Climate change and malaria in India

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The focus in this paper is to understand the likely influence of climate change on vector production and malaria transmission in India. A set of transmission windows typical to India have been developed, in terms of different temperature ranges for a particular range of relative humidity, by analysing the present climate trends and corresponding malaria incidences. Using these transmission window criteria, the most endemic malarious regions emerge as the central and eastern Indian regions of the country covering Madhya Pradesh, Jharkhand, Chhatisgarh, Orissa, West Bengal and Assam in the current climate conditions. Applying the same criteria under the future climate change conditions (results of HadRM2 using 1S92a scenario) in 2050s, it is projected that malaria is likely to persist in Orissa, West Bengal and southern parts of Assam, bordering north of West Bengal. However, it may shift from the central Indian region to the south western coastal states of Maharashtra, Karnataka and Kerala. Also the northern states, including Himachal Pradesh and Arunachal Pradesh, Nagaland, Manipur and Mizoram in the northeast may become malaria prone. The duration of the transmission windows is likely to widen in northern and western states and shorten in the southern states. The extent of vulnerability due to malaria depends on the prevailing socio-economic conditions. The increase or decrease in vulnerability due to climate change in the 2050s will therefore depend on the developmental path followed by India. Therefore it is important to understand the current adaptation mechanisms and improve the coping capacities of the vulnerable section of the population by helping to enhance their accessibility to health services, improved surveillance and forecasting technologies.

Keywords: Climate determinants, malaria incidence, *P. falciparum*, *P. vivax*, transmission window, vector.

CLIMATE signals observed over India in the last 100 years show an increasing trend in surface temperature by 0.3°C, a change in the spatial pattern of rainfall with respect to normal and occurrence of more intense and frequent extreme temperature, rainfall and cyclone events[1]. As a result, there is a growing concern about the changing pattern of some of the diseases over the years, across India that are directly influenced by the variable climate. Malaria, a vector-borne disease, falls under this category and is the focus of our study. It is endemic in all parts of India (Figure 1), except at elevations above 1800 m and in some coastal areas[2,3]. The principal vectors, which cause malaria in most parts of India, are the *An. culicifacies* – a rural vector, *An. stephensi* – an urban vector and *An. fluviatilis* a resident of hilly-forested areas. Periodic epidemics of malaria occur every five to seven years[2,4]. As recent as in the year 1998, about 20,000 people and an estimated 577,000 DALYs (disability-adjusted life years) were lost due to malaria in India[5].

Climate projections developed for India for the 2050s[1], using the regional model HadRM2 (see note 1) run on the IS92a (see note 2) emission scenario, indicate an increase in average temperature by 2–4°C during that period, an overall decrease in the number of rainy days by more than 15 days in western and central India and an increase by 5–10 days near foothills of Himalayas and in northeast India. The projections also indicate an overall increase in

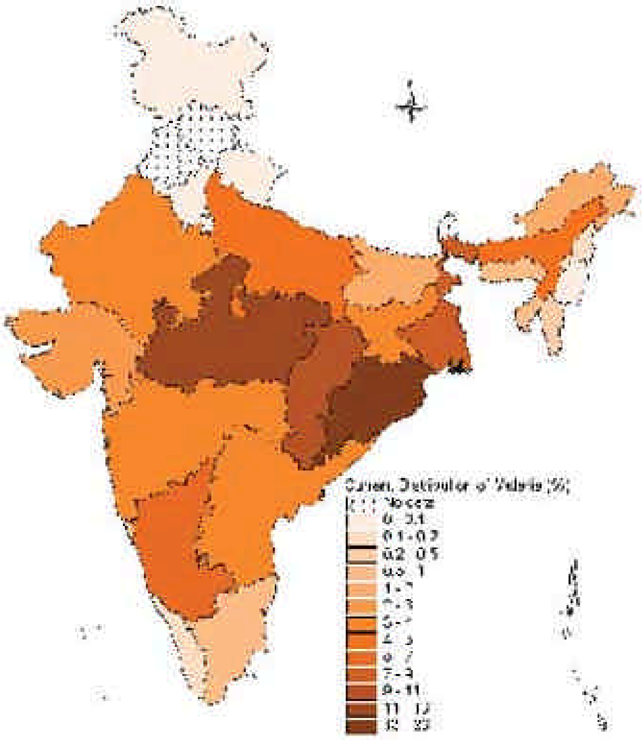

Figure 1. Status of malaria in India in terms of percentage of population generally affected by malaria in different states. Source: The X Plan, Planning Commission, 2002.

