Distribution and Transmission Dynamics of *Plasmodium falciparum* Malaria in Kenya

Essendi Miding'a Walter[1*] Shivairo Robert Shavulimo[2] Muleke Charles Inyagwa[2] Collins Mweresa[3]
1. Department of Biological Sciences, Egerton University, P. O. Box 536 – 20115, Egerton, Kenya.
2. Faculty of Veterinary Medicine and Surgery Egerton University, P. O. Box 536 – 20115, Egerton, Kenya
3. International Center for Insect Physiology and Ecology (ICIPE), P.O Box 30772-00100, Nairobi, Kenya.

Abstract
Plasmodium falciparum is the most popular and deadly malaria parasite in Kenya. Its transmission is dependent on numerous biotic and abiotic factors. Biotic factors include mosquito and malaria parasite density in the population and the proximity to mosquito breeding sites. Abiotic factors include socio-economic background of the population and malaria intervention strategies. These factors differ from one location to another and from one social setting to another. These variations ultimately influence malaria transmission in diverse locations and settings and limit the success in global approach to malaria control. This paper reviews the influence of both biotic and abiotic factors in relation to malaria transmission and the current status of these factors over time in Kenya. We hypothesize that changes in biotic and abiotic factors is responsible for the alteration in the mosquito and the *Plasmodium falciparum* density and distribution, hence malaria transmission in Kenya. An insight into these factors will guide in developing effective Malaria intervention strategies in the country.
Keywords: Malaria, *Plasmodium falciparum*, Risk factor, Transmission.

1. Introduction

Plasmodium falciparum is a protozoan parasite that causes malaria in humans. It is transmitted by the female *Anopheles* mosquito. Malignant malaria, caused by this species is the most dangerous form of malaria (Perlmann and Troye-Blomberg 2000) with the highest rates of morbidity and mortality. As of the latest World Health Organization report in 2014, there were 198 million cases of malaria worldwide in 2013, with an estimated death of 584,000 (WHO 2014). It is much more prevalent in sub-Saharan Africa than in many other regions of the world; in most African countries, over 75% of cases were due to *P. falciparum*, whereas in most other countries with malaria transmission, other, less virulent plasmodial species predominate. Almost every malarial death is caused by *P. Falciparum* (WHO 2008).

1.2 Life cycle of *Plasmodium falciparum*

The lifecycle of *Plasmodium* species is complex. Infection in humans begins with the bite of an infected female *Anopheles* mosquito. Sporozoites released from the salivary glands of the mosquito enter the bloodstream during feeding, quickly invading liver cells. Sporozoites are cleared from the circulation within 30 minutes. During the next 14 days, the liver-stage parasites differentiate and undergo asexual multiplication, resulting in numerous merozoites that burst from the hepatocyte. Each merozoite invades a red blood cell and undergoes an additional round of multiplication, producing 12-16 merozoites within a schizont (Sylvie Manguin 2008). The clinical manifestations of malaria, fever, and chills are associated with the synchronous rupture of the infected erythrocytes. The released merozoites go on to invade additional erythrocytes. Not all of the merozoites divide into schizonts; some differentiate into sexual forms, male and female gametocytes. These gametocytes are taken up by a female *Anopheles* mosquito during a blood meal. Within the mosquito midgut, the male gametocyte undergoes a rapid nuclear division, producing eight flagellated microgametes that fertilize the female macrogamete. The resulting ookinete traverses the mosquito gut wall and encysts on the exterior of the gut wall as an oocyst. Soon, the oocyst ruptures, releasing hundreds of sporozoites into the mosquito body cavity, where they eventually migrate to the mosquito salivary glands (Sylvie Manguin 2008).

1.3 Pathogenesis of *Plasmodium falciparum*

P. falciparum causes severe malaria via sequestration, a distinctive property not shared by any other human malaria. Within the 48-hour asexual blood stage cycle, the mature forms change the surface properties of infected red blood cells, causing them to stick to blood vessels (a process called cytoadherence). This leads to obstruction of the microcirculation and results in dysfunction of multiple organs, typically the brain in cerebral malaria (Dondorp *et al.,* 2004).

