Malaria and climate change

Dr Andrew Karanja Githeko, PhD
Climate Human Health Research Unit, Centre for Global Health Research, Kenya Medical Research Institute

Malaria is a disease that involves humans, mosquitoes, the plasmodium parasite and climate. It is a disease that affects millions of people particularly in the tropical region. About 90% of the reported malaria cases worldwide come from Africa[1]. There are several species of anopheles mosquitoes that transmit malaria however, the most efficient of these vectors are found in Africa and these are namely *Anopheles gambiae, An. arabiensis and An. funestus*. Two of these vectors *An. gambiae* and *An. funestus* more than 90% of their blood meals from human beings thus optimising the chance of transmitting the malaria parasite[2].

The development rate of mosquito larvae is temperature dependent: below 16°C development of *An. gambiae* mosquitoes stops and below 14°C they die. In cold temperatures the larvae develop very slowly and in many cases they may be eaten by predators and may never live to transmit the disease.

Once larvae emerge to become adults, the rate at which they feed on man is dependent upon the ambient temperature. At 17°C the female mosquitoes (*An. gambiae*) feed on humans every 4 days while at 25°C they take blood meals from humans every 2 days. Rainfall increases the breeding habitats for mosquitoes leading to increased population sizes and the rate of malaria transmission.

The rate of development of the malaria parasite in female mosquitoes is very sensitive to ambient temperature. The rate of the parasite development in the female mosquito has an exponential relationship to temperature. This means that very small increase in external temperature will reduce the time it takes for the parasite to mature several fold. In Western Kenya a 0.5°C increase in temperature since the 1970s can explain the eight-fold increase in malaria cases (Pascual 2009 http://www.ipsnews.net/news). The biology of malaria transmission is thus very sensitive to changes in the weather and climate.

It is now clear that climate change has taken place worldwide and some of the impacts are now obvious. For example many of the mountains in Africa, South America and even in New Zealand have lost glacier. Ice in the North Pole too has been melting at an unprecedented rate (http://nsidc.org/sotc/glacier_balance.html). In addition to the world becoming warmer there has been an observation of stronger and more frequent extreme events in recent times. These are signs of strong climate variability. Events such as the El Niño phenomenon can seasonally increase the local temperature and rainfall, leading to increased breeding of malaria vectors and the rate of development of malaria parasites in the vectors[3]. Furthermore under such weather regimes female mosquitoes feed on humans more frequently leading to increased malaria transmission.

Climate change is expected to lead to increased latitudinal and altitudinal warming. For example Southern Africa will become more suitable for malaria transmission and East African highlands will also become warmer and malaria transmission will be more intense. Malaria transmission will be possible in areas that were formally too cold for the development of the mosquitoes and the parasites. The threshold temperature for malaria transmission is 18°C mean annual temperature. Below the threshold, malaria transmission is not possible as female mosquitoes die before the malaria parasite can mature and become transmitted.

Climate change and malaria in the Commonwealth

While climate change will alter the patterns and spread of malaria transmission in some Commonwealth countries, other drivers of the disease include, social economic status of the country, type of vectors available, population immigration and vector dispersal. Africa will continue to carry the greatest burden of the disease and in particular Eastern and Southern Africa. Mountainous regions in South Asia are likely to experience an increase in transmission. The same applies to highland regions of South East Asia and Pacific countries. The United Kingdom, Europe and Canada and New Zealand are unlikely to be affected in the near future.

Policy-makers will need to take into consideration the new vulnerable regions and expand surveillance and control. It is essential that control is guided by research so as to increase the efficacy and cost-effectiveness of the control programmes.

Several members of the Commonwealth states are located in the tropics and in the subtropics and in many of them malaria is endemic. However within these countries certain areas have been spared of the disease mainly because the climate was not suitable for parasite development.

