Climate Change and Highland Malaria in the Tropics

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Abstract

The dramatic increase in the prevalence of malaria in highland areas of the tropics in recent decades has frequently been attributed to global warming. The history of the disease in six countries does not support this hypothesis; politics, economics and human activities, not climate, are the principal determinants of the changing pattern of transmission.

In recent years, there has been a marked increase in the incidence of malaria in mountain regions of the tropics. For example:

- Serious outbreaks are occurring with increasing frequency in the New Guinea highlands; until the 1950s, the disease was rare in the region.
- In 1986-88, a sudden, devastating epidemic occurred on the central plateau of the Madagascar Highlands; the disease had been virtually absent in the previous decades.
- Since the 1980s, the disease has become a serious public health problem in the West Kenya highlands; in previous decades, transmission had been relatively low.
- The Amani hills of northeastern Tanzania were once virtually malaria-free; prevalence has risen rapidly in the past three decades.
- Records at a well-staffed mission hospital in the highlands of southeastern Uganda show a 70-fold increase in incidence from the late 1960s to the mid-1990s, with a serious epidemic in 1994.
- In southern Rwanda, records at another well-staffed facility show a slow increase in incidence from 1983 onwards, with a sudden jump to more than twice the previous rate in 1987.

Many authors have suggested these changes can be attributed to global warming [e.g. *1-4*]. This article reviews the history of malaria in the affected areas, and the factors that are likely to have contributed to active transmission.

New Guinea Highlands

In the early 1930s, a human population estimated at 1,000,000, previously unknown to outsiders, was "discovered" in the mountains of New Guinea. These so-called "Stone Age people" appeared to be malaria free, apparently due to their unique state of isolation [*5*]. By contrast, the lowland coastal regions were highly malarious.

After World War II, there was a rapid increase in the number of small landholders growing *Arabica* coffee and other crops in the mountains. In the late 1940s, scientists warned that epidemic malaria had appeared in several highland areas at around 1,500 m, and that continued contact between the regions could bring disaster [*6*]. By the mid-1950s, further alarming outbreaks lead to the creation of laws that required employers of highlanders working on the coast to supply them with anti-malarials, and the responsibility to ensure that the medications were taken as prescribed. On repatriation, highlanders were held in compulsory quarantine for two weeks and given curative malaria therapy [*7, 8*].

These regulations failed to stop the emergence of the disease in the highlands, and its spread to many isolated valleys. The increase in prevalence was clearly attributable to a rapid increase of anopheline populations following the clearance of forest and the construction of roads, airstrips, plantations, mines, water impoundments, and other human artefacts that created suitable mosquito breeding habitats [*9*]. Several vectors were involved, including *Anopheles farauti* and *An. punctulatus* [*9*]. These species breed in open sunlit pools and are in many ways analogous to *An. gambiae* and *An. funestus*, the principal malaria vectors in sub-Saharan Africa.

Subsequent studies suggest that the parasite may have arrived in the highlands as early as the 1940s but did not become evident until forest clearance and development were more widespread. Whatever the chronology, the recent history of the disease is clearly attributable to the introduction of the parasite to non-immune populations and the proliferation of its vectors because of large-scale ecological change.

Madagascar Highlands

Irrigated rice culture was introduced to the Plateaux regions of Madagascar in the early 19th century, and the human population expanded rapidly. Malaria appears to have been absent until 1878, when a catastrophic epidemic occurred in the area around the capital, Tananarive (altitude ca. 1,200 m. Present name: Antananarivo). A second major epidemic occurred in 1895. Thereafter the disease became endemic. As in most of sub-Saharan Africa, *An. gambiae* and *An. funestus* were the principal vectors [*10*]. In 1949, the French administration initiated a major control campaign involving annual treatment of homes with DDT, and an extensive network of malaria clinics and dispensaries. Within ten years, the disease had virtually disappeared, but the clinics remained operational in order to treat sporadic outbreaks.

