National and regional impacts of climate change on malaria by 2030

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The article reports projection of malaria by 2030 using A1B scenario of PRECIS model basically derived from HadRM3. Malaria scenario has been defined in terms of opening of months of malaria transmission based on minimum required temperature and relative humidity for baseline (1961–1990) and by 2030. Detailed analysis has been done for four vulnerable sectors, viz. Himalayan region, northeast, the Western Ghats and coastal region. Some parts of Uttarakhand, Jammu and Kashmir and Arunachal Pradesh are likely to open transmission windows in new districts with increase in 4–6 months category of transmission. In the northeastern states, intensity of transmission is projected to increase from 7–9 months to 10–12 months. The Western Ghats is projected to be affected to a minimum, whereas in the east coastal districts, reduction in transmission months is likely due to increased temperature. As malaria transmission dynamics is multi-factorial, driven by agricultural practices, water availability, urbanization, migration, socio-economic conditions and intervention measures, projections based on climatic parameters alone should not be viewed with certainty rather they are for guidelines for preparedness in vulnerable areas and strengthen health infrastructure, effective health education and use of best available tools of intervention to cope with the threat of climate change.

Keywords: Climate change, malaria, relative humidity, transmission window, temperature.

Introduction

VECTOR-BORNE diseases (VBDs) are climate-sensitive as the pathogen has to complete some part of its development in insect/arthropod vectors like mosquitoes, sand flies, ticks, etc. Since these vectors are cold-blooded creatures, their developmental stages of life cycle and the development of parasite in their body (extrinsic incubation period) are affected by climatic conditions like temperature, rainfall, relative humidity, wind velocity etc. Seasonal fluctuations in VBDs are caused by fluctuating climatic conditions and are well known. The role of climatic factors has been studied extensively in the epidemiology of malaria due to its global public health importance[1–4]. The minimum temperature required for development of *Plasmodium vivax* parasite in anopheline mosquitoes is 14.5–16.5°C, whereas for *P. falciparum* it is 16.5–18°C (refs 5, 6). At 16°C, it will take 55 days for completion of sporogony of *P. vivax* whereas at 28°C the process can be completed in 7 days and at 18°C it will take 29 days[7]. The duration of sporogony in *Anopheles* mosquitoes decreases with increase in temperature from 20°C to 25°C (ref. 7). From 32°C to 39°C, there is high mortality in mosquitoes[5] and at 40°C, their daily survival becomes zero. The interplay between temperature and mosquitoes has recently been reviewed[8]. At increased temperatures, the rate of digestion of blood meal increases, which in turn accelerates the ovarian development, egg-laying, reduction in the duration of the gonotrophic cycle and more frequency of feeding on hosts, thus increasing the probability of transmission[5,6].

Distribution of malaria in turn is the reflection of suitable climatic conditions and availability of mosquito vectors in different parts of the country. In stable malaria, transmission continues almost throughout the year as the temperature, rainfall and resultant relative humidity are suitable for all the 12 months. The states having unstable malaria experience winters during which transmission does not take place. Areas with unstable malaria are epidemic-prone depending on the favourable conditions provided by unusually high rains at the threshold of the transmission season.

Recently, climate change has emerged as a new threat which is likely to affect spatial and temporal distribution of malaria and other VBDs. Studies undertaken globally for projections of malaria are based on global climate models which provide malaria scenario by 2100 (refs 9–12). Impact assessments in various sectors, including health, have been undertaken under the aegis of the National Communication Project I (refs 13, 14). Initial assessments were based on the HadRM2 model using IS92a scenario wherein the projections were made for 2050 (ref. 14).

In view of transmission dynamics of malaria depending on various factors like agricultural practices, urbanization, water scarcity, socio-economics, etc. long-term projections are of little value in developing preparedness plan to address the issue. In view of this, PRECIS model of A1B scenario which provided projection of climatic parameters by the year 2030 was used for assessment of

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malaria at national and regional level in India, with emphasis on the Himalayan region, northeastern states, the Western Ghats and coastal areas under the aegis of NATCOM II and the recently set up Indian Network for Climate Change Assessment (INCCA). The present assessment will elicit the most vulnerable areas of malaria due to climate change and pave the way for identifying remedial measures for addressing the potential threat in the country.

Material and methods

Extraction of data from PRECIS

A1B scenario of PRECIS model developed at Hadley Centre, UK Met Office and provided by the Indian Institute of Tropical Meteorology (IITM), Pune, provided baseline data based on 30 years average (1961–1990) and projection of temperature, rainfall and relative humidity (RH), wind velocity, surface roughness, canopy cover, etc. The model provides daily data. From the viewpoint of determining transmission windows of malaria, temperature and RH data were extracted. Data were extracted following the guidelines provided in extraction tool by IITM, Pune. Monthly temperature and RH for baseline and by 2030 were extracted for 1495 grids in the country. The grid size was $0.44° \times 0.44°$ (roughly $48.8 \text{ km} \times 48.8 \text{ km}$, covering a district). In districts with larger geographic area, there were up to six grids. The figures for average temperature provided in the model were found incorrect, which were rectified by calculating the same manually.

Extraction of regions of India

The extent of Himalayan, northeastern, Western Ghats and coastal areas was deduced from the website of Encarta (http://encarta.msn.com) in general; and http://www.uttaranchal.ws/him.htm (for the Uttarakhand details) http://gbpihed.gov.in/envis/ihr.png (for the Himalayan region), http://www.northeastindiadiary.com/map.htm/ (for the northeastern region), http://www.india9.com/i9show/Western-Ghats-13531.htm (for the Western Ghats) and http://en.wikipedia.org/wiki/Geography_of_India#Coasts3 (for coastal areas) in specific.

