# The environmental Risk Factors Significant to *Anopheles* Species Vector Mosquito Profusion, *P.falciparum, P.vivax* Parasite Development, and Malaria Transmission, Using Remote Sensing and Gis: Review Article

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## Abstract

The prevalence of spatial distribution and the seasonal variation of malaria epidemics in India have been most significantly determined by the environmental variables including climate, landscape, and the man made factors. The risk factors are acting as decisive factors on the development of *Anopheles* genus mosquitoes. The landscape environments (slope, altitude, land use / land covers), human settlements proximity to permanent water bodies of mosquito breeding habitats (lake, pool, streams, rivers, tanks etc), agricultural wet rice cultivation land, land use dynamics, population density, urbanization, increase of man water resource projects. The coefficient model of climate determinants (rainfall and temperature) with the mosquito abundance are highly associated with the Normalized Difference Vegetation Index (NDVI) value derived from multispectral satellite data, and is useful in the assess the ground situation of *Anopheline* malaria vector mosquito larval abundance 7 days in advance in the wet irrigation rice fields using remotely sensed data. The result of logistic regression model provides the spatial agreement between the observed and predicted values of larval index within buffer zones 2.5 KM around the trap location in the wet cultivation rice fields much appropriate for *Anopheline* vector mosquito breeding. However, transmission of *Plasmodium vivax* requires a minimum average temperature 15.0°C and transmission by *Plasmodium falciparum*, requires a minimum average temperature of 19.0°C. The *P.vivax* vector requires 15 to 25 days to complete the parasite development cycle within the temperature range between 15°C to 20°C, the relative humidity for both species requires range between 55% to 80% and its life cycle may be completed within 6 to 10 days, if the temperature range remains within 25°C to 30°C. Multivariate analysis could be predicted accurately the relative abundance of malaria vectors breeding habitats suitability and epidemics. The malaria cases in the endemic districts and the relative abundance of the malaria vectors are directly controlled by the climate variables with >85 % accuracy.

***Key words:*** *Anopheles genus mosquitoes, malaria vector breeding habitats, malaria endemic, environmental variables, climate factors, multivariate analysis, remote sensing, and GIS*

## Introduction

Malaria has been one of the most potent scourges of human population from time immemorial, and it remains, with tuberculosis and ADIS, one of the three major communicable diseases. Even a century after the discovery of malaria transmission through mosquitoes during 1897, malaria has stubbornly been endemic major public health problem in India, predominantly, in East, North East, Central, and North West India [1-4]. Malaria transmission in the tropical countries has been spatially most significant with poverty, ignorance, lack of knowledge, seasonal huge population movements, and socio-economic deprivation among the community,

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and the environmental variables including climate, landscape, and the man made factors, and are influenced decisive factors on the development of *Anopheles* genus vector mosquitoes, and are the intermediate host for the transmission of malaria parasites [3-5]. The landscape environments (slope, altitude, land use /land covers), human settlements proximity to permanent water bodies of mosquito breeding habitats (lake, pool, streams, rivers, tanks etc), agricultural wet rice cultivation land use, population density, urbanization, increase of water resource projects are added fueling to the vector abundance [6-9].

The developmental activities including urban growth, urban sprawl, urban agglomerations, and the related urban developments are the important witness of constructive progress of the country. However, the health issues of urban environment concern, the mosquito nuisance and the urban malaria has been a big challenging problem in India. The estimated annual prevalence of malaria was many folds approximately 75 times higher in 1950 than in 2019, and it has been gradually reduced through the national malaria programs [1,2,4]. The health programmers have joint hands with the environmental scientists to apply remote sensing, GIS, and GPS technology for mapping malaria mosquitogenic conditions in both rural and urban setup. Land use / land cover categories and has also been made spatial auto correlation with malaria endemic situation [9], examine the close association between the environmental changes and the malaria prevalence and the determinants of climate variables and malaria epidemics [10,11]. Remote sensing and GIS highbred techniques could be provided the relevant surrogate information relating to the spatial variation of the climate variables (land use / land cover categories, including wet irrigation rice cultivation areas) the malaria mosquito breeding habitats and the probability of malaria transmission risk [3,8,12,13]. It has been potentially used in delineating the mosquitogenic conditions in the urban environment [9], mapping the environmental variables [10], land use / land cover classes [14-16], and mosquito breeding habitats [6], breeding surfaces areas [11], and correlate with malaria cases [17-21]. The specific aquatic habitats with a particular wet irrigation rice plant communities support malaria vector mosquito juvenile breeding habitats [7,1318]. The Normalized Difference Vegetation Index (NDVI) values (-1 and +1) derived from the Multispectral Landsat TM satellite data[22-27] and, the Indian remote sensing of IRS LISS-I, LISS-II, LISS-III, and WiFS data were used to study the suitability of malaria mosquitoes vector breeding habitats[7,9].

