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Engineering based Environmental Management Strategies for Malaria Control: A review

[1*]Mokuolu Olubunmi A., [2]Mokuolu Olugbenga A.

[1]Department of Water Resources and Environmental Engineering, Faculty of Engineering andTechnology, University of Ilorin, Ilorin, Kwara state, Nigeria, [2]Department of Paediatrics and Child Health, Faculty of Clinical Sciences, College of Health Sciences, University of Ilorin, Ilorin, Kwara State Nigeria.

*Corresponding author:
Mokuolu Olubunmi A.
Telephone: +2348033378105

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Abstract

Malaria is a major public health problem. One third (3.3 billion people) of the world population in 97 countries and territories are at risk of malaria. In 2014, 550,000 malaria deaths were recorded.

Interventions by vector control with the use of Long Lasting Insecticide Nets (LLIN) and Indoor Residual Spraying (IRS) and use of Artemisinin-based Combination Therapy (ACT) for treatment of confirmed cases of uncomplicated malaria have been major drivers of the reductions in malaria morbidity and mortality reported over the last 15 years. Malaria mortality rates have fallen by 47% globally since 2000; by 54% in the WHO African Region and by 58% in African Children. A total of 4.3million deaths is estimated to have been averted between year 2000 and 2013. However, the burden of malaria in Sub-Sahara Africa (SSA) is still unacceptably high. The region has a malaria attributable mortality of 20% in children under five and also accounts for 90% of the global malaria deaths. Nigeria contributes a third of the global malaria deaths and spending on malaria illnesses is estimated to be $1billion per annum in the country.

Other intervention in the area of environmental management is being reviewed in this report as a further support to on-going efforts by WHO and Roll Back Malaria advocacy plan, action and investment to defeat malaria 2016-2030.

Environmental management by modifying the environment to reduce vector accounting for malaria transmission along with on-going efforts on prevention and treatments may bring to achieve the new global development framework for malaria elimination.

Key Words: Mosquito larvae, Environmental Management, Malaria Control, Control Hierarchy

Introduction

Malaria is a deadly disease, accounting for loss of millions of human lives. According to WHO, 2014 report [1], about 198million cases of malaria occurred globally in 2013 and the disease led to 584,000 deaths, an estimated 90% of all malaria deaths occur in Africa, children aged under 5 accounting for 78% of all deaths. The domestic funding for malaria in 2013 was estimated to be $527million representing 18% of total malaria funding for that year [1]. According to Bremen [2], the number of malaria cases may likely double in the next 20years without effective interventions.

The control of malaria involves three living beings and their environment. These include the larva, mosquito and man. These three have unique characteristics that help to sustain the "malaria chain" Man is highly mobile and able to facilitate the spread of the disease far and wide. Mosquitoes are moving, highly adaptable and have shown resistance to some insecticides [3,4]. Eggs and larvae are highly adaptable to various environmental situations. In the light of this chain, malaria control involves measures that are deployed to disrupt the chain in order to reduce malaria burden to a point where it is not of public health importance.

Current approaches to malaria control targets the various living beings in the malaria chain; these include (i) vector control through the use of insecticide-treated nets (ITNs) and long lasting insecticide treated nets (LLINs), indoor residual spraying (IRS) and, in some specific settings, larval control; (ii) chemoprevention for the most vulnerable populations, particularly pregnant women and infants; (iii) confirmation of malaria diagnosis through microscopy or Rapid Diagnostic Tests (RDTs) for every suspected case, and (iv) timely treatment with appropriate antimalarial medicines [5]. The important lesson from the foregoing is that effective malaria control must leverage on the various opportunities to interrupt the critical chain of man, mosquito and larva. So far malaria control efforts has addressed issues related to man as host (use of drugs for disease prevention and treatment), mosquitoes (use of insecticides, ITNs and LLINs). The environmental dimension as regarding larval reduction through larviciding is not very prominent in discussions on malaria control. In addition the impact of environmental factors for larval control, while generally acknowledged and recommended [1], is not properly quantified and demonstrated through empirical evidence. The absence of such evidence may have weakened advocacy that could enable policy makers to appreciate the direct relationship between the environment and malaria disease burden.

Thus, this review looked into the association between malaria and some of its engineering based environmental predisposing factors.

