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Spatial cognition: a geospatial analysis of vector borne disease transmission and the environment, using remote sensing and GIS

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Abstract
Background: The prevalence of geographical distribution of vector borne diseases has been increasingly public health important and challenging problems in more than 100 tropical countries and it has been affecting more than 50% of the population in the world, especially, it is very big problem in India. The change of vector borne disease epidemic transmission in to the endemic situation in the country has been caused by the land use / land cover changes, regional climate changes, increase of sea change population, urban agglomeration, industrial development and the past development of towns, consequently, the disease epidemics have been steadily increased too, and, besides, it has been found ubiquitous, such diseases known as, malaria, filariasis, JE, dengue and chikungunya, as a result, the increase of both mosquito nuisances and disease transmissions has become public health importance and very big challenging problems in India.

2. Materials and Methods: The data pertaining to vector borne diseases were collected and was attached to the district map using Arc View 3.2 GIS platform (ESRI, NIIT-Chennai, India) for preparation of disease prevalence in India. The district wise thematic information of geo-climatic variables (Mean Annual Temperature, Mean Annual Rainfall, Relative Humidity, Saturation Deficit, Altitude, Soils types and Population density), vector borne diseases were developed and the data set was imported into SPSS+ for geo-statistical analysis. Remote sensing and GIS is has the important role in the ecological mapping of vectors breading habitats. Remote sensing of IRS LISS I and LISS II data products were analyzed, using ERDAS Imagine 8.5 and was integrated into GIS for spatial analysis for classification. The integrated hybrid remote sensing and GIS techniques have been used to mapping the vector breeding potential areas vulnerable to risk of disease transmission.

Results and Discussion: The result shows that the possible information on reliable estimates of and mapping of malaria, filariasis, JE, and dengue vector breeding habitats, and facilitate to estimate the people at risk of vector borne disease transmission. The results of the present research study shows that spatial agreement was existed between the environmental variables and the vector borne disease epidemic transmission. The geographical distribution and the seasonal abundance of vector abundance and vector borne disease transmission have completely been controlled by the climate, landscape and the environmental variables.

Conclusion: The study has made for analyzing the spatial agreements between the environmental variables and vector borne disease transmission in India, and perhaps, the appreciation of GIS in the spatial and the ecological aspects of vector borne diseases towards the achievement of vector borne disease transmission control in India. and thus, the remote sensing and GIS has been provided the guidelines to choose appropriate control strategy and mapping disease transmission risk zones based on the information derived from the geo-statistical analysis of environmental variables in the country.

Keywords: Remote sensing, GIS, NDVI, vector borne disease, malaria, filariasis, JE, dengue, chikungunya, visceral leishmaniasis, breeding habitats

1. Introduction
The burden of vector borne diseases in India has become very challenging problem and increasing day by day. The prevalence of geographical distribution of vector borne diseases has been increasingly public health important and challenging problems in more than 100 tropical countries and it has been affecting more than 50% of the population in the world, especially, it is big problem in India (Fig. 1, 2a and 2b, 3, 4, 5 and 6).

The implementation of conventional method of vector control in the field has significant effect, however, the problem is not manageable and it has been increased steadily. Therefore, the present study is designed for spatial mapping of the geographical distribution and probability of vector borne disease transmission risk in India, using RS (remote sensing) and GIS (Geographical Information Systems) [1-52].

The geographical distribution and seasonal variation of vector abundance and vector borne disease transmission have completely been controlled by the climate, landscape and the environmental variables (land use / land cover, altitude, mean annual temperature, mean annual rainfall, potential evapotranspiration, readily available soil moisture, soil type's water logging potential, slope of the terrain, the NDVI - Normalized Difference Vegetation Index of remote sensing products, etc.,), [2-4, 6-14, 22-27, 45-48]. The present study is designed for mapping the spatial distribution of malaria, JE, filariasis, dengue, chikungunya and visceral leishmaniasis [15-29]. The information relevant to the vector borne diseases, and vector abundance in association with geo-climate determinant variables provides datum of guide lines to mapping of vertical and horizontal structure of the disease transmission risk [10-18, 22-27, 30-52] and to assess the community of the people at risk in different parts of the country [22-29].

Mapping disease distribution, spatial analysis and spatial modeling of disease epidemic transmission are increasingly important now days at global level as well as in the country level [31, 32], and the results obtained using remote sensing and GIS has potentially been vital role particularly in the designing and implementation of active disease control programmes, has already been used to demonstrating and implementing the programme for malaria [31, 32], tick and *Tsetse* – borne diseases [34-38] and onchocerciasis [34]. The success of the current and future control programme in country depends on the availability of up-to-date thematic maps of the distribution of the diseases within the country, at a suitable spatial resolution /scale relevant to control activities. Previous work in this area in the recent past has primarily focused on collating information on the prevalence of disease epidemics as well as endemic situation, and the potential use of availability of health resource allocation, and hence, should be given priority when and where planning control campaigns, based on the disease transmission risk map [16-18, 22-25, 31, 33, 39], however, indicates that, rather than focusing on individual districts or states, it may be sensible, if at all possible, to carry out the control activities to the whole country all together simultaneously, or at least all districts within discrete, high risk zones [33, 34].

The Remote sensing and GIS has been significantly developed for ecological modeling with special emphasis on vectors and vector borne diseases for the past 25 years [16, 27]. Land use / land cover dynamics, urban sprawl and irregular growth of urban development and industrial growths are fueled to the development of suitable environment fuelling for malaria, JE, and dengue epidemics and also providing conducing environment for malaria and filariasis endemic. The numbers of traditional, conventional, and modern scientific methods have been using for vector borne disease control, however, the conventional methods are based on the empirical knowledge, it was most conventional and crude method, laborious, expenditure, erroneous, and time consuming. Therefore, a rapid and advanced technology has been used for the replacement of conventional methods for mapping the problematic areas, and predicting the spatial assessments of disease transmission risk with reliable and 100% accuracy.

2. Aim and Objectives

The study is designed for a systematic review on the spatial cognition of vector borne disease transmission and the environment, using satellite remote sensing and GIS, the has in-built with fulfilling the following four fold objectives

1. To mapping the spatial distribution of vector borne diseases in India
2. To study the climate, landscape, and the environmental aspects of vector borne disease transmission in India
3. To study the spatial agreements between the geo-environmental variables and vector borne disease transmission in India
4. To analyses the spatial cognition: A geospatial modeling of geo-environmental aspects of vector borne disease transmission in India, using remote sensing and GIS

3. Materials and Methods

The study was designed for mapping the geographical distributions of vector borne diseases for the past 6 decades in India, and to analyze the present status of geographical distributions and studying the climate, landscape, and the environment determinants of vector borne diseases (such as, filariasis, malaria, Japanese Encephalitis (JE), visceral leishmaniasis, dengue and chikungunya) in India (Fig. 1, 2a and 2b, 3, 4, 5 and 6), using remote sensing and GIS. Gaining the preeminent understanding of the spatial aspects of vector borne disease transmission, vector ecology, mapping the occurrences of vector borne disease epidemics in different part of the country and surveillance towards the achievements of disease transmission control and management, using geographical information systems (GIS) is most productively significant scientific methods. The study has made for analyzing the spatial agreements between the environmental variables and vector borne disease transmission in India, and perhaps, the appreciation of GIS in the spatial and the ecological aspects of vector borne diseases towards the achievement of vector borne disease transmission control in India.

The data pertaining to the prevalence of vector borne diseases, layers of thematic map information of geo-climatic variables (mean annual temperature, mean annual rainfall, relative humidity, saturation deficiency) are to be collected for the research studies, and satellite remote sensing of land use / land cover information and the vegetation cover information over laid with vector borne disease prevalence data for stratification of disease transmission risk and the problematic areas. The geo-climatic variables data with vector borne disease data has to be integrated in to the Arc View 3.2 GIS platform for mapping geographical distribution and stratification of vector borne diseases and the spatial analysis of disease transmission in the country. The study has to be conducted for analyzing the spatial agreements between the disease epidemics and the environmental variables. The present study is including mapping of land use / land cover changes, vector breading habitats of *Cx.* genus, *An.* genus, *Ae.* genus, mosquitoes and sandfly. The image processing of IRS WiFS remote sensing data was carryout, using the maximum likelihood analysis for land use land cover classification, and a systematic grid sampling was applied for surveying and mapping of vector breeding habitats. The NDVI of land use / land cover categories derived from the indigenous satellite remote sensing data, using ERDAS Imagine 8.5, which was integrated with GIS for achieving the four fold aim and objectives of the research study. The general multivariate linear regression model was applied to find out the fitness of spatial association between the geo-climatic variables and the filariasis, malaria, JE, dengue and Visceral Leishmaniasis, using SPSS 10.0+ and the results have statistically significant and perfectly fit on the predicted surface of the filariasis, malaria, JE, and Visceral Leishmaniasis transmission risk zones in India [16-31].

