

Effect of climate change and deforestation on vector borne diseases in the North-Eastern Indian state of Mizoram bordering Myanmar

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Abstract

Background: Malaria and dengue are the two major vector-borne diseases in Mizoram. Malaria is endemic in Mizoram, and dengue was first reported only in 2012. It is well documented that climate change has a direct influence on the incidence and spread of vector-borne diseases. The study was designed to study the trends and impact of climate variables (temperature, rainfall and humidity) in the monsoon period (May to September) and deforestation on the incidence of dengue and malaria in Mizoram.

Methods: Temperature, rainfall and humidity data of Mizoram from 1979-2013 were obtained from the National Centers for Environmental Prediction Climate Forecast System Reanalysis and analyzed. Forest cover data of Mizoram was extracted from India State of Forest Report (ISFR) and Land Processes Distributed Active Archive Centre. Percent tree cover datasets of Advanced Very High Resolution Radiometer and Moderate Resolution Imaging Spectroradiometer missions were also used to study the association between deforestation and incidence of vector-borne diseases. The study used non-parametric tests to estimate long-term trends in the climate (temperature, rainfall, humidity) and forest cover variables. The trend and its magnitude are estimated through Mann-Kendall test and Sen's slope method. Year-wise dengue and malaria data were obtained from the State Vector Borne Disease Control Program, Mizoram.

Results: The Mann-Kendall test indicates that compared to maximum temperature, minimum temperature during the monsoon period is increasing ($p < 0.001$). The Sen's slope estimation also shows an average annual 0.02°C ($0.01 - 0.03$ at 95% CI) monotonic increasing trend of minimum temperature. The residuals of Sen's estimate show that temperature is increasing at an average of about $0.1^{\circ}\text{C}/\text{year}$ after 2007. Trends indicate that both rainfall and humidity are increasing ($p < 0.001$); on an average, there is a 20.45 mm increase in monsoon rainfall per year ($5.90 - 34.37$ at 95% CI), while

there is a 0.08% (0.02 – 0.18 at 95% CI) increase in relative humidity annually. IFSR data shows that there is an annual average decrease of 162 sq.km (272.81 – 37.53 at 95% CI, $p < 0.001$) in the dense forest cover. Mizoram in 2012 was the last state in India to report the incidence of dengue. Malaria transmission continues to be stable in Mizoram; compared to 2007, the cases have increased in 2019.

Conclusion: Over the study period, there is an $\sim 0.8^{\circ}\text{C}$ rise in the minimum temperature in the monsoon season which could have facilitated the establishment of *Aedes aegypti*, the major dengue vector in Mizoram. In addition, the increase in rainfall and humidity may have also helped the biology of *Ae. aegypti*. Deforestation could be one of the major factors responsible for the consistently high number of malaria cases in Mizoram.

Keywords: Climate change; Deforestation; Dengue; Malaria; Mizoram

Introduction

Climate change manifested by an increase in temperature has a direct influence on the transmission dynamics of the vector borne diseases by affecting mosquito density, survival, vectorial capacity and the extrinsic incubation period of the pathogen [1-4]. It is well documented that temperature has a non-linear effect on the transmission of mosquito-borne diseases, and the temperature threshold for optimum growth varies among the mosquito species, and the pathogen they harbor [5]. The optimum temperature where the reproduction number (R_0) peaks for *Ae. aegypti* and *Ae. albopictus* (dengue vectors) are 29°C and 26°C respectively, while for *Anopheles gambiae* (African malaria vector), the R_0 peaks at 25°C [1-3, 6, 7]. At temperatures higher and lower than the optimum, the R_0 is suppressed [1-3, 8-10]. The higher optimum temperature for dengue results in increased incidence at higher temperature range [1]. In some places, high dengue risk is also associated with vapor pressure and humidity [11, 12]. Multiple global climate models predict future climate to be more amenable for malaria transmission in the tropical highland regions [13]. Environmental change globally is greatly driven by anthropogenic land use [14, 15]. Deforestation, a major outcome of anthropogenic land use is linked with providing optimal conditions for the spread of mosquito borne infections such as dengue and malaria [16]. In amazon, deforestation has been shown to drive malaria transmission [17].