Environmental management and malaria control

The concept of modifying vector habitat to discourage larval development and/or human vector contact is generally referred to as environmental management or source reduction [6]. The World Health Organization in 1980 defined environmental management as: *The planning, organization, carrying out and monitoring of activities for the modification and/or manipulation of environmental factors or their interaction with man with a view to preventing or minimizing vector propagation and reducing man-vector-pathogen contact*.

This approach, which should be carried out prudently and skillfully, is naturalistic and involves an attempt to extend and intensify natural factors which limit vector breeding, survival and contact with man. Since the discovery of the role of *Anopheles* mosquitoes in malaria transmission over 100 years ago, malaria control programmes targeting potential mosquito larval breeding sites have helped reduce or eliminate malaria transmission. Habitat elimination or modification efforts include general programmes to reduce the abundance of all mosquitoes as well as more targeted species sanitation projects directed at the principal malaria vectors. The specific techniques of environmental management are generally grouped into three main categories – environmental modification, environmental manipulation, and modification of human habitations/behaviours [7, 6] . The first two categories generally target the larval stages, whereas the third may also target adult vectors.

Climatic and environmental factors affect *Anopheles* production, survival, speed of reproduction and parasitic life cycle. This relationship explains the distribution of *P. falciparum*. Rainfall and temperature play a major role, directly on *Anopheles* behaviour or indirectly on breeding sites. Vegetation is also an environmental factor depending on climatic evolutions, which influences the behavior of the vector directly and indirectly. Kelly-Hope *et al.,* [8] in their finding suggest that the abundance, distribution and malaria transmission of different malaria vectors are driven by different environmental factors. In regions with alternate dry and rainy seasons, the transmission of malaria is seasonal, epidemic or endemo-epidemic. The principal parameters influenced by rainfall and temperature are aggressiveness (depending on *Anopheles* density and on the length of their gonotrophic cycle), contagiousness and *Anopheles* mortality. The variation is highly structured across geographic and temporal sub-populations.

The high diversity during the rainy season, when transmission rate peaks, contrasts with the low diversity during the dry season, when both mosquito population size and malaria transmission rate are low [9].

Environmental management has brought important achievements in malaria control and overall improvement of health conditions. Environmental factors such as land cover, rainfall, altitude and temperature affect Anopheles breeding and have been used to predict malaria transmission risk. Areas with greater amounts of precipitation and higher temperatures are expected to have greater malaria prevalence, as these conditions favour breeding of many *Anopheline* species as well as parasite reproduction within the mosquitoes [10]. A community based environmental management for malaria control was conducted in Dar-es-Salaam between 2005 and 2007. After community sensitization, two drains were cleaned followed by maintenance. The result showed individual awareness of health risks and intervention goals were significantly higher among sensitized neighborhoods [11]. Environmental management was historically coordinated by authoritarian/ colonial regimes or by industries/corporations. Its successful implementation as part of an integrated vector management framework for malaria control under democratic governments can be possible if four conditions are observed: political will and commitment, community sensitization and participation, provision of financial resources for initial cleaning and structural repairs, and inter-sectoral collaboration. Such effort not only is expected to reduce malaria transmission, but has the potential to empower communities, improve health and environmental conditions, and ultimately contribute to poverty alleviation and sustainable development. Kelly-Hope *et al*.[8] , suggested that the abundance, distribution and malaria transmission of different malaria vectors are driven by different environmental factors. In a study conducted by Guthmann *et al.*[12], for a person living in the coastal region of the north of Peru, the risk of malaria was related to three major factors: the season of the year, the location of the village within the area and the location of the house within a village. The results suggest that the presence of water for irrigation played a major role in determining malaria risk. Environmental factors affect the biological cycle of both vector and parasite. Despite this strong relationship, environmental effects have rarely been included in malaria transmission models [9]. Remote-sensed data were coupled with field study data in order to drive a malaria transmission model. Control programmes, such as vector control, impregnated net use or early detection and treatment, should be tailored to environmental conditions. Environmental management integrated with pharmacological, insecticidal, and bednet interventions could substantially increase the chances of rolling back malaria was suggested by Utzinger *et al.,* [13].

