urban pest, infesting pet animals and causing discomfort and irritation in humans.

Fig. 6.3. The cat flea (left) and its life cycle (right)



Source: Rozendaal *(7)*.

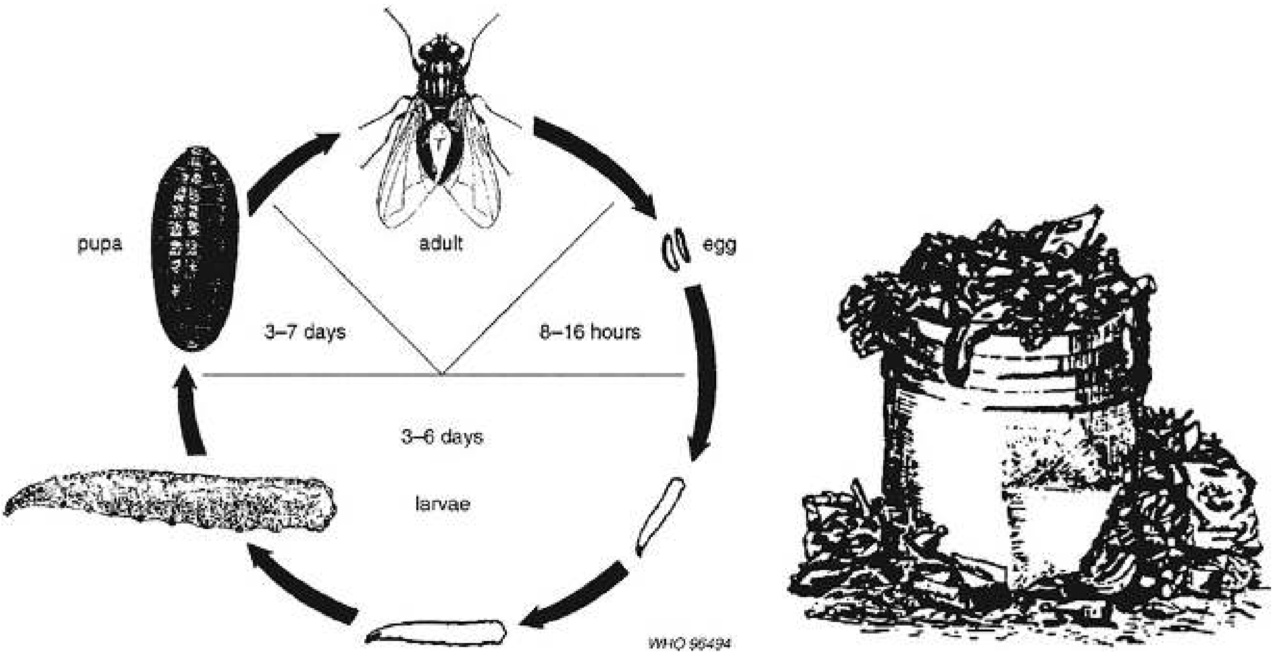
Human body lice

Lice are small bloodsucking insects that live as ectoparasites on the surface of mammals and birds. Three species have adapted to humans and occur worldwide: the head louse, the body louse and the pubic louse. The head louse is the most common and lives on the heads mainly of children, where the eggs, or nits, are glued to the base of a hair. Head lice are spread by close physical contact between people or by shared use of a comb. Lice infestations can cause severe irritation and itching. Generally, however, louse infestation can go unnoticed for weeks or months. Human body lice can also serve as vectors of disease pathogens, most notably typhus, as demonstrated in major epidemics in the past *(8)*. This disease is now treatable with antibiotics.

Flies

Houseflies (*Musca domestica*) live in close association with humans, feeding on their food and their organic waste (Fig. 6.4). Houseflies thrive especially in warm climates and high humidity. Animal dung attracts flies, which use dung heaps as food and breeding sites, resulting in huge numbers of flies. In warmer climates, a related species, filth flies (*M. sorbens*), is also common. Flies lay their eggs in masses in organic material, where the young maggots quickly hatch and feed. The pupa forms a strong capsule inside which it pupates. Flies are a major nuisance pest. As they feed on both food and waste, they can efficiently carry a number of diseases, most notably gastrointestinal diseases. Filth flies can also cause eye infections, including trachoma blindness, which is distributed widely in the tropics and subtropics.

Fig. 6.4. Life cycle of a housefly (left) and its breeding habitat (right)



Source: Rozendaal *(7)*.

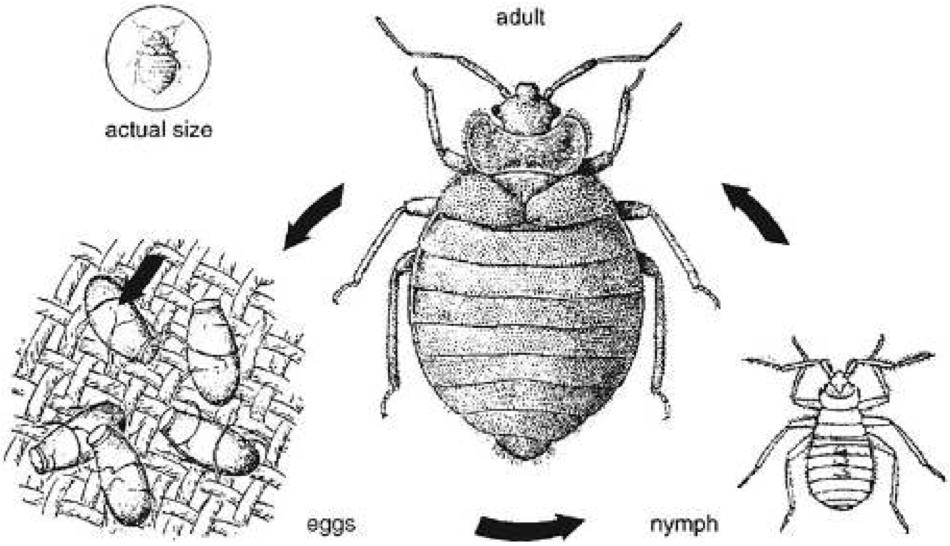
Mosquitoes

Mosquitoes can be a considerable nuisance in many parts of the world. Mosquito species are also the vectors of several human diseases, as discussed in previous sections. In countries with a temperate climate, mosquitoes are more important as a nuisance than as disease vectors. Especially, in areas near marshlands and in cities with poor drainage or areas prone to flooding, mosquitoes can be abundant, causing substantial discomfort to local residents.

Bedbugs

Bedbugs are flat, oval, reddish-brown bugs 6–7 mm long (Fig. 6.5). The adults and nymphs are wingless. Bedbugs feed on the blood of mammals or birds. Bedbug infestation has become an increasing problem in Australia and in some countries in Europe and North America, possibly because of increased travel for business and holidays, which may result in transport of bed bugs in luggage. Blood-feeding occurs at night, and the bites can cause discomfort and allergic skin reactions. Frequent biting can increase sensitivity, which may include nervousness, agitation and sleeplessness. Airborne allergens produced by bedbugs may cause asthma. A number of human pathogens have been isolated from bedbugs; however, it is not known whether the insect can act as a vector or a mechanical transmitter of human disease agents.

Fig. 6.5. Life cycle of a bedbug

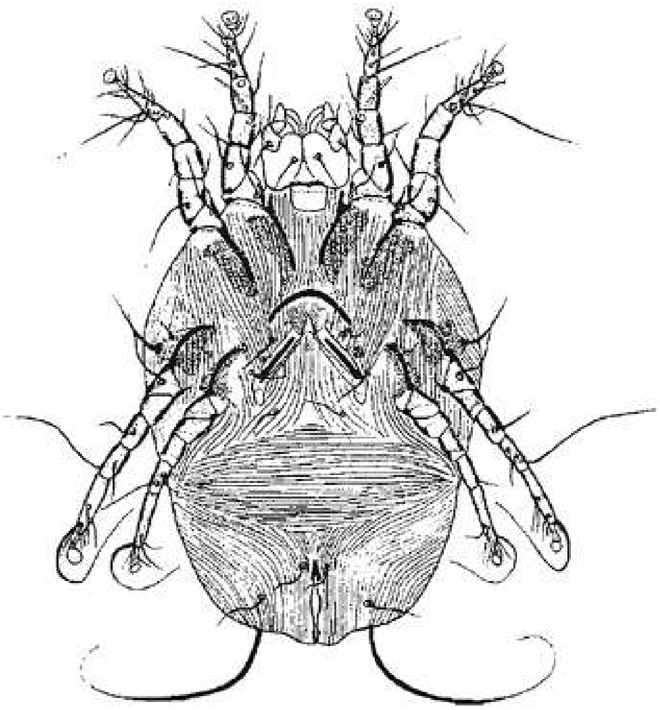


Source: Rozendaal *(7)*.

House dust mites

House dust mites, which are about 0.3 mm long, are associated with human dwellings all over the world (Fig. 6.6). The mites feed on scales of human skin present in bedding, mattresses and carpets. They are not harmful and do not transmit disease. Their public health importance is due to the allergens they produce, which that can result in several diseases, notably asthma. For their survival, dust mites are highly sensitive to a particular combination of temperature and relative humidity.

Fig. 6.6. House dust mite



Source: Rozendaal *(7)*.

Rodents

There are many species of rodent, but only a few are related to human activities and live in or around human dwellings. Major pest species are the brown rat, the roof rat and the house mouse, which infest houses and feed on food items. Not only do they damage food items, field crops, post-harvest products and property but they can also act as reservoirs of several zoonotic diseases *(9)*, including murine typhus, plague and salmonellosis. Rodents are hosts of ectoparasites (ticks, mites, fleas, lice) that can serve as vectors for these zoonotic disease pathogens to humans or domestic animals. Other types of rodent, such as squirrels and rabbits, may also serve as reservoirs for various zoonotic diseases, and human contact with these animals can result in disease outbreaks. Mice can harbour zoonotic pathogens, although major zoonotic outbreaks have mainly been associated with rats. An additional health concern is that rodents can produce allergens that cause asthma.

- What is the current situation of household pests in urban areas in your country? Which pests cause major problems?
- Which sections of society (e.g. according to socioeconomic background) suffer most from domestic pests in your country?

6.1.4 Urban vector-borne diseases

Several vector species are associated with the urban environment. *Ae. aegypti* and *Ae. albopictus* are urban vectors of arboviral diseases such as dengue, chikungunya, Zika and yellow fever. Dengue is strongly associated with urban or peri-urban environments. Urban centres often have many small artificial receptacles filled with water, either in cavities in the built environment, discarded plastic bottles, tins, used tyres and other objects that accumulate water after rains, or flowerpots, vases and water storage tanks. These small water bodies are favoured breeding sites for *Aedes* mosquitoes, which can transmit the arboviruses.

Cx. quinquefasciatus, a mosquito vector of lymphatic filariasis and several viral diseases, prefers to breed in polluted water and liquid waste drainage, which are generally more common in urban environments due to the concentration of people. Urbanization has been accompanied by an increase in lymphatic filariasis, except in West Africa, where *Cx. quinquefasciatus* does not transmit this disease *(10)*.

Disease vectors can adapt their behaviour to conditions created by humans in the urban environment. *Aedes* mosquitoes have adapted to breed in artificial containers, such as plastic bottles and used tyres. *Ae. aegypti* originally bred exclusively in natural habitats such as water-filled tree holes and leaf axils but has adapted to breeding in a variety of human-made containers and commonly breeds inside houses. *Culex* mosquitoes have adapted to breed in pit latrines, where they can reproduce in large numbers.

In regions where lymphatic filariasis is transmitted mainly by *Anopheles* mosquitoes (e.g. West Africa), the disease is confined mainly to rural environments. Cutaneous leishmaniasis can be common in urban areas. In Latin America, Chagas disease has been associated with poor housing conditions in urban centres.

Malaria has been associated with rural environments because of the preference of *Anopheles* mosquitoes that transmit the *Plasmodium* parasite to breed in clear, unpolluted, stagnant water bodies, which are common in rural but not in urban areas, where standing water is often too polluted for malaria vectors to breed. Consequently, malaria has long been a health problem mainly in the rural environment, although not all rural environments are malaria endemic. In one study, a consistent pattern of increased urbanization was associated with decreasing malaria transmission during the past century *(11)*, and the trends to urbanization in many countries may result in a further decrease in the prevalence of malaria. There are, however, indications that urban malaria may increase in importance (see, e.g. section 6.4).

Malaria entered many Indian cities with a piped water supply *(12)*, as the vector *An. stephensi* commonly breeds in overhead water storage tanks and other household water containers in cities, resulting in high vector densities and the spread of malaria. In Mauritius, *An. arabiensis* breeds on the flat roofs of concrete houses in standing water after rains *(13)*.

The penetration of malaria in African cities is facilitated by the efficiency of African vectors, where a small local population of vector mosquitoes can maintain the transmission cycle. The density of *Anopheles* is highest at the edges of African cities and decreases gradually towards the centre, although very low densities of these efficient vectors can still maintain malaria transmission. These observations explain why urban malaria is a problem in Africa, even when suitable vector breeding sites are scarce.

Expanding cities often contain mosaic patterns or zones of urban farming and horticulture, and these gardens provide new mosquito breeding sites, including for malaria vectors. The role of urban farming in the prevalence and spread of vector-borne diseases is still largely contested. It has been suggested that certain crop systems and agricultural practices and the proximity of people's houses to ponds, may increase the risk of malaria in urban areas in Africa. In Nigeria, *An. gambiae* appears to have adapted to breeding in polluted water bodies in Lagos, which could increase the burden of urban malaria.

– Do the urban conditions in your country prevent or encourage the breeding of disease vectors (e.g. dengue, malaria, lymphatic filariasis)?

6.2 Pest control methods

Preventive or control actions are essential to control common urban pests and the infectious diseases they can spread, some of which are effective against more than one pest (Table 6.4). In households, chemical pesticides should be used as the method of last resort, because of the risks of human exposure by contact or contamination of food stuffs and because pests can develop resistance to the pesticides used.

Table 6.4. Fast-acting anticoagulant rodenticides commonly used for control of rodents

Rodenticide	Formulation	Effect	Concentration (%)	WHO hazard classification of active ingredient
Brodifacoum	Bait, wax block	Anticoagulant[a]	0.005	Ia
Bromadiolone	Bait, oil-based, wax Block, powder concentrate	Anticoagulant[a]	0.005	Ia
	Tracking powder		0.1–2.0	
Bromethalin	Bait	Acute	0.005–0.01	Ia
Calciferol	Bait	Sub-acute	0.075–0.10	NA

(Continued)

Table 6.4. (Continued)

Rodenticide	Formulation	Effect	Concentration (%)	WHO hazard classification of active ingredient
Chlorophacinone	Bait	Anticoagulant	0.005–0.05	Ia
	Oil-based concentrate		0.25	
	Tracking powder		0.2	
Coumatetralyl	Wax block, bait	Anticoagulant	0.0375	Ib
	Tracking powder		0.75	
Difenacoum	Wax block, bait	Anticoagulant[a]	0.005	Ia
Difethialone	Wax block, bait	Anticoagulant[a]	0.0025	Ia
Diphacinone	Powder concentrate	Anticoagulant	0.1–0.5	Ia
	Water-soluble concentrate		0.1–2.0	
	Bait		0.005–0.05	
Flocoumafen	Wax briquette	Anticoagulant[a]	0.005	Ia
Warfarin	Concentrate	Anticoagulant	0.5–1.0	Ib
	Tracking powder, bait		0.025–0.05	
Zinc phosphide	Bait	Acute	1–5	Ib

Not all the compounds are registered for use in all countries *(9)*.

Ia: extremely hazardous; Ib: highly hazardous; NA: not available.

[a] Second-generation anticoagulant.

Most if not all problems associated with pests are directly related to human activity and behaviour, and therefore methods to prevent or control such problems depend mainly on improved measures at household or community level. Certain pests (e.g. rats, flies) readily move among houses in a community and thus require community-wide control.

Control measures should involve the community from the beginning. Educational and information campaigns for the public are therefore a major component of a government's strategy to control urban pests. People may not be aware of the influence of their domestic conditions, physical structures and behaviour on providing suitable conditions for pests to thrive and to become a nuisance or a public health concern. Intensified pest control involving the health sector and other relevant sectors is generally required when pests are more than a nuisance and serve as vectors, hosts or reservoirs of infectious diseases.

Pesticides and their application for the control of vectors and pests of public health importance, 2006. Geneva: World Health Organization; 2006 (https://iris.who.int/handle/10665/69223). *(9)*

6.2.1 Cockroach control

Control of cockroach infestation begins with ensuring the cleanliness of the domestic environment. The presence of adult insects could indicate newly arrived individuals, but the presence of nymphs indicates that a colony has been established. Preventive measures include removal of food sources, shelter and entry points. As pests like cockroaches need water to thrive, removal of water sources (e.g. repairing leaks, removing standing water) could contribute to control of these pests. Cleanliness and storage of food items in refrigerators or insect-proof cabinets are important preventive measures. Prevention should be extended to the outdoor environment to prevent the insects from entering houses. In urban environments, a house may be re-infested from neighbouring houses.

Effective control measures include bait-trapping, use of repellents and application of insecticides. Bait-trapping devices attract insects and trap and kill them *(14)*. The advantage of insecticidal baits over insecticide spraying is that much less insecticide is used, and baits are less toxic and odourless. The active ingredients used in baits include boric acid, carbamates, organophosphates, imidacloprid and fipronil. Effective baiting depends on where the baits are placed and requires knowledge about cockroach behaviour *(14)*. Cockroaches may become resistant to the insecticides used in baits, and they can adapt to baits by avoiding them. Repellents can be used in the hiding places of cockroaches. Spraying of insecticides is only partially effective because cockroach populations rapidly develop resistance. Moreover, some chemicals have a repellent effect on cockroaches, thus averting contact, and, hence, do not have a strong killing effect. Use of insecticides in the domestic environment can increase human health risks, through contact with the insecticide or through ingestion with food.

A combination of preventive and control measures, in integrated pest management, is usually the best approach to sustainable control, because it reduces reliance on insecticides and thus the risk of insecticide resistance. As cockroaches are clearly associated with the living environments of humans and animals, including rodents, control should be conducted by communities to ensure area-wide benefits and to prevent rapid re-invasion of cleaned houses. Unfortunately, there are few examples of community-based cockroach control in developing countries.

In buildings in housing developments in New York City (NY), USA, one integrated pest management intervention was more effective than regular application of pesticides in managing cockroaches *(15)*. The intervention consisted of mechanical and steam cleaning with soap, latex to seal crevices and baits with boric acid to kill the remaining cockroaches. Integrated pest management resulted in fewer cockroaches and lower levels of cockroach allergen in kitchens and bedrooms. Moreover, less pesticide was used than in the conventional control strategy.

The species of cockroach must be known, as some methods are effective only against a particular species. Lessons on domestic pests in school curricula can encourage participation in community pest control.

6.2.2 Flea control

For effective flea control, its life cycle should be understood (see Box 6.1). Nuisance fleas can be controlled by applying repellents to the skin or clothing and cleaning floors with a vacuum cleaner or swept and washed with detergent to remove eggs, larvae and pupal cocoons *(7)*. The tool used to remove eggs must be cleaned well, preferably outdoors. Application of insecticides to crevices in infested rooms can provide temporary relief, but flea populations recover quickly after spraying. In the control of fleas on cats and dogs, care should be taken when using insecticidal products such as shampoos or insecticidal collars, as these products are a hazard, especially for young children. Mechanical tools such as flea combs and other pet grooming tools should be used in integrated pest management, with use of chemical insecticides as a last resort.

Box 6.1. Flea life cycle

The female flea prefers to lay her eggs not on a dog or cat but in dark, damp places such as cracks in a floor or a corner. Most of the few eggs that are laid on a host animal soon fall off. The flea lays up to 20 eggs at a setting and may deposit as many as 400 during her lifetime.

Most flea eggs are laid when the humidity is high and temperatures are moderate. It takes only about 1 week for the eggs to hatch into small, white, toothy-mouthed worms. This larval form feeds on faeces, debris, hair and vegetation. Its growth cycle, depending on environmental conditions, is 10–200 days. Each larva then spins a cocoon and pupates for a period of 7 days to 1 year. Thus, one pair of adult fleas can result in the presence of the three stages of offspring – egg, larva, and adult – in a house for almost 2 years.

Source: Downs *(16)*.

When fleas are vectors of zoonotic diseases to humans, intensified control is required. Thus, in the event of an epidemic of bubonic plaque or typhus, control should be conducted on two fronts: insecticidal control of rodent fleas in the nests and burrows of rodent colonies and active control of rodent populations.

6.2.3 Control of human body lice

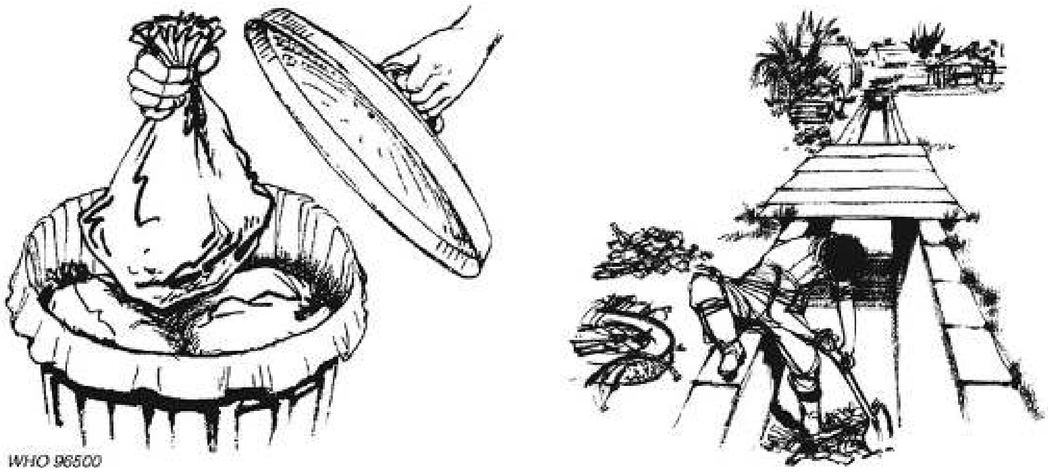
Lice control begins with good personal hygiene by regular washing with soap and warm water, combined with combing with a special louse comb to remove the nits from hair. Regular laundering of clothing in hot water or changing clothes is essential. A common control method is use of insecticides or insecticidal soaps; however, this introduces exposure to toxic chemicals and puts pesticides into the local water system. Children who have access to the soaps may mistake them for regular soap.

Lice are mainly a nuisance problem. Families or a community service commonly conduct individual or group treatment, for example by routine inspection of children in schools and mechanical removal of insects and nits. Short haircuts facilitate inspection of heads. The clothing of at-risk groups can be impregnated with insecticides, and use of ITNs also contributes to louse control. In the event of an epidemic of a pathogen transmitted by body lice, intensified louse control by public health services is required. Most louse-transmitted diseases can be controlled with antibiotic treatment. For more information on the control of body lice, see Burgess *(17)*.

6.2.4 Control of flies

House flies and filth flies are controlled mainly by prevention *(6)*, including hygiene and sanitation. Examples of preventive measures are personal hygiene, facial cleanliness, hand washing, safe storage of food items, construction of ventilated pit latrines, rubbish disposal and collection, regular cleaning of wastewater drains and channels, regular cleaning of poultry and livestock housing, removal of animal dung, construction of compost heaps and removal of rubbish dumps (Fig. 6.7).

Fig. 6.7. Left: Rubbish containers with tightly fitting lids to reduce fly breeding in cities. Right: Regular cleaning of drains to avoid fly breeding in accumulated rubbish



Source: Rozendaal *(7)*.

Most methods are effective only if implemented throughout a community or municipality; however, documented examples of community fly control are limited to studies on the use of insecticides *(18)*. Fly traps, including sticky traps, are commercially available. Traps are particularly effective indoors when combined with screening on windows and doors. Insecticides provide temporary relief from infestation, partially because flies can develop resistance to the insecticides used and are therefore not recommended as a public health control method.

6.2.5 Mosquito control

The methods for controlling nuisance mosquitoes are essentially the same as those for mosquito vector control, discussed in sections 1 and 2. Nuisance mosquitoes are controlled mainly by environmental management of breeding habitats and use of environmentally sound larvicides, such as *B. thuringiensis israelensis*, to treat natural swamps or flooded areas. Bed nets and repellents can provide personal protection against mosquito nuisance bites.

6.2.6 Bedbug control

Regular inspection of the hiding places of bedbugs (bedding, walls, crevices) and detection of their excreta, visible as black marks on bedding or walls, is required to confirm the presence of bedbug infestation. Once infestation is confirmed, several preventive and control measures can be used in a community through educational programmes or distribution of information. Community measures include physical removal and killing of bugs, use of a vacuum cleaner, sealed storage of clothing and bedding, filling cracks and crevices in walls and furniture, sealed plastic mattress covers, room ventilation, heating or cooling of rooms or mattresses, and steaming mattresses or clothes. These non-insecticidal methods are generally not sufficient to eliminate local infestations and supplemental use of insecticides may be required. Aerosols are commonly used to treat mattresses, walls and other hiding places of bedbugs. Carefully targeted residual insecticides could be sprayed by hand in the hiding places of bedbugs on walls or in crevices.

ITNs have also been effective in controlling bedbug infestation, by preventing their access to human hosts and actively killing the bugs upon contact *(19)*. It has been reported, however, that bed bugs develop strong resistance to the pyrethroids in treated bed nets *(20)*, which will increase the difficulty of controlling this pest; consequently, public education must be emphasized. In the USA, resistance to pyrethroid insecticides is already widespread, and, unless new tactics for bed bug management are found, further escalation of this public health problem should be anticipated.

6.2.7 Control of house dust mites

Finding house dust mite infestation is difficult, because the tiny organisms can burrow deeply inside mattresses and pillows. Dust mites and the allergens they produce can be controlled by room ventilation, as fluctuations in temperature and humidity help suppress populations. Vacuum cleaning of mattresses and beddings helps to remove some of the mites and dust that cause allergic reactions. Washing and dry cleaning of bedding and mattresses kill some of the mites and remove mite excreta and dust. Exposure of mattresses to direct sunlight kills some mites. Bedding that is impermeable to house dust mites is unlikely to be effective. Insecticides are not usually recommended for the control house dust mite because of their limited effectiveness and the risk to human health *(6)*.

6.2.8 Rodent control

Populations of rodents are limited by the amount of food available. Killing a large number of rats may temporarily reduce the pest problem, but, because of their high reproductive potential, the numbers rapidly return to pre-control levels if no additional measures are taken. Therefore, reducing the availability of food and of breeding places is essential. A strategy to control rodents should be based on a survey of the severity and nature of the infestation, identification of the rodent species and estimation of the population density (e.g. from droppings, runs and burrows). Potential hiding places for rodents include roof spaces, spaces under floors, basements, drains, sewers and outdoor shelters, which should be inspected *(9)*.

In most cities, rodents in sewers are controlled mainly with lethal chemicals, or rodenticides. Rodent management is conducted in urban environments usually in response to complaints by residents, with no preventive strategy for rodent control *(6)*. Toxic pesticides for rodent control, including illegal pesticides and improperly labelled pesticides, are readily available for domestic use in many cities, which poses a risk of exposure of children, as the products are usually placed on floors, and young children may place bait pellets in their mouth.

Structural and environmental improvements provide a preventive approach. For example, repair of defects in a sewerage system and sealing off points of entry help to prevent the movements of rats, and proper management and disposal of rubbish and refuse suppress rat reproduction. In South Africa, high-quality rat traps were widely adopted by communities as an alternative to the use of poisonous street pesticides *(21)*.

Integrated pest management for rodent control involves a combination of measures, including sanitation, maintenance of buildings, luring and trapping, and some use of the least toxic rodenticides. To be effective, integrated rodent control should be implemented with the active participation of communities, emphasizing preventive measures such as cleanliness and safe food storage.

- Which preventive methods of pest control would be acceptable to low socioeconomic sectors of society?
- What communication strategies would you recommend for this purpose?
- What roles could other public and private sectors (e.g. municipalities) play in urban pest control?

Rozendaal JA. Vector control: methods for use by individuals and communities. Geneva: World Health Organization; 1997:chapters 4–6 (https://iris.who.int/handle/10665/41968). *(7)*

6.3 Illegal use of pesticides in urban areas

6.3.1 Pesticide use in households

According to current international standards, no hazardous pesticide should be sold to consumers. The pesticides available for household use should be only of WHO Hazard Classification Category IV or less *(22)*. Household pesticides should be used only with strict enforcement of standards for labelling and child-resistant packaging. Pesticide products are suitable for household use only as commercially diluted formulations, ready to be sold over the counter. Aerosols and mosquito coils are good examples of household pesticides.

Exposure to household pesticides can occur in the domestic environment by inhalation of vapour, skin contact, hand-to-mouth contact (particularly in small children), accidental consumption and residues in water, on food and on sprayed plants or animals. Some countries (e.g. the Netherlands [Kingdom of the]) provide a services for householders and farmers to dispose of pesticide waste and other hazardous waste and have a communication strategy to discourage people from disposing of unwanted chemicals in their environment, which can pollute soil and groundwater. Disposal in a kitchen sink or in a toilet can reach sewage and will eventually be released into the environment.

Nalwanga E, Ssempebwa JC. Knowledge and practices of in-home pesticide use: A community survey in Uganda. J Environ Public Health. 2011;2011230894. doi:10.1155/2011/230894 *(23)*.

- Why should the safety requirements for household pesticides differ from those for other pesticides?
- What are the safety precautions for household pesticide in your country (e.g. in relation to labelling, use, storage and disposal)?
- Are unlabelled, decanted pesticides commonly used in households in your country?

6.3.2 Street pesticides: an emerging problem

"Street pesticides" are pesticides that are decanted from the original container into another container, such as a used drink container or medicine bottle, and sold without a label for unregistered purposes *(24)* (Fig. 6.8). The pesticides are mainly products that have been registered for use in agriculture but are re-packaged for household use against domestic pests, without the required instructions on use and safety. Street pesticides are sold at markets, public transport stations, taxi stands, on trains and door-to-door. Many street pesticides are highly hazardous compounds that are not suitable for household use, favoured for their rapid effect on pests but posing serious risks to householders and residents.

Fig. 6.8. Street pesticides being sold in South Africa

Source: photo courtesy of HA Rother, Cape Town University.

The scale and nature of the illegal trade in street pesticides is still largely unknown and undocumented. As they are illegal, street pesticides are difficult to study. Detailed studies were conducted recently in Cape Town, South Africa *(24,25)*, and a few documented reports are available from other countries, including Brazil *(26)* and the USA *(27)*. These studies probably represent the tip of the iceberg.

Several conditions favour the trade in street pesticides *(25)*. Poor socioeconomic conditions in an urban context, with few employment opportunities, can drive mainly young people to repackage, trade and sell unregulated pesticides. Environments with poor sanitation, accumulated rubbish, poor water supplies, poor housing conditions and high human density create high demand for pesticides, as the environment provides the ideal conditions for proliferation of pests such as cockroaches, rodents, flies and bedbugs. An ineffective regulatory environment also allows illegal use of pesticides. In the absence of adequate monitoring and enforcement, people can purchase agricultural pesticides, not comply with the instructions and use the pesticides for unregistered purposes. Street pesticides, particularly for agricultural purpose, are readily available to consumers in many countries, providing profits to pesticide manufacturers, who do not control or account for how their products are used. Furthermore, informal street vendors, including children, lack information and training in pesticide risks, resulting in a high-risk working environment.

Samples of street pesticides collected in Cape Town were mainly the organophosphate methamidophos and the carbamate aldicarb in high-concentration formulations. These compounds are highly hazardous and extremely hazardous, respectively, and are clearly not safe for street sale or household use. Vendors obtained the pesticides from local farmer cooperatives and informal distributors, and there was some indication that aldicarb was imported across the border. The vendors had stalls at informal markets or were mobile, moving through trains and stations or from door to door *(25)*.

The study also established several routes of exposure of vendors and children. The highest risk appeared to be during the packaging and mixing of pesticides, when skin can come into contact with the concentrated product. All the containers used were clearly inappropriate for a toxic chemical; some were even re-used and had begun to deteriorate. Some bore the label of the original product (e.g. water), increasing the risk of accidental consumption. Children were observed wrapping pesticides in newspaper or putting them into plastic bags. Pesticides were often sold beside food items and cigarettes, thus risking contamination.

6.3.3 Poisoning with street pesticides

The harmful side-effects of street pesticides are human poisoning and environmental pollution. The involvement of children and young people in selling street pesticides violates their human rights, representing child labour and childhood exposure to toxic substances *(25)*.

The number of incidents of notified pesticide poisoning was studied in Cape Town, South Africa, during 2003–2008. The number of paediatric exposures and poisonings remained relatively constant; however, the annual number due to pesticides increased markedly *(28)*. The numbers were probably underestimates, as many cases are not notified or detected. Most of the cases of pesticide poisoning cases resulted from oral ingestion and were due to cholinergic poisoning (i.e. due to organophosphates or carbamates), which is particularly serious and requires advanced medical care in a hospital. The socioeconomic background of the pesticide poisoning cases varied from extreme poverty to middle-class. Some 14% of all the pesticide poisoning incidents were confirmed to be due to street pesticides.

Young children and young adults are at particular risk of pesticide poisoning. Children absorb greater quantities of pesticide than adults due to hand-to-mouth habits, dietary patterns, explorative behaviour and playing close to the ground. Some illegal pesticide compounds are highly persistent and may result in continuous exposure when absorbed on items such as rugs and toys. Children are not only exposed more than adults but they are also more vulnerable to a given amount of pesticide because of their smaller body mass and their lower ability to detoxify pesticide compounds.

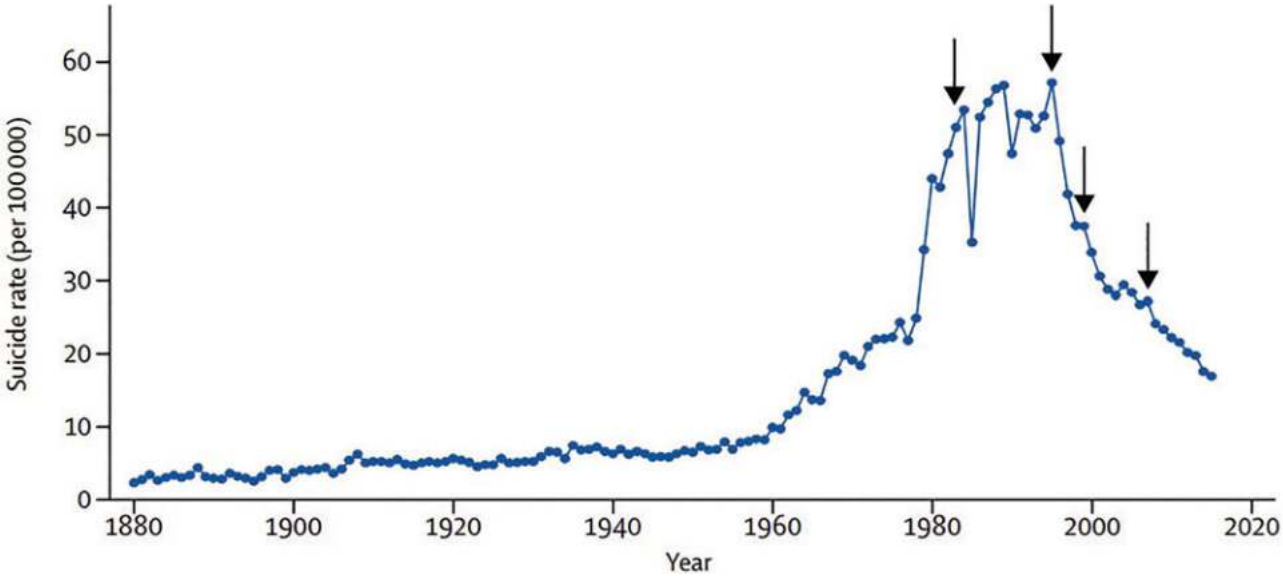
> Konradsen F, van der Hoek W, Cole DC, Hutchinson G, Daisley H, Singh S et al. Reducing acute poisoning in developing countries – options for restricting the availability of pesticides. Toxicology. 2003;192:249–61. doi:10.1016/s0300-483x(03)00339-1. *(29)*

6.3.4 Deliberate self-harm with pesticides

Pesticide self-poisoning is an important problem in LMICs, particularly in the Asia–Pacific region *(30)*. Pesticide poisoning accounts for approximately one third of all suicides globally *(30)*. The high toxicity of pesticide products results in a high rate of case fatality, which could be avoided by restricting hazardous compounds and products and regulating and enforcing acceptable use of pesticides. Some researchers have called for a ban on all highly hazardous pesticide compounds. Limiting the availability of hazardous compounds could reduce the number of fatal pesticide self-poisonings.

Sri Lanka provides a useful example. In 1995, all WHO Class I pesticides were banned for import or sale, and, in 1998, endosulfan was banned. These bans were accompanied by a sharp decrease in the rate of suicide (Fig. 6.9) *(31,32)*. Banning of these hazardous compounds did not appear to have a negative effect on agricultural crop production *(32)*.

Fig. 6.9. Incidence of suicide in Sri Lanka before, during and after bans on pesticides



Source: Knipe et al. *(33)*. Reproduced under the Creative Commons Attribution 4.0 International License (https://creativecommons.org/licenses/by/4.0/).