As per WHO, 93% of the population in India are at risk of malaria [18]. From 2000 to 2017, malaria morbidity and mortality in India have declined by 59% (2.03 million cases to 0.84 million) and 89% (932 deaths to 103) respectively [19]. While malaria has declined, dengue cases have continued to increase in India; from an incidence of 6.34/million in 1998-2009 to 34.81/million in 2010-2014 [20]. A nation-wide serosurvey carried out in 2017-18 estimates dengue seroprevalence in India to be 48.7%, with major prevalence in Southern region (76.9%) followed by Western

(62.3%) and Northern (60.3%), and the least in North-East (NE) region (5%) [21] that includes Mizoram.

Mizoram, located between latitude 21°58'N - 24°35'N and longitude 92°15'E - 93°29'E is a NE state that lies within the Indo-Myanmar region, and one of the four biodiversity hotspots in India [22]. Mizoram's altitude ranges from 500-2157m, and the tropical humid climate of Mizoram is characterized by short and dry winter (part of November to February, 11–24 °C), and long summer (March to September, 18–33 °C) [22]. The monsoon season starts in May and extends till September, and June to August account for ~80% of rainfall. The tribal population of the State is 94.43% [23]. Malaria is endemic in Mizoram for many decades, and is one of the highly malarious states in India [24]. While the malaria cases have continued to steeply decline in other states, Mizoram continues to have a stable malaria transmission. Compared to 2018 (3937 cases), the malaria cases more than doubled in 2019 (8543 cases) (Source: SVBDCP). Mizoram is also a key entry route for the drug resistant malaria parasites from Myanmar to mainland India [24]. Until the emergence of dengue in 2012 [25], malaria remained the major vector-borne disease in the state. In recent years, dengue has established as another important vector-borne disease in Mizoram. To assess the impact of climate change on vector-borne diseases in Mizoram, climatic variables of Mizoram from 1979-2014, and deforestation (1991-2019) were analyzed to see their association with epidemiology of dengue and malaria

Methods

Datasets

The NE state of Mizoram shares its international borders with Bangladesh and Myanmar in the west and east respectively. The Northern region shares domestic borders with Tripura, Assam, and Manipur (**Fig. 1**). Temperature, rainfall and humidity data of Mizoram from 1979-2014 were obtained from the National Centers for Environmental Prediction (NCEP) Climate Forecast System Reanalysis (CFSR) through <https://globalweather.tamu.edu/portal> and analyzed [26]. Mizoram receives 85 percent of its rainfall during the monsoon season (May-September) and as vector borne diseases usually peak during the monsoon season, only the meteorological conditions of the monsoon season were used for long-term temporal analysis. To avoid spatio-temporal interpolation errors and ensure statistical significance while averaging dynamic climatic parameters of multiple locations, the climatic data of the central location of Mizoram was used as a representative of the entire State. Furthermore, forest cover data of Mizoram was extracted from India State of Forest Reports (ISFR) (<https://www.fsi.nic.in/>) and Land Processes Distributed Active Archive Centre (LP DAAC). Although the Forest Survey of India (FSI) assesses the forest cover since 1987 and publishes reports on a two-year cycle, the methodology of assessing forest cover has been changed from time to time that results in varying long-term trends in the forest cover. Therefore the study uses only dense forest cover (> 40% canopy cover) for long-term forest cover change analysis. In addition, the study used Percent Tree Cover datasets of Advanced Very High Resolution Radiometer (AVHRR) and Moderate Resolution Imaging Spectroradiometer (MODIS) missions to understand the forest cover dynamics [27, 28] to study the association between deforestation and incidence of vector-borne diseases. Year-wise dengue and malaria data were obtained from the State Vector Borne Disease Control Program (SVBDPC), Mizoram.

