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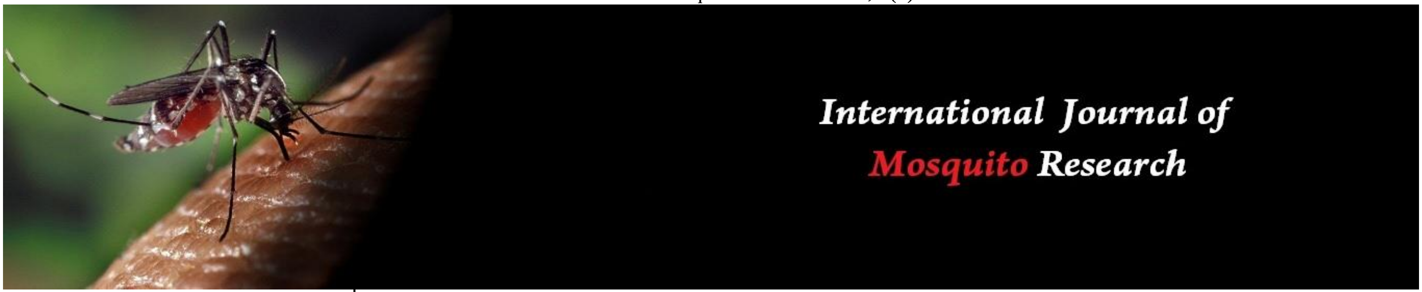

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Integrating geospatial techniques and environmental landscape variables for malaria risk in Vadodara district, Gujarat (India)

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Abstract
The environmental factors play a detrimental role in the development of all i.e. parasites, vectors and host and their relationship may be observed in terms the disease distribution and its pattern also shift. Landscape epidemiology defines how the temporal dynamics of host, vector and pathogen populations act together spatially within an accommodating environment to enable transmission.
Three major environmental landscape variables, *viz*. Climate, Vegetation and Land use are integrated and processed into Geospatial environment to assess malaria risk hazards. The study therefore assesses environmental landscape for mosquito habitat in Vadodara District.
The outcomes suggest that the landscape variables affect the sustainment of mosquito habitats and malaria transmission. The results indicate that the geographical distribution of malaria transmission and spatial diffusion are influenced by geo-climatic variables. It shows distinct seasonal patterns with very high suitability in North and west parts while eastern part have high habitat suitability. A glance at reported malaria cases, malaria seems to be under control excepting pockets with exception of eastern tribal part of district.

Keywords: Geospatial, malaria risk, landscape, Vadodara, epidemiology

1. Introduction
The concept of landscape includes the set of visible features of an area, including landforms, climates, flora and fauna, weather conditions, and human activity. Landscape epidemiology is based on the idea that diseases tend to be spatially limited, and that this spatial variation arises from abiotic and biotic conditions that can be outlined on maps [1, 2]. Taking into account these the severity of malaria is a function of the interaction between the parasite, the anopheles mosquito vector, the human host and the environment. Vector abundance, duration of the extrinsic incubation period and survival rate of the vector, combined with the probability of the vector feeding off a susceptible human host determine the risk of malaria infection, the stability of disease transmission, and seasonal patterns. Many factors are involved in determining the evolution of the parasite, the vector, the human and the environment.
The concept of landscape includes the set of visible features of an area, including landforms, climates, flora and fauna, weather conditions, and human activity. Landscape epidemiology is based on the idea that diseases tend to be spatially limited, and that this spatial variation arises from a-biotic and biotic conditions that can be outlined on maps. elements in landscape epidemiology, assessments of contemporaneous risk and future change in risk should be possible [2] Rainfall, temperature, humidity, vegetation and seasonality in weather and climate can all have an effect on the vector, the parasite and susceptibility of the human to the disease. Over the years, many tools have been developed to monitor these factors which are currently available. Three primary landscape variables, *viz*. Climate, Vegetation and Land use are integrated and processed into Geospatial environment to assess condition favorable for the survival of the malaria and its transmission.
Space and time variability of climate and more generally of environmental variables are expected to affect the morbidity and mortality pattern of human and animal diseases [3, 4, 5] with particular emphasis on vector-borne infections [6, 7]. Among the vector-borne human diseases, malaria has the potential to modify the area of distribution and the epidemic pattern in response to space-time Variation of temperature and rainfall, due to the role of these