Arrows show times of pesticide bans: 1984, parathion, methylparathion; 1995, all remaining WHO class I toxicity pesticides, including methamidophos and monocrotophos; 1998, endosulfan; 2008, dimethoate, fenthion and paraquat.

6.3.5 Mitigation strategies

The International Code of Conduct on Pesticide Management advises governments to take responsible action for adequate regulatory control of all pesticides. Control of the illegal trade and unintended use of pesticides at community level, particularly in urban settings and with poor socioeconomic conditions, is a major challenge for governments. Mitigation strategies include:

- updated legislation;
- establishment of surveillance systems;
- strategies to reduce use (e.g. integrated pest management, IVM);
- communication and education to raise awareness about the risks of pesticides;
- commitment by the industry to increase accountability and stewardship; and
- promotion of pest control in poverty alleviation strategies.

Legislation might have to be updated to address the emerging problem of street pesticides and inappropriate use of pesticides in communities. There have been calls to restrict the number of registered pesticides to a "minimum list" of relatively less dangerous pesticides that are compatible with integrated pest management *(34)*. The availability of fewer compounds would reduce the number of cases of severe poisoning and would facilitate prompt, appropriate diagnosis, treatment and management of poisoning cases. Use of pesticide products should be restricted.

In some countries, legislation might exist but the surveillance systems may not be adequate to monitor and control illegal trade and misuse of pesticides, particularly in peri-urban settings. Arresting street vendors may appear to be an effective measure, but it does not address the underlying causes of the emerging trade in street pesticides. Pest problems associated with poverty are a serious concern, and appropriate pest control strategies are required, with adequate policy support *(25)*. An important preventive strategy is reducing use. As most of the pesticides illegally traded on the streets are for agriculture, strategies to reduce the demand for and use of pesticides in agriculture, e.g. through integrated pest management, would be an effective approach *(35,36)*.

Another strategy is community education and awareness-raising. Fig. 6.10 provides an example of a tool for communication of pesticide risks. The studies in South Africa showed that street vendors had no information about the pesticides they were selling, as the local farmer cooperatives that had provided the pesticides had given them no instructions on safety precautions or possible health effects. Information about the risk of pesticide was obtained only by word of mouth, for example when someone was poisoned. The vendors could also not provide appropriate information on safety to their customers.

Fig. 6.10. Information materials used in a public awareness programme on the health risks of pesticides

Source: photo courtesy of HA Rother, Cape Town University.

Pesticide manufacturers should be accountable for how their products are sold, decanted and used for unregistered purposes. The International Code of Conduct on Pesticide Management states that the pesticide industry and governments should collaborate in post-registration surveillance and conduct monitoring to determine the fate of pesticides and their effects on health and the environment under operational conditions *(5)*. For example, in a country with uncontrolled street pesticide sales and unintended use of toxic products for domestic purposes, manufacturers should withdraw the products and introduce alternatives.

- What indications do you have (e.g. personal encounters, news coverage, documented reports) of the nature and scale of the trade in street pesticides in your country?
- Which street pesticide compounds are preferred by householders, and for what purpose?
- Think of ways in which poverty-related pests could be controlled sustainably, with little risk to health.

6.4 Control of malaria: the case of Dar es Salaam

In most settings, transmission of malaria is less intense in urban than in rural environments, and therefore most resources for malaria control in endemic countries are for rural areas. There may, however, be a significant risk of malaria outbreaks in urban centres, because city dwellers lose their partial immunity if they are not bitten by an infected mosquito at least once or twice a year. When malaria transmission does occur in a city, therefore, its non-immune residents may experience serious bouts of malaria. High concentrations of people in urban environments facilitate the emergence of epidemics.

Dar es Salaam, United Republic of Tanzania, has a long history of control of "urban malaria". Dar es Salaam is a coastal city situated near the equator. It has a humid tropical climate, with high temperatures and two rainy seasons. The urban area grew from 93 km^2 in 1978 to 418 km^2 in 1998. Transmission of malaria occurs throughout the year, *P. falciparum* being the parasite that accounts for most malaria cases. The parasites are transmitted locally by the vector species *An. gambiae*, which breed in temporary water bodies, and *An. funestus*, which breed in inland marshes. The same vector species occur in rural environments.

6.4.1 Early malaria control

Malaria control began in the late nineteenth century under German colonial rule, when quinine was administered to infected people and for prophylaxis to non-immune populations. The water from tides that surround the city were initially treated with oil to prevent vector breeding, but this intervention was not considered effective. An experiment in 1913 demonstrated that larval control by environmental management, combined with larviciding, had a greater effect on malaria than use of quinine *(37)*.

In the same year, an ordinance was issued for destruction of ponds and other water bodies that could harbour malaria vectors, which resulted in an estimated reduction of mosquito populations by 90%. After the First World War, under British colonial rule, malaria control was concentrated on drainage, straightening streams and clearing banks. After the Second World War, malaria control shifted to indoor spraying with DDT, aerial larviciding of marshlands and treatment with chloroquine.

In the 1960s, environmental management in urban malaria control was resumed. Major engineering works were conducted to improve drainage and to fill water bodies. Surveillance of mosquito breeding sites and community health promotion were initiated to reduce malaria transmission. An experiment conducted in the early 1970s in collaboration with WHO showed that interventions to reduce vector breeding substantially reduced the density of adult vectors. The interventions consisted of improved drainage, trimming the banks of streams and swamps and use of larvicides and oil in standing water and wetlands. After 13 months, the interventions had significantly reduced the density of *Anopheles* mosquitoes *(38)*.

Between 1972 and the early 1980s, however, environmental management was abandoned with a worsening economic situation, leaving chemotherapy as the only malaria control intervention in Dar es Salaam. During this period, the density of adult vectors in the city was reported to have increased 10 times.

6.4.2 The period 1988–1996

In 1988, an urban malaria control programme was started with the assistance of the Government of Japan. The aim of the project, which continued until 1996, was to reduce malaria prevalence to the lowest possible level and to encourage the participation of communities in preventing malaria transmission. The programme emphasized increasing awareness of malaria and involving communities in maintaining drains and removing standing water. A total of 211 health workers were trained in vector control, rapid diagnosis and treatment of malaria.

The vector control interventions included environmental management, chemical larviciding, IRS, ITNs and space spraying. In addition, polystyrene beads were used for control of *Cx. quinquefasciatus* breeding in latrines and septic tanks *(39)*. Improvement of drains to reduce water accumulation, wetland areas and temporarily flooded areas was an important component of vector control. Initially, only a few drains had normally flowing water, and the flow of several major drains was substantially improved during the programme.

Community participation was promoted by organizing seminars for community leaders, mass meetings for communities and training of over 200 volunteers, who made numerous house visits. In general, however, insufficient local capacity for vector control was established. Inclusion of nuisance control of *Cx. quinquefasciatus* proved to be essential for community acceptance and support for the programme.

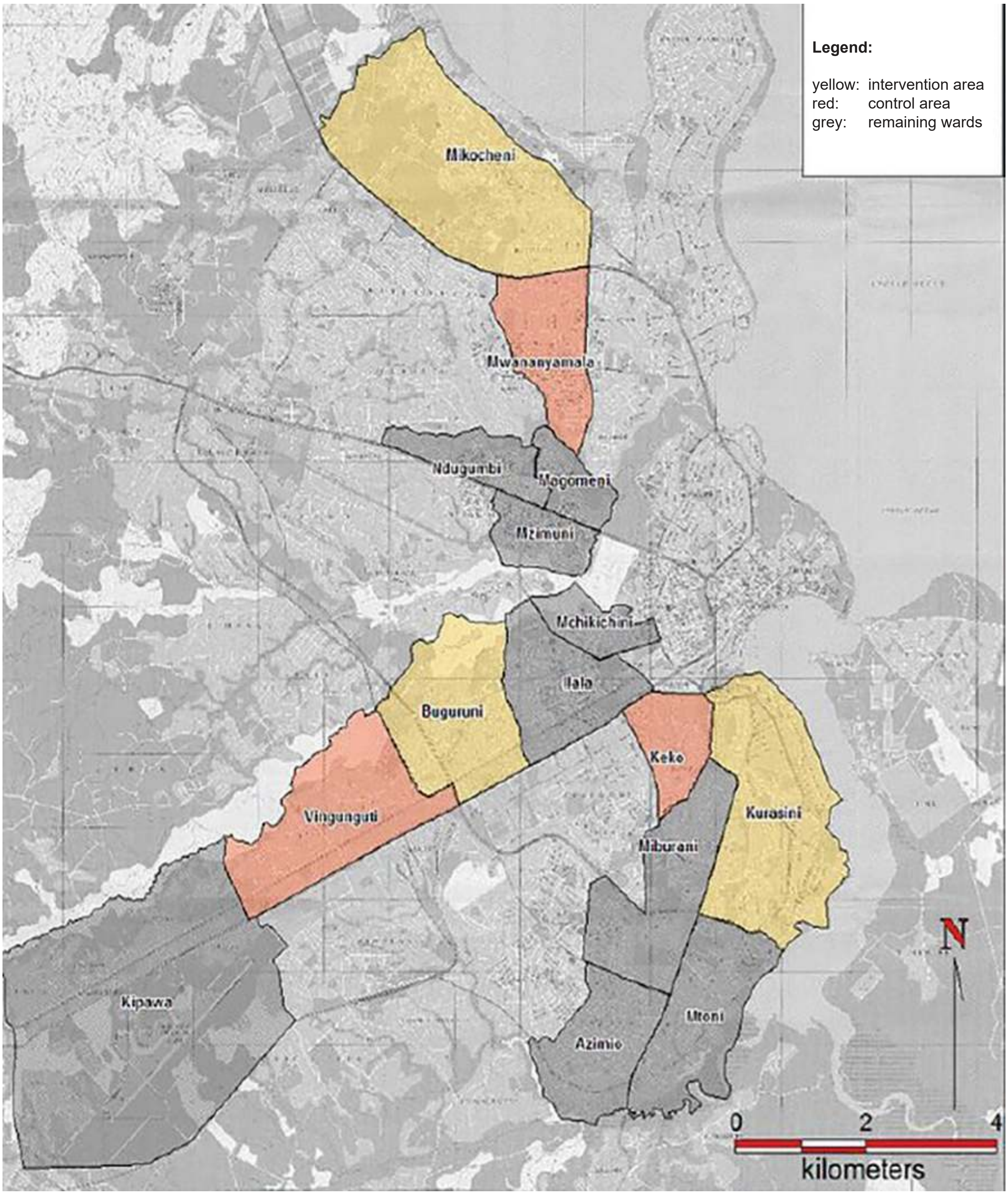
An important result of the programme was rehabilitation of the drainage system. Communities participated in clearing and maintaining drains and other environmental management activities. Although administration of chloroquine to schoolchildren who tested positive for malaria helped to reduce the prevalence, it was concluded that environmental management and larviciding were responsible for maintaining a low malaria prevalence. Another result of the programme was detailed malaria risk maps prepared from high-resolution aerial photographs. The maps were used to identify malaria breeding sites for vector control. In the diverse urban environment, where the main vector breeding sites were few and far apart, the maps were invaluable for stratifying areas according to transmission risk and breeding sites and subsequently planning interventions.

Limitations of the programme were lack of a monitoring and evaluation system to assess the impact of activities on mosquito populations and transmission intensity. Monitoring of schoolchildren did not allow evaluation of local vector control interventions, because the schools represented relatively large areas, and data on individual children were not linked to the locations of their homes. Another limitation of the programme was lack of integration into the city's health system. The programme and Government services were separate organizational structures. Lack of integration within the City Council was identified as one reason why the programme could not be sustained after the Japanese collaboration came to an end in 1996 *(37)*.

6.4.3 From 2003 onwards

In 2003, an urban malaria control programme was initiated in Dar es Salaam *(40)*. More recently, the city's health system, with decentralization of services, has been strengthened significantly and the drainage system has been rehabilitated. In 2003, the city health office formulated a plan for larval control in 15 city wards, with the participation of community members (Fig. 6.11) but with a vertical delivery system and reporting at the levels of ward, municipality and city. Maps obtained by remote sensing were supplemented by participatory mapping, which was updated weekly to capture temporary changes in vector breeding habitats.

Fig. 6.11. Wards included in the study area, specifying those targeted for larviciding



Source: Fillinger et al. *(41)*. Reproduced under the terms of the Creative Commons Attribution 2.0 License (https://creativecommons.org/licenses/by/2.0).

Yellow: wards targeted with larviciding; red: non-intervention wards; grey: remaining wards.

Development of community-based vector surveillance and response in 15 city wards improved the standard of vector larval surveillance, with 65 000 vector breeding habitats surveyed each week by 90 modestly paid community members (Fig. 6.12). Larval control was conducted by trained community members by application of one of two microbial larvicides: *B. thuringiensis israelensis* or *B. sphaericus*. Larviciding in the selected wards resulted in major reductions in larval breeding as compared with controls *(41)*. Larviciding also reduced the risk of malaria infection, at a level of protection comparable to that with ITNs *(42)*. Interventions against *Culex* mosquitoes were less effective.

Although the intervention began as a research project, it initiated institutional change. A hierarchical delivery structure was established, with centralized management but linkage to community service delivery and with clear partner roles and responsibilities. The programme evolved from a donor-driven to an internally funded project, with ownership by the City Council.

Fig. 6.12. Examples of inaccessible breeding habitats of *Anopheles* mosquitoes

Source: Fillinger et al. *(41)*. Reproduced under the terms of the Creative Commons Attribution 2.0 License (https://creativecommons.org/licenses/by/2.0).

6.4.4 Conclusions

Environmental management, community mobilization, larval control and nuisance mosquito control were necessary to control malaria in Dar es Salaam, where there a few vector breeding sites that are far apart. The effectiveness of these methods and strategies depends on detailed, regularly updated maps of urban areas as the basis for vector surveillance and response conducted by well-trained local people. Sustaining and upgrading the system of community-based surveillance and vector control in Dar es Salaam to achieve continued and increased control of urban malaria will remain a challenge. With recent use of bacterial larvicides, it is unclear whether environmental management, particularly maintenance of the drainage system, will continue to be adequate.

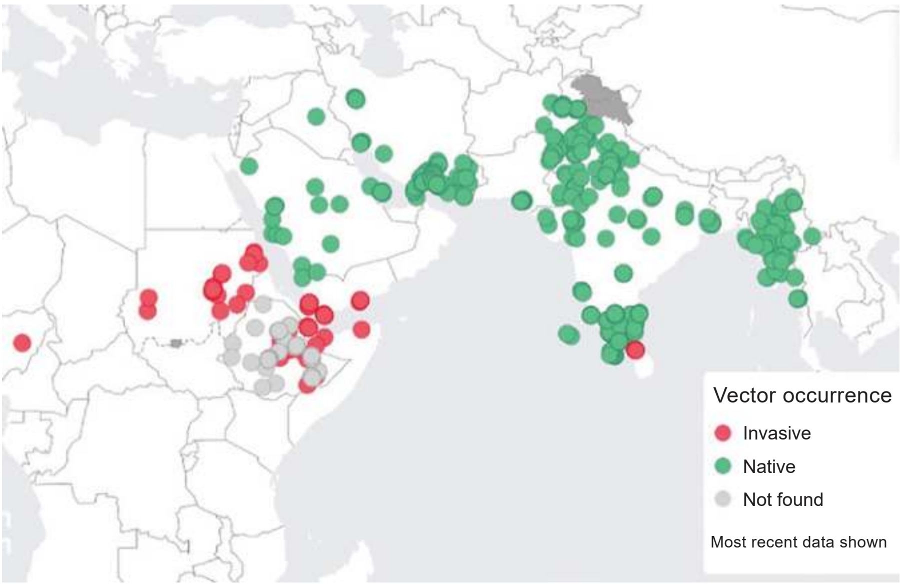
- Which vector control methods for malaria control would be suitable in urban areas in your country?
- What are the major challenges and obstacles to effective urban malaria control in your country?

6.5 Invasive *Anopheles stephensi* in African cities

An. stephensi is a malaria vector native to parts of Asia and the Middle East (Fig. 6.13). The species is unique among malaria vector species in that it occupies both rural and urban areas *(43)*. In the past decade or so, *An. stephensi* has extended its geographical range by invading the Horn of Africa and further down to Ethiopia and Sudan and even into Nigeria (Fig. 6.13) *(44)*. Although the African continent is known to harbour highly efficient malaria vectors, including *An. gambiae sensu stricto* and *An. funestus s.s.*, the relatively less efficient vector *An. stephensi* is highly adapted to urban environments. Although city centres have previously remained relatively free from malaria, the invasion of *An. stephensi* could change this situation in African urban areas.

Thus, while other species are confined mainly to rural or peri-urban areas, *An. stephensi* is common in cities in its native regions, where it often breeds in water tanks used for domestic purposes and in other human-made water containers (Fig. 6.14). *An. stephensi* is the main malaria vector in urban centres in some parts of South Asia. This species crossed into Africa in 2012 in Djibouti city, where it caused a major malaria outbreak *(45)*. The outbreak was remarkable because Djibouti was at the time approaching the pre-elimination phase of malaria. The species did not occur seasonally but all year round owing to the continuous availability of water storage tanks *(46)* (Fig. 6.14). In 2016, the species was recorded in Ethiopia, where it became widely distributed *(47)*. In 2018, it was reported in Sudan. This invasive species also recently invaded Sri Lanka, where it had not been reported previously.

Fig. 6.13. Native and invasive distribution of *Anopheles stephensi* as of 26 January 2023



The designations employed and the presentation of the material in this publication do not imply the expression of any opinion whatsoever on the part of WHO concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. Dotted and dashed lines on maps represent approximate border lines for which there may not yet be full agreement. Data source: Global Malaria Programme. Map production: Global Malaria Programme. World Health Organization. WHO 2023.

Source: WHO *(44)*.

Fig. 6.14. Examples of breeding sites of the invasive species *An. stephensi* in Ethiopia

Source: Balkew et al. *(47)*. Reproduced under the terms of the Creative Commons Attribution 4.0 International License (https://creativecommons.org/licenses/by/4.0/).

a: water tankers; b: construction water storage reservoirs; c: discarded tyres; d: buckets; e: steel drums; f: water tanks; g: temporary water storage reservoirs; h: *birkas*.

Use of spatial modelling of the species' preferred habitats has predicted that *An. stephensi* could invade many more African cities, putting 126 million people at risk *(48)*. WHO has urged countries in the region to be vigilant and to enhance their surveillance systems to detect *An. stephensi* as soon as possible. As programmes for vector-borne disease control have usually been confined to rural areas, many municipalities and city councils do not have adequate capacity or infrastructure for surveillance and control in their jurisdictions.

- Could there be suitable breeding conditions for *An. stephensi* in large cities in your country? Explain.
- How could the national malaria control programme in your country, which has focused on rural areas, tackle an outbreak of urban malaria transmitted by *An. stephensi*? What changes or adaptations are required in surveillance and control?

6.6 Control of urban dengue: the case of Singapore

Dengue is associated with urban environments because its vectors, particularly *Ae. aegypti* and *Ae. albopictus*, are adapted to breed in human-made containers and sites in and around people's houses and workplaces. The prevalence of dengue is increasing globally, because of urbanization and increased travel. As of 2022, there was no vaccine or effective medication against this arboviral disease; therefore, vector control is the only option. Effective vector control in an urban environment is a major challenge, as demonstrated below in the example of Singapore.

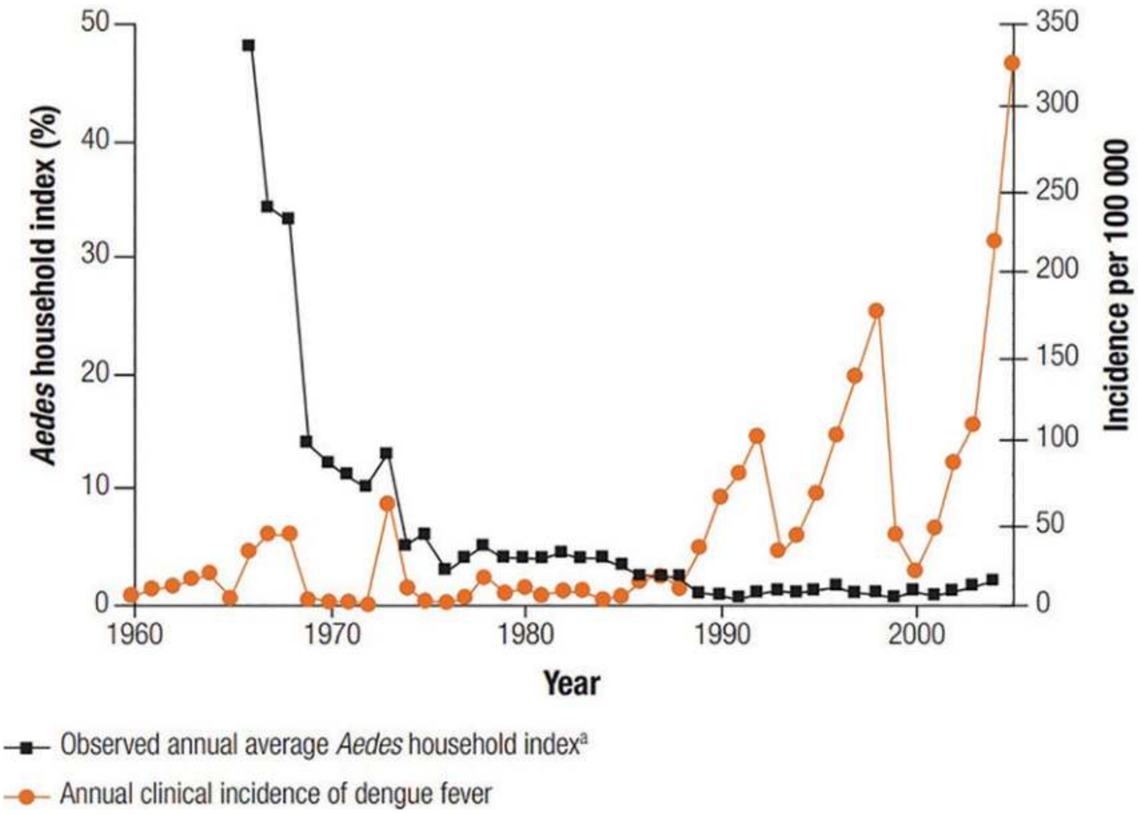
6.6.1 System of vector control

In the 1960s, dengue haemorrhagic fever, now known as "severe dengue", was a major cause of childhood deaths in Singapore. Dengue haemorrhagic fever was made a notifiable disease in 1966 and dengue fever in 1977. In 1966, a vector control unit was established by the Ministry of Health, and, in 1968, a vector control system was developed after a series of surveys and pilot studies *(49)*. The vector control system included routine surveillance of *Aedes* mosquitoes and systematic reduction of *Aedes* breeding sites to prevent transmission of dengue viruses. In a pilot study, it was concluded that sustained control of vector breeding sites would be feasible only with public participation, and the vector control system, public education and law enforcement were strengthened.

In 1968, legislation was enacted to discourage breeding of *Aedes* mosquitoes under the Destruction of Disease-bearing Insects Act. People who created conditions favourable for vector breeding were penalized. Roof gutters were not permitted on buildings in new developments, as they are difficult to access and maintain, and property owners were required to remove gutters on their houses if they were unable to maintain them satisfactorily. Construction sites were required to have an environmental control officer to oversee sanitation, hygiene and vector control on the site.

In the period 1968–1973, 1500 Government officers served as health educators and law enforcement officers for dengue control and conducted routine inspections of premises for the presence of *Aedes* larvae or pupae. The main measure used in vector surveillance was a "premises index" (or house index), which is the percentage of inspected premises found to have containers with larvae or pupae of *Aedes* species. The operations were highly successful. During implementation of the programme, the premises index dropped from over 30% to around 3%, indicating that vector breeding had been substantially reduced (Fig. 6.15). In 1972, the vector control unit and its mandate for dengue vector control were transferred from the Ministry of Health to the Ministry of Environment. Between 1973 and 1988, the number of dengue cases remained very low, and the premises index remained at about 2%, indicating limited opportunities for vector breeding (Fig. 6.15).

Fig. 6.15. Annual incidence rates of dengue fever and dengue haemorrhagic fever and the premises index, Singapore, 1966–2005



Source: Egger et al. *(50)*.

After 1989, however, the situation changed, with an increase in the number of cases of dengue fever, even though the premises index remained below 2%. This situation persists. What caused the number of dengue cases to drop initially but to resurge about 15 years later?

6.6.2 Role of immunity

People who have been infected with the dengue virus, whether they develop dengue fever or show no disease symptoms, develop lifelong protective immunity against the particular serotype of the virus. The high infection rates with dengue virus until the early 1970s indicate so-called "herd immunity", in which a large proportion of the community has become immune to infection with the virus, thus disrupting the propagation and spread of the disease. Loss of herd immunity arises after many years as a young human generation develops that has not been exposed to the dengue virus. An increasing proportion of people without immunity will increase the risk that dengue can spread in the community. In the late 1990s, low levels of immunity may have caused the return of dengue fever, despite low populations of the vector.

6.6.3 Other factors

Reduced immunity cannot fully explain the resurgence of dengue. Investigators found that people who spent time away from home during the day, at work or school, were much more likely to be infected that those who spent most of the day at home or in preschool care. In Singapore, people live in high-rise buildings, which usually have a low incidence of vector breeding, whereas schools, construction sites and factories have considerably higher premises indexes, indicating a higher risk of transmission. As a result of infection outside houses, a large percentage of dengue cases were in adults, whereas in most countries dengue is most common among children.

6.6.4 Changed surveillance system

Several components of the vector control programme remained unchanged in Singapore. In the current strategy, however, more emphasis is placed on case detection and case location. Vector surveillance became less of a priority in the control programme when the number of dengue cases remained low during the 1980s. Even when the number increased in the 1990s, vector surveillance was not implemented at the scale of the 1960s and early 1970s. With fewer inspections by vector control officers to people's homes and no educational or information programmes for the public, the motivation of the public to remove vector breeding sites may have been reduced.

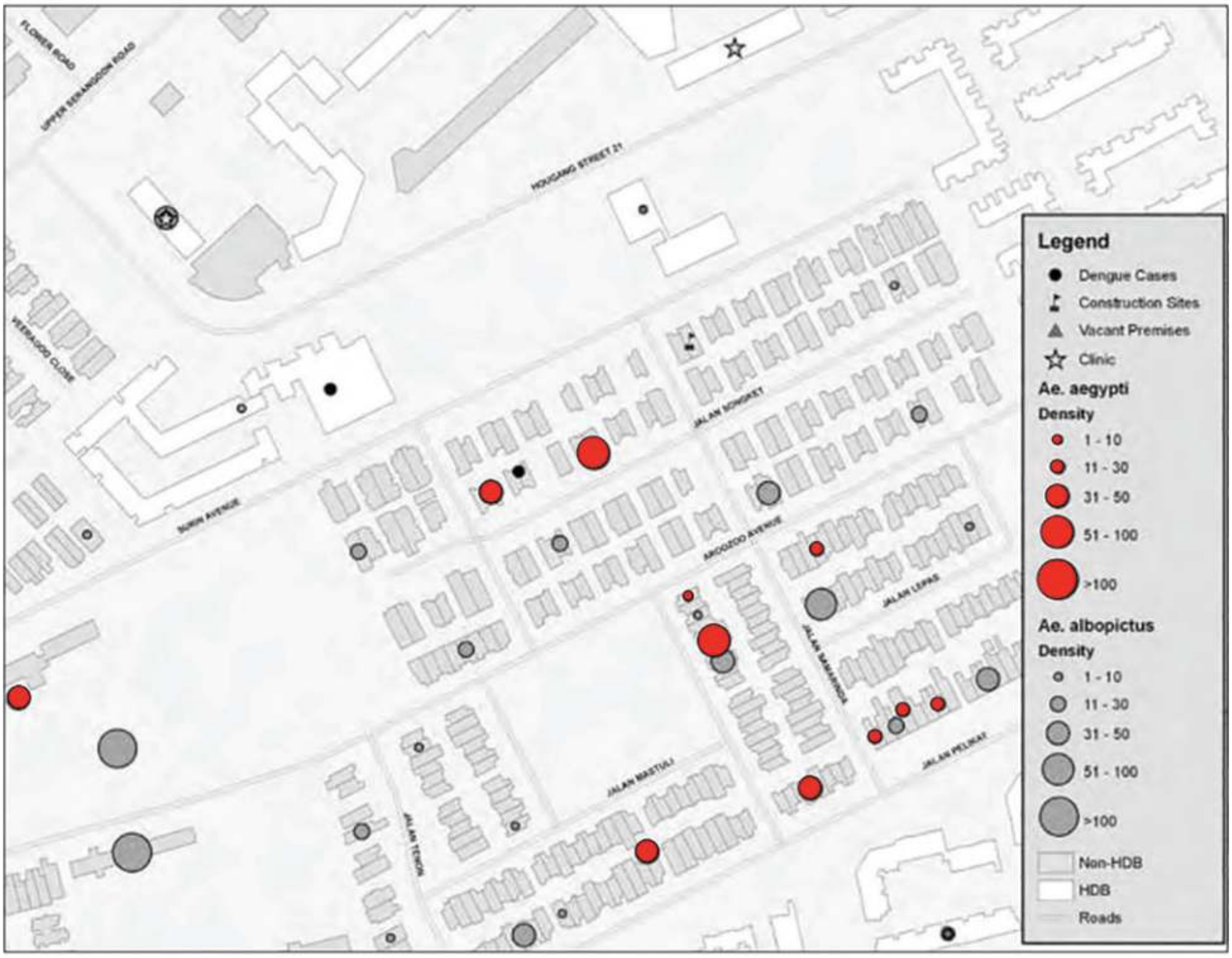
The programme chose to wait for a dengue case and to respond to the new case or a cluster of cases by intensive vector control at the site of transmission. This was done by space spraying (fogging) with organophosphate insecticides. Space spraying is, however, now considered to be ineffective in stopping epidemic transmission of dengue. Vector control based on regular surveillance was conducted only in areas that were considered particularly prone to dengue (Fig. 6.16).

The problem with the approach of emergency response, largely without preventive vector control, was that many dengue cases occurred outside of clusters. Also, some dengue infections were not noticed, such as when the infected people did not develop symptoms or had only a mild fever. The emergency response strategy alone can effectively deal with new incidences of disease but cannot prevent transmission and spread of the dengue virus.

Vector control by reducing vector breeding sites remains the best means of preventing dengue. The increase in the number of dengue cases in Singapore since the 1990s, combined with a high risk of transmission outside homes and the low level of herd immunity, indicate the need for a preventive strategy.

In the past, vector control decimated populations of *Aedes* mosquitoes by reducing the opportunities for breeding. Current levels of vector breeding are so low that inspection of premises yields very few observations of breeding. Nevertheless, these low populations can transmit dengue in an urban situation such as Singapore. Clearly, additional preventive tools are necessary for vector control. One that has been promoted is an improved type of ovitrap, a device that encourages *Aedes* females to deposit their eggs in a water-filled container, and the emerging adults are prevented from escaping by a wire mesh. The traps require regular inspection and maintenance, which may be difficult to achieve without community participation.

Fig. 6.16. Mapping of dengue cases and vector densities in Singapore



Source: WHO *(51)*.

Ovitraps have the advantage that they can be used for both surveillance and control. The traps allow monitoring of the density of mosquitoes, and they reduce mosquito population levels by killing eggs. Ovitraps were successfully used to eradicate local populations of *Aedes* mosquitoes around Singapore airport. Hence, use of ovitraps with involvement of the community will help detect and eliminate local *Aedes* populations in various urban settings.

Recently, Singapore began to use a novel oviposition trap, called the gravitrap, which is cylindrical, with a sticky inner surface to trap gravid female mosquitoes that are searching for an oviposition site *(52)*. The trap contains hay infusion as attractant. The gravitraps have been adopted by the Singapore programme for indoor use, and as many as 50 000 gravitraps have been reported to have been used in public housing estates in Singapore since 2017 *(53)*. The traps are monitored every 2 weeks, and the number of *Ae. aegypti* caught is used in a geographical information system for targeting source-reduction campaigns.

6.6.5 Conclusions

Several lessons can be learnt from the Singapore case study. Rigid legislation, vector control and emergency response resulted in a reduction in vector breeding sites, which kept dengue rates very low for many years. This was not, however, sufficient because, once the human population had become more susceptible, dengue resurged. The emergency response of vector control, including space spraying, is now considered insufficient to stop the transmission of dengue. The recent upsurge in cases highlights the importance of intensified vector control, which can be achieved only by active involvement of communities in surveillance and control. Ovitraps and gravitraps appear to be promising for increasing community participation, improving surveillance and eliminating local populations of *Aedes* mosquitoes.

– Identify ways in which urban communities could contribute to dengue prevention.
– What is your opinion of the use of space spraying outdoors (fogging), a commonly used method in many countries for dengue vector control?

Project assignment 6

Obtain information on the pests and vector-borne diseases in the urban environment in your country.

1. Which types of pests are most prevalent in urban settings? Contact specialists if necessary.
2. Which ministries, agencies or organizations are involved in urban pest control, and what is their strategy and roles?
3. Which types of vector-borne disease are most prevalent in urban settings? Contact specialists if necessary.
4. Which ministries, agencies or organizations are involved in pest control for urban vector-borne diseases, and what is their strategy and roles?
5. Reflect on the current situation of pests and vector-borne diseases in urban settings to identify shortcomings and propose solutions.

References

1. Lines J, Harpham T, Leake C, Schofield C. Trends, priorities and policy directions in the control of vector-borne diseases in urban environments. Health Policy Plan. 1994;9(2):113–29. doi:10.1093/heapol/9.2.113.
2. Keiser J, Utzinger J, De Castro MC, Smith TA, Tanner M, Singer BH. Urbanization in sub-Saharan Africa and implication for malaria control. Am J Trop Med Hyg. 2004;71(2_Suppl):118–27 (https://pubmed.ncbi.nlm.nih.gov/15331827/).
3. Knudsen AB, Slooff R. Vector-borne disease problems in rapid urbanization: new approaches to vector control. Bull World Health Organ. 1992;70:1–6 (https://iris.who.int/handle/10665/261519).
4. Hay SI, Guerra CA, Tatem AJ, Atkinson PM, Snow RW. Urbanization, malaria transmission and disease burden in Africa. Nature Rev Microbiol. 2005;3(1):81–90. doi:10.1038/nrmicro1069.
5. International Code of Conduct on Pesticide Management. Rome: Food and Agriculture Organization of the United Nations; 2014 (https://www.fao.org/3/I3604E/i3604e.pdf).
6. Bonnefoy X, Kampen H, Sweeney K. Public health significance of urban pests. Geneva: World Health Organization; 2008 (https://iris.who.int/handle/10665/107363).
7. Rozendaal JA. Vector control: methods for use by individuals and communities. Geneva: World Health Organization; 1997 (https://iris.who.int/handle/10665/41968).

8. Fournier PE, Ndihokubwayo JB, Guidran J, Kelly PJ, Raoult D. Human pathogens in body and head lice. Emerg Infect Dis. 2002;8(12):1515. doi:10.3201/eid0812.020111.

9. Pesticides and their application for the control of vectors and pests of public health importance. Geneva: World Health Organization; 2006 (https://iris.who.int/handle/10665/69223).

10. Curtis CF, Graves PM. Genetic variation in the ability of insects to transmit filariae, trypanosomes, and malarial parasites. In: Harris KF, editor. Current topics in vector research, Vol. I. New York: Praeger; 1983:31–62.

11. Tatem AJ, Gething PW, Smith DL, Hay SI. Urbanization and the global malaria recession. Malar J. 2013;12(1):133. doi:10.1186/1475-2875-12-133.

12. Sharma V, Mehrotra K. Malaria resurgence in India: a critical study. Soc Sci Med. 1986;22(8): 835–45. doi:10.1016/0277-9536(86)90238-8.

13. Gopaul AR, Konfortion P. Roof-top breeding of *Anopheles arabiensis* (Patton, 1905) and the spread of malaria in Mauritius. Mauritius Inst Bull. 1988;136–74 (https://www.africabib.org/rec.php?RID=Q00000403).

14. Tee HS, Lee CY. Sustainable cockroach management using insecticidal baits: Formulations, behavioural responses and issues. In: Dhang P, editor. Urban insect pests – Sustainable management strategies. Wallingford: CAB International; 2014:65–85 (http://www.chowyang.com/uploads/2/4/3/5/24359966/175-1.pdf).

15. Kass D, McKelvey W, Carlton E, Hernandez M, Chew G, Nagle S et al. Effectiveness of an integrated pest management intervention in controlling cockroaches, mice, and allergens in New York City public housing. Environ Health Perspect. 2009;117(8):1219–25. doi:10.1289/ehp.0800149.

16. Downs D. Natural flea control. Topeka (KS): Mother Earth News; 2023 (https://www.motherearthnews.com/homesteading-and-livestock/natural-flea-control-zmaz87jazgoe/).

17. Burgess IF. Human lice and their control. Annu Rev Entomol. 2004;49(1):457–81. doi:10.1146/annurev.ento.49.061802.123253.

