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The changing climate and the changing malaria, the double health challenge

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Abstract
Global climate change coupled with the burden of malaria present incapacitating challenge in the health sector. There is increasing body of evidence of the profound impact of climate change on the health status of individuals particularly among people in developing countries. The impacts of climate change are well-defined on vector borne diseases which affect various health care policies and interventions aimed to address and improve human health. Malaria, a leading cause of morbidity and mortality in resource poor countries, is a climate sensitive disease. An understanding of the influence of climate change on malaria dynamics and epidemiology is a fundamental component in assessing the changes in the spatial and temporal distribution of human risk for the disease. This review presents evidence of the profound and projected impacts of climate change on malaria, the dynamic change and burden of malaria epidemiology and the close climate-malaria interactions.

Keywords: Global climate change, dynamic change, climate, malaria

Introduction
Over the years the issue of climate change on human health ranging from its impact on food security and its contribution to the emergence, resurgence as well as redistribution of vector borne diseases has gained attention in the scientific domain. According to the inter-governmental panel on climate change (IPCC), climate change is a change in the state of the climate that can be identified (e.g. using statistical tests) by changes in the mean and/or the variability of its properties that persists for an extended period, typically decades or longer. Thus, a change in climate over time that is attributed to natural variability or human activity [1].
The most prevalent infectious diseases particularly those transmitted by insects, are highly sensitive to climate variation [2]. The potential of climate change to increase the transmission intensity and distribution of highly pathogenic parasites to levels uncontrollable by current management strategies is less in doubt.
One of the common tropical diseases associated with climate change is malaria. Malaria is mainly known as a disease sensitive to climatic changes [3, 4]. The biological characteristics as well as the geographic distribution of the malaria parasite (Plasmodium) and its vector (Anopheles mosquitoes) are sensitive to climate variables such as temperature, humidity and rainfall particularly in tropical regions. Malaria, a protozoan disease, caused by the bite of an infected female mosquito is among the world leading cause of morbidity and mortality [5, 6]. The disease distribution, spatial limits and seasonal activity are sensitive to climate factors, as well as the local capacity to address its prevalence.

Malaria burden and epidemiology
Epidemiological evidence show that the threat and burden of malaria is overwhelming and has persisted for centuries. Malaria prevalence is still a pressing issue in the concept of human health improvement. Globally, an estimated 3.3 billion people are at risk of being infected with malaria, and further 1.2 billion people are at high risk particularly in endemic regions [7]. Even though pragmatic measures and interventions have been implemented to reduce the incidence of malaria in Africa, the disease remain a major cause of illness and death particularly among under 5 children [8]. According to the World Health Organization (WHO), global estimate of malaria deaths was reported to be 429, 000 in 2015 with 92% (394680) of these deaths occurring in the African region. Almost all of these deaths (99%) were caused by *Plasmodium falciparum* [9]. It is the leading cause of childhood mortality in the Africa region.

Although estimates show that global malaria incidence has decreased by 18%, from 76 to 63 cases per 1000 population at risk, between 2010 and 2016, mortality rate associated with malaria is still alarming.
Malaria is currently mainly confined to tropical areas and poorer countries. The global burden of mortality is unevenly distributed and over the past decade, WHO reports have always tagged Africa as the heaviest burden of malaria compared to other regions. For instance, in 2015 and 2016, of the respective 215 and 216 million global malaria cases, the Africa region alone accounted for 90% [10]. The tropical Africa climate and poor environmental factors which favour the survival of malaria anopheles mosquito vector and parasite may partly explain the high prevalence of malaria in this region.
Understanding the determinants of malaria transmission, and how they are affected by climate is important to understanding how communities and individuals may adapt to an increasingly dynamic environment and implement appropriate strategies to address the burden of malaria.