Meteorological variables on the ecology and the behaviour of the vectors as well as on their environment [8]. Temperature affects malaria transmission in various ways [9] influencing, for example, the sporogonic period of the Plasmodium parasite, the developmental period of the aquatic stages of the vector and the fecundity of the adult. Rainfall affects malaria acting not only on persistence of water bodies but also on physical and bio-chemical characteristics of aquatic environments hosting the pre-imaginal stages of mosquito vectors. The significant studies were made to attribute the spatial relationship between the Land use / land cover changes, geo-climate variables, and the malaria disease transmission [10, 15].

Climate is one of the direct factors responsible for development of any form of life and its sustenance. This growth and development of various species is directed by the type of interaction of the species in its natural setup of the environment. The changes brought in by the anthropogenic activities have affected this interaction from micro level to global level. These changes are largely attributed to climate change and it is now a matter of concern as it is anticipated that the morbidity and mortality will increase owingo the shift in the climatic characteristics and global disease pattern. The environmental factors play a detrimental role in the development of all i.e. parasites, vectors and host and their relationship may be observed in terms the disease distribution and its pattern also shift. Among this the mosquito menace is one, spreading one of the many of the communicable disease, malaria which is widely spread also endemic and in cases becoming fatal to the community.

Among many diseases one of the global concerns is of vector borne disease-Malaria. Some environmental parameters like humidity, precipitation, temperature, land cover are known to have specific roles in influencing larval habitats and promoting malaria transmissions [16, 17]. The development of the Plasmodium parasites, as well as the sporogonic cycle is also largely temperature-dependent. Because all these environmental parameters are remotely sensed by satellites, remote sensing and Geographic Information System (GIS) are now the essential tools for analyzing, modelling and predicting malaria transmissions. Climate forecast that uses satellite data to predict climatic conditions weeks to months ahead has also become an important method for projecting disease risks into the future as demonstrated by Thomson *et al.* [18]. The satellite data used in this study for modelling malaria incidence include precipitation measured by the Tropical Rainfall Measuring Mission (TRMM) as well as land surface temperature and vegetation index from the Moderate resolution Imaging Spectro radiometer (MODIS) [19, 22]. It is well established that the dominant cause of transmission of malaria is related to the meteorological and environmental factors. The malaria transmission can also be as result attributed to the indoor habitat and the residential layout especially in rural area were in domesticated animals are in backyard or in front of house, again enhance the transmission. Therefore the understanding of the essential condition and environment interaction becomes an essential to understand the geographical phenomenon. Land use and land cover as product of development and available resources for habitat suitability.

1.1 Ecology of Malaria

1.1.1 Land Surface Temperature

Temperature is one of the main indicators as it influences all parts of the malaria transmission cycle. Temperature has an effect on both the vector and the parasite. For the vector, it affects the juvenile development rates, the length of the gonotrophic cycle and survivorship of both juvenile and adult stages with an optimal temperature and upper and lower lethal boundaries.

For the parasite it effects the extrinsic incubation period. Land surface temperature (LST) can be estimated from thermal infrared (IR) sensors. LST is an index of environmental temperature (soil or vegetative) and radiometric surface temperature Goetz *et al*., McMichael *et al*. [23,24] contends that climate variability, specifically temperature, impacts the incubation rate and breeding activity of certain species of mosquitoes and is considered one of the key environmental contributors to malaria transmission. Bi *et al*. (2003) extensive 12-year data analysis of climatic variables and malaria transmission provided evidence of a direct relationship between temperature and the critical stages of mosquito development [25].

1.1.2 Vegetation Index

Vegetation type and growth stage may play an important role in determining vector abundance irrespective of their association with rainfall. At any geographical location, plant production depends on climatic factors such as amount of precipitation received, temperature and altitude as well as human activities, factors which also affect malaria transmission [26]. Therefore, even though vegetation production and malaria transmission may be two completely independent events in nature, they are linked by similar climatic and environmental factors e.g. humidity and temperature. This confluence provides an opportunity to link the patterns of these two natural events, but also the potential to predict likelihood of malaria exposure at any geographical location on the basis of vegetation production trends.