Climate change and malaria in Africa

All the drivers of malaria transmission are found in abundance of Africa and climate change is a new addition. Since the late 1980s there were reports of malaria epidemics particularly in the East African Highlands[3, 4, 5, 6]. In many of these regions there was widespread parasite resistance to chloroquine[7] and in addition there was virtually no vector control. At that time it was not clear whether the epidemics were as a result of environmental change or due to the effects of drug resistance and lack of vector control. A detailed study of climate and malaria epidemics indicated that the epidemics were associated with incidents of El Niño[8, 9]. These events were characterized by abnormal warming and wetness. Weak and late interventions failed to contain the outbreaks leading to severe health outcomes. Kenya, Uganda, Burundi, Tanzania, Eritrea, Ethiopia and Rwanda reported severe malaria epidemics in the late 1980s to 2003). This period had two very strong El Niños and a number of weak events (1982, 1988, 1990-1994, 1997-8, 2003).

Malaria epidemics have also occurred in typically semi-arid and arid areas that are subject to flooding during abnormally wet periods. Botswana[10] and Mozambique[11] have experience such events. North Kenya which is an arid region experienced a severe malaria epidemic during the 1997–8 El Niño due to prolonged flooding[12]. The same areas suffered a severe Rift Valley Fever.

In KwaZulu Natal, South Africa, where malaria control operations are intense, climate appears to drive the inter-annual variation of malaria incidence. In Zimbabwe projected changes in temperature and precipitation could alter the geographic distribution of malaria with previously unsuitable highlands with dense human population becoming suitable for transmission by 2100 assuming that no malaria interventions are effected[13].

From 1850–2005 the earth has warmed by 0.7°C and is likely to warm further at a rate of 0.2°C per decade[14].

Climate change and malaria in Asia

The climate of the Asian region is typically tropical and highly suitable for malaria transmission. The region has a long history of malaria control but which has been constrained by insecticide and drug resistance. It has a rich diversity of malaria vectors adapted to its equally rich ecological diversity. The formally malaria free mountainous regions will become vulnerable to malaria transmission.

Malaria is endemic in all of India except at elevations above 1,800 metres and in some coastal areas[15]. India is the largest member of the Commonwealth countries. The country had 10.2 million malaria cases in 2006. Two of the major malaria species Plasmodium falciparum and Plasmodium vivax are found in the country. The major malaria vectors are *An. culicifacies, An. dirus, An. fluviatilis, An. minimus, An. philippinensis* and *An. Stephensi*. Despite a doubling of government and external financing in malaria interventions between 2004 and 2007 there has been little effect on the prevalence of *P. falciparum*. In fact there was a small upsurge in 2007. *Plasmodium falciparum* thrives better in warmer climate. Climate change is expected to increase the suitability of north eastern India regions for malaria transmission (Uttar Pradesh, Bihar, Karnataka, Orissa, Rajasthan, Madhya Pradesh and Pondicherry).

Historically India controlled malaria using indoor spraying with DDT[16]. The programme was largely successful and brought malaria cases from 70 million cases in 1953 to 2 million cases in 1985. Wide scale insecticide resistance had occurred by this period. From 1990 malaria morbidity and mortality began to increase and large scale epidemics occurred in 1994 throughout India. Insecticide treated bed nets are now the most common vector control tool in India but their impact on disease prevalence has been small. A substantial up scaling of indoor residual spraying has been implemented[16].

Pakistan presents a much clearer picture with regard to malaria and climate change. It had been observed that malaria in the Northwestern Frontier Province had an increasing prevalence of *P. falciparum* malaria. Investigations indicated that the mean temperature for November and December had increase by 2 and 1.5°C respectively from 1876-1981. Rainfall and humidity had also increased for that period. The proportion of *P. falciparum* cases and the prevalence of malaria cases were highly correlated with the observed meteorological changes[17]. These trends will be expected to continue with climate change.

Climate Change and malaria in the Caribbean

The Caribbean region is likely to experience an increased frequency of extreme events resulting in floods and droughts. Few studies have been carried out to determine the relationship between malaria and climate change. Nevertheless it is expected that flooding would increase mosquito populations leading to increased transmission. Studies have shown that climate change will have a significant impact on dengue fever in the Caribbean.

