International Journal of Mosquito Research

ISSN: **2348-5906**
CODEN: **IJMRK2**
IJMR 2014; 1 (1): 20-28

Received: 19-02-2014
Accepted: 26-02-2014

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A geo-spatial modeling for mapping of filariasis transmission risk in India, using remote sensing and GIS

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ABSTRACT

The study was designed for mapping the filariasis transmission risk using geo-climatic variables. The application of remote sensing and GIS in the present study is mainly focused on profiling the areas at risk of filariasis transmission. The filariasis disease is caused by the *Culex* genus mosquito vector. The survival and longevity of infected filariasis vector mosquitoes are spatially determined by the geo-climatic variables. The geo-climatic variables are contiguous in nature, to relate the filariasis endemicity (mF and disease), a spatial interpolation or Kriging could provide the predicted surface of filariasis transmission in the areas where no information is available or areas at remote and difficult locality where to conduct a survey is not possible. Therefore, the geo-statistical analysis of GIS spatial interpolation or Kriging method was applied for obtaining the values for constructing the continuous surface of predicted filariasis surface for stratification of the areas for mapping of filariasis endemicity with accuracy of 93.4% statistically significant and sensitivity of 97.6% (95% confidence interval). The geo-statistical predictive model shows that the observed value of the filariasis prevalence and the predicted value of filariasis surface were correctly classified with statistically significant and perfectly fit on the predicted surface of the filariasis risk zones. The geo-statistical analysis was applied for establishing the spatial autocorrelation between the geo-climatic variables and the surface map of predicted filariasis risk zone which is statistically significant with 72.3% accuracy. The predicted map of filariasis transmission risk zone is useful for decision making and choosing the appropriate control strategy for implementing the filariasis control program in India where the filariasis transmission risk is high and moderate.

Keywords: GIS mapping, spatial modeling, Kriging, geo-statistical analysis, climate variables, mapping filariasis transmission risk

1. Introduction

The potential use of remote sensing and GIS applications is for gaining better understanding of spatial epidemiology and disease transmission for control and management of the disease for the past 25 years. There are a complex of phenomenon functioning on the geographical distribution of the prevalence of the disease of disease, however, the natural determinants, particularly, the geo-climatic variables are the most important determinant key factors for complete control over the vector survival and disease transmission [7, 11-15, 18, 20]. The geo-statistical analysis was carried out for predicting the filariasis transmission risk zone in India and a constructive GIS spatial mapping was primarily applied to improve the visualization of filariasis transmission risk with high accuracy. The filariasis transmission risk zones (FTRZ) map result is useful to the programmers for decision making for choosing appropriate control strategy to both vector and disease control where the filariasis transmission risk are high and moderate [3, 4, 8, 9, 10, 15, 18]. The first phase study of district level mapping of geographical distribution of filariasis in India shows the clear picture of the filariasis endemicity in the country, the causative infection (mF) and the symptomatic filariasis is about 429.32 million [18] It shows the regional trend of high endemic, moderately endemic, low endemic and non-endemic districts. However, in reality, the trend is never restricting with artificial administrative boundary, and it is spatially determined. The probability density function and the quantiles methods, clearly indicates that the problem of filariasis is not constant all over the country but shows clear regional trends [18]. To classify the areas correctly with the real situation of the filariasis transmission risk and generating the data for predicting the real

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picture of filariasis situation in the country, a huge sample points are needed at less than 10 Km interval [25]. A linear discriminant geostatistical model was carried out for producing the predicted filariasis transmission risk in Tamil Nadu state in India using the selected geo-environmental variables including the indigenous satellite IRS WiFS data [19]. In view of the practicability and feasibility of mapping the real situation of filariasis transmission risk India, a reconnaissance blood sample survey, a huge manpower, and heavy cost is to be involved. Therefore, the present study was aimed for appreciating the efficiency of remote sensing and GIS for applying the Geo-statistical modeling for producing the filariasis transmission risk in India using the geo-climatic variables. The result obtained from the present study was found useful for mapping the filariasis transmission risk zones at the nation level on 1:50,000 scale using the Block Kriging with 10km X 10KM Grid Cell data sets for deriving the continuous spatial trends of filariasis transmission risk map in India [11, 25] and the model was correctly classified with accuracy of 93.4% and sensitivity of 100% (95% confidence and with less than 5% precision of allowed estimated error limit).