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*For correspondence. (e-mail: sumana@winrockindia.org) the rainy day intensity by 1–4 mm/day except for small areas in northwest India where the rainfall intensities may decrease by 1 mm/day. Such changes in the climate may affect vector-borne disease in several ways, namely, their survival and reproduction rates; the intensity and temporal pattern of vector activity; and the rates of development, survival and reproduction of pathogens within vectors[6,7].

Considering the present endemic nature of malaria in India, this study focuses on an assessment of the climate determinants governing malaria transmission in India and makes an attempt to assess the likely extent of malarial activity in the event of the projected climate change in the future.

Climate determinants and malaria in India

For most *Anopheles* vector species of malaria, the optimal temperature range for their development lies[8] within 20°C to 30°C. However, transmission of *P. vivax* requires a minimum average temperature of 15°C and transmission by *P. falciparum*, requires a minimum temperature of 19°C. The transmission window in terms of the temperature range should extend over a period of time for completion of the sporogeny[9]. Malarial survival is also dependent on the time of the year, i.e. the wet or dry season[10]. However, no clear relationship has been observed between the positive malaria cases and the annual precipitation[11,12]. Some actually contend that the amount of rainfall may be secondary in its effects on malaria to the number of rainy days or the degree of wetness that exists after a rain event. Also, if the average monthly relative humidity is below 55 per cent[13] and above 80 per cent[14] the life span of the mosquito gets so shortened that the scope of malaria transmission diminishes.

Positive cases of malaria are reported throughout the year in India[2,4], as a right combination of average temperature, rainfall and precipitation conditions persists across the country over all the seasons in some part or the other. To establish the conditions conducive to malaria transmission, the all India 30-year average monthly temperature, relative humidity and precipitation covering the period 1970 to 2000 taken from various IMD publications were plotted against the average all India monthly malarial cases reported for the same period[2,4] (Figure 2). It is noted that the average relative humidity range (55 to 80 per cent) remains conducive to malaria transmission, only between the months of May to October, which coincides with the maximum number of positive malarial cases reported during this period. Meanwhile, the average temperature remains between the range of 15 to 30°C throughout the year, i.e. from January to December, which falls within the temperature transmission window of malaria. Though only during May to October a substantial amount of rainfall is recorded, but the malarial cases still persist in the months when the average rainfall is almost nil. This further strengthens the observations of researchers cited earlier in this paper, that rainfall and numbers of malaria cases do not have a direct correlation.

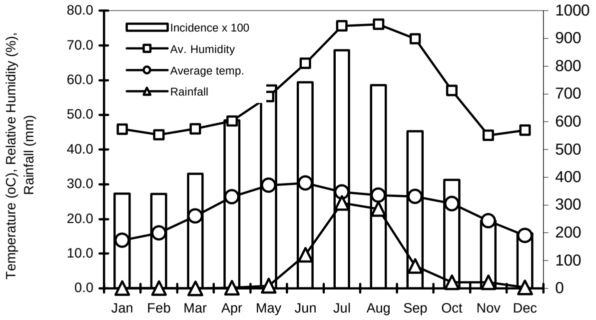

Figure 2. Trends of average monthly temperature, precipitation, relative humidity and malaria cases in India between the period 1970 and 2000.