Climate change and malaria in Canada

Currently there seems to be no documented malaria vectors in Canada although *Anopheles freeborni* and *Anopheles quadrimaculatus* occur near the Canadian and United States border. Malaria cases in Canada are found in travellers and refugees[18]. Establishment of vectors could indicate a risk, however, the long Canadian winters are still a barrier to transmission. It has been suggested climate change will increase transmissibility conditions in the next 30–50 years but the country has the means to contain such transmission[19].

Climate change and malaria in Australia and New Zealand

Malaria was eradicated from Australia in 1981 but the vector Anopheles farauti sensu lato was not. Australian temperatures have increased by an average of 0.9°C since 1950. Northwest and Central Australia have experience increased precipitation whereas the rest of the country has become drier. The best estimate of warming in Australia by the year 2030 relative to 1990 is 1°C. (http://www. climatechangeinaustralia.gov.au). These trends suggest that conditions for the breeding of malaria vectors may become better leading to larger populations of vectors. Cases of malaria in Australia originate from travellers and immigrants. These conditions suggest that there will be an increased risk of local malaria transmission given the current climate trends in the northwest region and this risk could increase towards the south[14]. However the risk seems small because the vectors have a preference to feed on animals rather than humans. No local malaria transmission has been documented in New Zealand.

Climate change and malaria in the United Kingdom

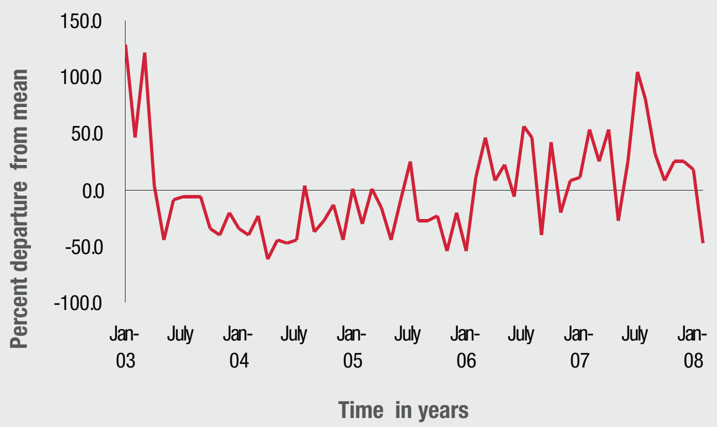
From 1987–2006, 39,300 cases of malaria have been reported in the United Kingdom from people travelling to endemic areas. The number of cases with *P. falciparum* malaria is increasing with increased travel particularly to Africa[20]. Mosquito species, found in the UK are; *Anopheles atroparvus, An. algeriensis , An. messeae, An. claviger,* and *Anopheles plumbeus*. The later, has the potential to become infected with malaria parasites. However most of the European anopheles are refractory to *P. falciparum* from East Africa and probably from other African regions. While there is a possibility of vector anophelines migrating and settling in the UK, the possibility of establishing a transmission cycle is very small because the chance of a vector finding an infected host is very small. Secondly many of the infected people will be treated before they become infective to mosquitoes with the exception of immigrants from endemic areas. Climate change in the UK could include very severe winters and this would virtually eradicate any immigrant tropical malaria vectors.

Climate change and malaria in the South Pacific

With the exception of Papua New Guinea, (< 18,000 meters) Vanuatu, and the Solomon Islands the South Pacific is free of malaria. Malaria is a leading cause of morbidity and mortality in Papua New Guinea resulting in about 1.7 million cases in 2003. The World Health

Organization recorded 4,986 malaria cases in the Western Highlands province in 2005, compared with 638 cases in 2000. About 40% of Papua New Guineans live in the highlands, where there used to be no malaria or low epidemic outbreaks. The malaria epidemic of 1997–8 in the highlands which was predominated by *P. falciparum* is consistent with a response to anomalous warming and precipitation suggesting that malaria trends in PNG may follow similar trends to those of the East African highlands. The burden of malaria is likely to increase in PNG with climate change.

