

## Is Global Warming likely to cause an increased incidence of Malaria?

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**Abstract:** The rise in the average temperature of earth has been described as global warming which is mainly attributed to the increasing phenomenon of the greenhouse effect. It is believed that global warming can have several harmful effects on human health, both directly and indirectly. Since malaria is greatly influenced by climatic conditions because of its direct relationship with the mosquito population, it is widely assumed that its incidence is likely to increase in a future warmer world .

This review article discusses the two contradictory views regarding the association of global warming with an increased incidence of malaria. On one hand, there are many who believe that there is a strong association between the recent increase in malaria incidence and global warming. They predict that as global warming continues, malaria is set to spread in locations where previously it was limited, due to cooler climate. On the other hand, several theories have been put forward which are quite contrary to this prediction. There are multiple other factors which are accountable for the recent upsurge of malaria: for example drug resistance, mosquito control programs, public health facilities, and living standards.

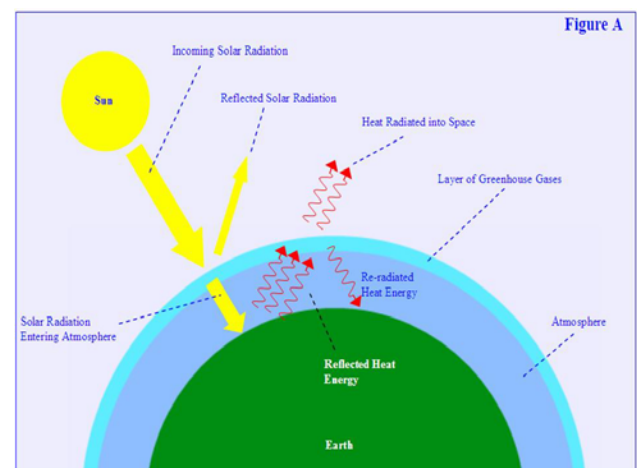
**Key words:** *Malaria, Global warming, Greenhouse effect, Drug resistance, Control program.*

Global warming is the increase in average temperature around the world. Now it has been proven without any doubt that the temperature of the earth is rising. According to the Intergovernmental Panel on Climate Change (IPCC) report, 2001, the average global air temperature has increased 0.6 degrees centigrade (10 Fahrenheit) since 1861. They predict that it will rise by another 1.4 to 5.8 degrees centigrade by the year 2100 [1]. From a public health viewpoint, this rise in temperature is of great significance. Though global warming is a gradual process, it threatens to have serious consequences over time [2]. Some of the ill effects are quite obvious and agreed upon by nearly everyone in the field. Examples are the rise in sea level, flooding, change in global rain patterns, change in food production, and the direct effects of heat on health [3]. However there are some areas that are quite controversial and strongly debated. One of them is the likelihood of an increase in the incidence of vector-borne diseases, namely malaria, in response to increasing global temperature and climate changes.

### Global warming and the greenhouse effect

The greenhouse effect is a natural phenomenon and important for maintaining a constant temperature on the planet Earth. A layer of gases, known as the greenhouse gases, are present in the Earth's atmosphere. These include water vapours, carbon dioxide, methane, and ozone. Sunlight reaches earth by passing through the atmosphere. It is composed of a range of energies which are known as the solar spectrum. From this spectrum much of the radiation is reflected back into space from the clouds and other atmospheric particles, while some is absorbed into the atmosphere. About 50% of the sun's energy, mostly in the form of visible light, reaches the surface of Earth. Some of this energy changes to infrared heat and is reflected back into the atmosphere. The majority of this radiation goes back into space, while some is trapped within the atmosphere because of the surrounding greenhouse gasses [4,5]. These trapped infrared radiations play an important role in maintaining a constant temperature (apart from the seasonal variability)

necessary for the propagation and continuation of all living things in a sustainable environment (Figure 1). The amount of heat trapped is dependent upon the amount of greenhouse gasses in the atmosphere. Due to industrial expansion in recent years, and other human activities like deforestation and burning of fossil fuels, there has been an increase in the concentration of carbon dioxide and other greenhouse gases. This change in the concentration of greenhouse gases has led to an increased entrapment of solar radiation within the atmosphere, causing an overall increase in global temperature [4,5] (Figure 2). As human industrial activities and burning of fossil fuel continues, the temperature of earth continues to rise. Many scientists believe that this continual rise in temperature may have direct consequences for all living beings, including the humans [1].