2. Current pattern of Malaria transmission in Kenya

Malaria still remains a major public health problem in Kenya. It accounts for about 31% of outpatient consultations and 5% of hospital admissions. *Plasmodium falciparum*, which causes the most severe form of malaria, is the most common and accounts for over 98% of all malaria infections in the country. The major malaria vectors in Kenya are *Anopheles gambiae* complex (*Anopheles gambiae* s.s, *Anopheles arabiensis*, *Anopheles merus*) and *Anopheles funestus*. About 70% of the Kenyan population is at risk for malaria. The majority of the at-risk populations live in areas of epidemic and seasonal malaria transmission where *P.*

falciparum parasite prevalence is usually less than 5%. However, an estimated 12 million people live in endemic areas, one-third of who live in areas where parasite prevalence is estimated to be equal to or greater than 40%. Kenya has been stratified into four epidemiological zones in accordance to the level of the risk.

2.1.1 Endemic areas

Endemic areas are those around Lake Victoria in western Kenya and in the coastal regions of the country. They are characterized by stable malaria with altitudes ranging from 0 to 1,300 meters. Malaria transmission in endemic areas is intense throughout the year with *P. falciparum* prevalence between 20% to 40% and high annual entomological inoculation rates. Of the total population, 29% lives in a malaria-endemic zone.

2.1.2 Highland epidemic-prone areas

Malaria transmission in the western highlands is seasonal with considerable year-to-year variation. The entire population is vulnerable and case fatality rates during an epidemic can be up to ten times greater than in endemic regions. Approximately 20% of Kenyans live in these areas; the malaria prevalence in these areas ranges from 1% to 5%, but can be as high as 10% to 20%.

2.1.3 Seasonal malaria transmission areas

This epidemiological zone comprises arid and semi-arid areas of northern and southeastern parts of the country which experience short periods of intense malaria transmission during the rainy seasons. Approximately 21% of the population lives within these arid/semi-arid areas of the country; the malaria prevalence is less than 5%.

2.1.4 Low malaria risk areas

This zone covers the central highlands of Kenya including Nairobi. Approximately 30% of the population lives in areas where there is little to no malaria transmission.

2.2 Risk Factors for Malaria

Malaria patterns reflect a composite of heterogeneities in vector distribution, human-vector contact and human host factors (Greenwood *et al*., 1989; Greenwood *et al*., 2002). Well known risk factors for malaria can be categorized into two; biotic and abiotic factors. Abiotic factors are of two types; environmental and non-environmental factors. Environmental factors include meteorological conditions, topography, presence of water bodies and vegetation coverage. Non-environmental factors include presence of vertebrate and invertebrate hosts. Biotic factors influence the presence and population of suitable malaria vectors in the population and the proximity of their breeding sites to human habitats.

Abiotic factors include human activities and low socio-economic conditions like poor household construction, poverty, ethnicity, unemployment and type of (Clarke *et al*., 2002). Poverty and low educational levels limits the use of effective antimalarial drugs which results in development of drug resistance and persistence of drug resistant parasites due to dispersal of mutant genes within the population.

3. Biotic Factors in Relation to Malaria Risk

3.1 Meteorological factors

Meteorological factors are important determinants of malaria transmission. Temperature, rainfall and humidity have been associated with the dynamics of malaria vector population and, therefore; with the transmission of the disease. Ambient temperature plays a major role in the life cycle of the vector. The development of the parasite within the mosquito, sporogonic cycle, is dependent on temperature. The sporogonic cycle takes about 9 to 10 days at temperatures of 28°C, but stops at temperatures below 16°C (Lindsay *et al*., 1996). The daily survival of the vector is dependent on temperature as well. At temperatures between 16°C and 36°C, the daily survival is about 90%. This survival drops rapidly at temperatures above 36°C. The highest proportion of vectors surviving the incubation period is observed at temperatures between 28° and 32°C (Craig, 1999; Craig, 2004). The gonotrophic cycle, which is the time between two blood meals of the vector, is short at higher temperatures because the digestion speed increases. Therefore, higher temperatures result in more frequent vector-host contact. Several field studies have reported the impact of ambient temperature on malaria outcomes. In South Africa for instance, Craig and colleagues (Craig, 2004) identified a significant correlation between temperature and the number of malaria cases. Mean maximum daily temperatures from January to October of the preceding season were positively associated with the incidence of clinical cases of malaria. In Ethiopia, minimum temperature was associated with malaria in a cold district whose minimum temperature was below 12°C; while in a hot district which had a minimum temperature above 12°C, the effect was not significant (Teklehaimanot, 2004).