2. Rationale of the study

Lymphatic filariasis represents a major vector-borne, public health problem in India. The disease has been known in the country for millennia, the earliest known description of symptoms dating to 600 B.C. [21] Current estimates indicate that about 38% (48 million) of the cases of lymphatic filariasis occurring globally are to be found in India [10]. The existence of a national programme for filariasis control designated the National Filariasis Control Programme (NFCP)] since 1955, attests to the recognition by health planners of the public health importance of the disease in India [21-23]. India is also a signatory to the resolution 50.29 of the 1998 World Health Assembly, calling for the elimination of lymphatic filariasis as a public health problem globally [10]

The traditional methods of filariasis survey are time consuming, static, laborious, and highly expansive and the results are influenced by human factor. It has been observed that by the time the filariasis delimitation surveys are completed, the situation has already changed, and also, these surveys cannot be conducted in reconnaissance scale and it can't be repeated in short time interval. For example, a complete survey of the whole country has not been possible even 50 years after the inception of the National program. The complexity of filariasis survey resulted unreliable data especially due to night blood sampling and the extensive geographical area and the time of sample collection.

Since, the Mass Drug Administration (MDA) is being suggested globally for the elimination of lymphatic filariasis, which needs to re-examination of the principles of transmission on epidemiological angle in relation to geo-environmental variables for formulating the interventions, using remote sensing and GIS tool that may have to be applied in a more scientific manner. The prevalence of infection and disease is dynamic, influenced by several factors including environmental and geographical, besides the factors related to host, parasite and vectors, and demographic and developmental transitions. Besides, it is possible to predict the occurrence of vector-borne diseases based on geographical, environmental and climate variables. These could be obtained through space-borne (remote sensing) data, which is repetitive, reliable, quick and economical for the larger geographical area (country level). Therefore, the present study was designed to develop a datum of baseline systems to mapping filariasis transmission risk, using remote sensing and GIS, and hence, monitoring, control and the management of lymphatic filariasis successfully.

3. Study area

The study area India, is located wholly in the northern hemisphere and the geographical extent of the main land is from 8^0 4' 28" N to 37^0 17' 53" N latitudes and from 680 7' 53" E to 970 24' 47" E longitudes. The Andaman and Nicobar Islands extends towards southeast, the name of the island is called Grater Nicobar and the southernmost tip of the island is Indira point located at 6^0 45' N latitudes. The total geographical area is 3, 287, 240 sq. kms, and the political administrative area consists of 28 States and 7 Union territories (The National Informatics Center, India). The total population of the country is 1, 027,015,247, male 531,277,078 and the female is 495,738,169 (Census of India, 2001). The geographical description of the area is snow-capped peaks to deserts, plains, hills, plateaus, coastal and the forest lands. The latitudinal extent of India from Jammu and Kashmir in the North to Kanyakumari in the South is 3,211 km and the longitudinal extent of from Rann of Kutch in the West to Arunachal Pradesh in the East is 2,933 km. The annual mean Temperature is 25-27.5^{o}C and it receives rainfall by both monsoons of South-West monsoon (June - Sep.) and North-East Monsoon (Oct. - Feb.). The rainfall is moderate to high, with an annual average of 800 mm to 3000 mm.

4. Materials and Methods

The district level digital map was created on 1:50000 scale for the study area (South India). The available filariasis data was attached to the district map using Arc View 3.2 GIS platform (ESRI, NIIT-Chennai, India) for preparation of filariasis distribution map (Fig.1). District wise thematic information of geo-climatic variables (Mean Annual Temperature, Mean Annual Rainfall, Relative Humidity, Saturation Deficit, Altitude, Soils types and Population density) filariasis endemicity was developed and the data set was imported into SPSS for geo-statistical analysis. The general multivariate linear regression model was applied to find out the fitness of spatial association between the geo-climatic variables and the filariasis endemicity is statistically significant and perfectly fit on the predicted surface of the filariasis risk zones. The result shows that the collective of all geo-climatic variables contributing 72.3% and are facilitate to the filariasis transmission risk in India (Fig. 7).

4.1. GIS data base construction:

District level digital map of India (Survey of India administrative boundary maps -Scale 1:250,000) was created. All GIS database are developed, using Map Info Professional 4.5, and Arc-view 3.2 GIS software (ESRI, Redlands, CA) and ERDAS IMAGINE 8.3 (ERDAS, Atlanta, GA) Image processing software.

4.2. Geo-environmental and climate data source

Geo-environmental factors *viz*., altitude, temperature, rainfall, relative humidity, soil type, saturation deficit and Land use/ land cover level-I categories were considered for the present study. The data pertaining to soil, and agro-ecological features were obtained from the National Bureau of Soil and Land Use Planning, Nagpur. The climate variables/weather data, in detail was received from the Indian Meteorological Department, Pune, India.