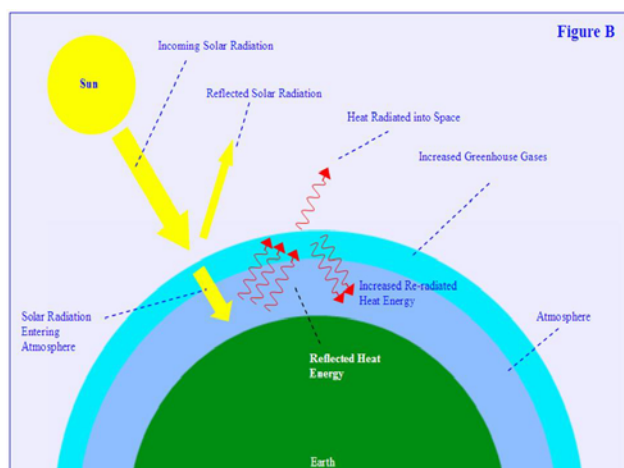


**Figure 1** Normal greenhouse effect responsible for maintaining constant temperature on earth.

### Effects of global warming

There has been much speculation and forecasting regarding the impact of global warming upon our future. Since it is a very slow process with a wide range of implications, there is no straightforward answer. Some of these speculations are already becoming reality, like the

melting of polar ice caps and glaciers, rising sea levels, changing weather systems, and climate changes [6]. There also have been reports of freshwater shortages, coral reef bleaching, and an increase in surface temperatures [7]. Patz and Kovats have identified six major areas of concern to human health in response to this ongoing climate change. They call these the "hotspots in climate change and human health" Their list includes heat waves, rise in sea levels, flooding, drought, malnutrition, El Nino effects, and highland malaria [8]. Most of the above mentioned effects are a result of the direct consequences of global warming, however, there are some indirect effects of global warming as well, which are not always obvious but still worth mentioning and potentially very serious. At the top of this list is the prediction by some scientists and epidemiologists that due to the rising global temperature, more areas of the world will become favourable for the survival of tropical insects like mosquitoes. This could lead to the spread of these insects towards more northern and southern hemispheres and to higher altitudes. Some species of mosquito act as disease vectors and are responsible for the spread of illnesses like malaria, Dengue fever, and Yellow fever. Hence, global warming can increase the incidence of these diseases [7].



**Figure 2** Increased greenhouse effect due to increase in greenhouse gases leading to global warming

### Epidemiology of Malaria

The epidemiology of malaria is very complex and multi-focal. It depends upon the ecology of the prevalent main vector species, the biology of the causative organism that is plasmodium, the resistance and immunity of the host, and last but not least, climate factors such as temperature, rainfall, and humidity. Malaria is an infectious disease caused by a unicellular organism known as plasmodium, which enters the human body through a mosquito bite [9,10]. Not all mosquitoes are capable of transmitting this disease. Mostly it is the female Anopheles mosquito, which becomes infected by plasmodium when it bites an infected human. These plasmodia then enter the salivary glands of the mosquito where they develop and are then ready to enter an uninfected human when the mosquito bites again. It is endemic in warmer climate regions of the world including Asia, Africa, Central and South America and certain Caribbean Islands. The disease is characterized by high-grade fever with rigors and chills, excessive sweating, anaemia and extreme exhaustion.

There are different species of the organism plasmodium. A certain species called plasmodium falciparum can lead to a dangerous condition called cerebral malaria which can be fatal unless treated promptly [9,10]. According to the WHO, malaria causes more than a million deaths annually, most of them in Africa and other tropical regions.

### Relationship of malaria with temperature and climate

One of the important reasons for this high incidence in tropical regions is the suitable climate and temperature, necessary for the development and survival of both mosquitoes as well as the parasite plasmodium. It is obvious that malaria cannot occur in the climates where mosquitoes do not survive. For the optimal development of Anopheles mosquitoes, the temperatures should be around 20 to 30 degrees centigrade. In addition, other factors necessary for mosquito development are high humidity, small stagnant pools of water, and availability of food [2]. The surrounding temperature also affects the development of plasmodium within the mosquito and it decreases with increasing temperature. However in colder conditions, this development time can exceed the total life span of a mosquito [7]. Therefore the total life span of the mosquito is very important; it shortens with very high temperatures [11]. Apart from the seasonal variability, the daily maximum and minimum temperatures are also important for the development of plasmodium within the mosquito. Other climatic factors that are important include the fact that mosquitoes tend to flourish in areas with high humidity and ample rainfall. The above effects of temperature and climate on malaria have led many to believe that global warming will result in the spread of this disease, possibly to areas where previously it did not exist. The recent increase in malaria incidence in east African highlands and some Asian and South American countries has been attributed to global warming [7]. Nevertheless there are many other factors that might account for the increased incidence of malaria. It is very difficult to estimate the effects of temperature on malaria, and to forecast the future impact of global warming due to the complex epidemiology of the disease and other factors associated with it.

