ENVIRONMENTAL MANAGEMENT FOR MALARIA CONTROL

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ABSTRACT

Environmental management for malaria control is defined as any planned physical activities that through transformation of land, water and vegetation will result in the prevention, reduction or elimination of malaria. In planning and implementing these activities, full consideration must be given to their long-term effects and benefits and to the preservation of the quality of environment and they need to be fully and closely coordinated with water, land and agricultural development projects.

Environmental management activities for malaria control can be classified as source reduction, dealing mainly with physical alteration of the environment; environmental manipulation, introducing temporary environmental changes and the reduction and prevention of man-vector contact by site selection, mosquito proofing of dwellings and personal protection.

For anti-malaria programmes to employ these activities they need to re-train the staff, re-orient the services and set up pilot operations for feasibility studies.

INTRODUCTION

Environmental management for malaria control is a broad term covering any planned physical transformation of land, water and

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** UNEP/WHO meeting on the bio-environmental methods of control of malaria. Lima, Peru, 10-15 December 1975, vegetation that not only results in the prevention, elimination, or reduction of malaria, but also maintains the quality of the environment and minimizes adverse effects.

Most environmental management activities are directed towards mosquito source reduction, which deals exclusively with waters where mosquito vectors of malaria lay eggs, breed, and propagate. Thus, the elimination and reduction of breeding sites through physical changes of the environment, as well as the prevention of mosquito breeding sources through appropriate engineering design and the correct operation and maintenance of water development schemes, are among the major activities involved.

Environmental management may also include activites leading to a reduction or prevention of the breeding and development of mosquito vectors through environmental manipulation. Physical manipulation of the environment may so change conditions in breeding places that mosquito development is seriously reduced or prevented. Changing salinity, flushing streams, water fluctuation in impoundment reservoirs, pollution with organic wastes, the production of shade, or exposure to the sun are all among environmental manipulation activities.

Environmental management also includes activities directed towards the prevention or reduction of man-vector contact. These include «site selection» - the establishment of populations and communities away from the reach of mosquitos or where they are least exposed to mosquito bites and infection risks. They may also include intervention operations such as the mosquito proofing of houses and the use of mosquito nets, which may need to be complemented by the utilization of repellent compounds or plants.

1. Source reduction and elimination

These are planned activities that physically alter the environment, often permanently. They reduce or eliminate mosquito breeding sites or prevent their creation. Drainage and filling are the major methods used for mosquito source reduction and elimination.

Source reduction or elimination may be simple activities such as filling small pockets of water; cleaning and clearing of banks of lakes, rivers, canals and ditches; removal of obstructing silt and weeds and re-establishment of flow; stopping of seepages. Sometimes more complicated source reduction activities may be required such as the construction of levees, the circulation of tidal waters, the drainage of large swamps or excess irrigation water, the correction and straightening of waterways, and flood control and diversion of waste water for irrigation and other useful purposes.

It is apparent that while simple source reduction and elimination are within the executive competence and available resources of antimalaria programmes, the more complicated operations need skilled knowledge and manpower, specialized services, and often considerable financial investment. As such they should be planned and carried out by the competent services and administrations, with antimalaria services playing a catalytic role in their promotion and initiation and a collaborating role in their planning, realization and operation.

On the other hand, besides health improvement, these projects provide other great benefits. They produce more water for irrigation and for domestic, industrial or recreational use, and they may make additional land available for agricultural extension or housing development. They will thus enjoy public support and will obtain greater priority in financial aid. Health authorities and antimalaria services must study the health aspects of such projects and seek assistance to investigate other advantages and benefits and formulate proposals jointly with other specialized services for consideration by the authorities.

The degree of involvement of antimalaria services in source reduction operations depends very much on the aims of the malaria project and the available and potential capability of the service to handle these operations. To be of any significant assistance in carrying out source reduction activities or in prompting and assisting other agencies to carry them out, there is an acute need for qualified staff and for a long-term programme of staff training. The varying local topography and land and water utilization imply that each situation should be studied and assessed separately and that methods appropriate to local conditions should be selected.

During the planning stage, alterations of the environment resulting from source reduction activities need to be studied and their impact carefully appraised. The plan should clearly show the environmental changes that are expected to result from the implemention of the projects and the safeguards and countermeasures that may be need in order to minimize their effects. Above all it must be shown that the changes will not be of a nature and extent that would cause undue harm to the environment or adversely affect local flora and fauna.

1.1 Drainage

Drainage is an operation designed to remove and dispose of excess or unwanted water. It could also be described as the reverse of irrigation. Applied to rain-water it should collect, carry and dispose of the water from the surface of the ground before mosquitos can breed and develop to the adult stage.