NDVI has also been used as a surrogate for rainfall estimate. Vegetation plays an important role in vector breeding, feeding, and resting sites. A number of vegetation indices have been used in remote sensing and Earth science disciplines. The most widely used index is the Normalized Difference Vegetation Index (NDVI) (Tucker, 1979). Vegetation indices are widely used in different fields of research to assess conditions of plants at different places and times [27]. NDVI Spectral vegetation indices (VI) are algorithms used to analyze, pixel-by-pixel, vegetation biomass and vigor using the digital reflectance values of a combination of spectral bands using mathematical operations. It is determined by transforming the digital values of the visible wavelengths in Channel 1 (0.58 to 0.68 μm) and near-infrared wavelengths in Channel 2(0.72 to 1.10 μm) to achieve representative values of photosynthetic activity. It is expressed as follows:

$$NDVI = \frac{(\text{Channel 2-Channel 1})}{\text{Channel 2+ Channels 1}}$$

It is generally known for most eco-zones, that the higher the NDVI value, the higher vegetation activity, and at 0.4 and greater an area is thought to be almost entirely covered by forest, greenery, or other vegetation [27, 28 29].

1.1.3 Land Cover Type

LCT is directly related to the malaria burden through its impact on breeding sites and on the adult mosquito survival rate and dispersal. Land use / land cover changes (dry land agriculture to irrigation wet cultivation) and the growth stage of vegetation types may perhaps play an important role in determining vector abundance. A combination of regional climate changes (temperature, rainfall, and humidity) and land use / land cover changes have been fueled to promoting the vector borne disease epidemics in newer areas [30, 31]. The LCT dataset is captured at a 1 km spatial resolution and is classified into 17 thematic classes of land use and land cover defined by the IGBP Type 1, global vegetation classification scheme. The scheme includes 11 natural vegetation classes and three developed land classes [32]. Taking into account these elements in landscape epidemiology, assessments of contemporaneous risk and future change in risk should be possible. Rainfall, temperature, humidity, vegetation and seasonality in weather and climate can all have an effect on the vector, the parasite and susceptibility of the human to the disease. Over the years, many tools have been developed to monitor these factors which are currently available. Three primary landscape variables, *viz*. Climate, Vegetation and Land use are integrated and processed into Geospatial environment to assess condition favorable for the survival of the malaria and its transmission.

Table 1: List of land covers parameter with linkage of the malaria, Beck *et al*. [32] (2000)

Remotely Sensed Factors	Description
Vegetation/ Crop style	Breeding, resting and feed habitats.
Vegetation Green up (Response to a precipitation event)	Timing of habitat creation
Deforestation	Habitat creation(Sunlight pools)
Flooded Forest	Mosquito Habitat
Flooding	Mosquito Habitat
Permanent Water	Breeding Habitat
Wetlands	Breeding Habitat
Soil Moisture	Breeding Habitat
Canals/ Ephemeral stream	Dry season mosquito breeding habitat
Human Settlements	Source of infected human, population at risk for transmission.

Table 2: Land Cover Type (LCT) IGBP Type 1 Global Classification scheme, USGS (2007a)

Class	Modis Land cover	Class	Modis Land cover
	IGBP (Type 1)		IGBP (Type 1)
0	Water	10	Grasslands
1	Evergreen Needle leaf forest	11	Permanent wetlands
2	Evergreen Broad leaf forest	12	Croplands
3	Deciduous Needle leaf forest	13	Urban and built-up
4	Deciduous Broad leaf forest	14	Cropland/Natural vegetation mosaic
5	Mixed forest	15	Snow and ice
6	Closed shrub lands	16	Barren or sparsely vegetated
7	Open shrub lands	254	Unclassified
8	Woody savannas	255	Fill Value
9	Savannas		

2. Study Area

Vadodara District is situated between 21° 49´ and 22° 47´ N latitudes and 72° 50´ and 74° 17´ E longitudes, occupying 7,550 sq.km. Area. The district has 12 Taluka among which 4 Talukas are predominantly tribal. Physiographically, Vadodara district is bounded by River Mahi in west and River Narmada and hilly tracks in east. The area is characterized by rugged and undulating topography owing to the offshoots of hilly tracts in the east, covered by the deciduous vegetation. The western region is characterized by the vast alluvial plains. Kawant Taluka has the maximum hilly terrain. The area is drained by the Dhadhar River and Orsang River a tributary of Narmada River.