Determination of transmission windows of malaria

Transmission windows (TWs) of malaria were determined keeping in view the lower cut-off temperature as 18°C and upper as 32°C (ref. 15) and RH from > 55% (ref. 3). Keeping in view the climatic suitability for the number of months transmission is open, TWs were categorized into I–V (category I, not a single month is open; category II, 1–3 months open; category III, 4–6 months; category IV, 7–9 months open and category V, 10–12 months open continuously for malaria transmission) for country level. Indigenous transmission of malaria is possible if TW is open for 3 months continuously[15], therefore, for analyses at regional level, more categories, i.e. TW open for 1–2 month and 3 months were also made. TWs open for more than 6 months indicate stability of malaria transmission. TWs were determined for baseline (1961–1990) and for the projection year 2030, based on temperature alone, as well in combination with temperature and RH to compare the effect of just temperature rise with combined effect of temperature and RH, which affects the longevity of the mosquitoes.

Generation of maps in GIS format

Based on the data derived from PRECIS model and exported to excel, TWs were determined and categorized. The inputs were fed in ArcGIS 9.3 software for generation of region/area-wise maps with district boundaries.

Results

Impacts of climate change at the national level

Based on minimum required temperature for ensuing transmission of malaria, a district-wise map of India was generated to show the distribution of different categories of TWs under baseline and projected scenario by 2030 (Figure 1 *a*). Details of the number of pixels under different categories are given in Table 1. Data for 42 pixels were not available. In the baseline scenario, 140 pixels are totally closed for transmission while by 2030, there is opening of five pixels. In all the categories from II to IV there is increase in the number of pixels by 2030, while under category V there is reduction. When the map of baseline TWs determined based on temperature alone (Figure 1 *a*) is compared with reported incidence of malaria in 2009 (Figure 2), there is mismatch in endemicity level, particularly in the southwestern part of India.

TWs determined based on minimum required temperature and RH (Figure 1 *b*) show overall lesser number of pixels for categories IV and V in the baseline as well as the projected scenario (Table 2). Detailed analysis of four regions of India, viz. the Himalayan region, northeastern states, the Western Ghats and the coastal region was also done to find the vulnerability at district level and the additional population at risk.

Impacts at the regional level

Himalayan region: Under the Himalayan region, states like Jammu and Kashmir, Himachal Pradesh, Uttarakhand, Sikkim, West Bengal and Arunachal Pradesh are included

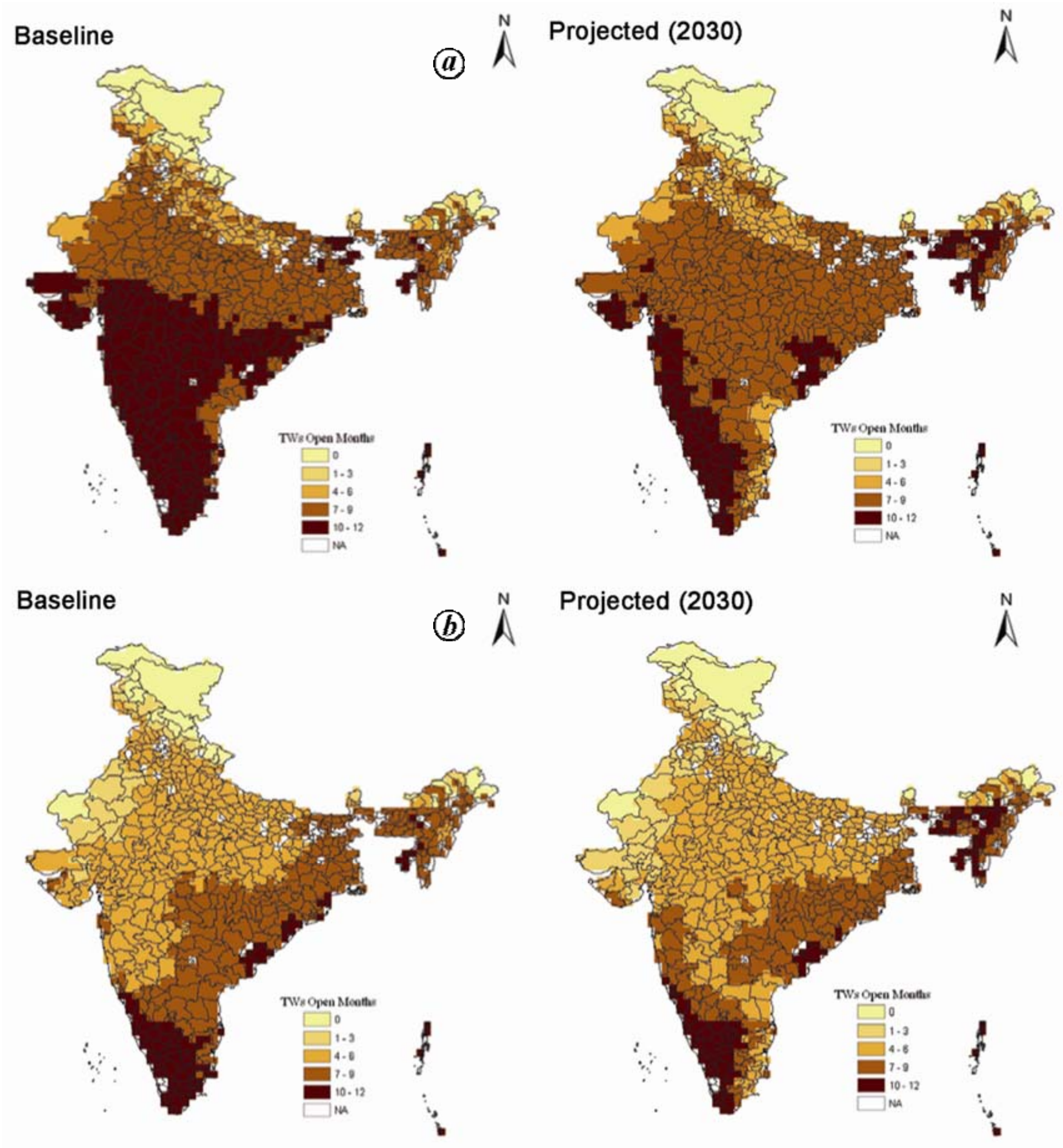

Figure 1. Transmission window (TW) of malaria, based on temperature (***a***) and temperature and relative humidity (RH) (***b***) using A1B scenario for baseline and by the year 2030.