The objectives of drainage may be land reclamation, increased production, protection of roads and railways, or health and environmental improvement. Drainage for mosquito control is one of the most effective and permanent methods of mosquito prevention, reduction, or elimination. When properly designed and constructed, drainage systems operate for many years with little maintenance. The overall costs compare, therefore, very favourably with other less permanent or repetitive measures.

As early as 1902 in Malaya a simple method of drainage considerably reduced the number of deaths from malaria in two towns. By 1920 drainage was extensively used in many countries for malaria control. Drainage systems built during the period 1920-1940 are still operating in Malaysia, Mauritius, India, the Philippines and many other countries. In Malaysia alone in the late 1960s it was estimated that over 5400 km of drains of different categories existed under the national malaria service management.

In modern antimalaria programmes very little use has been made of drainage as a means of vector control. exceptions are the programmes in Italy and Cyprus, and the method has also been applied recently in Jorden, where the elusive habits of the vector *Anopheles sergenti* are an obstacle to the interruption of transmission by residual spraying.

Drainage can be accomplished by various methods including the use of shrubs and trees. The major methods, however, are the digging of open ditches, the laying of underground drains, and pumping or vertical drainage. The method chosen and its cost depend on (1) the extent of water areas to be drained; (2) the slope or gradient available; (3) the soil texture and conditions; (4) the climate (e.g. rainfall and temperature) and (5) the possibilities of disposing of the water.

1.1.1 Open drainage

There are drains and ditches with side slopes made of earth, compacted earth, masonry or concrete, dug to carry, usually by gravity, the excess surface and irrigation water. The shape and gradient of the drain depends on the volume of the water to be drained and the topography of the land.

The side slope of the drain or ditch depends on the soil texture. Compcated soil, such as clay, resists the sliding on the side slopes better than sandy soils. The degree of slope can be steeper with clay soil but not less than 1:1. For softer, sandy solis 2:1 or 3:1 is recommended.

The gradient or fall of the ditch depends mainly on the land topography and ranges from 0.0005 to 0.006.[6]

Ditching is a simple operation when it involves the removal of small pokets of water. In this case, hand-cut ditches are simply dug following the slope of the land. The profile of the ditch depends on the type of soil and the texture of the land - trapezoidal with side slopes of 2 or 3 to 1 for soft, sandy soils, V-shaped for soil of medium compaction, and near rectangular for compact and firm soils.

The process is more complicated when the work consists of drainage of large swamps, excess irrigation water, coastal marshes or groundwater. The work is even more complex when the same drainage system is also to evacuate storm water and urban wastewater. Here various specialists are required for preliminary investigations, feasibility studies, engineering survey and design, and for the construction and operation of the system. In addition to the engineering staff, a topographer and possibly a geologist and hydrologist may also be required. When excess irrigation water or natural swamps are to be drained the services of agronomists and environmentalists must be secured.

The designing of a large drain, its cross-sectional form and gradient can be calculated using various equations. For less important projects, however, simple estimations are adequate.[6]

For important undertakings, detailed topographical and hydrological surveys must be made to establish overall maps of the area, the layout and cross-section of the drains, and the mode of operation. Hydrological studies are needed to collect data on amount, intensity, frequency and season of rainfalls, the size of the runoff or watershed area, and its shape and topography.

Socioeconomic studies should include an appraisal of the benefits and inconveniences of the scheme for the communities involved, taking into consideration both long- and short - term effects.

Technical studies must include an examination of various possible alternative designs and solutions, using as a basis the cost/effectiveness of the various methods and their impact on human health and the environment.

Large drains, especially those receiving several types of discharge, especially rainfall, have large seasonal fluctuations in flow. In most cases the discharge in certain seasons consists of a meagre flow in the bottom of the drain, which creates favourable habitats for mosquito breeding. A vast network of drains may thus create an enormous mosqutio problem. If , for economic reasons, separate drains cannot be constructed for different types of discharge, then low flow inverts or closed conduits of suitable sizes must be installed in the bottom of the drain to evacuate the discharges during the low discharge or dry seasons.

1.1.1.1 Excavation

Ditches and large drains may be excavated by hand, by machine, or by explosives.

(a) Small and medium drainage ditches may be excavated by hand. Trapezoidal ditches may have a bottom width of about 20cm to 2.5 m. Using ordinary manual tools, a labourer can dig about 3 m^3 per day in soils of medium compaction. Such ditches dug in firm or relatively compact solis may last for many years with little maintenance, especially if the discharge is seasonal.