4.3. Filariasis data source

The district level estimate of filariasis prevalence has been derived from the unpublished results of the filariasis surveys run by the National Filariasis Control Programme (NFCP) and also the data from the individual publications. The fact involved in estimating the district level prevalence was to identify and to allocate the point data to a district. Mean prevalence was calculated for the districts in which more than one survey results were available, by taking the weighted mean of the individual survey results, with weights given according to the sample size [10]. Note that those running the NFCP surveys essentially sampled all individuals within randomly selected households within (randomly) selected towns/villages in each district [21, 23]. As data on the ages and sexes of the subjects were difficult to obtain or unavailable for the majority of the districts surveyed, most of the data analyzed for the present study are simply the summary values of prevalence (for whole, undifferentiated samples) reported to the NFCP. Since, these data come from many surveys; the bias resulting from demographic differences in the subjects is not likely to be great. It is clear, nonetheless, that some caution is warranted in interpreting the present data. Note also that, in the case of districts in which only one survey had been conducted, the prevalence recorded in that survey was simply assigned to the entire district. All data were abstracted using a standard proforma, which recorded the district name, dates of surveys, numbers of individuals examined and the numbers positive for microfilaraemia (of brugian and bancroftian), and symptomatic disease.

The NFCP surveys began in the 1950s, in urban districts known to be endemic for lymphatic filariasis, and have since been progressively extended to cover other districts, particularly in the rural regions of the country [21, 23] The first step in estimating the district-level prevalence was to identify and allocate the point data held by the NFCP to a district. The records held by the NFCP, however, varied from a single survey location to several locations within a district, and also spanned more than 6 decades, from the 1950s to 2012, across the districts surveyed.

5. Mapping spatial distribution of filariasis prevalence in India

The Map Info 4.5 GIS software was used for compiling the existing database on the distribution of lymphatic filariasis in India, and have now been used to develop the first maps at district-level (the level at which control against this parasite will be enacted in India) of filariasis endemicity in this country. The prevalent of lymphatic filariasis is endemic in 18 States and 6 Union Territories In India (Fig.1), there have been types of filariasis *viz*.,, the *Wuchereria bancrofti* parasite of Bancroftian filariasis transmitted by *Culex quinquefasciatus*, the *Brugia malayi* parasite of Brugian filariasis transmitted by *Mansonia annulifera* and *Mansonia uniformis* and, the prevalent of sub periodic filariasis in Andaman and Nicobar Islands has been transmitted by *Aedes niveus* mosquitoes.[11-15,1819,21-23]

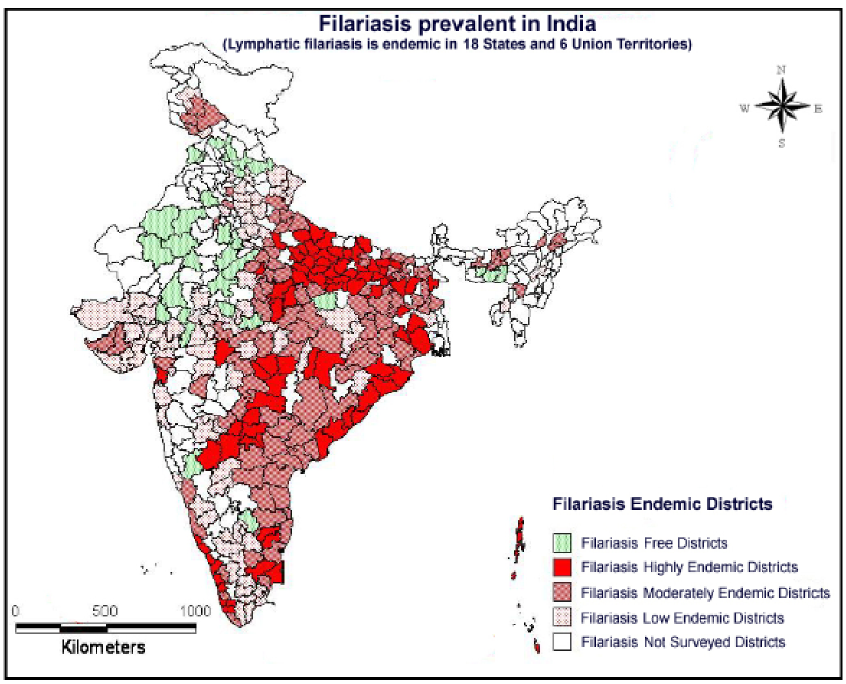


Fig 1: Filariasis endemics in India as on 2012.