The spatial distributions of malaria epidemics are not spatially ubiquitous, and have been continuously registered confirmed cases in the tropical regions, particularly, where the environmental variables and climate parameters are constructively supported. The study of land use / land cover changes, climate determinants and landscape ecology of mosquito immature breeding habitats and malaria epidemics, and the environmental determinants of both malaria endemics and epidemics in the developing world including India for the several decades [20,4,26]. Remote sensing and geographical information systems (GIS) has essentially applied in studying the landscape environment, vector ecological, and climate determinants and its influences on the spatial distribution, and seasonal variation of malaria parasitic disease transmission with reference to space and time [7,15,16.23,24,27]. The spatial auto correlation between vectors and malaria epidemics, the environmental factors and vector abundance are the fundamental keys to prevention measure to malaria control. There have been several research studies established that mosquito abundance is highly determined by the climate variables, particularly, the duration, intensity, and amount of rainfall, temperature, and relative humidity, and as a result, the total areas of larval breeding sites are influenced the spatial relationship between larval habitat availability and adult mosquito abundance [28]. Remote sensing data pooled in the spatial database engine was used to mapping and analyzing layers of thematic map information pertaining to immature larval habitats, land use / land cover categories, human settlements, population density, housing structures, water features, and hydrologic schemes were overlaid with adult mosquito abundance [7,13]. The environmental heterogeneity has effected on malaria vector mosquito juvenile larval habitats, and the spatial distribution of *An. gambiae* and *An. funestus* adult female mosquitoes, the most important malaria vectors [28]. A geo-spatial analysis method has been used to study the spatial autocorrelation between the adult mosquito abundance among houses in the settlement clusters and the malaria epidemics with cross-correlation between adult mosquito abundance and geo-environmental risk factors, statistically significant [7,25].

### Rationale of the Study

This study is planned to review the efficacy of remote sensing data utility, GIS techniques for geographical analysis of malaria transmission, and assessing the people at risk of parasitic infection within the endemic regions and the non endemic regions. The results obtained from the study provides information for gaining a better understanding of the spatial distribution of malaria parasitic disease transmission and the disease diffusion with site specifications of different geographical locations at different time points. The significant studies were made to attribute the spatial relationship between the geo-climate variables and the malaria disease transmission [17,18,19,29-31], Land use / land cover changes and increasing the spatial extension of vector breeding habitats, the environmental determinants and the vector abundance / vector density [20,32-35]. The low cost remote sensing and GIS for mapping malaria transmission and gaining the knowledge on the environmental aspects of malaria vector mosquito habitats, vector abundance, and vector density are increasingly important for designing a rapid method of disease surveillance for monitoring and control.

### Prevalence of malaria epidemics problem in India

The malaria endemic problem is major concern in the 14 states and the highland areas of north eastern states, central and eastern states, and the eight other states of India have highly public health important. Malaria epidemic has drastically reduced in India 112.5 times for the past 70 years, and the graph illustrate the decline of malaria epidemics in India for the past 30 years, at the same time, India alone has contributed 75 % of the burden of malaria epidemics in the South East Asia [1,2]. The Indian subcontinent has malaria endemic problems especially in the North-eastern states (Assam, Arunachal Pradesh, Manipur, Meghalaya, Nagaland), Orissa, Chhattisgarh, West Bengal, Rajasthan, Gujarat, Jharkhand, Karnataka, Madhya Pradesh, Uttar Pradesh, Haryana, Maharashtra, Tamil Nadu and Andhra Pradesh. The map explains that malaria prevalence is highest in Odisha (formerly Orissa) state, and followed by Jharkhand, Chhattisgarh, Madhya Pradesh, Gujarat, Maharashtra, West Bengal, Uttar Pradesh, Rajasthan, Assam, Andhra Pradesh, Haryana, Meghalaya, and so on. Based on the malaria occurrences of malaria API index value (Annual Parasite Index) for different states at the district level, the problematic endemic states of was used for the spatial analysis of malaria transmission endemic risk zones.