Rainfall provides water in the breeding sites for mosquitoes to lay their eggs, and ensures a suitable relative humidity of at least 50 to 60% to prolong mosquito survival. Relative humidity below 60% shortens the life span of the mosquitoes. The onset of the rainy season is associated with an increase in vector abundance (Gill, 2002) (Fig. 1). In Nairobi, outbreaks of malaria occurred in 1940 after heavy rains (Lindsay *et al*., 1998). In western Kenya, malaria epidemics have spread from 3 to 15 districts during the past 13 years, often with devastating effects (Githeko *et al*., 2006). Some of these epidemics have been associated with extreme weather events, such as the El Niño Southern Oscillation event in 1997- 1998, which caused heavy rainfall and flooding in eastern Africa (WMO, 2010).
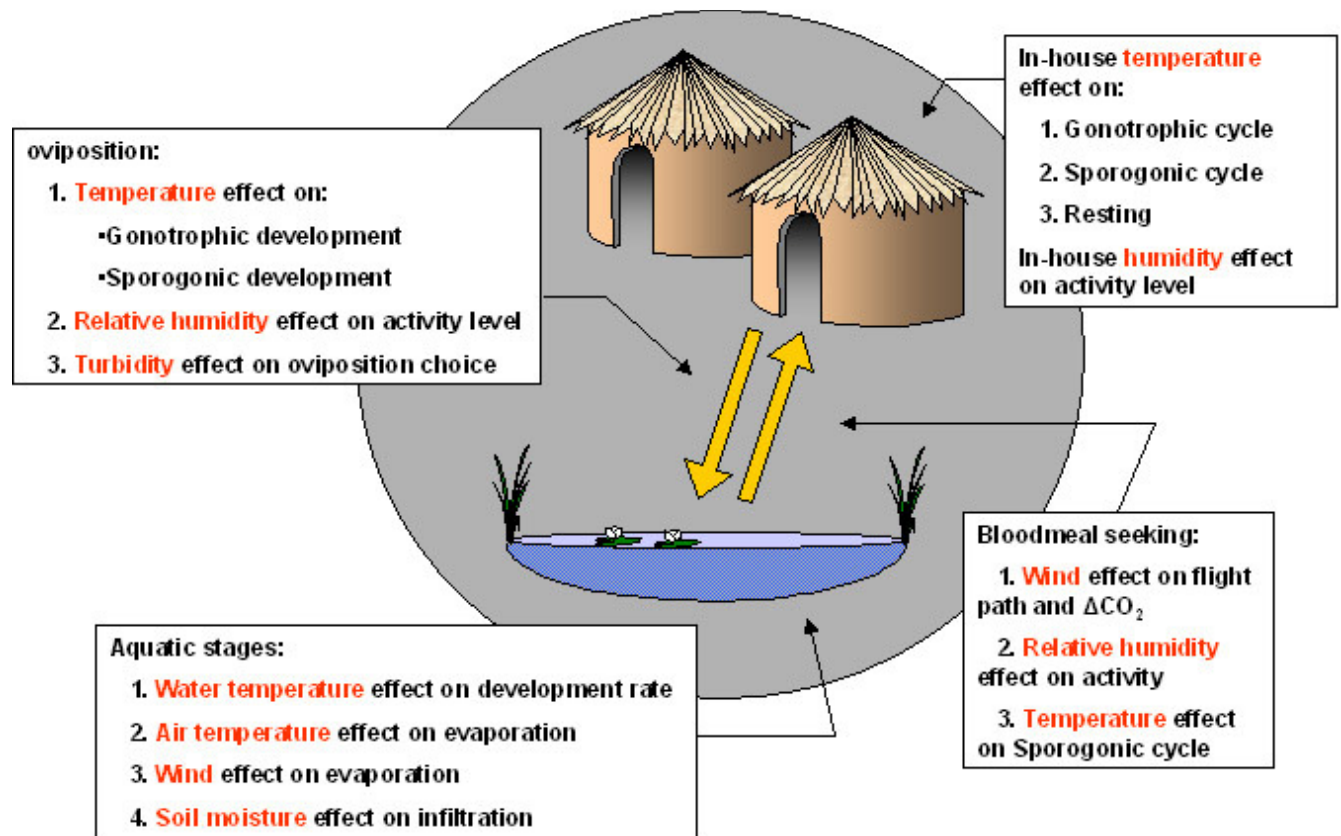
Figure. 1: Meteorological influence on malaria transmission (Gill, 2002).