Analysis of long-term trends of climate variables and deforestation

The study used MAKESENS template (<https://en.ilmatietaenlaitos.fi/makesens>) to estimate long-term trends in the climate (temperature, rainfall, humidity) and forest cover variables. The trend and its magnitude are estimated through Mann-Kendall test and Sen's slope method. Both the methods are nonparametric tests where the Mann-Kendall test is good to detect monotonic trend and the Sen's slope method is a linear model which is suitable for estimating true slope of an existing long-term trend (as change per year).

Mann-Kendall Test

The Mann-Kendall test is widely used to determine whether a time series has a monotonic upward or downward trend [29]. The non-parametric Mann-Kendall test does not require the data to be linear or normally distributed, has low sensitivity to abrupt breaks in time series, and is well suited to study the nature of climatic variations in Mizoram. For the time series x_1, \dots, x_n , the Mann-Kendall test uses the following statistic:

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^n \text{sign}(x_j - x_i)$$

If $S > 0$, then the later observations in the time series tend to be larger than those that appeared earlier in the time series, while the reverse is true if $S < 0$. The variance of S is calculated by

$$\text{var} = \frac{1}{18} \left[n(n-1)(2n+5) - \sum_t f_t(f_t-1)(2f_t+5) \right]$$

where t varies over the set of tied ranks, and f_t is the frequency of appearance of rank t . The value of S and var are used to compute the test statistics Z as follows:

$$z = \begin{cases} (S - 1)/se, & S > 0 \\ 0, & S = 0 \\ (S + 1)/se, & S < 0 \end{cases}$$

where se = the square root of var. The presence of a statistically significant trend is evaluated using the Z value. If Z appears greater than $Z_{\alpha/2}$ (α denotes the level of significance), then the trend is considered as significant. The value for $Z_{\alpha/2}$ is obtained from the standard normal cumulative distribution tables for α - 0.001, 0.01, 0.05 and 0.1. At α - 0.01, there is a 1% probability that the values x_i are from a random distribution, and an error is made in the direction of the trend; thus the existence of a monotonic trend is highly probable.

Sen's Slope

As the least squares estimation method is sensitive to outliers, and not valid when the data elements do not fit a straight line, the nonparametric Sen's slope method was used for the set of climate and forest pairs (i, x_i) where x_i is a time series. Sen's slope is defined as

$$Q_i = \frac{x_j - x_k}{j - k}$$

where $j > k$. The Sen's slope is the median of the N values of Q_i . The N values of Q_i are ranked from the smallest to the largest. The confidence interval for Sen's slope can be calculated as (lower, upper) where

$$N = C(n, 2) \quad k = se \cdot z_{crit}$$

$$lower = x_{(N-k)/2} \quad upper = x_{(N+k)/2+1}$$

N = the number of pairs of time series elements (x_i, x_j) where $i < j$ and se = the standard error for the Mann-Kendall Test.

Results

The long term average (1979-2013) of meteorological data of the monsoon season (May to September) shows that Mizoram receives an average rainfall of 2647 mm, and the average relative humidity is 87%. The average maximum and minimum temperature during the monsoon period (May-September) is 29.5⁰C and 21⁰C respectively. The average distribution and trends of maximum temperature, minimum temperature, rainfall, and relative humidity of Mizoram (central region) during the monsoon season from 1979-2013 are shown in **Fig. 2**. The trend shows that the recorded annual values of rainfall, temperature and humidity deviate in a cyclical manner, and are gradually increasing in the recent years. The time series values of temperature, rainfall and relative humidity show an increasing trend. The Mann-Kendall test indicates that compared to maximum temperature, minimum temperature during the monsoon period is increasing ($p < 0.001$). The Sen's slope estimation also shows a monotonic positive (increasing) trend of minimum temperature at the rate of 0.02⁰C per year (0.01 - 0.03 at 95% CI). Analysis of the residuals of Sen's estimate indicate that minimum temperature is increasing at an average of about 0.1⁰C/year after 2007. The annual series of maximum temperature (usually denotes the day time) do not show a positive or negative trend of statistical significance. The residuals of Sen's slope estimator indicate a clear decreasing trend in the early 80's, and is then increasing, thus the trend is neither positive nor negative. However, the maximum temperature in the monsoon months show an increasing trend after 2005. Even though, the total rainfall and relative humidity during the monsoon period vary from year to year, trends indicate that both rainfall and humidity are increasing ($p < 0.001$); on an average, there is a 20.45 mm increase in rainfall per year (5.90 – 34.37 at 95% CI), while there is a 0.08%(0.02 – 0.18 at 95% CI) increase in relative humidity annually.