### Geo-Spatial predictive model for analyzing the malaria epidemic transmission trend

The wealth of malaria vectors are influenced by the climate, and environmental variables, immature malaria vectors larvae are mostly presented in the small water pools nearby human activities [34,35,39]. The geo-spatial analyses of malaria epidemic transmission have been provided the trend of future spatial diffusion accurately, and added improved precise result with predictive models, proviso, it needs to improve with refining the existing models with the empirical knowledge of environmental observations, ground truth studies, and laboratory experiments. The GIS was used to construct the thematic maps of different ecological zones, and epidemiological mapping of malaria distribution with respect to space and time. GIS techniques were extended to spatial analysis of vector abundance, vector density, parasite ratio, the community at risk of malaria disease transmission as perennial, seasonal, bi-seasonal, sporadic epidemics etc., it allows the layers of information of different mosquito species, different environmental variables (mosquito habitats, breeding sources, mosquito ecology, site specific location) and climatic variables (Temperature, relative humidity, saturation deficiency and rainfall). The indication of reproduction rate (*Ro*) of the disease is warning signal for malaria epidemic situation when *Ro* value is greater than (0), in a Boolean situation, where climate is suitable (1) or unsuitable

(0). The predicted Boolean thresholds value of the combination of temperature–rainfall was considered for mapping the probability of malaria transmission based on the threshold value 1 is suitable and where malaria is expected to occur, and value 0 means, malaria is expected not to occur, would be ignoring climate, landscape, and environmental spatial variations, and natural uncertainty. A fuzzy analysis provides the key elements for mapping the areas of climatic conditions where most suitable, unsuitable, moderately suitable or in between, semi-suitable for malaria vector species (A*nopheles genus)* and the malaria disease transmission. The geo-spatial analysis of superimposed overlay thematic maps of climate variables on the malaria epidemic prevalence map to construct a spatial modeling for prediction of both horizontal and vertical magnitude of malaria transmission risk in the both endemic and non-endemic regions [3,7,1719,29-31,37]. The results of the documents of published research works show that the geographical distribution of malaria transmission and spatial diffusion are greatly influenced by climate determinants, and the environmental variables.

**Land Use / Land Cover Transforms and Malaria epidemics**

Land use / land cover changes (dry land agriculture to irrigation wet irrigation crop cultivation) and the growth stage of land cover changes of vegetation types may perhaps play an important role in determining vector abundance, irrespective of their association with other variables [7,13,34]. Vegetation is playing important role in the vector potential, which surrounds the environment for breeding sites (and thereby provides potential resting sites, sugar-feeding supplies for adult mosquitoes and protection from climatic conditions) may also be important in determining the abundance of mosquitoes associated with the breeding site [28-39]. The early period of irrigation rice crops wet cultivation 2-6 weeks provide potential breeding sites for *Anopheles mosquitoes*, it has been changed when the rice plants grownup, and form a dense canopy cover over the water protected from larvae breeding (Palaniyandi M, 2014, Wood BL, et al., 1991 and 1992). The regional climate change (temperature, rainfall, and humidity) and land use / land cover changes are fueled to promoting a new emerging vector borne diseases in many newer areas [3,12,21]. There have been evidenced by growing incidence of malaria epidemics in different parts of our country, and more frequently in the regions where the extended irrigation areas by construction of water resource development projects/ irrigation canals, and as a result, has been fueled for malaria vector mosquito abundance and it has been evidenced that a few classical studies were conducted on malaria and JE epidemic in Thar Desert in India [3,12,21], respectively, the *Anopheles* genus malaria vector mosquitoes and *Culex tritaeniorhynchus* JE vector mosquitoes found heavy breeding in the areas where the introduction of wet irrigation through the Indira Gandhi water resource project in the absolutely dry region/ semi desert areas of Rajasthan state in India. The result shows that water leakage throughout the irrigation canals and drinking water lines, and land use / land cover changes from dry land to wet irrigation rice cultivation land, and thus, the disease outbreak in and around of the buffer zone of 2.5 Km of water resource projects (Irrigation Canals, lake, perennial or semi-perennial river / stream, water pools), and wet irrigation rice cultivation agriculture areas, [3,12,21]. The type of wet irrigation rice crops are the potential breeding sites for *Anopheles* malaria vector mosquitoes, and determining the abundance of mosquitoes associated with the number of breeding sites [13,14].