Meteorological factors also determine human behavior which may increase contact with *Anopheles* mosquitoes between dusk and dawn, when the *Anopheles* are most active. For instance, high temperatures may encourage people to sleep outdoors or discourage them from using bed nets and blankets.

In Kenya, climate change is projected to increase malaria transmission in many areas. In areas where malaria already occurs, transmission intensity is expected to increase along with the length of the transmission season. It is also expected that malaria will spread into new locations, particularly the higher altitudes of the highlands, where its prevalence is not currently actively monitored or forecasted. Communities living at altitudes above 1,100 meters are more vulnerable to malaria epidemics due to lack of immunity, lack of preparedness, climate variability and other factors. Approximately 13 to 20 million Kenyans are at risk of malaria, with the percentage at risk potentially increasing as climate change facilitates the movement of malaria transmission up the highlands.

3.2 Topography

Elevation has long been recognized to be associated with malaria due to its association with cooler temperatures (Hay *et al*., 2002) which slow down the development of anopheline vectors and the *Plasmodium* parasites they transmit (Minakawa, 2006). Variation in the topography of the land may also play an important role in determining regions of suitability for mosquito breeding at smaller spatial scales (Balls, 2003). Malaria risk may diminish within a few hundred meters from known breeding sites (Gamage-Mendis *et al*., 1991), although a number of vector and environmental factors have been found to influence this range (Staedke, 2003). In highland regions of Kenya, where unstable malaria transmission may result in part from the very low numbers of anopheline mosquito vectors (Bodker, 2003), the proximity of houses to locations with suitable topography for mosquito breeding is an important determinant of malaria risk (Carter, 2000).

Breeding sites for *Anopheles* mosquitoes may occur where water collects and pools for a period of time that is sufficient to permit larval development and adult emergence (Minakawa, 2006; Githeko *et al*., 2006; Munga *et al*., 2009). Small temporary pools and larger more permanent ones are more likely to exist in flat, relatively low-lying regions (Carter, 2000). Increased human activities such as brick making, construction of dams and fish ponds, water tanks, swimming pools, tyre tracks and irrigation fields provide artificial vector breeding sites. Some of these sites are common in Kenya and may contain all life stages of *An. gambiae*, suggesting that they are particularly productive habitats (Munga *et al*., 2009).

3. 3 Water bodies

Malaria is inextricably tied to water. Because malaria vectors utilize naturally occurring water bodies for breeding, malaria cannot exist in regions where environmental conditions prohibit the formation and persistence

of natural water bodies (Guofa *et al*., 2007). Mosquito larval habitats are normally clustered along the river valleys or streams in hilly areas of Kenyan highlands. Where a house is located has an important impact in malaria risk. Studies have shown that people who reside near mosquito breeding sites have a higher malaria risk (Van der Hoek *et al*., 1998). Due to high population densities and lack of space for construction, most people resort to constructing their houses near water bodies. Thus, through its effects on the spatial distribution of larval habitats and human settlement patterns, water bodies can have a significant impact on human malaria transmission.

3.4 Vegetation

According to UNEP, 6.2% or about 3,522,000 hectares of Kenya is forested. However, between 1990 and 2000, Kenya lost an average of 12,600 hectares of forest per year. This amounted to an average annual deforestation rate of 0.34%.