Figure 2: Trend in inpatient malaria cases in Tumutumu hospital Nyeri district. The spike, in cases in 2003 was due to an El Niño event. Data collection in the hospital started in 2003. There is an upward trend in the inpatient cases (Githeko unpublished data)



Climate change and malaria in South East Asia

Malaysia and neighbouring countries have hot and humid tropical climate suitable for malaria transmission. The country has one of the oldest malaria control programmes and has managed to reduce malaria transmission significantly and reporting only 5,569 cases in 2006[21]. The country has plans to eradicate the disease by 2050. There have been recent unpublished reports of new malaria in the highlands of Malaysia which would be consistent with spreading of the disease in higher altitudes. The country should increase surveillance in areas that could become suitable for transmission due to climate change. In the past successful malaria programs have seen reversals of malaria trends and this should serve as a lesson that malaria eradication will not be easy. Furthermore immigrants could reintroduce the disease after successful control campaigns.

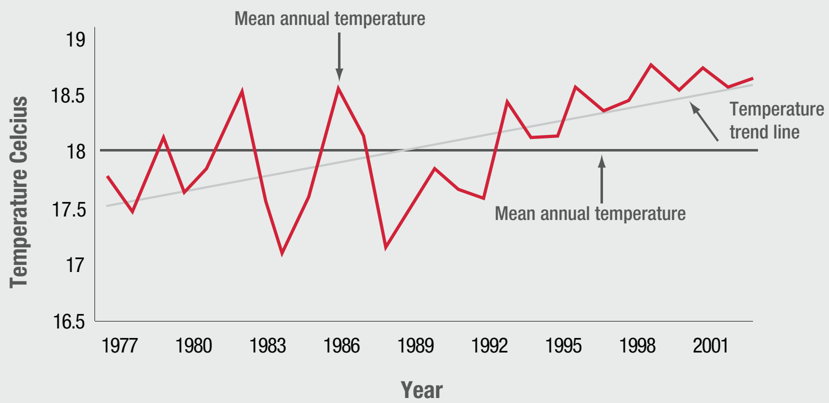
Case study: malaria and climate change in the Central Kenya Highlands

Nyeri district lies at 1,768 meters above sea level. The mean annual temperature prior to 1994 was between 17.4°C and 18.2°C and the annual rainfall was about 2,000 mm. The district is located south of Mt Kenya and was once considered cool and is indeed suitable for tea, coffee and pedigree cattle. Prior to the 1990's malaria was unknown in the area. In the last few decades it was noted that snow on the mountain was disappearing fast and rivers originating from the mountain were shrinking over time. In 2005 the malaria vector An. arabiensis[22] was collected near Karatina in Nyeri district (1,720 meters above sea level) and Naru Moru an area north of Nyeri (1,921 m a.s.l.). This was the first record of a malaria vector in this part of the Central Kenya Highlands. Throughout the latter half of the 1990s and into early 2000's sporadic cases of malaria were reported in the area but it was assumed that this was imported malaria. However investigations indicated that malaria infections were widespread and people who had not traveled were getting infections.

The most revealing and compelling indicators of why malaria had moved into the Central Kenya Highlands came from temperature data analysis.

Analysis of the climate data indicated that prior to 1993; the mean annual temperature fluctuated between 17.4°C and 18.2°C. However, from 1994 onwards the mean annual temperature rose permanently above 18°C (Figure 1). This temperature is the threshold for malaria transmission and this departure coincided with the first reports of malaria cases in the area. Since 1994 the numbers of malaria cases have continued to rise. In 2003 the numbers of malaria cases in one hospitals rose by 100% (Figure 2). This was an El Niño year which was characterised by anomalously warm and wet event toward the end of the year. Malaria transmission in central Kenya is now well established although it is considered unstable. Low and unstable malaria transmission can lead to epidemics particularly in none-immune populations. The human population in the Central Kenya has had little or no encounter with malaria and is thus considered non-immune.