The distribution and trends of forest and tree cover in Mizoram from 1987-2019 are shown in **Fig. 3**. More than 85% of the total geographic area of Mizoram is covered by forest. Satellite observations show that the average percent tree cover of the state is more than 80%. Trends indicate that both the forest and tree cover density are gradually decreasing. Strikingly, the proportion of dense forest cover has drastically reduced after 2000. From 9,780 sq.km in 1999, there is an alarming decrease in the areal extent of the dense forest cover to 5,957 sq.km in 2019. The statistical trend analysis of the last two decades of the FSI data shows that there is an annual average decrease of 162 sq.km (272.81 – 37.53 at 95% CI, $p < 0.001$) in the dense forest cover, and the decrease is notably high in the early part of this century. **Table 1** shows the summary of Mann-Kendall test and Sen's slope estimate of climate and forest cover variables.

Figure 4 shows the distribution of malaria (2007 – 2019) and dengue cases (2012 – 2019) in Mizoram. The first report of dengue was in 2012 (6 cases), and the cases gradually increased and peaked in 2016 (580 cases), and is followed by a gradual decline with 42 cases in 2019. Malaria cases have been consistently high, and except in 2018, every year in the study period has reported >5000 cases. The gradual increase in cases from 2007 to 2010 coincides with resistance to chloroquine, and the reduction in cases, starting from 2011 coincides with the introduction of Artemisinin Combination Therapy (ACT) (Artesunate-Sulphadoxine Pyrimethamine) as the first line antimalarial. Again, the sharp increase from 2013 to 2015 coincides with the resistance to the partner drug Sulphadoxine Pyrimethamine (SP), and replacement of SP with Lumefantrine in the ACT. The substantial decrease in malaria cases from 2016 onwards could be attributed to the efficacy of the ACT. Compared to 2007, the malaria cases in 2019 are higher.

Discussion

Even though dengue fevers were first reported in India in 1946 [30], the first epidemic of dengue hemorrhagic fever occurred in 1963-64 in the Eastern coast [31-36], and by mid 2000s, dengue has spread to most parts of the country [37]. Mizoram in 2012 was the last state to report the incidence of dengue. The factors affecting dengue incidence and spread are multifactorial: temperature, rainfall, host immunity, vector-control measures implemented, urbanization, altitude, travel, and socio-economic factors, all affect disease transmission. Among the different factors, temperature is the key determinant that determines the incidence and spread of vector-borne diseases, as it directly affects the fitness of the vector and the pathogen [1-3, 8-10]

Epidemiological studies carried out in early 2000s in Mizoram reported only the presence of *Aedes albopictus* [38]. However, a district-wide survey carried out in 2009-11 identified the presence of *Aedes aegypti* in Mamit district, and *Ae. albopictus* in three (Aizawl, Lunglei and Serchip) of the six districts surveyed [39]. The cooler optimum temperature (26°C) for R_0 peak of *Ae. albopictus* would have enabled its earlier spread in Mizoram. Even though, dengue cases were first reported in 2012, the first report of dengue outbreak was reported in August 2016 in Aizawl, the capital city of Mizoram, and *Ae. aegypti* was determined as the vector responsible [40]. Aizawl's summer temperature ranges from 21-27°C, and is the lowest among all districts in Mizoram [39]. The optimum temperature range for survival of *Ae. aegypti* is 21.3–34.0°C [7]. The optimum temperature for peak R_0 of *Ae. aegypti* is 29°C [1-3, 6], and clearly, the 1°C increase in the minimum temperature over the last three decades in the monsoon season would have facilitated the establishment of *Ae. aegypti* in Mizoram. Simulation model using temperature as a covariate shows a strong positive correlation with extrinsic incubation period of the virus and temperature [20]. In India, dengue outbreaks are predicted to occur during monsoon and post-monsoon seasons