Manual excavation is rather slow and sometimes difficult in alluvial terrain with stony or rocky substrata, and the occasional use of an excavating machine or explosives is essential.

(b) Excavation by machine is applied to large drains of 3 m to 30 m width. The equipment used includes power shovels, power cranes, power trench excavators, ploughs, and scrapers, as well as hand tools. The choice of heavy excavating equipment much depends on the size of the project, the type of soil, and the cost of bringing the equipment to the operation site.

In general, a power crane with a drag-line bucket is most suitable for long stretches of ditches. Trenching machines greatly facilitate cutting side slopes, and tractor-drawn ploughs and scrapers can be used economically to cut shallow drains in soft ground.

Before excavation begins, the ground should be cleared of dense vegetation, stones, and trees. Vegetation can be cut mechanically with mowers, burned or killed with herbicides, and stones and tree trunks can be removed with explosives.

(c) Ditching with explosives (dynamite) has been used extensively for mosquito control. It is a simple, rapid and economical method of ditching, especially in inaccessible areas and where soils is soft and muddy or where heavy equipment cannot enter.

Ditches 1-12m wide, 0.75-3 m deep, and of unlimited length can be blasted with little or no soil piles on the banks.[7] The dimensions of the ditch can be regulated by the amount of explosives and the pattern of planting them. In very wet, soft soil, 1 kg of dynamite will usually excavate about 1.7 m^3 of soil. Knowing the cross-section of the ditch (side slopes are normally 1:1) the volume of the soil to be removed and the amount of explosives and their placing can be calculated and defined.

Narrow and shallow ditches can be blasted out with a single line of holes 45 cm apart, with usually one or sometimes two sticks of dynamite in each hole. For larger drains two or more lines of holes will usually be required and, depending on the weight of the earth to be displaced, possibly more sticks per hole and a different spacing of the holes. Dynamite cartridges are placed one above the other or packed together at the bottom of the hole. The spacing of holes varies with the number of sticks placed in them; 3-5 sticks require 60 cm spacing, 6 sticks 90 cm, and 10 sticks 105 cm. The depth of the holes should usually be above the bottom of the ditch by about one-quarter of the total depth of the ditch. A test blast should normally be made in each area to obtain necessary basic and design data for the operation.

There are two methods of detonation, namely propagation and electrical. The propagation method is simpler; one charge of dynamite is primed and detonation of the others is effected by the explosive impulse in wet soil. The electrical method is used less extensively, and mainly in drier soil where the detonation method is not practicable. The dynamite used for ditching is 50% straight nitroglycerine.

1.1.1.2 Lining ditches and drains

Drainage dtiches and drains are usually left unlined, especially when used in agriculture, owing to the high cost of lining. In certain conditions (e.g., heavy rainfall, unstable ground, or where the cost of maintenance is high) part or all of the ditch may be lined. Drainage ditches are usually provided with a bottom lining in the shape of an invert to help evacuate the low flow and to prevent formation of stagnant pools where mosquitos can breed.

Different materials ranging from wood to stone and concrete may be used for lining ditches. Precast units are more economical and simple to install, especially in small ditches where side slopes and bottom units may be rapidly installed by one or two unskilled labourers. For larger drains reinforced concrete inverts and slabs may be installed using power cranes. Where labour is cheap and bricks and stones are available, linings may be cast in place.

To avoid silt deposits in drains, the water velocity should be above 0.6 m/s. Ditches with narrow bottoms and high flow velocities may need to have lined side slopes. The sodding of side slopes with grass is sometimes adequate for lower flow velocities.

Before lining, the subgrade should be well graded and if necessary replaced with sand, gravel, or firm dirt. Sometimes it may be necessary to lay a 10 cm underdrain in very wet subsoil to stabilize the linings. Also weepholes 2.5 cm in diameter should be provided in side slopes and bottom linings to lower the water table of the surrounding land if it is unduly wet or to increase the humidity of normally dry land.

1.1.2 Subsoil drainage

Subsoil drainage may be considerably more expensive than open drainage, but it is usually maintenance-free and the structure, if properly built, functions for years. Above all it does not physically alter the environment but causes optimum conditions for plants, urbanization, and recreation. It is mostly used in urban areas, for sports grounds or where the surface must be regular, and for agricultural ground when land is expensive.

In this type of drainage, the underground seepage is removed by means of underground conduits and is discharged into open drains or streams. Clay tiles, cement or corrugated metal pipes with holes in the underside, stones, or branches and trunks of tress and bamboo, may be used.