4. Result and Discussion

There are complex of phenomenon functioning on the geographical distribution of the prevalence of the disease, however, the natural determinants, particularly, the geo-climatic variables are most important determinant key factors complete control over the vector survival and disease transmission. The prevalence of vector borne diseases (filariasis, malaria, JE, dengue, chikungunya, and visceral leishmaniasis) caused by the vector mosquitoes namely *Culex quinquefasciatus and mansonia, Anopheles* genus mosquitoes, *Culex* genus mosquitoes and *Aedes* genus mosquitoes respectively, and which has been spread over most of the regions in the country [15-29]. The spatial epidemiology of diseases occurrences and disease transmission in the world are directly controlled by climate, landscape and the environments, and consequently, the result provides that the vegetation indices has the importance role in the determining of profusion of mosquitoes vectors, and the relationship between the vector-borne disease transmission and the epidemiology of disease epidemic at the local and regional level [1-52].

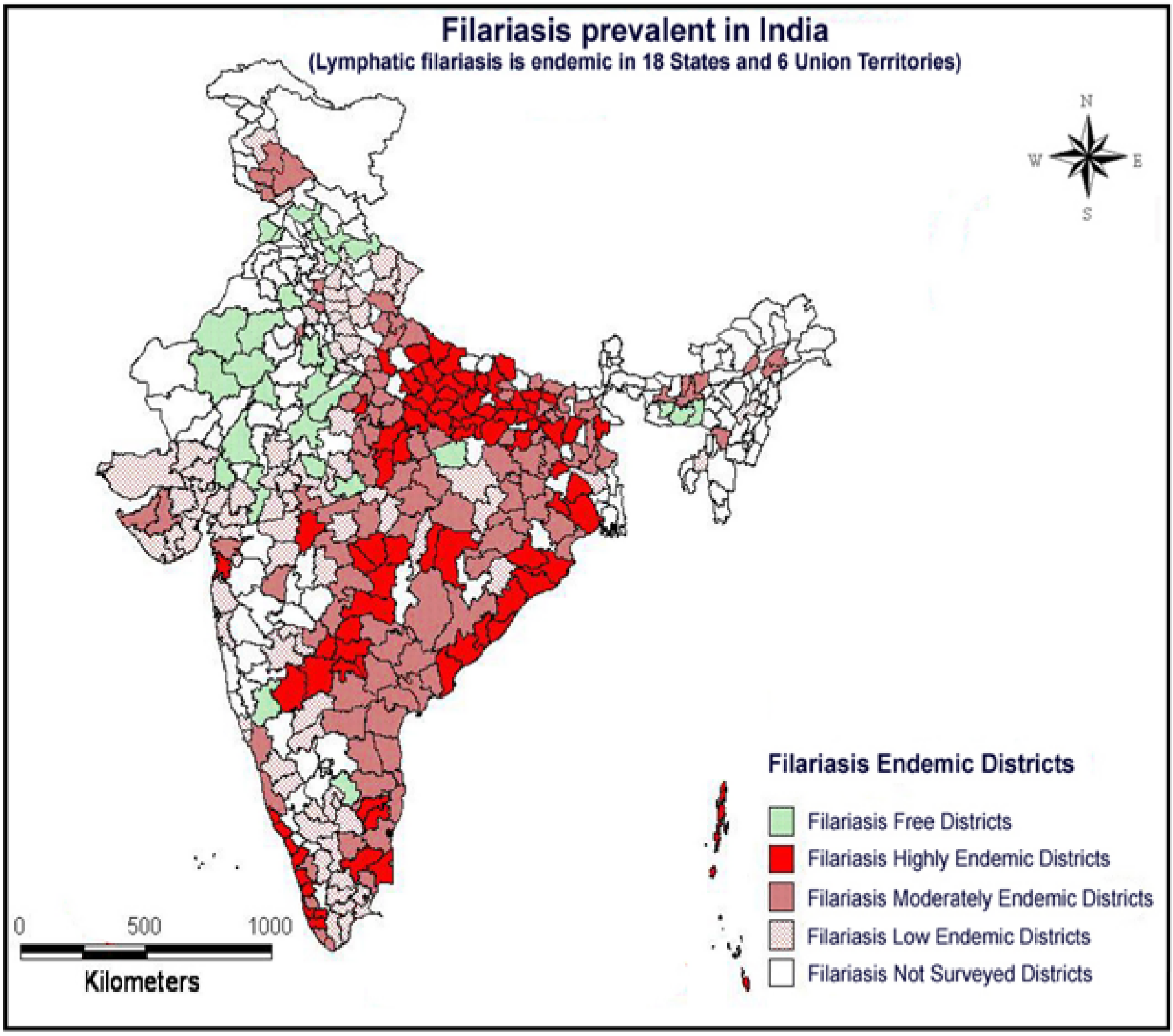
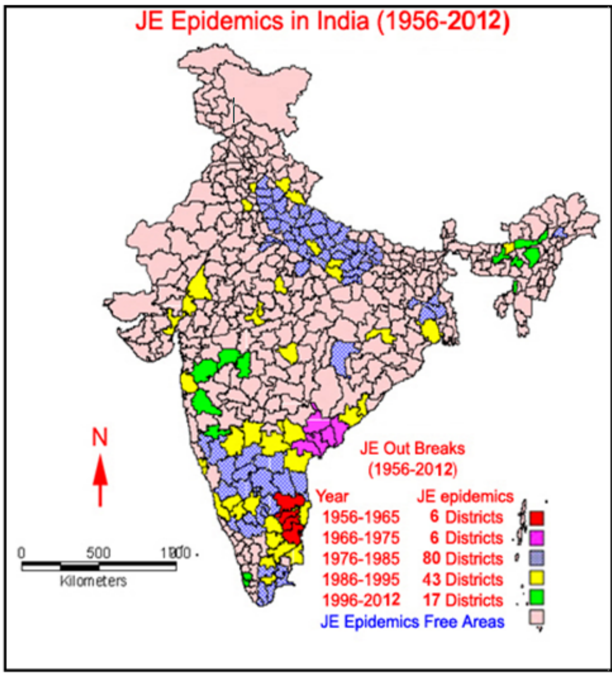


Fig 1: Filariasis Endemics in India as on 2012, source: M.Palaniyandi, 2014



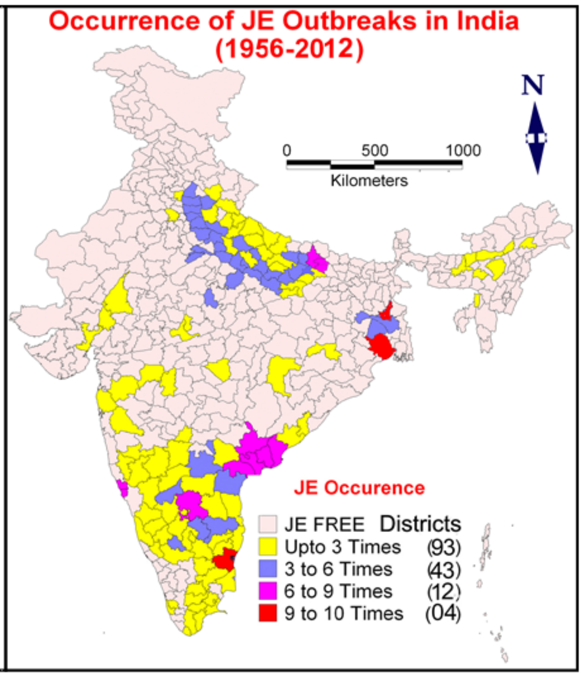


Fig 2a: The first report of JE epidemics across the country and the spatial diffusion of JE epidemics in the newer areas, where the intensive wet cultivation is being practiced.(1956-2012), source: M.Palaniyandi, 2013

Fig 2b: The repeated occurrence of JE epidemics in the country and the spatial diffusion of JE epidemics in the newer areas where the intensive wet cultivation was practiced (1956-2012)., source: M.Palaniyandi, 2013