Though the broad malaria transmission window in terms of temperature is between 15 and 40°C, the number of days required for a vector to complete its cycle varies according to the number of days a particular range of temperature persists provided the relative humidity remains conducive. For example, it has been observed in India, that the *P. vivax* vector requires 15 to 25 days to complete its cycle if the temperature remains within 15°C to 20°C, and its life cycle may get completed even within 6 to 10 days, if the temperature range remains within 25°C to 30°C[15]. In both the cases the relative humidity remains within 55 to 80 per cent. Considering this as a lead, an attempt was made to extract the number of days when positive malarial cases reported within a particular temperature range and relative humidity. This was done by simultaneously scanning daily values of temperature, humidity and the reported *P. falciparum* and *P. vivax* cases for the period May to October when the average relative humidity on a national level remains within 55 to 80 per cent. The analysis was carried out for the period 1995 to 2000.

It was identified that for *P. vivax*, on average, the humidity levels remained between 55 and 80 per cent in the May to October period for 15 to 20 days when the temperature fluctuated between 15 and 20°C; for 10 to 20 days when the temperature fluctuated between 20 and 25°C and for 6 to 10 days when the temperature fluctuated between 25 to 30°C. Similarly, for *P. falciparum* the humidity remained between 55 and 80 per cent when the temperature varied between 20 and 25°C for 20 to 30 days, between 25 and 30°C for 15 to 25 days and between 30 and 35°C between 8 and 12 days respectively. These temperature ranges for *P. falciparum* and *P. vivax* are classified as class I, II and III respectively (Table 1), and it is clear that while moving from class I through III, as the absolute value of temperature increases, the number of days that the temperature remains within each range decreases, therefore the time for which the vector thrives also decreases with increase in temperature. This conclusion is likely to have a significant effect under the projected climate change scenario for India when the temperatures are to increase by 2–4°C with respect to the current climate.

The next exercise done was to apply the class I, II and III criteria of temperature to the daily weather generated by HadRM2 control climate scenario for the period 1980 to 2000. We observe that repeatedly, the class I, II and III criteria are satisfied in the states of Madhya Pradesh, Chhatisgarh, Jharkhand, Orissa, West Bengal and Assam (Figure 3), proving that these states are the most endemic regions of malaria in India. Comparing this with Figure 1, these very states coincide with the ones where maximum number of population is affected by malaria in India.

A large number of studies also relate El Niño Southern Oscillation (ENSO) (see note 3) to malaria epidemics[16–18]. Our analysis for the period 1961–1998 at the national level indicates that if the number of incidences in a particular year is less than the decadal average, then for that year incidences are influenced by La-Nina (see note 4). On the other hand, when the number of incidences in a particular year exceeds the decadal average, then the incidences of this particular year are influenced by El-Nino (Figure 4). El-Nino and La-Nino years are also years which coincide with deficit and excess rainfall years, but all excess and deficit rainfall years are not El-Nino or La-Nina years. Though there is a general tendency for the malaria incidences also to coincide with droughts and floods, however, the separation is not as good as that is observed in case of El Nino/La Nina events.

Table 1. Climate determinants for malaria parasite development in mosquito vector and transmission

	Class	Transmission window (°C)	Corresponding no. of days when malarial parasite thrives
P. vivax	Class I	15–20	20 ± 5 days
	Class II	20–25	15 ± 5 days
	Class III	25–30	8 ± 2 days
P. falciparum	Class I	20–25	25 ± 5 days
	Class II	25–30	20 ± 5 days
	Class III	30–35	10 ± 2 days

Figure 3. Endemic regions of malaria identified by applying the class I, II, III criteria to the control scenario generated by HadRM2 for the period 1980 to 2000.