Clay pipes of 10, 15 or 20 cm diameter are most frequently used. They may be laid on the bottom of a properly graded ditch at depths ranging from 0.6 to 1.8 m. Pipes 30 cm in diameter can be used for the dual purpose of subsoil drainage and storm sewer.

Subsoil drains must be provided with inspection wells or joint boxes about every 28 metres or at the joining of two lines. The boxes should be dug at least 30 cm below the grade of the tiles in order to collect sand and infiltrated silt and debris. When the system is also used for storm water collection and removal, intakes with stone, gravel, and sand screens need to be provided.

The clay pipes may be laid tightly together or with a small aperture between them of about 2.5 cm. The inequalities in joints usually allow for adequate water penetration. In acid soil it is necessary to use vitrified clay or cement pipes more than 3 cm thick.

1.1.3 Vertical drainage

When the topography of the land does not allow removal of the surface water or ground-water by gravity flow, or when the cost of pumping is less than the maintenance cost of an outlet drain or ditch, the excess surface water or groundwater may be removed by pumping. The area to be drained in this way should be surveyed and a system of drains and laterals should be designed to collect water in one or a few central wells or sumps for evacuation by pumping to distant areas. Drains of this type were constructed in the Pontine marshes of Italy and many are still operating successfully.

Sometimes the volume of water to be drained is small and in this case pumping can be dispensed with. Instead, central wells or sumps and the connected drains can be extended to hold the drained water. The water thus collected can be treated with larvicides periodically, or larvivorous fish may be introduced to control mosquito breeding.

Major pumping projects are complex undertakings and require the services of a hydraulic engineer specialized in drainage pumping.

Many high-capacity low-head pumps have been designed and are available for use in land reclamation projects.[6]

1.2 Filling and deepening

The filling of depressions and wet areas is one of the most permanent methods of source elimination. Limited deepening and filling must be a principal feature in every antimalaria programme as it requires no special knowledge or skill nor any sophisticated equipment or important funding. Sometimes communities in rural areas and municipalities can be stimulated to carry out the work without a charge to malaria services. Sometimes also public works departments, the army, and private firms can furnish the equipment and know-how for planning and execution of major filling schemes.

Deepening is usually an economical method of source reduction.

It may considerably reduce water areas that would otherwise require expensive water management or chemical treatment for mosquito control. Through dyking or deepening, shallow breeding sources of less than 60 or 90 cm can be converted to limited impoundments with little or no need for treatment against mosquito larvae.

Minor filling and deepening can be done manually using a hand shovel, or animal drawn scrapers. The earth from surrounding elevations can be used to fill and level the depressions. Major projects, however, need engineering skill and machinery and may be very expensive, especially if the filling material is to be hauled in. In urban areas, arrangements may be made with contractors to dump excavated material or municipal garbage on the project sites.

Filling can also be effected by flooding low areas with silt-bearing water. In this method the water is allowed to stand and lose its suspended silt before leaving the fill through a gate, normally V-shaped. Also, silt from the bottom of canals and waterways can be pumped or dredged out to fill depressions. In another method, high-powered water jets may be used to wash out silt and deposit it in nearby depressions.

2. Environmental manipulation

These are activities that normally do not create permanent alterations of the environment, their effects are rather temporary and the changes introduced are usually reversible. For instance, water fluctuation in impoundments, alteration of the salinity of water, shading water from or exposing it to the sun are activities that may be halted at any time and subsequently the situation should soon return to normal.

Environmental manipulation measures are mostly simple operations requiring relatively moderate specialized knowledge or services for their implementation, operation, and maintenance. However, the planning of these activities in antimalaria programmes and sometimes the design and construction of devices require skilled knowledge and personnel.

In planning these activities it must be ascertained that the modification of the environment leading to the control of one vector mosquito will not result in the propagation of another possibly more dangerous species. For instance, clearing vegetation from breeding places in order to expose them to the sun, while controlling breeding of a number of anopheline vectors of malaria (e.g., *A. funestus* and *A. hyrcanus*)[3] may open the way for the establishment of sun-loving species (e.g., *A. gambiae, A. culicifacies, A. sundaicus, A. philippinensis*). Similarly the environmental effects of such modifications need to be investigated in respect of other vectors of communicable diseases and on the environment in general.

Some of these measures, such as pollution by organic waste, need careful scrutiny of their public health and environmental impact. Others (e.g., flushing of streams and river beds) may involve accidents and hazards to the population inhabiting the area. Thus adequate safety provisions should be built into the project.