The construction of dams and development of irrigation schemes will provide many poor African farmers with greater food security, an improved diet and increased income. Nonetheless, there is concern that the introduction or expansion of irrigation systems in malaria-endemic areas may lead to a risk of malaria transmission, by creating more breeding habitat for vectors and extending the length of the transmission season. This may be of enormous public health importance in areas of fringe transmission, such as the Ethiopian Highlands, where people have little or no immunity to malaria [14]. Environmental management has proven valuable in preventing or mitigating malaria and other vector-borne diseases sometimes exacerbated by large-scale water projects.

Environmental modification involves a physical change (often long-term) to potential mosquito breeding areas designed to prevent, eliminate, or reduce vector habitat. The principal methods of achieving these changes include drainage, land leveling, and filling. Draining operations include creating ditches or drains to keep water moving and to carry water used as breeding sites by mosquitoes away in a managed way. Drains may be lined or unlined and located at the surface or subsoil level. In some instances, marshes have been drained through pumping. In addition to complete elimination of wetlands, modification projects can involve creating channels to increase water flow in areas of standing water, filling small ponds or water collecting depressions, or changing banks of water impoundments to reduce mosquito populations. Because slow-moving pools with heavy vegetation in rivers and streams can create larval breeding sites for certain vector species, regarding streams and even straightening river banks may reduce vector populations. Some of these activities require regular maintenance, whereas others are permanent changes to the landscape (although they may require substantial initial effort to establish). Environmental modification can address the problem of human-made vector breeding sites associated with water-holding structures in mini-dams and small scale irrigation projects. The creation of favourable vector habitat may be avoided through careful design. The efficacy of environmental modification to reduce or eliminate malaria vector breeding habitats depends both on the initial design and construction of the project as well as regular maintenance. Although some drainage efforts create permanent, self-sustaining changes to the environment, many modification projects require regular maintenance. Poorly maintained drainage projects may actually increase larval breeding habitat [6].

Solid waste and malaria relationship

Solid waste comprises all the waste arising from human and animal activities that are normally solid and are discarded as useless or unwanted disposal. Wastes can be generated by *natural* phenomena such as wind, erosion, precipitation, volcanic eruptions, flooding of river banks, atmospheric fallouts, among others and by human activities including domestic; commercial, industrial and agricultural practices [15,16]. Poor solid waste management will result in an unpleasant and often unsafe environment to live or work in. In addition, piles of refuse can be a fire hazard. In urban areas refuse often ends up in drainage systems, creating drainage problems. Pollution caused by poor management of waste can create serious environmental problems. According to Ajao *et al*. [17], access to sanitation is essential in preventing diseases spread by unsanitary conditions and by water contaminated with human waste. They also reported that access to safe water is significantly associated with life expectancy.

Drainage systems are frequently used for defecation. The solid waste that accumulates in the system is often contaminated, and is a health risk to those who have to handle it. Organic waste from households, restaurants, and markets attracts rats, which are potential hosts for many infections (e.g. *leptospirosis*, plague). Organic waste also serves as food and a place to rest and hide for domestic flies, which can transmit faecal-oral infections and infections spread by direct contact, and cockroaches, which can transmit faecal-oral infections. Other animals which use refuse dumps to rest and hide include mosquitoes, sandflies, vector of *leishmaniasis, bartonellosis,* and several arboviruses; and reduviid bugs, which can transmit American *trypanosomiasis.* Refuse often includes materials which can collect rainwater, such as tin cans, jars, and old car tyres. *Aedes* mosquitoes, which transmit *filariasis,* urban yellow fever, dengue fever, and several other arboviral infections, can breed in these small water-filled vessels poorly managed waste often ends up in ponds, reservoirs, or drainage systems.

The refuse often blocks drainage channels, resulting in the ponding of water. As these surface waters are often polluted with organic waste, breeding sites for *Culex* mosquitoes and domestic flies are created. A solid waste management scheme can be a large, complex, and expensive enterprise, with many people, materials, and funds required for good operation. In rural areas much of the refuse is reused (e.g. feed for animals, containers, toys) and solid waste will often be less of a problem. In high-density (peri-) urban areas, however, waste may become a serious problem if poorly managed. If on-site burial or burning is not possible, waste has to be collected. If affordable, household bins will usually be the most appropriate way of collecting and storing household wastes. Where this is not feasible, communal storage of the waste will be necessary. A study by Nkwocha, *et al.*, [18] revealed that there was a strong association between distance from the waste dumpsite and malaria disease in the overall subjects sample by the researchers in Eastern part of Nigeria. Part of solid waste management is making sure that refuse does not end up in drainage systems or surface water. Common environmental diseases as revealed in a study by Celestino *et al*. [19] include malaria disease.