Figure 1: Crossing the malaria transmission threshold temperature in Nyeri District Central Kenya Highlands where malaria was established for the 1st time in the 1990s. (Githeko unpublished data)



The shift of malaria into the Central Kenya highlands was expected but not as soon as it happened. This shift is particularly interesting because it can be explained by the change in the mean annual temperature; the biological mechanism explaining the latitudinal and altitudinal shift of malaria. The occurrence of malaria in the Western Kenya Highlands was attributed to multiple factors such as drug resistance, mobility of people, lack of vector control and land use change. In the Central Highlands the only change that occurred and that lead to malaria was the mean annual temperature.

Gaps in responses, policies and research

Recent malaria interventions in Africa have had significant impacts on the prevalence of the disease. Malaria prevalence in a rice irrigations scheme in centrals Kenya lowlands decreased from 40% to zero after the ownership of insecticide treated net reached 90%[23]. Recent unpublished data (Githeko 2009) indicates malaria has disappear in some parts the Western Kenya Highlands following the distribution of free insecticide treated bed nets by the Kenya government. Malaria transmission in the fringe areas is normally quite weak and amenable to control. Nevertheless it can lead to very severe forms of the disease because of luck of immunity[24]. Transmission in these areas can be easily controlled by targeted interventions. However targeted interventions require an investment in research to map out the main source of vector breeding. In many cases there is no need for blanket indoor residual spraying (IRS). Targeting the main source of vectors can make substantial savings and simplify logistics. For example in highlands areas the vast majority of vectors are found a few hundred meters close to the breeding sites and only such areas should be treated with IRS.

There will be need to undertake new entomological research into areas that have been invaded by malaria vectors and where transmission is taking place. Research also needs to be undertaken in areas that are likely to be invaded by vectors and these include areas whose mean annual temperature is just below 18°C. Parasitological surveys should be regularly carried out in such areas so that transmission can be detected in the early staged and control measures put in place. It is essential that climate data is examined regularly to determine changes in the suitability of the habitats for malaria transmission. Traditionally such activities would not be undertaken by National Malaria Control Programmes (NMCP). A policy change requiring the inclusion of climate data by NMCPs will be required for these activities to be undertaken.

Many of the old generation entomologists have little knowledge on the mathematical relationships between meteorological parameters and malaria. Yet such parameters can explain many of the changes in prevalence that are being observed in *P. vivax, P. falciparum* and even *P. malaria*.

Vector species ratios for example between *An. gambiae* and *An. arabiensis* are likely to change under the global warming scenarios. A rearrangement of the vectorial systems will lead to new transmission characteristics. It is essential that research is undertaken to reveal the impacts of climate change on vector populations.

Recommendations

- Climate change must be included as an important driver of malaria.
- Vulnerability mapping should be carried out to identify areas that malaria is likely to invaded as the climate changes.
- Climate data should be used in identifying vulnerable areas.
- Entomological and parasitological surveillance should be undertaken in vulnerable areas.
- Research on integrated malaria control should be enhanced with the intent of developing cost effective malaria control strategies.
- New entomological studies on the effects of climate change on malaria vectors by should be initiated.
- Early interventions in newly malaria colonized areas should be encouraged. ◆

Dr Andrew Karanja Githeko completed his BSc in Chemistry and Zoology at the University of Nairobi in 1981. In 1985 he completed MSc in Applied Parasitology and Medical Entomology at the Liverpool School of Tropical Medicine. In 1992 he completed his PhD at LSTM in Medical Entomology. He started his career at the Kenya Medical Research Institute (KEMRI) as an Assistant Research Officer in 1981 and rose to become a Chief Research Officer in 2004 and head of the Climate and Human health Research Unit. Having worked for IPCC since 1998 and among other IPCC scientists was awarded a Nobel Peace Prize Certificate.