18. Emerson PM, Lindsay SW, Walraven GEL, Faal H, Bogh C, Lowe K et al. Effect of fly control on trachoma and diarrhoea. Lancet. 1999;353(9162):1401–3. doi:10.1016/S0140-6736(98)09158-2.

19. Charlwood JD, Dagoro H. Collateral effects of bednets impregnated with permethrin against bedbugs (Cimicidae) in Papua New Guinea. Trans R Soc Trop Med Hyg. 1989;83:261. doi:10.1016/0035-9203(89)90672-x.

20. Myamba J, Maxwell CA, Asidi A, Curtis CF. Pyrethroid resistance in tropical bedbugs, *Cimex hemipterus*, associated with use of treated bednets. Med Vet Entomol. 2002;16(4):448–51. doi:10.1046/j.1365-2915.2002.00389.x.

21. Roomaney RA, Ehrlich R, Rother HA. The acceptability of rat trap use over pesticides for rodent control in two poor urban communities in South Africa. Environ Health. 2012;11(1):32. doi:10.1186/1476-069X-11-32.

22. The WHO recommended classification of pesticides by hazard and guidelines to classification: 2009. Geneva: International Programme on Chemical Safety, World Health Organization; 2010 (https://iris.who.int/handle/10665/44271).

23. Nalwanga E, Ssempebwa JC. Knowledge and practices of in-home pesticide use: a community survey in Uganda. J Environ Public Health. 2011;2011:230894. doi:10.1155/2011/230894.

24. Rother HA. Poverty, pests and pesticides sold of South Africa's streets. Implications for women and health. Women Environ. 2008;Fall/winter:36–40.

25. Rother HA. Falling through the regulatory cracks: street selling of pesticides and poisoning among urban youth in South Africa. Int J Occup Environ Health. 2010;16(2):202–13. doi:10.1179/107735210799160336.

26. Lima JS, Reis CAG. Poisoning due to illegal use of carbamates as a rodenticide in Rio de Janeiro. Clin Toxicol. 1995;33(6):687–90. doi:10.3109/15563659509010629.

27. Landrigan PJ, Claudio L, Markowitz SB, Berkowitz GS, Brenner BL, Romero H et al. Pesticides and inner-city children: exposures, risks, and prevention. Environ Health Perspect. 1999;107 (Suppl 3):431–7. doi:10.1289/ehp.99107s3431.

28. Balme KH, Roberts JC, Glasstone M, Curling L, Rother H, London L et al. Pesticide poisonings at a tertiary children's hospital in South Africa: an increasing problem. Clin Toxicol. 2010;48(9):928–34. doi:10.3109/15563650.2010.534482.

29. Konradsen F, van der Hoek W, Cole DC, Hutchinson G, Daisley H, Singh S et al. Reducing acute poisoning in developing countries – options for restricting the availability of pesticides. Toxicology. 2003;192(2–3):249–61. doi:10.1016/s0300-483x(03)00339-1.

30. Gunnell D, Eddleston M, Phillips M, Konradsen F. The global distribution of fatal pesticide self-poisoning: systematic review. BMC Public Health. 2007;7(1):357. doi:10.1186/1471-2458-7-357.

31. Gunnell D, Fernando R, Hewagama M, Priyangika W, Konradsen F, Eddleston M. The impact of pesticide regulations on suicide in Sri Lanka. Int J Epidemiol. 2007;36(6):1235–42. doi:10.1093/ije/dym164.

32. Manuweera G, Eddleston M, Egodage S, Buckley NA. Do targeted bans of insecticides to prevent deaths from self-poisoning result in reduced agricultural output? Environ Health Perspect. 2008;116(4):492. doi:10.1289/ehp.11029.

33. Knipe DW, Gunnell D, Eddleston M. Preventing deaths from pesticide self-poisoning –learning from Sri Lanka's success. Lancet Glob Health. 2017;5(7):e651–2. doi:10.1016/S2214-109X(17)30208-5.

34. Eddleston M, Karalliedde L, Buckley N, Fernando R, Hutchinson G, Isbister G et al. Pesticide poisoning in the developing world – a minimum pesticides list. Lancet. 2002;360(9340):1163–7. doi:10.1016/s0140-6736(02)11204-9.

35. Mancini F. Impact of integrated pest management farmer field schools on health, farming systems, the environment, and livelihoods of cotton growers in Southern India. PhD Thesis. Wageningen: Wageningen Universiteit; 2006 (https://edepot.wur.nl/121783).

36. Kogan M. Integrated pest management theory and practice. Entomol Exp Appl. 1988;49:59–70. doi:10.1146/annurev.ento.43.1.243.

37. De Castro MC, Yamagata Y, Mtasiwa D, Tanner M, Utzinger J, Keiser J et al. Integrated urban malaria control: A case study in Dar es Salaam, Tanzania. Am J Trop Med Hyg. 2004;71(2_Suppl):103–17 (https://pubmed.ncbi.nlm.nih.gov/15331826/).

38. Bang Y, Sabuni I, Tonn R. Integrated control of urban mosquitoes in Dar es Salaam using community sanitation supplemented by larviciding. East Afr Med J. 1975;52(10):578 (https://pubmed.ncbi.nlm.nih.gov/54247/).

39. Chavasse DC, Lines JD, Ichimori K, Majala AR, Minjas JN, Marijani J. Mosquito control in Dar es Salaam. II. Impact of expanded polystyrene beads and pyriproxyfen treatment of breeding sites on *Culex quinquefasciatus* densities. Med Vet Entomol. 1995;9(2):147–54. doi:10.1111/j.1365-2915.1995.tb00171.x.

40. Mukabana WR, Kannady K, Kiama GM, Ijumba JN, Mathenge EM, Kiche I et al. Ecologists can enable communities to implement malaria vector control in Africa. Malar J. 2006;5:9. doi:10.1186/1475-2875-5-9.

41. Fillinger U, Kannady K, William G, Vanek MJ, Dongus S, Nyika D et al. A tool box for operational mosquito larval control: preliminary results and early lessons from the Urban Malaria Control Programme in Dar es Salaam, Tanzania. Malar J. 2008;7:20. doi:10.1186/1475-2875-7-20.

42. Maheu-Giroux M, Castro MC. Impact of community-based larviciding on the prevalence of malaria infection in Dar es Salaam, Tanzania. PloS One. 2013;8(8):e71638. doi:10.1371/journal.pone.0071638.

43. Takken W, Lindsay S. Increased threat of urban malaria from *Anopheles stephensi* mosquitoes, Africa. Emerg Infect Dis. 2019;25(7):1431. doi:10.3201/eid2507.190301.

44. Malaria threats map. Geneva: World Health Organization; 2023 (https://apps.who.int/malaria/maps/threats/).

45. Faulde MK, Rueda LM, Khaireh BA. First record of the Asian malaria vector *Anopheles stephensi* and its possible role in the resurgence of malaria in Djibouti, Horn of Africa. Acta Trop. 2014;139:39–43. doi:10.1016/j.actatropica.2014.06.016.

46. Seyfarth M, Khaireh BA, Abdi AA, Bouh SM, Faulde MK. Five years following first detection of *Anopheles stephensi* (Diptera: Culicidae) in Djibouti, Horn of Africa: populations established – malaria emerging. Parasitol Res. 2019;118(3):725-32. doi:10.1007/s00436-019-06213-0.

47. Balkew M, Mumba P, Dengela D, Yohannes G, Getachew D, Yared S et al. Geographical distribution of *Anopheles stephensi* in eastern Ethiopia. Parasit Vectors. 2020;13(1):1–8. doi:10.1186/s13071-020-3904-y.

48. Sinka ME, Pironon S, Massey NC, Longbottom J, Hemingway J, Moyes CL et al. A new malaria vector in Africa: predicting the expansion range of *Anopheles stephensi* and identifying the urban populations at risk. Proc Natl Acad Sci U S A. 2020;117(40):24900–8. doi:10.1073/pnas.2003976117.

49. Ooi EE, Goh KT, Gubler DJ. Dengue prevention and 35 years of vector control in Singapore. Emerg Infect Dis. 2006;12(6):887–93. doi:10.3201/10.3201/eid1206.051210.

50. Egger JR, Ooi EE, Kelly DW, Woolhouse ME, Davies CR, Coleman PG. Reconstructing historical changes in the force of infection of dengue fever in Singapore: implications for surveillance and control. Bull World Health Organ. 2008;86:187–96. doi:10.2471/blt.07.040170.

51. Dengue: guidelines for diagnosis, treatment, prevention and control. Geneva: World Health Organization, Special Programme for Research and Training in Tropical Diseases; 2009 (https://iris.who.int/handle/10665/44188).

52. Lee C, Vythilingam I, Chong CS, Razak MAA, Tan CH, Liew C et al. Gravitraps for management of dengue clusters in Singapore. Am J Trop Med Hyg. 2013;88(5):888. doi:10.4269/ajtmh.12-0329.

53. Sim S, Ng LC, Lindsay SW, Wilson AL. A greener vision for vector control: the example of the Singapore dengue control programme. PLoS Negl Trop Dis. 2020;14(8):e0008428. doi:10.1371/journal.pntd.0008428.

Recommended reading

Alirol E, Getaz L, Stoll B, Chappuis F, Loutan L. Urbanisation and infectious diseases in a globalised world. Lancet Infect Dis. 2011;11(2):131–41. doi:10.1016/S1473-3099(10)70223-1.

Bonnefoy X, Kampen H, Sweeney K. Public health significance of urban pests. Geneva: World Health Organization; 2008:chapters 14, 15 (https://iris.who.int/handle/10665/107363).

Ooi EE, Goh KT, Gubler DJ. Dengue prevention and 35 years of vector control in Singapore. Emerg Infect Dis. 2006;12:887–93. doi:10.3201/10.3201/eid1206.051210.

Rother HA. Falling through the regulatory cracks: street selling of pesticides and poisoning among urban youth in South Africa. Int J Occup Environ Health. 2010;16(2):202–13. doi:10.1179/107735210799160336.

7

Pesticide legislation and regulatory control of use

Contents

Learning objectives

By the end of this course, students should be able to:

- describe the major uses of vector control insecticides;
- comment critically on the requirements and shortcomings of legislation and regulatory control of vector control insecticides;
- analyse national public health pesticide management; and
- demonstrate understanding of the controversy around use of DDT for disease vector control.

7.1 Background

Several vector-borne diseases cause human suffering, particularly among children and poor and marginalized people. Most cases globally are due to malaria and schistosomiasis, followed by dengue, chikungunya and lymphatic filariasis (Table 7.1). Malaria is responsible for most deaths annually, followed by dengue, chikungunya, schistosomiasis and Chagas disease. These diseases are also a burden for national health systems, with recurring costs for treatment and case management, and an economic burden in terms of lost working days, school absenteeism and loss of foreign investment and tourism.

The suffering due to vector-borne diseases is considered to be unacceptable, because means are available for controlling the diseases *(1,2)*. Vector control plays a major role in the control and elimination of most vector-borne diseases, and IVM has been advocated to increase the effectiveness, efficiency and sustainability of vector control *(3)*. The transition to IVM in countries has, however, generally been slow, due largely to shortcomings in policy and financial support. The GVCR has called for use of efficacious interventions and the availability of high-quality vector control products. This requires adequate capacity for optimal application while minimizing the risks of pesticides to health and the environment *(4)*.

Table 7.1. Annual numbers of cases of and deaths due to vector-borne diseases globally

Disease	No. of cases[a]	No. of deaths	Vector
Malaria	229 000 000	409 000	Anopheline mosquitoes
Chagas disease	6 500 000	10 000	Triatomine bugs
Dengue and chikungunya	112 000 000	40 000	Aedine mosquitoes
Human African trypanosomiasis	1116	NA	Tsetse flies
Leishmaniases (visceral and cutaneous)	291 038	491	Sand flies
Lymphatic filariasis	51 400 000	NA	Mosquitoes
Onchocerciasis	21 000 000	NA	Blackflies
Schistosomiasis	236 000 000	24 000	Snails

Sources: WHO *(1,2)*

NA: not available.

[a] Lymphatic filariasis: no. of people infected; onchocerciasis: no. of cases; schistosomiasis: no. of people who required MDA.

Most current methods of vector control rely on pesticides, predominantly insecticides and some molluscicides (for control of schistosomiasis). These pesticides must therefore be used effectively, efficiently and sustainably, with little risk to humans and the environment by ensuring appropriate legislation, regulation and practices of pesticide management.

7.2 Insecticide use for vector control

After observation of the insecticidal properties of DDT in the 1940s, insecticides became the mainstay of vector control. Use of insecticides is particularly common in programmes to control malaria, dengue, leishmaniases and Chagas disease. Use of insecticides in malaria control has increased recently, with massive scaling-up of vector control interventions, which has resulted in substantial reductions in the malaria burden in endemic countries, particularly in sub-Saharan Africa. The heavy reliance on insecticides for vector control is controversial, because it poses risks to human health and to the environment. Furthermore, the development of resistance to insecticides is a growing threat for the continued effectiveness of vector control with insecticides.

7.2.1 Amounts of insecticides used globally

In the context of pesticide management, it is important to understand the amounts used and the purposes of use of vector control insecticides. Extensive data are available for the periods 2000–2009 *(5)* and 2010–2019 *(6)*. During the past decade, vector control insecticides were used mainly for residual spraying, followed by space spraying and larviciding (Table 7.2) *(6)*. The insecticide class most used for vector control, in terms of amounts of product, were the organochlorines, DDT being the only product applied by residual spraying. Organochlorine use was by far the highest in the South-East Asia Region, followed by the African Region. African countries used considerable amounts of organophosphates, carbamates, pyrethroids and neonicotinoids for residual spraying.

Table 7.2. Annual use of insecticides for vector control by residual and space spraying, by region, type of application and insecticide class, in metric tonnes of active ingredient

WHO region	Residual spraying					Space spraying				ITN kits	Larviciding			
	OC	OP	C	PY	NN	OP	C	PY	NN	PY	OP	BL	IGR	SP
African	337	388	335	34	35	0	0	0	0	0	3	0	0	0
Americas	0	6	253	28	0	1038	34	44	0	0	58	43	14	10
South-East Asian	2977	62	3	26	0	13	0	5	0	0	18	37	1	0
European	0	1	0	0	0	0	0	0	0	0	0	0	0	0
Eastern Mediterranean	0	0	35	14	1	0	0	11	0	0	15	2	5	5
Western Pacific	0	1	5	11	0	17	0	15	0	2	5	2	0	0
All	3314	457	631	112	36	1068	34	75	0	2	99	84	20	16

Source: WHO *(6)*.

Insecticide class: BL: bacterial larvicides; C: carbamates; IGR: insect growth regulators; ITN: insecticide treated nets; NN: neonicotinoids; OC: organochlorines; OP: organophosphates; PY: pyrethroids; SP: spinosyns.

Almost all (99%) residual spraying was conducted indoors (IRS). Space spraying was used mainly in the Americas, usually with organophosphate products. ITN kits, which, in the past, were used periodically to treat bed nets manually, have been largely replaced by factory-treated nets, and use of insecticides in ITN kits was negligible in the past decade. Bacterial larvicides were used in almost the same amounts as organophosphate larvicides (predominantly temephos). Use of other larvicide classes, notably spinosyns and insect growth regulators, was lower.

The insecticides were used mainly against malaria (61.3%), followed by dengue (23.7%), leishmaniases (12.5%) and Chagas disease (2.2%) (Table 7.3). The most commonly used products were DDT, deltamethrin, alpha-cypermethrin, lambda-cyhalothrin and bendiocarb. The data do not include the quantity of insecticides in factory-treated ITNs. A variety of insecticide classes were used for malaria control, but use of organochlorines (DDT) dominated (Table 7.3). DDT was also used in the control of visceral leishmaniasis in India. Neonicotinoids were used only for control of malaria. Organophosphates were the main insecticide class used for dengue vector control. Bacterial larvicides, insect growth regulators and spinosyns were used less commonly in the control of dengue than for other diseases. Vectors of Chagas disease were controlled mainly with carbamates.

Table 7.3. Annual global use of insecticides for vector control, as reported to WHO, by disease (or public health pest) and insecticide class, expressed in metric tonnes of active ingredient

Disease or pest	Vectors	Insecticide class[a]								Total
		OC	OP	C	PY	NN	BL	IGR	SP	
Disease										
Malaria	Anopheline mosquitoes	2619	526	358	96	36	23	3	3	3662
Dengue	Aedine mosquitoes	0	1097	173	71	0	61	17	13	1433
Leishmaniases	Phlebotomine sand flies	695	0	16	14	0	0	0	0	725
Chagas disease	Triatomine bugs	0	0	118	9	0	0	0	0	127
Lymphatic filariasis	Mosquitoes	0	0	12	0	0	0	0	0	12
Flea- and lice-borne diseases	Fleas, lice	0	0	0	3	0	0	0	0	3
Zika virus disease	Aedine mosquitoes	0	1	0	1	0	0	0	0	1
Chikungunya	Aedine mosquitoes	0	1	0	0	0	0	0	0	1
Japanese encephalitis	Culicine mosquitoes	0	0	0	1	0	0	0	0	1
Onchocerciasis	Simuliid blackflies	0	0	0	0	0	0	0	0	0
Schistosomiasis	Snails	0	0	0	0	0	0	0	0	0
Tungiasis	Sandfleas	0	0	0	0	0	0	0	0	0
Tick-borne diseases	Ticks	0	0	0	0	0	0	0	0	0
Pests										
Nuisance mosquitoes	–	0	23	5	16	0	2	0	1	47
Flies and other pests	–	0	0	3	0	0	0	0	0	3

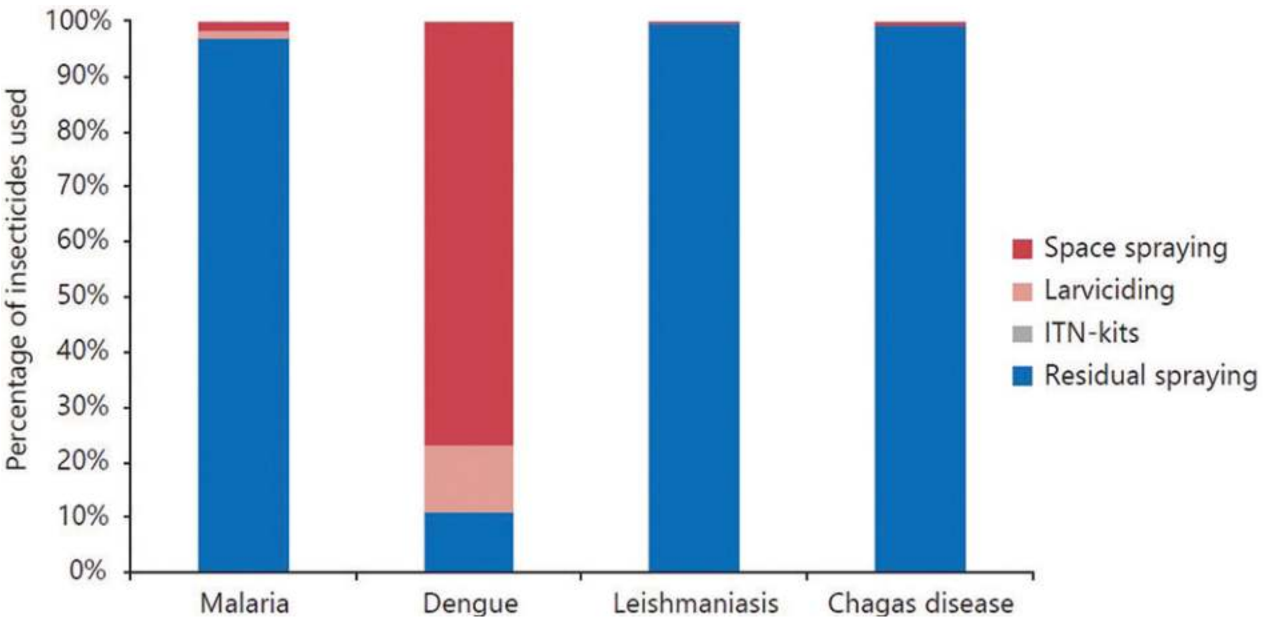
Source: WHO *(6)*.

Data were weighted and pooled for the period 2010–2019.

[a]BL: bacterial larvicides; C: carbamates; IGR: insect growth regulators; NN: neonicotinoids; OC: organochlorines; OP: organophosphates; PY: pyrethroids; SP: spinosyns.

For control of malaria, leishmaniases and Chagas disease, insecticides were applied mainly by residual spraying (Fig. 7.1), while insecticides for dengue control were applied mainly by space spraying, followed by residual spraying and larviciding.

Fig. 7.1. Contributions of four types of intervention to use of insecticides for vector control (excluding ITNs) for four main diseases



Source: WHO *(6)*.

van den Berg H, da Silva Bezerra HS, Al-Eryani S, Chanda E, Nagpal BN, Knox TB et al. Recent trends in global insecticide use for disease vector control and potential implications for resistance management. Sci Rep. 2021;11(1):23867. doi:10.1038/s41598-021-03367-9. *(7)*

In your country, is there a mechanism for collecting and reporting data on use of vector control insecticides? If not, how could this be established? If there is, is it effective, and are the data used?

7.2.2 Spray utility

The total amounts of pesticides used in tonnes of active ingredient do not clearly reflect the extent of public health use, as some pesticides are effective at much lower dosages than others, and the amounts do not show the scale of use, their effectiveness in protecting people, their potential hazard or the risk of insecticide resistance. Pesticide risk managers also need information on the "spray utility" of pesticides in relation to the application rate.

The application rate is expressed in grams of active ingredient per square metre (g a.i./m^2) of sprayable surface (for IRS) or per hectare (for space spraying or larviciding). DDT is recommended at a dosage of

1–2 g a.i./m^2, whereas most pyrethroids are used at only 0.025 g a.i./m^2. Hence, much larger surfaces can be sprayed with 10 kg of a pyrethroid than with 10 kg of DDT.

"Spray utility" is the recommended surface or target area covered by a given amount of active ingredient. Public health insecticides can be separated roughly into two main categories: those with low spray utility (i.e. high recommended dosage) and those with high spray utility (i.e. low recommended dosage). The recommended application rate of organochlorines, organophosphates and carbamates in IRS is about 1.5 g a.i./m^2 *(8)*. An exception is the carbamate bendiocarb, for which the recommended rate (0.1–0.4 g a.i./m^2) is lower than those for other carbamates because of its chemical properties. This group has low spray utility, so that higher amounts of product are required to cover a unit area.

The recommended application rate of pyrethroids is about 0.025 g a.i./m^2, which is equivalent to 1/60th of the dosage of most insecticides in the group organochlorines, organophosphates and carbamates. Hence, the surface area covered with a given amount of active ingredient of pyrethroids is approximately 60 times higher for than that covered by compounds in the first group of organochlorines, organophosphates and carbamates. This is an important consideration in interpreting data on insecticide use.

Differences in spray utility have several implications. In DDT spraying programmes, for example, the cost of transport is significantly increased because of the high application rate. Pyrethroids are much more toxic per gram of product than DDT, and therefore more precautions are necessary during preparation of spray tanks and during spraying. Spray utility must be interpreted correctly in analysing data on insecticide use in vector control, for example to calculate the populations at risk that have been covered by interventions with pyrethroids and other insecticides, such as DDT.

When the spray utility of different insecticide classes differs widely, would there be logistical problems if a programme decides to rotate insecticide classes in order to manage insecticide resistance?

The tables above indicate that much less pyrethroid was used globally, in tonnes of active ingredient, than the organochlorine DDT; however, when the spray utility and the surface area covered are considered, the contribution of pyrethroids is multiplied by a factor of 60. As a result, pyrethroids constitute a major proportion of global insecticide use in terms of spray coverage. Because of their large-scale use, pyrethroids are the insecticides with the highest potential human exposure and the highest risk for development of insecticide resistance.

The dominance of pyrethroids in vector control should be considered carefully by risk managers in designing sustainable strategies of control. A shift to other insecticides could increase exposure of humans and the environment or could raise issues of waste disposal. For DDT, which is listed in the Stockholm Convention, risk managers should develop a phased risk management plan that includes gradual phasing out of DDT and use of alternative products and IVM strategies. A shift from DDT to pyrethroids implies a change in the safety requirements for sprayers, as pyrethroids are much more acutely toxic to humans upon contact than DDT. As pyrethroids are effective at very low application rates, special measures are required for handling the products and preparing spray tanks for field use.

The extremely high spray coverage of pyrethroids in Africa is also highly relevant in the context of insecticide resistance. Currently, all ITN products contain pyrethroids *(9)*, and resistance of malaria mosquitoes to pyrethroids is spreading rapidly in Africa.

Risk managers should consider all the stages in the life cycle of a pesticide to determine the differences among compounds, methods and risks. The analysis should be the basis of plans for risk reduction in relation to each chemical compound.

Why is it important to compare the amounts of insecticides by spray utility, or area covered, instead of the amount of active ingredient?

Risk managers should know the insecticide compounds used in vector control. Each insecticide compound has specific implications for risks to human health and the environment and also for cost, effectiveness and risk of resistance. Risk managers and policy-makers could use decision analysis models in deciding on use of insecticide compounds for vector control *(10)*. This can involve several layers of decision-making and complex trade-offs, for instance for an insecticide that reduces the risk of disease but increases the risk of adverse effects on human health and the environment.

7.2.3 Trends in insecticide spray coverage

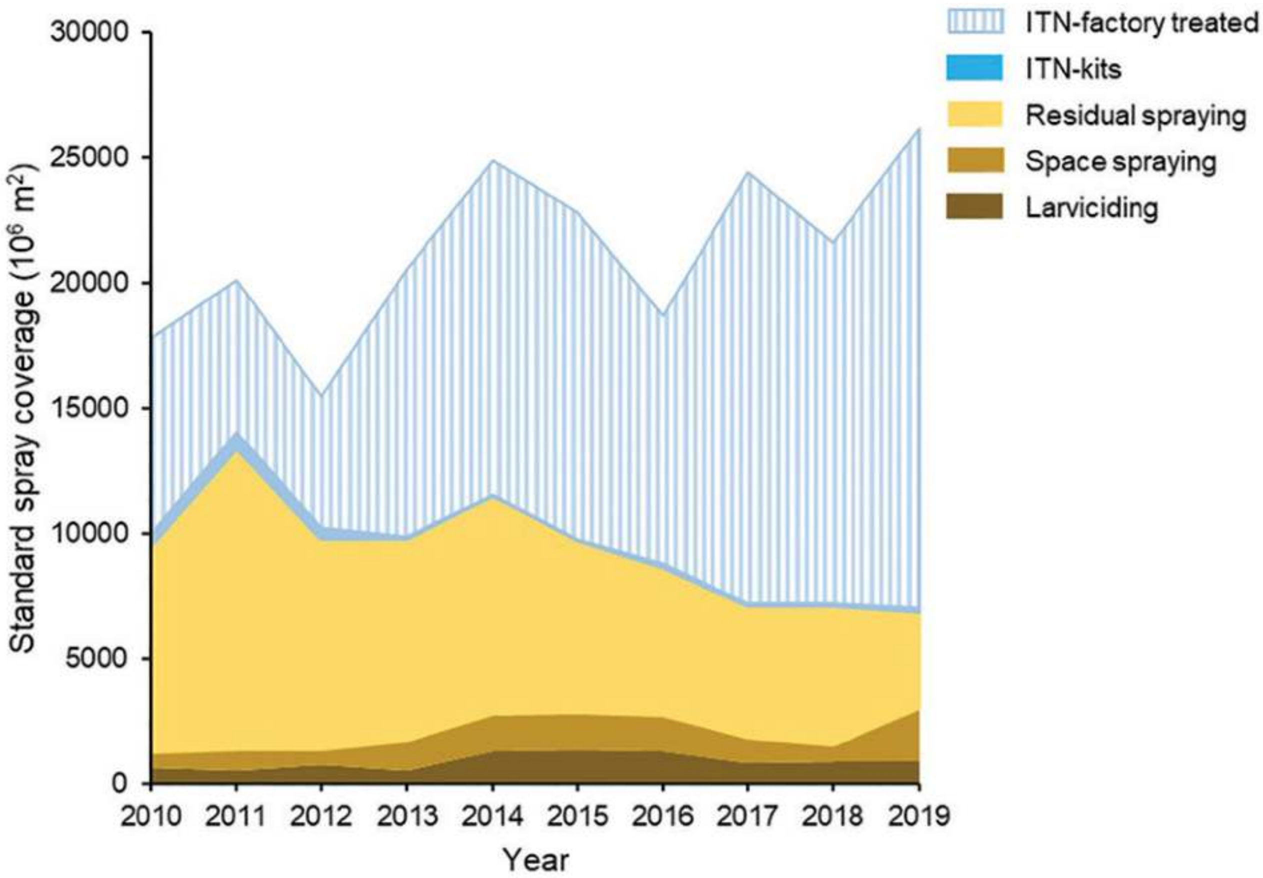
In an analysis of patterns of insecticide use for vector control, insecticide use was referred to in terms of "spray coverage" rather than physical amounts *(7)*. "Standard spray coverage" was defined as the surface covered by a given amount of active ingredient in a single application of IRS, on the assumption that the operations complied with internationally recommended application rates. This allows comparison of insecticide active ingredient and of types of intervention. Factory-treated ITNs accounted for 55% of global insecticide use for vector control in terms of the "standard spray coverage" (Fig. 7.2) and was therefore the main insecticidal intervention. An increasing contribution of ITNs was seen during 2010–2019, suggesting that distribution of ITNs has been increasing. Notable fluctuations in ITN distribution were probably due to fluctuations in delivery of the nets. Use of ITN kits was low and decreasing.

Why is it important to include the insecticides used in ITNs in global estimates of insecticide use, even if they are not sprayed but remain within the net fabric?

Residual spraying represented about one third of all interventions for vector control with insecticides and decreased substantially during the reporting period. Some 97.2% of residual spraying was indoors. Space spraying made an overall contribution of 5.5% and larviciding, 4%.

Global use of DDT decreased by 62.0% during the study period: 13 countries reported DDT use in 2010, and five countries were still using DDT in 2019.

Fig. 7.2. Area graph of global use of vector control insecticides by intervention type



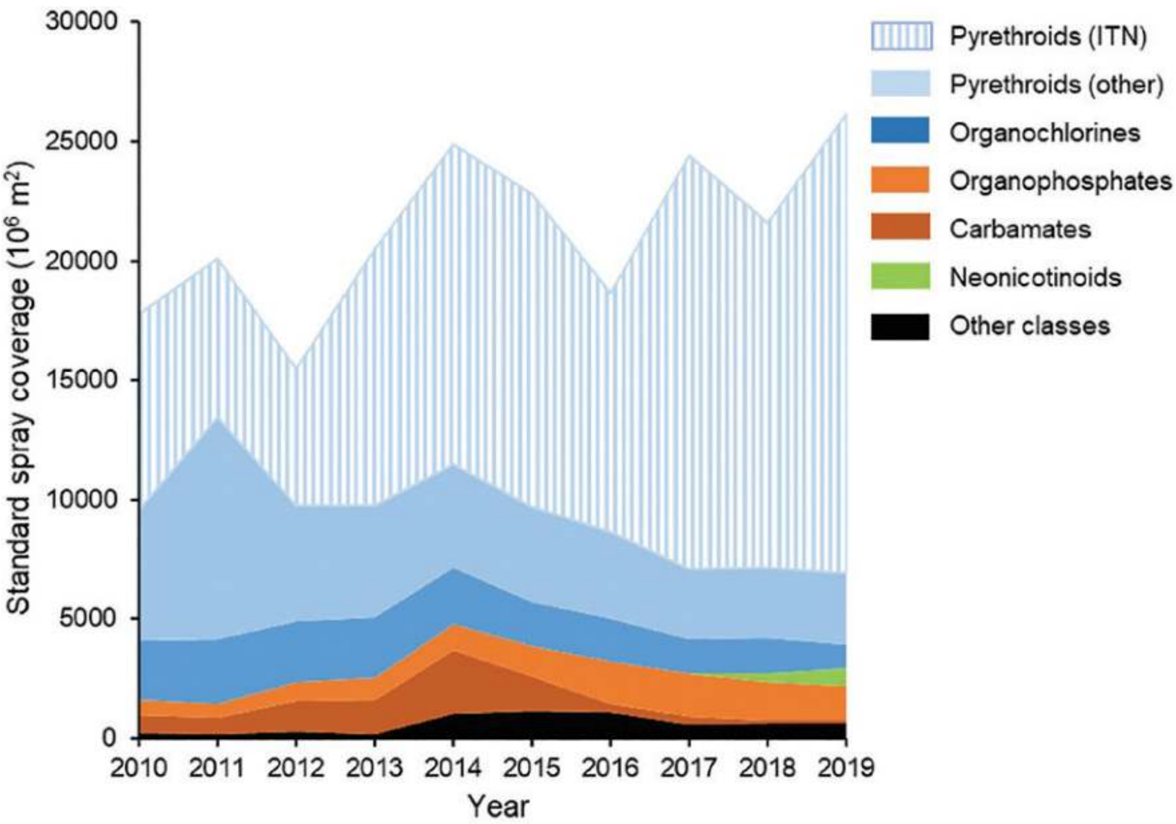
Source: van den Berg et al. *(7)*. Reproduced under the Creative Commons Attribution 4.0 International License (https://creativecommons.org/licenses/by/4.0/).

Results are pooled for the four main diseases – malaria, dengue, leishmaniases, Chagas disease – and are expressed as standard spray coverage.

Fig. 7.2 shows a trend of increased use of insecticides in ITNs and decreased use for vector control spraying operations. As a risk manager, discuss the implications of these trends for risks to human health and the environment and for insecticide resistance.

Fig. 7.3 presents global insecticide use (in standard spray coverage) by insecticide class. Pyrethroids dominated increasingly during the period 2010–2019, due entirely to increased ITN distribution. With use of pyrethroids in spraying operations, they represented the bulk of insecticide use. Use of organochlorines (DDT) decreased, while the contribution of organophosphates increased. Use of neonicotinoids, recently introduced for vector control, increased in 2018 and 2019 for use in malaria control in Africa. Other insecticide classes (e.g. bacterial insecticides) made relatively minor contributions.

Fig. 7.3. Area graph of vector control insecticide use by insecticide class



Source: modified from van den Berg et al. *(7)* with the original data. Reproduced under the Creative Commons Attribution 4.0 International License (https://creativecommons.org/licenses/by/4.0/).

Results are pooled for the four main diseases (malaria, dengue, leishmaniases, Chagas disease) and expressed in standard spray coverage. The striped pattern indicates use of insecticides in ITNs; other areas indicate use in spraying operations (i.e. residual spraying, space spraying, larviciding). Shades of blue and red indicate sub-groups within a mode of action. “Other classes” are bacterial larvicides, insect growth regulators, spinosyns and pyrroles.

In Figs 7.2 and 7.3, why do you think larvicides (e.g. bacterial larvicides) have not contributed more substantially to insecticides used in vector control?

Use of insecticides for vector control has thus been dominated by pyrethroids, at least when expressed in terms of “spray utility” and not tonnes of active ingredient The global contribution of pyrethroids to total insecticide consumption for vector control has increased steadily, especially in the African Region, mainly for use in ITNs for malaria control.

7.3 Principles of pesticide management

The three general principles of pesticide management are:

- manage pesticides appropriately to reduce their risks,
- ensure their effective use, and
- do so throughout all stages of the pesticide life-cycle.

7.3.1 Reduce risks

Pesticides pose several types of risk: risks to spray workers who prepare, mix, apply and rinse the insecticide product during spray operations; risks to the general public, who may be exposed through contact with insecticide applied in or around their house, school or work environment; risks to the environment through insecticide drift or contamination of soil, water or dust; and the risk of insecticide resistance, which develops when insect populations are regularly exposed to insecticides. The aim of pesticide management is to reduce all these risks.

The risk reduction measures discussed here are:

- IVM, a general strategy which contributes to reduce reliance on chemical insecticides for vector control, instead combining various methods and non-chemical preventive methods;
- quality control and registration of pesticides to reduce risks by preventing use of sub-standard, counterfeit or highly hazardous products for vector control and household pest control, and labelling in local languages to ensure proper use by professionals and households;
- personal protective measures with appropriate equipment to protect spray workers in routine spray operations and routine health monitoring of spray workers to detect exposure to pesticides at an early stage;
- proper transport, storage and disposal practices to reduce the risks of accidental pesticide spills and contamination, risks due to accumulation of obsolete pesticides, and risks of environmental contamination and human exposure to pesticides after disposal; and
- insecticide resistance management supported by monitoring, proactive management of rotational insecticide use and mosaic insecticide use to delay or prevent the development of resistance.