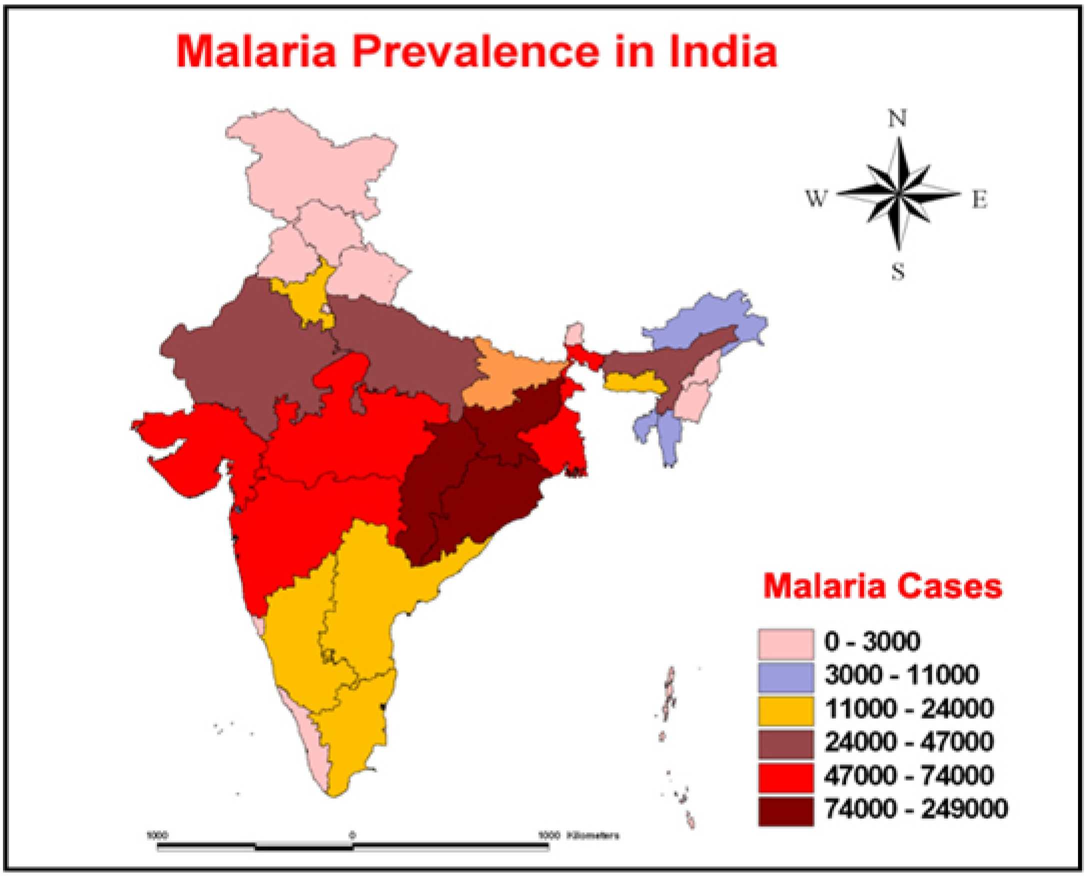


Fig 3: The malaria prevalence of States and the Union Territories in India, as on 2012, Source: M.Palaniyandi, 2013

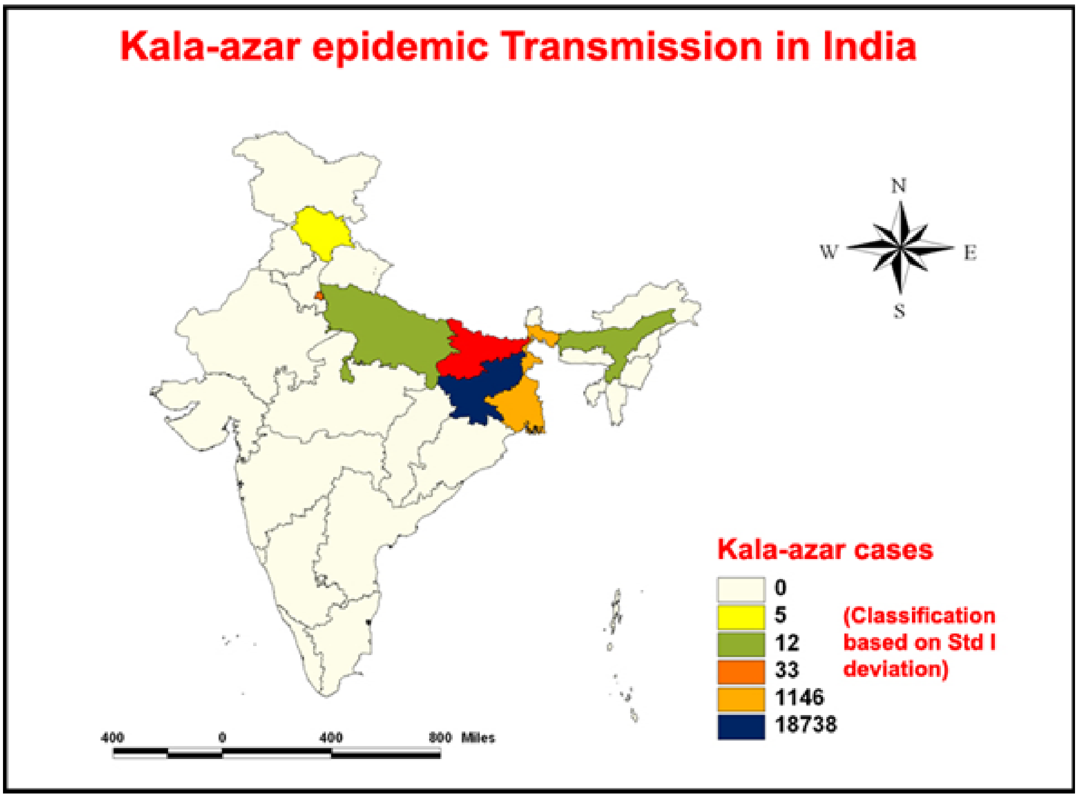


Fig 4: Visceral Leishmaniasis distribution in the selected states of India (2012), source: M.Palaniyandi, *et al.*, 2014 (in press)