The health issues related to drainage water management can be grouped in three categories: water related vector-borne diseases; faecal/orally transmitted diseases; and chronic health issues related to exposure to residues of agrochemicals [19].

According to Tunde *et al.* [20] on the incidence of malaria, weather variables bring about the increase rate of the ailment with exception of rainfall which is inversely related with upward trend of malaria. The main climatic elements that induce malaria are temperature, relative humidity and sunshine hours. These elements are lethal to mosquitoes and the parasites because where temperatures are close to the physiological tolerance limit of the parasites, a small temperature increase would be lethal to the parasite and malaria transmission would therefore decrease. At low temperatures, a small increase in temperature will greatly increase the risk of malaria transmission. Moreover, when the temperature increases, the incidence of malaria would increase irrespective of rainfall amount or the duration on the surface. Mosquitoes only take the advantage of stagnant water or pool of water in the environment as a breeding ground but when there is decrease in temperature below the threshold of survival, the mosquitoes will die off, reducing the morbidity at such period of time.

In tropical and subtropical regions there is a close link between the presence of excess water (due to lack of adequate drainage) and the transmission of water related vector-borne diseases. Malaria is an important water related vector-borne diseases.

Proximity to stagnant water

In a study carried out on Koka reservoir in Ethiopia [21], the frequency of malaria diagnosis in fever clinics was correlated with distance of residence from the margin of the Koka reservoir. Annual as well as seasonal malaria case rates were determined in cohorts residing < 3, 3–6 and 6–9 km from the reservoir. *Plasmodium falciparum* risk was compared with that of *Plasmodium vivax*. A multiple variable regression model was used to explore associations between malaria case rates and proximity to the reservoir, controlling for other suspected influences on malaria transmission. Malaria prevalence rates among people living within 3 km of the reservoir were about 1.5 times as great as for those living between 3 and 6 km from the reservoir and 2.3 times as great for those living 6–9 km from the reservoir. Proximity to the reservoir was associated with greater malaria case rates in periods of more intense transmission.

(*Plasmodium falciparum* is most prevalent in communities located close to the reservoir and *P. vivax* in more distant villages). The presence of the reservoir, coupled with inter-annual climatic variations, explains more than half of the region's variability in malaria case rates.

Household types

The findings of the study on household risk factors for clinical malaria in a semi-urban area of Burkina Faso suggest that modification of the household environment could be a feasible way to reduce the risk of malaria particularly in semi-urban areas [22].

A parasitological cross-sectional survey was undertaken from September 2000 through February 2001 to estimate the prevalence of malaria parasitemia in Eritrea. A total of 12,937 individuals from 176 villages were screened for both *Plasmodium falciparum* and *Plasmodium vivax* parasite species using the OptiMal Rapid Diagnostic Test. Malaria prevalence was generally low but highly focal and variable with the proportion of parasitemia at 2.2% (range: 0.4% to 6.5%). Despite no significant differences in age or sex-specific prevalence rates, 7% of households accounted for the positive cases and 90% of these were *P. falciparum*. Multivariate regression analyses revealed that mud walls were positively associated with malaria infection (OR [odds ratio] = 1.6 [95% CI: 1.2, 2.2], $P < 0.008$) [23]. Thus indicating that for countries with low and seasonal malaria transmission, such information can help programs design improved strategic interventions.

Better engineering design of dams, irrigation schemes that allow for alterations in level and flow of water, and flushing of reservoirs can help reduce the availability of vector habitats. In addition, irrigation schemes that permit intermittent irrigation of fields, as well as alternation between cycles of irrigated and non-irrigated crops, have proven very successful in controlling Anopheles mosquitoes in rice-growing regions of China, India, and other parts of Asia (Keller, 2008). Such schemes control vectors by disrupting breeding cycles. However, improved design or redesign of water resource systems, irrigation systems, and dams is most likely to occur when major infrastructure investments are being planned, and thus it is critical that health and environment issues be considered by development actors at the outset of design processes through effective health impact assessmen [24]. The occurrence of malaria is mainly due to the environmental features around the homes, and not so much to individual behaviours or population habits [25,26]. Although malaria incidence is associated with a complex array of variables, their data gave a clear picture of where households should not be build, and how the peridomestic space should be kept to minimize the risk of malaria. In their findings [27] Coker *et al.,* revealed that houses in the high density areas have the worst property and environmental characteristics followed by houses in the medium density area.