The map shows the spatial pattern of filariasis endemicity [The prevalence (%) of microfilaraemia added to the prevalence (%) of filarial disease] at the district level. Based on the level of endemicity, these districts have been stratified as each one of high (>10%), moderate (1-10%) and low endemicity (<1%), using the quantile- mapping approach.[18] The high and moderate endemic districts are situated along the eastern and western coastal belt and river basins whereas the low endemic ones are situated at the interior plains [11, 18, 19] As on 2012, the 33 million people are positive for microfilaraemia, 23 million people affected with symptomatic filariasis, The 473 million people potentially at the risk of filarial infection (Source: National Vector Borne Disease Control Program, NVBDCP, Ministry of Health & Family Welfare, Government of India, New Delhi, India)

5.1. Advantage of the existing data

The existing historical back records and the individual published data have been used for creating the filariasis incidence for the past 6 decades, and mapping filariasis distribution for the entire country as well as for estimating the population at risk of filariasis infection in rural as well as in the urban agglomeration in the country (Fig 2. and Fig 3.). The same data was also captured in to geo-statistical analysis for finding the spatial agreements between the geo-environmental variables and the filariasis endemicity.

The results obtained from the geo-statistical analysis bring in to the GIS environment for developing the GIS based geo-environmental filariasis risk model for predicting the filariasis risk of the entire study region.

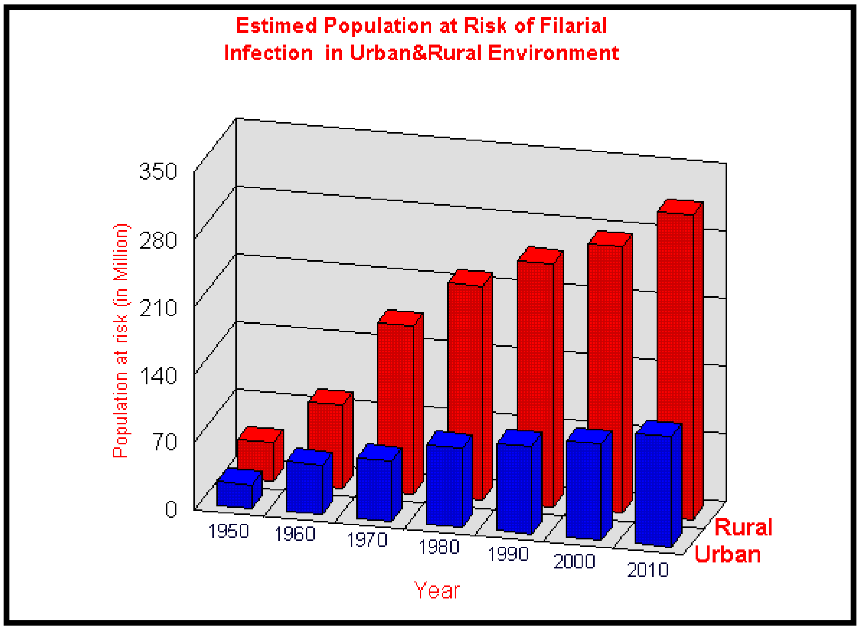
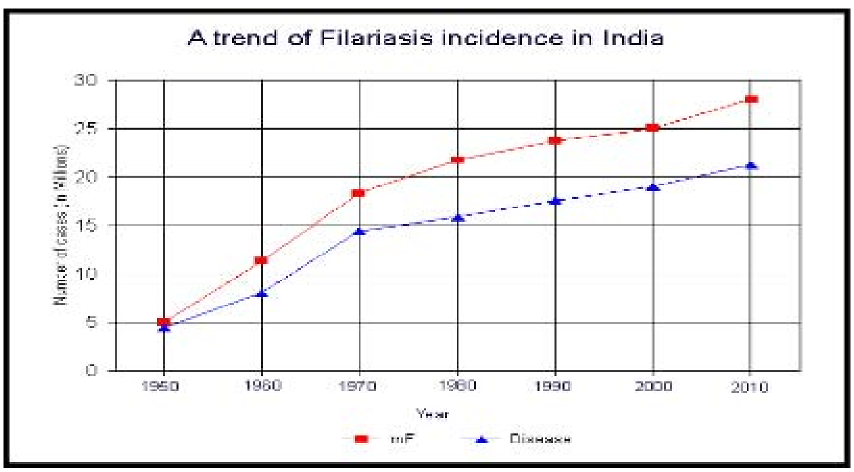


Fig 2: The estimated population at risk of filariasis infection in India



Graph 1: A trend of Filariasis incidence in India

5.2. Shortcoming of the available filariasis data

The data pertaining to the filariasis was very old and it was conducted at different point of time periods by the individuals and the National Filariasis Control Program (NFCP), New Delhi, India. (Fig. 4), and further, most of the time, these surveys were conducted in small isolated locality village or town, and hence, these data do not represent the real situation of the district. In the case of districts in which only one survey had been conducted the prevalence recorded in that survey was simply assigned to the entire district. However, the point data may not be appropriate for calculating mean prevalence of the region or district. It is to be noted that in some districts no data or no information is available. Further, observations made from the VCRC unpublished study revealed that there has been wide spatial bias of filariasis endemicity at the micro level below 1:50,000 scale.