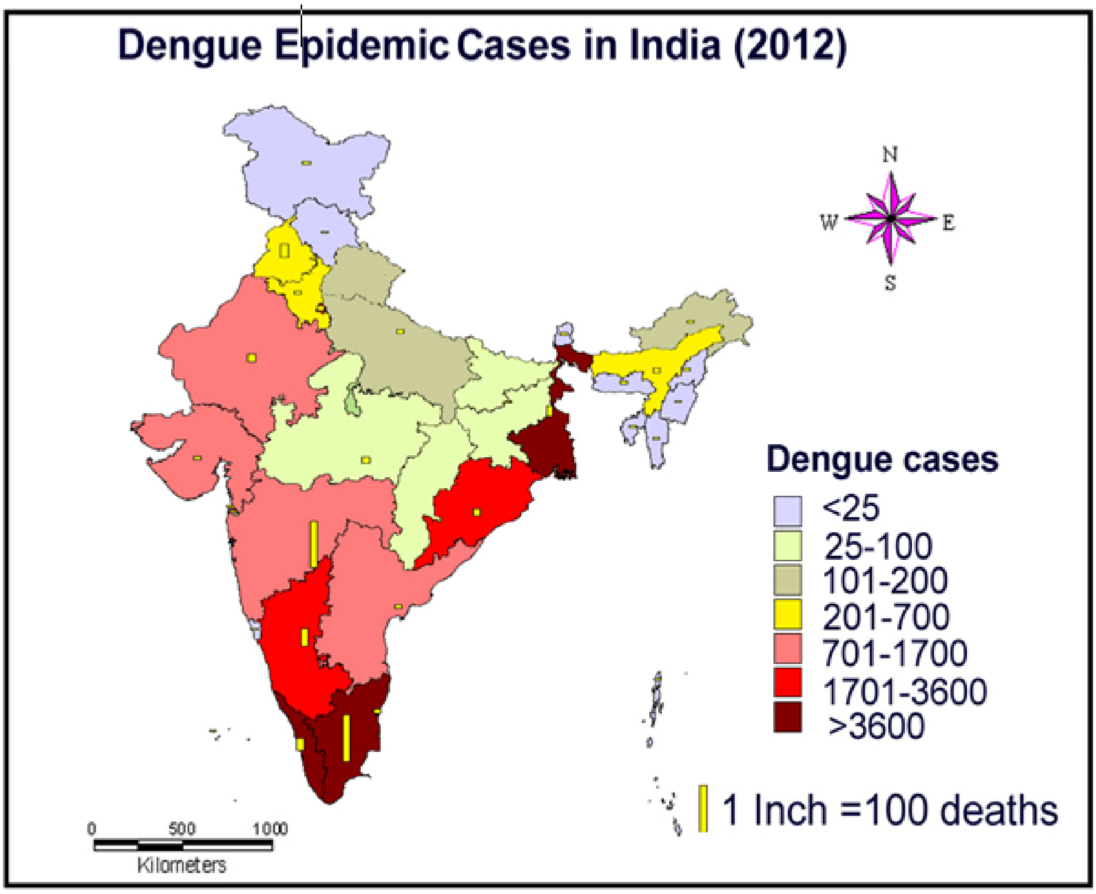


Fig 5: The dengue epidemics in India (2012), source: M.Palaniyandi, 2013

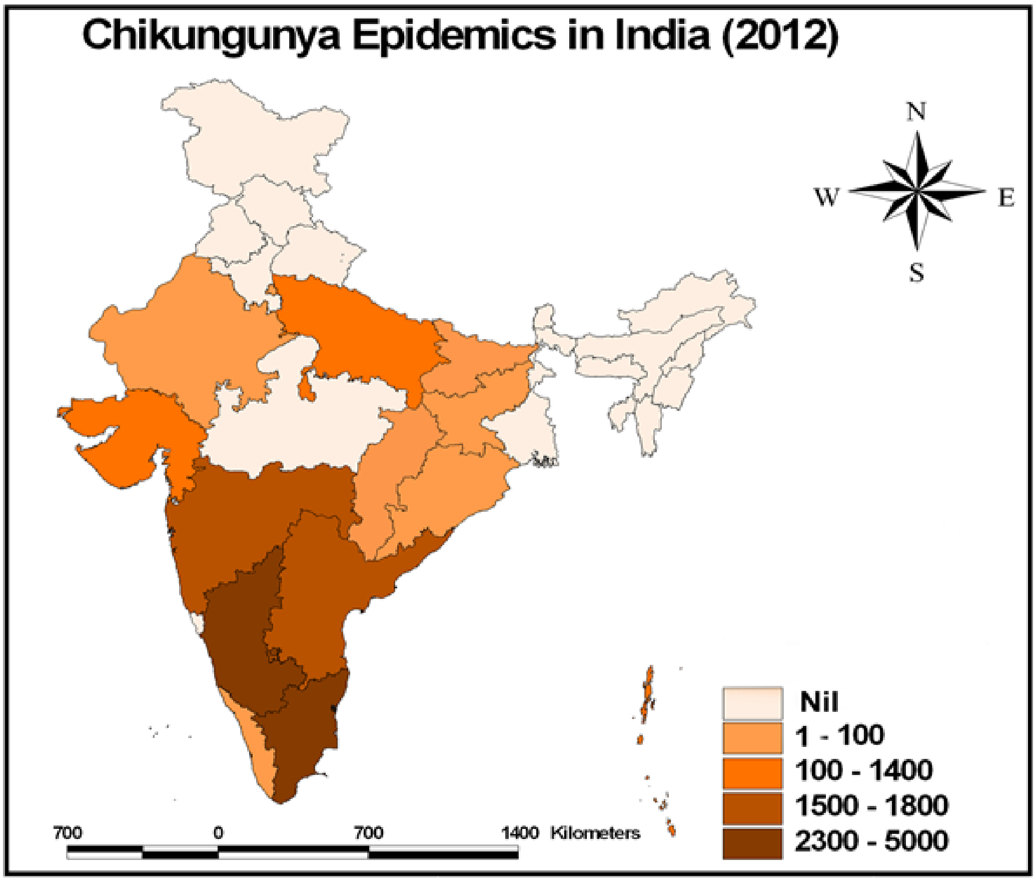


Fig 6: The Chikungunya epidemics in India (2012), source: M.Palaniyandi, 2013

A. Climate, landscape and the environments of vector borne disease transmission: The increase of climate change particularly influence the increase in the rate of mosquito breeding, especially, malaria, JE, and dengue vector mosquitoes. Climate has vital role within thresholds for mosquito and parasite survival. The climate change (temperature, rainfall and humidity, saturation deficit (SD) are important determinants of vector breeding and survival [3, 10-12, 27]. Thus, it is speculated that the distribution of vector borne disease transmission is respond to climate suitability. The spatial predictions about the direction, magnitude and location of changes in climatic suitability for vector borne disease transmission including malaria transmission are drawn largely from temperature dependencies. Perhaps, landscapes of highlands are particularly vulnerable to increased transmission because even a small rise in temperature can greatly raise the altitudinal limit of malaria to populations that have acquired little functional immunity. Global scale mathematical models have predicted an increase in both geographic range and transmission intensity of malaria, based on climate and landscape and the environment variables under future climate scenarios, using multivariate geo-statistical analysis [1-52].

B. Remote sensing and GIS to spatial prediction of vector borne diseases: The remote sensing is a reliable, repetitive, and real time data coverage, which provides the information relevant to the vector ecology including the breeding habitats, surrogate environments, and land use / land cover changes [16, 18, 19, 27, 30, 47-49]. The application of remote sensing under the GIS umbrella was used to study the vector ecology, mapping the disease distribution, and geo-spatial modeling of both vertical and horizontal direction of disease transmission with respect to the space and time. The study has been designed for using the geo-environmental and climatic risk variables integrated with satellite remote sensing data, and GPS applications in to the GIS platform for conducting systematic reconnaissance survey for collecting the both immature and adult mosquitoes of malaria, JE, filariasis, dengue and chikungunya vectors. Remote sensing and GIS has to be used to analyze the malaria, JE vector ecology and mapping the vector breeding potential surface habitats positives for immature of vector mosquitoes [16-18, 22-27]. GIS software to be used for mapping the geographical distribution of vector borne disease transmission in India. GIS has to be used to studying and analyzing the environmental aspects of vector borne disease transmission in India [15-29].

Information on the spatial relationships between disease vectors and environmental factors is fundamental to vector-borne disease control. It is well known that mosquito abundance is associated with the climate variables, especially the amount of rainfall and thus the number of larval breeding sites, the spatial relationship between larval habitat availability and adult mosquito abundance [16-18, 22-25, [30, 36, 37, 42, 45-48]. Geographic information system (GIS) was used to mapping and analyzing layers of thematic information of larval habitats, land use/land cover categories, human population distribution, house structure, and hydrologic schemes were overlaid with adult mosquito abundance [16-18, 22-25]. Geo-spatial analysis was used to determine the spatial autocorrelation in adult mosquito abundance among houses in the settlement clusters and the cross-correlation between adult mosquito abundance and geo-environmental factors [4-13, 16, 27].

The Remote sensing and GIS has been significantly developed for ecological modeling with special emphasis on vectors and vector borne diseases for the past 25 years [24, 27]. Land use/land cover dynamics, urban sprawl and irregular growth of urban development and industrial growths are fueled to the development of suitable environment fuelling for malaria, JE, and dengue epidemics and also providing conducing environment for malaria and filariasis endemic. The numbers of traditional, conventional, and modern scientific methods have been using for vector borne disease control, however, the conventional methods are based on the empirical knowledge, it was most conventional and crude method, laborious, expenditure, erroneous, and time consuming. Therefore, a rapid and advanced technology has been used for the replacement of conventional methods for mapping the problematic areas, and predicting the spatial assessments of disease transmission risk with reliable, repetitive real time accuracy [1-52].

The hybrid techniques of remote sensing and GIS are used to rapid epidemiological mapping of the relevant information to understanding the spatial variation of the vector biodiversity, vector abundance [1-4, 26, 33, 44-52], and the active infection state of vector borne disease transmission, disease surveillance, and perhaps, provide the disease epidemiological information [1-4, 20-22, 51] along with geo-coordinates of site specification combined with multispectral satellite data of geo-environmental determinants risk variables [1-4] including climate, landscape, and the environments of vector ecology in the urban agglomeration of human settlements as well as breeding habitats environment in the country sides [16-22]. The survival and longevity of infected mosquitoes and the prevalence of the disease are spatially determined by the geo-climatic variables [1-4, 6-13, 30-33, 37, 44-52]. The application of remote sensing was used for studying the relationship between the environment and vector abundance [16, 26].

Perhaps, the hybrid remote sensing within geographic information system (GIS) is readily available and reliable with high accuracy [16, 27, 30] which is able to read, process, analyze, and present spatially-related data for effective interpretation and has been used for mapping, analyzing and modeling the environmental aspects of vector borne disease transmission in different parts of the country. The data pertaining to the prevalence of vector borne diseases, layers of thematic map information of geo-climatic variables (mean annual temperature, mean annual rainfall, relative humidity, saturation deficiency) has been collected for the research studies, and satellite remote sensing of land use / land cover information and the vegetation cover information over laid with vector borne disease prevalence data for stratification of disease transmission risk and the problematic areas. The geo-climatic variables data with vector borne disease data has been integrated in to the GIS platform for mapping geographical distribution and stratification of vector borne diseases and the spatial transmission disease in India.