[41]. In addition to temperature, rainfall [20, 42, 43] and humidity [44-47] have also been shown to have a positive correlation with dengue incidence. However, excess rainfall could also have a deleterious effect by flushing out the aquatic stages from the breeding sites [48]. In Mizoram, from 1979-2013, there was a 3% increase (86 - 89%) in relative humidity, and a 700 mm increase (2250 – 2950 mm) in monsoon rainfall. Clearly, it is evident that in the last three decades, there has been a significant change in the climatic variables favoring the growth of dengue vectors, especially *Aedes aegypti*. Until 2011, *Ae. aegypti* was not a vector in Aizawl [39], and its introduction in this decade should also be attributed to other non-climatic factors - increased local and international travel, urbanization, globalization, trade, change in demography, and lack of regular domestic water supply [49]. Infected travelers are an important source of dengue transmission [50], and in recent years their numbers have increased [51].

From 0.72 per million in 1998, incidence of dengue cases has progressively increased to 61/million population in 2013 [20], and sero-surveillance carried out in 2017-18 indicates a seropositivity of 48.7% in India [21]. In addition to human migration and urbanization, this rapid spread of dengue across all parts of India might have been facilitated by the change in favorable climatic conditions, as observed in Mizoram. Vector borne diseases, especially malaria and dengue, are highly correlated with El Niño and La Niño events [52] [41].

Analysis of past dengue outbreaks and experimental studies show that *Aedes aegypti* is the dominant driver of large-scale outbreaks [53]. Future studies should focus on the distribution and density of *Ae. aegypti* and *Ae. albopictus* in Mizoram. Studying the spatio-temporal trends of *Aedes* population will help evaluate and course-correct the vector control strategies in the state, and may also help predict future disease trends.

Malaria is the major vector-borne disease, and a serious public health concern in Mizoram. *Plasmodium falciparum* is responsible for the majority of the cases, and accounts for >90% of the malaria cases [22]. Based on the cumulative cases from 2008-2018, and population density, 1.1% of the total population is estimated to be affected by malaria on an average per year, and is the second most malarious state in NE India after Meghalaya [24]. Over the last decade, there has been a steep fall in malaria cases throughout India, mainly attributed to the public health measures and introduction of artemisinin combination therapy, but in Mizoram, compared to 2007 (470 cases / 0.1 million population), the cases have increased to 659 cases / 0.1 million population in 2019. This is the only state in the country where cases in 2019 (659 cases / 0.1 million population) have nearly doubled from 2018 (361 cases / 0.1 million population). The NE States have thick forest cover, and have significant tribal population. The forested rugged terrains, poor accessibility, frequent natural hazards and very efficient anthropophilic vectors (*An. baimaii* and *An. minimus*) greatly hinder malaria control efforts in this region [24]. In addition, significant deforestation in Mizoram – a net decline in forest cover (1079 sq.km) from 1987-2019, the highest among all states could be an important factor in malaria transmission. Importantly, as per FSI reports, the dense forest cover has been decreased three times higher than the net forest cover from 2001 to 2019 (~3000 sq.km). Shifting system of agriculture, also called as Jhum cultivation is the major reason for deforestation in Mizoram. In this system, the selected forest area is cleared of trees and vegetation, and then burnt to increase the potash content in soil for fertility. Crops are then grown in this land for a limited period of years [54]. The other direct causes of deforestation in Mizoram are fuel wood collection, excessive harvesting/extraction of timber and non-timber forest products [55]. The underlying and indirect reasons for deforestation include unemployment, lack of awareness, lack of industries and poor road connectivity [55]. Deforestation reduces biodiversity