6. Geo-Statistical analysis

6.1. Spatial Interpolation:

A GIS based spatial interpolation was made for predicting and filling the value for the area that has no information or the area was not surveyed. The Inverse Distance Weighted (IDW) spatial interpolation technique was applied for predicting the filariasis for the blank area based on the pair of 12 neighboring sample points with the power of 3, and the Spline spatial interpolation method was also performed for further smoothening of surface of spatial trend of filariasis transmission [11].

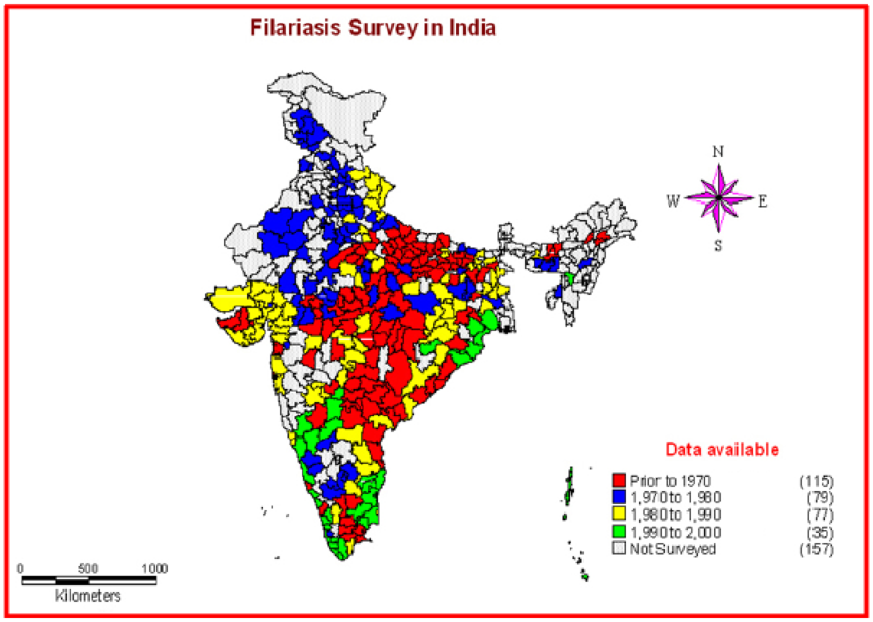


Fig 4: The available filariasis data held by the National Filariasis Control Program (NFCP), and the filariasis survey have been conducted by the Individuals in India for the past 6 decades in different locations at different period of time intervals

6.2. Geo-Statistical analysis of determinant variables:

6.2.1. Parametric value: Initially, simple correlation between environmental variables (altitude, water vapour, rainfall, relative humidity and saturation deficit) and filarial endemicity was examined, using Pearson's correlation.

6.2.2. Non-Parametric value: The relationship of other variable ('dummy indicators') like vegetation, land use / land cover and soil types and demographic structure with filarial endemicity were analyzed, using Spearman's correlation.

6.2.3. Multivariate analysis: A multiple linear regression – stepwise remove method was used for identifying the key variables amongst the risk variables as listed above using the SPSS 10.0 for windows software.

7. Results and Discussion

7.1. Spatial analysis:

The Exploratory data analysis (EDA) was adopted and used visualization methods specific to the analysis of spatial data, such as data posting and contour/perspective plots (effective for initial assessments of spatial trends in the data), geo-statistical methods, and large-scale trend modeling methods (fitting of trend surfaces and generalized additive modeling), to investigate the probability of spatial structure of filariasis infection. For geo-statistical data, posting data methods not only allow the display of sampling locations but by varying the size of the plotting symbol proportional to the plotted attribute value also the visualization of spatial clusters, and spatial trends in the data [11, 25]

7.2. Geo-Statistical analysis:

Small-scale spatial dependency or structure in the present data was investigated by semivariogram analysis. The semivariogram provides a measure of spatial correlation by describing how sample data are related with distance and direction [1]. The shape of this plot summarizes the type of spatial structure or dependence and the range of distance over which this dependence occurs. If there is spatial dependence among the data, typically increases with separation distance, may level off and even decrease after a certain distance [7].