The present study is containing the detailed information on geo-statistical and spatial analysis of climate, landscape and environment variables in association with prevalence of vector borne diseases in India. It was used for mapping the mosquito vector breeding habitats facilitate to estimate the people at risk of disease transmission [45]. Geo-statistical modeling approaches are highly reliable, accurate and cost effective for studying the climate, landscape, and the geo-environmental aspects of vector borne disease transmission in India and thus, preparing control programme successfully [16, 18-22, 25, 26]. The results obtained shows that spatial agreement was existed between the environmental variables and the vector borne diseases. To beyond the all these problems, the remote sensing and GIS has been provided the guide lines for mapping transmission risk zones based on the information derived from the geo-statistical analysis of environmental variables in the country. Thus, the techniques has provided the datum of useful guidelines for studying the past, present and the future scenario of disease transmission, and hence, the tool has been used as the datum of baseline for mapping and modeling of spatial prediction of vector borne disease transmission, and prioritizing the areas for taking appropriate prevent measures to control vector borne disease transmission in the country early in advance [16, 23, 25, 27, 28, 31, 42, 43].

4.1 Filariasis Transmission in India

A. The geo-statistical analysis of geo-climate variables

The results of Pearson' Bivariate auto correlation analysis shows that the degree of spatial agreement between the geo-climatic variables and the filarial endemicity was examined, the annual mean temperature ($r = 0.649$, $p < 0.05$) and annual mean rainfall ($r = 0.641$, $p < 0.05$), relative humidity ($r = 0.642$, p value < 0.01), saturation deficit (r value $= 0.631$, p value <0.01) and the filariasis endemicity is significant negatively with altitude (r value $= 0.644$, $p < 0.05$). Based on the analysis, the rank score for each of the risk variables were assigned to the spatial agreement and contribution of each variable with filariasis transmission. The contribution of each variables was estimated that the mean annual temperature (64.9%), saturation deficit (63%), and followed by the altitude (64.4%), relative humidity (64.2%), rain fall (64%) and soil types (61%). However, it is observed from the analysis that the spatial association between the single variable and filariasis endemicity has less significant, whereas, the multivariate analysis shows that a strong spatial agreement is observed between the multiple variables and filariasis endemicity. A significant association is observed between filariasis endemicity and saturation deficit ($r = 0.631$, $p < 0.01$). Filariasis and temperature with rainfall ($r = 0.642$, $p < 0.05$), and saturation deficit (SD) with rainfall ($r = 0.737$, $p < 0.05$). Filariasis and saturation deficit (SD), rainfall with altitude ($r = 0.816$, $p < 0.05$). Also, Multivariate analysis models predict the significant level of individual variable and the combined effect more

Number of variables in association with filariasis transmission. The results shows that the effect of saturation deficit (SD) individual variable with the filariasis transmission has insignificant and it has statistically significant when added with precipitation and again it has more significant with added variable of Altitude. The combined effectiveness of two and more variables Rainfall, Saturation deficit and altitude were calculated. The contribution of collective effect of the geo-climatic variables on filariasis transmission and the filariasis prevalence are spatially determined with 72.3% statistically significant (Fig.7a and 7b) [18, 23].

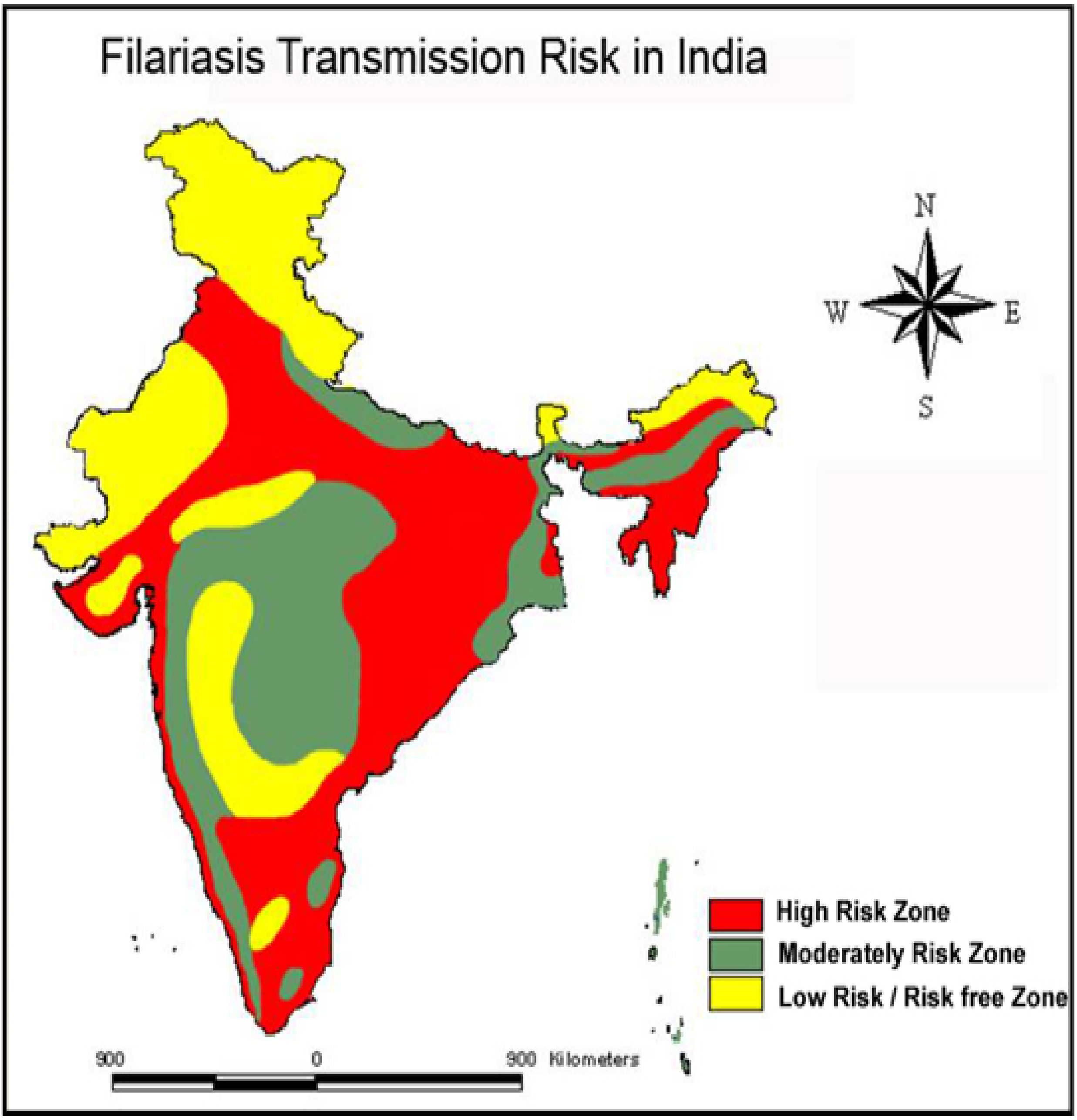


Fig 6a: Filariasis Transmission Risk Map of India. Source: M.Palaniyandi, 2014

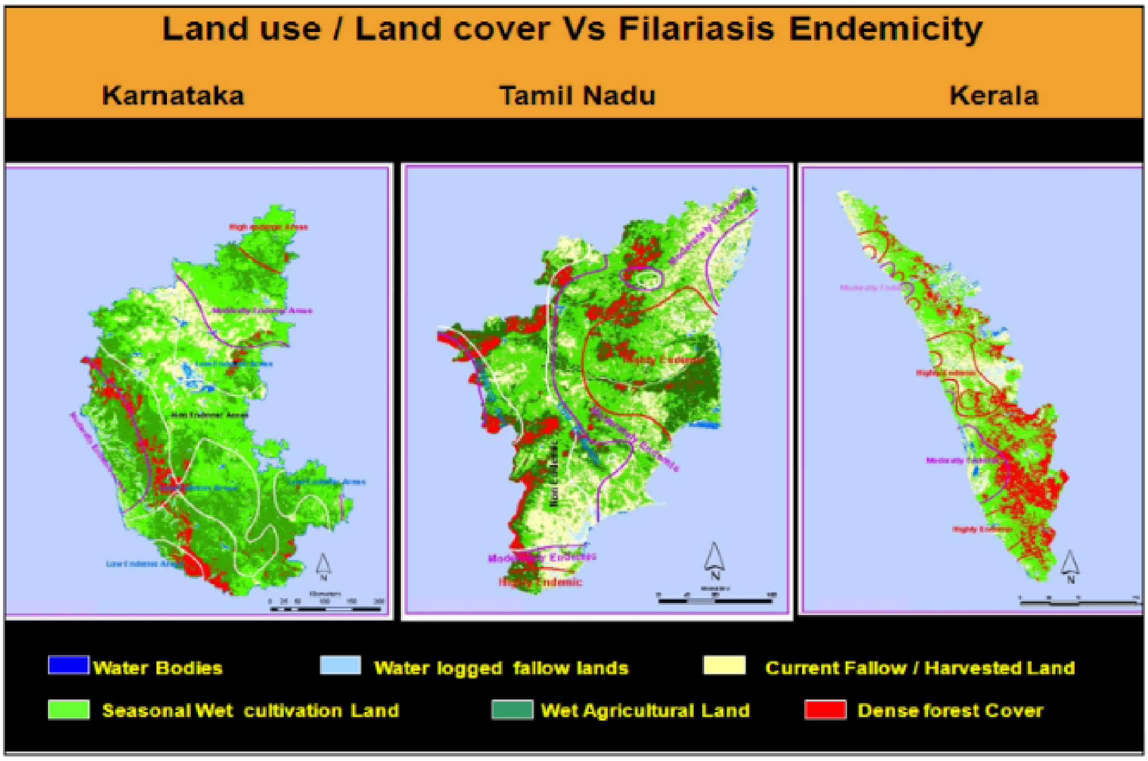


Fig 6b: The spatial relationship between the IRS WiFS data and the Filariasis Endemicity in Karnataka, Tamil Nadu and Kerala states of South India, The Filariasis Endemicity level contour map is overlaid on land use / land cover map derived from satellite data. Source: M.Palaniyandi, 2014