**Weather determinants and Malaria transmission**

The climate determinants are most important in limiting transmission and distribution of malaria on a large scale than the micro scale [17,19,20,29-31], and hence, meteorological variables (Temperature, humidity, saturation deficiency, and rainfall) are used for predicting the malaria epidemics in advance. The determinants of malaria transmission are very complex and many, such as, mosquito ecology, mosquito breeding habitats, mosquito abundance and density, human activities, human and vector genetics, proximity of human and vector contact, etc., *Anopheles* malaria vector mosquito breeding found primarily in the pools where rainwater collected during the monsoon. It has also been found in large quantities during the inter-monsoonal period, and semi-permanent pools supplied water by the irrigation canals, and rainfall during the monsoon season, and permanent water source in the pools have been found the major breeding grounds for wealthy *Anopheles* immature breeding in Sri Lanka [34], and malaria non-endemic regions turn to become endemics in India [3,12,21].

**Temperature and precipitation influence on malaria transmission**

Temperature has the most significance role in the determinants of the vector survival, parasite development, parasite incubation, and the malaria disease transmission. In India, climate factors, principally, temperature range between 20°C and 30°C most favorable for *Anopheles* malaria vector mosquito species survival and profusion. However, transmission of *Plasmodium vivax* requires a minimum temperature 15°C, and transmission of *Plasmodium falciparum*, requires a minimum temperature of 19°C. The influence of temperature on the transmission cycle of the malaria parasite *Plasmodium falciparum,* and *Plasmodium vivax* are numerous, and has specific impact, and significant effects on the period of parasite development ($n$) and mosquito survival ($p$), which are contributing the most important in malaria epidemics [20]. There have several studies been demonstrated that the annual distribution of precipitation, the amount of rainfall, the number of rainy days, duration and intensity of rainfall, and the atmospheric humidity, and degree of soil wetness has significant effects on malaria prevalence.

**Relative Humidity and Saturation Deficiency influence on malaria transmission**

The rainfall and humidity are important determinants of vector breeding and survival Predictions about the spatial diffusion, direction, magnitude and the suitability specific location for malaria epidemic changes and malaria transmission are drawn largely from temperature dependencies. There were many pioneers carried out studies on the interaction and the influence of climatic conditions with respect to malaria transmission in many of the arid and semi-arid areas [7,12,21]. Rainfall and humidity on vector populations and, the influence of sturdiness of precipitation on malaria transmission current scenarios and the distribution of malaria transmission is most associated with types of landscape environments (rural, high lands and hilly lands). The climatic condition of relative humidity with a particular bandwidth of temperature interval could provide past, present, and the future spatial trends of corresponding spatial movements of malaria occurrence. The life span of the mosquito gets so shortened and the malaria transmission is remarkably diminished where the region has experienced with mean monthly relative humidity is $< 55$ % and $> 80$ % [7,12,21].

**Table.1. A multivariate geo-statistical model for predicting the malaria transmission**

| Model Prediction | | | | |
|---|---|---|---|---|
| **Model** | **R value** | **R square** | **Adjusted R square** | **Std Error of the Estimate** |
| 1 | 0.631a | 0.398 | 0.387 | 5.9753 |
| 2 | 0.683b | 0.467 | 0.456 | 5.3264 |
| 3 | 0.684c | 0.468 | 0.458 | 4.5432 |

a.