Table 1. Pixel of transmission windows of malaria under different categories in India (based on temperature)

Scenario	Class					
	I (0)	II (1–3)	III (4–6)	IV (7–9)	V (10–12)	Remarks (Data not available)
Baseline	140	16	132	602	563	42
Projection (by 2030)	135	23	188	857	250	42

with altogether 55 districts. Details of TWs based on temperature alone are given in Figure 3*a* and Table 3. Under the Himalayan region, two districts show opening of TWs from 0 to 3 months in Jammu and Kashmir and Uttarakhand, i.e. Anantnag and Uttarkashi districts respectively. The population of these districts is 11.7 lakh and 16,220 respectively. There is projected increase in TWs from 3 to 4–6 in Uttarakhand, Sikkim and Arunachal Pradesh. In Una District, Himachal Pradesh and some districts of Jammu and Kashmir, reduction in the

Table 2. Pixel of transmission windows of malaria under different categories in India (based on temperature and relative humidity (RH))

	Class					
Scenario	I (0)	II (1–3)	III (4–6)	IV (7–9)	V (10–12)	Remarks (Data not available)
Baseline	160	118	593	456	126	42
Projection (by 2030)	155	152	652	363	131	42

Table 3. Transmission windows of malaria in the Himalayan region based on temperature (A1B scenario, projection by 2030)

		Number of open months of TWs		
State	District showing change in TWs	Baseline	Projected	Additional/ affected month
Arunachal Pradesh (9)	East Kameng (Seppa)	5	6	September
	Upper Subansiri (Dap.)	1	2	August
	Upper Subansiri(Ziro)	2	3	September
	West Kameng (Bomdila)	3	4	September
	West Siang	3	4	September
Himachal Pradesh (12)	Una	8	7	June
Jammu and Kashmir (15)	Punch	5	4	May
	Rajauri	5	4	May
	Udhampur	4	3	May
	Anantnag	0	2	July, August
Sikkim (4)	East District	4	5	September
	West District	3	4	September
Uttarakhand (13)	Champawat	5	6	April
	Garhwal	7	8	March
	Hardwar	5	7	March, May
	Uttarkashi	1	3	July, August
West Bengal (2)	Darjeeling	8	9	November
	Jalpaiguri	8	9	November

Figures in parenthesis denote the number of districts in the state. Of the total 55 districts, data of five districts were not available.

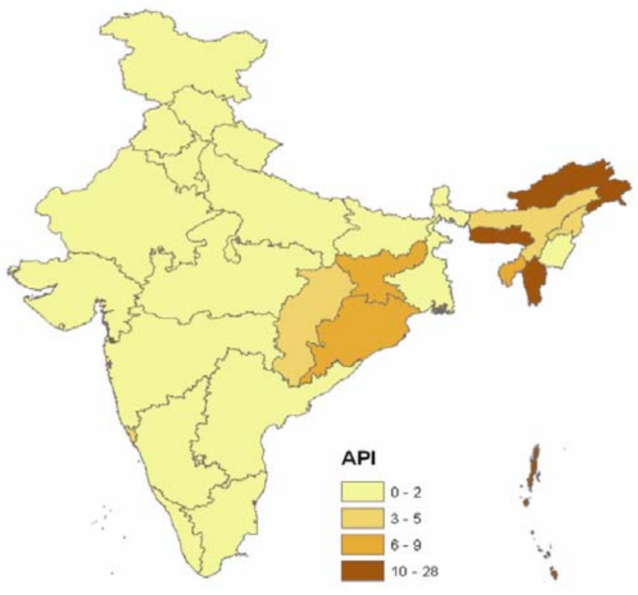

Figure 2. Endemicity of malaria in India (2009). (Source: data from NVBDCP.)

number of open months for malaria transmission is visible. There is no district with 10–12 month TW category under the Himalayan region.

TWs were also determined based on both temperature and RH (Figure 4 *a* and Table 4), which show lesser number of pixels in category IV. The seasonality of malaria in the representative district of Uttarakhand, i.e. Dehradun (Figure 5) corroborates with the baseline map (Figures 3 *a* and 4 *a*).

Northeastern region: This region consists of seven states, namely Assam, Meghalaya, Arunachal Pradesh, Nagaland, Manipur, Tripura and Mizoram. The region is characterized by mountainous and plains. Due to steep mountain slopes inaccessibility is a problem and most parts of the states are not utilized properly for land use and other developmental activities. There is diversity in terms of physical, ecological, ethnic and socio-cultural aspects. The region is rich in water resources and biodiversity, particularly evergreen forest and medicinal