### Global warming will increase malaria!

#### What evidence supports this?

Significant numbers of studies correlate the recent increase in the incidence of malaria to global warming. While there is no clear-cut evidence in support of this view, many studies do point towards a positive correlation between global warming and malaria.

### Relationship of El Nino with Malaria

There are many climatic fluctuations which have been occurring naturally for long periods of time. An example is El Nino, occurring irregularly every two to seven years, and lasting 12 to 18 months. There is evidence that these natural climatic fluctuations have intensified in magnitude during the last three decades due to global warming. This and the fact that El- Nino events are responsible for increased incidence of malaria also leads to the conclusion that global warming will result in an overall increased incidence of malaria [7]. El Nino is characterised by a change in wind direction due to a low pressure over the eastern Pacific Ocean and Indonesia. This results in a change of atmospheric temperature and precipitation, and

a rise in sea level temperature of more than 0.5 degrees centigrade across the central tropical Pacific Ocean [4]. There have been reports of an increase in the incidence of certain infectious diseases during the El Nino events. Malaria upsurge in many areas is also correlated to El-Nino events and there have been cases of intensified endemic and epidemic malaria in Pakistan, Sri Lanka, Colombia, Venezuela and Peru following an El Nino event [7].

#### **Prediction of malaria with the help of mathematical models**

A retrospective study was conducted in the highlands of Madagascar of both temperature trends and malaria incidence. There was an increased incidence of malaria in this region from 1987 to 1989 including the great epidemic in 1987-88, with an estimated mortality somewhere between 30,000 and 300,000. In this particular study, a time series analysis was done to examine the relationship of temperature records during this period upon the incidence of malaria. The results were quite interesting. Though there was no clear relationship of average yearly temperature with malaria, there was an apparent association with minimum temperatures during December and January as a result of an increased incidence in malaria the proceeding year. A rise in minimum temperature of 1 degree centigrade, from 15.5 to 16.5 degrees centigrade could account for 24 additional cases per 1000 of population. This point highlights the association between malaria and climate cannot be disregarded easily and deserves further investigation [12]. Another model known as the compartment model was used to see the effects of global warming and socio-economic conditions on malaria incidence simultaneously. The results showed that temperature does play an important role in malaria transmission. The effects of global warming on malaria will be a major challenge, however the effects of social and environmental factors were considerably higher than that of temperature alone [13]. Many other mathematical models have made similar forecasts regarding the future of malaria. Apart from the direct effects of temperature on the mosquitoes, floods and droughts, which might result due to global warming, will also have some favourable effects on mosquito population by creating new breeding grounds for these insects [2]. Some of the models have projected an increase in the zone of potential malaria transmission from an area containing 45% of the world's population to an area containing about 60% by the end of 21st century [15].

#### **Historical and current evidence**

Examining the history of malaria in Britain, a total of 8,209 deaths due to malaria were reported between 1840 and 1910. All these deaths showed a positive relationship with the mean temperature, in land water coverage and total precipitation. It was calculated that an increase or decrease of 1 degree centigrade was responsible for an increase or decrease in malaria deaths of 8.3% and 6.5% respectively. Assuming that the impact of temperature would proportionally be the same, and that global warming continues at the same pace, by the year 2050 there could be an increased risk of malaria transmission in the United Kingdom by 8-15% [14].

There have been reports of a recent increase in malaria incidence in many parts of the world including the USA, Korean Peninsula, parts of Southern Europe and the former Soviet Union. These outbreaks of malaria have been linked to increasing average temperatures favouring the predictions that global warming will lead to a further increase in malaria incidence [15].

#### **Global warming will increase malaria: Why do many disagree?**

Many scientists and epidemiologists do not agree with the fact that global warming will increase in the incidence of malaria. They have some strong arguments against this theory and many studies have supported their viewpoint.