An examination of the correlation coefficients between the detrended malaria incidence series for current year (lag 0) and for previous year (lag-1) with respect to year of malaria incidence and seasonal rainfall shows that the rainfall over few subdivisions in previous October as well as in May of the current year has strong bearing on malaria incidences over these subdivisions (Figure 5). Rainfall during October over Gujarat, Maharashtra, Rajasthan, Madhya Pradesh, Karnataka and Andhra Pradesh is positively correlated with malaria incidences in following year in these areas (with correlation coefficient, 0.52). This is because the rainfall in October in the previous year creates favourable conditions for a good vegetation growth and hence retention of optimum humidity conditions required for breeding of the mosquitoes in the subsequent year. It is also seen that the rainfall in May over Saurashtra and Kutch and over east coast of India is negatively correlated with malaria incidences (correlation coefficient is –0.52). If the rainfall in May in the current year is high, it will wipe out the breeding of mosquitoes and in turn decreases the cases of malaria in these areas during the peak season of incidences between July to October (also refer to Figure 2).

Analysis of the trends of northern hemispheric temperature (NHT) and sea surface temperature (SST) over eastern equatorial Pacific and malaria incidences over India for the period 1980 to 2000, indicates that SST during March, April and May (MAM) months is negatively correlated with malaria incidences while the NHT during January are positively correlated with malaria incidences over India. Spatial patterns of correlation between malaria incidences and global SST are plotted in Figure 6 for MAM season. Cold temperature anomalies over eastern Pacific south of equator to about 20°S and east of 120°W in MAM season seems to be favourable for malaria incidences over India. It is also seen from this that cold temperature anomalies over this region are favourable for subsequent summer monsoon rainfall to be good.

Impacts of climate change

According to the projections in the third assessment of the Inter Governmental Panel on Climate Change (IPCC)[6],

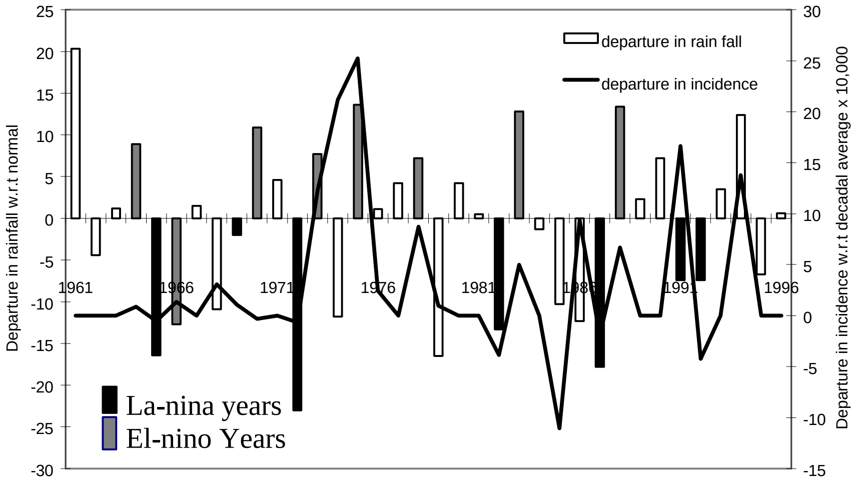

Figure 4. Correlation between malaria incidence and El-Nino Southern Oscillation.