Climate variables and their variability on malaria transmission

The variation in climate variables may directly affect the behavior and geographical distribution of malaria vectors and the life cycle of the parasite, and thus change the incidence and epidemiology of the disease. Indirectly, climate change could also have an effect by influencing environmental factors such as vegetation and the availability of breeding sites. The distribution of different malaria vectors, diversity in geography and environmental conditions result in variable endemicity of malaria. The influence of abiotic and biotic factors strongly determine the distribution and population dynamics of malaria. Climate change variables widely reported to influence the transmission and distribution of malaria epidemiology include temperature, humidity, rainfall and humidity [11]. These have been reported to have a profound effect on vector and parasite survival and activity. The impact can be either in influencing the anopheles mosquito vector of the disease or the malaria parasite development. The high concentrations of anthropogenic greenhouse gasses, carbon dioxide, methane, nitrous oxide and tropospheric ozone (CO_2, CH_4, N_2O, O_3) affect the climate and its variables. Climate variables predicts, to a large extent, the natural distribution of malaria. Rainfall, temperature and relative humidity primarily affects mosquito breeding, mosquito longevity, increase the vectorial capacity, parasite development rate and consequently increase in malaria prevalence particularly in high risk populations (Fig 1).

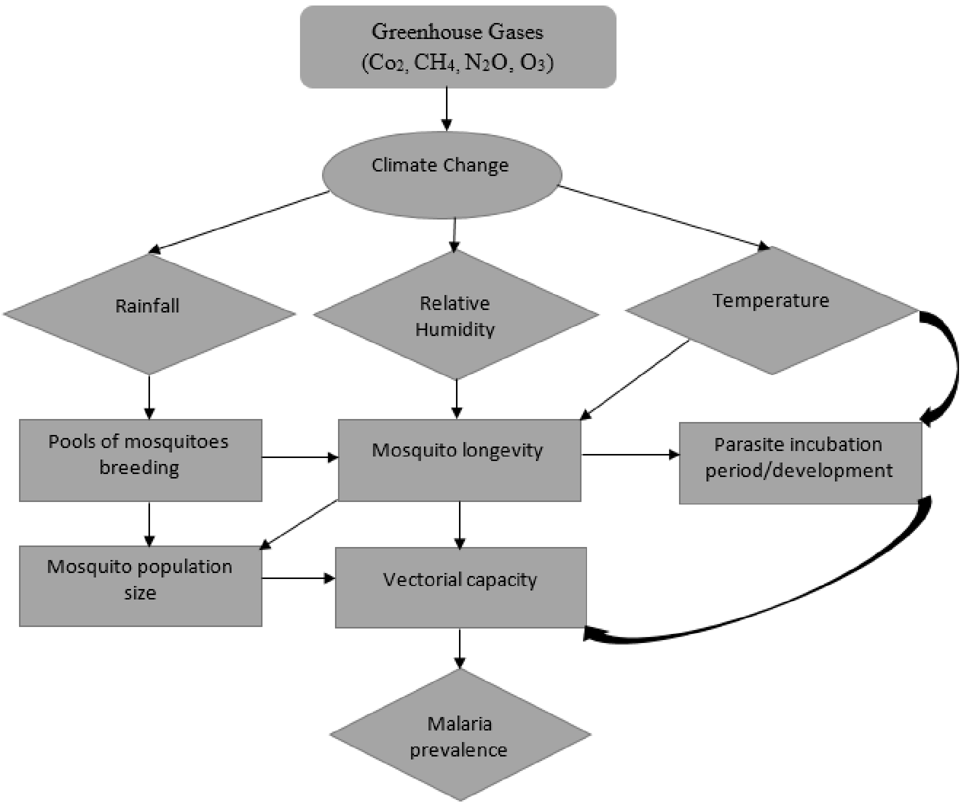

Fig 1: Relationship between climate variables and malaria transmission

Rainfall and malaria transmission

Rainfall intensity is considered a key determinant of the transport of pathogenic parasites and plays a crucial role in malaria epidemiology. Rainfall provides the medium for the aquatic stages of the mosquito life cycle. The length of rainy and dry seasons and the interval between seasons affects larvae and adult vector development and abundance. Transmission of many parasitic diseases including malaria is confined to the rainy season. Rain provides the breeding sites for mosquitoes and helps create a humid environment, which prolongs the life of vectors. In a study to determine the effects of rainfall and evapotranspiration on the temporal dynamics of Anopheles gambiae s.s. and Anopheles arabiensis in Kenya, Koenraadt and colleagues [12] reported a significant correlation of rainfall with increase in the number of An. gambiae s.l. larval habitats during the first 6 weeks of their 5 month study period. Rain may prove beneficial to mosquito breeding if moderate, but if excessive it may also flush out the mosquito larvae. In an assessment of association between climate and infectious diseases, Jaenisch and Patz [13] reported that extreme rainfall or precipitation can reduce malaria prevalence by washing away anopheles mosquitoes from breeding grounds. Rainfall may also increase the relative humidity and hence the longevity of the adult mosquito. A high relative humidity prolongs the life of the mosquito. Humidity greater than 60% is optimal for Anopheles to survive and helps the parasite to complete the necessary life cycle so that it can transmit the infection.