7.3.2 Effective use

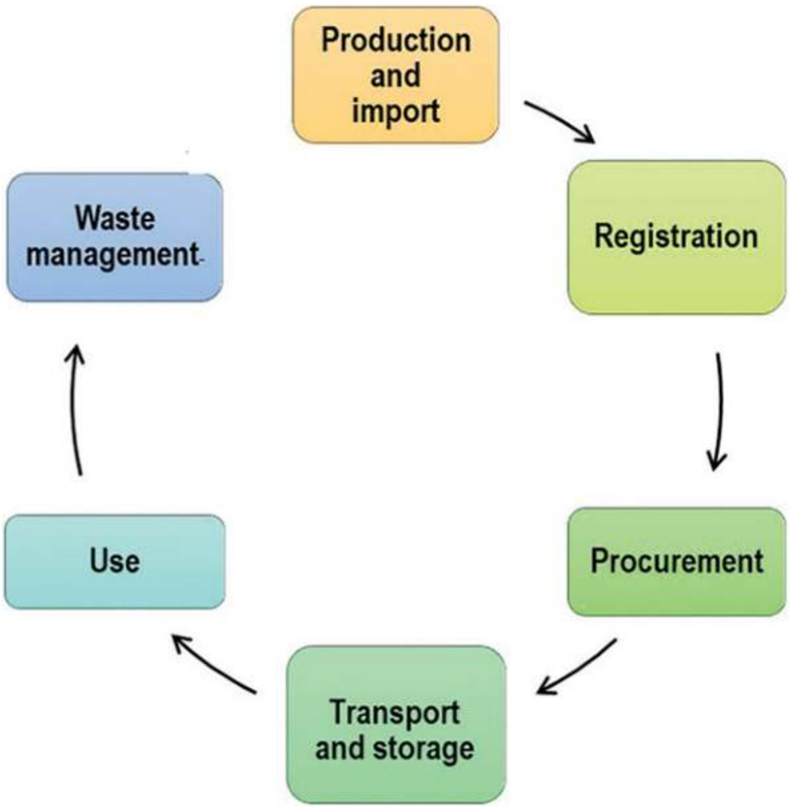
Vector control insecticides are used to kill or repel the vectors of disease pathogens. Hence, the insecticide should be effective in controlling or repelling the vector. When the effectiveness is compromised, for example because of a poor decision or poor application, resources will be wasted and unnecessary risks incurred.

Several means are available to ensure the effectiveness of insecticides. Pesticide registration and quality control are designed to ensure that high-quality products of proven effectiveness are available for use. Evidence-based decision-making consists of deciding on an optimal method of control that is based on empirical evidence. Coordination between programmes (e.g. for malaria and dengue) and between sectors (e.g. health and agriculture) can increase the coverage and effectiveness of vector control interventions. For example, malaria and dengue programmes could share their capacity and equipment for vector surveillance and monitoring insecticide resistance. Management of insecticide resistance can maintain or increase the effectiveness of insecticide interventions. Correct labelling, good operational practices and maintenance of spray equipment are also important to ensure the optimal effectiveness of insecticide use for vector control.

7.3.3 Life-cycle approach

Risks and effectiveness are influenced at several stages of the pesticide life cycle (Fig. 7.4). Therefore, good pesticide management must be respected at all stages, from manufacture, import, registration, procurement, transport, storage, use to waste management (disposal). The practices at each stage can affect the risks and effective use. In Fig. 4, the cycle is not closed because, once pesticides are used or disposed of, they cannot be used in another cycle.

Fig. 7.4. The pesticide life cycle



Source: van den Berg et al. *(11)*. Reproduced under the Creative Commons BY license (https://creativecommons.org/licenses/by-nc-nd/3.0 IGO/).

van den Berg H, Gu B, Grenier B, Kohlschmid E, Al-Eryani S, da Silva Bezerra HS, et al. Pesticide lifecycle management in agriculture and public health: Where are the gaps? Sci Total Environ. 2020;742:140598. doi:10.1016/j.scitotenv.2020.140598, *(11)*

7.4 International policy instruments

International policy instruments relevant to the use of vector control insecticides include three legal instruments and international guidance. These are the Stockholm Convention on Persistent Organic Pollutants, the Rotterdam Convention on the Prior Informed Consent Procedure for Certain Hazardous Chemicals and Pesticides in International Trade, the Basel Convention on the Control of Transboundary Movements of Hazardous Waste and their Disposal, and the International Code of Conduct on Pesticide Management.

7.4.1 Stockholm Convention

The Stockholm Convention on Persistent Organic Pollutants lists the pollutants targeted for global elimination. A persistent organic pollutant is a chemical that, once released, persists in the environment, undergoes long-range environmental transport and has adverse environmental and/or health effects.

DDT is listed as a persistent organic pollutant in the Convention, although use of DDT in IRS for disease vector control is allowed as an acceptable purpose.

Some countries continue to use DDT to control malaria vectors. Practices for managing DDT, from registration and storage to application and disposal, should be adhered to wherever DDT is used.

7.4.2 Rotterdam Convention

The Rotterdam Convention on the Prior Informed Consent Procedure for Certain Hazardous Chemicals and Pesticides in International Trade is an instrument for monitoring the movement of hazardous chemicals, which are subject to the Prior Informed Consent procedure.

DDT is listed as hazardous chemical under the Rotterdam Convention. Exports of DDT are allowed only if the State of import has consented to future import through an import response. The import responses are published in the Prior Informed Consent Circular, which is updated every 6 months. Import restrictions under the Rotterdam Convention are expected to prevent the accumulation of unwanted DDT stockpiles and wastes. Several countries still have stockpiles of obsolete DDT that accumulated before the Rotterdam Convention entered into force.

7.4.3 Basel Convention

The Basel Convention on the Control of Transboundary Movements of Hazardous Waste and their Disposal promotes environmentally sound management of hazardous wastes and restricts transboundary movement of hazardous wastes, except where the conditions of environmentally sound management are met. Countries have the right to prohibit import of hazardous waste, such as DDT waste, for disposal.

DDT is covered under the Basel Convention as an eco-toxic substance. The Convention can assist in managing environmentally sound disposal of unwanted stockpiles of insecticides, contaminated waste and other obsolete pesticides.

7.4.4 International Code of Conduct

The International Code of Conduct on Pesticide Management guides government regulators, the private sector and other stakeholders on “best practices” in the management of pesticides throughout their life cycle – from production to disposal *(12)*. Its aim is to strengthen the capacity of developing countries to regulate, evaluate and enforce effective control of pesticides.

A series of technical guidelines have been published to elaborate on specific articles of the Code, such as on pesticide legislation or pesticide procurement. The guidelines have been summarized, with web links, in a recent document from FAO and WHO *(13)*.

7.5 Pesticide legislation

Legislation can be used by authorities to exercise control over the management and use of pesticides to ensure that the interests of users, health and the environment are properly protected *(14)*. Pesticide law is the core of pesticide legislation, while the issues raised in the law are regulated in further detail in pesticide regulations.

Since the Code of Conduct was first published, awareness of the hazards of pesticides has increased, and, now, almost every country has some type of pesticide legislation. The comprehensiveness and currency of the legislation, however, varies. Countries should update their pesticide legislation regularly.

7.5.1 Requirements for legislation

- Legislation should have a well-defined scope and should preferably cover all types of pesticides or identify groups of pesticides that are not covered
- Legislation should cover all aspects of the pesticide life cycle, including manufacturing, formulation, packaging, advertising, distribution, storage, use and final disposal of the pesticide product and/or its containers.
- Pesticide legislation should be made consistent with other relevant legislation (e.g. on environmental protection or human health). National legislation should be made consistent with regional initiatives and international agreements on pesticide management.
- Countries should have clearly defined institutional pesticide authority(ies), with clear responsibilities and mandates, and a pesticide registration board, a pesticide registrar and a registration system, with infrastructure for registration and enforcement.
- Pesticide legislation should be adapted to local conditions of pesticide use (e.g. availability of personal protective equipment [PPE] and climatic conditions during spray operations).
- Legislation on vector control insecticides should take into account the context of an IVM policy and indicate that pesticides are only one of several options for the control of vectors of human diseases. Legislation should be supported by policies to promote less use and judicious use of pesticides (e.g. IVM training, research on alternatives, use of low-risk products).

Management of vector control insecticides is particularly difficult in countries in which health systems or vector control programmes are decentralized, with transfer of decision-making on the use of pesticides from national to local, district or provincial level. As a result, insecticides procured directly by district health offices may not meet the national standards of product quality, and training, supervision and methods of application may not be available. A national policy and guidelines on pesticide management (including vector control insecticides) is therefore crucial.

International guidelines are available to assist countries in developing legislation on pesticide management. The guidelines call on countries and parties to establish or strengthen capacity for regulation of the sound management of pesticides *(15)*. While most countries have legislation on the control of agricultural pesticides, a significant number do not have regulations for public health pesticides (including vector control insecticides), which could therefore “fall through the cracks” of the legal system.

Why is it problematic if national legislation does not cover vector control insecticides? Think of examples or situations in which this is a problem.

The international standards are promoted under the International Code of Conduct on Pesticide Management *(12)* and two World Health Assembly resolutions, WHA 63.25 and WHA 63.26 *(16)*. These international instruments call upon national governments to cooperate with pesticide exporting and importing countries, the pesticide industry and international and nongovernmental organizations on the sound management of pesticides in agriculture and public health.

7.5.2 Situation of pesticide legislation

A global survey has been conducted jointly by FAO and WHO to establish the global situation of pesticide management as a basis for risk management *(17)*. Most (95%) countries reported that they had pesticide legislation (Table 7.4); however, the scope and provisions of national pesticide legislation varied widely. For example, the legislation covered public health pesticides in only 60% of countries, while that in the other 40% addressed agricultural pesticides only. Biopesticides, including bacterial larviciding compounds such as *B. thuringiensis israelensis* and *B. sphaericus*, were covered by pesticide regulations in 81% of countries. Thus, the legislation in some countries should be extended to cover these important alternatives to chemical pesticides.

> In your opinion, what are the underlying institutional reasons for coverage in the pesticide legislation of some countries of agricultural pesticides but not public health pesticides?

Table 7.4. General legal provisions for pesticide legislation

Item	%	N
Pesticide legislation in place	95	56
Public health pesticides covered by legislation	60	53
Biopesticides covered by legislation in place	81	52
Legal provisions for re-registration in place	84	56
Legal provisions on highly hazardous pesticides	35	55
Policy on sub-standard/counterfeited pesticides in place	67	51

Source: WHO (17).

%: percentage of responding countries with a positive score; N: number of responding countries.

Legal provisions for re-registration allow periodic re-evaluation of whether a pesticide product is still required after several years. Such a provision was in place in 81% of countries. Most (65%) countries had no legal provisions on highly hazardous pesticides, which are pesticides acknowledged to present particularly high acute or chronic hazards to the environment or human health, especially when used on small farms or in domestic settings with manual equipment *(12)*. This is a serious concern and must be addressed. Policy to prevent and prohibit the production, sale, distribution or use of sub-standard or counterfeit pesticides was reported by 67% of countries (Table 7.4) but in only a few countries in Africa.

> Why is legislation on periodic re-registration of pesticide products important?

Legislation on manufacturing, including pesticide formulation, existed in 69% of countries, indicating further gaps in the global situation (Table 7.5). More countries had legislation on pesticide labelling (89%). Labelling of pesticide containers is important to convey information to end users about the methods of use, safety and proper disposal. Labels should be approved by the responsible authority and should include cautionary messages about the hazard of the pesticide compound and instructions on personal protection for applicators. Labelling should be in accordance with the criteria of the Globally Harmonized System of Classification and Labelling of Chemicals according to their health, physical and environmental hazards. Most countries did not have proper legislation on the retailing, advertising and on-line sales of pesticides and particularly for on-line sales of pesticides (Table 7.5).

Table 7.5. Legal provisions for pesticide manufacture and trade

Legislation in place	%	N
On manufacture	69	54
On pesticide labelling	89	55
To control pesticide retailing	45	53
To control pesticide advertising	40	53
To control on-line sales	24	51

Source: WHO *(17)*.

%: percentage of responding countries with a positive score; N: number of responding countries.

Identify the specific risks if legislation on pesticide advertising and on-line pesticide sales is not in place.

Pesticides must be safely stored, transported and disposed of to ensure the quality of products and to minimize contamination of the environment. In the global survey on pesticide management, only half of all countries had national legislation on pesticide storage, transport and waste management, and legislation was particularly weak or absent in lower-income countries (Table 7.6). Safe storage, transport and waste management are especially important in vector control programmes, in which large quantities of insecticides are used. If there are no legal provisions for safe pesticide storage, transport and waste management, unnecessary human exposure and environmental pollution are likely. Fig. 7.5 shows an expired stock of DDT awaiting disposal.

Table 7.6. Legal provisions for pesticide transport, storage and waste management

Legislation in place	%	N
Safe storage of pesticides	56	55
Safe transport of pesticides	47	51
Disposal of obsolete pesticides	51	51
Disposal of empty containers	42	50

Source: WHO *(17)*.

%: percentage of responding countries with a positive score; N: number of responding countries.

What are the legal provisions for pesticide management in your country?

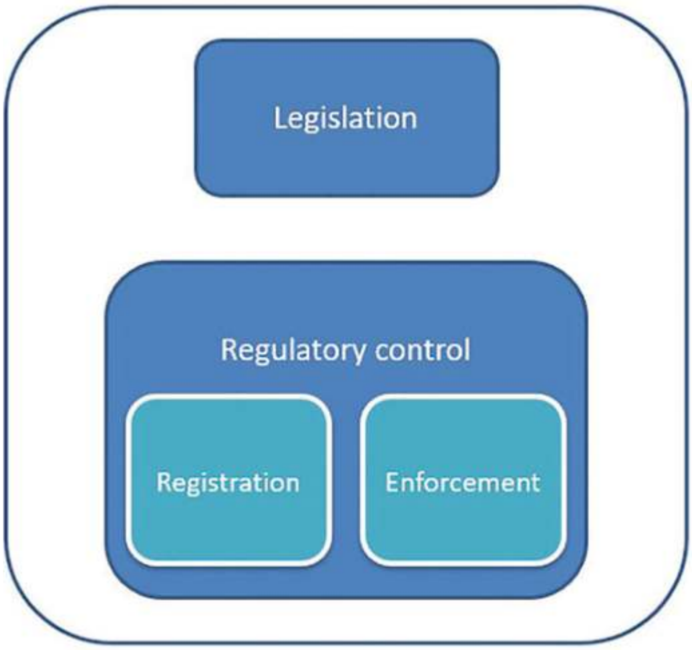
Fig. 7.5. Date-expired stocks of DDT before disposal, Mauritius, 2007 (left); Bangladesh, 2019 (right)

Source: photos courtesy of H. van den Berg (left); Rajpal S. Yadav/WHO (right).

7.6 Pesticide regulatory control

Regulatory control over public health pesticides includes pesticide registration and enforcement of legislation by a national authority. Legislation, registration and enforcement are thus the three instruments with which national authorities control the management of pesticides (Fig. 7.6).

Fig. 7.6. Instruments for control of the management of public health pesticides



7.6.1 Unit of authority

Pesticide regulatory control is increasingly complex as the number of pesticide products increases and the requirements for registration and use become stricter. The Code of Conduct therefore recommends that one central authority be responsible for regulatory control of all pesticides, both agricultural and for public health, and their legislation *(12)*. A single unit of authority facilitates oversight and regulatory control, which will streamline and speed up the process of registration. In most countries, the ministry of agriculture is the central authority responsible for regulation of pesticides. Public health pesticides must be of the same priority in regulatory control as agricultural pesticides. Currently, this is not the case in some countries.

WHO further recommends that, in countries where public health pesticides are not under the authority of the ministry of health, this ministry should be represented on the national committee or pesticide board and participate actively in assessment, safety evaluation and development of policies and guidelines on all public health pesticides in the country *(14)*. Particularly in a vector-borne disease emergency, when importation and procurement of a new vector control product must be accelerated, special legislative consideration should be given to selected insecticides. This will require active participation of the health ministry on a pesticide board.

Pesticide regulators should be aware of the specific requirements for the management of public health pesticides, which differ in several respects from those for agricultural pesticides. Public health pesticides are used to protect people in and around their houses against pests and vector-borne diseases transmitted by insects. Interventions with pesticides in close proximity to humans and their pests increases the risk of human exposure. Consequently, WHO recommends only a few insecticide compounds for use indoors and even fewer for use in bed nets. Use of pesticides for household purposes potentially puts those compounds within reach of children.

- If your country has one regulatory authority for pesticides, does it operate effectively, or does it have any problems?
- If your country does not have one regulatory authority, what prevents establishment of such an authority?

7.6.2 Pesticide registration

Pesticide registration is the process in which a responsible national government authority approves the sale and use of a pesticide after evaluation of comprehensive scientific data that demonstrate that the product is effective for the intended purposes and does not pose an unacceptable risk to human or animal health or to the environment *(14)*. Pesticide registration enables authorities to determine which products they can permit to be sold and used and for what purposes, and to exercise control over aspects such as quality, use levels, labelling and packaging.

Some countries have separate registration authorities for agriculture and public health products or a registration authority that covers agricultural pesticides only. This leads to lack of harmonization of standards on pesticides. FAO and WHO encourage governments to integrate ministerial responsibilities for regulatory control of pesticides, with one central pesticide authority and, preferably, one law that applies to all pesticides.

Some pesticides are restricted for certain uses or for use by certain agencies. As discussed in above, registration is based on an appraisal of comprehensive scientific data on the pesticide product that indicates that the product will be effective and will not pose unacceptable risks to human health or the environment. Registration is usually coordinated by a registrar and evaluated by a designated committee or pesticides board with representation of several sectors.

Applicants submit a registration dossier to the registrar that meets the stipulated data requirements. The dossier is assessed by qualified technical experts, who evaluate the data on efficacy and effects on human and environmental effects. A decision is made on whether to register the pesticide product according to certain criteria.

After registration of a pesticide, post-registration activities are conducted to ensure that the intended standards of pesticide management and use are respected. Certain vector control products, such as DDT, are often illegally traded and used in agriculture and for domestic purposes. To prevent or contain unauthorized trade and use, the health and agriculture sectors should collaborate on post-registration monitoring. Coding and tracking pesticide sachets or containers (track-and-trace systems) can also be used to monitor misuse and illegal trade of the pesticide products used in a vector control programme *(18)*. An example of such a system is shown in Box 7.1). Violations of government regulations should be countered by appropriate punitive measures *(19)*.

Box 7.1. Example of a system to track-and-trace pesticide sachets used in IRS

"On reception at the district office, count all sachets and stamp them with the district stamp, if appropriate, and register the count in the stock book.

"The storekeeper issues only enough refills for the day's operations to each spray operator. Each spray operator's code is written on the sachets issued. The spray operator must sign for these sachets in the logbook.

"At the end of each spray day, all spray operators sign the logbook for their empty and full sachets. Both the storekeeper and the supervisor compare the number of sachets returned with the number issued. Stock remaining should equal the stock issued in the morning, minus the number of sachets used during the day. The number of sachets used should be equal to the number of can refills.

"The storekeeper submits insecticide stock balances and sign-in/sign-out logs to the data manager."

Source: RTI International *(18)*.

To ensure an effective system of registration for public health pesticides, national guidelines should be available on all aspects of registration, including data requirements, steps and procedures to promote transparency *(20)*. According to the global survey, only 41–43% of countries had published guidelines on pesticide registration and data requirements (Table 7.7).

Table 7.7. Conditions of pesticide registration

Condition	%	N
Guideline on data requirements for pesticide registration	41	57
Guideline on pesticide registration	43	56
More than 10 staff working on pesticide registration	43	56
Identification of registered highly hazardous pesticides completed	63	54

Source: WHO *(17)*.

%: percentage of responding countries with a positive score; N: number of responding countries.

Pesticide registration is labour-intensive. Assessment of applicants' dossiers for pesticide products, which contain large datasets from field and laboratory tests, requires adequate human resources, as does post-registration monitoring of use, trade and management of pesticides. In many countries, particularly low-income countries in Africa and Latin America, 10 or fewer staff work on pesticide registration (Table 7.7). Although highly hazardous pesticides require special attention from registration authorities, identification of these pesticides among those registered had been completed in only 63% of countries, and only a few countries had used strategies to reduce the risks of these pesticides *(17)*. FAO, in collaboration with WHO, has established an on-line Pesticide Registration Toolkit to support pesticide registrars in evaluating pesticides and making decisions *(21)*. The target users are primarily in lower- and middle-income countries *(17)*.

Data requirements

The registration process depends on the availability of scientific data, collected locally or abroad. The registration status of a pesticide in the country of origin is useful information for a country that plans to import or use the pesticide. If registration in the country of origin strictly followed the rules, its registration status in that country could be useful for deciding to accept use of the pesticide for a specific use. The data and information commonly assessed for registration of a public health pesticides are: identity, physical and chemical properties, detailed use, classification, packaging, labelling, impact on human health, residues, fate and behaviour in the environment, effects on non-target species, and efficacy *(17)*.

Periodic review

Most insecticides registered for the control of adult mosquitoes were developed several decades ago. There are few new products for mosquito control because the market is smaller than that for agricultural pesticides and because of the complex procedure and cost involved in registration in many countries. When adulticides for mosquito control were registered decades previously, the data that supported their registrations may be outdated and not meet current requirements. Furthermore, the conditions in which pesticides are used in countries may change over time. In particular, populations of pests and vectors are rapidly developing resistance to insecticides in many countries.

The Code of Conduct recommends that countries establish a procedure for re-registration and periodic review of pesticides. This requires collection of new data and appropriate regulatory action as indicated by the data. An obstacle to regular re-registration is the considerable cost involved in most countries. In the European Union, a directive forbids use of insecticides for mosquito control, which leaves countries without products to control invasive mosquitoes *(22)*.

In a previous survey, 73% of the countries surveyed reported that a provision in their legislation required periodic review and re-registration of pesticides *(23)*. Risk managers should determine whether their country will conduct periodic reviews. Periodic review is costly, however, for pesticide distributors and end-users, and this is a particular problem in small markets such as in developing countries.

Regional coordination

Because of the complexity of pesticide registration, which requires accurate, contemporary data and capacity, countries in some regions or sub-regions could collaborate on this issue. Regional pesticide registration can ensure harmonization of pesticide registration requirements and improve the efficiency of registration by sharing work and data and avoiding duplication of effort.

In the global survey, almost 50% of countries reported that they were part of a regional pesticide registration scheme. The highest participation in such schemes was recorded in the African Region; examples are the Comité Sahélien des Pesticides, the Southern African Pesticide Regulators Forum and the Central Africa Inter-State Pesticides Committee. Examples of regional pesticide schemes elsewhere are the technical committee on pesticides in the Andean region, and the European Union programme on plant protection products and biocides.

Countries can also collaborate on aspects such as pesticide quality control, which demands specialized skills and expensive laboratory equipment. Small or resource-poor countries cannot establish national pesticide laboratories but could share work and establish laboratory capacity at subregional or regional level to make the best use of available resources. In regional schemes, risk managers must ensure that the standards and criteria are agreed by all participating countries and that flexible measures are included to account for differences between countries. Regional schemes could also prevent accumulation of stockpiles of public health pesticides in countries.

In a few words, what are the advantages and disadvantages of regional pesticide schemes?

7.6.3 Compliance and enforcement

Enforcement is critical in the management of public health pesticides. National rules and regulations on pesticides should be strictly enforced by the government agency responsible for managing pesticides *(19)*. Enforcement requires up-to-date information on compliance obtained by monitoring adherence to safety standards at sites of production, import, distribution and retail of pesticides and also monitoring of pesticide quality, use and application, environmental pollution, and human poisoning.

Pesticide quality control

Quality control involves determination of the quantity of active ingredient(s) and relevant impurities and the suitability of formulations. Countries must have access to suitable laboratory facilities for analysing pesticides, including vector control insecticides. Poor-quality pesticides, which are common in low- and middle-income countries, can increase health and environmental risks and reduce efficacy.

In the global survey, 59% of responding countries had a national pesticide quality control (testing) laboratory (Fig. 7.7), although fewer countries in the African and Western Pacific regions had a laboratory (Table 7.8) *(17)*. Two thirds of countries measured the active ingredient for pesticide quality control, while just over half also analysed the physical and chemical properties of the pesticides (Table 7.8). In 16% of countries, pesticide samples were sent regularly to a laboratory in another country for analysis.

Investment in quality control is important in large-scale vector control programmes in which large quantities of pesticide are used and the lives of human populations are at stake. The quality of the pesticides used should be maintained to ensure their efficacy for public health interventions. All public health pesticides should be obtained from trusted sources and samples of tested in appropriate laboratories. A large number of registered products complicates pesticide quality control. Risk managers should make balanced decisions on testing of public health pesticides according to criteria such as the public health significance of the intervention in which the pesticides are used, the cost of testing, the number of products, and options for regional coordination.

Fig. 7.7. A pesticide analysis laboratory

Source: photo courtesy of H. van den Berg.

Table 7.8. Quality control, monitoring and enforcement of pesticide regulations

Item	%	N
Pesticide legislation extensively monitored	47	55
Pesticide legislation extensively enforced	47	55
National laboratory for quality control in place	59	54
Laboratory capacity for analysis of active ingredients	66	56
Laboratory capacity for analysis of physical–chemical properties	54	54

Source: WHO *(19)*.

%: percentage of responding countries with a positive score; N: number of responding countries.

Compliance

Even in countries with adequate pesticide legislation, there may be no monitoring or enforcement of compliance. In the global survey, 47% of countries reported that legislation on public health pesticides was monitored and enforced extensively (Table 7.8). Monitoring of compliance requires effective coordination and efficient use of resources for inspections when necessary, including inspection of pesticide production sites for safety systems, inspection of importers and distributors to prevent the entry and distribution of prohibited pesticides, and inspection of retailers to ensure their compliance with national legal provisions. Government inspectors should report to national regulatory authorities for corrective follow-up actions as required.

Inspection should also involve post-registration surveillance, particularly of the conditions and purposes of pesticide use, and collection of data on pollution and poisoning, with geographical coverage, representing all public and private sectors in which pesticides are used *(24)*.

Enforcement

Enforcement includes investigation and legal action to ensure compliance with national pesticide regulations. Enforcement is based on information collected by monitoring compliance. Violations of regulations should be brought to the attention of authorities. The response to violations should be fair, predictable and proportional.

Enforcement requires good collaboration between inspectors and departments of customs, trade and police. Pesticide inspectors should be trained in specific aspects of public health pesticides to ensure that they are used for their intended purposes: to control vectors or domestic pests and reduce the risk of human exposure due to domestic use. Unfortunately, few countries have adequate schemes to enforce pesticide regulations; only 33% of countries reported that pesticide legislation on public health pesticides was extensively enforced *(17)*.

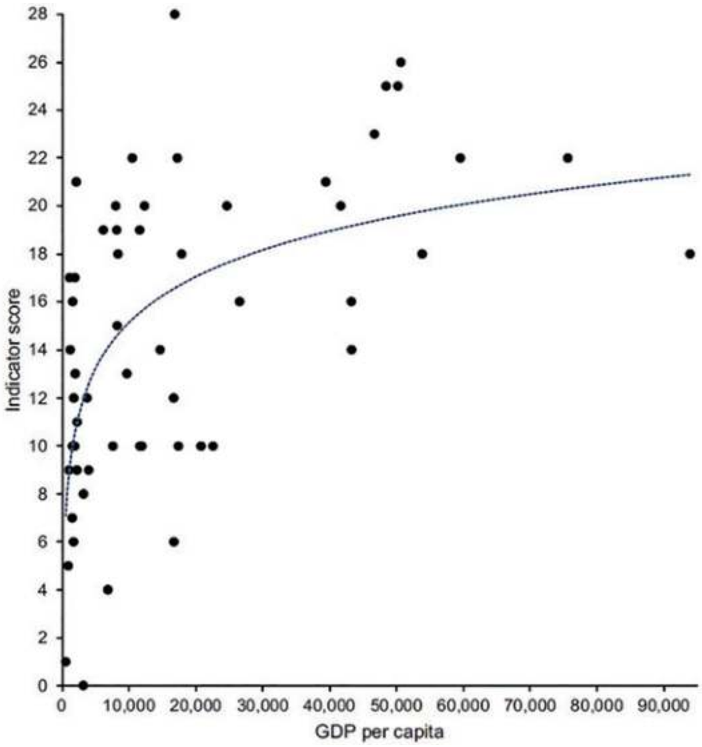
Monitoring and effective enforcement are also necessary for trade in illegal and counterfeit, adulterated or substandard public health pesticide products, including cross-border movement *(25)*.

Sub-standard and counterfeit pesticides used in public health are considered a "major to moderate problem" in most countries, particularly in the African, Americas and European regions. Consequently, pesticide quality should be checked routinely with samples obtained from pesticide outlets.

In your country, which aspects of pesticide quality control, compliance monitoring and enforcement are lacking or weak?

A study in 56 countries showed a clear pattern among 28 indicators of pesticide legislation, regulatory control and socioeconomic level (Fig. 7.8). Resource-poor countries had substantially lower scores than middle- and higher-income countries. Thus, resource-poor countries had poorer pesticide regulatory control, resulting in higher risks than richer countries.

Fig. 7.8. Relations between pesticide regulatory control and standard of living



Source: van den Berg et al. *(11)*. Reproduced under the Creative Commons 3.0 license (https://creativecommons.org/licenses/by/3.0/).

Indicator scores (number of positive indicators among 28 indicators) versus GDP per capita purchasing power parity (2017 international US$) for 56 countries.

7.7 Needs assessment of pesticide management

A country's system of legislation and regulatory control of public health pesticides should be based on assessments of the current situation and an analysis of any gaps in the current system of vector control. A situation analysis and a problem analysis are the basis for assessing the policy, managerial, infrastructure and human resource needs, or requirements, for vector control. A situation analysis and a needs assessment therefore inform policy on pesticide management.

7.7.1 Situation analysis

A situation analysis of existing legal, institutional, technical and administrative conditions is a first step in developing a national action plan for improving public health pesticide management. WHO has developed a tool for situation analysis for public health pesticide management *(26)*. The main elements are assessment of:

- legislative control of public health pesticides;
- other chemical-related legal instruments relevant to the management of public health pesticides;
- vector and public health pest management;
- activities by research institutions, industry and civil society organizations in the management of public health pesticides;
- participation in international conventions and agreements related to pesticide management;
- other relevant pesticide management activities;
- pesticide poisoning;
- public education;
- collaboration with international, regional or bilateral organizations and countries on pesticide (including public health pesticide) management;
- information exchange and consultation;
- formulation and repackaging;
- pesticide storage and waste management, including disposal;
- financial resources available and required for public health pesticide management; and
- other relevant Information.

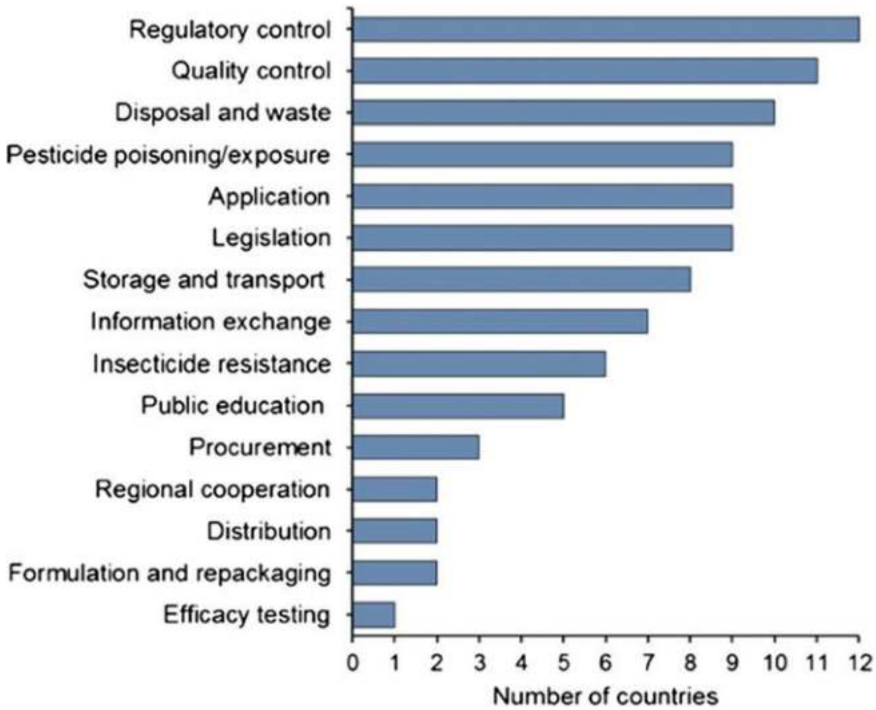
The tool for situation analysis was used in a multi-country WHO project, which provided valuable lessons, revealing both strong points and shortcomings in the spectrum of pesticide management practices *(27)*. Most countries had inadequate legislation on procurement, transport, storage and disposal of public health pesticides. Several did not have appropriate stock management capacity, storage facilities or disposal mechanisms and lacked guidelines on procurement, transport, storage, use and waste disposal. Countries reported inadequate capacity or guidelines for preparing dossiers for registration of public health pesticides. Only half of the countries had a fully operational quality control laboratory, and they reported poor intersectoral coordination and lack of or inadequate implementation of national policies for IVM and pesticide management. These results suggest inadequate implementation of the Code of Conduct. The situation analyses and their documentation have increased awareness in countries about shortcomings in pesticide management and the importance of identifying areas for improvement.

Guidelines on situation analysis for public health pesticide management. Geneva: World Health Organization; 2005 (https://iris.who.int/handle/10665/69006). *(26)*

7.7.2 Needs assessment

The outcomes of the situation analyses were subsequently used by countries for needs assessment to develop national action plans for strengthening the management of pesticides, particularly those for public health use. Fig. 7.9 shows the needs for action in 12 countries. The topics most commonly selected were: regulatory control, quality control, legislation, disposal, application, and monitoring of pesticide poisoning or exposure. Each national action plan included an average of eight topics.

Fig. 7.9. Frequency of mention of topics in national action plans on pesticide management



Source: van den Berg et al. *(27)*. Reproduced under the Creative Commons Attribution 4.0 International License (https://creativecommons.org/licenses/by/4.0/).

Numbers of countries that had incorporated each topic in their action plan

In view of the large number of actions per country, plans that include all the action points would probably be too ambitious. Hence, countries should prioritize certain activities in their plans and seek external donor support for implementation.

The situation analysis for pesticide management overlaps with the guidelines for a vector control needs assessment developed by WHO *(28)*. The guidelines have a broader scope, covering all aspects of vector control, policies, institutional aspects, intersectoral collaboration and community participation.

7.8 The DDT controversy

Decisions on the selection and use of insecticides for vector control, supported by legislation and regulation, should be based on an analysis of cost, effectiveness, social acceptability and risks *(10)*. Decisions can be complex when difficult trade-offs are to be made. An example is DDT, which has proven effectiveness in controlling malaria and, until recently, visceral leishmaniasis, but which also causes environmental pollution and affects human health. The first global malaria eradication campaign was based on periodic, intensive use of DDT in IRS for 3–5 years to interrupt malaria (see section 5.1). After the campaign ended, in 1969, partly due to widespread resistance to DDT in vector populations, use of DDT was stopped in many countries, although it remained effective and continues to be used in some countries.

7.8.1 The debate

Publication of the book *Silent Spring* by Rachel Carson in 1962 raised controversy about the safety of DDT for human health and the environment. Many western countries officially banned the use of DDT *(29)*, while several malaria-endemic countries continued to use DDT in IRS. It was considered to be effective, to have longer residual activity than other insecticides and was cheaper than the alternative insecticides. DDT did not have apparent acute toxic effects. When, in the late twentieth century, DDT was named as one of the 12 persistent organic pollutants (the "dirty dozen") in negotiations that led to the Stockholm Convention, new debate began about the continued need for DDT.

During the same period, in 1966, another important development was the change by South Africa from a policy of using DDT in IRS to use of pyrethroids. Soon after this policy change was implemented, however, the highly efficient vector *An. funestus*, which had been eradicated locally, reinvaded the country because it had developed resistance to pyrethroids but not to DDT. Furthermore, IRS with pyrethroids was a failure. Outcry about the negative consequences of the policy change, with mounting numbers of malaria cases, soon led to reversion to the policy of using DDT. Although the Stockholm Convention intended to impose a global ban on DDT, fierce debate was held on whether DDT use should be continued for malaria control or be banned globally. It should be noted that the situation in southern Africa was unique, because of the role of *An. funestus* in malaria transmission, its resistance to pyrethroids and its susceptibility to DDT.

The Stockholm Convention made an exception for DDT by including its continued acceptable use for disease vector control. Hence, DDT continues to be acceptable for disease vector control, provided that the guidelines and recommendations of WHO and the Stockholm Convention are met, until locally appropriate, cost-effective alternatives are available for a sustainable transition from DDT *(30)*, and that best practices are used to protect spray workers and residents in treated households from exposure arising from IRS with DDT *(31)*.

In your opinion, what would have been the consequence if DDT had not been exempted for the acceptable purpose of vector control?

Some countries still depend on DDT to protect people against malaria in settings where malaria is endemic and where the vector species rests inside people's houses and is still susceptible to the chemical. The low cost, ease of application and extended residual activity of DDT make it preferable to other chemicals in resource-poor health services. In a few countries, malaria mosquitoes have been surprisingly slow to develop resistance to DDT. In other countries and areas, however, DDT has lost its efficacy or continues to be used despite various levels of resistance in the vectors. The debate on use of DDT continues *(32,33)*.