Environmental manipulation generally produces partial control of the species involved. To achieve an appreciable degree of control they may need to be supplemented with other methods of malaria control. The measures available, though mostly quite effective, have limited application possibilities. They can be applied only in certain specific types of mosquito habitats and seldom to all types of breeding places. Accordingly, flushing of streams can only control that part of the species population that breed in the streams. The remaining breeding areas may need separate types of treatment.

Similarly, water level fluctuation may be feasible only in impoundment reservoirs or in streams and pools where cascades may be produced. Likewise, pollution with organic wastes, changing water salinity, exposure to the sun, and shading have selective application and thus yield partial control. Nevertheless, in view of their simplicity and low maintenance costs, their use must be considered where species breed in habitats liable to be controlled by these methods. Where inadequate, they may be supplemented with other malaria control methods.

2.1 Methods of environmental manipulation

In the early part of this century and up until 1940, malariologists utilized various methods to modify environmental conditions specific to different species. They were mainly physical methods but sometimes biological or chemical agents were also used. Fermi[4] reported the use of fish (*Cyprinus carpio* var. *speculairs*) to clear marginal weeds in a lake in Sardinia thus exposing the larvae to sunlight, wave action, water flow, and predators. Other workers have used chemical herbicides to remove weeds in lakes, canals, and ponds. In fact, the use of herbicides is an essential feature in many vector control operations and must be considered seriously in antimalaria programmes.

The most important methods of environmental manipulation ar described in the following sections.

2.1.1. Water level fluctuation

This method is quite effective and feasible in imporndment reservouis. The principle involved consists of stranding and drowning mosquito larvae by lowering and raising the water level in lakes. To be effective, the duration of the fluctuation cycle should not exceed the period of development from larvae to adult mosquitos, normally a week to ten days. It is important that, at the low point of the cycle, water is drawn out of marginal vegetation in order to expose the larvae to predators, the sun, and wave action. Normally with water level fluctuation, a certain degree of control of some weeds and plants is also obtained.[5]

Water level fluctuation may be combined with the seasonal recession of reservoirs for increased effectiveness. Sometimes shoreline maintenance and filling of marginal water pockets and pools, or in certain seasons limited larviciding, need to be combined with water leve management to increase effectiveness.

The degree of fluctuation depends on the character of the shoreline, type of vegetation, and the species of mosquito involved. It may vary from 45 cm to 60 cm for cyclical fluctuation and 60 cm to 90 cm for seasonal recession.

2.1.2. Flushing of streams

Periodical flushing has been used as an effective means of controlling certain species of anopheline mosquitos that breed in sterams. The principle involves the collection and sudden release of a great volume of water periodically to flush away mosquito larvae, pupae and eggs. In the process, some larvae are stranded and some are taken unharmed downstream, where they need to be destroyed by other physical naturalistic or chemical methods. A secondary effect, perhaps just as important, is the alteration of breeding areas by water flow and removal of protective vegetation.

The flushing cycles need to be adjusted to the larval development cycle from eggs to adults - usually one week, but sometimes less in more favourable climates.

Flushing is most effective in steep valleys with sufficient flow to allow release of an adequate volume of water at needed intervals and over a sufficiently long stretch of the stream.

Many simple and hand-operated devices or automatic siphons and sluices have been used.[6] Also, various gates constructed in small dams may be utilized to produce periodical flushing. Automatic devices, however, have the advantage of requiring little maintenance and a few or no manpower for operation. Such structures may last for many years and thus in the long run they cost very little to the programme.

Flushing has been proved quite effective against *A. minimus, A. fluviatilis, A. maculatus* and *A. aconitus.* Larvae of some species like *A. gambiae* seem to manage to survive flushing by moving with the first flush to slack water at the edge, submerge and lay quiet for hours at the bottom. When the flood subsides, larvae come to the surface and swim back to their breeding place.

Flushing may cause erosion of the banks near the flushing point. Where stream beds widen, it may need to be narrowed with rocks and certainly the inhabitants, especially children, should be warned against bathing or washing near the stream at flushing hours.

2.1.3 Changing water salinity

Some important malaria vectors, e.g., *A. sundaicus, A. subpictus, A. aquasalis* and salt water *A. gambiae* var. *melas,* are true coastal brackish water breeders[3] and some of them require a certain degree of salinity for optimum breeding and larvae survival in contrast with the inland brackish water breeders, e.g., *A. multicolor,* which may be able to change their habits and breed in a much wider range of salinity.