The climate is characterized by hot summer and dryness in non-rainy season. Vadodara district situated in the tropical region is relatively dry except the month of monsoon i.e. June to September. May is the hottest month while January is the coldest month The temperature in summer may go up to 45 º C and in winter temperature goes up to 10 º C except some extreme. The district received on an average of 1077 mm during the year 2007-2010. The annual rainfall of the district is 475.2mm.About 95% of rain received during South-west monsoon season from June to September.

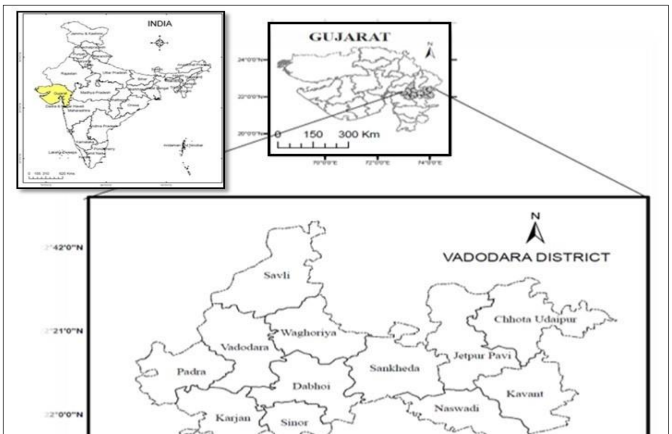

Fig 1: Study Area

3. Objective

The major work is to identify the landscape variables of malaria susceptibility. The study includes identification of breeding habitats of mosquito and creates a risk map to provide reliable information for aadequate malaria control measure. Also, a spatio-temporal study of monthly, seasonal and annual situation is carried out for consistently suitable habitat and complimentary conditions for malaria prevalence through the year.

4. Materials and Methods

Data Set include: The MODIS derived Surface Temperature regime (LST), Vegetation Index (NDVI), accumulated Precipitation (Mean Monthly) from the TRMM and MODIS and Land cover Type I (LCT) data USGS products are used as inputs into the GIS spatial model. Additionally, Epidemiology data is from District Malaria Office, Vadodara for the year 2011. The study considers the data of all the 79 PHC in the study area for the analysis.

4.1 Methodology

For modeling, a variety of data sources are needed to provide the landscape variables Three primary landscape variables, *viz*. Climate, Vegetation and Land use are integrated and processed into Geospatial environment to assess condition favorable for the existence of the malaria and its transmission**.** Primarily the satellite derived precipitation data from the TRMM and MODIS.

The raw values of the integer-based EVI and LST inputs were scaled to science parameter values using factors provided by USGS LPDAAC online documentation USGS. The thematic-based LCT parameter values were defined during the initial preprocessing steps and did not require scaling or converting of digital values.

The LST input was multiplied by a scale factor of 0.02 and further processed to convert from Kelvin temperature units to degree Celsius units. This conversion was necessary to match the standard temperature units commonly used in the region.

All the parameters were subjected to the classification as per their suitability to produce mosquito breeding condition and the sustenance of the habitat individually as established through literature survey. The purpose of the classification scheme was to rank the input's parameter values into defined categories representing different levels of risk of malaria transmission to human populations. The ranked inputs were then processed by the mathematical decision rule to formulize a final risk output.

The Weighted Index Overlay Analysis (WIOA) of three variables was performed to identify the impact of these on malaria susceptibility risk. Weighted Overlay is a technique for applying a common measurement scale of values to diverse and dissimilar inputs to create an integrated analysis.

It is used to identify the best or most preferred locations for a specific phenomenon by simultaneous assessment of many different factors. The thematic layers of all the parameters are reclassified, based on the favorable conditions for the breeding of the mosquito in consultation with experts. The ranked input was then processed by the raster analysis. The higher the malaria transmission risk the higher the score.