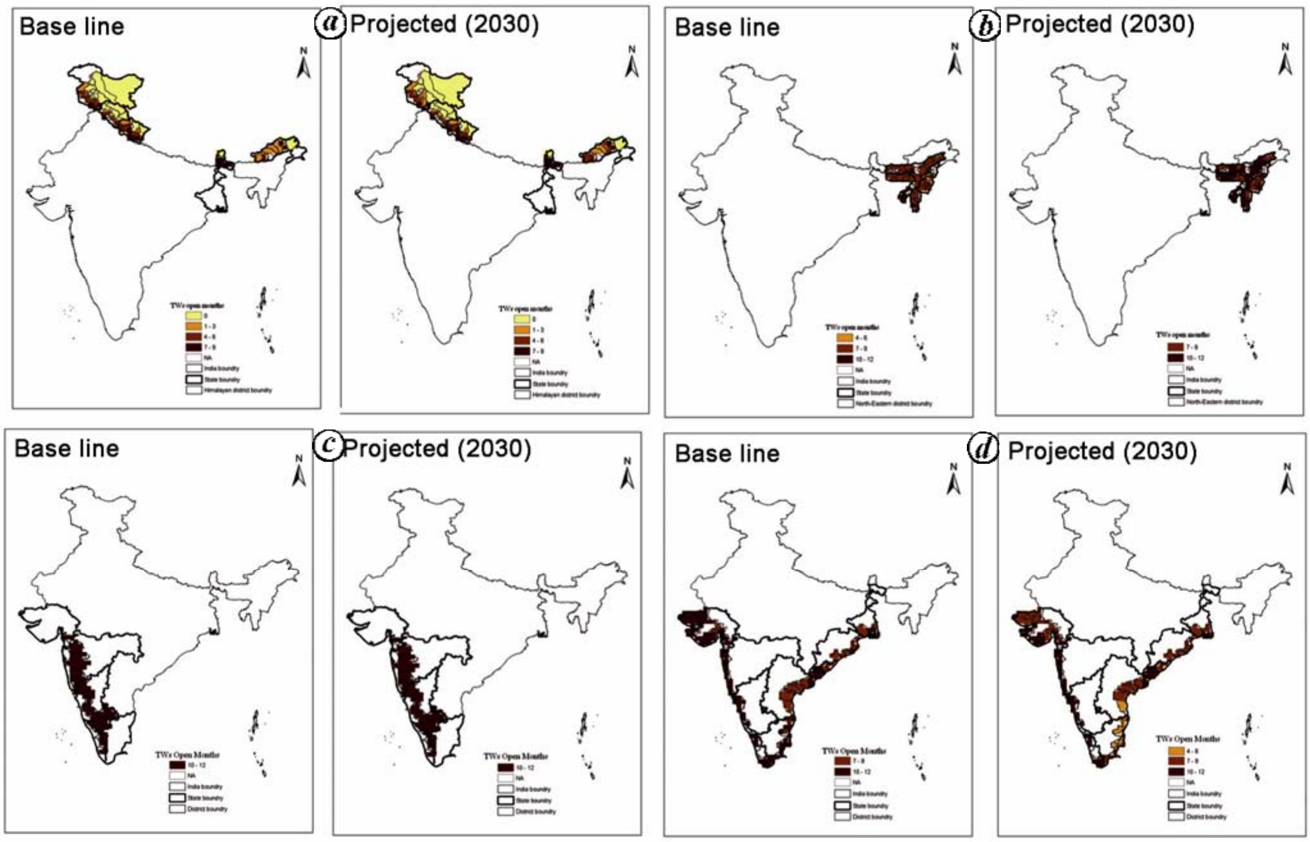

Figure 3. Transmission windows of malaria based on temperature in the Himalayan region (***a***), northeastern region (***b***), the Western Ghats (***c***) and coastal region (***d***) using A1B scenario for baseline and by 2030.

Table 4. Transmission windows of malaria based on temperature and RH in the Himalayan region (A1B scenario, projection by 2030)

State	District showing change in TWs	Number of open months of TWs		Additional/ affected month open
		Baseline	Projected	
Arunachal Pradesh (9)	East Kameng (Seppa)	5	6	October
	Upper Subansiri (Dap.)	1	2	August
	Upper Subansiri (Ziro)	2	3	September
	West Kameng (Bomdila)	3	4	September
	West Siang	3	4	September
Himachal Pradesh (12)	Hamirpur	4	5	April, May
	Kangra	3	4	May
	Sirmaur	4	5	May, October
	Una	4	6	March, May
Jammu and Kashmir (15)	Anantnag	0	2	July, August
	Jammu	4	6	March, May
	Udhampur	3	2	June
Sikkim (4)	East District	4	5	September
	West District	3	4	September
Uttarakhand (13)	Almora	4	5	May
	Bageshwar	0	1	June
	Garhwal	5	4	June
	U S Nagar	4	5	November
	Uttarkashi	1	2	July, August
West Bengal (2)	Darjeeling	7	9	March, November
	Jalpaiguri	8	9	November