A. sundaicus is known to require an optimum salinity of 8-10 thousand ppm, though larvae have been found in waters with a salinity of up to 24-30 thousand ppm.[3] The lower salinity where breeding may not take place is not precisely known, but it is assumed to be around 3-30 ppm, which may be very close to fresh water. On the other hand, *A. gambiae* var. *melas* may breed in water ranging from fresh water up to seawater, but breeding is usually greatly reduced well below 100% seawater salinity. The optimum salinity range for *A. aquasalis* is estimated at about 10 thousand ppm.

It is not known whether chloride salinity is the determining factor or whether other substances, e.g., organic matter and minerals, or tidal movements, play a role in limiting the breeding of vectors. The indication is, however, that increasing salinity deters the female from egg laying.[3] Several successful attempts have been made in the past t control mosquitos through changes in water salinity. Hackett (1937 eliminated *A. elutus* in Durazzo (Albania)[4] by increasing the salinity c a coastal marsh to about 24 thousand ppm. Similarly *A. albimanus* wa controlled in Jamaica and *A. gambiae* in Lagos, Nigeria.

In Malaysia *A. sundaicus* and in Italy *A. elutus* were controlled b reducing salinity and by constructing dykes and gates to preven seawater from invading coastal marshes.

2.1.4. Shading or exposing to sun and light

It has been known for some time that certain anopheline specie prefer sunny breeding places (e.g., *A. gambiae*) while others prefer shady habitats (e.g., *A. umbrosus* and *A. balabacensis*). Utilizing these characteristics, malariologists have used trees (e.g., *Ficus benjamina*, *Tithonia diversifolia* and *Cassia alata*), thatch, or other means to shade breeding places, and some have obtained good results. Others have cleared jungles or removed vegetation to allow diurnal and nocturnal light to reach mosquito habitats. Examining these works, one sometimes wonders if it would not have been easier simply to fill in small holes and depressions where water collected. The method certainly has application in small drinking-water reservoirs, wells, or long streams, and is being used in Assam and India.

Light and shade appear to be basic factors in differentiating species habitats; it is certain that they regulate other factors such as temperature and type of vegetation found in the breeding places. The effect of these secondary factors on the species development is considered quite important by many workers.

2.1.5 Pollution with organic matter

Organic matter, wastes, and effluent from factories have been used to pollute breeding places and control larvae. The method, though generally effective, cannot be widely applied. It creates obnoxious odours and colours, and may interfere with the domestic use of water. It may also encourage the propagation of other mosquitos (e.g., *Culex*) and cause great nuisance problems.

2.1.6 Desiccation by trees

This has been used very widely. Many malarious countries have used trees to dry up swamps and marshes. *Eucalyptus robusta* and *E. globosus* are the trees most widely used, and their smell is said to be repellent to mosquitos. Other species of eucalyptus (e.g., *E. saligna*) were planted in South Africa with success. Shrubs and leguminous plants (*Cassia hirsuta, C. alata* and *Crotalleria anagyroides*) have also been used with good results.

Trees should be spaced so that evaporation from the ground is not reduced by their cover.

The rate of evaporation depends on light, heat, and humidity[10] and varies from zero to 300 $g/m^2/h$ of larvae area. The elm is estimated to have 7 million leaves, giving an area of about 2 hectares. Beech forest is estimated to evaporate in the summer 35,000 tonnes of water per hectare.[10]

2.1.7

Mosquito breeding can be controlled by periodical flooding or dewatering of the larval habitats. This may include areas inundated by seasonal rainwater, accidental overflow, or excess irrigation water. Periodical flooding or water evacuation can be achieved ecomonically by pumping.

Portable high-capacity pumps powered by internal combustion engines are readily available. Such a pump, with a discharge diameter of 7.5 cm, will displace 80 m^3 of water per hour against a 12 m head. There are also large trailer-mounted pumps of 20 cm discharge diameter. The selection of pumps depends not only on the maximum capacity of water to be removed but also on the accessibility of the area to motor vehicles.

2.1.8 Management of rice-fields

Rice-fields in many parts of the world are important habitats for the breeding of mosquitos in general, and anopheline mosquitos in particular. For instance, *A. hyrcanus* in Afghanistan, *A. culicifacies* in Iran, *A. pharoensis* in Egypt and *A. aconitus* in Indonesia breed abundantly in rice-fields.

Mosquito control has been achieved in rice-fields with varying degrees of success with the use of chemical larvicides, mosquito fish, and environmental management. The latter includes regulation of irrigation and agricultural practices and management of vegetation growth. Clean and well graded canals and drains, proper banking and levelling of paddies, prevention of water seepage and overflow, and filling of depressions are among useful land and water management works.