There is increasing body of evidence on the positive association between malaria incidence and rainfall. Akinbobola and Omotosho [14] reported a positive association of rainfall and humidity with malaria incidence in their study to predict malaria occurrence in Southwest and North central Nigeria using meteorological parameters. In another study to determine the short-term effect of rainfall on suspected malaria episodes at Magaria, Niger, Jusot and Alto [15] reported registration of more than 13,000 suspected malaria episodes which corresponded to an annual cumulative incidence rate of 4.7%. The overall excess risk of suspected malaria episodes for an increase of 1 mm of rainfall after 40 days of exposures was estimated at 7.2 %. Similarly, Odongo-Aginya and colleagues [16] confirmed a direct relationship between malaria transmission, parasite density and monthly rainfall in Entebbe Municipality, Uganda. Other investigators in Africa [17-19] and china [20] have reported a similar positive association of malaria and rainfall. However, few authors have reported no association or negative association of malaria with rainfall. In Iran, a recent study by Mohammadkhani and Khanjani [21] reported no significant association between malaria incidence and rainfall as well as humidity and concluded that temperature is among the effective climatic parameters on the incidence of malaria which should be considered in planning for control and prevention of the disease.

Effect of temperature on malaria transmission

Studies on temperature changes shows that there has been a rise in average daily temperatures during the last fifty years, present surface temperatures appear to be warmer than in the past years [22, 23]. Thus, the rate of temperature increase has nearly doubled in the last five decades [24] and predictions from the Intergovernmental Panel on Climate Change (IPCC) indicate that the average global surface temperature could rise from 1.4-5.8 ºC by the year 2100 [25]. Temperature determines the rate at which mosquitoes develop into adults, the frequency of their blood feeding, the rate with which parasites are acquired and, the incubation time of the parasite within the mosquito [22]. These influences must be compared with the opposing effects that high temperatures exert in reducing adult mosquito survival. For instance, in Tanzania, the annual number of mosquito bites per person drops precipitously at high elevations because the cool climate at high altitude impairs mosquito development rates [26]. In addition, cooler temperatures at high altitudes slow the development of infectious agents so that they cannot complete their life cycles. As a result, in Africa, human settlements at high altitude are relatively free of malaria [27].

Malaria parasite is dependent on mosquito and as a result the female mosquito has to live long enough for the parasite to complete its development. Between certain limits, longevity of a mosquito decreases with rising temperature and increases with increasing relative humidity [28-30]. Mosquitoes prefer humidity above 60%, and optimum temperature for mosquito survival is in the range of 20-25°C [22, 31]. Excessive temperatures usually above 40 °C will increase mortality, and there is a threshold temperature above which death occurs. Temperature affects the developmental period related to different stages of a mosquito’s lifecycle: blood feeding rate; gonotrophic cycle and longevity [22].

At increased temperatures, the rate of digestion of blood-meal increases, which in turn accelerates ovarian development, egg laying, reduction in gonotrophic cycle and a greater frequency of feeding on hosts, thereby increasing the probability of transmission [22, 23]. A reduction in the duration of the gonotrophic cycle would make the vectors bite more frequently, thereby increasing the probability of malaria transmission. It takes about 10 days for an egg to reach the adult stage of an anopheline mosquito at an optimum temperature of 28 °C. At lower temperature, the duration gets prolonged while at increased temperature the duration is reduced. However, at more than 40 °C, mortality occurs in adult mosquitoes [22, 25]. Reduction in the duration of gonotrophic cycle and in the extrinsic incubation period of malaria parasite is related with increased rate of transmission. These two entomological variables are especially sensitive to changes in environmental temperature, being reduced with increments in temperature.

Warmer temperatures accelerate physiological processes of the mosquito vector, leading to increased activity such as biting rate, growth, development and reproduction [22, 32].