Van Dyk JC, Bouwman H, Barnhoorn IEJ, Bornman MS. DDT contamination from indoor residual spraying for malaria control. Sci Total Environ. 2010;408:2745–52. doi:10.1016/j.scitotenv.2010.03.002. *(34)*

7.8.2 Environmental concerns

DDT is a highly persistent molecule, especially at moderate-to-low temperatures. It is toxic and degrades slowly, resulting in bioaccumulation and trans-boundary movement *(29)*. It degrades only slowly into its main metabolites. The half-life of DDT can be up to 15 years in temperate soils. When ingested with food or dust, DDT readily binds to fatty tissue in animals and humans. Because it is so stable, it accumulates inside the body and concentrates in particular in animals at the top of the food chain (such as birds of prey). DDT is highly toxic to insects, shrimps and fish and causes thinning of bird egg-shells. Because of wide-scale use of DDT in agriculture in the past, DDT is still present in places where its use was stopped decades ago. Although much smaller quantities are currently used in vector control than previously in agriculture, some of the DDT sprayed indoors will eventually reach the environment.

7.8.3 Adverse health effects

DDT is not acutely toxic to humans but can have chronic effects after constant exposure; consequently, the harmful health effects of DDT were not known in the 1950s. Many studies have been conducted on the possible health effects of DDT, mostly in Europe and North America, where people were exposed to DDT used in agriculture. A comprehensive analysis of studies on the health effects of DDT, known as the "Pine River Statement", included 494 studies published between 2003 and 2008. It concluded that DDT and its breakdown product dichlorodiphenyldichloroethylene (DDE) can be associated with health outcomes such as breast cancer, diabetes, decreased semen quality, spontaneous abortion and impaired neurodevelopment in children *(35)*. The Statement urged that studies be conducted on DDT use in malaria control. Several further studies on the human health effects of DDT have been published, some of which addressed use for malaria control *(36)*. Of the 22 epidemiological studies published after 2009, 12 showed significant associations between exposure to DDT and some condition.

In 2011, the WHO published a substantive review on the human health aspects of use of DDT in IRS *(31)*. The range of serum levels of DDT and DDE in households that had received IRS varied widely among studies, and the levels were generally below potential levels of concern for populations. The authors stated, however, that

> in some areas, the exposures in treated residences have been higher than potential levels of concern. Efforts are needed to implement best practices to protect residents in treated households from exposures arising from indoor residual spraying (IRS). Of particular concern would be women of childbearing age who live in DDT IRS-treated dwellings and transfer of DDT and DDE to the foetus in pregnancy and to the infant via lactation.

IRS spray workers could be exposed to potential levels of concern, and WHO recommended measures to protect these workers from exposure to DDT *(31)*.

In some situations, therefore, DDT is still necessary to protect people against malaria transmission. Recent evidence on its adverse health effects, however, has created the paradox of DDT being "good" but also "not safe". In this situation, it has been suggested that the precautionary principle be applied by reducing the risk of exposure of inhabitants and applicators to DDT *(36)*.

Few studies have been conducted on the health effects of DDT used in IRS for malaria control. Studies in Mexico and South Africa indicate that the body tissues of people living in houses routinely sprayed with DDT can contain high concentrations of DDT. Venda Health Examination of Mothers, Babies and their Environment is a recent cohort study of children and mothers in Vhembe district, Limpopo, South Africa, exposed to DDT during IRS operations. The results show, for example, that the serum levels of p,p'-DDT/DDE in children exceeded those of their mothers during the first years of life *(37)*, and exposure to DDT increased the number of childhood infections (e.g. in the respiratory tract), mainly in infants who were weaned prematurely *(38)*. Another study showed a weak positive association in children between exposure to DDT and allergies that cause wheezing or whistling in the chest *(39)*. Prenatal exposure to DDT, DDE and pyrethroid insecticides was associated with changes in neonatal thyroid hormones *(40)*.

As part of the Vehembe study, a pilot community education programme was initiated in Limpopo, South Africa, to reduce the exposure of residents to IRS insecticides (DDT and pyrethroids) *(41)*. The activities included drama and songs in villages, which increased residents' knowledge about risk-reduction measures. This suggests that community interventions could reduce the risk of exposure to insecticide of residents of houses treated by IRS.

7.8.4 Risk of exposure of inhabitants

Houses that are sprayed routinely receive about 100 g of DDT per application; however, DDT can accumulate in a domestic environment with annual or semi-annual applications. An assessment known as the "total homestead environment approach" was used in South Africa to measure all possible ways in which people are exposed to DDT in a sprayed home environment *(34,42)*. The approach includes measuring levels of chemicals in air and in indoor dust and also in the outdoor environment. For example, sweeping DDT dust from indoors to outdoors resulted in high levels of DDT in the soil around sprayed houses and in chickens kept near the houses. The approach provided evidence that DDT is present continuously in the indoor air of sprayed houses for almost 3 months after spraying. Several studies have shown DDT levels in breast milk that often exceed the tolerable daily intake for adults *(43)*.

Why is the total homestead environment approach to DDT relevant to human health?

7.8.5 WHO's position on DDT

Under the Stockholm Convention, WHO is mandated to provide guidance to countries on use of DDT for disease vector control. The position of WHO, published in 2011, is to continue to include DDT as a choice of insecticide for IRS *(30)*. An important consideration is the small number of insecticides from which a country can choose. In certain situations (notably in southern Africa), DDT remains a cost-effective choice in areas in which vector populations have developed resistance to other popular insecticide classes. Calculations of cost-effectiveness have been based on the direct costs of operations and do not include the costs of unintended consequences of insecticide use, such as adverse environmental or health effects.

WHO stated that it

> recommends DDT only for IRS. Countries can use DDT for as long as necessary, in the quantity needed, provided that the guidelines and recommendations of WHO and the Stockholm Convention are all met, and until locally appropriate and cost-effective alternatives are available for a sustainable transition from DDT (Box 7.2).

This statement could, however, be challenged by considering evidence of adverse effects caused by DDT on human health and the global environment.

Box 7.2. Conditions for the use of DDT

As DDT is one of the 12 insecticides recommended by WHO for IRS, the prerequisites for safe, effective implementation of IRS apply to DDT, including knowledge of the susceptibility of vectors and proper monitoring of insecticide resistance.

Use of DDT for IRS must be closely monitored and reported to WHO and to the Secretariat of the Stockholm Convention.

To avoid undue exposure of householders and spray operators to DDT, standard operating procedures and national guidelines should be developed and strictly followed. Appropriate management of DDT also includes adoption and enforcement of stringent rules and regulations to avoid leakage (into agriculture, for example) and misuse (when used for example in domestic hygiene), including the possibility of appropriate legal measures in the event that individuals or entities do not comply with this condition.

To complement continued review of information on the safety of DDT by the International Programme on Chemical Safety, appropriate monitoring strategies should be established and used to better characterize exposure of humans and the environment to DDT under the operational conditions in which DDT is used for vector control.

The status of insecticide resistance, including to DDT, must be monitored continuously in order to select insecticides to which vectors are susceptible and to implement resistance-management tactics, such as rotation of unrelated insecticides.

The continued use of DDT should be evaluated regularly by the Parties to the Stockholm Convention and reports made to WHO and the secretariat of the Stockholm Convention. The results of such evaluations will depend on: the insecticide resistance status of local vectors; the availability of alternative insecticides, control methods and strategies; and the level of funding allocated to malaria vector control.

Source: WHO *(30)*.

In 2011, WHO concluded that DDT was still necessary for use in disease vector control, simply because there was no alternative of equivalent efficacy and operational feasibility, especially for high-transmission areas. WHO also recognized that appropriate measures should be established for sound management of pesticides in general and particularly of DDT and that alternative products and methods be developed.

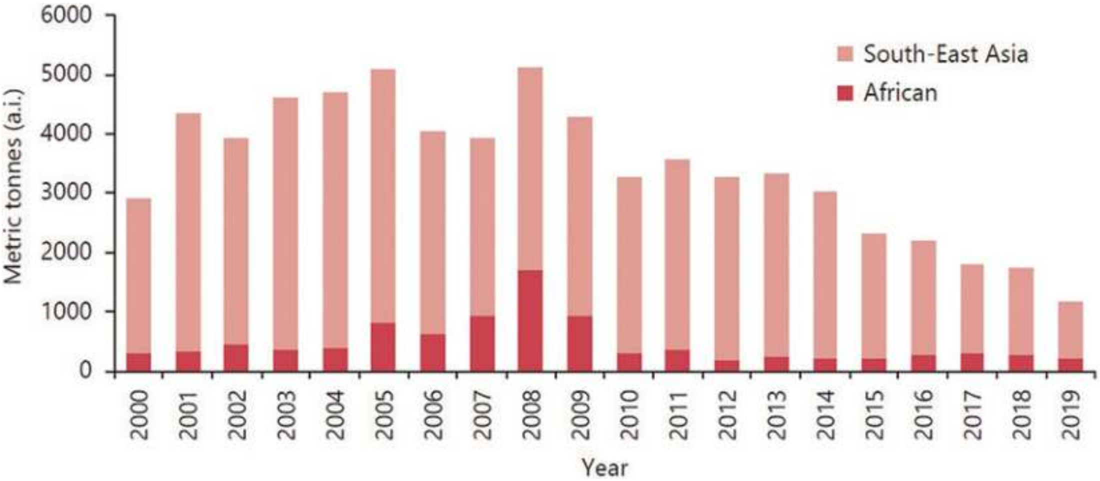
The strict conditions for the use of DDT outlined in Box 7.2 may be difficult to achieve in countries without sufficient enforcement mechanisms and resources for training and monitoring. In particular, some countries do not have adequate routine insecticide susceptibility testing. Furthermore, there are few data from monitoring the exposure of spray operators and household members to DDT used indoors, as this requires specialist training and studies. No studies have been found in which the actual conditions under which countries use DDT are described, and the topic requires urgent attention.

The use of DDT in malaria vector control. WHO position statement. Geneva: World Health Organization; 2011 (https://iris.who.int/handle/10665/69945). *(30)*

7.8.6 Trends in use of DDT

The Stockholm Convention entered into force in 2004. Preparations begun in 2001 ad included advocacy for phasing-out DDT. Between 2001 and 2004, there was intense debate about the continued use of DDT for disease vector control. Several African countries reported continued need for DDT for malaria control, while other countries and entities called for a global ban on DDT. During this period, several African countries increased their use of DDT. This pattern is shown in Fig. 7.10. Global use of DDT reached a peak around 2005, followed by a gradual decrease between 2006 and 2014. After that, the decrease in global use of DDT became steeper, with a 64% decrease between 2014 and 2019.

Fig. 7.10. Annual global use of DDT for vector control (diseases combined) in two WHO regions



Source: WHO *(6)*.

Most DDT has been used in South Asia and particularly in India. A smaller proportion has been used in the African Region, with the highest use in Zimbabwe (Table 7.9).

Table 7.9. Cumulative DDT use during 2010–2019

Country	DDT use (a.i. in MT)
India	23 095
Zimbabwe	1 549
Namibia	363
South Africa	356
Mozambique	136
Gambia	54
Zambia	44
Eritrea	36
Botswana	27
Eswatini	18
Mauritius	0
Senegal	0

Source: adapted from WHO *(6)*.
a.i.: active ingredient; MT: metric tonne.

DDT was used mainly for malaria vector control. A smaller proportion (10–25% of annual use) was used for control of visceral leishmaniasis in India. This stopped in 2016, when resistance to DDT was detected in the sand fly vectors, and pyrethroids were used instead *(44,45)*.

The number of countries using DDT was 10–12 in 2000–2010, 6–8 in 2011–2015 and only 4–5 in 2016–2019. In 2019, only five countries, India, Namibia, South Africa, Zambia and Zimbabwe, reported use of DDT *(6)*. The decrease in use of DDT has several possible explanations. When capacity for monitoring insecticide resistance was built in several African countries during the past decade, some found that their malaria vectors had become resistant to DDT. Those countries, Ethiopia (in 2010), Zambia (in 2011) and Eritrea (in 2012), stopped using DDT and changed to other insecticides for IRS or to ITNs. India stopped using DDT against visceral leishmaniasis in 2016 in response to DDT resistance, as discussed above. The resistance of insect vectors to DDT is thus an important reason for the decrease in global use.

In addition, the Stockholm Convention is likely to have influenced use of DDT by stipulating the acceptable purpose and conditions of use and by promoting the development and use of alternative products, methods and strategies for disease vector control. The Stockholm Convention has actively proposed use of IVM, a long-term strategy that will reduce reliance on DDT through collaboration within the health sector and with other sectors, evidence-based targeting and use of several vector control methods when feasible *(3)*.

Recently, a number of novel insecticide products have become available, with long residual activity for use in IRS. These products include repurposed formulations of existing vector control insecticides and products in a new class of insecticides for vector control (neonicotinoids) that was previously available only for agriculture. These new products have been widely accepted in several African countries *(7)*. The disadvantage of these new products is their high cost, and countries that have used them have depended on external donor funding for their procurement.

The decrease in DDT use will probably continue, and it is possible that the Conference of the Parties to the Stockholm Convention will advance global phasing-out of DDT.

- What criteria would you suggest should be used by countries to decide on, or justify, the use of DDT?
- What is your opinion on continued use of DDT for malaria control?

7.9 International evaluation of vector control insecticide products

For 60 years, WHO has coordinated and supported international development, evaluation and adoption of new insecticide products for vector control. In 1960, WHO established the WHO Pesticide Evaluation Scheme to support the malaria eradication campaign and the control of other vector-borne diseases by testing vector control insecticides. The Scheme gradually extended its responsibility to testing public health pesticides, including household insecticides (e.g. mosquito coils, aerosols), pesticides applied directly to humans (e.g. repellents) and products for professional pest management *(46)*. The Scheme promoted and coordinated testing and evaluation of public health pesticides with oversight of phased evaluation of pesticide products submitted by pesticide manufacturers, and produced international recommendations for national regulatory authorities and disease control programmes. Government representatives, manufacturers of pesticides and pesticide application equipment, WHO collaborating centres and research institutions participated in testing and evaluating insecticide products. The

Scheme provides a network of testing laboratories and risk assessment models, testing guidelines and specifications for pesticide quality control.

In 2001, WHO established a unit for prequalifying pharmaceutical products for use by all United Nations agencies, other organizations and countries. In 2016, the WHO Pesticide Evaluation Scheme was gradually transformed into a system for prequalifying vector control products, within the same prequalification system. The mandate of the new unit, the Prequalification Unit Vector Control Product Assessment Team, is to increase access to safe, high-quality, effective vector control products. The Team assesses dossiers on vector control products, prequalifies products manufactured to a high quality *(9)* and inspects manufacturing sites. The Team plans to contribute to building the capacity of regulatory authorities in Member States. The Prequalification Team has assessed only products in classes of interventions for which a WHO policy recommendation has been issued, which are ITNs, IRS products, space spray products and larvicides.

The full list of WHO-prequalified products is available on the WHO website and is regularly updated *(47)*. As of February 2022, the Team had prequalified a total of 27 insecticide products for IRS, 25 products for ITNs, 12 products for space spraying and 21 products for larviciding. All the prequalified ITN products contain pyrethroids. Some of the products have been prequalified on the basis of previous recommendations by the WHO Pesticide Evaluation Scheme. It has not prequalified any products containing DDT. Several IRS and ITN products are currently being developed and tested. Large-scale field trials are under way in malaria-endemic countries to evaluate their efficacy for potential use in insecticide resistance management strategies.

For products belonging to novel intervention classes for which no policy recommendation has yet been established by WHO (e.g. spatial repellents), the WHO Vector Control Advisory Group provides scientific assessments, reviews the design of trials and assesses the results to determine their public health value (i.e. epidemiological impact on disease). Several novel products for vector control are being developed, including attractive targeted sugar baits, endectocides, eave tubes and spatial repellents. Some are at an advanced stage of evaluation (Box 7.3), and the evidence on sugar baits, eave tubes and spatial repellents indicates that they may be promising.

Box 7.3. Novel vector control interventions

Attractive targeted sugar baits exploit the natural sugar-feeding behaviour of vector mosquitoes. They lure mosquitoes into a toxic bait and kill them. Initial field results from Mali indicate a promising impact on malaria transmission *(48)*.

Endectocides are drugs (such as ivermectin) that are commonly used for nematode control in humans and animals. They also kill mosquitoes that take a blood meal from a recently treated person or animal and could therefore be used in vector control *(49)*. Field trials are under way.

Eave tubes are plastic tubes with static, insecticide-coated mesh that kills mosquitoes that enter a house fitted with these tubes. In a field trial, eave tubes combined with house screening had a major impact on the incidence of malaria; however, it is not clear how effective each of the two interventions is on its own *(50)*. A trial is in progress.

Spatial repellents deployed in enclosed spaces can have a protective effect by interrupting human–vector contact. Initial results suggest that application of spatial repellents in a specific context prevented malaria infection *(51)*. Further trials are under way to verify the effect.

Section 7 raises several policy issues relevant to vector control insecticides.

- Life-cycle management is essential, with risk reduction measures supported by legislation at each stage of the life cycle and tailored to the public health pesticide compound used.
- Central oversight or coordination is critical for effective pesticide regulatory control, which includes public health pesticides.
- The cost of registration of public health pesticides is problematic in smaller markets, but functional coordination at regional level could solve this problem.
- The dominance of pyrethroids in vector control is raising concern, in view of the escalating problem of pyrethroid resistance in disease vectors.
- Decision analysis is necessary to make balanced policy choices on vector control insecticides on the basis of contextual factors and expected impacts (intentional or unintentional).
- Situation analysis and needs assessment are essential in development of national strategies on pesticide management and IVM for identifying what is required for legislation and regulatory control of public health pesticides.

Project assignment 7

Obtain information on the legislation and regulatory control of vector control insecticides in your country. Contact relevant specialists or authorities, if necessary. Please address each of the following points.

1. Are vector control insecticides registered in your country? If yes, give a brief description of the registration authority and the process of registration (evaluation of technical data on efficacy and risk assessment, periodic review, whether registration is for general or for specific uses, the agencies involved).
2. Does your country have legislation on the labelling, safety measures (e.g. PPE), health monitoring of spray operators, storage, transport and disposal of vector control insecticides?
3. What is the situation in your country with regards to quality control of vector control insecticides? Are laboratories available, and are they accessible by health programmes for quality control of vector control insecticides?
4. Are trade and use of unauthorized pesticides (e.g. DDT) monitored routinely, and are punitive measures in place to enforce compliance?

Reflect on this situation analysis, identify critical weaknesses and propose mitigating measures.

References

1. World malaria report 2020. Geneva: World Health Organization; 2020 (https://iris.who.int/handle/10665/337660).
2. Ending the neglect to attain the Sustainable Development Goals: a road map for neglected tropical diseases 2021–2030. Geneva: World Health Organization; 2020 (https://iris.who.int/handle/10665/338565).
3. Handbook for integrated vector management. Geneva: World Health Organization; 2012 (https://iris.who.int/handle/10665/44768).
4. Global vector control response 2017–2030. Geneva: World Health Organization; 2017 (https://iris.who.int/handle/10665/259205).
5. Global use of insecticides for vector-borne disease control: a 10-year assessment, 2000–2009. Geneva: World Health Organization; 2011 (https://iris.who.int/handle/10665/44670).
6. Global use of insecticides for vector-borne disease control: a 10-year assessment (2010–2019). Sixth edition. Geneva: World Health Organization; 2021 (https://iris.who.int/handle/10665/345573).

7. van den Berg H, da Silva Bezerra HS, Al-Eryani S, Chanda E, Nagpal BN, Knox TB et al. Recent trends in global insecticide use for disease vector control and potential implications for resistance management. Sci Rep. 2021;11(1):23867. doi: 10.1038/s41598-021-03367-9.

8. Malaria vector control: decision making criteria and procedures for judicious use of insecticides. Geneva: World Health Organization; 2002 (https://iris.who.int/handle/10665/67365).

9. Vector control product prequalification. Geneva: World Health Organization; 2022 (https://extranet.who.int/prequal/vector-control-products/prequalified-product-list).

10. Kramer RA, Dickinson KL, Anderson RM, Fowler VG, Miranda ML, Mutero CM et al. Using decision analysis to improve malaria control policy making. Health Policy. 2009;92:133–40. doi:10.1016/j.healthpol.2009.02.011.

11. van den Berg H, Gu B, Grenier B, Kohlschmid E, Al-Eryani S, da Silva Bezerra HS et al. Pesticide lifecycle management in agriculture and public health: Where are the gaps? Sci Total Environ. 2020;742:140598. doi:10.1016/j.scitotenv.2020.140598.

12. International Code of Conduct on Pesticide Management. Rome and Geneva: Food and Agriculture Organization and World Health Organization; 2014 (http://www.fao.org/fileadmin/templates/agphome/documents/Pests_Pesticides/Code/CODE_2014Sep_ENG.pdf).

13. Managing pesticides in agriculture and public health – A compendium of FAO and WHO guidelines and other resources. Second edition. Rome: Food and Agriculture Organization of the United Nations and World Health Organization; 2021 (https://www.fao.org/documents/card/en/c/cb3179en).

14. Guidelines on the management of public health pesticides (WHO/CDS/WHOPES/2003.7). Geneva: World Health Organization; 2003 (https://www.fao.org/documents/card/en/c/cb3179en).

15. International Code of Conduct on Pesticide Management – Guidelines on Pesticide Legislation. Rome and Geneva: Food and Agriculture Organization of the United Nations and World Health Organization; 2020 (https://www.fao.org/3/i3604e/i3604e.pdf).

16. Sixty-third World Health Assembly, Geneva 17–21 May 2010, Resolutions and decisions. Geneva: World Health Organization; 2010 (http://apps.who.int/gb/ebwha/pdf_files/WHA63-REC1/WHA63_REC1-en.pdf).

17. Global situation of pesticide management in agriculture and public health. Report of a 2018 WHO–FAO survey. Geneva and Rome: World Health Organization and Food and Agriculture Organization of the United Nations; 2019 (https://iris.who.int/handle/10665/329971).

18. Indoor residual spraying (IRS) for malaria control indefinite quantity contract (IQC) task. Order 1. IRS training guide for spray operations. Research Triangle Park (NC): RTI International; 2009 (https://d1u4sg1s9ptc4z.cloudfront.net/uploads/2021/03/irs_training-1.pdf).

19. Guidelines on compliance and enforcement of a pesticide regulatory programme. Rome: Food and Agriculture Organization; 2006 (https://www.fao.org/publications/card/en/c/25d99be5-8f7b-43a4-b32a-13bfa240c899/).

20. Guidelines for the registration of pesticides. International Code of Conduct on the Distribution and Use of Pesticides. Geneva and Rome: World Health Organization and Food and Agriculture Organization; 2010 (https://iris.who.int/handle/10665/70293).

21. FAO Pesticide Registration Toolkit. Rome: Food and Agriculture Organization; 2019 (https://www.fao.org/publications/card/en/c/CA3814EN/).

22. Scholte EJ, Dik M, Justicia AI, Den Hartog W, Schoelitsz B, Brooks M et al. Findings and control of two invasive exotic mosquito species, *Aedes albopictus* and *Ae. atropalpus* (Diptera: Culicidae) in the Netherlands, 2011. Eur Mosquito Bull. 2012;30:1–14 (https://e-m-b.myspecies.info/).

23. Matthews G, Zaim M, Yadav RS, Soares A, Hii J, Ameneshewa B et al. Status of legislation and regulatory control of public health pesticides in countries endemic with or at risk of major vector-borne diseases. Environ Health Perspect. 2011;119(11):1517–22. doi:10.1289/ehp.1103637.

24. Guidelines on public health pesticide management policy. New Delhi: World Health Organization Regional Office for South-East Asia; 2010 (https://iris.who.int/handle/10665/205194).

25. Guidelines for quality control of pesticides. Rome and Geneva: Food and Agriculture Organization of the United Nations and World Health Organization; 2011 (https://iris.who.int/handle/10665/70574).

26. Guidelines on situation analysis for public health pesticide management. Geneva: World Health Organization; 2005 (https://iris.who.int/handle/10665/69006).

27. van den Berg H, Yadav RS, Zaim M. Strengthening public health pesticide management in countries endemic with malaria or other major vector-borne diseases: an evaluation of three strategies. Malar J. 2014;13(1):368. doi:10.1186/1475-2875-13-368.

28. Framework for a national vector control needs assessment. Geneva: World Health Organization; 2017 (https://iris.who.int/handle/10665/259405).

29. Bouwman H, Bornman R, van den Berg H, Kylin H. DDT: Fifty years since Silent Spring. In: Late lessons from early warnings: science, precaution, innovation (EEA Report No. 1/2013). Copenhagen: European Environment Agency; 2013:272–91 (https://www.eea.europa.eu/publications/late-lessons-2).

30. The use of DDT in malaria vector control. WHO position statement. Geneva: World Health Organization; 2011 (https://iris.who.int/handle/10665/69945).

31. DDT in indoor residual spraying: human health aspects (Environ Health Criteria 241). Geneva: World Health Organization; 2011 (https://iris.who.int/handle/10665/44560).

32. Herren HR, Mbogo C. The role of DDT in malaria control. Environ Health Perspect. 2010;118(7):A282–3. doi:10.1289/ehp.1002279.

33. Roberts D, Tren R. DDT in malaria control: Roberts and Tren respond. Environ Health Perspect. 2010;118(7):A283. doi:10.1289/ehp.1002279R.

34. Van Dyk JC, Bouwman H, Barnhoorn IEJ, Bornman MS. DDT contamination from indoor residual spraying for malaria control. Sci Total Environ. 2010;408:2745–52. doi:10.1016/j.scitotenv.2010.03.002.

35. Eskenazi B, Chevrier J, Rosas LG, Anderson HA, Bornman MS, Bouwman H et al. The Pine River Statement: human health consequences of DDT use. Environ Health Perspect. 2009;117(9):1359–67. doi:10.1289/ehp.11748.

36. Bouwman H, van den Berg H, Kylin H. DDT and malaria prevention: addressing the paradox. Environ Health Perspect. 2011;119(6):744–7. doi:10.1289/ehp.1002127.

37. Verner MA, Chevrier J, Ngueta G, Rauch S, Bornman R, Eskenazi B. Early-life exposure to p, p'-DDT and p, p'-DDE in South African children participating in the VHEMBE study: An assessment using repeated serum measurements and pharmacokinetic modeling. Environ Int. 2018;119:478–84. doi:10.1016/j.envint.2018.07.010.

38. Huang J, Eskenazi B, Bornman R, Rauch S, Chevrier J. Maternal peripartum serum DDT/E and urinary pyrethroid metabolite concentrations and child infections at 2 years in the VHEMBE birth cohort. Environ Health Perspect. 2018;126(6):067006-01-08. doi:10.1289/EHP2657.

39. Huq F, Obida M, Bornman R, Di Lenardo T, Chevrier J. Associations between prenatal exposure to DDT and DDE and allergy symptoms and diagnoses in the Venda Health Examination of Mothers, Babies and their Environment (VHEMBE), South Africa. Environ Res. 2020;15:109366. doi:10.1016/j.envres.2020.109366.

40. Chevrier J, Rauch S, Obida M, Crause M, Bornman R, Eskenazi B. Sex and poverty modify associations between maternal peripartum concentrations of DDT/E and pyrethroid metabolites and thyroid hormone levels in neonates participating in the VHEMBE study, South Africa. Environ Int. 2019;131:104958. doi:10.1016/j.envint.2019.104958.

41. Eskenazi B, Levine DI, Rauch S, Obida M, Crause M, Bornman R et al. A community-based education programme to reduce insecticide exposure from indoor residual spraying in Limpopo, South Africa. Malar J. 2019;18(1):199. doi:10.1186/s12936-019-2828-5.

42. Sereda BL, Meinhardt HR. Contamination of the water environment in malaria endemic areas of KwaZulu-Natal, South Africa by DDT and its metabolites. Bull Environ Contam Toxicol. 2005;75:538–45. doi:10.1007/s00128-005-0785-x.

43. Bouwman H, Cooppan R, Reinecke A, Becker P. Levels of DDT and metabolites in breast milk from Kwa-Zulu mothers after DDT application for malaria control. Bull World Health Organi. 1990;68(6):761–8 (https://iris.who.int/handle/10665/261377).

44. Coleman M, Foster GM, Deb R, Singh RP, Ismail HM, Shivam P et al. DDT-based indoor residual spraying suboptimal for visceral leishmaniasis elimination in India. Proc Natl Acad Sci U S A. 2015;112(28):8573–8. doi:10.1073/pnas.1507782112.

45. Dhiman RC, Yadav RS. Insecticide resistance in phlebotomine - in Southeast Asia with emphasis on the Indian subcontinent. Infect Dis Poverty. 2016;5(1):106. doi:10.1186/s40249-016-0200-3.

46. WHO pesticide evaluation scheme: 50 years of global leadership. Geneva: World Health Organization; 2010 (https://iris.who.int/handle/10665/44305).

47. Vector control prequalification. Geneva: World Health Organization; 2023 (https://extranet.who.int/prequal/vector-control-products/prequalified-product-list).

48. Traore MM, Junnila A, Traore SF, Doumbia S, Revay EE, Kravchenko VD, et al. Large-scale field trial of attractive toxic sugar baits (ATSB) for the control of malaria vector mosquitoes in Mali, West Africa. Malaria Journal. 2020;19(1): 1–16. doi:10.1186/s12936-020-3132-0.

49. Khaligh FG, Jafari A, Silivanova E, Levchenko M, Rahimi B, Gholizadeh S. Endectocides as a complementary intervention in the malaria control program: a systematic review. Systematic reviews. 2021;10:30. doi:10.1186/s13643-021-01578-9.

50. Sternberg ED, Cook J, Alou LPA, Assi SB, Koffi AA, Doudou DT, et al. Impact and cost-effectiveness of a lethal house lure against malaria transmission in central Côte d'Ivoire: a two-arm, cluster-randomised controlled trial. The Lancet. 2021;397(10276):805–15. doi:10.1016/S0140-6736(21)00250-6.

51. Syafruddin D, Asih PB, Rozi IE, Permana DH, Nur Hidayati AP, Syahrani L, et al. Efficacy of a spatial repellent for control of malaria in Indonesia: a cluster-randomized controlled trial. Am J Trop Med Hyg. 2020;103(1):344-58. doi:10.4269/ajtmh.19-0554.

Recommended reading

Bouwman H, van den Berg H, Kylin H. DDT and malaria prevention: addressing the paradox. Environ Health Perspect. 2011;119(6):744–7. doi:10.1289/ehp.1002127.

Global situation of pesticide management in agriculture and public health. Report of a 2018 WHO–FAO survey. Geneva and Rome: World Health Organization and Food and Agriculture Organization of the United Nations; 2019 (https://iris.who.int/handle/10665/329971).

Global use of insecticides for vector-borne disease control: a 10-year assessment (2010–2019). Sixth edition. Geneva: World Health Organization; 2021 (https://iris.who.int/handle/10665/345573).

8

Management of insecticides in vector control programmes

Contents

Learning objectives

By the end of this course, students should be able to:

- understand how the organizational and institutional factors influence insecticide management for vector control;
- comment on the requirements for procurement, safety measures, storage and disposal of vector control insecticides;
- describe the requirements for effective monitoring of insecticide resistance; and
- demonstrate understanding of strategies to manage insecticide resistance in vector populations.

8.1 Institutional and organizational aspects

8.1.1 Organizational structures of vector control

To be functional and effective, pesticide management in vector control should be supported by specific national policies and guidelines. The main policies relevant to vector control pesticide management are a national policy on IVM and a national policy on pesticide management *(1,2)*. No national policy on IVM was reported by 51% (48) of responding countries in a global survey, conducted by FAO and WHO *(3)*, while 74% (69) reported a national vector control unit. It should be noted, however, that countries have different perceptions and definitions of IVM.

For implementation of the policies, it is considered advantageous to have a national coordinating unit, or core unit, on vector control, with responsibility for all vector control activities. The unit coordinates disease-specific programmes in order to harmonize their work, share resources, coordinate monitoring and evaluation, avoid duplication and reduce wastage of resources. A vector control unit should ideally have a mandate for all diseases prevalent in the country.

The organization of a vector control programme can be centralized or decentralized. In a centralized programme, vector control is planned and financed by national health agencies *(4)*. Programmes for malaria control or elimination are commonly centralized, with distribution of ITNs and IRS generally planned centrally. These programmes originate from the first global malaria eradication campaign, which also had a highly centralized structure. Programmes for control of visceral leishmaniasis are also often centralized.

In a decentralized vector control programme, planning, financing and implementation are the responsibility of provincial, district or municipal health authorities. Dengue control programmes are often decentralized to district or municipal health offices, as dengue control relies mainly on source reduction to suppress vector populations, and the community is mobilized for active involvement. Such activities require a local approach and are facilitated by a decentralized structure, as work with local partners is more straightforward. Decentralized dengue programmes are usually funded by a budget allocation from the district or municipality, and local priorities determine the budget allocation. Hence, investment in dengue control, procurement of vector control products and equipment, and training of field staff may vary widely (in quantity and quality) among districts.

The advantage of a centralized structure is that activities are set in national planning, procurement is done centrally according to national guidelines, and training follows national standards. The quality and safety of insecticide management for vector control thus benefits from centralized standards and guidelines. In contrast, in a decentralized programme, standards may be different in each district, which might compromise the quality and safety of vector control insecticide management *(4)*. In many countries, centralized malaria control programmes rely to a large extent on external financial support from donors and face uncertainty when donor support is stopped.

Most African countries have only one vector-borne disease control programme, namely, a malaria control programme. Other vector-borne diseases are generally not addressed in dedicated control programmes. In countries in Asia, Latin America and the Middle East, there is usually more than one vector-borne disease control programme. For example, Nepal has programmes for malaria, leishmaniases and dengue.

WHO advocates for coordination among vector control programmes in a country *(5)*, for more efficient use of technical and logistic resources through sharing of information, laboratories and human resources. For example, a malaria programme may have laboratory capacity for testing insecticide susceptibility, while the dengue programme does not; therefore, sharing of resources will benefit the other programme. In most countries that have more than one vector-borne disease control programme, however, there has been little coordination or sharing for issues of vector surveillance or vector control *(4)*. In other countries, the entomological expertise and infrastructure available in the malaria programme were used for vector surveillance in the dengue programme.

How are the vector control programme(s) in your country organized with regard to the aspects discussed above (core unit; centralized or decentralized structure; coordination among programmes)?

8.1.2 Intersectoral coordination

Intersectoral collaboration on vector control has been neglected. Some but not all countries have an intersectoral committee or task force for IVM, with representatives from sectors such as forestry, agriculture, transport, buildings, local government and education. The mandate of this committee is to explore the roles that each sector could play in the prevention and control of vector-borne diseases. Unfortunately, the existence of such a committee is no assurance of effective intersectoral action. It is difficult to establish functional collaboration of vector control among sectors. Collaboration between the ministries of health and agriculture is vital for timely registration and quality control of vector control insecticides to ensure timely availability of effective products. The health sector should be well represented on the pesticides board. Coordination between health and agriculture ministries is also vital for managing insecticide resistance. In most countries, more insecticides are used in agriculture than for vector control; however, use of agricultural insecticide is known to accelerate the development of resistance in malaria vectors, particularly in intensively sprayed commercial cropping systems *(6)*.

The neonicotinoid clothianidin is a novel insecticide class that was recently introduced for vector control but which has been widely used in agriculture for several decades. A study in Cameroon showed that malaria vectors were resistant to this novel insecticide even before it was introduced for vector control, due, apparently, to intensive agricultural use. Household insecticide products used to combat household pests can also contribute to the development of resistance in disease vectors, again indicating the importance of a joint strategy among sectors for managing insecticide resistance.

8.1.3 Entomological capacity

Entomological expertise, surveillance equipment and laboratory facilities are required for insecticide management. Entomological knowledge and skills are necessary to identify the species of local disease vectors and their biting and resting behaviour. Entomological surveillance is necessary to determine the geographical distribution and seasonal occurrence of vector species. Insecticide resistance must be monitored to detect the levels of resistance in vector populations. These activities are required to select efficacious vector control interventions and insecticide products and to target them when and where necessary to ensure judicious use. Entomological capacity is thus indispensable for effective, continued use of vector control insecticides and to minimize wastage of insecticide resources.

A worldwide shortage of public health entomologists has been reported, particularly in countries endemic for vector-borne diseases. Many countries do not provide adequate training or education on vector control and public health entomology, and there are limited career opportunities for public health entomologists. There are also too few entomology laboratories for processing field samples, monitoring insecticide resistance and conducting operational studies *(7)*.

Decisions must be made to ensure the success of vector control. Decisions include the optimal timing and targeting of interventions and selection of locally appropriate vector control methods and insecticide products. Programme managers should acquire the necessary skills and knowledge for decision-making in certified training courses. As chemical insecticides are commonly used in vector control programmes, programme managers and other staff involved in the transport, storage, handling, application and disposal of vector control pesticides should be trained in safe, effective application of public health pesticides and in their life-cycle management. Good decisions are essential for optimal selection of products and for implementing vector control.

The global survey showed that decision-makers were trained in vector control in only 38% (89) of the countries, and they were trained in pesticide management in only 28% (91) of countries. This implies a serious deficiency in capacity-building. Those responsible for decision-making and for implementation of vector control programmes (such as programme managers) should have been trained in vector control and pesticide management.

In a study of six countries in Asia and the Middle East, the number of entomologists ranged from zero to four per vector control programme *(4)*. One of the countries had no entomologist for any vector control programme. In the other countries, entomologists were attached to malaria programmes, mainly at central level, supported by technicians in districts. Health authorities were concerned about the continuity of entomological capacity once malaria has been eliminated *(3)*. The shortage of entomological capacity was most urgent in the programmes on dengue and on visceral leishmaniasis. The study also showed that tertiary education in medical entomology was very limited in all six countries and that there were few graduate entomologists to potentially be recruited for programmes. Similar studies are not known to be available for African countries.