The country became independent in 1960 and later realigned itself with the Soviet Union. After a military takeover in 1975 and the enforcement of a new plan of "scientific socialism," the economy went into disastrous decline. Medication was in short supply, and in 1980 all but one of the clinics were closed. The ferocity of the transmission that followed was fuelled by the lack of immunity of the population, the absence of treatment centres, and the shortage of medication. In addition, because of the breakdown of law and order, people began keeping their cattle inside their houses at night to guard against theft, thereby bringing themselves in greater contact the primarily zoophilic vector *An. arabiensis*. During the epidemic, there were press reports of 100,000 to 400,000 deaths, although investigators concluded that the true figure was probably 10,000 to 25,000.The situation was corrected in the period 1993-1995 by re-instituting DDT treatments and re-opening the dispensaries. Despite several claims that transmission was the result of unusually warm temperatures, the meteorological record shows remarkable stability of temperatures over the past 30 years [*10*]. All the evidence indicates that the tragedy was brought about by the breakdown of successful control in a highly endemic area because of socio-economic factors [*11*].

Kenya Highlands

Malaria was not recorded in the Kenya Highlands until the second decade of the 20th century [*12, 13*]. It began to appear after the clearance of forests for the development of tea estates and the importation of infected labourers. Initially the disease was mainly apparent below 1,500 m and was rare in Nairobi (1,680 m), the capital. The first sizeable epidemic (1918-19) was attributed to the return of local soldiers from Tanzania. Thereafter, transmission moved to progressively higher altitudes, with major transmission in Nairobi and in the farming district around Eldoret (2,040 m). Six epidemics were recorded between the two World Wars. During World War II, there were epidemics in the Londiani district (2,250-2,490 m) and even at a farm near Mount Timboroa, at 2,490-2,550 m [*14*]. Transmission could occur at these altitudes because the adult mosquitoes rest indoors, where temperatures are 3-5 ^{0}C higher than outside. In the 1940s, British entomologists referred to this as "hut malaria" and even suggested that the disease could be eliminated by persuading women to move their cooking fires outdoors, to make their homes colder!

The fundamental cause of this progressive upward advance of malaria was widespread deforestation and development as the areas were opened up for large farming ventures [*14*]. The construction of roads and railways generated innumerable infested "borrow pits"—flooded depressions left by excavation for materials—and also contributed to the dispersal of the mosquito. Milldams on rivers interfered with natural drainage. The introduction of the ox wagon led to a proliferation of rough rural roads; water in the wheel ruts provided further prolific breeding sites for vectors. These and many other factors caused a drastic change of ecology that favoured the anopheline vectors and brought active transmission to the Highlands. The disease continued to be a serious public health problem until the 1950s, when the colonial government organized an extensive control program, after which the area was essentially malaria free until the 1970s.

The tea-growing estates (1,780-2,225 m) in the Kericho district have an extensive medical service for employees and their dependents that was initiated in 1925. Health care at the central hospital of Unilever Tea

Kenya (formerly Brooke Bond Kenya Ltd.) is extended to some 100,000 inhabitants of the region. However, there is no attempt at mosquito control, and malaria has re-emerged as a serious problem. A published study showed epidemics in almost every year from 1990-1997, with a mean annual attack rates of around 50% [*15*]. Peak transmission was from May to July, after the principal rainy season and before mean monthly temperatures drop below 18 ^{0}C. A questionnaire survey (June 1997) indicated that only 8% of patients had travelled to areas with known malaria transmission in the previous 30 days.

It has been suggested that the main factor in this recrudescence is increased resistance to antimalarial drugs, as well as the unsupervised use of ineffective medications, but the picture is not entirely clear [*16*]. Whatever the cause, the history of multiple epidemics in the earlier part of the century, including many at higher altitudes, makes it un-necessary to infer climate change as a contributory factor. Moreover, a set of well-maintained meteorological records shows no significant change in temperature over recent decades [*11, 15, 17, 18*]. Indeed, in a detailed report to the World Health Organization [*19*], a group of malaria specialists based in Nairobi dismissed those who claim a global warming link as "scientific Nostradamuses".