Predictors (constant): Temperature, Relative Humidity (RH)

b. Predictors (constant): Temperature, Relative Humidity (RH), Saturation Deficit (SD)

c. Predictors (constant): Temperature, Relative Humidity (RH),Saturation Deficit (SD), Precipitation / Rain Fall (RF)

**The cumulative effects of climate risk factors on malaria epidemic transmission**

The cumulative effects of climate risk factors on malaria epidemic transmission has significantly increased when include one and above risk factors, result shows that the effect of temperature added with relative humidity on malaria epidemics, and has relatively significant p value <0.05, temperature, relative humidity and saturation deficit has good significant r value = 0.683, p value <0.05, and finally, the temperature, add with relative humidity, saturation deficit and precipitation has perfect fit with spatial agreement and statistically significant, r value = 0.684, p < 0.05, and consequently, concluded that the cumulative effects of the climate variables provides not only the good agreements, but also blindly fueled to both vector abundance and disease epidemics. The malaria cases in the endemic districts and the relative abundance of the malaria vectors are directly controlled by the climate variables and the results show that a spatial agreement between the climate variables (independent) and the malaria cases (dependence) was existed [3]. The four possible geo-climatic variables were included in the analysis, out of four variables and the combined effect of multivariables has statistically significant. Pearson's auto correlation coefficient was applied to analyzing the degree of association between the geo-climatic variables (temperature, rainfall, relative humidity, and saturation deficit) and malaria endemic areas. The rural and highland malaria cases India has the spatially significant with the range of population density, it means the village settlement clusters within the range of population between 100 and 1100 has mostly affected by malaria transmission across the country [3]. Multivariate analysis provides the strong relationship between the geo-climatic variables and malaria transmission [3]. The delimitation, stratification and mapping of malaria transmission risk zones and estimation of disease burden and the population at the risk of disease transmission in the community is the datum of baseline for decision making and disease control in the country [7,15,16,22-28].

**Remote Sensing and GIS for mapping of *Anopheles genus* vector mosquitos' ecology**

The multispectral remotely sensed data has been integrated with GIS for mapping malaria vector abundance and the disease epidemics in the rural areas and high land hilly regions for different climate season [3,37]. The normalized differential vegetation index (NDVI) has spatially auto correlated with aquatic environment of *Anopheles genus* vector mosquitoes breading habitats and the model has fitted [7,13,22-28,38]. The *An. culicifacies* – a rural vector, and *An. fluviatilis* a resident of hilly-forested and high lands are causes malaria in the most part of India except the regions at elevations >1800m and in some of the coastal belt (Palaniyandi M, 2013). The the suitable larval habitats are spatially determined by the climate variables (Bhattacharya S, et al., 2006), especially, the amount of rainfall received in the areas, and thus, the adult mosquito abundance was spatially constrained, and has spatially significant [28]. The Normalized Difference Vegetation Index (NDVI) derived from the formula (Infrared band values – red band values / Infrared band values + red band values) and the values of NDVI between (-) 1 and (+) 1. The values are standardized, and are recorded well within these limits for image analysis and interpretation: NDVI value range between 0.0-0.2 appear to bare ground, 0.2-0.7 denotes the presence of actively photosynthesizing plants, and the negative values designates water bodies. The logistic regression model applied to predict the malaria vector mosquitoes immature population in the rice field based on the field collected samples, the result provides the spatial agreement between the observed and predicted values r=0.76 sensitivity, and specificity of 0.78 of larval index [13]. The coefficient model of rainfall and temperature with the mosquito abundance are highly correlated with the normalized difference vegetation index (NDVI) derived from NOAA- AVHRR satellite data, and used to evaluate to project the mosquito larval population profusion 7 days in advance, similarly, a study was conducted to estimate the *Anopheline* malaria vector mosquito abundance in the mosquito habitats of rice fields using remote sensing spectral signatures. The multispectral and multi-temporal IRS WiFS, Landsat-TM data were critically analyzed to mapping land cover categories of swamp and pasture, was found suitable field for the *An. albimanus,* malaria vector species immature larvae, and GIS buffering technique was applied to ground truth field samples to predict high and low vector abundance areas with 90% accuracy [7,26,27].