> What is the entomological capacity for vector control, including expertise and infrastructure, in your country?

8.1.4 Community awareness

Community awareness, understanding and compliance with use of vector control pesticides determines the success of vector control programmes. For example, in IRS programmes, lack of community awareness may mean that householders paint or wash recently sprayed indoor surfaces, which not only increases the exposure of household members to the insecticides but also reduce the efficacy of IRS (see Box 8.1). Therefore, public awareness programmes on aspects of safety and precautionary measures should accompany use of vector control insecticides.

In a recent survey, 40% of countries worldwide had a public awareness programme on public health pesticide use *(8)*. Thus, in most countries, the public is not sufficiently informed after application of vector control pesticides in their houses.

Box **8.1.** Compliance with IRS

In a study in KwaZulu-Natal in the early 1990s, 48–64% of houses were replastered soon after IRS. The householders reported that they had re-plastered their walls to fill cracks that appeared frequently, for a social event such as a wedding. or family members returning on leave or to remove the smell and deposits of DDT, the last being the reason given by 75% of people.

They understood malaria symptoms but insufficiently understood the role of mosquitoes in transmitting malaria parasites and how sprayed walls reduced the risk of transmission. It was concluded that a comprehensive health education package was necessary to inform communities about the importance of complying with the IRS intervention. Alternative solutions were recommended. A partial solution would be to replace DDT with pyrethroids for IRS to reduce the problem of smell and stains.

Source: Mnzava et al. *(9)*.

Public awareness programmes should be conducted by personnel qualified in methods of behavioural change or social marketing. For such programmes, several desired behaviours and the barriers to adopting them are identified, and tools are selected to change behaviour. Monitoring and evaluation are conducted to determine the effect of the programme. Tools for awareness-raising include public relations, campaigns, advertising, interpersonal communication, radio broadcasts, magazine articles, leaflets, posters, newspaper articles, religious meetings, school, community meetings, market meetings and meetings at health facilities.

Public awareness is particularly important regarding appropriate use of ITNs (Fig. 8.1). Insecticide-treated bed nets are known to be effective in reducing malaria morbidity and mortality, and appropriate use of ITNs is a major factor in determining how effective the intervention will be.

Fig. 8.1. Training in hanging and using bed nets, Malawi

Source: photo courtesy of H. van den Berg.

Reasons given for low use of bed nets are high temperatures at night in the dry season, changing sleeping places during the night and no repair of torn nets. Communities should be made aware that malaria mosquitoes are not the same as nuisance mosquitoes (e.g. *Culex* species); when no nuisance mosquitoes are noted at night, malaria could still be transmitted because malaria mosquitoes are not noticed when a person is asleep. Educational programmes or educational components attached to ITN strategies are necessary to optimize use of ITNs (Box 8.2).

Box 8.2. Education to increase compliance with hanging, using, maintenance and repair of long-lasting insecticidal nets (LLIN)

The efficacy of LLIN depends to a large extent on their hanging, use, maintenance and repair during their 3–5 years of useful life. A study in Ethiopia showed the effects of training heads of household in use of nets *(10)*. Village residents were identified and trained for 5 days to train others in proper use of LLIN. The best practices included proper hanging of nets at the four corners of the bed or mattress with locally made wooden posts, determining whether the net is new or old and proper anchoring of the ends of the net under the mattress or bed. The trainers trained the heads of all households in each neighbourhood using posters and manuals. After 5 days, use of LLIN was demonstrated in houses. A community network was also established, with regular communication among district health officers, trained village residents and the researchers. After 12 months, proper use of nets in the community had improved by 30%. The conclusion was that household training had a marked positive effect on use of LLIN.

Unpublished work from Nigeria showed that communication on behavioural change during home visits and community events and mobilization of community leaders substantially improved appropriate use of the bed nets. The interventions included monthly home visits, demonstrations of net hanging, days for net mending and washing, and workshops to make posts for hanging the nets. After the intervention, the proportions of nets hung at the appropriate height and of people sleeping under the nets had increased substantially. The feasibility of such intensive interventions remains to be seen at other locations.

Why do you think community awareness-raising is given limited attention in vector control programmes in many countries?

8.1.5 International support

Several strategies are available for strengthening the management of vector control insecticides, at global, regional and national level. At global level, internationally agreed standards, guidelines, and pesticide specifications are necessary to assist national authorities and programme managers in pesticide management in designing legislation, regulation and practices for pesticide management (Table 8.1).

The WHO regions have also provided guidance on developing policy on public health pesticide management (Table 8.2) to raise awareness in countries about the importance of national policy and guidelines.

WHO has assisted countries in conducting situation analyses and planning action to improve pesticide management in accordance with each country's legislative, institutional and biological (e.g. vector behavioural) factors. It was found that most countries had shortcomings or gaps in pesticide management practices, with considerable differences between countries. The activity increased awareness among stakeholders about their deficiencies in pesticide management. The required elements are listed in Box 8.3.

Table 8.1. WHO and/or FAO guidance on components of the management of public health pesticide

Component	Guidance	Year published
Legislation	Pesticide legislation	2020
	Highly hazardous pesticides	2016
Registration	Good labelling practice for pesticides	2022
	Registration of microbial, botanical and semiochemical pest control agents for plant protection and public health uses	2017
	Pesticide registration toolkit	2016
	Data requirements for pesticide registration	2013
	Registration of pesticides	2010
Procurement	Pesticide licencing schemes	2021
	Licensing of pest control operators	2015
	Procuring public health pesticides	2012
	Pesticide advertising	2010
Application	Aerial application of pesticides	2023
	Manual for monitoring insecticide resistance in mosquito vectors and selecting appropriate interventions	2022
	Operational manual on leishmaniasis vector control, surveillance, monitoring and evaluation	2022
	Aircraft disinsection methods and procedures	2021
	Personal protection, pesticide handling and applying pesticides	2020
	Equipment for vector control: specification guidelines	2018
	Indoor residual spraying	2013
	Decision-making for judicious use of insecticides	2005
	Space spray application	2003
Disposal	Management options of empty pesticide containers	2008
	Prevention of accumulation of obsolete pesticides	1995
Compliance and enforcement	Monitoring the observance and implementation of the Code of Conduct	2023
	Use of pesticide regulation to prevent suicide	2023
	Inspection of pesticide producers, importers, distributors and retailers	2020
	Quality control of pesticides	2011
	Reporting incidents of pesticide exposure	2009
	Compliance and enforcement of a pesticide regulatory programme	2006
	Quality assurance of national laboratories	2005

Source: FAO/WHO *(11)*.

For up-to-date information, see the WHO webpage (https://www.who.int/teams/control-of-neglected-tropical-diseases/interventions/strategies/vector-control) or the FAO webpage (https://www.fao.org/agriculture/crops/thematic-sitemap/theme/pests/en/).

Box 8.3. **Elements required for a public health pesticide management policy**

1. Introduce the Code of Conduct on use of pesticides into national policy.
2. Implement a national IVM policy with relevant regulations.
3. Establish a national vector control unit that collaborates with the national pesticide authority board or committee.
4. Ensure a system for monitoring and evaluating use of public health pesticides, such as collecting data on pesticide use and poisonings.

8.2 Pesticide procurement

Timely procurement of good-quality pesticide products efficiently and transparently is vital for any vector control programme in which insecticide-based products are used. Vector control insecticides are usually procured by the government or by international agencies. Clear guidelines for procurement should be available *(12)*, as the risks of poor procurement are receiving sub-standard insecticide products or products that are not appropriate for the local context, at uncompetitive prices. The timing of procurement of pesticides in the correct amounts is essential to ensure their availability before the disease transmission season and to avoid stocks of obsolete products. Procurement of household pesticides should be preceded by labelling and by training and monitoring of pesticide retailers. As procurement of vector control insecticides is a specialized field, it is considered desirable for procurement to be centralized in one ministry *(13,14)*.

Countries should have national guidelines on procurement to ensure transparency, to foster competition among pesticide manufacturers and to ensure access to good-quality pesticide products. Public tenders ensure transparency and fair bidding. Competition ensures that good-quality products are purchased at the right price. The guidelines should include quality control to ensure that only good-quality products are procured.

Public tendering consists of procurement through bidding. Tendering in pesticide procurement gives a government the opportunity to obtain pesticides at optimal prices and in a transparent manner. An advantage of tendering is that it allows the government to set certain conditions, such as for stewardship support, training of spray operators or disposal of empty pesticide containers *(13)*. A disadvantage of tendering is the time it takes. A commitment to after-sales stewardship, such as information packages and specific training in use of the pesticide products, is important. The Code of Conduct calls on pesticide manufacturers to advise governments on life-cycle management of their products. In a global survey conducted by FAO and WHO, 61% of the countries reported that they had guidelines on procurement of vector control insecticides; 66% procured vector control insecticides through public tendering; and the procurement arrangement in 58% of countries included a commitment to after-sales stewardship by the pesticide manufacturer or distributer (Table 8.2).

An insecticide product should be selected on the basis of evidence of its effectiveness, cost, residual activity, the susceptibility of target vectors and a resistance management strategy, public acceptability, and risks to human health and the environment. Although insecticide susceptibility status was used by 82% of countries as a criterion for selecting a vector control insecticide product (Table 8.2), some do not have the capacity for testing susceptibility, indicating that the procurement requirements cannot be met in some countries, unless vector samples are tested abroad. Selection of an insecticide product should be consistent with the Global Plan for Insecticide Resistance Management *(15)*, which stipulates, for example, that areas with high coverage of pyrethroid-treated bed nets should not use the same pyrethroid insecticide class for IRS, as this would accelerate the development of resistance.

Table 8.2. Conditions of procurement of vector control insecticides in a global survey

Condition	%	N
Guidance available for procurement of vector control pesticides	61	89
Procurement of vector control pesticides by public tender	66	87
Procurement includes commitment to after-sale stewardship	58	92
Insecticide susceptibility status a criterion for selection	82	91
Difficulty in estimating amounts necessary for routine use	17	89
Difficulty in estimating amounts necessary for emergencies	29	91
Quality control (before and/or after shipment) required for procurement	51	91
Procurement requirements aligned with those of other countries	33	90

Source: WHO *(17)*.

%: percentage of responding countries with a positive score; N: number of responding countries.

Timely provision of vector control pesticides is critical in outbreaks of vector-borne disease, requiring swift, efficient procurement for immediate use. When stocks are insufficient to control an outbreak, provision should be made for procurement of the necessary pesticides *(13)*. In the survey, 29% of countries reported problems in estimating the amounts of vector control insecticides required in emergencies (Table 8.2), indicating that emergency preparedness should be improved. In emergency control of locust infestations, arrangements were made in which the donor supported repacking and movement of an excess pesticide stock from one country to another, ensuring a swift response to the outbreak *(13)*. No documented examples were found of application of such an arrangement in response to outbreaks of vector-borne diseases *(13)*. It should be noted that, in such arrangements, the provisions of the Basel and Rotterdam Conventions must be observed.

Ideally, any insecticide product procured for vector control should be controlled for quality. Quality control before shipment ensures that substandard products are not procured locally or imported into the country. Quality control at the time of arrival in the country ensures that the expected product has been shipped. Surprisingly, only half of the countries in the survey reported that quality control was a requirement for insecticide procurement (Table 8.2). Countries appeared to have limited access to functioning laboratories for quality control, or laboratories were available only for agricultural pesticides. The survey indication that procurement procedures and requirements should be improved in many countries.

What are the main requirements for procurement of vector control insecticides?

In the global survey, vector control insecticide products for malaria control were procured centrally or nationally in 67% of countries, while those for control of arboviral diseases (e.g. dengue, chikungunya) and other vector-borne diseases (e.g. leishmaniases, Chagas disease) were less commonly procured centrally (Table 8.3). In 70% of countries, procurement of vector control insecticides was decentralized, for example to districts, municipalities or the private sector.

WHO-recommended products were procured centrally in 75% of countries and by subnational entities in 54%. WHO quality standards were used in 84% of countries with centralized procurement and in 52% of those with decentralized procurement. This indicates that decentralized procurement programmes are less likely to consider WHO-recommended products and to conduct costly quality control. Most programmes on dengue

Table 8.3. Procedures for procurement of vector control insecticides in a global survey

Procedure	%	N
Central procurement for malaria control	67	92
Central procurement for arbovirus control	51	90
Central procurement for control of other vector-borne diseases	51	88
Decentralized procurement of vector control pesticides	70	91
Only WHO-recommended products procured centrally	75	89
Only WHO-recommended products procured at decentralized level	54	63
WHO quality standards used for centralized procurement	84	89
WHO quality standards used for decentralized procurement	52	63

Source: adapted from van den Berg et al. *(16)*.

%: percentage of responding countries with a positive score; N: number of responding countries.

relied on decentralized procurement of vector control insecticides. National health authorities in many countries therefore have no or little control over the vector control insecticides that are procured locally.

Centralized procurement has clear advantages over decentralized procurement, because it is more efficient, gives the authorities control of product selection and better means for negotiation of price and quality, is more likely to include quality control, and may be more effective in preventing accumulation of expired stocks. Decentralized vector control programmes, particularly for dengue, should therefore develop centralized coordination of the procurement of vector control insecticides.

Guidelines for procuring public health pesticides. Geneva: World Health Organization; 2012 (https://iris.who.int/handle/10665/44856). *(13)*

Why are vector control insecticides better procured centrally rather than decentrally? What is the situation in your country with regards to this issue?

8.3 Insecticide application and safety measures

As insecticides are currently the main tool for vector control in most disease-endemic countries, "judicious" use of insecticides is an important element of IVM to ensure that the effectiveness of current insecticidal tools and strategies can be sustained. Over-reliance on and over-use of insecticides for vector control accelerates the development of insecticide resistance in vector populations and increases risks for human health and the environment. In an IVM strategy, decisions are based on evidence, appraisal of the available tools, prioritization of non-chemical tools and use of insecticides as a last resort. "Judicious" use of insecticides is sensible, well-informed application of insecticides resulting from decisions on what, where, when and how to apply an insecticide (Table 8.4).

Table 8.4. Issues and considerations in judicious use of vector control insecticides

	What	Where	When	How
Decision on judicious use	Insecticide class, compound, formulation and dosage	Locations	Timing and frequency of application	Method and quality of application
Considerations	Efficacy, safety, quality, acceptability, cost-effectiveness, insecticide resistance management	Targeting, coverage, available resources, resistance status	Seasonal variation in vectors and disease incidence, duration of effect	Vector ecology and behaviour, skill of operators, quality of equipment, safety

Source: adapted from WHO *(17)*.

Several aspects should be considered in selecting an insecticide product, such as efficacy, safety, quality, acceptability, cost-effectiveness and insecticide resistance management (e.g. current resistance status, whether products should be rotated). For all vector control insecticides, risk managers should apply the substitution principle *(18)*, which is:

> if the risks to the environment and human health can be reduced by replacing a chemical substance or product either by another substance or by some non-chemical technology, then this replacement should take place. All decisions on such substitutions should be based on the best available evidence.

A decision on where to spray should include consideration of the groups at risk or hotspots of transmission, the level of coverage required, the available resources and the resistance status of local vector populations. Considerations in relation to the timing and frequency of application are the seasonal patterns of vector densities and disease incidence and the duration of effect of the insecticide. How an insecticide is applied and the quality of application depend on the skill of operators, the quality of the equipment and safety of precautionary measures.

Control of disease vectors with insecticides should not pose risks to humans or domestic animals in and around the household. Exposure to chemical pesticides of applicators, communities and the environment should be minimized. People who apply and handle pesticides are at particular risk of direct contact with the chemicals. In tropical climates, although use of protective equipment may cause discomfort, it is nevertheless essential for reducing exposure. In countries that do not have access to the correct PPE for spray workers, some are unprotected during spraying. In the survey, 69% of countries reported that they had guidelines for safety in vector control spraying (Table 8.5). Use of PPE vector control operations was reported to be mandatory in 75% of countries, but the extent to which use of PPE is monitored or enforced is not known. Safety measures also include use of experienced sprayers, control flow valves and compliance with WHO specifications (Fig. 8.2).

Table 8.5. Safety precautions for vector control insecticide application in a global survey

Precaution	%	N
Guidelines for safety of vector control spray workers	69	91
Use of mandatory PPE for vector control operations	75	93
Monitoring of exposure of spray workers to pesticides	30	92
Pest control operators required to be licensed or certified	64	89
Quality control of vector control spray equipment	39	93

Source: adapted from van den Berg et al. *(8,16)*.

%: percentage of responding countries with a positive score; N: number of responding countries.

Fig. 8.2. Indoor residual spraying with a hand-operated sprayer equipped with a control flow valve and the operator wearing PPE

Source: WHO *(19)*.

The risk of exposure is highest during mixing of concentrated insecticide product for the spray tank, when there is risk of skin contact with the concentrated product. PPE comprises a head cover, goggles, a face mask, long sleeves, gloves, trousers and boots. After spraying, the spray equipment should be washed and the contaminated rinse water (rinsate) collected and used in spraying the next day.

In order to detect exposure to insecticides proactively, countries should have a system for routine monitoring of exposure of applicators, for example before and after a spraying season, as stated in Article 5.1.3 of the Code of Conduct. People who have been exposed to insecticides should receive the necessary treatment and care by a medical officer. In the survey, only 30% of countries reported that they had a programme for monitoring pesticide applicators in vector control operations (Table 8.5). This major shortcoming of vector control programmes could adversely affect the health of spray workers. Even if a country has general legislation on occupational health and safety, covering all workers, it may not account for the special situation of vector control.

Control of vectors and pests is in many countries is conducted by professional operators, who should have certified training in good insecticide application techniques, with precautionary measures for the community. The training of operators should thus include handling, preparing and properly applying vector control pesticides and also safety precautions and measures for protection of the public and the environment. The effectiveness of insecticides depends to a large extent on how well they have been applied, such as providing good spray coverage with proper use and maintenance of spay equipment. In some countries, sprayers are recruited temporarily as necessary, without appropriate training or regular refresher training.

In the survey, 64% of countries reported that pest control operators are required to be licensed and certified (Table 8.5). In countries in which pesticide applicators are hired temporarily or seasonally, it is difficult to institute a certification scheme. There is little published information on certification schemes in countries.

Specifications for the equipment used to apply vector control pesticides have been published by WHO *(19)*. Routine maintenance of pesticide application equipment ensures that pesticides are applied safely (e.g.

no leakage, low risk of contamination), with efficient use of the pesticide product (e.g. appropriate droplet size). The situation in the field, however, is that only 39% of countries reported a scheme for quality control of vector control spray equipment.

- Are temporary spray workers hired for vector control operations in your country?
- If yes, do they receive the necessary training, refresher training and worker safety measures?

8.4 Storage, transport and disposal

8.4.1 Storage

Pesticides must be stored safely to maintain their quality and to minimize contamination of the environment. Central and local storage facilities should comply with standard safety and security requirements *(20)*, including the location of storage (not near houses, schools, public places, water courses or flood-prone areas), the design (well ventilated, impermeable floor, adequate space for empty containers) and security (fenced, locked, emergency access, warning signs). To prevent accumulation of obsolete stocks, stocks should be managed according to the “first-in-first-out” principle *(20)*. The shelf-life of each pesticide should be checked routinely, daily use should be tracked, and inventories kept up to date and organized. Systematic recording can help storekeepers to detect any misuse or disappearance of pesticides. Pesticides that are past their expiry date should be reviewed case by case, as old products may still be usable at an adjusted dosage rate, unless they contain toxic impurities *(21)*. Usually, the pesticide manufacturer is requested to reanalyse the batch and issue a certificate of analysis, thereby extending the expiry date.

Vector control insecticides are commonly stored in well-built warehouses centrally and in districts or provinces. Newly procured insecticides are initially stored in a central facility, from which they are distributed to peripheral storage facilities to supply local spray operations. In the global survey, 60% of countries reported that they had adequate, safe, secure facilities for storage of vector control insecticides, while 45% reported such storage at peripheral level (Table 8.6). Trained storekeepers were present at central facilities in 72% of countries and at peripheral level in 59% of countries. In another study, storage facilities at peripheral level were found to be of a questionable standard, and there was often no purpose-made room for storing pesticides *(4)*. Storage facilities at peripheral level thus present a particular risk for environmental and human safety; furthermore, they may accumulate outdated or obsolete insecticides due to lack of a trained storekeeper and proper stock management.

Table 8.6. Storage of vector control insecticides in a global survey

Storage situation	%	N
Secure pesticide storage facilities at central level	60	89
Secure pesticide storage facilities at peripheral level	45	91
Trained pesticide storekeepers at central level	72	89
Trained pesticide storekeepers at peripheral level	59	87

Source: adapted from FAO/WHO *(22)*.

%: percentage of responding countries with a positive score; N: number pf responding countries.

8.4.2 Transport

The transport of public health pesticides should be controlled by legislation to ensure minimal human exposure and environmental contamination. Drivers should be trained in safe transport of insecticides, understand the information on insecticide labels and be capable of dealing with emergencies such as accidents, contamination and spills *(20)*. Legislation on safe transport of pesticides specifies that pesticides should never be transported with items for human or animal consumption, clothing, drugs or toys. Vehicles should be adapted for safe transport, and precaution should be taken to avoid spillage. In the global survey, personnel who transported vector control insecticides were trained in safety and emergency response in only 39% of countries (Table 8.7).

Table 8.7. Transport and disposal of vector control insecticides in a global survey

Disposition	%	N
Pesticide transport personnel trained in safety and emergency response	39	91
Guidance on sound disposal of vector control pesticide containers	38	91
No accumulation of obsolete vector control insecticides	60	92
Policy to prevent accumulation of obsolete pesticides	32	92

Source: adapted from FAO/WHO *(22)*.

%: percentage of responding countries with a positive score; N: number pf responding countries.

8.4.3 Disposal

Sound methods for disposing of obsolete pesticides and pesticide waste are necessary to prevent human exposure and environmental pollution. Pesticide waste includes rinsate from daily spraying operations, leftover amounts of pesticide, empty pesticide containers, spills, contaminated soil and obsolete products. Obsolete products include date-expired products that could be used during their shelf-life; they also include stocks procured for a disease outbreak or pest invasion, sub-standard products that failed quality checks or counterfeit products (illegally manufactured or imported or not registered) confiscated during inspections. A national inventory of insecticides procured for vector control should be maintained. For example, countries that are party to the Stockholm Convention may have up-to-date data on their national inventories of DDT waste *(23)*. Obsolete pesticides should be stored securely until they are centralized, labelled, safeguarded and shipped for disposal *(24,25)*. Worn-out spray equipment should also be properly disposed of.

Used pesticide containers are an often neglected by-product of spray operations *(20)*. Containers with a residual amount of pesticide product that have not been rinsed properly pose a risk of purposeful or accidental misuse for unintended purposes, such as for storing food items and water. The risk is particularly high for household pesticides used against domestic pests. Each product should therefore be labelled with the words “not for storage of food or water for human or animal consumption”. Pesticide waste should be separated from other types of waste. Some countries have established schemes for recycling or disposing of empty pesticide containers *(26)*.

Practices of storage and disposal of vector control insecticides centrally and peripherally would clearly benefit from defined national guidelines, standard protocols, training and investment.

8.5 Insecticide resistance

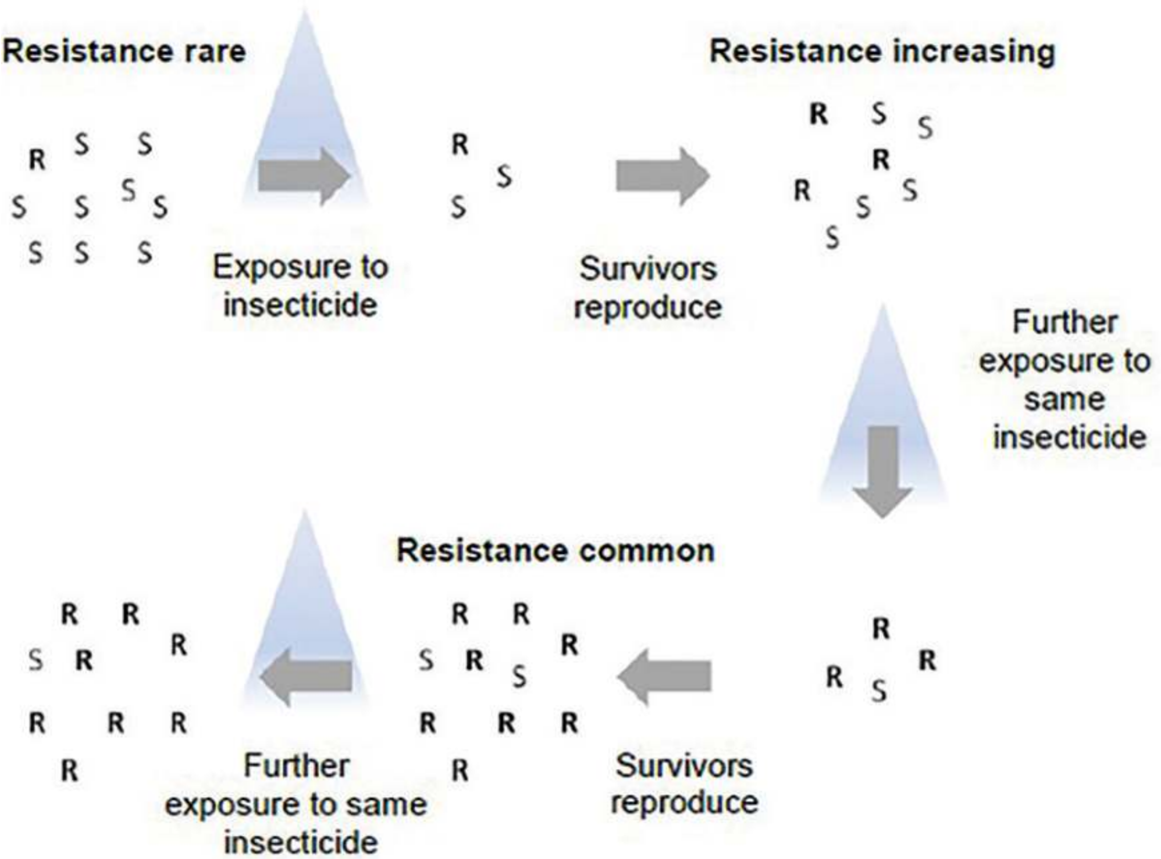
8.5.1 Background

Selection for resistance

Widespread use of insecticides places pressure on vector populations to become resistant to an insecticide. Resistance is a heritable characteristic that circulates or spreads in a vector population. The development of resistance is an inherent characteristic of all species of living organism whereby they can adapt to changing circumstances. When a factor of change (e.g. an insecticide) is introduced, those individuals in a population that have characteristics that give them a relative advantage over other individuals, give their genes a disproportionate share in future generations, resulting in a gradual shift in the genetic make-up of the population. If the new trait is of the genetically dominant type, it can become established in the population. This selection process results in evolutionary change.

Very few individuals in a population have natural resistance to an insecticide. Although these individuals are initially rare, repeated use of an insecticide will allow them to contribute more offspring to the next generation than individuals that lack the resistance trait (Fig. 8.3). Repeated use of the insecticide will thus increase the number of resistance genes in the population, resulting in a partly or predominantly resistant population.

Fig. 8.3. Possible scenario for development of resistance in a mosquito population



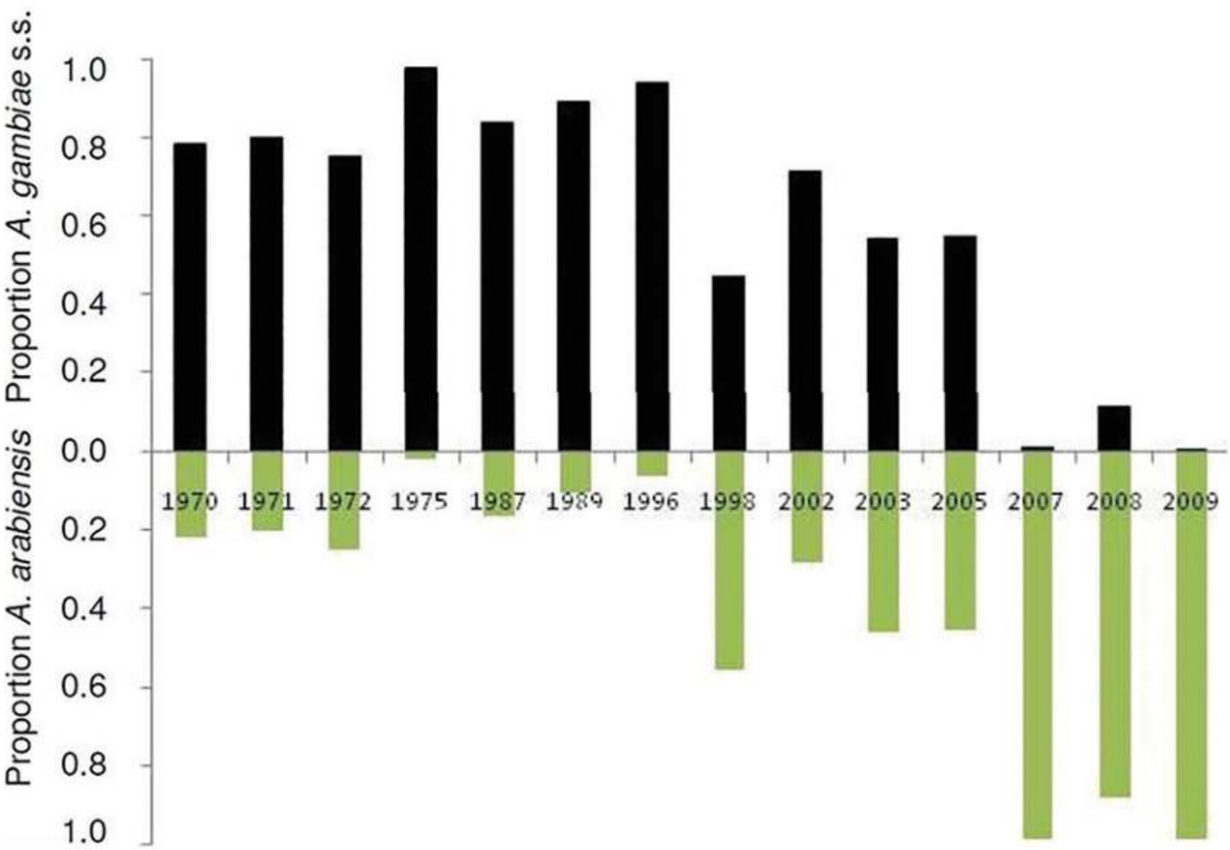
Source: Corbel & N'Guessan *(27)*. Reproduced under the terms of the Creative Commons Attribution 3.0 License (https://creativecommons.org/licenses/by/3.0).

Resistance mechanisms

There are several mechanisms of insecticide resistance. A common one is "metabolic resistance", in which particular enzyme systems in insects are enhanced that quickly degrade or metabolize absorbed insecticides before they have a toxic effect. Three groups of enzymes may be responsible for metabolic resistance: esterases, monooxygenases and glutathione *S*-transferases. Overproduction of these enzymes as an evolutionary response to insecticide selection pressure can confer resistance. Metabolic resistance has been recorded in all the major insecticide classes used for vector control: organochlorines, organophosphates, carbamates and pyrethroids *(28)*.

Another common mechanism of insecticide resistance is "target-site resistance". Insecticides are targeted to act at specific receptor sites in the insect's body, usually in the nervous system. In insects with target-site resistance, the insecticide cannot effectively bind to the target site (e.g. tarsi) and therefore does not have the intended lethal effect on the insect. A widespread target-site resistance gene is the "knock-down resistance" (*kdr*) gene, which makes the insect's nerves insensitive to contact with pyrethroids and DDT. The *kdr* gene thus confers what is called "cross-resistance" between DDT and pyrethroids. *kdr*-resistance in vector populations was caused by the massive use of DDT in agriculture and health in the past, and it still confers resistance to pyrethroids in insect populations.

Fig. 8.4. Proportions of adult females of two sibling species of *An. gambiae* mosquitoes collected near Kisumu, Kenya



Source: Bayoh et al. *(31)*. Reproduced under the terms of the Creative Commons Attribution License (https://creativecommons.org/licenses/by/2.0).

An. gambiae sensu stricto (top, black bars) and *An. arabiensis* (bottom, green bars). The latter has a tendency to bite outdoors.

Resistance to a particular insecticide usually also confers resistance to other compounds in the same class. Thus, if a population is resistant to the pyrethroid deltamethrin, it is probably also resistant to other pyrethroids, such as lambda-cyhalothrin. Target-site resistance to organophosphate and carbamate insecticides is due to mutations at the acetylcholinesterase target site in the nerve cell synapses of insects. The mutated forms result in reduced sensitivity to these insecticides.

Resistance is not restricted to insecticides. Insect populations can potentially adapt, or become resistant, to any type of intervention. "Behavioural resistance" refers to adaptation of a population's behaviour to avoid exposure to, for example, bed nets or insecticides. Interventions can also prompt replacement of vector populations with those of closely related, "sibling" species *(29)*.

Extensive use of bed nets over several years may result in mosquito populations that gradually bite earlier in the evening, before people go to sleep under a net. Likewise, IRS may cause mosquitoes gradually to prefer biting outdoors. Such patterns are due to a change in the behaviour of a vector population or replacement of a population by a sibling species. Reports from Senegal indicate that widespread use of ITNs has caused *An. funestus* to adapt its biting time from night to day *(30)*. Fig. 8.4 shows an example of replacement of a population of *An. gambiae sensu stricto* by a sibling species, *An. arabiensis*, after widespread use of ITNs.

- In the example shown in Fig. 8.4, explain why *An. gambiae sensu stricto* became less common in the latter years.
- Also explain why *An. arabiensis* became more common. What was their advantage?

Causes of resistance

Resistance to insecticides has been attributed to their use in vector control. There are a number of well-documented examples of the role of IRS and ITNs in selecting for insecticide resistance, and selection for resistance will inevitably increase with scaling-up of vector control programmes.

Other sources of resistance are the use of insecticides in agriculture and domestic use against household pests. Agricultural use of insecticides is much larger than their public health use *(32)*. Vectors that breed in or near agricultural areas may be exposed to insecticides during their larval and pupal stage, which contributes to the development of resistance. Cropping systems, such as for cotton, often require intensive use of insecticides, and this has been associated with the development of resistance in malaria vectors that breed in those areas. A review has been published of the contribution of agricultural insecticide use to insecticide resistance in African malaria vectors *(5)*.

The recent massive increase in use of bed nets and indoor spraying, particularly in African countries, has probably had a major impact on increasing resistance in malaria vectors *(16)*.

Pyrethroids are the insecticide class of particular concern. Their characteristics make them ideal for vector control, as they act rapidly, pose a relatively low risk for health and are relatively cheap to produce. No other insecticide class combines this set of desirable characteristics. All the available ITN products contain pyrethroids as the active ingredient, and they are also widely used in IRS and space spraying (see section 7). Major selection pressure for pyrethroid resistance is thus placed on disease vectors, particularly in Africa where use of ITNs has increased massively.

The insecticides used in public health were not purposely developed for public health but are essentially agricultural insecticides that are approved for public health. Pyrethroids are widely used in agriculture.

Therefore, coordination with the agricultural sector is essential in order to extend the useful period of vector control methods *(28)*.

- Why is insecticide use on cotton crops and other intensively sprayed crops a concern for malaria vector control?
- How could insecticide use in public health and agriculture be coordinated to ensure maximum benefits in both sectors?
- Is insecticide use in agriculture and public health coordinated in your country?

Fitness cost

As discussed above, a resistance gene can give a mosquito an advantage over other mosquitoes in a situation in which insecticide is applied. Even when no insecticide is applied, however, mosquitoes without the resistance gene are usually in an advantageous position because of the so-called "fitness cost" of resistance. A mosquito that is resistant is usually less competitive in another characteristic (for example fewer offspring or smaller wings). A high fitness cost implies that, when insecticide spraying is stopped, resistant mosquitoes are at a disadvantage and the susceptible mosquitoes gradually take over ("revert") and dominate the population again (Box 8.4).

Box 8.4. **Example of disappearance of resistance after removal of selection pressure**

In Colombia in 2005–2006, resistance to pyrethroids and DDT was identified in *An. darlingi*. It was quickly decided to change to fenitrothion, an organophosphate with a different mode of action, for IRS. Rapid implementation of this alternative, thereby removing the selection pressure, reduced the frequency of resistance. In 2010, susceptibility tests showed that the frequency of resistance genes in the vector population had fallen below the level of detection, and pyrethroids were once again introduced into the IRS programme, albeit on a more limited scale.

Source: WHO *(15)*.

Some resistance management strategies rely on the fitness cost associated with resistance genes on the assumption that the resistance genes, once selected by insecticide use, will disappear once the selection pressure is removed (e.g. change of vector control method; change in insecticide class used). There is, however, little information on fitness costs of resistance in most situations *(33)*. Some forms of metabolic resistance are accompanied by a relatively high fitness cost, implying that a resistant population can revert to its normal situation once spraying with the implicated insecticide is stopped for a certain time. In a study in Surat, India, once the selection pressure of insecticides was removed, pyrethroid resistance reversed within 2–3 years. Resistance to DDT and malathion, however, was not reversed even after their use had been stopped 30 years (DDT) and 9 years (malathion) previously, possibly because the resistance had become "fixed" in the population *(34)*.