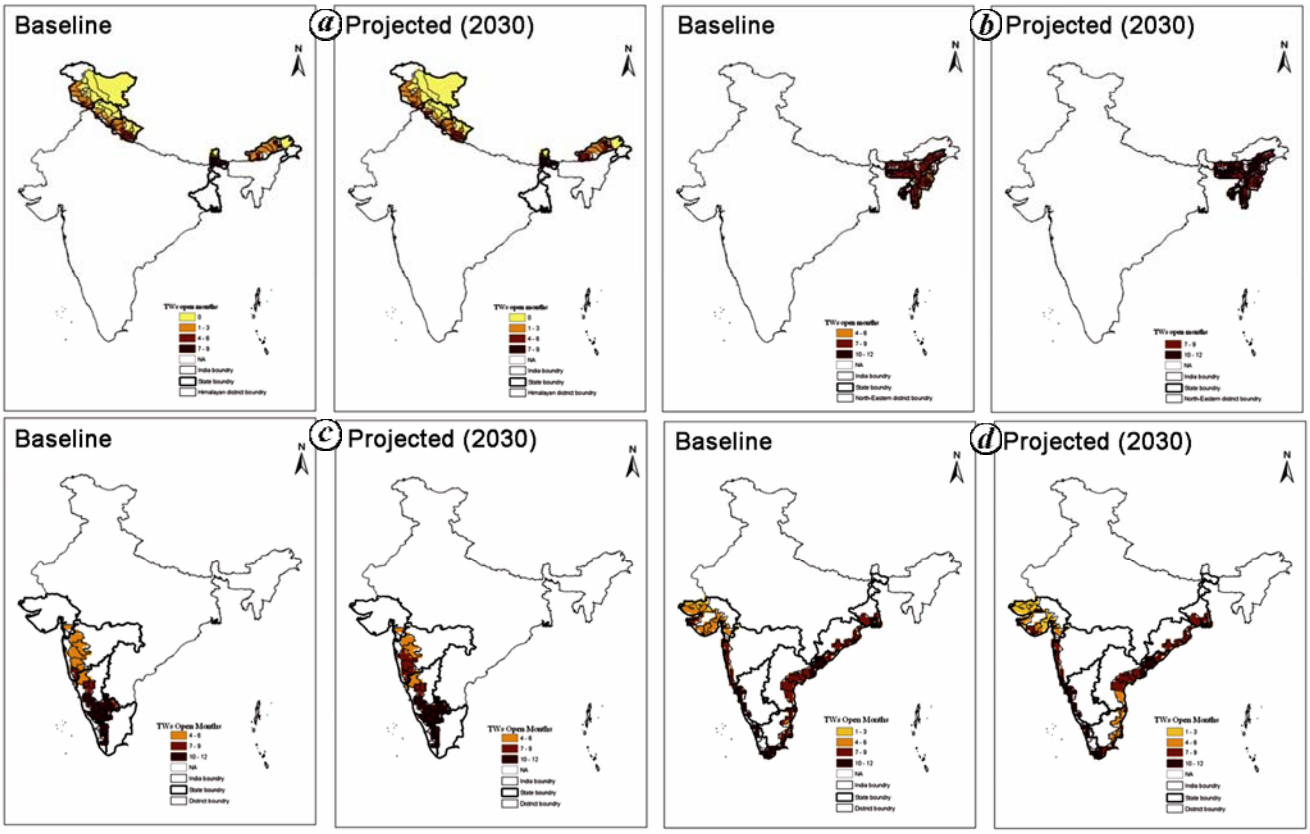

Figure 4. Transmission windows of malaria, based on temperature and RH in the Himalayan region (***a***), northeastern region (***b***), the Western Ghats (***c***) and coastal region (***d***) using A1B scenario for baseline and by 2030.

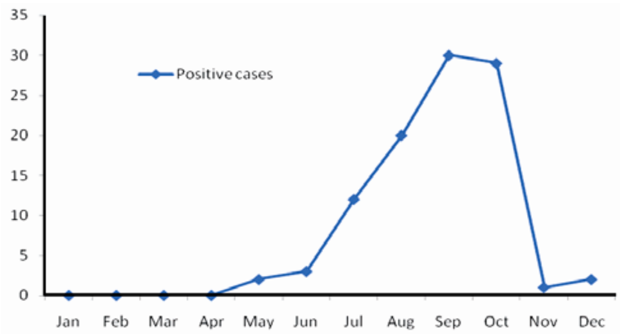

Figure 5. Seasonality of malaria transmission in Dehradun (Uttarakhand). (Source: State Programme Office, Uttarakhand.)

plants. Jhum cultivation is a characteristic feature of the region, which entails the farmer community to stay in the jungles for weeks together. Heavy rainfall leads to high humidity throughout the year. Temperature is moderate for most part of the year, with mild winters. These climatic characteristics make the region highly conducive for mosquito breeding, survival and transmission of VBDs. Six states of India covering 59 districts have been discussed under this region, except Arunachal Pradesh which has been dealt under the Himalayan region.

Under this region there are 59 districts in six states. There is not a single pixel in the 0–3 months TW open category (Figure 3 *b* and Table 5). By 2030, there is sharp increase in category V, indicating stability of malaria transmission. Meghalaya, Mizoram and Assam show more stability of malaria transmission. The category of TWs open for 4–6 months also disappears in the projected scenario. TWs determined based on temperature and RH also reveal almost similar projections (Figure 4 *b* and Table 6). The seasonality of malaria cases in Karbi Anglong (Assam), a representative district of the northeastern states, also shows transmission of malaria for seven or more months (Figure 6).

Western Ghats: The Western Ghats runs along the western coast of India comprising 30 districts from the states of Maharashtra, Goa, Karnataka, Kerala and Tamil Nadu. The average elevation is around 900 m and the highest point is reached at Anamudi peak (2695 m). Konkan coast comprises of the northern portion of the Ghats and Malabar, the southern part. The hilly region east of the Ghats in Maharashtra is Desh, whereas the eastern hills of central Karnataka are known as the Malnad region. Scrub jungles, grasslands, dry and moist deciduous forests, semi-evergreen and evergreen forests are the

Table 5. Transmission windows of malaria in the northeastern region based on temperature (A1B scenario, projection by 2030)

			Number of months open for malaria transmission						
State	Number of districts		0	1–2	3	4–6	7–9	10–12	Data not available
Assam	23	Baseline	0	0	0	0	18	1	4
		Projection	0	0	0	0	5	14	4
Mizoram	8	Baseline	0	0	0	0	6	1	1
		Projection	0	0	0	0	3	4	1
Manipur	9	Baseline	0	0	0	1	6	0	2
		Projection	0	0	0	0	6	1	2
Meghalaya	7	Baseline	0	0	0	0	7	0	0
		Projection	0	0	0	0	3	4	0
Nagaland	8	Baseline	0	0	0	1	4	0	3
		Projection	0	0	0	0	5	0	3
Tripura	4	Baseline	0	0	0	0	0	3	1
		Projection	0	0	0	0	0	3	1
Total	59	Baseline	0	0	0	2	41	5	11
		Projection	0	0	0	0	22	26	11

Table 6. Transmission windows of malaria in the northeastern region based on temperature and RH (A1B scenario, projection by 2030)

			Number of months open for malaria transmission						
State	Number of districts		0	1–2	3	4–6	7–9	10–12	Data not available
Assam	23	Baseline	0	0	0	0	17	2	4
		Projection	0	0	0	0	5	14	4
Mizoram	8	Baseline	0	0	0	0	6	1	1
		Projection	0	0	0	0	3	4	1
Manipur	9	Baseline	0	0	0	1	6	0	2
		Projection	0	0	0	0	6	1	2
Meghalaya	7	Baseline	0	0	0	0	6	1	0
		Projection	0	0	0	0	3	4	0
Nagaland	8	Baseline	0	0	0	1	4	0	3
		Projection	0	0	0	0	5	0	3
Tripura	4	Baseline	0	0	0	0	0	3	1
		Projection	0	0	0	0	0	3	1
Total	59	Baseline	0	0	0	2	39	7	11
		Projection	0	0	0	0	22	26	11