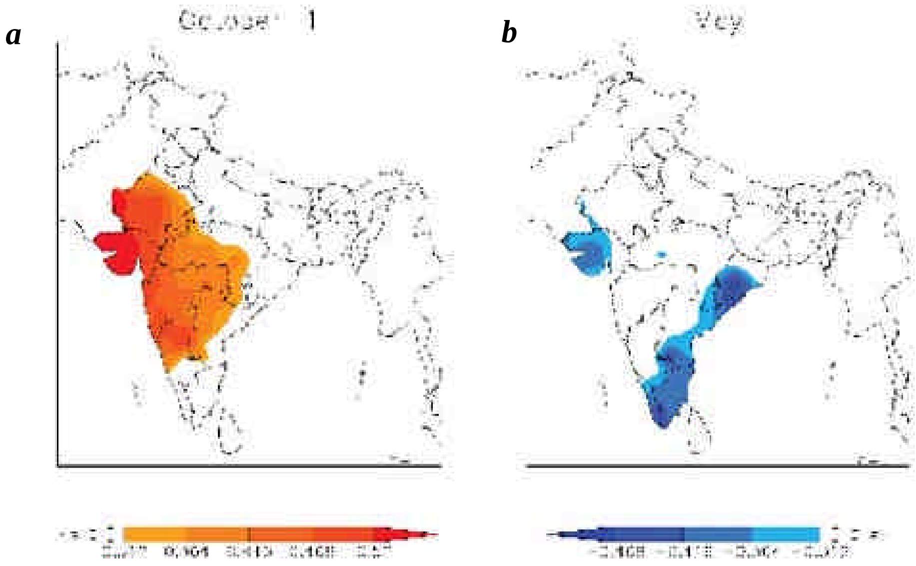

Figure 5. ***a***, Rainfall in October in the previous (October-1) year coincides with increase in malaria incidence in the subsequent year in southern western parts of India. ***b***, Rainfall in May wipes out malaria incidences. The bars below refer to the coefficient of correlation between rainfall and malaria incidence.

the global climate may warm by 1.4 to 5.8°C and precipitation may increase up to 7 per cent, and global sea level will rise from 0.09 to 0.88 m by the year 2100. Several mathematical and computer models have attempted to link all of the factors that affect malaria transmission to assess the effect of projected global climate change on malaria. These models generally relate variables associated with human-induced change in climate parameters (such as temperature, precipitation, relative humidity, and wind); environmental factors (such as drought and desertification, sea level rise, changing vegetation and agricultural practices); parasite development rate, vector population, death rate, breeding places, density, insecticide resistance, and the human population. The change in immune status and spread of pathogens into new areas are also considered by these models[19,20]. Such model indicates that the number of people in developing countries that are likely to be at risk of malaria infection will increase by 5–15% because of climate change, depending on which the Global Circulation Model (GCM) and climate change scenario is used. The areas that are expected to have the most increase in malaria transmission are ones that is at the fringes of transmission now. The population in these areas having low levels of immunity is

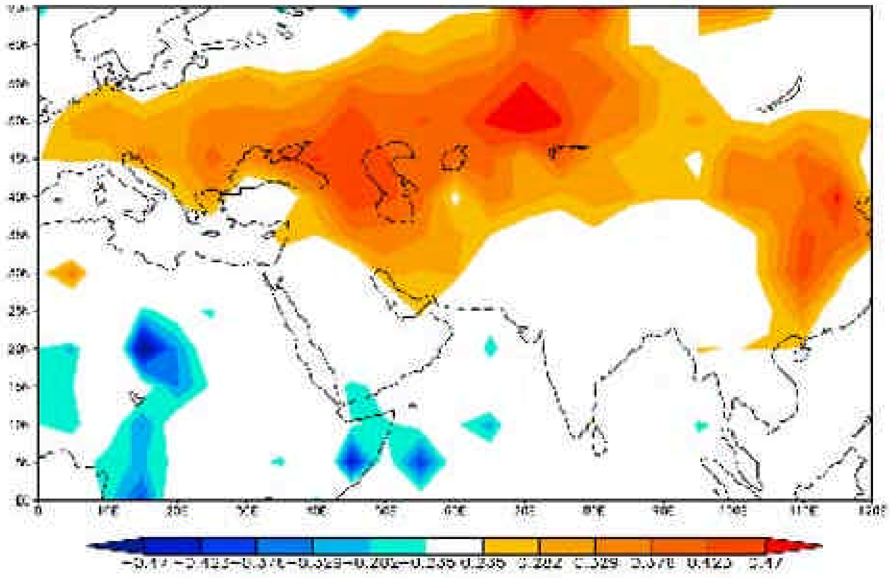

Figure 6. Northern hemispheric temperature in January is positively correlated with incidences of malaria (coefficient of correlation ranging between 0.2 and 0.5), and SSTs in March, April and May are negatively correlated with malaria incidence (coefficient of correlation ranging between –0.47 and –0.24).