Intermittent irrigation has been used in many situations to control the breeding of malaria vectors in rice-fields, with varying and often contradictory results. In Portugal, where *A. maculipennis* was reduced by 80%[8], the intermittent flooding of rice-fields has been made compulsory by law as a means of malaria control. Similar results were obtained in southern India, and the USSR (Armenia). Different regimens have been used for flooding and drying, depending largely on the species involved and the climatological conditions. Periods of 1-3 weeks' irrigation and of several days for drying have been used in different areas.

Water flow has also been used to sweep away larvae resting on the water surface. In Mexico, where rice was planted in trenches, *Anopheles pseudopunctipennis* was almost totally eliminated by water flow.

The rice-field is such a complex ecological entity that no single method of control can be recommended for general use. The answer may be an integrated use of all methods of control planned and utilized for each situation.

Intermittent irrigation requires careful levelling of land to prevent the formation of pools in the paddies when irrigation stops. Intermittent irrigation may carry mosquito larvae to distant areas and create additional problems. However, it is advantageous where water is scarce and additional land is available for agricultural extension.

3. Reduction and prevention of man-mosquito contact

Reduction and prevention of man-mosquito contact can be defined as all operations and means used to reduce and prevent mosquito vectors from biting man, without necessarily attempting to destroy or control the species. This may include a number of measures, e.g., site selection, personal protection and mosquito proofing of houses.

Whatever the measure or means used, the prevention or reduction of man-mosquito contact is expected to result in a reduction or prevention of infection of man by mosquito and mosquito by man.

3.1 Site selection

As early as 1899, Ross said «as we can now identify the dangerous mosquito and discover where it breeds, we could build our houses the necessary distance from them and so avoid the disease».[4]

In fact, many rural communities in India, Malaysia and other countries were built on high ground and away from the breeding areas of mosquito vectors, with good results. «Site selection» has probably been used even before the role of mosquitos in transmitting malaria was known. Throughout malarious areas in Asia and other continents, it can be observed that rural communities are built up on elevations and away from marshes, swamps and other mosquito producing waters.

Site selection for mosquito control in the modern world has serious limitations. It can be applied where new communities are set up and to compsites for labourers, or the army. Its efficaçy may be limited as it may not always be possible to establish communities sufficiently far away from sources of water. Nevertheless, site selection should be considered as an added measure of protection against malaria wherver feasible.

3.2 Mosquito proofing of dwellings

Some 40 years ago, Hackett and Missiroli showed that different types of houses have different tropism to mosquitos and that this depends mainly on how easily they can enter and obtain a blood meal. Therefore, the previous deterrent factors (e.g., better ventilation, good lighting, and dryness) were no longer considered to be serious measures of mosquito proofing.

The screening of doors and windows and the obstruction of all other openings has remained the principal measure. It is obvious that it cannot be applied efficiently in many rural areas where the type of houses and material of construction, and perhaps climatic conditions and habits of the population, do not allow satisfactory inplementation of the method. On the other hand, the screening of houses can be an effective and economical method of malaria control in urban situations, where the whole, or at least a part, of the house can be mosquito proofed. Furthermore, the measure would be popular as it prevents the entering of other pest mosquitos and files and thus helps in the control of a number of other diseases.

Screens made of various materials, aperture sizes and mesh numbers are aivalable for mosquito proofing. The size of aperture depends on the size of mosquito involved and the degree of aeration needed; it may range from 0.175 cm to 0.175 cm. The mesh number depends on the wire diameter used. For instance, for an aperture of 0.125 cm and a wire diameter of 0.015 cm, an 18-mesh screep (i.e., 18 spaces per 2.5 cm) would be required. Mosquito proofing of houses may need to be combined with other measures of mosquito control, e.g., application of pyrethrin aerosol.

3.3 Individual protection

In the absence of mosquito proofing, mosquito nets can be used in malarious areas. Also special clothing comprising boots, gloves, and hats provided with veils made of screen or netting material can be used. The most practical and efficient protection can be derived from the use of repellants, e.g., dimethyl phthalate, Rutgers 612, and Indalone.

Summary and Conclusions

4. Environmental management in antimalaria programmes

As can be noted from the foregoing, environmental management includes a great number of physical and environmental operations quite varied in nature and type and in the kind of results they produce when applied to field conditions. They range from simple filling of wet land to complex multipurpose construction projects involving extensive drainage, dyking, land reclamation, and flood control.

Environmental management, like any other malaria control measure, has its limitations. Usually, its methods produce partial results or may take a long time to become fully operational. Consequently, where quick results are essential, they need to be combined, at least in the initial stages, with other methods of vector control (e.g., chemical methods) or with chemotherapy. Some of the methods can be applied only to certain specific situations and thus cover only part of the mosquito sources. Their wide application might involve complex operations requiring highly skilled manpower and a large investment of funds, both of which are at present lacking in antimalaria programmes.