Amani Hills, Tanzania

In 1902, the German colonial administration built a field station at 1,000 m in the Amani hills (altitude 600-1000 m) of the eastern Usambara Mountains in north-eastern Tanzania. The heavily forested area had a relatively cool climate and was considered malaria free. For many years, Europeans living on the coast spent time there during the hotter months of the rainy season.

Logging and extensive clearance for agriculture and general settlement began in the 1960s. Malaria specialists [*20*] predicted that this deforestation, along with road construction, and the proliferation of dams, ponds, ditches, furrows, road ruts and other breeding sites would open up the area to *An. gambiae* and *An. funestus*. Until then, both species had been scarce or absent because they prefer open sunlit breeding sites. In the period 1967 to 1978, the human population doubled, mainly by an influx of people from the highly malarious coastal region. At the same time, malaria became increasingly common. By 1980-82, 61% of infants less than one year old who attended a clinic were positive for malaria, and most of them (91%) had not left the area in the weeks preceding their illness [*21*].

As in the Kericho tea estates, the Amani station maintained a good meteorological record, although it is incomplete after 1977. In the first half of the century, mean annual temperatures ranged from 12.8 ^{0}C to 15.6 ^{0}C. In the 1960s, there was a sudden warming, directly attributable to the elimination of shade by deforestation. After this the recorded temperatures are remarkably consistent for about 10 years, ranging from 20.0 ^{0}C to 20.8 ^{0}C until re-forestation resulted in a steady cooling trend of about 0.46 ^{0}C per year. By 1975, the mean annual average was back to 17.4 ^{0}C, but malaria incidence remained high, apparently because indoor temperatures were several degrees higher than those at the field station. In a recent study, mean annual prevalence of parasitaemia among 6-71 month-old children ranged from 33-76% [*22*].

The factors leading to the emergence of malaria in Amani were similar to those in New Guinea and Kenya: a major ecological disturbance—deforestation and settlement—created a new habitat for effective vectors, and the elimination of shade resulted in a marked change in local climate. In addition, the prevalence of the parasite was augmented by an influx of infected people. More recently, substantial resistance to chloroquine has been documented in all three areas, although the drug is still widely used by the local populations.

Uganda Highlands

Over the past thirty years, there has been a marked emergence of malaria in the Runkungiri and Kabale districts of southeast Uganda. There has been a steady increase in the incidence of the disease among outpatients at Kisizi Mission Hospital (alt. 1,650 m), and there was a major epidemic in 1994. Peak transmission is generally in July, the driest, coldest month of the year [*11*].

Endemic foci of the disease at 1,800-2,000 m were recognized in the area as early as 1919, and epidemic transmission has been known since 1948 [*23*]. A malaria eradication program was set up in 1961, and extensive surveys showed that prevalence was very low at altitudes above 1,500 m, except at certain lakesides up to 1,900 m. As in Kenya, Tanzania and neighbouring countries, transmission could occur at these higher altitudes because the adult mosquitoes rest indoors, where temperatures were 3-5^{0}C higher than outdoors [*24*]. Indoor spraying continued from 1963 to 1966.

In maps drawn prior to 1961, the human population was mainly distributed on hillsides above 1,500 m. The valley bottoms were mostly *Papyrus* marsh. Since then, population growth has been rapid (more than 3% per year). Many inhabitants have moved off the hills to cultivate the marshland with food crops and fishponds. The elimination of papyrus has created habitat for *An. gambiae* and *An. funestus* and this has led to increased transmission [*25*]. In 1994, rainfall was more than twice normal, so the vector was probably especially abundant. The increasing prevalence of the disease is thus attributable to the changes in agriculture and ecology that accompanied a massive increase in population in an area of unstable endemic transmission [*11*], not to any change in climate.