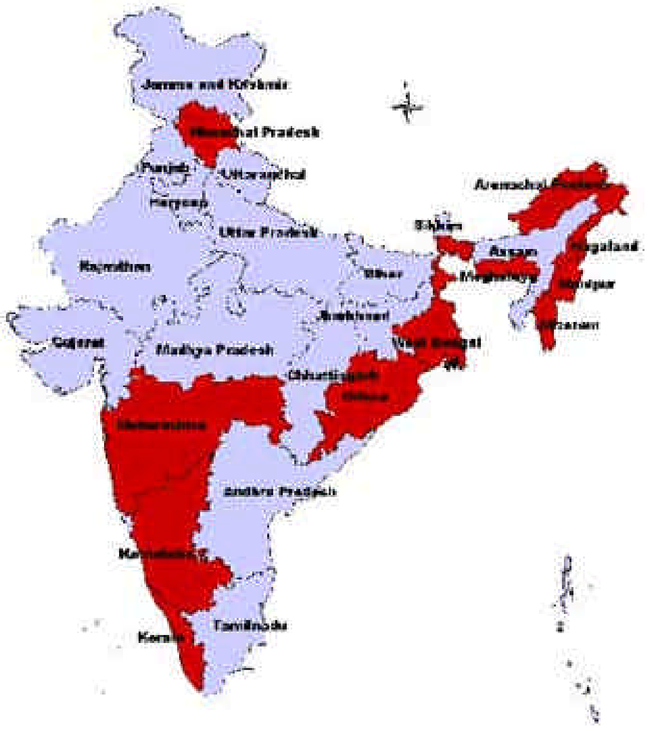

Figure 7. Regions likely to be affected by malaria according to the climate change projections derived from HadRM2 runs of the IS92a scenario for India.

likely to experience recurrence of epidemics unless appropriate control efforts are put in place to effectively reduce the impact of the epidemics.

No such model exists for the Indian conditions specifically. In this paper, a preliminary attempt has been made to link the climate change projections with the likely spatial distribution of malarious regions in India and the transmission windows. It is justifiable to consider that the temperature ranges within which malaria transmission takes place under the current climate conditions will remain the same even when the climate changes. Therefore, the class I, II and III transmission windows determined for the current climate, when applied on IS92a emission scenario driven HadRM2 projections of daily temperature and relative humidity for the 2050s, indicate that Orissa and West Bengal and the southern parts of Assam will still remain malarious under the changed climate conditions. However, the central states of Madhya Pradesh, Chattisgarh and Jharkhand will no longer remain endemic to malaria. Areas like the coastal states of Maharashtra, Karnataka and Kerala in the south, hilly areas like Himachal Pradesh in the North and the Arunachal Pradesh, Nagaland, Manipur and Mizoram in the northeast emerge as regions where transmission windows for malaria will open up. Figure 7 shows this scenario. It is clear from this analysis that areas which are now free of malaria such as Himachal Pradesh, where the average altitude is above 1800 m, may become malaria prone under the changed climate conditions in the 2050s.

However the length of the transmission windows will vary across these states as the temperature goes up in the climate change regime. The projected increase in temperature and changes in relative humidity is likely to increase the transmission windows during winter months in northern India due to increase in lower limit of required conditions. On the other hand, the states like West Bengal and Orissa where the average temperature is around 32–34°C, may experience reduction in transmission widows by few months, due to increase in upper limit of temperature.

Adaptation options in the climate change regime

Malaria affects 40% of the world population spread over 92 countries[19]. Despite extensive measures taken since the early fifties in India, both by the central government and state governments to combat the debilitating disease[2,4], it has become endemic in the central, south eastern and north eastern parts of the country. With climate change it is expected that the disease may spread to newer areas (Figure 7). Therefore, adaptation to climate change is a key concern now, specially considering the fact that the climate projections and the likely anticipated changes in the existing disease conditions are highly uncertain, and the capacities to adapt to the adverse impacts of climate change may not be sufficient. In spite of these uncertainties, we need to acknowledge that some degree of climate change is certain in the future, and in order to combat with the changing disease conditions, we need some degree of preparedness. We need to strengthen our present capacities devised to combat the adverse effects of the current climate variability and develop new capabilities. One small measure in this direction has been taken in this paper whereby the India-specific transmission windows have been developed for the transmissions of *P. vivax* and *P. falciparum*.