Tree canopy coverage exhibits a significant effect on mosquito abundance in houses hence malaria infections (Afrane *et al*., 2006). Tree canopy reduces the water temperature of larval habitats surrounding the houses because canopy cover reduces the amount of solar radiation reaching the larval habitats. In addition, the algal contents, one major food source of *Anopheles gambiae s. s*. larvae, considerably decreases in larval habitats in the forest than in the farmland. Thus, land cover affects larval survivorship and adult productivity through its effects on water temperature and nutrients in the aquatic habitats. Air temperature inside a house is also affected by tree canopy.

Houses located in deforested areas show a 1.2–1.8°C higher average temperature than those in the forested area (Afrane *et al*., *2006*). As a consequence of increased air temperature, the duration of gonotrophic cycles is shortened by approximately 1.5 days, implying increased daily biting frequency and increase in malaria prevalence (Gunawardena *et al*., 1998). In Kenya, continued deforestation is expected to increase the density of competent malaria vectors, hence malaria transmission.

3.5 Human hosts and malaria vectors

Malaria transmission depends upon the presence of suitable vectors and human hosts, as well as that of the *Plasmodium* parasite. In the African highlands, the principal vector appears to be *Anopheles gambiae s.s. Anopheles arabiensis s.s* and *Anopheles funestus s.s* are important secondary vectors in most cases and can create foci of relatively stable transmission in some localities (Goufa *et al.,* 2007)). The malaria transmission cycle is not complete without available human hosts. According to the United Nations Statistics Division, the population of Kenya was estimated to be 46 445 079 people as of January 2015. This was an increase of 2.46 % compared to the population of 45 329 520 the year before. The report further projects that the population of Kenya will increase by 3,132 persons daily in 2015 (http://countrymeters.info/en/Kenya). Continued increase in population translates into large populations at risk of infection (Snow *et al*., 2005).

4. Abiotic Factors in Relation to Malaria Risk

4.1 Human activities

Human activities may alter malaria transmission dynamics by increasing the emergence of efficient vectors, for example, by increasing the number of breeding sites through land use change, reduction in vector control activities and/or by increasing contact between man and vector through occupational activities which involve seasonal migration. In Kenya, the most important impacts on transmission are probably brought about by water resource development and land use change and particularly by land clearance for agricultural development (Afrane *et al*., 2006). In Cameroun, for example, forest clearance for cultivation has been associated with invasion of malaria vectors such as *Anopheles gambiae.* Dam construction has also had demonstrable effects on local levels of malaria transmission, as evidenced in Kenya (Ijumba *et al*., 2008). The issue of rice cultivation is perhaps more complex in Africa than elsewhere; in Madagascar the association between rice fields which support *Anopheles funestus* and malaria risk has been clearly demonstrated (Lepers, 1991).

4.2 Socio-economic conditions of human

Studies examining malaria incidence by socio-economic status on a smaller scale use various variables such as asset ownership, housing conditions, and educational attainment (Galup *et al*., 2001).

4.2.1 Poverty

Evidence from a Tanzanian demographic surveillance site (DSS) (de Savigny *et al*., 2002) indicates that poor children under five years of age had higher risks of death than those in the least-poor socio-economic quintiles. Another asset-based study investigated the role of a large number of potential socio-economic risk factors for malaria in a matched case control study in the Gambia (Koram *et al*., 1995).

Kenya is one of the most unequal countries in the sub-region. 42% of their population of 46 million lives below the poverty line. According to the United Nations Statistics Division, the dependency ratio in Kenya stood at 81.5% as at January 2015 (http://countrymeters.info/en/Kenya). Access to basic quality services such as health care, education, clean water and sanitation, is often a luxury for many people. Large segments of the population, including the burgeoning urban poor, are highly vulnerable to climatic, economic and social shocks.

Malaria is often associated with poverty; the poor are most affected, likely because they have reduced access to

medical services and information, and the lowest ability to avoid working in malaria epidemic areas. Poor individuals cannot afford cash crop production. Richer families who grow cash crops are more likely to afford personal protective measures like bed nets and insecticide sprays against mosquitoes than poorer families (Essendi *et al.,* 2012).

4.2.3 Level of education

A majority of Kenyans are still stuck at low levels of educational achievement. Specifically, 62 % of youth aged 15-34 years have below secondary level education, 34% have secondary education, and only 1% has university education (GoK 2003).