4.2 Malaria Transmission in India

A. The cumulative effects of climate variables on malaria transmission

The spatial relationship between the climate variables and the *Anopheles* genus malaria vector shows that the model fitted with statistically significant [1-4, 7-15, 20, 25-27, 44, 47-52] The most *Anopheles* vector species of malaria, the optimal temperature range for their development take place within 20 to 30 °C. However, transmission of *P. vivax* requires a minimum average temperature of 15 °C and transmission by *P. falciparum*, requires a minimum temperature of 19 °C. It has been observed in India, that the *P. vivax* vector requires 15 to 25 days to complete its cycle if the temperature remains within 15 to 20 °C, the relative humidity for both species remains within 55 to 80% and its life cycle maybe get completed even within 6 to 10 days, if the temperature range remains within 25 to 30 °C. The relative abundance of the malaria vectors are directly controlled by the climate variables. The multivariate geostatistical model predicted accurately the spatial association of the malaria cases with climate variables and the relative abundance of malaria vectors breeding habitats suitability [1-4, 7-15, 25-27, 45-49].

The temperature and relative humidity has relatively significant r value = 0.631, $p < 0.05$, temperature, relative humidity and saturation deficit has good significant r value = 0.683, $p < 0.05$, temperature, relative humidity, saturation deficit and precipitation has spatially good agreement and statistically significant of r value = 0.684, $p < 0.05$, and hence the cumulative effects of the climate variables provides the good agreements. The malaria cases in the endemic districts and the relative abundance of the malaria vectors are directly or indirectly controlled by the climate variables, and thus, the geo-statistical model could be provided the predicted value of the probability of malaria transmission risk in India, and thus, the results used to mapping the areas of suitable for relatively abundance of malaria vector species with 85% to 90% accuracy, (Fig.7) [25-27].

4.3 JE Transmission in India

A. The geo-environmental aspects of JE Epidemics in India

The environmental risk factors of land use / land cover changes and the climate variables are fueling for JE vector mosquito breeding, vector survival, JE adult vector mosquito abundance and the JE epidemics in different parts of the country for the past 58 years. One of the difficulties associated with achieving a desired control of disease was that the combinations of many diverse and complex of risk factors are contributing to the disease infection and spatial diffusion of the JE transmission, however, the presents of JE vector abundance, density, and the vector survival are being extremely associated with climate variables (temperature, relative humidity, rainfall, floods) and the environmental variables including the landscape environment (altitude) and land use/land cover categories (Fig. 8), the number of larval breeding sites, soil alkalinity, water temperature, water turbidity and water hardness of breading sources [6, 7, 19].

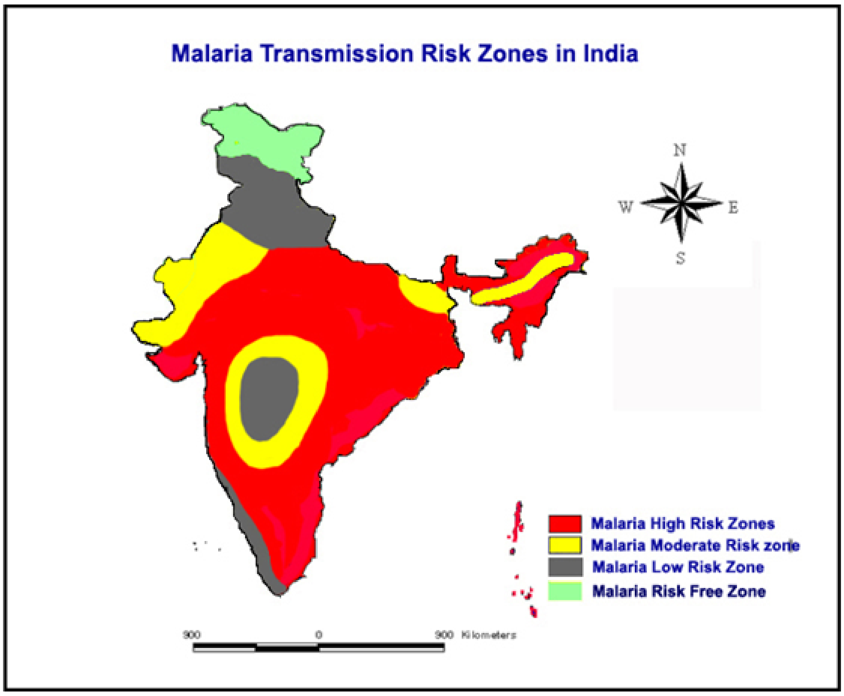


Fig 7: Malaria transmission risk in India, Map Source: M.Palaniyandi 2013

The environmental transition and climate variables are principally fueling for mosquito JE vector mosquito abundance and the disease outbreak in the place of year round regular irrigation intensive rice cultivation [6, 7, 19, 47-49]. A close association was found between the JE epidemic and the occurrence of heavy flood [19]. The spatial overlay analysis provides the high correlation between the intensive irrigation rice cultivation, land use / land cover categories and JE epidemics [6, 7, 19, 45, 47-49]. The intensive irrigation rice cultivation areas are potential for mosquitoes breeding sites (and thereby provide potential resting sites, sugar-feeding supplies for adult mosquitoes and protection from climatic conditions) and which are directly playing important role in determining the abundance of mosquitoes (Wood, *et al*., 1991 and 1992). These variables have most role and probably causing the conducing environments for survival of JE vector mosquitoes mainly *Culex vishnui* group (*Culex tritaeniorhynchus, Cx. Vishnui, Cx. pseudovishnui, Cx. whitmorei, Cx. epidesmus, Cx. fuscocephala, Cx. gelidus, and Cx. bitaeniorhynchus*) and it was found 4-6 weeks after rice transplantation and the extensive epidemic of encephalitis occurred in most part of Southern India, between the months of August to December. The regional scale climate change (temperature, rainfall, and humidity) and the environmental disturbances (land use / land cover changes, ecological changes) are the key factors fueled to promoting the breeding site and the JE epidemics in the virgin newer areas of the country. The spatial relationship between land use / land cover changes (dry land to Wetland), the wet cultivation agriculture practice land use categories derived from remote sensing of IRS WiFS data has very good spatial agreement with JE epidemics in different parts of India produce the results of statistically significant (r=0.625, p value <0.05), it was constructively classified for identifying the JE epidemic risk zones in Karnataka State with 93.4% accuracy with 100% specificity, and further it was close association with land use categories of satellite remote sensing of Kharif season crop land and Rabi crop season land use categories of India [19].