7.3. Spatial interpolation:

Kriging is a linear interpolation procedure that allows the prediction of unsampled values of a variate that shows spatial correlation [3, 4, 5]. It calculates predictions of unsampled values based on the model of the covariance of the observations (estimated for example by the fits of the various semivariogram Kriging is a linear interpolation procedure that allows the prediction of unsampled values of a variate that shows spatial correlation. It calculates predictions of unsampled values based on the model of the covariance of the observations (estimated for example by the fits of the various semivariogram models) at known locations. Large-scale spatial trends in the data were estimated in the present study by either conducting trend surface analysis using weighted least squares or by fitting generalized additive models (GAMs) [2, 11, 16, 17, 25] using coordinates of the sample location and any other spatial covariate as predictors of the filariasis transmission risk in the country [9, 11, 20, 25]

7.4. Spatial trend surface of filariasis transmission

The hypothetical theory of geographical distribution of geo-climatic variables spatially continuous and the influence of the variables on the prevalence of the filariasis disease transmission is highly determined and it was assumed that the values nearby are more likely to be similar than values far apart.[11] The geo-statistical functions produce the predicted surface of filarial transmission risk map for those areas where no information is available or the survey was not conducted. The geo-statistical methods (Variogram analysis and Kriging) are powerful tools facilitate to analyze the mapped variables and underlying the relationship between the spatial structures of geographical datasets [2, 6, 16, 17] Spatial interpolation technique was used for estimating the values from the measured values in a given geographical area for un-sampled locations Among the different methods of spatial interpolation, the Inverse Distance Weighted (IDW) method was used for estimating the values of filariasis transmission risk. The IDW method was provided the surface grid values using a linearly weighted combination of the sampled point procedure. The weighted value of each sample point is declining with the increasing distance to the estimated grid points [25]. The general assumption in spatial interpolation is that the nearer samples have more influence than the points at distant one. The IDW method allows the data sets to controlling the significance of this influence by changing the power in the IDW formula [11, 25]. The greater the weighting power, the less effect do sample values far from the grid sample point on its value [7]. As the weighing power increases the grid sample point value approaches the value of the nearest sample point. With a smaller power, the weights are more evenly distributed among the neighboring data points, and the resulting surface becomes smoother. This method assumes that the surface is being driven by the local variation, which can be captured through the neighborhood 12 sample sites with the weighted power value of 2. A common power value is 2, because, the IDW performs a weighted average, the calculated grid values cannot be greater than the highest or less than the lowest value of the input sample points. Therefore, it cannot be created ridges or valleys if these extremes have not been already sampled.

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

A multivariate geo-statistical analysis model provides the significant level of individual variable and the combined effect more number of variables in association with filariasis transmission. The results show 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, SD and altitude were calculated (Table. 1). The contribution of collective effect of the geo-climatic variables on filariasis transmission and the filariasis prevalence are spatially determined with 72.3% accuracy.

Table 1: A multivariate geo-statistical model for predicting the consequence of filariasis transmission risk in India

Model prediction				
Model	**R value**	**R square**	**Adjusted R square**	**Std Error of the Estimate**
1	0.631a	0.398	0.373	5.9861
2	0.737b	0.543	0.503	5.3286
3	0.816c	0.666	0.620	4.6567

a. Predictors (constant): (SD)

b. Predictors (constant): (SD), Precipitation / Rainfall (RF)

c. Predictors (Constant): (SD), Precipitation / Rainfall (RF), Altitude (ALT)

7.6. Geo-Climatic variables and filariasis transmission risk in India

The delimitation, stratification and mapping of risk zones of vector-borne diseases including filariasis 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 [3, 4, 8, 9, 20, 24] The geo-statistical analysis of linear multivariate analysis provides the strong relationship between the filariasis and the geo-climatic variables. The seven possible geo-climatic filariasis risk variables (as stated above) are included in the analysis, out of seven variables, the combined effect of three variables (altitude, rainfall and saturation deficit) has statistically significant with 72.3% accuracy [11] (Table 1).

The study has produced the clear picture of the impact of determinant variables on the prevalence of filariasis endemicity and the filariasis transmission risk zones in the country [11, 25] Pearson's correlation coefficient was applied to analyzing the degree of association between the geo-climatic variables (temperature, rainfall, relative humidity, saturation deficit, and altitude) and filarial endemicity. The results show that spatial agreement was existed and it was appropriately describe the variation in disease occurrence in the regional scale [2-5, 11, 16, 17, 20, 24, 25] Spearman's correlation coefficient was applied to analyzing the qualitative in nature of variables (climate zones and land use/land cover), filarial endemicity were found significant with these measured variables (Fig5.). While the above methods were used to measure the association between the filariasis and the individual variable separately, the multivariate analysis was applied to fit the model and the results obtained that the spatial agreement was statistically significant when the variables are analyzed simultaneously.