Vegetation

In specific settings, time-limited changes in local vegetation, shade, and drainage patterns provide an effective way to reduce vector habitats. For instance, the creation of shade over the breeding grounds of malaria vectors that prefer sunny locales can help reduce vector propagation. Conversely, for malaria vectors that thrive in shadier habitats, the removal of overgrowth, weeds, and aquatic plants may significantly reduce breeding potential and thus vector abundance. In Oaxaca, Mexico, the clearance of algae from rivers, in a sustained community action programme, has been an important component in an integrated nationwide malaria control programme that has reduced malaria incidence from 15,121 cases in 1998, to 4,996 cases in 2001[24]. Highly cultivated areas have increased suitable habitat for most of the primary vectors, which are non-forest and prefer sunlight, while urbanized areas tend to have reduced vector breeding habitat, although decreased sanitary conditions in urban areas may promote vector breeding in some instances [10].

Agricultural practices may also create new breeding sites or increase the productivity of certain breeding sites. Irrigated rice fields are known to breed *An. gambiae s.l.*, particularly early in the season before the rice vegetation canopy is well-developed. Other irrigation structures, such as wells, may provide permanent breeding sites with few larval predators close to human habitations, as observed in urban Dakar, Senegal. Breeding sites created by the construction of thousands of small dams in Ethiopia have been shown to increase the incidence of malaria in communities near the dams by a factor of seven. Non-application of environmental management practices contributed to abundant vectors of malaria and disease transmission[6,28].

The presence of vegetation and floating plants are important for optimal breeding conditions. First, the plants are larval food and, more importantly, they provide shelter from predators and protection against wave movement. Therefore, mosquito larvae are not found on the open surfaces of large water bodies. The abundance of a number of species is linked to the presence of specific plants. In a study by Mokuolu *et al.,* [29] presence of weeds in a peri-urban community contributed to its high malaria prevalence. A major intervention by Opiyo *et al.,*[30] was bush clearing even though these are ineffective for malaria prevention according to the researchers.

Hierarchy of control

The universal hierarchy of control can be applied to the control of malaria disease. Hierarchy of control can be defined as a list of measures designed to control risks which are considered in order of priority, effectiveness or importance. It begins with elimination to the least effective Physical Protective Equipment (PPE). The general control hierarchy in descending order is Eliminate, Reduce, Isolation, Control, PPE, and Discipline. Environmental modification may be additional application with ongoing prevention through the use of Insecticide Treated Net (ITN), Long Lasting Insecticide Net (LLIN), Indoor Residual Spraying (IRS), for effective control of malaria diseases to achieve the targeted malaria elimination by 2030.

Conclusion and Recommendation

Malaria is a deadly disease that had claimed many lives. Environmental management is the modification of the environment to reduce vector accounting for malaria transmission. This along with ongoing efforts on prevention and treatments may haste targeted malaria elimination.

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Authors Column

Dr. Olubunmi Ajike MOKUOLU is a lecturer and researcher in the Department of Water Resources and Environmental Engineering, Faculty of Engineering and Technology, University of Ilorin, Ilorin, Kwara State, Nigeria. Her recent work is in Public Health Engineering, specifically on engineering principles to reduce Public Health problems. She is a master trainer in Medical Waste Management (MWM) and has trained over 1000 participants ranging from hospital Cleaners to hospital Consultants on MWM from source to disposal.

She has mentored a number of pupil Engineers who are themselves at various levels of career developments.

Dr. Mokuolu is a co-examiner at professional examinations, her membership of professional associations includes: The Nigerian society of Engineers (NSE), Institution of Civil Engineers, Association of professional women Engineers (APWEN), and the American society of Civil Engineers. She is a chartered Engineer, registered with the Council for the Regulation of Engineering in Nigeria (COREN). She has held several positions in her state branch of the NSE and has served as Chairman of several Committees and Board member of the Society. She was the first female to serve in the Executive Committee of NSE Ilorin branch. She was Chairman APWEN in 2011 to 2012 and made her impact in Girl child engineering education and other community services. She has won to her credit many awards including “The woman of impact” in Kwara 2015.

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