The association of malaria incidence and transmission with temperature is more documented than any other climatic variable. Githeko *et al*. [33] compared monthly climate and malaria data in highlands of Kenya and found a close association between malaria transmission and monthly maximum temperature anomalies over three years (1997–2000). In Warri metropolis in Nigeria, a significant relationship has been found between malaria incidence and average temperature [34]. Oluleye & Akinbobola [18] have also reported on the profound effect of temperature on malaria in Lagos, Nigeria. To confirm these findings, Mohammadkhani and Khanjani reported temperature as the most effective climatic variable associated with malaria incidence in Kerman, South East Iran [21]. The authors further documented that a 1ºC increase in maximum temperature in a given month is associated with 15% and 19% increase on malaria incidence on the same and subsequent month, respectively (p=0.001). Likewise results by Li *et al*. in China revealed that each 1°C rise of temperature corresponds to an increase of 0.90% in the monthly number of malaria cases [35]. Alemu and colleagues also showed that both monthly minimum and maximum temperature was positively related with malaria in South West Ethiopia [17]. These available consistent evidence show the strong influence of temperature and hence the need to consider it in malaria control programmes.

Effect of Relative humidity on malaria transmission

Relative humidity (RH) refers to the amount of moisture in the air, expressed as a percentage. Relative humidity affects malaria transmission through its effect on the activity and survival of mosquitoes. Mosquitoes, like all insects, have tolerable range of temperature and humidity. They survive better and become more active under conditions of high humidity. This explains why mosquitoes are more active and prefer feeding during the night when relative humidity of the environment is higher. Low levels of relative humidity are known to decrease the lifespan of mosquitoes. The high surface area to volume ratio of mosquitoes makes them especially sensitive to desiccation at low humidity levels. Although, *An. gambiae* longevity has been reported not to be substantially affected by relative humidity at ranges greater than 60%, RH <10% is fatal, usually within hours [36].

Relative humidity below 60% decreases the lifespan of mosquitoes resulting in little or no malaria transmission. Thus, longevity of mosquitoes increases with increasing humidity, usually above 60% [5]. In a study to determine the effect of different relative humidity and temperatures on egg-production and longevity of adults of *anopheles (myzomyia) pharoensis* theob, Gaaboub *et al.* reported on a significant increase on mean longevity of the female mosquitoes when relative humidity increased from 50% to 90% under temperatures of 20 ^{0}C and 26 ^{0}C [37]. Bayoh and Lindsay [38] measured the longevity of *An. gambiae sensu stricto* (*s.s.*) at 40%, 60%, 80% and 100% RH at temperature of 5°C intervals from 5°C to 40°C. The authors assumed that the daily probability of survival is independent of mosquito age, and observed little difference in survival between 60-100% RH, but survival was slightly reduced at 40% RH. A recent study by Onyishi *et al*. [39] have reported on the positive correlation of RH with malaria prevalence in Nsukka, a tropical urban metropolis in Nigeria.

In the application of molecular technique to *An. gambiae s.s.* at 42% RH [40] and 30% RH [41] revealed that mosquitoes had undergone physiologic responses to desiccation stress, decreasing their water loss. Mosquitoes held without food or water survived for an average of 15.6 hours at 30% RH compared to 26.2 hours at 70% RH [41].

Several studies [14, 17, 36] have reported on the positive association of either the abundance of mosquitoes or the incidence of malaria with relative humidity. For instance in China, RH has been reported to be related with the number of malaria cases, where a relative humidity below 60% shortened the life span of the mosquito. There was a decline in the risk of clinical malaria while above 60% relative humidity the infection rate increased significantly. The authors further confirmed that the malaria risk at 80% humidity was twice as high as that of 60% [42, 43]. The transmission potential of anopheles mosquitoes is dependent on relative humidity among other factors.

Conclusion

Climate variables are potential cofounders in malaria transmission. Rainfall affects the breeding sites of the malaria vector, anopheles mosquito and result in their abundance; temperature and relative humidity affects the anopheles mosquito longevity and parasite development. The effects of these climate variables and their variability increases anopheles mosquito transmission potential. Efforts and interventions that aim to address malaria need to take into account the impact of seasonal and long-term climate variables and their variability on malaria transmission. Thus, integrating climatic factors as an adjunct to other control measures could be effective way to address malaria prevalence in populations.

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