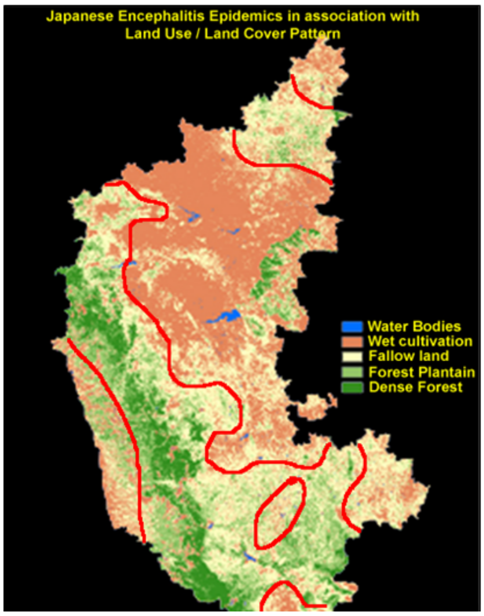


Fig 6.6: The spatial association between the land use categories of satellite remote sensing IRS WiFS data of Karnataka State in India, Source: M.Palaniyandi, 2013

The NDVI values derived from the image processing of IRS WiFS data, provides the value of < 0.0 – 0.22 corresponds to wet cultivation rice cultivation areas with breeding habitats positives for Culex genus immature JE vector mosquitoes species (*Culex tritaeniorhynchus, Cx. Vishnui, Cx. pseudovishnui, Cx. whitmorei, Cx. epidesmus, Cx. fuscocephala, Cx. gelidus*, and *Cx. bitaeniorhynchus*) *positives*, and the NDVI value > 0.2 and < 0.4 vegetation indicates shows the actively photosynthesizing vegetation, provides guidelines to stratification of areas under vulnerable to the high risk of JE transmission, and followed by the >0.4 to <0.6 and the <0.022 and < 0.0.13, having the moderate risk of JE transmission during the Kharif and Rabi crop seasons, and it was found 4-6 weeks after rice transplantation and subsequently, which has been supporting for the extensive of JE epidemic across the country [19]. The spatial relationship between land use / land cover changes (dry land to Wetland), the wet cultivation agriculture practice land use categories derived from remote sensing of IRS WiFS data has very good spatial agreement with JE epidemics in different parts of India produce the results of statistically significant (r=0.625, p value <0.05), it was constructively classified for identifying the JE epidemic risk zones with statistically significant of greatest accuracy, (Fig. 9a) [19].

4.4 Dengue and Chikungunya Transmission

A. The environmental aspects of dengue and chikungunya transmission

The environmental aspects of *Aedes* species vector mosquitoes breeding and the both dengue and chikungunya epidemics across the country [9, 11, 17, 22, 24, 26, 35] for the recent years have been revealed as followings: 1) the regulation of irregular drinking water supply and it was supplied once in a week or 10 days, and hence, the village people have practice of drinking water storage using big plastic container/ vessels and cement container. 2). The replacement of bottled cool drinks by consuming the tender coconut is welcome, but, a gigantic level of disposal of tender coconut cell found in the major cities of highways where the place of floating population was important for tourist attractions and, the vendors coffee bars, hotels and the petty shop business in the highways, serve them cool drinks and tea, coffee milk etc in the disposal cups. 3). There were a large number of domestic animals found (monkey, buffalo, donkey, dong, cat, rat, cow, goat, etc.) in the affected villages as known hidden host of dengue and chikungunya virus load. 4). the spatial association between the geo-climatic variables and the dengue and chikungunya epidemics has statistically significant with mean annual temperature r = 0.638, and p value < 0.05, relative humidity has result of r=0.674, p value <0.05, and the cumulative effect of r =0.78, p<0.01), and perfectly fit on the dengue and chikungunya transmission risk zone [17]. The result shows that the mean annual temperature and relative humidity of climate determinants, the ranges between 17 to 27 ^{0}C and 60 to 80% respectively, with 95% significant and 5 % precision, confidential interval of (CI= 0.64 to 0.0.793, n=94), n= Number of districts, and estimated error of 2.6 to 3.8%, and hence the temperature and relative humidity has been providing most suitable environment for fueling the huge number of profusion of *Aedes* mosquito species breeding [17] during the monsoon climate season of both southwest monsoon and the northeast monsoon from April to November and the vulnerability of epidemics reported during the months of mid July to mid November period of the year, since 2006. 5). the dengue and chikungunya epidemics were reported from the coastal districts of Pondicherry and Tamil Nadu where the areas was marked for prone to tsunami and cyclone, and hence, the abandon of houses and it was associated with the huge number of containers of damaged house hold things in the coastal areas suitable for *Aedes aegypti* mosquitoes breeding. 6). The chikungunya in Kerala was most associated with massive number of coconut cell using for collection of rubber milk in the rubber plantation in Kerala which has been most suitable climate condition (temperature and relative humidity) for year round enormous quantity of *Ae. albopictus, mosquitoes* breeding and high number in the southwest monsoon. 7). the lack of awareness of the common people about the vector mosquitoes, disease transmissions, vector breeding habitats and the source reduction of vector mosquitoes breeding habitats. 8). The 65% of the entomological posts was kept vacant in all over the country as on 2012. 9) Based on the newspaper source, moderate rain during the summer, a week interval of drinking water supply, absence/negligence of block wise periodical entomological survey of dengue vectors for source reduction of vector breeding and lack of awareness of the common people are causing the collective responsible for creating conducing environment for fuelling for propagation of chikungunya vectors and chikungunya epidemics in different part of the country during 2012. 10) A survey on mosquitoes control evaluation was conducted by the author with field technicians of VCRC at Pondicherry urban areas where the intermittent dengue out breaks during 2010-2011, and 11) it was observed that the larvae and pupae of both dengue and chikungunya vector species (*Aedes aegypti and Aedes albopictus)* was found enormous numbers in the selected 4 blocks. 12) The manmade environment in the urban / rural settlement areas (domestics and peripheral-domestics areas) was creating the conducing environment fuelling for propagation of chikungunya vector mosquitoes breeding. 13) The NDVI values derived from IRS remote sensing data provides that the NDVI value of <0.0–0.2 corresponds to dense settlement areas with breeding habitats positives for both dengue and chikungunya immature vector mosquitoes species (*Aedes aegypti and Aedes albopictus) positives*, and the NDVI value > 0.2 and < 0.4 vegetation indicates shows the high income planned settlements and professional institutions with presence of actively photosynthesizing vegetation (Fig.9b), provides guidelines to stratification of areas under vulnerable to the dengue and chikungunya transmission [17, 51].

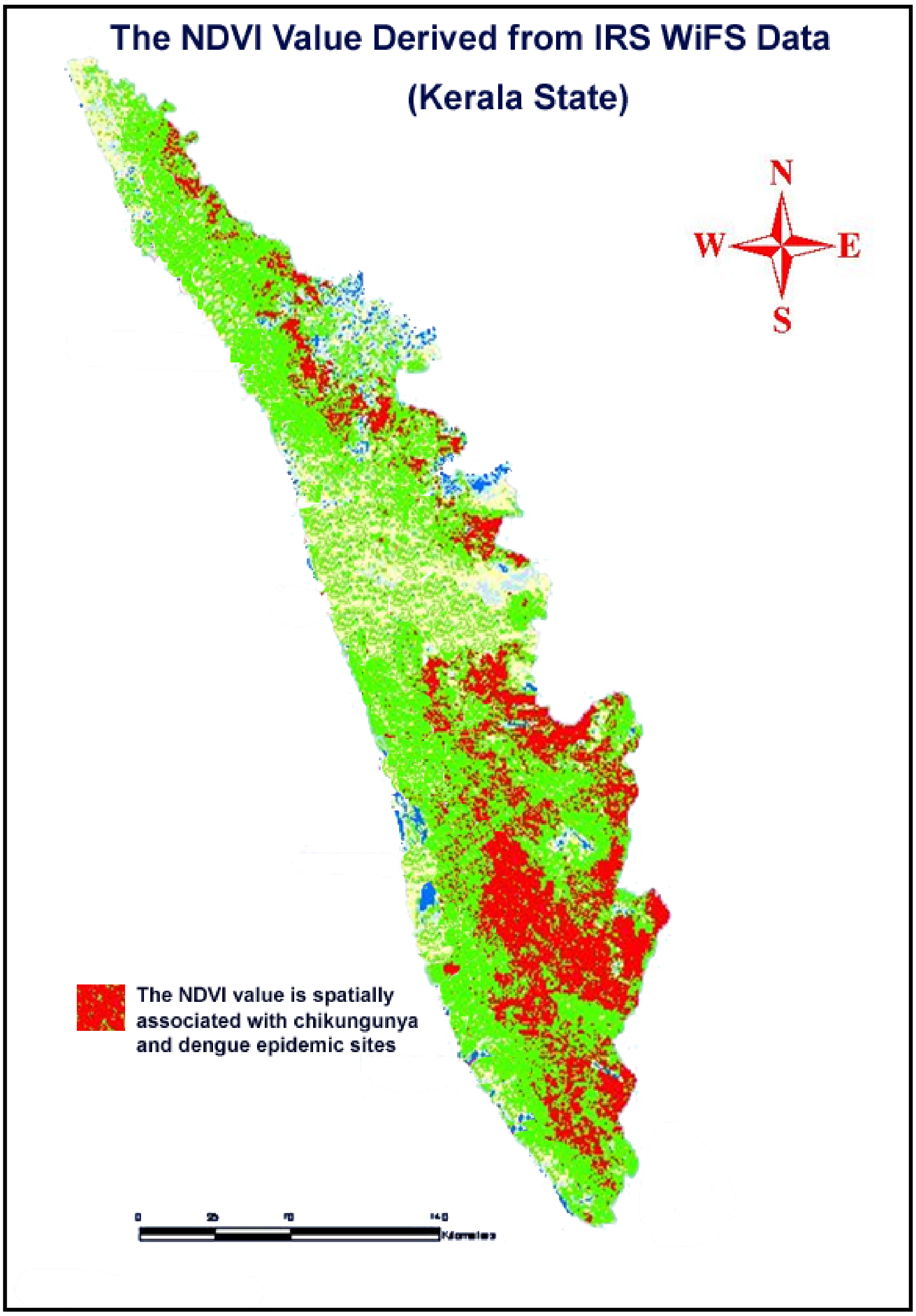


Fig 6.7: The spatial association between the NDVI value of IRS WiFS data and dengue and chikungunya epidemics transmission areas in Kerala state. Source: M.Palaniyandi, 2014.