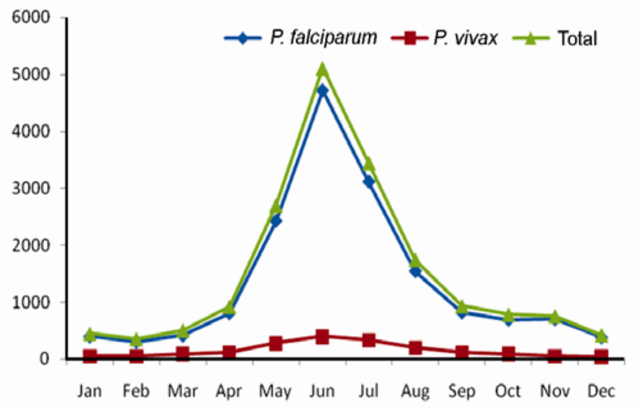

Figure 6. Seasonality of malaria transmission in Karbi Anglong (Assam). (Source: Office of DMO, Karbi Anglong.)

vegetation along the Ghats. Agasthyamalai Hills and the Silent Valley are the two main centres of diversity. The only Biodiversity reserve in the Western Ghats is the Nilgiri Biosphere Reserve.

The rainfall is heavy, which has preserved the flora and fauna in this region. The Sahyadri Mountains absorb monsoon rains and release them gradually over the rest of the year, thus keeping the regions of South India sufficiently wet. Perennial rivers like the Godavari, Krishna, Kaveri and their tributaries flow into the Bay of Bengal.

Under this region, all the districts show TWs open for 10–12 months and none of the 30 districts is affected by projected rise in temperature (Figure 3*c* and Table 7). When TWs were determined based on both temperature and RH, the category of 4–6 months and 7–9 months

Table 7. Transmission windows of malaria in the Western Ghats based on temperature (A1B baseline and projected scenario by 2030)

			Number of months open for malaria transmission						
State	Number of districts		0	1–2	3	4–6	7–9	10–12	Data not available
Gujarat	2	Baseline	0	0	0	0	0	1	1
		Projection	0	0	0	0	0	1	1
Maharashtra	6	Baseline	0	0	0	0	0	6	0
		Projection	0	0	0	0	0	6	0
Karnataka	15	Baseline	0	0	0	0	0	15	0
		Projection	0	0	0	0	0	15	0
Kerala	5	Baseline	0	0	0	0	0	4	1
		Projection	0	0	0	0	0	4	1
Tamil Nadu	2	Baseline	0	0	0	0	0	2	0
		Projection	0	0	0	0	0	2	0
Total	30	Baseline	0	0	0	0	0	28	2
		Projection	0	0	0	0	0	28	2

Table 8. Transmission windows of malaria in the Western Ghats based on minimum required temperature and RH (A1B scenario, projection by 2030)

			Number of months open for malaria transmission						
State	Number of districts		0	1–2	3	4–6	7–9	10–12	Data not available
Gujarat	2	Baseline	0	0	0	1	0	0	1
		Projection	0	0	0	1	0	0	1
Maharashtra	6	Baseline	0	0	0	5	1	0	0
		Projection	0	0	0	0	6	0	0
Karnataka	15	Baseline	0	0	0	1	4	10	0
		Projection	0	0	0	1	3	11	0
Kerala	5	Baseline	0	0	0	0	0	4	1
		Projection	0	0	0	0	0	4	1
Tamil Nadu	2	Baseline	0	0	0	0	0	2	0
		Projection	0	0	0	0	0	2	0
Total	30	Baseline	0	0	0	7	5	16	2
		Projection	0	0	0	2	9	17	2

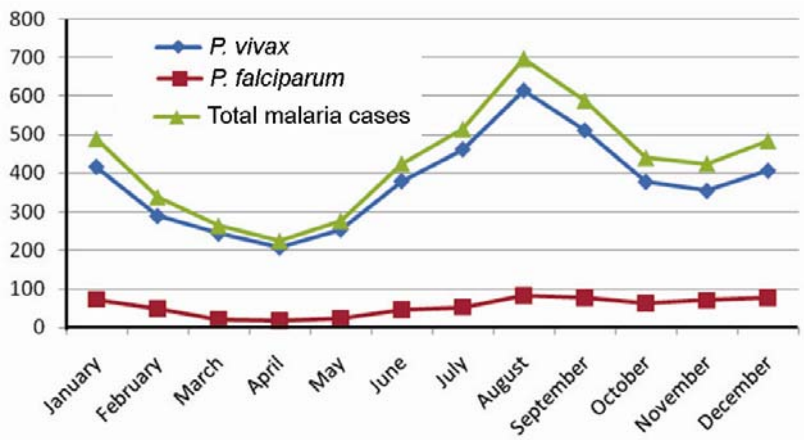

Figure 7. Seasonality of malaria transmission in Mangalore (Karnataka). (Source: Office of DMO, Mangalore.)

open TWs are visible in the baseline as well as projected scenario (Figure 4*c* and Table 8). If we compare the existing seasonal occurrence of malaria cases in a representative district of the Western Ghats, Mangalore (Karnataka), transmission continues for more than 7–9 months (Figure 7).

Table 9. Transmission windows of malaria in coastal areas based on minimum required temperature (baseline and projected scenario 2030)

State	Number of districts		Number of months open for malaria transmission						
			0	1–2	3	4–6	7–9	10–12	Data not available
Gujarat	14	Baseline	0	0	0	0	1	12	1
		Projection	0	0	0	0	7	6	1
Maharashtra	5	Baseline	0	0	0	0	0	4	1
		Projection	0	0	0	0	0	4	1
Goa	2	Baseline	0	0	0	0	0	2	0
		Projection	0	0	0	0	0	2	0
Daman and Diu	2	Baseline	0	0	0	0	0	0	2
		Projection	0	0	0	0	0	0	2
Dadra and Nagar Haveli	1	Baseline	0	0	0	0	0	1	0
		Projection	0	0	0	0	0	1	0
Karnataka	3	Baseline	0	0	0	0	0	3	0
		Projection	0	0	0	0	0	3	0
Kerala	9	Baseline	0	0	0	0	0	6	3
		Projection	0	0	0	0	0	6	3
Tamil Nadu	13	Baseline	0	0	0	0	4	9	0
		Projection	0	0	0	7	4	2	0
Andhra Pradesh	9	Baseline	0	0	0	0	7	2	0
		Projection	0	0	0	1	6	2	0
Puduchery	3	Baseline	0	0	0	0	0	0	3
		Projection	0	0	0	0	0	0	3
Orissa	7	Baseline	0	0	0	0	6	1	0
		Projection	0	0	0	0	7	0	0
West Bengal	3	Baseline	0	0	0	0	2	1	0
		Projection	0	0	0	0	3	0	0
Andaman and Nicobar Islands	2	Baseline	0	0	0	0	0	2	0
		Projection	0	0	0	0	0	2	0
Lakshadweep Islands	1	Baseline	0	0	0	0	0	0	1
		Projection	0	0	0	0	0	0	1
Total	74	Baseline	0	0	0	0	20	43	11
		Projection	0	0	0	8	27	28	11