and favors vector replication as it upsets the ecological balance [56]. Loss in forest cover will affect the vector breeding sites, change the microclimate suitability for the parasite development, and increase human contact and biting rates [57, 58]. Studies have shown that deforestation is linked to increased malaria incidence [17, 59-61]. In Mizoram, the effect of climate change on malaria transmission is hard to assess as it is endemic in the state for many decades. However, the continuous stable transmission of malaria in this region, while it has steeply decreased in other parts of the country strongly suggest an important association between deforestation and malaria transmission. Deforestation has also been suggested to lead to an increase in temperature, especially at a local level [62]. The consistent decrease in forest cover in Mizoram may also have contributed to the local increase in temperature, underscoring how a change in one variable can affect the delicate balance in the ecosystem.

Conclusions

Even though the transmission dynamics of vector-borne diseases is multifactorial, temperature is a key determinant, and the $\sim 0.8^{\circ}\text{C}$ rise in the minimum temperature in the monsoon season over the study period could be a major facilitating factor for the establishment of the dengue vector in Mizoram. Continuous and significant deforestation, especially dense forest over the years may have played a direct role in malaria incidence, and also contributed to the local rise in temperature.

Abbreviations

IFSR: India State of Forest Report; FSI: Forest Survey of India; LPDAAC: Land Processes Distributed Active Archive Centre; AVHRR: Advanced Very High Resolution Radiometer (AVHRR); MODIS: Moderate Resolution Imaging Spectroradiometer; SVBDCP: State Vector Borne Disease Control Program; *Ae. aegypti*: *Aedes aegypti*; *An. minimus*: *Anopheles minimus*

Declarations**Ethics approval and consent to participate**

Not applicable.

Consent for publication

Not applicable.

Availability of data and material

The materials and other data generated from this study are available from the corresponding author on reasonable request.

Competing interests

The authors declare that they have no competing interests.

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Authors' contributions

PBN conceptualized and wrote the manuscript, BK analyzed the data, made the figures and wrote the manuscript, DKS, PL, LP and KK helped in literature review and wrote the manuscript

Availability of data and materials

The datasets used and analyzed using the current study are available from the corresponding author on reasonable request

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Table 1: Mann-Kendall test and Sen’s slope estimate of temperature, rainfall and humidity of monsoon period and dense forest cover

Figure Legends

Fig. 1. Location and general topography of Mizoram. Inset map shows the location of Mizoram in India. The light green tint shows the density of natural vegetation. The dark brown line denotes international boundary line

Fig.2. Long-term (1979-2013) average distribution and trends of climate variables. Red line, green line, light blue bars and orange dots denote maximum temperature, minimum temperature, rainfall and relative humidity respectively of central Mizoram during the monsoon season (May to September). The dotted lines of respective colour show the estimated trend of maximum temperature (no trend), minimum temperature (increasing), rainfall (increasing) and relative humidity (increasing) through the Sen’s slope method.

Fig. 3. Long-term distribution and trends of forest and tree cover in Mizoram (1987-2019).

The tinted (light green) area shows the temporal pattern of the total forest cover, and the solid green line represents the proportion of dense forest cover (>40% tree cover). The dotted green line shows the decreasing trend of dense forest cover. The blue dot and red diamond markers indicate the average percent tree cover in Mizoram estimated through satellite missions of MODIS and AVHRR respectively.

Fig. 4. Temporal distribution of malaria and dengue in Mizoram (2007-2019). The blue bars denote dynamics of total number of Malaria cases and the solid red line represents the emergence and peak of Dengue cases in the State (Source: State Vector Borne Disease Control Program).