4.5 Visceral Leishmaniasis Transmission in India

A. Climate, landscape, and the environment of Visceral Leishmaniasis transmission

The geo-climatic aspects related to the occurrence of Visceral Leishmaniasis**,** sandfly fever and Cutaneous Leishmaniasis are highly determined by the geo-climatic and the variables [7, 31]. The Visceral Leishmaniasis vector abundance found in the period of months between June and September; with *P. argentipes* most active profusion when the temperature is range between 27.5 and 31 °C (Bhunia *et al*., 2010). The impact of temperature on sandfly populations is rapid and direct the distribution vegetation condition and synoptic temperature to an overall accuracy of more than 80% (Thanyapraneedkul *et al*., 2009). The geographical and seasonal distribution of the major vectors *Phlebotomus martini and Phlebotomus orientalis* of kala-azar (Visceral Leishmaniasis) is analyzed using geographic information system (GIS), the best fit for the distribution *of P. martini* is the dry season composite NDVI 0.07-0.38 and LST 22-33 C with a predictive value of 93.8%, and the best fit for *P. orientalis* is the wet season composite NDVI -0.01 to 0.34 (Fig. 9c), and Land Surface Temperature (LST) 23–34 ^{0}C with a predictive value of 96.3%. The predictive

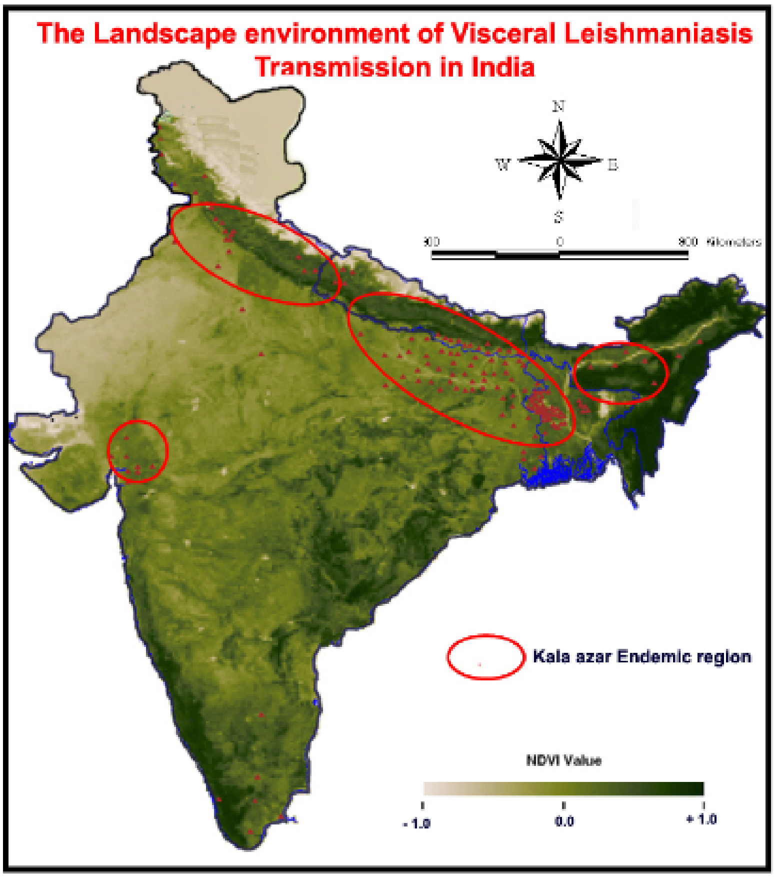


Fig 9: The Visceral Leishmaniasis / Kala-azar endemic data is overlaid on the mean NDVI value map of IRS WiFS data of India, the geographical distribution of Visceral Leishmaniasis is spatially associated with mean composite NDVI value range between 0.08 - 0.53, (95% significance and 5% error precision with confidence interval, CI- 0.413 -0.544), p value <0.001. Source: M.Palaniyandi, et al., 2014

climate model shows the best fit with the average altitude (12 m-1900 m), average annual mean temperature (15-30 ^{0}C), annual rainfall (274 mm -1212 mm), average annual potential evapotranspirations (1264-1938 mm) and readily available soil moisture (62-113 mm) for *P. martini* and average altitude (200 m-2200 m), annual rainfall (I80 mm-1050 mm), annual mean temperature (16-36 ^{0}C) and readily available soil moisture (67-108 mm), alluvial and black cotton soils dark coloured alkaline in nature (pH 7.2–8.5), calcareous with chief inorganic constituents of silicon, iron and aluminium most suitable for both *P.orietalis and Phlebotomus papatasi.* The stratification of Kala-azar transmission risk areas was classified, based on the climate variables including the temperature difference between areas suitable and unsuitable for sandfly survival and profusion of vector found to be ± 4 ºC and hence, the stratification of the areas under risk of disease transmission have been incredibly sensitive and statistically significant [13-15, 27, 31, 34, 36, 52].

In India, the specific crop vegetation types have been correlated with Kala-azar transmission. For example, a study shows that during summer (March-June) and rainy season (July-October) there was increasing trend of irrigation as well as water areas, with edible shrubs and plants, alluvial soil type, dark coloured alkaline in nature (pH 7.2– 8.5), calcareous with chief inorganic constituents of silicon, iron and aluminium, This nature of soil enhances its capability of retaining water as well as successful growth and abundance of edible shrubs, plants or agricultural crops. However, in non-endemic study sites, red and yellow laterite soils, with non-porous granular particles are not only acidic in nature (pH value 5.9–6.1) but are also of less water retaining capacity. This does not assist the growth / propagation of shrub/soft-stemmed plants [31].

While in endemic sites thatched, mud plastered roof tops of households with crack and crevices on it as well as on walls may serve as effective day-resting habitats for these nocturnal feeder species, mainly tiled, dry, non-porous roof tops without any cracks / crevices in endemic foci cannot be a resting habitat for the adult population. Again loose, wet solid with rich organic debris, on house floors in endemic sites not only serve as a very good resting habitat/food source for thriving and probation of immature stages of vector sandfly, but also act as resting habitat of newly emerged adult population. Thereby, to some extent, factors in micro focus like housing pattern/house floors also determines vector abundance/resting place. As vegetation and human settlements support the thriving of adult population by providing food and shelter, the adult densities were correlated with spatial changes in vegetation cover and human settlements. Because of parallel increasing trend of adult population was observed in these seasons thus indicative of the positive correlation.

5. Conclusion

The application of remote sensing and GIS has been significantly developed over the past 25 years for ecological modeling with special emphasis on vectors and vector-borne diseases. These studies were conducted on the appreciation of remote sensing and GIS applications to the study of vectors' biodiversity, vector presence, vector abundance and the vector-borne diseases with respect to space and time. This study was made for appreciation of remote sensing and GIS application to study the environmental aspects and ecological modeling of vector borne disease transmission. The integrated hybrid remote sensing and GIS techniques must be used to mapping the vector breeding potential areas vulnerable to risk of disease transmission and could be provided the possible information on reliable estimates of and mapping of malaria, filariasis, JE, and dengue vector breeding habitats, and facilitate to estimate the people at risk of vector borne disease transmission. The results of the present research study shows that spatial agreement was existed between the environmental variables and the vector borne disease epidemic transmission, and thus, the remote sensing and GIS tool has been provided the guidelines to choose appropriate control strategy and mapping disease transmission risk zones based on the information derived from the geo-statistical analysis of environmental variables in the country. The application of remote sensing, GIS and GPS are effectively usefulness for detection, identification, delineate and mapping of vector mosquitoes potential breeding surface areas and studying the mosquitogenic conditions in the urban agglomeration as well as in the country side areas, and also provides meaningful spatial solutions to control and management of the vector borne disease transmission in the country.

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