References

1. World Health Organization, *Africa Malaria Report*, 2003. Geneva, World Health Organization.
2. Githeko, A. K., Service, M. W., Mbogo, et al. 1994. Origin of blood meals in indoor and outdoor resting malaria vectors in western Kenya. *Acta Tropica* 58: 307-316
3. Githeko AK, and Ndegwa W, 2001. Predicting malaria epidemics using climate data in Kenyan highlands: a tool for decision makers, *Global Change and Human Health*. 2: 54-63
4. Abeku TA, van Oortmarssen GJ, Borsboom G, 2003. Spatial and temporal variations of malaria epidemic risk in Ethiopia: factors involved and implications. *Acta Trop*. 87:331-40.
5. Zhou G, Minakawa N, Githeko AK, Yan G, 2004. Association between climate variability and malaria epidemics in the East African highlands. *Proceedings of the National Academy of Sciences* 101:2375-80.
6. Pascual M, Ahumada JA, Chaves LF, et al 2006. Malaria resurgence in the East African highlands: temperature trends revisited. *Proceedings of the National Academy of Sciences* 103:5829-34.
7. EANMAT, 2001 Monitoring antimalarial drug resistance within National Malaria Control Programmes: the EANMAT experience. *Tropical Medicine and International Health*. 6:891-8.
8. Kovats RS, Bouma MJ, Hajat S, Worrall E, et al. 2003. El Niño and health. *Lancet*. 362:1481-9.
9. Anyamba A, Chretien JP, Small J, et al. 2006. Developing global climate anomalies suggest potential disease risks for 2006-2007. *International Journal Health Geographics*. 5:60.
10. Thomson MC, Doblas-Reyes FJ, Mason, et al 2006. Malaria early warnings based on seasonal climate forecasts from multi-model ensembles. *Nature.439:576-9*.
11. Sidley P, 2000. Malaria epidemic expected in Mozambique. British Medical Journal 320:669.
12. Brown V, Abdir Issak M, Rossi M, et al. 1998. Epidemic of malaria in north-eastern Kenya. *Lancet*. 352:1356-7.
13. Ebi KI, Hartman J, Chan N, et al 2005. Climate suitability for stable malaria transmission in Zimbabwe under different climate change scenarios. *Climate Change* 73: 375-393
14. IPCC, 2007: Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 996 pp.
15. Sharma, VP. 1996. Re-emergence of malaria in India. Indian Journal of Medical Research, 103: 26-45.
16. World Health Organization, World malaria Report, 2008. Geneva World Health Organization.
17. Bouma MJ, Dye C, van der Kaay HJ, 1996. Falciparum malaria and climate change in the northwest frontier province of Pakistan. *American Journal of Tropical Medicine and Hygiene*.55:131-7.
18. MacLean JD, Demers AM, Ndao et al 2004.Malaria epidemics and surveillance systems in Canada. *Emerg Infect Dis*. 2004 10:1195-201.
19. Berrang-Ford L, Maclean JD, Gyorkos TW, et al. 2009. Climate change and malaria in Canada: a systems approach. *Interdiscip Perspect Infect Dis*. 2009;2009:385487
20. Smith AD, Bradley DJ, Smith V, et al. 2008. Imported malaria and high risk groups: observational study using UK surveillance data 1987-2006. *BMJ*. 3;337:
21. Vythilingam I, Noorazian YM, Huat TC, et al 2008 Plasmodium knowlesi in humans, macaques and mosquitoes in peninsular Malaysia. *Parasit Vectors*. 2008 1:26.
22. Chen H, Githeko AK, Zhou G, et al. 2006. New records of Anopheles arabiensis breeding on the Mount Kenya highlands indicate indigenous malaria transmission. *Malaria Journal*. 2006 Mar 7;5:17.
23. Okech BA, Mwobobia IK, Kamau et al. 2008. Use of integrated malaria management reduces malaria in Kenya. PLoS ONE. 3:e4050.
24. Noland GS, Hendel-Paterson B, Min XM, et al. 2008, Low prevalence of antibodies to preerythrocytic but not blood-stage Plasmodium falciparum antigens in an area of unstable malaria transmission compared to prevalence in an area of stable malaria transmission. *Infections and Immunity*. 76:5721-8.