Despite their partial effectiveness, simple environmental management works are always useful in antimalaria programmes. Selected intelligently and adapted to local conditions and possibilities, they may produce effective control in many situations. For instance, limited filling anddrainage,environmental manipulation, and mosquito proofing of dwellings are within the operational capability of the antimalaria programmes or can be accomodated with limited financial adjustment and staff training.

Larger and more complicated operations can be negotiated with competent services (e.g., municipalities, public works or agricultural departments, and the army) and carried out with their technical and financial help and assistance. Water development or agricultural extension projects normally have the means and interest and often the expertise and equipment to implement important environmental management works. If sound proposals are formulated and the health and other benefits are demonstrated, there is usually no difficulty in obtaining cooperation.

4.2 Planning

The planning of environmental management operations must be preceded by detailed studies of the needs and objectives to be attained and the methods to be selected in relation to local conditions and requirements. In the selection of the methods of control, every effort must be made to avoid undesirable changes in the immediate or surrounding environment.

In any antimalaria programme, environmental management (especially source reduction and elimination) must be a basic component because its effects accumulate over the years, thus progressively economizing in resources and allowing an increasing expansion of the programme. An antimalaria programme devoting a small percentage of its budget to source reduction and elimination can progressively expand its repetitive operations as elimination or reduction of breeding areas reduces mosquito breeding and the need for chemical treatment. Breeding areas thus eliminated may require a certain amount of maintenance, but this is often a small fraction of the gains accrued.

An ideal plan would be to devote a part of the annual control budget, say 10% to simple source reduction and the rest to chemical or biological operations requiring repetitive applications or maintenance. In the course of time, permanently eliminated breeding areas may be dropped from the programme and new areas taken over for source reduction and chemical treatment. After a few years of operation, the programme may extend its coverage considerably and thus with the same budget protect a greater number of the population.

As experience accumulates and the programme's expertise increases, more complicated work can be undertaken and ultimately chemical treatment may be reduced to areas where source reduction has not been feasible.

4.3 Practical steps for implementation

The first step in implementation is to prepare and train staff and organize pilot studies of the operational feasibility and requirements of environmental management activities. At a later stage, the organization of the malaria services must be reorientated.

4.3.1. Preparation and training of staff

A knowledge of field conditions and local possibilities as well as methods and means of environmental management are essential for rational planning. Therefore, staff need to be conversant with various methods and the equipment needed to apply them in order to be able to plan operations corresponding to each field condition. As experience accumulates, the staff may be trained in more complicated operations using more sophisticated techniques and equipment. For this, however, some programmes may require more highly qualified staff with a background in sanitary engineering and environmental management.

4.3.2 Pilot operations

Pilot operations are aimed at investigating the feasibility and implications (including the environmental impact) of various environmental management methods and their cost/ effectiveness and cost/ benefit relationship under different conditions. They are also aimed at developing appropriate operational procedures and practices for field application.

It may be necessary to organize several pilot operations in different programmes, priority being given to programmes and areas where the operations are most needed or have a greater prospect of success. Areas with victor resistance problems, development projects, urban situations, and arid or semi-arid malarious areas are among those to which high pripority should be given.

Qualified engineering staff as well as epidemiologists and entomologists should be permanently assigned to pilot operations, and consultant environmentalists, sociologists and perhaps economists should be available.

Pilot operations should be large enough to cover a wide variety of field conditions and to allow conclusive assessment of results. A duration of at least five years is considered necessary, but the results may be available for application to programmes from the thirs year.

Such pilot operations can be usde for the practical training of staff.

4.3.3 Reorientation

When staff training and pilot operations are well under way, stuides should beign on ways of reorienting the malaria services. This reorientation should allow for the absorbtion of the trained staff, who will carry out the planned activities.

Programme reorientation involves a reorganization of the service in relation to new objectives and activities. It requires a gradual change of emphasis towards more long-term studies and programming and calls for the closer coordination of activities and collaboration with development projects.

Similarly, reorientation should be introduced to the provincial and field services and units. There is a need fro a gradual transfer of decision making and planning powers to provincial units, which need to have the authority and ability to study, plan, organize and coordinate activities within the general plan and the national policy for malaria control.

An important feature of reorientation must be provision for a continuous progress towards an integrated control programme and a comprehensive approach that not only pursues the primary objective of controlling malaria, but also makes every effort to obtain the maximum benefit from the programme in other related fields, such as general health and agriculture.

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