Educational attainment appears to have a strong influence on an individual's labor market activity. Compared to employed individuals, the openly unemployed and inactive youths have a higher proportion of individuals who "never went to school." In addition, about 90 % of all employed individuals whose highest level of education is primary school are engaged in vulnerable jobs, compared to 61 percent and 21 percent for those with at least secondary and university qualifications, respectively. Other census-related data indicates that about 40 percent of Kenya's youth either "never attended school" or "did not complete primary education."

Despite the country's free primary and secondary education policy that greatly subsidizes basic education, it is estimated that about 14% of the approximately 10.6 million children (aged between 5 and 14 years) left school or never attended school in 2009, and about 68% of secondary school-age youth (between 14-17) were not in school. These children are likely to become youths with little employable labor market skills over the next decade (GoK 2010).

Education levels of individuals play a significant role in reduction of malaria infections. Tertiary level of education confers more knowledge on an individual to recognize malaria signs and symptoms and to seek prompt treatment. This is also in agreement with previous studies. For instance, in Nigeria, Fawole and Onadeko (2001) found a statistically significant difference in the malaria "knowledge score" of mothers, and their occupation. Knowledge was higher among those who were skilled or professionals than among the unemployed or unskilled category.

4.2.3 Unemployment in Kenya

The unemployment problem is global and presents a particularly difficult labor market experience for youth. Youth in Kenya are experiencing much higher unemployment rates than the rest of the Kenyan population, as seen in Table 1. In 2005/06, youths aged 15-19 and 20-24 years had unemployment rates of 25% and 24%, respectively—about double the overall unemployment of 12.7% for the entire working-age group. Based on the 2009 census, the open unemployment rates declined for youth, but among youth aged 15-19 and 20-24 years these rates were about 15.8% and 13.1%, respectively—relative to a total unemployment rate of 8.6%.

There is a substantial variation in unemployment rates in urban and rural regions. In 2005/06 as well as 2009, the respective urban total unemployment rates of 19.9% and 11.0% were about twice as large as the rural rates. Like the national trends, within these regions, youth unemployment was much larger than that of the working-age population. In urban areas in 2009, for instance, the overall unemployment rate was about 11.0% relative to a youth (20-24 years) unemployment rate of 19.1% (KNBS 2008).

Unemployment is associated with poor health seeking behaviors, malnutrition, poor housing structures, a lack of protection against mosquito bites and lack of prophylaxis, all of which increases malaria transmission among the unemployed and poor individuals in Kenya.

4.2.4 Type of occupation

Certain occupations place individuals at greater risk of malaria infection than others. Agricultural labourers, for instance, may not only place themselves at risk through increased contact with the malaria vector but also, through their movement, place others at greater risk by contributing to the spread of the disease (Service, 1991; Martens *et al*., 2000). Consequently, occupation may reflect both socio-economic status and differential risk of exposure through occupational attributes.

4.2.5 Inaccessibility to information

In Kenya, digital migration came into effect in 2015 and the switch off from analogue to digital television raised concerns among ordinary Kenyans. First, only 10% of Kenyans can afford the set top boxes for digital transmission (http://digitalkenya.go.ke/news-updates). These digital set to boxes require a monthly subscription fee which goes as high as KSH 5,000 depending on the service provider. It has been observed that most Kenyans who live below poverty line have been locked out of watching television after this migration took effect, thus essentially denying them crucial information on malaria control programs.

4.2.6 Health seeking behaviours

In Kenya, some people presume that diseases arise from breaking taboos, witchcraft, evil eyes and spirit possession. These individuals therefore resort to traditional healing which include use of herbs, use of prayers, religious signs and symbols and rites and rituals. Conventional therapy is given a second resort in case traditional treatment fails. Some believe that ITNs are uncomfortable and a bad omen, hence they convert the freely given bed nets into other uses such as poultry keeping (Abubakar 2013).