Coastal areas: Coastal areas in India are quite long consisting of 74 districts in 14 states on the eastern and western parts in the south. The Western Coastal Plain is a narrow strip of land ranging from 50 to 100 km in width. It extends from Gujarat in the north and extends through Maharashtra, Goa, Karnataka and Kerala. Numerous rivers and backwaters inundate the region. Originating in the Western Ghats, the rivers are fast-flowing and mostly perennial, leading to the formation of estuaries. Major rivers flowing into the sea are the Tapi, Narmada, Mandovi and Zuari. The coast is divided into three parts, namely Konkan, which is situated in Maharashtra, Goa and northern parts of Karnataka; the Kanara in Karnataka, and the Malabar coast in Kerala. Vegetation is mostly deciduous, but in the Malabar coast moist forests constitute a unique ecoregion.

The Eastern Coastal Plain extends from West Bengal in the north to Tamil Nadu in the south. The Mahanadi, Godavari, Kaveri and Krishna are the rivers that drain into the area and their deltas occupy most of the area. The temperature in the coastal regions exceeds 30°C coupled with high humidity. The region receives both the north-east and southwest monsoon rains. Annual rainfall in this region averages between 1000 and 3000 mm. The width of the plains varies between 100 and 130 km. The plains are divided into six regions – the Mahanadi delta, the southern Andhra Pradesh plain, the Krishna–Godavari delta, the Kanyakumari coast, the Coromandel coast and sandy coastal.

The Andaman and Nicobar Islands is located in the Indian Ocean. It has over 570 islands, out of which only 38 are permanently inhabited. Lakshadweep is the smallest island in India and is located in the Arabian Sea. It consists of twelve coral atolls, three coral reefs, five banks and numerous islets. Tall, green coconut palms turn this land into a tropical paradise. Moderate temperatures not exceeding 36°C and high humidity make the island suitable for almost perennial transmission of malaria.

Under coastal areas in India, a total of 71 districts in 12 states are included. PRECIS data for Daman and Diu,

Table 10. Transmission windows of malaria based on minimum required temperature and RH (baseline and projected scenario 2030)

State	Number of districts		Number of months open for malaria transmission						
			0	1–2	3	4–6	7–9	10–12	Data not available
Gujarat	14	Baseline	0	0	2	9	1	1	1
		Projection	0	1	4	4	2	2	1
Maharashtra	5	Baseline	0	0	0	0	4	0	1
		Projection	0	0	0	0	3	1	1
Goa	2	Baseline	0	0	0	0	1	1	0
		Projection	0	0	0	0	0	2	0
Daman and Diu	2	Baseline	0	0	0	0	0	0	2
		Projection	0	0	0	0	0	0	2
Dadra and Nagar Haveli	1	Baseline	0	0	0	1	0	0	0
		Projection	0	0	0	0	1	0	0
Karnataka	3	Baseline	0	0	0	0	0	3	0
		Projection	0	0	0	0	0	3	0
Kerala	9	Baseline	0	0	0	0	0	6	3
		Projection	0	0	0	0	0	6	3
Tamil Nadu	13	Baseline	0	0	0	1	6	6	0
		Projection	0	0	0	7	4	2	0
Andhra Pradesh	9	Baseline	0	0	0	0	7	2	0
		Projection	0	0	0	1	6	2	0
Puduchery	3	Baseline	0	0	0	0	0	0	3
		Projection	0	0	0	0	0	0	3
Orissa	7	Baseline	0	0	0	0	6	1	0
		Projection	0	0	0	0	7	0	0
West Bengal	3	Baseline	0	0	0	0	2	1	0
		Projection	0	0	0	0	3	0	0
Andaman and Nicobar Islands	2	Baseline	0	0	0	0	0	2	0
		Projection	0	0	0	0	0	2	0
Lakshadweep Islands	1	Baseline	0	0	0	0	0	0	1
		Projection	0	0	0	0	0	0	1
Total	74	Baseline	0	0	2	11	27	23	11
		Projection	0	1	4	12	26	20	11

Lakshadweep and Puducherry were not available. Not a single district had closed or 1–3 month or 4–6 month open TWs (Figure 3 *d* and Table 9). Districts of Andaman and Nicobar Islands, Maharashtra, Dadra and Nagar Haveli, Goa, Karnataka and Kerala under this region remain unaffected in the projected scenario. There is reduction in months of TWs of 10–12 in Gujarat, Tamil Nadu, Orissa and West Bengal due to increase in temperature by the year 2030. In the western coast there is no change from Gujarat downwards.

TWs determined based on both temperature and RH (Figure 4 *d* and Table 10) show reduction in the number of months of TW the same way as shown in Figure 3 *d* and Table 9. However, in districts of Gujarat falling under this region, baseline TWs show even 3 months and 4–6 months open TWs. It does not seem to match with the seasonality of malaria in Gujarat as reflected by epidemiological data from a representative coastal district of the state, i.e. Surat which show transmission for more than 4–6 months (Figure 8), indicating that the transmission in microniche. Projected scenario for districts falling under this region shows reduction in even 4–6 months category and shifting towards lower categories (Table 10).