The pace of development of resistance and the pace of reversal to susceptibility depend on several variables, including the intensity of insecticide use, the fitness cost of a vector species, the specific resistance mechanism and the rate of immigration of susceptible vectors from other areas *(35,36)*. The pace of pyrethroid resistance in malaria vectors in sub-Saharan Africa was high between 2005 and 2017 when ITN and IRS campaigns were being introduced *(37)*. In some countries, pyrethroid resistance developed within 3 years of an ITN or IRS campaign. In Zambia, a considerable reduction in pyrethroid resistance in *An. funestus* was reported 2 years after pyrethroids were replaced with pirimiphos-methyl for IRS *(38)*, which suggested that reversal to susceptibility was taking place.

Why is it important to know the fitness cost of resistance in a vector species?

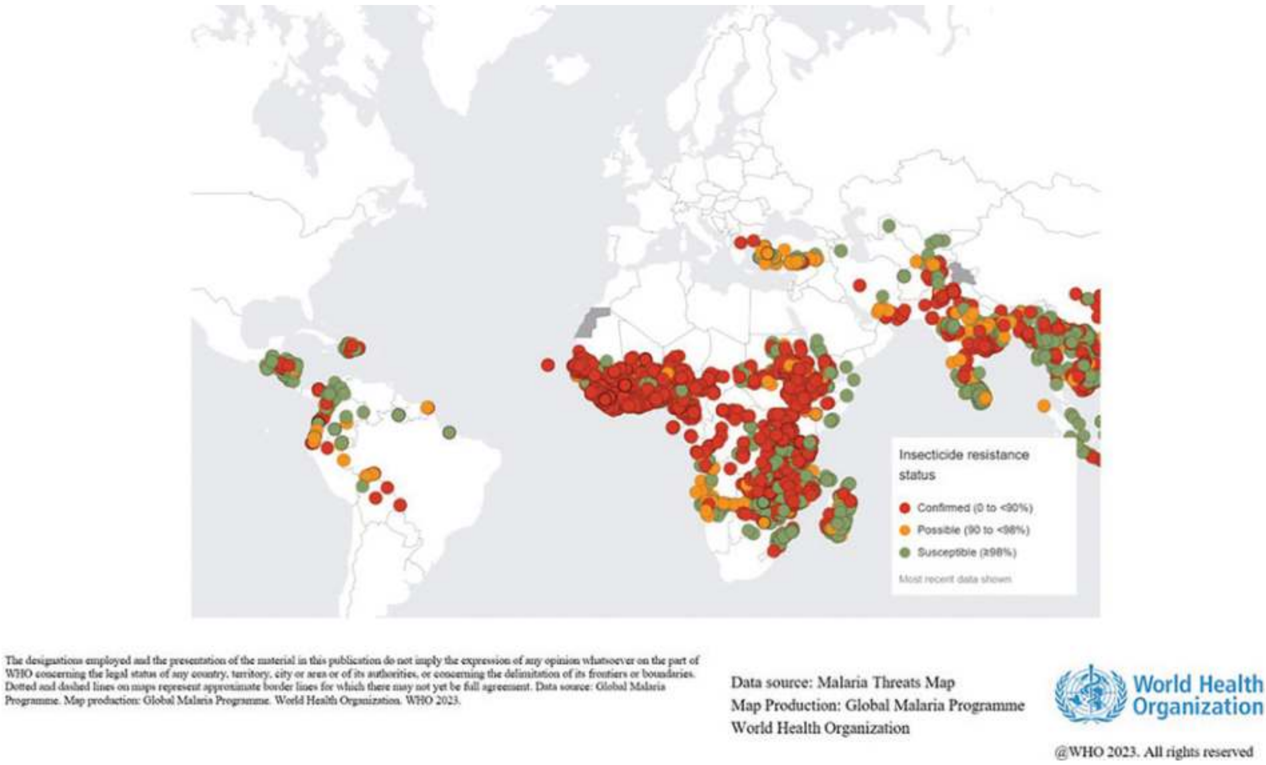
8.5.2 The situation of insecticide resistance

Vector control interventions, particularly ITN and IRS, have recently been scaled up in many countries *(39)*. These interventions are based predominantly on use of pyrethroids, although there is also considerable use of DDT, carbamates, organophosphates and, recently, neonicotinoids in IRS (see section 7). The reliance on pyrethroids is particularly worrying because they are used in every ITN product; as of 2022, there was no ITN product that did not contain a pyrethroid. Increases in the frequency and intensity of pyrethroid resistance could reduce the efficacy of malaria vector control. The efficacy of pyrethroids in ITN must be preserved for as long as possible, as the pyrethroids used have a mass killing effect on the vector population *(40)*. Without an effective insecticide, the nets will provide less protection against malaria transmission, despite the physical barrier of an intact net *(41)*.

Pyrethroid resistance has been recorded in malaria vectors in most endemic countries, and it has been reported that *kdr*-resistance genes are spreading rapidly in West Africa and towards East and southern Africa. Where *kdr*-resistance is found, the options for alternative insecticides have been critically reduced. Furthermore, metabolic resistance has also been spreading.

WHO maintains a global database of geo-referenced data on the results of insecticide susceptibility tests on malaria vectors in order to map resistance threats *(42)*. The data show that pyrethroid resistance is widespread in all regions (Fig. 8.5).

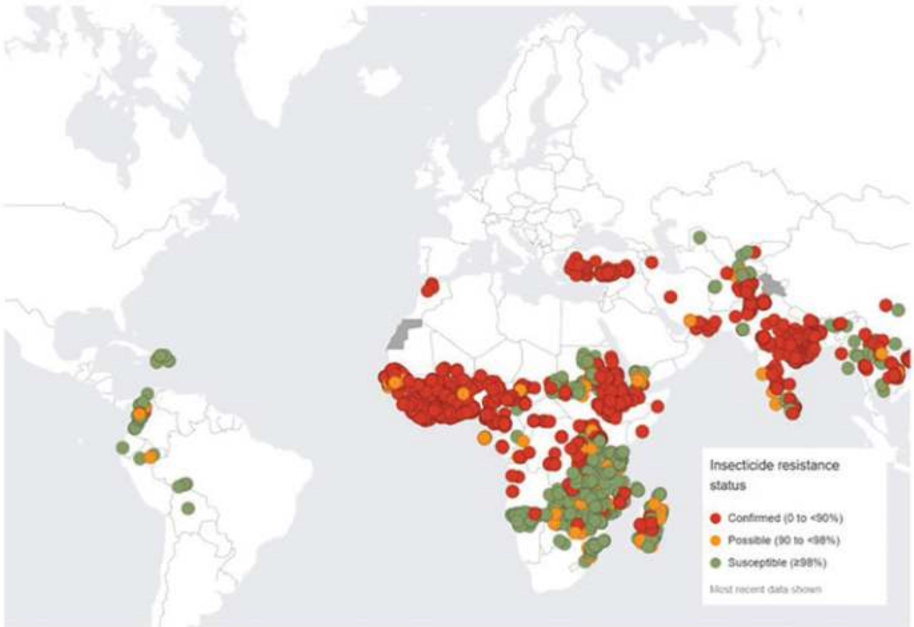
Fig. 8.5. Distribution of pyrethroid resistance in malaria vectors according to data from susceptibility tests, January 2023



Source: WHO *(42)*.

Resistance to organochlorines has been less common in southern Africa (Fig. 8.6) but is common in other parts of Africa and South Asia, probably due to extensive agricultural use of DDT in the past. High levels of resistance in malaria vectors to DDT have been reported in Eritrea, Ethiopia, Uganda and Zambia. In India, malaria vectors in several regions are resistant to DDT, and the vector of visceral leishmaniasis has been found to be highly resistant to DDT. In response, several countries have decided to stop use of DDT for IRS. Cross-resistance between pyrethroids and DDT is common in malaria vectors across Africa *(43,44)*.

Fig. 8.6. Distribution of organochlorine resistance in malaria vectors according to data from susceptibility tests, January 2023



The designations employed and the presentation of the material in this publication do not imply the expression of any opinion whatsoever on the part of WHO concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. Dotted and dashed lines on maps represent approximate border lines for which there may not yet be full agreement. Data source: Global Malaria Programme. Map production: Global Malaria Programme. World Health Organization. WHO 2023.

Data source: Malaria Threats Map
Map Production: Global Malaria Programme
World Health Organization

World Health Organization

Source: WHO *(42)*.

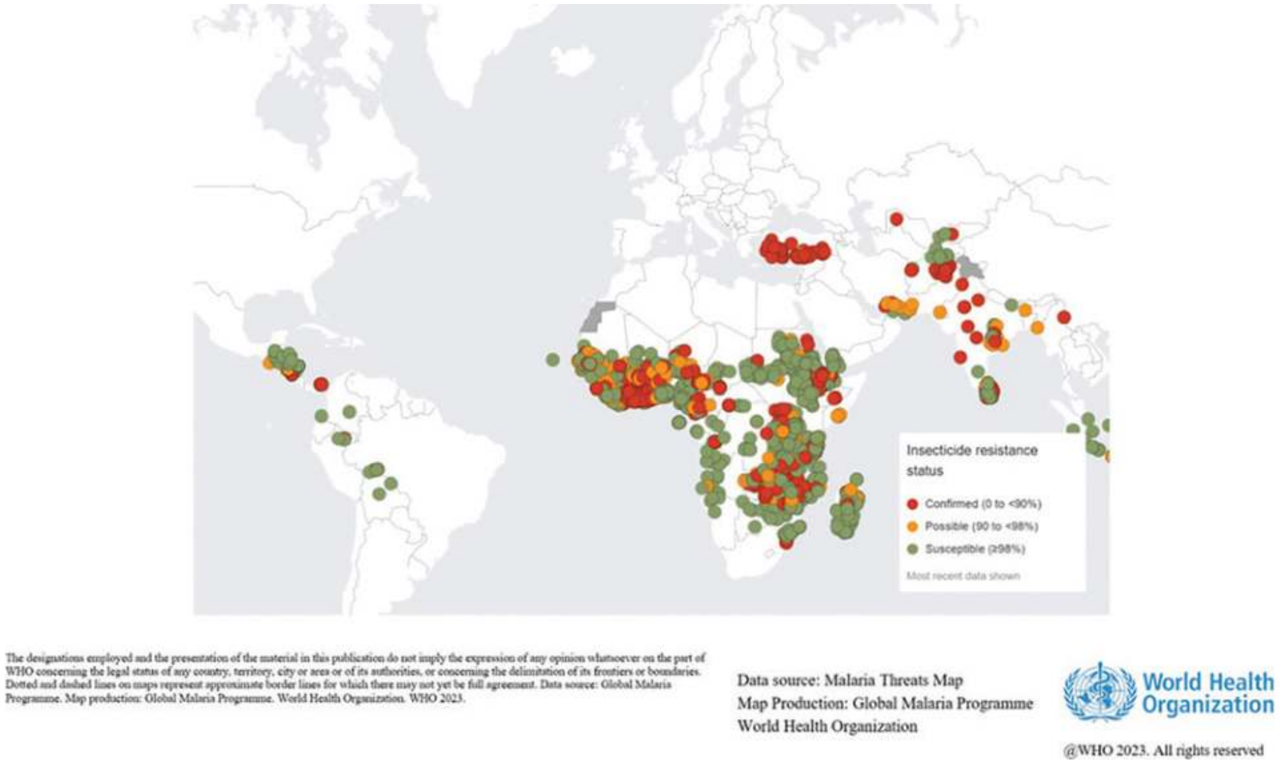
Carbamate resistance varies more widely by region (Fig. 8.7). Organophosphate resistance is less common on the African continent but is common in South Asia (Fig. 8.8). "Multiple resistance" is also becoming increasingly common. In parts of India, populations of malaria vectors have developed resistance to three or four classes of insecticide, seriously compromising control. In Africa, combinations of metabolic and target-site resistance mechanisms have been reported.

Resistance in dengue vectors is also very common. The vector mosquito *Ae. aegypti* has developed resistance to the conventional classes of insecticides. Resistance to pyrethroids (Fig. 8.9) is common owing to their widespread use in space spraying and for domestic purposes, and resistance to temephos is due to its widespread use in larviciding, although the contribution of bacterial larvicides has recently been increasing *(45)*.

Pyrethroid resistance has also become common in the vectors of Chagas disease and leishmaniases *(46,47)*.

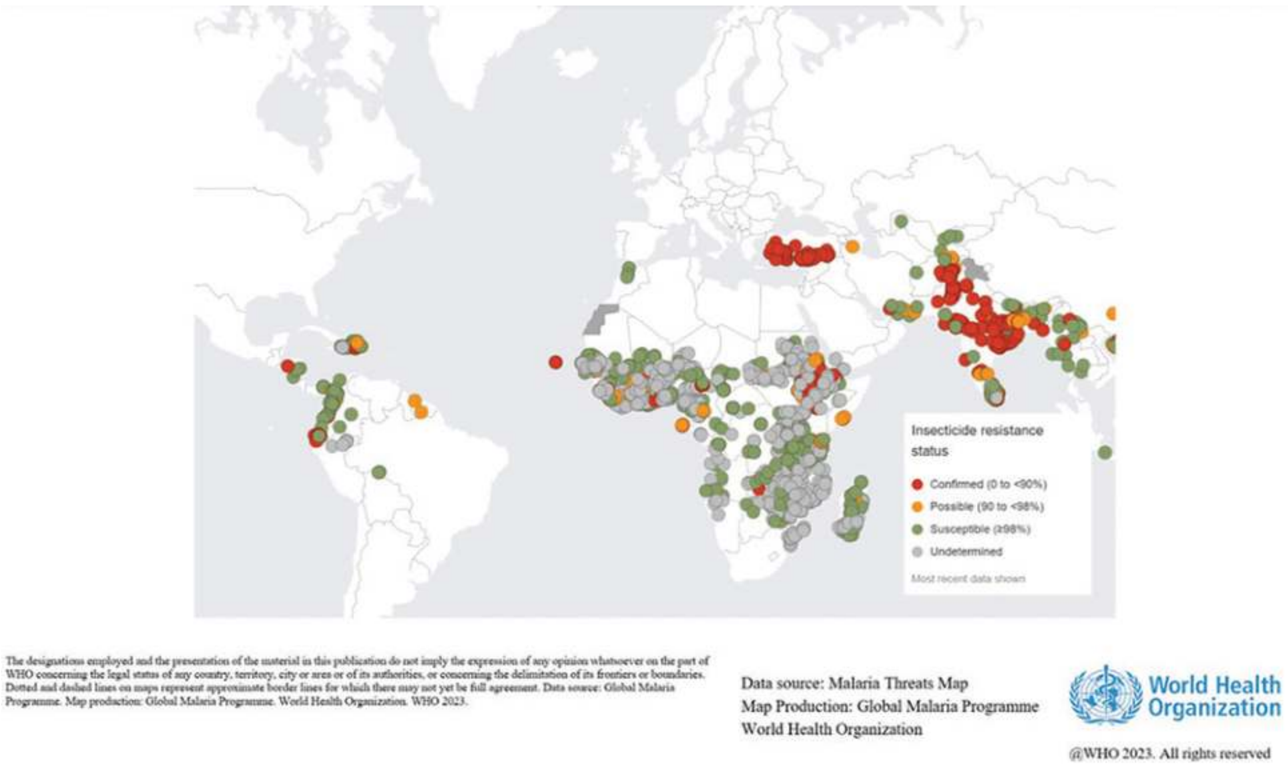
Given the information provided in Figs 8.5–8.9, what do you foresee for the future of disease vector control?

Fig. 8.7. Distribution of carbamate resistance in malaria vectors according to data from susceptibility tests, January 2023



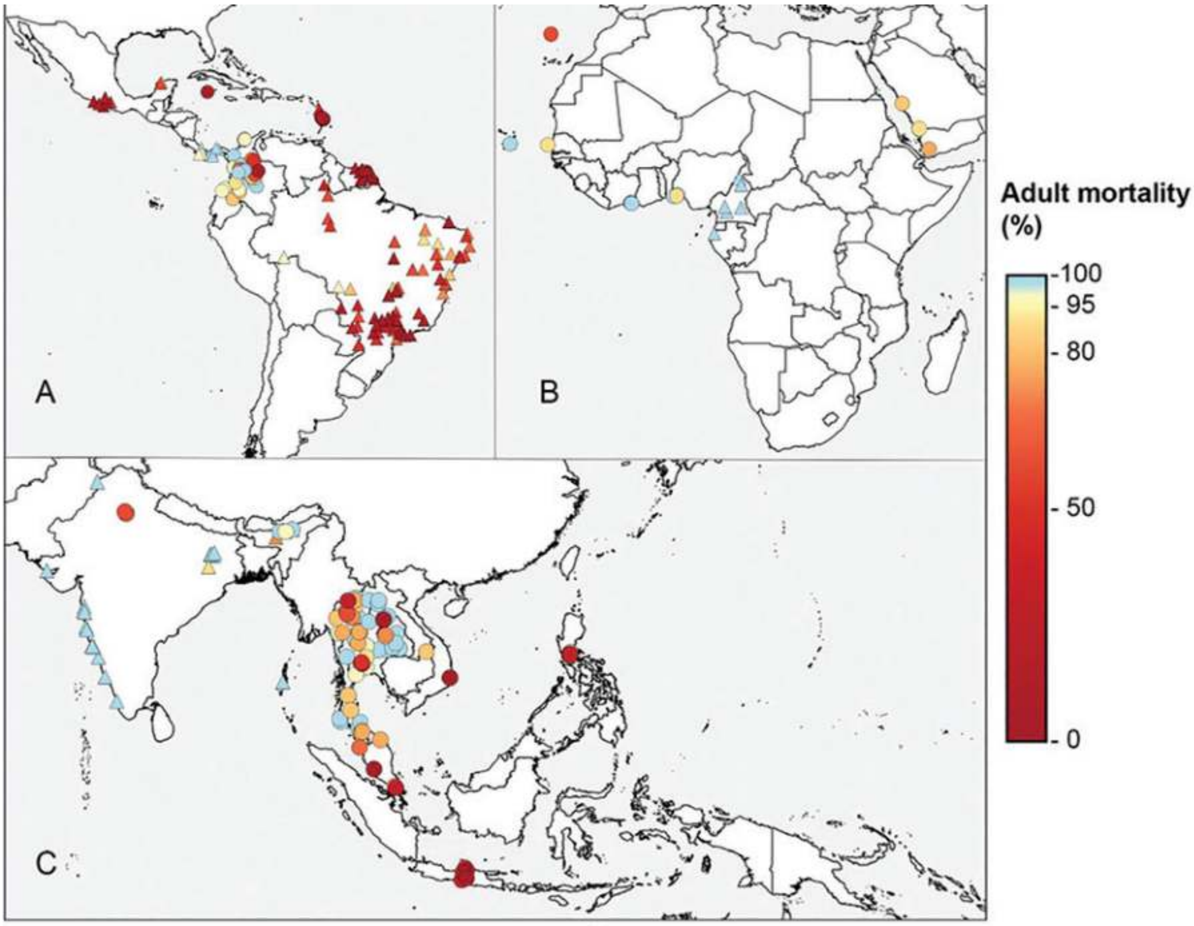
Source: WHO *(42)*.

Fig. 8.8. Distribution of organophosphate resistance in malaria vectors based on data from susceptibility tests, January 2023



Source: WHO *(43)*.

Fig. 8.9. Frequency of resistance to deltamethrin in *Aedes aegypti*, 2006–2015



Source: Moyes et al. *(45)*. Reproduced under the Creative Commons Attribution 4.0 International License (https://creativecommons.org/licenses/by/4.0/).

Low adult mortality indicates a high level of resistance. (A) Americas; (B) Africa/Arabian Peninsula; (C) Asia

8.5.3 Monitoring of insecticide resistance

Routine monitoring of the susceptibility of vector populations to insecticides should be a component of any control programme in which insecticides are used. Qualified personnel and adequate resources should be available for monitoring to ensure the effectiveness of a control programme, reduce wastage of resources and safeguard the few insecticidal options available for vector control to ensure that they remain effective for as long as possible. Resistance monitoring includes selection of sentinel sites for systematic monitoring, insecticide susceptibility tests (bioassays), field observations to verify continued effectiveness and the possibility of a decision to shift to other insecticide products or non-insecticide products.

- Learning unit 6. Monitoring and management of insecticide resistance. In: Malaria entomology and vector control. Guide for participants. Geneva: World Health Organization; 2013 (https://iris.who.int/handle/10665/85890). *(48)*
- Manual for monitoring insecticide resistance in mosquito vectors and selecting appropriate interventions. Geneva: World Health Organization; 2022 (https://iris.who.int/handle/10665/356964). *(49)*

Sentinel sites

Insecticide resistance can develop in response to local changes in the exposure of insect development stages to insecticides. Changes in the susceptibility of vector populations should be monitored at an adequate number of fixed locations, or sentinel sites, selected to represent different epidemiological and ecological zones, with at least one site per zone in which human populations are at highest risk of vector-borne diseases (notably malaria) against which insecticides interventions are being used. One sentinel site per 500 000 nets distributed or per 200 000 houses sprayed has been proposed as an approximate guide for malaria control programmes.

Use of fixed sites helps to reduce natural variation in the data collected and facilitates monitoring of changes over time. Sentinel sites can include locations at which there is known to be extensive use of insecticides in agriculture, which could contribute to the development of resistance in mosquito vectors.

The current recommendation is that vector susceptibility to all four classes of vector control insecticides be tested several times a year in accordance with seasons and/or the calendar of agricultural crops. Areas in which insecticides are used in both vector control and agriculture may require more intensive monitoring because of the additional selection pressure for resistance *(50)*.

Insecticide susceptibility tests

The most common methods for detecting resistance to insecticides in a population of adult insects are the standard WHO tube test for adulticides and a WHO bottle bioassay for insecticides that cannot be impregnated onto filter papers *(49–51)*. Filter papers are treated with a standard concentration of an insecticide, the "discriminating concentration", which is twice the concentration estimated to kill 99.9–100% of the susceptible mosquito strain. Bioassays have also been developed for other vectors, such as sand flies *(52)*. WHO test kits for determining resistance in mosquito adults and larvae and other vector species can be purchased using the WHO catalogue and order form available from the web site *(53)*. The US Centers for Disease Control and Prevention have also developed a method *(54)*. The main difference from the WHO method is that the end-point of efficacy (i.e. mortality) in the WHO test is measured 24 h after a 1-h exposure, while the end-point in the US method is measured after 30 min of exposure (45 min for DDT) *(49)*.

For testing adulticide products, mosquitoes are exposed for a fixed period, usually 1 h, inside a standard plastic tube lined with insecticide-impregnated filter paper (Fig. 8.10). For testing new slow-acting insecticides, such as chlorfenapyr, discriminating concentrations should be added for longer, such as ≤ 72 rather than 24 h. After 1 h, the test insects are transferred to empty (holding) tubes for 24 h, after which mortality is recorded. Testing of susceptibility to insect growth regulators (e.g. pyriproxyfen) requires a total of 7 days *(49, 55)*.

Mosquitoes with resistance traits may become more susceptible as they grow older *(57)*. Therefore, the mosquitoes tested should preferably be 3–5 days old. Although mosquitoes collected in the field are used to monitor resistance operationally, it is preferable to obtain mosquitoes that have emerged from field-collected larvae or pupae in a laboratory, or, even better, to obtain the F_1 generation from field-collected adult mosquitoes. The age of laboratory-emerged mosquitoes is more uniform than that of adults collected in the wild, resulting in more accurate test results. For practical reasons and in view of the difficulty of capturing large numbers of synchronized sand flies, bioassays with sand flies are conducted with 2–7-day-old, non-blood fed females *(52)*.

Fig. 8.10. A vector control staff testing for insecticide susceptibility

Source: photo courtesy of Vaishali Verma, ICMR-National Institute of Malaria Research, India.

The percentage mortality after a 24-h holding period is calculated and interpreted, as presented in Table 8.8. Control oil- or acetone-treated papers are tested in parallel for comparison. Any dead mosquitoes in the control tubes or bottles will have died from causes other than the insecticide, and it is recommended that the mortality rate be corrected for those deaths in the control tubes or bottles, especially when the rate is above a certain level *(49, 52)*. Test solutions for bioassays with different types of larvicides are available.

Table 8.8. Interpretation of the results of an insecticide susceptibility test for adult mosquitoes and sand flies

Mortality (%)	Interpretation
98–100	Susceptible
< 98	Suggests resistance and indicates further investigation/confirmation
90–97	Presence of resistant genes in the vector population must be confirmed in additional bioassays with the same insecticide and the same population or in the progeny of any surviving mosquitoes or sand flies (reared under insectary conditions) and/or by conducting molecular assays for known resistance mechanisms. If at least two additional tests consistently show mortality < 98%, resistance is confirmed.
< 90	Confirmation of resistant genes in the test population by additional bioassay may be unnecessary, as long as a minimum of 100 mosquitoes of each species was tested. The mechanisms and distribution of resistance should be further investigated.
When resistance is confirmed	Pre-emptive action must be taken to manage insecticide resistance and to ensure that the effectiveness of the insecticides used for vector control is preserved.

Source: WHO *(49,52)*.

Several more sophisticated techniques, with biochemical and molecular assays, are available for detecting insecticide resistance *(28)*. These techniques can be used identify the resistance mechanism and the presence of resistance genes in the population, even in mosquitoes that do not themselves have the resistance trait but that carry a non-dominant (heterozygous) gene that could result in the resistance trait in its offspring. The advantages of these methods are clear: they can detect resistance when it is still rare in a vector population, and they can identify the gene and mechanisms that cause resistance. Their disadvantage is their cost and the equipment and skill necessary to perform them.

The cone bioassay is a WHO-recommended method for monitoring the entomological efficacy or residual action of insecticidal interventions in operational programmes by determining how long the insecticide remains active on treated substrates (e.g. wall, net fabric) *(56)*. These tests are not susceptibility tests, and only susceptible vector populations should be used. Mosquitoes are exposed in a small cone-shaped apparatus to a sprayed surface or an insecticidal net fabric for a fixed period. The rate of mortality indicates the efficacy of the insecticidal method against susceptible vector populations.

- Why should only vectors that are susceptible to the insecticide be used?
- How do the objectives of the cone assay and the susceptibility test differ?

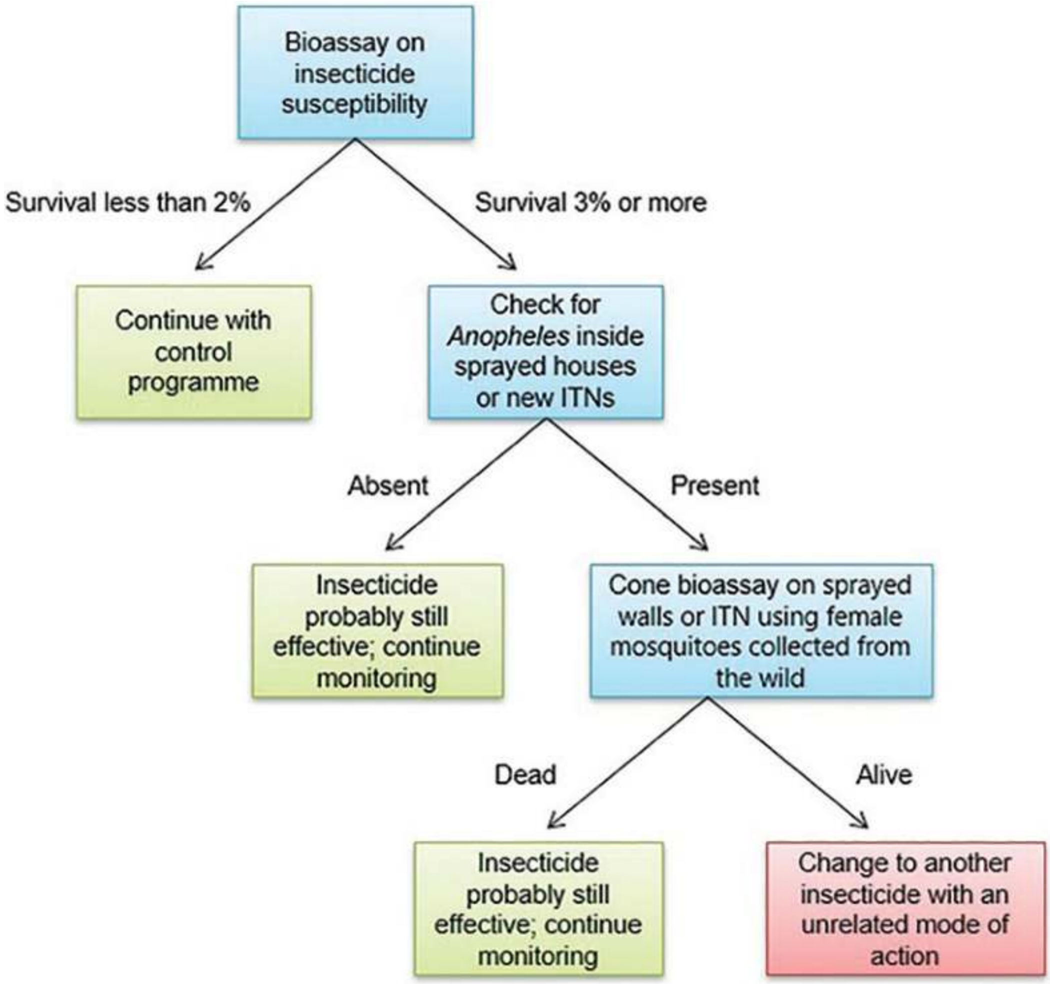
Resistance mechanisms

When bioassays for insecticide susceptibility indicate a survival rate of ≥ 2% of exposed mosquitoes, biochemical tests should be conducted to identify the genetic mechanism that causes resistance (the "resistance mechanism") *(49)*. Information on the resistance mechanism can indicate the likelihood of loss of efficacy of the intervention, the likelihood of cross-resistance or the potential for the resistance genes to spread geographically. For example, the target site *kdr* mutation, which confers resistance against pyrethroids, is likely to confer cross-resistance to DDT in the same vector population. Research on resistance mechanisms is labour- and resource-intensive, requiring specialized expertise and equipment *(49)*.

Steps in decisions

Routine monitoring at sentinel sites is necessary to study the development of resistance, in both mosquito vectors and non-mosquito vectors. Regular monitoring is essential to detect the emergence of resistance at an early stage, before the genes have spread, and to guide timely changes in the selection of insecticides or alternative measures or strategies to reduce the selection pressure. Susceptibility testing in combination with field observations and cone bioassays can be used to detect loss of efficacy and form the basis for deciding whether to change the insecticide. The cone bioassay is used to determine whether local, field-caught mosquitoes or non-mosquito vectors are killed after exposure for 30 min to a sprayed wall surface or ITN material (Fig. 8.11). It is essential to determine the baseline susceptibility of local vector populations to the insecticide before starting a new vector control programme or a new intervention.

Fig. 8.11. Steps in deciding whether to monitor insecticide resistance in *Anopheles* vectors



Data from monitoring insecticide susceptibility and loss of efficacy are useful only if they are disseminated to those responsible for making decisions on vector control interventions, who are programme managers and their technical advisors.

Capacity for resistance monitoring

Most countries with endemic vector-borne disease lack expertise for monitoring insecticide resistance and also for laboratory and insect-rearing facilities *(7,58)*. Regional cooperation and networking are useful for sharing expertise and information on insecticide resistance monitoring. Development of the basic competence and capacity for monitoring insecticide resistance can be difficult for countries with a high burden of vector-borne diseases. If laboratory facilities, equipment and materials are not available, collaboration could be sought with a neighbouring country or the region. The basic requirements, however, are skilled staff and regular monitoring.

Reporting of susceptibility

Insecticide resistance that develops in one country may also affect neighbouring countries. It has been shown that resistance genes can sweep through a country within 1 year *(59)*. In the Global Plan for Insecticide Resistance Management *(15)*, countries are encouraged to share data on insecticide susceptibility testing. Countries should establish national databases of the results of resistance testing and communicate the data to WHO for inclusion in an aggregated global database managed by WHO *(42)*.

8.5.4 Loss of efficacy

An important question is whether reduced susceptibility to a particular insecticide will reduce the efficacy of the intervention in which the insecticide is used. Reduced susceptibility does not necessarily imply an equivalent loss in efficacy or control failure at field level. In IRS, lower mortality in bioassays could indicate reduced mortality in sprayed houses. An unknown factor, however, is the excito-repellent effect that an insecticide may have on a vector. Resistant mosquitoes that come into contact with an insecticide on a sprayed surface may not be killed but may be repelled to some extent by the insecticide, which may cause the vector to leave the house, thus reducing the risk of disease transmission. In bioassay test tubes, vector specimens cannot leave the tube and are exposed directly to the insecticide on the test paper.

In the case of ITNs, not only the possible repellent effect of the insecticide but also the physical barrier of the net should be considered. Hence, an intact net could still prevent transmission of a disease pathogen even if the vector has become resistant to the insecticide in the net fabric. The mass-killing effect of the insecticide on the vector population would, however, be reduced or absent. The insecticidal (killing) action may make a larger contribution to transmission reduction than protection by the physical barrier of the net, especially if the vectors prefer to feed on humans rather than animals *(40)*.

In a study coordinated by WHO in five countries in which the vector populations showed various levels of resistance to pyrethroids, ITNs continued to protect (partially) sleepers *(60)*. For example, in West Africa, ITNs continued to protect against malaria transmission despite the presence of *kdr* genes in vector populations.

Individual mosquitoes of resistant strains become more susceptible to insecticides as they age, which is epidemiologically relevant for the efficacy of vector control interventions, as only older mosquitoes can become infectious with malaria parasites *(57)*.

A new wave of metabolic resistance against pyrethroids has swept across Africa, from southern Africa northwards, and is observed in both *An. gambiae s.s* and *An. funestus*. In Malawi, for example, complete susceptibility changed to country-wide resistance within 1 year *(59,61)*. It is especially worrying that the level of resistance imposed by this mutation is several orders of magnitude higher than that caused by the *kdr* gene. The combination of metabolic and *kdr* resistance could reduce the effectiveness of ITNs.

— Why is it easier to conduct bioassays for insecticide susceptibility than to determine loss of efficacy?

8.5.5 Management of insecticide resistance

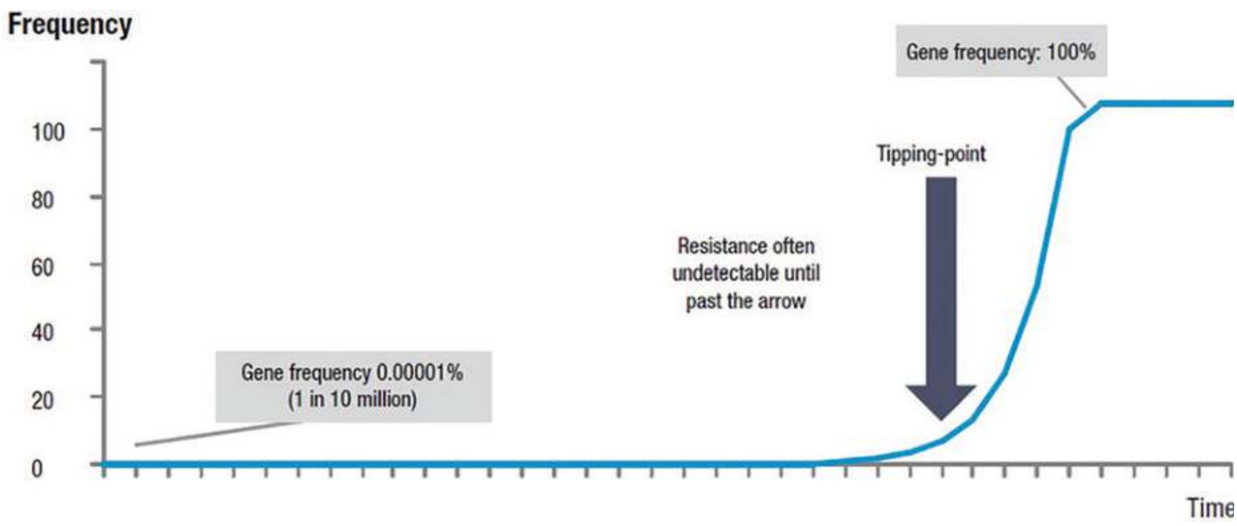
Monitoring should be conducted routinely at sentinel sites to determine whether resistance is developing and to guide its management. Resistance management requires a functioning system of monitoring and data dissemination. Detection of resistance in a vector population at an early stage, before the "tipping point" (see Box 8.5), increases the possibility of preventing the further development and spread of resistance genes in the vector population. Detection of resistance only when it is already widespread in the vector population will restrict the options for and the feasibility of resistance management *(29)*. If resistance increases to a very high frequency due to continued use of the same insecticide product, it could become "fixed" in the vector population and be impossible to reverse.

Most work in the management of insecticide resistance in disease vectors has been for malaria vectors. Only limited attention has been given so far to managing insecticide resistance in the vectors of dengue, leishmaniasis or Chagas disease.

