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Hot topic or hot air? Climate change and malaria resurgence in East African highlands

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Abstract

Climate has a significant impact on malaria incidence and we have predicted that forecast climate changes might cause some modifications to the present global distribution of malaria close to its present boundaries. However, it is quite another matter to attribute recent resurgences of malaria in the highlands of East Africa to climate change. Analyses of malaria time-series at such sites have shown that malaria incidence has increased in the absence of co-varying changes in climate. We find the widespread increase in resistance of the malaria parasite to drugs and the decrease in vector control activities to be more likely driving forces behind the malaria resurgence.

Plasmodium falciparum malaria takes a life in Africa every 30 seconds [1], and this rate is increasing [2]. Strong evidence has accumulated that the world has warmed by ~0.6°C over the past century [3], with a range of ecological consequences [4]. Many have concluded that the reported malaria increases and the re-emergence of other vector-borne diseases are likely to be the result of these climatic changes [5-10]. On the basis of the sensitivity of vector-borne diseases to climate [11], and using projections of incomplete biological models [12,13], widespread increases in global malaria burden have also been predicted [14-16]. However, there has been considerable dissent by specialists in malaria epidemiology concerning both the cause of recent malaria resurgences [17-20] and to what such climate changes might augur [21,22]. Although reports of malaria increases are not confined to high-

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altitude locations [2], this debate has become focused on the highland regions of Africa [23] because malaria is limited by low temperatures at such elevations [24]; hence, these locations are considered sensitive sentinels to temperature increases. Furthermore, it is often assumed that highland populations are immunologically naive and therefore at particular risk from malaria resurgences [25], although this assumption about the immunity status of highland populations has been questioned [20].

Evidence for possible causes of malaria resurgences

Since the early 1980s, there have been massive percentage increases in *P. falciparum* burden at African highland locations (Fig. 1). Possible causes are discussed below.

Meteorological changes

Although the world appears to have warmed over the past 100 years [3], malaria does not respond to approximated global averages, and the bulk of this warming trend (and precipitation increases) has occurred in the northern and, to a lesser extent, southern temperate and polar latitudes [3,4]. When climatic changes were investigated in the highlands of equatorial Africa [19], the Augmented Dickey Fuller (ADF) test revealed no evidence for significant trends in climate at four highland sites (Kericho, Kabale, Gikonko and Muhanga) contemporary with the malaria resurgences. This was true for mean, minimum and maximum temperatures, as well as for rainfall, vapour pressure and combinations of meteorological variables necessary for malaria transmission [24]. In essence, climate and climate variability had not changed, so could not have caused the malaria resurgences.

Identical ADF analyses have been extended to test the significance of any trends in the meteorological variables at Debre Zeit, Amani and Analaroa (Table 1). In common with the other East African sites [19], Amani revealed no trends in any of the meteorological variables over any time period. By contrast, Debre Zeit and Analaroa exhibited significant warming trends during 1970–1995. Interestingly, these two sites lie at the latitudinal edge of the East African highlands and suffered the greatest increases in malaria (Fig. 1), but even here the malaria resurgence cannot be attributed with any certainty solely to climate change because of concomitant changes in other factors detailed below.

Drug resistance

Chloroquine (CQ) resistance, first reported in East Africa in 1978 among non-immune tourists [26], has now been verified in all tropical African countries [27], where this drug commonly remains the first-line treatment for malaria [28]. Although there is a lack of systematic longitudinal evidence for the onset of resistance and its evolution in populations, there is quantitative information that, during the past two decades, CQ resistance has spread geographically, increased in prevalence within its range, and intensified in its severity of clinical failure (from predominantly RI-type to RII- and RIII-type responses [27,29]). Among the sites we have highlighted, CQ resistance has been identified as an important factor in the malaria resurgence on the Kericho tea estates [30], where climate, the environment, the human population and its structure, health care provision and malaria control measures are known not to have changed [31]. Likewise, the malaria resurgence in the Usambara mountains has been linked to the rise in antimalarial drug resistance [32], rather than previously postulated local climatic changes in Amani [33]. At Gikonko, climate was originally asserted to have caused increases in malaria incidence [34], although the significance of the trends in the temperature variables was not tested, and the case for drug resistance was dismissed on the basis of two local estimates made just one year apart (1986 and 1987) [35], even though malaria resurgence was documented throughout Rwanda. The suggestion that climate change was responsible for epidemics across the highlands of Burundi was supported by only four measures of the mean January temperature, between 1993 and 2001, from one location with no statistical analyses [36]. This was in the face of unequivocal evidence of the importance of CQ resistance in the region [37], whose continued use could have contributed to the widespread epidemic [38]. Only at Debre Zeit does the emergence of CQ resistance sometime after 1992 [39] preclude its being a factor in the malaria increase.