Discussion

Projections for malaria based on different methodologies have been made earlier[13,14]. The current projections are for near time, i.e. by 2030 and are almost at the district level (48.8 km × 48.8 km) for the whole of India, with emphasis on four sectors.

The projections based on temperature alone, and both temperature and RH differ in the number of months of transmission opening. When we compare Figure 1 *a* and *b*, we find that the western side of India, particularly the central and southern parts exhibit TWs open for 10–12 months, while in Figure 1 *b* this category is drastically reduced to 7–9 months. Current malaria endemicity as

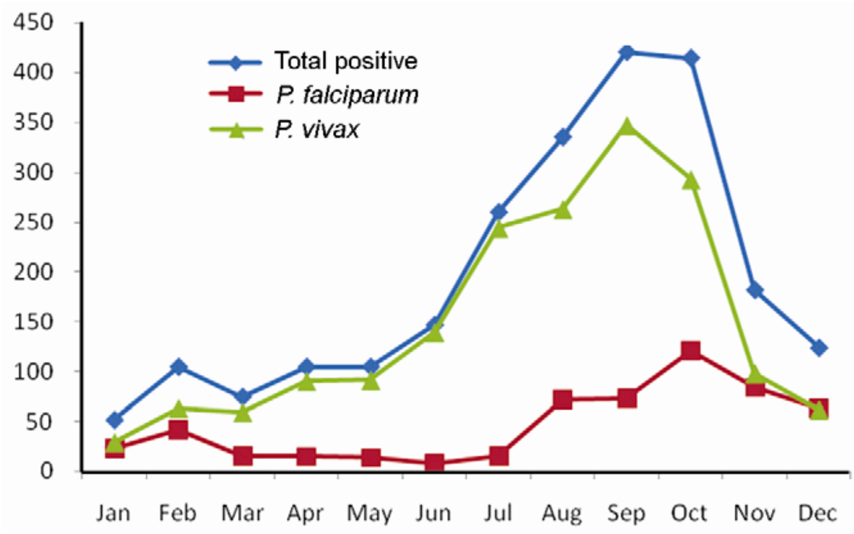

Figure 8. Seasonality of malaria transmission in Surat (Gujarat). (Source: Joint Director, Malaria and Filaria, Government of Gujarat.)

seen in Figure 2 also shows low intensity of the disease in western and southern parts of India, which corroborates with Figure 1 *b*. It shows that TWs determined using both temperature and RH are closer to the reported distribution of malaria.

Projections based on temperature reveal introduction of new foci in Jammu and Kashmir, Uttarakhand, increased intensity in Arunachal Pradesh, and increase in the opening of more transmission months in the districts of the Himalayan region, northeastern states and the Western Ghats. The northeastern states are projected to show a rise in transmission intensity.

Districts under the Western Ghats are not likely to experience any change by 2030 as all the 28 districts show opening of TWs for 10–12 months in the baseline as well as projected scenario. But TWs based on both temperature and RH show reduced intensity in the number of open months for transmission in the baseline and slight increase by 2030.

The eastern coastal areas are projected to experience reduction in the number of months open for transmission, which is basically due to increased temperature cutting off the upper limit of transmission suitability. However, it has been seen in Rajasthan that at even at higher temperature transmission of malaria may continue[16], indicating that mosquitoes have adapted to micro-niche to the avoid higher temperature. In view of this, there may be no reduction in transmission months due to increased temperatures.

When the projections based on temperature alone and both temperature and RH are compared with occurrence of malaria cases, there is mismatch between findings of temperature and RH and current seasonality in the Western Ghats and coastal areas. This indicates that there is dissimilarity in the outside climatic conditions and resting habitats of mosquito vectors, and they seek a micro-niche for their resting to get the required RH for survival. Therefore, for the western part of India which experiences dry spell, determination of TWs based on temperature and RH is desirable.

The reason of almost similar projections with temperature and both temperature and RH in the northeastern states may be due to heavy rainfall and prevalent high RH, where the windows of transmission are not closed due to low RH.

Malaria transmission dynamics is multi-factorial, driven by agricultural practices, water availability, urbanization, migration, socio-economic conditions and intervention measures. Therefore, projections based on climatic parameters alone should not be viewed with certainty rather they are for guidelines for preparedness.

Current impacts of climate change on malaria are based on climatic parameters only. In view of various determinants, viz. developmental, sociological and ecological aspects of malaria[15], assessments need to be refined attributable to climate change alone. Expanding the region of impact assessments at district level, development of capacities to detect abrupt changes in climate and hence disease detection and prevalence, capturing all cases by improving surveillance and assessing the cost of adaptation are desired. It has been amply cited by the IPCC[12] that it will be economical to undertake adaptation measures before hand, than the loss caused due to threat of climate change. Unless we know the economics of climate change, it is difficult to convince policymakers for allocation of resources. Well-planned intervention measures for malaria control are already in place with supervision from a central body, i.e. NVBDCP. The assessment provided in the present study should help programme managers to keep a vigil on the occurrence of cases in vulnerable areas and strengthen health infrastructure, effective health education and use of best available tools of intervention to cope with the threat of climate change.

Uncertainties and limitations of PRECIS model and data

- The data on temperature and RH provided by the model are at the resolution of 48 km × 48 km, which cannot delineate differences in hills and valleys in the Himalayas and some parts of the northeastern region and even in the plains.
- Analyses have been done using mean temperature, studies are warranted using diurnal temperature[17].
- Mitigation measures can change the scenarios.
- The projections made for transmission windows may be affected drastically by intervention measures, ecological changes and socio-economics of the communities.

Knowledge and research gaps

- In some geographic areas, TWs show suitability for less number of months while the occurrence of cases reflects transmission for longer periods. This suggests the presence of a micro-niche which needs to be studied in detail, particularly in areas like Gujarat and Rajasthan.
- Based on the outputs of open months for malaria transmission, validation is needed at the district level to determine cut-off limits of transmission for temperature, RH and rainfall.
- The study should be expanded to other VBDs in India.
- The outcome of projections is based on only climatic parameters alone, which if integrated with intervention measures, socio-economics and immunity of the population would provide a holistic projection.

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