As malaria occurrence is not only a function of climate determinants, but is also controlled by the prevailing socio-economic conditions, therefore adaptation measures also should encompass this aspect. Some of the measures that can be envisaged at this juncture which can help to reduce the vulnerability to malaria under climate change conditions, may include:

- Improve medical health services
- Greater accessibility to medical health services
- Identification of vulnerable areas by developing vector-specific regional maps
- Development of a robust predictive model linking climate and incidence
- Improved surveillance and monitoring systems
- Improved infrastructure to avoid breeding
- Develop Integrated Environmental Management Plans
- Public education.

A combination of these options can be used in addition to the ongoing efforts of the Government to control malaria such as the National Malaria Eradication Programme and others[2,4,21] to reduce the vulnerability of the population towards malaria under the future climate projections.

Conclusion

Considering the present endemic nature of malaria in India, this study assesses the climate parameters governing current malaria transmission in India and the likely extent of malarial activity in the future due to climate change. This study indicates the dominant role of temperature and relative humidity in malaria transmission. Thus, a new set of transmission windows termed as class I, II and III have been developed in terms of temperature, governing the transmission of *P. vivax* and *P. falciparum* in India (Table 1). Using the transmission window criteria thus developed, malaria is found to be endemic in the central and eastern Indian regions of the country covering Madhya Pradesh, Jharkhand, Chhattisgarh, Orissa, West Bengal and Assam for the current climate.

Applying the same criteria under the climate change conditions in the 2050s, derived from HadRM2 using 1S92a scenario, it is projected that malaria is likely to persist in Orissa, West Bengal and southern parts of Assam, bordering north of West Bengal. However, it may shift from the central Indian region to the south western coastal states of Maharashtra, Karnataka and Kerala. Also the northern states, including Himachal Pradesh may become malaria prone in the future climate change regime. The duration of the transmission windows is likely to widen in northern and western states and shorten in the southern states.

The research results presented here, *vis-à-vis* the relationship between malaria and its climate determinants and the projected distribution of malaria in the 2050s is not conclusive by itself. The extent of vulnerability due to malaria also depends on determinants other than the climate such as environmental factors, the parasite development rates, the vector population, and the prevailing socio-economic conditions and hence the adaptive capacity of the human population too. Therefore, an integrated research is required for a better assessment of malaria transmission under the future climate change scenario.

The increase or decrease in vulnerability due to climate change in the 2050s will therefore not only depend on the changing climate scenario but also on the developmental path to be followed by India in the future. However, attempts need to be made in the present context itself to improve the accessibility to health services and improve the surveillance, medical and forecasting technologies to prepare us to combat with the exacerbated impacts of climate change.

Notes

1. HaDRM2 (Hadley Center Regional Model, Ver. 2.): The HadRM2 is a high-resolution climate model that covers a limited area of the globe, integrating the atmosphere and land surface components of climate system, and containing representations of the important processes within the climate system (e.g., cloud, radiation, rainfall,

soil hydrology, etc.). The horizontal resolution of HadRM2 is 50 km × 50 km with 19 hybrid coordinate vertical levels.

2. An emission scenario described in the IPCC Second Scientific Assessment Report, 1995.
3. El Niño Southern Oscillation (ENSO): is an anomalous oceanographic and atmospheric event in the equatorial Pacific Ocean that usually occurs every three to seven years and is characterized by an increase in the sea-surface temperature in the eastern equatorial Pacific Ocean. ENSO is thought to be responsible for anomalous climatic conditions spanning most of the globe. Many of the resulting impacts of El Niño are negative, causing drought, famine, and floods.
4. La Niña is characterized by unusually cold ocean temperatures in the equatorial Pacific, compared to El Niño, which is characterized by unusually warm ocean temperatures in the equatorial Pacific.

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