#### **The History of Malaria: Why did malaria disappear from Europe and USA?**

Looking at the history of malaria, there is evidence that it dates back to more than 10,000 years BC, in the Neolithic era. This is the period in human history when there was a transition from the Stone Age to the early beginning of farming and tool making. Around 7000 BC, the ancient Greeks and Romans introduced proper agricultural methods, which led to increasingly favourable conditions for the development of mosquitoes. The first literary mention of malaria dates to about 900 BC. The famous ancient Greek physician Hippocrates (460-377 B.C) was the first to give a detailed description of malaria and its association with the wetlands. In the Middle Ages, there was a warming period in the world, which peaked in 1200 A.D. This was a time of significant technological and agricultural advancement especially in Europe. However, this time period also accounts for the spread of malaria in this continent going as far north as Scandinavia. Even through the cooler periods of the 16th and 17th centuries, known as the little ice age, malaria persisted throughout Europe [16]. In Britain, the historical records show that malaria caused a high level of mortality between the 15th to 19th centuries [14]. The major decline of malaria in Europe started in the second half of the 19th Century, which cannot be attributed to climate change since it occurred during a warming phase of the continent. The factors that have been described for this drastic change are improved drainage and reclamation of swampy lands for cultivation, an increase in farm animals thus driving mosquitoes away from feeding on the humans, changes in demographics and living conditions, and an improvement in housing. Other important factors were improvements in medical care, availability of anti-malarial drugs, and deliberate control of mosquitoes. Another interesting thing to note is that while malaria was declining in much of Europe, it persisted in many parts of Russia in the same latitudes having similar climatic conditions, the only difference being the development in agriculture, housing, and public health facilities [16].

In the USA, mosquito borne diseases were a major public health problem. From the 1600s to mid 1900s malaria was endemic, with occasional epidemics. By the middle of the 20th century, malaria disappeared from the country along with the other mosquito borne diseases like Dengue and Yellow fever. This decline was attributed to over all improvements in living conditions and better public health measures [11]. All of the above examples show that malaria was not limited solely by environmental

factors and it was once prevalent in the cooler regions of the world as well.

### **Upsurge of malaria in Africa: Is global warming to be blamed?**

There has been an increase in the incidence of malaria in many parts of the world during the last decade, especially in the African continent. This has been attributed to a variety of changes, including global warming. In the highland tea estates of Kenya, malaria has returned after an absence of nearly 30 years, where previously it had a very low incidence due to unfavourable climatic conditions for the malaria vector. It was investigated whether global warming could be blamed. The meteorological data from 1966 to 1995 of the mean monthly temperature and total monthly rainfall showed no significant changes. Even when evaluated from a wider perspective of mean, maximum, and minimum monthly temperatures, precipitation and vapour pressure, no significant change could be demonstrated. These results did not support the widespread speculation that changing climate and increasing temperature are responsible for the malaria resurgence [17]. Other studies have been conducted in the east African highlands for the malaria resurgence in the region. All the plausible causes were considered and investigated but no significant correlation could be made between the rising incidence of malaria and changes in climate [18,19].

A mathematical model called as the fuzzy logic climate model was used to see the future trends of malaria in the African continent. It assessed the climate suitability of the coming years for malaria transmission and showed a reduction in the climate suitability for malaria transmission in most of the continent during the period of the next 30 years. However, later in the century, an increase in the climatic potential for malaria transmission was seen in some densely populated highland areas and the Horn of Africa [20].

Other arguments and evidence against the theory

Many other arguments and evidence go against the theory of the increased incidence of malaria due to global warming. The main disagreement is that most of the predictions have been made considering one or at most two climatic factors. They have not taken into consideration other more significant factors in the recent upsurge of malaria, such as the resistance to drugs and failure of mosquito control programs. The models, which are used to predict the future of malaria, do not even show an accurate picture of the current malaria situation [20]. Even the future of the climate is not certain and there is a possibility that some of the locations, which currently have a high incidence of malaria, will become less favourable for mosquito development due to global warming and climate changes. On the other hand, areas which are currently not suitable for malaria transmission might become more favourable for mosquito development and malaria transmission. So the overall incidence of malaria can remain the same but there could be a shift in the geographical distribution [21].

### **How do we explain the recent upsurge of malaria?**

The next important question to address is that if global warming is not the cause of the recent trends of increasing malaria incidence, then what is the true cause?