7.7. Remote sensing data analysis

Space-borne data (IRS WiFS data) on various time points acquired by the NRSA, Hyderabad was processed jointly with technical experts of the collaborating institute of Regional Remote Sensing Service Centre (RRSSC-B), Bangalore, India. The processed image files were calibrated for producing the Normalized Differences Vegetation Index (NDVI) by the given standard formula:

$$\frac{\text{Infrared - Red}}{\text{Infrared + Red}} \text{ (or) } [(\text{Band4 - Band3})/(\text{Band4+Band3})]$$

The NDVI was further calibrated into composite NDVI value for defining the land use / land cover level-I categories for different filariasis endemic zones.

7.8. Remote sensing of filariasis transmission in India

The remote sensing information derived from the calibrations of NDVI from the red and infrared spectral DN values alone has insignificance with filariasis distribution, because there are complex of several phenomenon influencing the filariasis transmission, However, soil moisture with vegetation cover information of the remote sensing false colour composite DN values from 145 to 158 are valuable and statistically significant. Whereas, remote sensing and GIS has the efficient utility value in the application of geo-statistical modeling to generate a "filariasis transmission risk map", using the selected environmental variables (vegetation indices of land use / land cover categories) demonstrate the filariasis spatial pattern, quantified clustering and demonstrated the potential of GIS application in vector-borne disease epidemiology (Fig 6.). The appreciation of GIS for optimum allocation of the patients to the health service centers with <1km distance coverage for filariasis morbidity management and control [13-15] the rapid method of prediction and mapping potential breeding habitats areas of *Culex* genus of filariasis vector in the both urban and rural environment with rapid epidemiological mapping of lymphatic filariasis [11-15] GIS also used to generating the data for predicting the real picture of filariasis situation, a huge sample points are needed at less than 10 km interval [25], and added with satellite remote sensing data with geo-environmental risk variables used earlier in the filariasis risk map was integrated in to the GIS to classify the areas correctly with the real situation of the filariasis transmission risk in the country [11, 13] is provided with the results of area under vulnerable to risk of filariasis transmission in India was statistically significant with 93.8% accuracy (Fig7.).

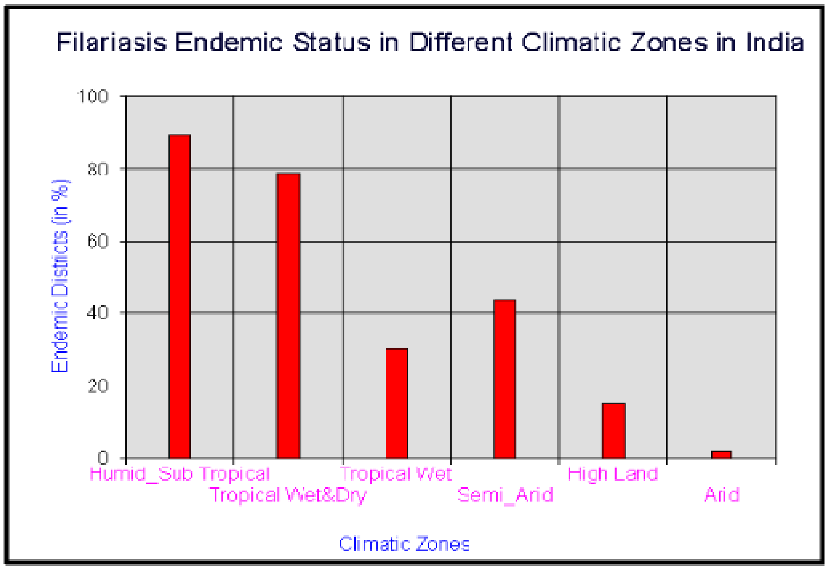


Fig 5: The climate zones of the collective of all geo-climatic variables contributing nearly 72.3% and are facilitate to the filariasis transmission risk in India