Table 1: Unemployment rates (%) in Kenya by Age Group and Sex, 1998/99–2009

Age brackets	1998/99			2005/06			2009		
	Total	Male	Female	Total	Male	Female	Total	Male	Female
Total (rural + urban)									
15-19	24.3	21.8	26.4	25.0	22.4	27.7	15.8	16.5	15.1
20-24	27.1	19.0	33.9	24.2	21.0	27.3	13.1	13.6	12.6
15-64	**14.6**	**9.8**	**19.3**	**12.7**	**11.2**	**14.3**	**8.6**	**8.8**	**8.3**
Urban									
15-19	47.0	56.2	42.8	16.1	15.1	16.8	27.2	29.4	25.5
20-24	47.3	27.2	58.7	34.9	33.7	35.8	19.1	17.7	20.4
25-29	25.1	9.0	38.8	24.8	24.6	24.9	10.9	9.4	12.7
30-34	14.3	4.8	27.5	8.0	8.0	7.9	7.6	6.5	9.2
15-64	**25.1**	**12.5**	**38.1**	**19.9**	**15.0**	**25.9**	**11.0**	**-**	**-**
Rural									
15-19	15.9	14.3	17.8	21.3	22.2	20.5	13.0	13.8	12.0
20-24	15.1	15.5	14.5	30.7	29.3	32.0	9.9	11.4	8.5
25-29	8.6	7.6	9.5	17.8	17.1	18.5	6.9	8.0	5.8
30-34	8.2	4.8	10.9	8.6	8.1	9.1	5.6	6.3	4.9
15-64	**9.4**	**8.3**	**10.4**	**9.8**	**9.5**	**10.2**	**5.6**	**-**	**-**

Sources: Central Bureau of Statistics – Kenya (2003), Kenya National Bureau of Statistics (2008) and computations from the 2009 Kenya Population and Housing Census data.

4.3 House hold construction

Kenya, like many other developing countries has failed to attain the goals and objectives of housing policies and plans geared for low income groups; this is reflected in the mismatch of available housing forms. A significant percentage of urban residents occupy informal settlements characterized by poorly constructed houses and poor drainage system (Mitullah 1992). The household characteristics influence mosquito populations; hence mosquito bites and malaria transmissions. Low incidence of malaria infections are associated with houses that contain brick walls, iron-roof and cemented floors with eaves and screens. Closed eaves reduce the population of mosquitoes getting into the house. Metal roof and brick walls deny the blood fed mosquitoes suitable resting surfaces otherwise provided by mud walls and grass thatched roof hence protective against malaria. Cemented floors and permanent walls are linked to a higher economic status in a family due to the ability to afford the expensive materials and skilled labour involved in the construction, hence the ability to afford the malaria mitigation strategies (Essendi *et al.,* 2012).

4.4 Ethnicity

Data has shown that ethnicity might be an important marker of socioeconomic inequalities even among the poor (Brokerhoff *et al*., 2000). It is reported that ethnicity may influence norms and attitudes toward health and education, resulting in disparities in immunization rates, child mortality, and number of antenatal care visits in some countries. Kenya has a total of 42 tribes with various cultural and social practices, beliefs, attitudes and activities. These contribute to variations in health care approaches, health seeking behaviours, protection against mosquito bites and malaria transmission in the country.

Implications for control

Malaria transmission in Kenya is highly unpredictable and dynamic varying from one location to another and from one social setting to another. Control strategies should therefore adopt an element of spatial targeting rather than a uniform blanket targeting a wide area. For instance, vector breeding sites are common in slum areas (Mourou, 2012) and in areas where irrigation is practiced (Chaki *et al.,* 2009; Yadouléton *et al.,* 2010). Here, emphasis should be placed on both removal of breeding sites and protective measures for the local population. Socio-economic empowerment of Kenyans, such as provision of better education, employment, better housing facilities and piped water should also be improved. Provision of toilets may help to remove some breeding sites (Fobil *et al.,* 2011). Communities of low socioeconomic status are less likely to be able to afford protective measures such as ITNs and IRS and treatments such as ACTs, so distribution programs and education campaigns should be targeted at these communities (Doannio *et al.,* 2004; De Beaudrap *et al.,* 2011)

Conclusions

The studies selected for this paper provide a well-rounded picture of the range of factors that contribute to malaria transmission in Kenya. Clearly, there is great variation from one location to another and from one social setting to another depending on numerous biotic and abiotic factors. However, from a holistic analysis, it is clear that there are patterns of malaria transmission, an understanding of which will help to inform the development of future urban malaria control programs.

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