The NDVI values derived from red and infrared satellite data have been used for mapping the areas suitable at the early stage of rice growing season 2-6 weeks, usually found likely to have ideal grounds for *Anopheles* species higher immature larval mosquito densities (Palaniyandi, M, 2014). The Indian remote sensing satellites (IRS) Linear Imaging and Self Scanning, IRS LISS I, LISS-II and LISS III data were used for mapping 'mosquitogenic' conditions and mapping malaria vector breeding habitats with high and low larval density fields [9,15,16]. The human dwellings and livestock sheds data location map was overlaid on multispectral remotely sensed data, and a linear multiple discriminant analysis was enabled added advantage of mapping the host availability of *anopheles genus breeding* habitats suitability with 85% accuracy, and 100 % sensitivity [32]. The remote sensing of Landsat TM, IRS LISS-I, LISS-II, LISS-III, and IRS WiFS data were used to analyze the areas suitable for mapping vector breeding habitats, and assessing the vector abundance [9,15,16]. Subsequently, it helps to assess the mosquito abundance for mapping the seasonality and the occurrence of malaria transmission intensity [3-8,17,20,23,30-33]. The integrated remote sensing, GIS and GPS have been used for the delineating, portraying mapping, monitoring, continuous surveillance, and risk assessment of epidemic transmission in advance [3-8,15,16,22-28,39].

Mapping malaria risk zones and Forecasting epidemics

Remotely sensed imagery data was used to understand the spatial distribution and the abundance of mosquitoes, mosquito habitats and mosquito borne diseases from large scale (Block or District level) to small scale regional/ state/ national level and also it helps to predictions of malaria seasonality. In the present decade, the satellite image processing and GIS software are widely useful to research workers in developing countries like India where the malaria challenge is the greatest. The logical step towards developing the malaria epidemics risk model based on the environmental determinants and climate variables guide us for decision making to both malaria vector mosquitoes control and the malaria epidemic control at the national level. Considering the climate determinants governing malaria transmission in India, remote sensing and GIS provides datum of information to assess the probability of spatial extent of malarial transmission associated with projected climate changes. Perhaps, based on the current endemic situation and the spatial nature of malaria in India, GIS is applied for spatial and temporal aspects of ecological modeling of malaria transmission risk with readily available climatic variables, and geographic data (land use / land cover) obtained from aerial and space borne sensors, and the epidemiological data obtained from national health services or hospital records. Thus, remote sensing and GIS assist to produce the constructive maps for highlights the "mosquitogenic condition" using geo-climatic variables and the predicted surface of the disease, provided entomological data as the additional data fueled to classify the areas into four categories of region i.e. 1.stable malaria region, 2.epidemic malaria region, 3.malaria free region, 4.spatial sifting or spatial diffusion of malaria region, and further steps to take action plan for both vector mosquito and malaria epidemic control activities.

Conclusion

Beyond mapping, the utility of remote sensing and GIS are widely appreciated for the geographical analysis of the *Anopheles* immature mosquito breeding habitats, and linking with land use/ land cover changes, water bodies, river/streams, etc., and identifying the range of suitable climate variables (temperature, humidity, and saturation deficiency, rainfall) for delineating the malaria prevalence, and diffusion of malaria transmission. It has been used to obtain the information pertains climate, landscape, and the environmental variables relevant to

*Anopheles* species vector mosquitoes breeding potential habitats, immature larvae peaks seasons, mosquito abundance, parasite development, epidemics seasons and spatial variations under the GIS spatial engine. The spatial analysis of malaria cases and climate variables providing the decision support tools for prioritizing the areas for vector control, and prevent the possible outbreaks of malaria epidemic as well. Therefore, the following areas were classified into four major categories, and hence, recommended for the control operation, particularly, vector mosquito immature population in the given areas, such as; (i) coastal region with dense human settlements, (ii) dense population in the foothill areas, (iii) marshy areas / Industrial areas with low density population settlements and (iv) semi-urban in the peripherals of the metropolitan, (v), mega water resource projects irrigation wet cultivation areas, (vi) dense settlement areas with high density population and low income areas, (vii) settlements in the newly developed irrigation canals and wet cultivation areas, (viii) dense forest and high land / hilly areas in the country.

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