Short Review
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East African Highland Malaria Resurgence Independent of Climate Change

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It is estimated that *Plasmodium falciparum* malaria takes a life every 30 s[1,2]. Most of these deaths are in the under 5-year-old population of sub-Saharan Africa (SSA). In addition to this massive mortality, an estimated 300–500 million fevers per annum cause untold misery and an economic impact globally that is only now being estimated[3]. Unbelievably, there is considerable evidence that even this dire situation is deteriorating, as many parts of SSA have documented considerable malaria resurgences in the last 2 decades[4,5]. In parallel, global attention has also been focused on the impact on our climate system of the exponential increase in energy consumption of the human population. The scientific community is now of the majority opinion that our world has warmed by approximately 0.6°C over the past century, probably due to human activities[6]. These two developments have fuelled the notion that reported increases in malaria (as well as other diseases) are a direct result of global temperature increases[7,8,9,10,11]

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although many have questioned these interpretations[4,12,13]. Such speculation has been particularly intense for highland areas where malaria transmission is classically thought to be limited by low temperatures[14]. These ideas, however, have not been tested scientifically.

There has been surprisingly little primary research directed at the impact of climate change on infectious disease epidemiology. A substantial amount of the published literature consists of reviews of the incontrovertible evidence that infectious diseases are influenced by meteorological factors and are thus potentially susceptible to the influence of climate change[8,15]. Many have gone an important step further, however, and asserted that these changes are already manifest[7,10]. It is this position that is challenged by some recent work (see below). Particularly worrying among these developments are proclamations from bodies such as the Intergovernmental Panel on Climate Change (IPCC)[16]; for example:

> "Many vector-, food-, and water-borne infectious diseases are known to be sensitive to changes in climatic conditions. From the results of most predictive model studies, there is *medium to high confidence*[a] that, under climate change scenarios, there would be a net increase in the geographic range of potential transmission of malaria and dengue, two vector-borne infections each of which currently impinge on 40–50% of the world population[b]. Within their present ranges, these and many other infectious diseases would tend to increase in incidence and seasonality, although regional decreases would occur in some infectious diseases. In all cases, however, actual disease occurrence is strongly influenced by local environmental conditions, socioeconomic circumstances, and public health infrastructure."

The reason for including footnote "b" is that seven vs. one study might constitute an overwhelming majority opinion, if these seven studies were independent and each showed novel results. In fact most are by the same author using the same technique. Concerns about the impact of such statements on policy makers were part of the impetus for the following study, recently published in *Nature*[19], in which evidence was sought to link definitively local climate change to increased malaria incidence.

This study looked in detail at four highland sites (>1500 m) in East Africa (Kenya[20,21,22], Uganda[23,24], Rwanda[25], and Burundi[26]) where malaria resurgences had been reported in the last 2 decades. The Augmented-Dickey Fuller[27,28,29] statistical test revealed no evidence for significant trends in climate[30,31] at these highland sites, either over the last century or during the last 2 decades contemporary with the malaria resurgence. This was true for mean, minimum, and maximum temperatures, as well as rainfall, vapor pressure, and combinations of meteorological variables suitable for malaria transmission. Instead, temperature and rainfall have fluctuated over the past century, with considerable spatial heterogeneity across East Africa. Such temporal and spatial variation disrupts any simple relationship between longer-term epidemiological patterns and climate. Alternative explanations for these resurgences might be found in the massive increase in population, the precipitous rise of chloroquine resistance and the lack of capacity in vector control services, although none of these were tested explicitly.

These findings are consistent with recent meteorological work that found marked and variable trends in climate across East Africa[32]. Further work that has analyzed climate variability trends by determining the statistical distributions of climatic indices commonly used for measuring climate change[33] found none of the following quantities to have displayed significant trends in variability during the last century: sea level, annual precipitation amount, drought severity, monsoon rainfall, or the El Niño Southern Oscillation.

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[a] High is a 67–95% chance and medium a 33–67% chance.

[b] Eight studies have modeled the effects of climate change on these diseases, five on malaria and three on dengue. Seven use a biological, or processed-based approach[17], and one uses a statistical approach[18]. (Additional referencing is our own.)

Our hope is that this research may help focus attention back to the real and immediate causes of these malaria resurgences, rather than fuel further speculation on the future impact of climate change. Reversing, even delaying, global climate change seems an intractable problem for the global community in the short term. By comparison, addressing the need for effective and affordable drug treatments for a disease that is both preventable and treatable should not be so complex. The fact that drug resistance rather than climate change is among the more probable causes for recent malaria resurgence means that we have a route by which the international community can act.

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