The monthly habitat suitability was performed on the basis of the environmental parameters using the accumulated the rainfall, monthly temperature, vegetation density and land cover. According to the favorable condition of breeding sites, eco-regions were identified at district levels. Only in the monsoon month due to cloud cover the values are monthly estimates on the basis of trends in previous year.

Table 3: Temperature ranges that sustain mosquito habitats, Bi *et al*. (2003) [31].

Temperature Range (°C)	Description
>25 °	Needed to complete the mosquito lifecycle and must be maintained for at least nine days
20°-30 °	Optimal temperature range to acquire and transmit the parasite
20°-27°	Extrinsic incubation period of the parasite shortens dramatically
≤16° or ≥ 30°	Negative impact on the growth rate of the mosquito and the propagation rate of the parasite is reduced.

Table 4: Variable influence score for the habitat suitability

Range (LST °C)	Score	Range (NDVI)	Score	Range (LCT TYPE I)	Score
≤18 and ≥35	1	<0.2	1	3,9,10,13,254	2
18-22	2	0.2-0.4	2	5,7,8,14	3
22-26	3	0.4-0.6	3	2,4,6,11,12	4
26-30	4	0.6-0.8	4	1,0,15,16	1
30-35	2	>.8	2		

4.2 Epidemiology Data

The monthly, provincial malaria data compiled from District Malaria Office

Vadodara for the year 2011 at PHC level. The study considers the data of 79 PHC in the study area for the analysis. These data are based on passive detection, mainly established malaria cases reported by PHC. The data do not provide information on parasite species. Thus, the data only include symptomatic cases. There may be a significant number of asymptomatic cases among repeatedly infected adults. In addition, there are an unknown number of symptomatic cases among the migrant and displaced people who may not have sought or received treatment from public health organizations for a variety of reasons. The malaria cases used in the analyses therefore reflect the lower bound of the true prevalence.

5. Results and Discussion

Landscape predictors used in the study has shown the larger affinity of the region to act as favorable ground for the mosquito breeding site. Weighted overlay analysis of three variables is showing a large portion of study area as susceptible to habitat of malaria vectors and transmission. As observed in terms of incidence of malaria in the area, there are 3-4 pockets of high incidence. This also coincides with malaria Susceptible Eco-regions which are identified using three primary landscape variables, *viz*. Climate, Vegetation and Land use. The epidemiological data shows malaria is under control except in few PHCs. This could be either due to under reporting due to Accessibility. Preference to Private practitioner, Diagnosis problem, also important is KAP of people in the area. The outcomes suggest that the landscape variables affect the sustainment of mosquito habitats and malaria transmission. There exists a multitude of other factors and conditions, such as demographics, migration trend socio-economics, biological factors, National Malaria program control and eradication, need to be investigated and incorporated to draw a significant conclusion.

It shows distinct seasonal patterns with very high suitability in North and west parts while eastern part have high habitat suitability in December, January and February months which gradually moves to high and then moderate in months of June to September again changes to high and very high category of habitat suitability.

The varied characteristic of eastern area is rugged topography, high rainfall, forest and dominated by tribal population. Forests with hilly land forms are more malariogenic, as their slopes form small rapid streams that facilitate breeding of efficient malaria vectors [35]. Vadodara district forms a part of the great Gujarat plain. The eastern portion of the district comprising the Chhota Udepur, the Kavant, the Jambughoda and the Naswadi taluka is hilly terrain with several ridges, plateaus and isolated relict hills. Vegetation near human habitation increases the population of forest malaria vectors and thus increases malaria transmission [36].