The answer to this question is not that simple and may be different in different locations. This is because of the complex epidemiology of the malarial parasite and vector and its relationship to the host and environment. Many plausible causes have been explained. The important ones are discussed below:

#### **1. Resistance to drugs**

Resistance to the chloroquine, which is the front line treatment of malaria, is one of the major reasons of malaria resurgence in many parts of the world, especially in the tropical African countries. It was first reported in 1978 in the East African states. Chloroquine resistance has been identified as an important factor for the resurgence of malaria in Kericho tea states of Africa, where other factors like climate, human population, health care provision, and mosquito control measures remained unchanged [17,19,20].

#### **2. Poor vector control**

Malaria cannot spread without mosquitoes. Therefore mosquito control is one of the best measures for malaria eradication. Many countries in Africa had an effective vector control program. There has been a massive decrease in these control efforts resulting in an increase in the mosquito population of that area. The history of malaria in Madagascar proves this point further. In 1878 there was a severe epidemic of malaria in Madagascar. A massive Malaria eradication program was launched there in 1949, which introduced the use of DDT for mosquito control in addition to malaria treatment centres. There was an enormous reduction in malaria by the year 1960. The process of spraying started to slow down, and by 1975, it was completely stopped and even the treatment centres were closed because of the very low malaria incidence. Four years later, malaria started to increase again. It continued to increase over the next decade and there was a severe epidemic in 1988. DDT spraying was re-introduced in 1993 and has been continued, reducing the malaria incidence to 10% of the 1988 levels [19].

#### **3. Provision of health services**

Health care provision is an important factor for determining the overall health of a community, especially when it comes to the control of infectious diseases. Although there is not much quantitative data available on health services in many parts of malaria resurgence, there is sufficient information that the population served by each hospital bed has increased over the past few decades in many parts of Africa. It was also observed that the regional decline in per capita health provision was coincident with a re-emergence of malaria in many of these regions [19].

#### **4. Change in the land use**

Land uses also affects malaria transmission. Mosquitoes tend to occur in wetlands, marshy areas, and areas with thick vegetation. Land covered with vegetations is shown to be directly related to malaria incidence, as mosquitoes tend to flourish in such areas. With the expansion of villages and towns, deforestation, and building of dams,



human populations have come closer to the wilderness, resulting in close proximity to mosquito breeding grounds [22]. It has also been shown that many sites of malaria resurgence have become slightly greener due to increasing vegetations [19].

### 5. Population growth and migration

An increase in population results in an increase in the susceptible human reservoirs. If there is no simultaneous improvement in health care facilities and living standards, it will lead to an increase in the incidence of malaria. This has been the case in many of the east African countries that have shown increased malaria incidence along with simultaneous increases in population of more than 50% since 1980 [19].

Migration and human travel is also one of the factors, which can result in the spread of malaria from one area to another. If a person with malaria travels to another area of unstable malaria transmission, he can transmit the disease to the local population who will have a very low immunity to the disease. This is one of the reasons for the spread of the disease to higher altitudes in Africa. Because of easy and frequent travelling between the continents, malaria cases have reached many European countries and the USA in recent years [11]. However, for the disease to prosper, there have to be suitable local conditions in the area where it has migrated to, for example poor health facilities, abundance of the mosquito vector, and poor living standards. Since this is not the case, malaria has not been able to progress in these developed countries [11,23].

### Lessons to be taken seriously

The relationship between climate and malaria is a complex one and will be very different according to location. There is no denying the fact that malaria transmission is related to climate and temperature. The disease vector and the causative organisms are both dependant upon these factors. However there are many more aspects to the disease, which cannot be ignored and play a vital role in its incidence. Therefore a prediction about the future of malaria in the entire world cannot be made based on projections derived from some locations and considering only a few of the parameters. Besides, most of the recent malaria resurgence can be explained by reasons other than the climatic changes.

### Conclusion

Global warming alone will not be of a great significance in the upsurge of malaria unless it is accompanied by a deterioration in other parameters like public health facilities, resistance to antimalarial drugs, decreased mosquito control measures, population growth and migration trends.

It is very difficult to estimate what the other factors will be like in the future and therefore no accurate prediction about malaria can truly be made.

As public health workers, it would be more justifiable for us to exert our efforts on these other parameters for the eradication and control of malaria.

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