Box 8.5. **The concept of the "tipping point"**

Resistance can occur at low but gradually increasing frequency in a vector population for many years without being detected. When the "tipping-point" is reached, however, resistance can increase extremely rapidly; for example, the frequency of a resistance gene that is initially 1 in 10 million can double for a long time before it reaches 1% and becomes detectable in a population. At that point, theoretically, only another six generations of frequency doubling of resistant genes are necessary before resistance reaches a frequency of over 50% *(15)*. See Fig. 8.12.

Fig. 8.12. Frequency at which a resistance gene can double



- Global plan for insecticide resistance management in malaria vectors. Geneva: World Health Organization; 2012 (https://iris.who.int/handle/10665/44846). *(15)*
- Mnzava AP, Knox TB, Temu EA, Trett A, Fornadel C, Hemingway J et al. Implementation of the global plan for insecticide resistance management in malaria vectors: progress, challenges and the way forward. Malar J. 2015;14(1):173. doi:10.1186/s12936-015-0693-4. *(62)*
- Hemingway J, Ranson H, Magill A, Kolaczinski J, Fornadel C, Gimnig J et al. Averting a malaria disaster: Will insecticide resistance derail malaria control? Lancet. 2016;387(10029):1785–8. doi:10.1016/S0140-6736(15)00417-1. *(63)*

The strategies for insecticide resistance management include rotation of insecticides to delay or prevent selection of resistance; use of insecticide products in geographically mosaic patterns or mixtures of two or more insecticides; and novel insecticide products and use of non-chemical control methods.

Ethical considerations do not allow use of at-risk communities for sustaining populations of susceptible mosquitoes in order to prevent development of resistance against proven interventions, as the susceptible vectors would place people unnecessarily at risk of disease transmission. Reliance on residual insecticides also poses a problem, in that they cannot easily be rotated in time. This is particularly true for LLIN, which retain their efficacy for 3 years. The insecticides are thus continuously present, which could accelerate the development of resistance due to their constant availability to vector populations.

A basic principle of resistance management is to minimize continuous exposure of vector populations to insecticides with a certain mode of action in order to prevent gradual selection of resistance. This involves restricting the use of insecticides in space and in time. Restriction of use in space is achieved by treating only certain areas while leaving other areas untreated; this is called "mosaic use" of insecticides. Restriction in time is achieved by limiting the period of exposure of vector populations to insecticides with a single mode of action, which is called "rotation". The availability of alternative products and methods of vector control (including non-chemical methods) is essential for effective resistance management.

Experience in agriculture has demonstrated that restriction of insecticides in space and time can prevent the build-up of resistance. The crop that receives the highest amounts of insecticides globally is cotton. To manage the development of resistance in the cotton bollworm, Australia and the USA have used schemes in which use of pyrethroids on all crops was allowed for only 42 days a year *(64)*. Use of genetically modified cotton with a gene that continuously produces the *B. thuringiensis* (*Bt*) toxin in crops removed the requirement for restricting insecticide use in time but necessitated restriction in space *(65)*. So-called "refuge areas" of cotton were established, which are areas of land that are planted with cotton without the *Bt* gene and provide a refuge for bollworms susceptible to the *Bt* gene, in anticipation of the development of resistance of bollworm populations to the *Bt* gene and to dilute and prevent any build-up of *Bt* resistance in the insect population. This experience shows that effective resistance management requires drastic, proven measures.

A strategy in which several insecticides are used in rotation, such as switching every year, may be more costly in the short term, as more costly compounds are added. A rotation programme with insecticides with several modes of action also has implications for registration and procurement, as several products must be registered and available. Furthermore, safety precautions and operational use may change with a change to another product, and stock management must ensure the availability of the right product and prevent accumulation of outdated products. Thus, several sectors – pesticide registration, procurement, operations, stock management – are actively involved in a rotation strategy. In the long term, the cost will be lower than in the absence of resistance management, which would ultimately result in control failure.

Examples of resistance management in vector control for public health are limited *(28,66)*. In the only available controlled trial of resistance management, combining compounds in rotation or mosaics, did not prevent an increase in pyrethroid resistance (Box 8.6). Box 8.7 presents an example of successful resistance management.

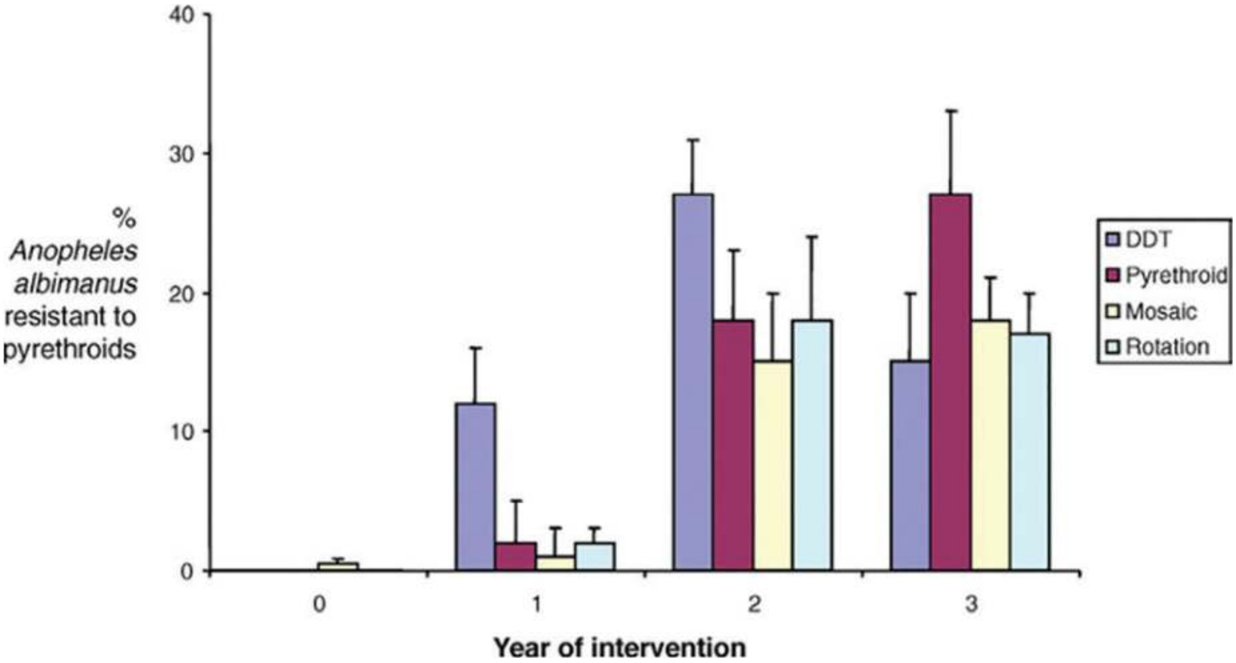
Box 8.6. Resistance management of disease vectors in Mexico

Along the Pacific Coast of Chiapas, Mexico, high levels of resistance in *An. albimanus* to four major classes of insecticides, organochlorines, organophosphates, carbamates and pyrethroids, had developed by the end of the 1970s. The resistance was due to high insecticide use in agriculture and simultaneous use of DDT in IRS for malaria control. During the 1980s and 1990s, however, insecticide use in agriculture decreased drastically, eventually resulting in a regression of insecticide resistance, or reverted susceptibility, in vector populations to organophosphates, carbamates and pyrethroids *(66)*.

DDT resistance remained high because DDT continued to be used in IRS for malaria control. Hence, a study on the effectiveness of a resistance management strategy was conducted, covering 24 villages with different IRS treatments *(66,67)*. Villages were assigned to one of four treatments, each with a recurring cycle of IRS: two applications of DDT per year; three applications of a pyrethroid per year; three spray applications per year of a spatial mosaic of an organophosphate and a pyrethroid; or annual rotation of an organophosphate, a pyrethroid and a carbamate.

The trial lasted for 3 years. Pyrethroid resistance increased with all insecticide treatments (Fig. 8.13). It has been noted that use of simple bioassays such as the WHO susceptibility test for resistance can result in underestimation of resistance in the field, where behavioural resistance can further reduce the effectiveness of an intervention.

Fig. 8.13. Increased pyrethroid resistance in Mexico despite rotation or mosaic use of other insecticide classes



Sources: Read et al. *(33)*, Penilla et al. *(67)*. Reproduced under the Creative Commons Attribution 4.0 International License (https://creativecommons.org/licenses/by/4.0/).

Box 8.7. **Onchocerciasis Control Programme in West Africa**

An example of successful insecticide resistance management is the Onchocerciasis Control Programme in West Africa, which was almost entirely based on vector control consisting of weekly application of chemical and bacterial larvicides in the breeding sites of the *Simulium* blackfly larvae in rivers and streams *(68)*. The organophosphate temephos had been used repeatedly, but, after development of extensive resistance, larvicides with four different modes of action were used in rotation, with routine monitoring to guide the choice of insecticide. Resistance to temephos reversed to a point that it could be reintroduced in the rotation scheme, without building-up of resistance.

Annual patterns of insecticide selection for IRS and space spraying were examined in an analysis of insecticide use patterns throughout the world *(69)*. A simple equation was developed to quantify the degree of "proactive" insecticide resistance management adopted in countries, denoted *R*. The authors determined the frequency of rotation of insecticides and mosaic use of insecticides and analysed the insecticide modes of action used over several years. Parameter *R* is 0 for countries that use insecticides with a single mode of action year after year, which implies that the country did not manage resistance. Conversely, *R* has a value of 10.0 for a country in which insecticides with three modes of action are rotated annually (i.e. each used once every 3 years). The average extent of resistance management of malaria vectors was, however, generally poor and did not improve over time (Table 8.9). Several countries in Africa (Botswana, Eswatini, Madagascar, Mozambique, Zambia and Zimbabwe), however, have adopted a reasonable-to-good level of resistance management, whereas countries in Latin America and the Caribbean and in the Asia-Pacific region had poor resistance management, including for malaria, dengue, leishmaniases and Chagas disease, with spraying regimes based mainly on pyrethroids, which were applied year after year, even when resistance was detected.

Table 8.9. Extent of proactive resistance management for disease vector control by region

Geopolitical region	Vector-borne disease	2010–2014	2015–2019	N
Africa	Malaria	3.0	3.6	17
Asia–Pacific	Malaria	1.6	0.7	9
	Dengue	1.6	1.6	7
	Leishmaniases	0.8	0.4	5
Latin American and the Caribbean	Malaria	0.6	1.0	7
	Dengue	1.4	2.0	7
	Chagas disease	0.7	0.7	3

Source: van den Berg et al. *(69)*.

Values are for parameter *R*, a collective measure of the extent of rotation and mosaic or combination spraying with insecticides with different modes of action in countries (N) in two 5-year periods

The poor results for resistance management may have various explanations. Some countries still do not have a national plan for managing insecticide resistance *(62)*, and several have no system for monitoring insecticide resistance *(7,58)*. Others may have insufficient options for rotating insecticides with different modes of action.

– What is the main reason for inadequate management of insecticide resistance in disease vectors in your country, if applicable?

Use of insecticides in mosaics or mixtures of two or more products is not yet used widely. A prerequisite of resistance management is that insecticides be used "judiciously" and with good pesticide management practices. Targeted, judicious use of insecticides requires data on the location of disease cases and transmission. When geospatial information is lacking, the aim of a programme may be full coverage with vector control; however, as more information on the spatial distribution of disease and disease transmission becomes available, more targeted vector control is feasible, used only where the disease is circulating, with an insecticide product to which the local vectors are susceptible (Box 8.8).

Box 8.8. **Insecticide resistance management in Zambia**

Since 2011, data on resistance to insecticides in malaria vectors have been collected systematically in Zambia as the basis for its insecticide resistance management strategy. In 2011, a decision was made to withdraw use of DDT from IRS and to introduce a mosaic of insecticide products in accordance with local data on insecticide susceptibility. Carbamates were used in the Northern, Muchinga and Copperbelt provinces, organophosphates in Eastern province, and pyrethroids in the rest of the country.

In 2012, the latest data were reviewed, and a rotational scheme was introduced, with the mosaic scheme. Organophosphates were rotated with carbamates in Northern, Muchinga and Copperbelt provinces, but, in the other provinces, the same insecticides were used as before, because the organophosphate pirimiphos-methyl was not available in sufficient quantities; furthermore, this chemical is more costly than alternative IRS insecticides.

In 2013, resistance to all the insecticide classes except organophosphates was detected in all provinces. The organophosphate pirimiphos-methyl was again sprayed only in Northern, Muchinga and Copperbelt provinces and not in all provinces due to its high cost.

The main challenge to the IRM strategy was thus a shortage of effective options *(38)*.

Mixtures are combinations of unrelated active ingredients in a single insecticide product. An example is Fludora® Fusion, a combination of clothianidin and deltamethrin. Mixtures or combination products are easily used in the wrong context. Although Fludora® Fusion has been adopted for malaria control by IRS programmes in several African countries, WHO recommends that IRS insecticides be used only where the vectors are susceptible to the insecticides. Hence, when Fludora® Fusion is used, the vectors should be susceptible to both pyrethroids and neonicotinoids; however, there is a real risk that countries use this combination product in areas where vector populations have developed resistance to pyrethroids.

With widespread development of resistance resulting from recent increases in malaria vector control, sustainable prevention of resistance is no longer possible in most countries *(70)*. The objective in many countries, therefore, is to delay the build-up of resistance. The option of rotating insecticides is, however, severely limited by the choice of insecticides recommended for vector control, as illustrated in the example from Zambia (Box 8.8). As of 2023, 27 insecticide products have been prequalified for use in IRS *(71)*, but these products have only four different modes of action (pyrethroids, carbamates, organophosphates and neonicotinoids). Moreover, all the available ITN products contain pyrethroids *(71)*.

In areas where there is already resistance, strategies must be found to slow the spread of resistance genes in vector populations, with the aim of preserving the effectiveness of the few available vector control tools, particularly ITNs, for as long as possible, until new methods or tools become available *(70)*. A long-term strategy for resistance management is to reduce the selection pressure for insecticide resistance through IVM. IVM involves re-orientation of disease control programmes by increasing collaboration within the health sector and with other sectors, using evidence-based decision-making, precise targeting of interventions and use of several vector control methods (including non-chemical methods) where practicable. Insecticides should be used judiciously by using good pesticide management practices *(5)* to reduce the pressure for selection of insecticide resistance.

Development of novel insecticide products

In response to high levels of pyrethroid resistance in malaria vectors, manufacturers have recently modified standard ITNs by adding the insecticide synergist PBO. At the dose used, PBO is not insecticidal on its own but enhances the effect of the primary insecticide (the pyrethroid). It essentially increases exposure of the vector to the insecticide, as if the dose of the insecticide had been increased. Hence, pyrethroid–PBO ITNs increase the rate of mortality of the vector population, even resistant populations, and reduce blood feeding as compared with standard ITNs. ITNs with added PBO are therefore more effective in areas where vectors have developed metabolic resistance to pyrethroids *(72)*.

As of 2022, the WHO had prequalified six recently developed ITN products that contain a pyrethroid and PBO *(71)*. During 18 months of field use, pyrethroid–PBO ITNs reduced malaria prevalence more effectively than ITNs with pyrethroid alone in areas where malaria vectors are highly resistant to pyrethroids. Questions remain, however, about the length of action of PBO in nets, as LLIN are supposed to last for 3 years *(73)*.

In the medium and longer term, vector populations will adapt to the pyrethroid–PBO combination because of selection pressure to develop resistance, even in the presence of PBO. For example, in a study in Mozambique, a pyrethroid–PBO ITN was reported to have lost efficacy against the vector *An. funestus (74)*.

– What future role do you foresee for pyrethroid–PBO ITNs in areas with pyrethroid-resistant malaria vectors?

Other dual-insecticide ITN products have become available, which contain a pyrethroid and a second insecticide of an unrelated insecticide class. A recently prequalified ITN product, for example, contains a pyrethroid and a pyrrole insecticide (chlorfenapyr), and another product contains a pyrethroid with an insect growth regulator (pyriproxyfen).

A number of other products for use in IRS have become available during the past decade. These include a micro-encapsulated formulation of pirimiphos-methyl (organophosphate) and two clothianidin-based products (neonicotinoids), which have been prequalified for use in IRS *(71)*. These products add new or unrelated modes of action to the arsenal that has been available to field programmes. Unfortunately, these products are considerably more expensive than pyrethroids; thus, in a replacement strategy with the same budget allocation, malaria control programmes will not be able to cover the same number of houses or population as with standard products.

Development and use of alternative vector control interventions

Use of larvicides is much less common than use of adulticides for vector control. Most insecticides are used to control adult vectors, not the larval stages. In the context of insecticide resistance management, however, larvicides deserve greater attention. Several products with unique, unrelated modes of action have been prequalified for larviciding that are not available for vector adulticiding *(62,71)*. These include bacterial larvicides, insect growth regulators, spinosyns and mechanical barriers.

Non-insecticidal tools, technologies and approaches should also be used to overcome insecticide resistance, as advocated in the Global Vector Control Response 2017–2030 *(75)*. These include house improvement, source reduction and environmental management. Section 7.9 discusses several novel vector control products that are being developed, such as attractive toxic sugar baits, endectocides, eave tubes and spatial repellents. Most of these novel methods are being developed for malaria vector control. Tools that are being evaluated for *Aedes* control include the sterile insect technique, use of *Wolbachia* for control of dengue virus and spatial repellents. New tools for sand fly vector control include peri-domestic residual spraying and systemic insecticides and endectocides. Source reduction has been an important component of dengue vector control. Ultimately, reduced reliance on insecticides will reduce the pressure for development of insecticide resistance and will increase the prospects for sustainable vector control.

– In your opinion, should an insecticide resistance management strategy limit its scope to insecticide products or should it include non-insecticidal approaches?

Project assignment 8

1. Describe the process used for procuring vector control insecticides in your country, and propose improvements by addressing the following questions:
   a. Which agency(ies) is responsible for procuring vector control insecticides?
   b. Is procurement centralized or also done by districts and municipalities?
   c. Is there coordination among vector control programmes for insecticide procurement?
   d. Are products selected according to up-to-date data on insecticide susceptibility and in accordance with WHO recommendations?
   e. Are guidelines available to ensure efficient, transparent, fair procurement?
   f. Is the quality of procured products controlled by an independent, certified laboratory?
   g. Is use of PPE in vector control operations monitored and enforced?
   h. Propose improvements to the system of procurement of vector control insecticides in your country.
2. Review recent data on insecticide susceptibility in disease vectors (e.g. malaria or dengue vectors) in your country or in a neighbouring country if appropriate.
   a. Which vector species are monitored, how regularly and at how many sentinel sites?
   b. State whether you consider that the monitoring data are adequate and whether they are used to guide decisions on vector control.
   c. Outline the actions taken by the vector control programme to prevent or delay the development of insecticide resistance. Identify shortcomings, and propose improvements to the strategy of insecticide resistance management.

References

1. Guidelines on public health pesticide management policy for the WHO African Region. Geneva: World Health Organization; 2011 (https://iris.who.int/handle/10665/97939).

2. Guidelines on public health pesticide management policy. New Delhi: World Health Organization Regional Office for South-East Asia; 2010 (https://iris.who.int/handle/10665/205194).

3. Global situation of pesticide management in agriculture and public health. Report of a 2018 WHO–FAO survey. Geneva and Rome: World Health Organization and Food and Agriculture Organization of the United Nations; 2019 (https://iris.who.int/handle/10665/329971).

4. van den Berg H, Velayudhan R, Yadav RS. Management of insecticides for use in disease vector control: Lessons from six countries in Asia and the Middle East. PLoS Negl Trop Dis. 2021;15(4):e0009358. doi:10.1371/journal.pntd.0009358.

5. Handbook for integrated vector management. Geneva: World Health Organization; 2012 (https://iris.who.int/handle/10665/44768).

6. Reid MC, McKenzie FE. The contribution of agricultural insecticide use to increasing insecticide resistance in African malaria vectors. Malar J. 2016;15(1):107. doi:10.1186/s12936-016-1162-4.

7. Russell TL, Farlow R, Min M, Espino E, Mnzava A, Burkot TR. Capacity of national malaria control programmes to implement vector surveillance: a global analysis. Malar J. 2020;19(1):1–9. doi:10.1186/s12936-020-03493-1.

8. van den Berg H, Gu B, Grenier B, Kohlschmid E, Al-Eryani S, da Silva Bezerra HS et al. Pesticide lifecycle management in agriculture and public health: Where are the gaps? Sci Total Environ. 2020;742:140598. doi:10.1016/j.scitotenv.2020.140598.

9. Mnzava AEP, Ntuli M, Ngxongo S, le Sueur D, Sharp B. House re-plastering as a reason to shift from DDT spraying to synthetic pyrethroids in KwaZulu-Natal. S Afr Med J Public Health 1998;88:1024–8.

10. Deribew A, Birhanu Z, Sena L, Dejene T, Reda AA, Sudhakar M et al. The effect of household heads training on long-lasting insecticide-treated bed nets utilization: a cluster randomized controlled trial in Ethiopia. Malar J. 2012;11(1):99. doi:10.1186/1475-2875-11-99.

11. Managing pesticides in agriculture and public health – A compendium of FAO and WHO guidelines and other resources. Second edition. Rome: Food and Agriculture Organization of the United Nations, World Health Organization; 2021 (https://www.fao.org/documents/card/en/c/cb3179en).

12. van den Berg H, Yadav RS, Zaim M. Strengthening public health pesticide management in countries endemic with malaria or other major vector-borne diseases: an evaluation of three strategies. Malar J. 2014;13(1):368. doi:10.1186/1475-2875-13-368.

13. Guidelines for procurement of public health pesticides. Geneva: World Health Organization; 2012 (https://iris.who.int/handle/10665/44856).

14. Matthews G, Zaim M, Yadav RS, Soares A, Hii J, Ameneshewa B et al. Status of legislation and regulatory control of public health pesticides in countries endemic with or at risk of major vector-borne diseases. Environ Health Perspect. 2011;119(11):1517–22. doi:10.1289/ehp.1103637.

15. Global plan for insecticide resistance management in malaria vectors. Geneva: World Health Organization; 2012 (https://iris.who.int/handle/10665/44846).

16. van den Berg H, Al-Eryani S, Chanda E, Gasimov E, Nagpal BN, da Silva Bezerra HS et al. Management of insecticides for use in disease vector control: a global survey. BMC Infect Dis. 2021;21:468. doi:10.1186/s12879-021-06155-y.

17. Decision-making for the judicious use of insecticides. Geneva: World Health Organization; 2004 (https://iris.who.int/handle/10665/68781).

18. The substitution principle (KEMI Report No. 8/07). Stockholm: Swedish Chemicals Agency; 2007 (https://www.kemi.se/en/publications/reports/2007/report-8-07-the-substitution-principle).

19. Equipment for vector control specification guidelines, second edition. Geneva: World Health Organization; 2018 (https://iris.who.int/handle/10665/272410).

20. Pesticide storage and stock control manual.. Rome: Food and Agriculture Organization of the United Nations; 1996 (http://www.fao.org/docrep/V8966E/V8966E00.htm).

21. Guidelines for quality control of pesticides. Geneva: Food and Agriculture Organization of the United Nations, World Health Organization; 2011 (https://www.who.int/publications/i/item/who-htm-ntd-whopes-2011.4).

22. Global situation of pesticide management in agriculture and public health. Report of a 2018 WHO–FAO survey. Geneva: World Health Organization, Food and Agriculture Organization of the United Nations; 2019 (https://iris.who.int/handle/10665/329971).

23. Stockholm Convention. National implementation plans. Nairobi: United Nations Environment Programme; 2019 (http://chm.pops.int/implementation/NationalImplementationPlans/NIPTransmission/tabid/253/default.aspx).

24. Technical guidelines for the environmentally sound management of wastes consisting of, containing or contaminated with 1,1,1 trichloro 2,2 bis(4 chlorophenyl)ethane (DDT). Geneva: United Nations Environment Programme; 2006 (https://digitallibrary.un.org/record/699748?ln=en).

25. FAO training manual for inventory taking of obsolete pesticides. Rome: Food and Agriculture Organization of the United Nations; 2001 (https://www.fao.org/3/x9899/x9899.pdf).

26. Guidelines on management options for empty pesticide containers. Rome: Food and Agriculture Organization of the United Nations, World Health Organization; 2008 (https://www.fao.org/3/bt563e/bt563e.pdf).

27. Corbel V, N'Guessan R. Distribution, mechanisms, impact and management of insecticide resistance in malaria vectors: a pragmatic review. In: *Anopheles* mosquitoes – New insights into malaria vectors. London: IntechOpen; 2013 (https://www.intechopen.com/chapters/43899).

28. Prevention and management of insecticide resistance in vectors of public health importance. Second edition. Waynesville (OH): Insecticide Resistance Action Committee; 2011 (https://irac-online.org/content/uploads/2009/09/VM-Layout-v2.6_LR.pdf).

29. Riveron JM, Tchouakui M, Mugenzi L, Menze BD, Chiang MC, Wondji CS. Insecticide resistance in malaria vectors: an update at a global scale. In: Towards malaria elimination – a leap forward. London: IntechOpen; 2018 (https://www.intechopen.com/chapters/62169).

30. Sougoufara S, Diédhiou SM, Doucouré S, Diagne N, Sembène PM, Harry M et al. Biting by *Anopheles funestus* in broad daylight after use of long-lasting insecticidal nets: a new challenge to malaria elimination. Malar J. 2014;13(125). doi:10.1186/1475-2875-13-125.

31. Bayoh MN, Mathias DK, Odiere MR, Mutuku FM, Kamau L, Gimnig JE et al. *Anopheles gambiae*: historical population decline associated with regional distribution of insecticide-treated bed nets in western Nyanza Province, Kenya. Malar J. 2010;9(1):62. doi:10.1186/1475-2875-9-62.

32. Grube A, Donaldson D, Kiely T, Wu L. Pesticides industry sales and usage: 2006 and 2007 market estimates. Washington DC: United States Environmental Protection Agency; 2011 (https://www.epa.gov/sites/default/files/2015-10/documents/market_estimates2007.pdf).

33. Read AF, Lynch PA, Thomas MB. How to make evolution-proof insecticides for malaria control. PLoS Biol. 2009;7(4):e1000058. doi:10.1371/journal.pbio.1000058.

34. Raghavendra K, Verma V, Srivastava H, Gunasekaran K, Sreehari U, Dash A. Persistence of DDT, malathion & deltamethrin resistance in *Anopheles culicifacies* after their sequential withdrawal from indoor residual spraying in Surat District, India. Indian J Med Res. 2010;132:260–4 (https://pubmed.ncbi.nlm.nih.gov/20847371/).

35. Gould F, Brown ZS, Kuzma J. Wicked evolution: Can we address the sociobiological dilemma of pesticide resistance? Science. 2018;360(6390):728–32. doi:10.1126/science.aar3780.

36. Tabashnik BE. Managing resistance with multiple pesticide tactics: theory, evidence, and recommendations. J Econ Entomolo. 1989;82(5):1263–9. doi:10.1093/jee/82.5.1263.

37. Hancock PA, Hendriks CJ, Tangena JA, Gibson H, Hemingway J, Coleman M et al. Mapping trends in insecticide resistance phenotypes in African malaria vectors. PLoS Biol. 2020;18(6):e3000633. doi:10.1371/journal.pbio.3000633.

38. Chanda E, Thomsen EK, Musapa M, Kamuliwo M, Brogdon WG, Norris DE et al. An operational framework for insecticide resistance management planning. Emerg Infect Dis. 2016;22(5):773–9. doi:10.3201/eid2205.150984.

39. World malaria report 2014. Geneva: World Health Organization; 2014 (https://iris.who.int/handle/10665/144852).

40. Killeen GF. Control of malaria vectors and management of insecticide resistance through universal coverage with next-generation insecticide-treated nets. Lancet. 2020;395(10233):1394–400. doi:10.1016/S0140-6736(20)30745-5.

41. Lindsay SW, Gibson ME. Bednets revisited – old idea, new angle. Parasitol Today. 1988;4(10):270–2. doi: 10.1016/0169-4758(88)90017-8.

42. Malaria threats map. Vector insecticide resistance. Geneva: World Health Organization; 2023 (https://apps.who.int/malaria/maps/threats/).

43. Ranson H, N'Guessan R, Lines J, Moiroux N, Nkuni Z, Corbel V. Pyrethroid resistance in African anopheline mosquitoes: What are the implications for malaria control? Trends Parasitol. 2011;27:91–8. doi:10.1016/j.pt.2010.08.004.

44. Hancock PA, Wiebe A, Gleave KA, Bhatt S, Cameron E, Trett A et al. Associated patterns of insecticide resistance in field populations of malaria vectors across Africa. Proc Natl Acad Sci U S A. 2018;115(23):5938–43. doi:10.1073/pnas.1801826115.

45. Moyes CL, Vontas J, Martins AJ, Ng LC, Koou SY, Dusfour I et al. Contemporary status of insecticide resistance in the major *Aedes* vectors of arboviruses infecting humans. PLoS Negl Trop Dis. 2017;11(7):e0005625. doi:10.1371/journal.pntd.0005625.

46. Gomez MB, Diotaiuti LG, Gorla DE. Distribution of pyrethroid resistant populations of *Triatoma infestans* in the Southern Cone of South America. PLoS Negl Trop Dis. 2016;10(3):e0004561. doi:10.1371/journal.pntd.0004561.

47. Dhiman RC, Yadav RS. Insecticide resistance in phlebotomine sandflies in Southeast Asia with emphasis on the Indian subcontinent. Infect Dis Poverty. 2016;5(1):106. doi:10.1186/s40249-016-0200-3.

48. Malaria entomology and vector control. Guide for participants. Geneva: World Health Organization; 2013 (https://iris.who.int/handle/10665/85890).

49. Manual for monitoring insecticide resistance in mosquito vectors and selecting appropriate interventions. Geneva: World Health Organization; 2022 (https://iris.who.int/handle/10665/356964).

50. Standard operating procedure for testing insecticide susceptibility of adult mosquitoes in WHO tube tests, WHO Tube test/01/14 January 2022. Geneva: World Health Organization; 2022 (https://iris.who.int/handle/10665/352316).

51. Standard operating procedure for testing insecticide susceptibility of adult mosquitoes in WHO bottle bioassays, WHO Bottle-bioassay/01/14 January 2022. Geneva: World Health Organization; 2022 (https://iris.who.int/handle/10665/352312).

52. Determining discriminating concentrations of insecticides for monitoring resistance in sand flies: report of a multi-centre laboratory study and WHO expert consultations. Geneva: World Health Organization; 2022 (https://iris.who.int/handle/10665/365552).

53. Procurement of test kits. In: WHO/Control Neglected Tropical Diseases [website]. Geneva: World Health Organization; 2023 (https://www.who.int/teams/control-of-neglected-tropical-diseases/interventions/strategies/vector-control/insecticide-resistance).

54. Guideline for evaluating insecticide resistance in vectors using the CDC bottle bioassay. Atlanta: US Centers for Disease Control and Prevention; 2023 (https://www.cdc.gov/parasites/education_training/lab/bottlebioassay.html).

55. Standard operating procedure for evaluating the sterilizing properties of pyriproxyfen in adult female mosquitoes in WHO bottle bioassays, PPXN-Bioassay/01/14 January 2022. World Health Organization (https://iris.who.int/handle/10665/352317).

56. Guidelines for testing mosquito adulticides for indoor residual spraying and treatment of mosquito nets. Geneva: World Health Organization; 2006 (https://iris.who.int/handle/10665/69296).

57. Jones CM, Sanou A, Guelbeogo WM, Sagnon NF, Johnson PCD, Ranson H. Aging partially restores the efficacy of malaria vector control in insecticide-resistant populations of *Anopheles gambiae s.l.* from Burkina Faso. Malar J. 2012;11:24. doi:10.1186/1475-2875-11-24.

58. Burkot TR, Farlow R, Min M, Espino E, Mnzava A, Russell TL. A global analysis of national malaria control programme vector surveillance by elimination and control status in 2018. Malar J. 2019;18(1):1–12. doi:10.1186/s12936-019-3041-2.

59. Hemingway J. The role of vector control in stopping the transmission of malaria: threats and opportunities. Phil Trans R Soc B Biol Sci. 2014;369(1645):20130431. doi:10.1098/rstb.2013.0431.

60. Kleinschmidt I, Bradley J, Knox TB, Mnzava AP, Kafy HT, Mbogo C et al. Implications of insecticide resistance for malaria vector control with long-lasting insecticidal nets: a WHO-coordinated, prospective, international, observational cohort study. Lancet Infect Dis. 2018;18(6):640–9. doi:10.1016/S1473-3099(18)30172-5.

61. Riveron JM, Irving H, Ndula M, Barnes KG, Ibrahim SS, Paine MJI et al. Directionally selected cytochrome P450 alleles are driving the spread of pyrethroid resistance in the major malaria vector *Anopheles funestus*. Proc Natl Acad Sci U S A. 2013;110(1):252–7. doi:10.1073/pnas.1216705110.

62. Mnzava AP, Knox TB, Temu EA, Trett A, Fornadel C, Hemingway J et al. Implementation of the global plan for insecticide resistance management in malaria vectors: progress, challenges and the way forward. Malar J. 2015;14(1):173. doi:10.1186/s12936-015-0693-4.

63. Hemingway J, Ranson H, Magill A, Kolaczinski J, Fornadel C, Gimnig J et al. Averting a malaria disaster: Will insecticide resistance derail malaria control? Lancet. 2016;387(10029):1785–8. doi:10.1016/S0140-6736(15)00417-1.

64. Forrester NW. Designing, implementing and servicing an insecticide resistance management strategy. Pestic Sci. 1990;28:167–79. doi:10.1002/ps.2780280205.

65. Andow DA, Fitt GP, Grafius EJ, Jackson RE, Radcliffe EB, Ragsdale DW et al. Pesticide and transgenic plant resistance management in the field. In: Whalon ME, Mota-Sanchez D, Hollingworth RM, editors. Global pesticide resistance in arthropods. Wallingford: CAB International; 2008:118–45 (https://www.cabidigitallibrary.org/doi/book/10.1079/9781845933531.0000).

66. Penilla RP, Rodriguez AD, Hemingway J, Torres JL, Arredondo-Jimenez JI, Rodriguez MH. Resistance management strategies in malaria vector mosquito control. Baseline data for a large scale field trial against *Anopheles albimanus* in Mexico. Med Vet Entomol. 1998;12:217–33. doi:10.1046/j.1365-2915.1998.00123.x.

67. Penilla RP, Rodríguez AD, Hemingway J, Trejo A, López AD, Rodríguez MH. Cytochrome P450-based resistance mechanism and pyrethroid resistance in the field *Anopheles albimanus* resistance management trial. Pestic Biochem Physiol. 2007;89(2):111–7. doi:10.1016/j.pestbp.2007.03.004.

68. Davies JB. Sixty years of onchocerciasis vector control: A chronological summary with comments on eradication, reinvasion, and insecticide resistance. Annu Rev Entomol. 1994;39(1):23–45. doi:10.1146/annurev.en.39.010194.000323.

69. van den Berg H, da Silva Bezerra HS, Al-Eryani S, Chanda E, Nagpal BN, Knox TB et al. Recent trends in global insecticide use for disease vector control and potential implications for resistance management. Sci Rep. 2021;11(1):23867. doi:10.1038/s41598-021-03367-9.

70. The technical basis for coordinated action against insecticide resistance: preserving the effectiveness of modern malaria vector control: meeting report. Geneva: World Health Organization; 2011 (https://iris.who.int/handle/10665/44526).

71. Vector control product prequalification. Geneva: World Health Organization; 2022 (https://extranet.who.int/prequal/vector-control-products/prequalified-product-list).

72. Conditions for deployment of mosquito nets treated with a pyrethroid and piperonyl butoxide. Geneva: World Health Organization; 2017 (https://iris.who.int/handle/10665/258939).

73. Gleave K, Lissenden N, Richardson M, Choi L, Ranson H. Piperonyl butoxide (PBO) combined with pyrethroids in insecticide-treated nets to prevent malaria in Africa. Cochrane Database Syst Rev. 2018;(11):CD012776. doi:10.1002/14651858.CD012776.pub3.

74. Riveron JM, Huijben S, Tchapga W, Tchouakui M, Wondji MJ, Tchoupo M et al. Escalation of pyrethroid resistance in the malaria vector *Anopheles funestus* induces a loss of efficacy of piperonyl butoxide-based insecticide-treated nets in Mozambique. J Infect Dis. 2019;220(3):467–75. doi:10.1093/infdis/jiz139.

75. Global vector control response 2017–2030. Geneva: World Health Organization; 2017 (https://iris.who.int/handle/10665/259205).

Recommended reading

van den Berg H, Velayudhan R, Yadav RS. Management of insecticides for use in disease vector control: Lessons from six countries in Asia and the Middle East. PLoS Negl Trop Dis. 2021;15(4):e0009358. doi:10.1371/journal.pntd.0009358.

Chanda E, Thomsen EK, Musapa M, Kamuliwo M, Brogdon WG, Norris DE et al. An operational framework for insecticide resistance management planning. Emerg Infect Dis. 2016;22(5):773–9. doi:10.3201/eid2205.150984.

Prevention and management of insecticide resistance in vectors of public health importance. Second edition. Waynesville (OH): Insecticide Resistance Action Committee; 2011:Chapters 4,5 https://irac-online.org/content/uploads/2009/09/VM-Layout-v2.6_LR.pdf).

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