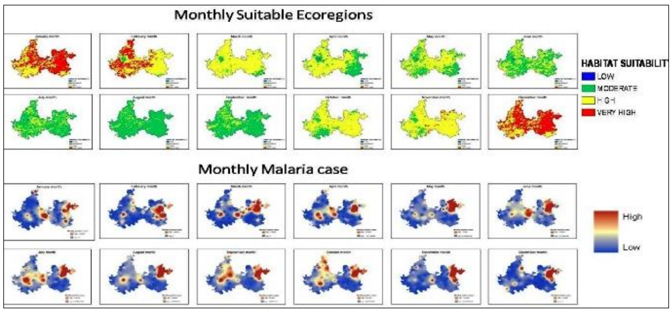

Fig 2: Monthly suitable Eco regions and distribution of malaria cases reported

Figure shows the locations of habitat suitability based on vegetation, land use and temperature and monthly malaria reported cases. The data do not provide information on parasite species.

It shows distinct seasonal patterns with very high suitability in North and west parts while eastern part have high habitat suitability in December, January and February months which gradually moves to high and then moderate in months of June to September again changes to high and very high category of habitat suitability.

A glance at reported malaria cases, malaria seems to be under control excepting pockets with exception of eastern part of district. Overall this may also be due to significant number of asymptomatic cases among repeatedly infected adults and there are an unknown number of symptomatic cases among the migrant who may not have wanted or received treatment from PHC for a variety of reasons like illiteracy and strong traditional beliefs and practices also leads to native treatment for malaria. The southern and eastern parts of the study area are rendered inaccessible in combination of the PHC availability and road connectivity (Bhatt. B, Joshi, J, 2013). Hence, this could be another factor for not seeking timely and complete treatment by tribal population. Drainage into the swamps of various rivers in the region can cause risk. The district was divided into three *viz*., high, moderate and low risk zones based on the weighted overlay analysis.

The derived eco-regions also conclude that the region is susceptible to malaria as it has conducive condition for the malaria penetration and transmission throughout the year. Looking to the spatial distribution of the positive cases, it closely coincides with the eco-regions identified. The eco-regions in winter months are wide spread in the district, which can be attributed to the cropland in the plain and vegetation presence in the eastern hilly terrain (refer Figure 3).

This study lacks the other dimension of the lag time period of transmission and also the no. of human carrier and reservoir of the parasite which is difficult to quantify in such a large area.

The monthly incidence data is the actual cases notified but when the disease burden is estimated annually, the eco-regions for each month were subjected to weighted sum analysis for annual eco-regions. The higher monthly cumulated sum suggested the higher suitability (refer figure3). The outcomes suggest that the landscape variables affect the sustainment of mosquito habitats and malaria transmission. According to the incidence pattern in 2011, it is apparent that the northern Sankheda Taluka reported high incidence wherein, the ecological parameter are also conducive to that region. On the other hand, a highly dissected hill in the southern Kawant area becomes less suitable for the mosquito growth and malaria incidence are also less due to less water logging.

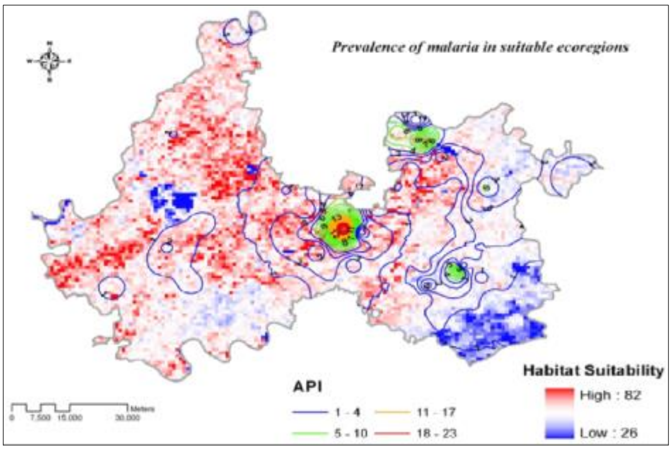

Fig 3: Suitable Ecoregions

6. Conclusion

Development of eco-regional maps based on landscape elements, distributions of vectors, and malaria incidence to improve understanding and prediction of malaria transmission at the landscape scale is the target of the present communication. Although the environmental drivers that determine the life cycles of the vector, host and the Plasmodium parasite are complex, they can be monitored and analyzed using newly available Geo-spatial technologies. Eco-regional mapping can act as important tools for integrated malaria control programs and define priority areas and appropriate interventions. The spatial approach of the disease incident data reporting can ease the understanding of the disease.

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