Vector control

Many countries in Africa at one time maintained effective vector-control services. Quantitative indicators of declines in such services are rarely published; however, by chance, massive decreases in previously successful vector-control efforts have been documented at the two sites mentioned above where climate has also changed in the past two decades.

In the Debre Zeit sector, the amount of DDT applied by indoor residual spraying for malaria control decreased from an average of 26 000 kg per annum (1965–1979) to only 4000 kg per annum (1980–1993), coincident with the period of most marked malaria resurgence [39]. The number of houses sprayed and the proportion of the population protected also decreased by a similar magnitude [39].

The history of malaria in the highlands of Madagascar has also been comprehensively described [40]. In 1878, a severe epidemic swept the Madagascan highlands following the extensive development of rice irrigation, and the disease soon became endemic. In 1949, a malaria eradication programme was introduced using DDT spraying in combination with malaria treatment centres. By 1960, the incidence of malaria was massively reduced and spraying was terminated in all but three foci. In 1975, spraying in these foci was also stopped and the treatment centers were closed four years later. Malaria gradually increased over the next decade, culminating in a severe epidemic in 1988. Since 1993, DDT spraying has been re-introduced and has successfully and continually reduced malaria to less than 10% of 1988 levels. Although there have been small, yet significant, increases in temperature (Table 1), the stepwise changes in malaria incidence follow the variation in control activities much more closely.

Health service provision

Little quantitative information exists on the state of public and private health service provision in most sub-Saharan countries, but in East Africa the population served by each hospital bed increased considerably between 1980 and 1990 [41] in all countries except Rwanda, where there was a marginal decrease (Fig. 2a). The situation at specific sites cannot be inferred from these national data, but they do provide evidence of a regional decline in per caput health service provision coincident with many of the malaria resurgences.

Land-use change

Land cover and land use has a significant impact on malaria transmission [42]. The normalized difference vegetation index (NDVI) is a measure of the amount of photosynthetically active vegetation, and is thus a proxy for land cover [43]. Many studies have reported positive associations between the NDVI and malaria incidence [44,45]. Interestingly, during the period of malaria resurgence, most sites have greened by a small amount (<8%), suggesting that conditions might have become marginally more conducive to malaria (Fig. 2b). The exceptions are at Debre Zeit and Analaroa, where decreased NDVI is consistent with local temperature increases. These NDVI data are at too coarse a spatial resolution (8 × 8 km) to indicate the exact nature of the land use changes and serve only to document the overall change in vegetation coverage at each of the sites.

Population growth and urbanization

In each of the East African countries investigated, populations have increased by more than 50% since 1980 (Fig. 2c). Without significant improvements in health care provision (Fig. 2a), malaria will have become harder to treat and control, simply because the susceptible reservoir of humans has expanded. However, the urban proportion has more than doubled since 1980 so that, by the year 2000, 26% of the 65 million East Africans were urban dwellers. This is estimated to increase to 44% by 2030 because virtually all of the population doubling of the region during this time will be concentrated in urban areas [46]. The reduction in malaria risk with increased urbanization is well known [47]. At 159 sites across Africa where annual entomological inoculation rates had been recorded, people in rural areas received on average 146 *P. falciparum*-infected bites per annum, compared with 14 for urban residents [42]. In contrast to the high profile of future climate scenarios, the impact of urbanization trends on the future malaria burden has received too little attention.

The most parsimonious explanation

The evidence that climate change is the most significant factor in recent malaria resurgences in the highlands of East Africa is at best equivocal, at worst unfounded. At five of the seven sites (Kericho, Kabale, Gikonko, Muhanga and Amani), climate has not changed significantly. At the two other sites, where malaria up-surges were most marked (Debre Zeit and Analaroa), temperatures have shown significant long-term increases; however, the collapse of vector control at these sites shows equally good, if not better, matches to changes in malaria incidence, especially at Analaroa where malaria declined again rapidly on the resumption of house spraying. The role of the spread and intensification of antimalarial drug resistance, particularly to CQ, is also particularly persuasive because it explains both increased transmission (increased number of drug-suppressed infections producing gametocytes) and increased severity of the disease (treatment failure owing to lack of affordable, effective drugs). However, it should be emphasized that such changes are occurring against a site-specific background of decreases in vector control, decreasing per caput health service provision, a greening of the landscape and massive increase in population.