Rwanda Highlands

Rwanda lies close to the equator, adjacent to Uganda. Most of the country is at an elevation above 1,500 m. Population density is the highest in Africa, although more than 90% of the people live in rural areas. Traditional settlement is not in villages, but in homesteads scattered across the hillsides of the mountainous terrain, with several hundred persons per square mile. In the past few decades, population increase has been extremely high—more than half of the inhabitants are less than 16 years old—and is far above the productive capacity of the environment. In 1972, this situation was exacerbated by an influx of 60,000 refugees from neighbouring Burundi.

Data from around the country indicate that the incidence of malaria has risen steadily in recent decades. The reasons for this increase have not been investigated, but are probably similar to those in neighbouring countries. For example, outbreaks in the 1980s were attributed to a new road that facilitated travel to malarious lowland areas [*26*]. In addition, as in Uganda, population pressures have led to increased utilization of valley bottoms, where settlements are more concentrated and transmission is more likely. Indeed, an association between marsh clearing and an increase in malaria was noted around Butare as early as 1946 [*27*]. In neighbouring Burundi, a country with similar topography and culture, an association between rice cultivation and malaria in the Rusizi Valley was noted in the 1980s [*28*].

The Gikonko Health Centre in southern Rwanda is a well-staffed facility that serves a population of 38,000 people who live at a mean altitude of 1,500 m. Malaria records for the period 1983-1990 show a slow increase in incidence from 1984-1986, followed by a sudden jump in 1987. This dramatic rise—a 501% increase in incidence in the second half of the year—was especially marked among people living at higher elevations. A haematologist, M. E. Loevinsohn, who visited the area after the event, concluded that this sudden change was an example of the "substantial epidemiological effect" of the impact of climatic factors on malaria "that are expected … near or astride the altitude and latitude limits" of its transmission [*29*]. He supported his claim with a regression model that showed an auto-correlation coefficient (incidence *vs*. temperature and rainfall) of 0.89 ($p<0.001$). He ruled out other factors—cessation of control measures, chloroquine resistance, population movement, road construction, rice-cultivation, and the timing of a famine—that could have contributed to transmission.

At first glance, Loevinsohn's conclusions appear persuasive. The Gikonko data are considered unusually reliable, and the coincidence between the sudden jump in incidence and "above normal" warm wet weather in 1987 is striking. However, if the area were truly at the altitudinal "limit" of transmission, we would expect incidence to have declined in 1988 and 1989, when temperatures returned to "normal," and to have increased again in 1990, when it was again nearly 0.5^{0}C warmer than the "norm". In fact, the increased incidence remained stable from 1987 onwards, irrespective of the weather.

Loevinsohn's study is one of the most oft-quoted examples of a link between climate change and transmission, yet an issue that continues to escape mention is that, in the period 1984-88, the World Health Organization (WHO) supervised a complete re-organization of the national disease surveillance system, with special emphasis on malaria. The $1.6 million project involved a redefinition of the list of reportable diseases, an ongoing *in vivo* study system designed to improve reporting of confirmed malaria cases, follow-up supervision to check surveillance data, and a routine of regional feedback letters and graphs. According to those involved in the project (CDC medical entomologists Sexton, R, and Stekete, R., personal communications, and [*30*]), the sudden jump in incidence in 1987 coincided with the implementation of the new surveillance system, and there is no reason to suspect climate as a factor.

Conclusions

These examples clearly underscore the need to avoid simplistic reasoning in seeking to explain the appearance of "new" malaria at high altitude in the tropics. In every case, transmission was well below the local maximum altitudinal limit, and there is no evidence that temperature played any role in the increase of incidence. As in South America [*31*], another important factor was the cessation of house spraying with residual insecticides such as DDT. The other significant variables are all attributable to the population explosion, increased mobility of the population, and major changes in the local ecology as a result of human activities.

Highland malaria serves to illustrate the complexity of the natural history of this and other mosquito-borne diseases, and the manner in which the interplay of climate, ecology, vector biology, human activities and many other factors defy simplistic analysis. The recent resurgence of these diseases is a major cause for concern, but there is no reason to attribute it to "global warming": the principal determinants are politics, economics and human activities. A creative and organized application of resources is urgently required to control these diseases, irrespective of future climate change.

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