Policy considerations

The threat from climate change is not a top priority for African nations faced with a contemporary resurgence in malaria. Our hope is that the research reviewed here might help focus attention on the real and immediate causes of these malaria resurgences, rather than fuel further speculation on the future epidemiological impacts of climate change. Although predictions of the impact of forecast climate surfaces [e.g. the high scenario from the HadCM2 experiment described on the Intergovernmental Panel on Climate Change website (http://ipcc-ddc.cru.uea.ac.uk)] do show parts of the highlands of East Africa and Ethiopia becoming newly suitable for malaria by 2050 [22], reversing, or even delaying, such global climate change will not address the problems faced by Africans at risk from malaria today. By comparison, addressing the need for effective and affordable drug treatments [48] for a disease that is both preventable and treatable offers a direct route by which the international community can act now to save lives.

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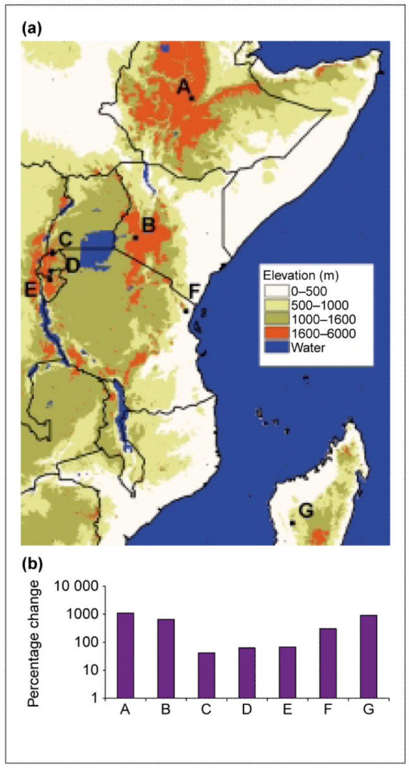

Fig. 1.

(a) A digital elevation model showing reported malaria resurgence in high altitude regions of East Africa: Debre Zeit, Ethiopia (A) (A.N. Tulu, PhD thesis, University of London, 1996); Kericho, Kenya (B) [30,31]; Kabale, Uganda (C) [49,50]; Gikonko, Rwanda (D) [34]; Muhanga, Burundi (E) [51]; Amani, Tanzania (F) [32,33]; and Analaroa, Madagascar (G) [52]. The highland areas surrounding A–E are extensive and the sites are not spatially isolated 'highland' islands. F and G have been included so as to be comprehensive regarding cited reports of malaria resurgences in highland areas. (b) Percentage change of incidence of *Plasmodium falciparum* malaria (1980–2000). Data are for the longest interval that cases were reported during this period. Where possible, a five-year average annual incidence was taken at the temporal extremes of the data.

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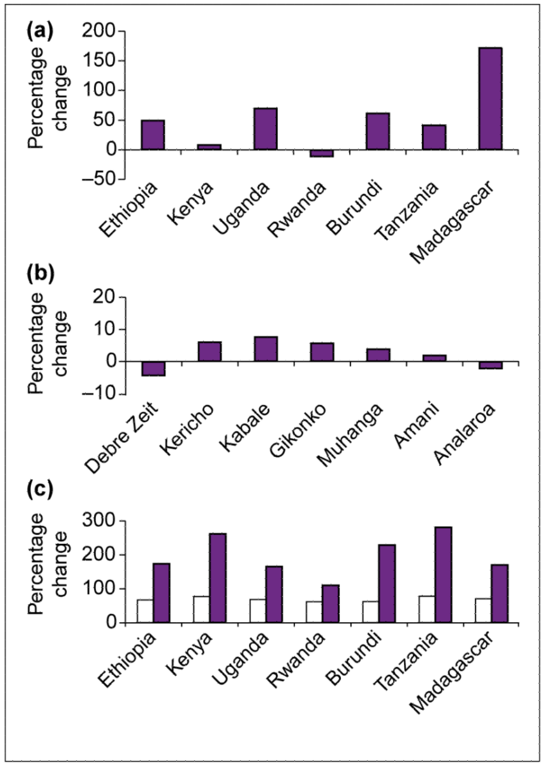

Fig. 2.

(a) The percentage change in population per hospital bed using data for 1980 and for 1990 (the only times available). These data were abstracted from the World Bank Africa Database on CD-ROM [41]. (b) The percentage change in normalized difference vegetation index (NDVI) derived from the Pathfinder AVHRR Land dataset [53]; the 1981–1985 average is compared with the 1996–2000 average for each site. (c) The percentage change in the human population – total (open bars) and urban (solid bars) – between 1980 and 2000, also abstracted from the World Bank Africa Database on CD-ROM [41].

Table 1

Trend of monthly meteorological variables at three sites in the highlands of East Africa, 1970–1995[a]

	p	ADF	β	t	p-value	τ α	Q	Sig. Q
Debre Zeit, central Ethiopia (8.75 N, 38.99 E; 1490–2200 m)[b]								
Temp min. (°C)	1	**− 6.73** °	0.0133	**2.43**	0.0156	0.0035	22.5240	0.9611
Temp mean (°C)	2	**−5.02**	0.0108	**2.57**	0.0106	0.1532	28.9200	0.7929
Temp max. (°C)	1	**−8.20**	0.0202	**3.17**	0.0017	0.1179	33.4282	0.5915
Rainfall (mm)	2	**−11.13**	0.0603	0.23	0.8209	−0.0645	37.6854	0.3921
Vapour pressure (hPa)	1	**−6.52**	0.0102	**2.44**	0.0155	0.0029	24.6356	0.9240
Amani, north–east Tanzania (5.10 S, 38.63 E, 600–1000 m)[b]								
	p	**ADF**	**β**	**t**	**p–value**	**τ α**	**Q**	**Sig. Q**
Temp min. (°C)	4	**−3.51**	0.0032	0.99	0.3223	−0.1605	44.0236	0.1684
Temp mean (°C)	2	**−5.95**	0.0031	1.01	0.3156	−0.0712	49.0893	0.0716
Temp max. (°C)	1	**−8.41**	−0.0012	−0.28	0.7782	0.0024	56.8429	0.0149
Rainfall (mm)	6	**−5.21**	0.3319	0.65	0.5141	0.1973	50.8691	0.0513
Vapour pressure (hPa)	4	**−3.59**	0.0499	1.01	0.3159	−0.1575	42.8075	0.2021
Analaroa, central plateau Madagascar (18.85 S, 45.49 E, 1500 m)[b]								
	p	**ADF**	**β**	**t**	**p–value**	**τ α**	**Q**	**Sig. Q**
Temp min. (°C)	2	**−7.22**	0.0058	1.47	0.1433	−0.1166	61.0848	0.0056
Temp mean (°C)	1	**−8.31**	0.0087	**2.49**	0.0133	−0.0215	67.5492	0.0011
Temp max. (°°C)	6	**−4.63**	0.0121	**2.77**	0.0060	−0.0226	42.6762	0.2060
Rainfall (mm)	1	**−13.31**	0.0262	0.09	0.9288	−0.1257	46.7825	0.1077
Vapour pressure (hPa)	2	**−7.18**	0.0092	1.67	0.0961	−0.1478	56.0451	0.0177

[a]Methodological and statistical details for these tests follow the methods outlined in Ref. [19]. p is the number of lagged differenced dependent variables selected. ADF is the Augmented Dickey Fuller *t* test for $\gamma = 0$. The 5% critical value is −3.45. Exact p-values are not available for the ADF and $\tau\alpha$ statistics. The distribution of the t-statistic for the slope parameter β has the standard t distribution under the assumption that $\gamma < 0$. $\tau\alpha$ is the t-statistic for the intercept term in the autoregression without a linear time trend. This is the appropriate test for a trend if $\gamma = 0$. Its 5% critical value is 2.54. The Q statistic is a Portmanteau test for general serial correlation and is distributed as Chi-square. The significance is shown in the final column (Sig. Q). Figures in bold denote significance at the 5% level.

[b]Information in brackets corresponds to the geo-location and elevation range information details for each site.