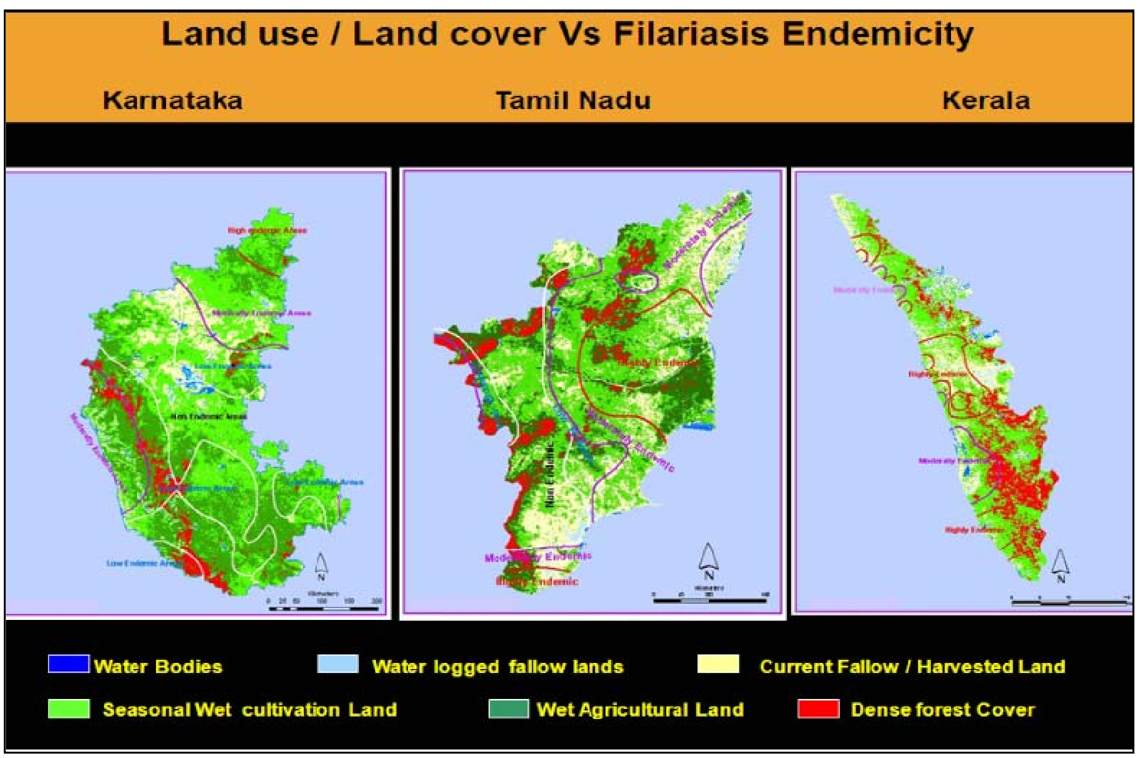


Fig 6: The spatial relationship between the IRS WiFS data and the Filariasis Endemicity in Karnataka, Tamil Nadu and Kerala states of South India, The Filariasis Endemicity level contour map is overlaid on land use / land cover map derived from satellite data.

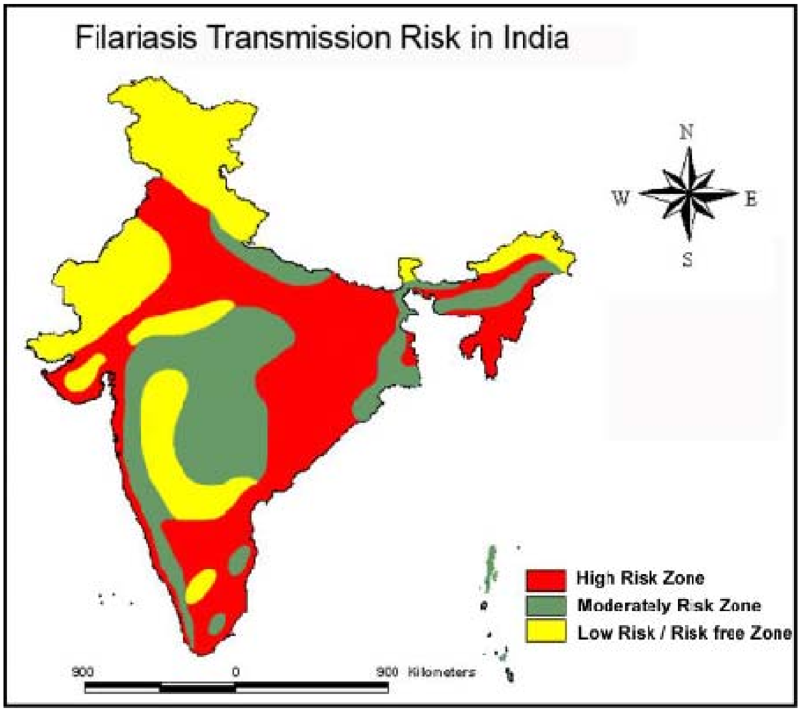


Fig 7: Filariasis Transmission Risk Zones in India, based on climate, landscape and the environmental variables. (Map source: Palaniyandi, 2013)

7.9. Climate, landscape, and the environments of Filariasis Transmission risk in India

The delimitation, stratification and mapping of risk zones of vector-borne diseases including filariasis 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 [3, 4, 8, 24] The geo-statistical analysis of linear multivariate analysis provides the strong relationship between the filariasis and the geo-climatic variables. The seven possible geo-climatic filariasis risk variables (as stated above) are included in the analysis, out of seven variables, the combined effect of three variables (altitude, rainfall and saturation deficit) has statistically significant with 72.3% accuracy [11] The study has produced the clear picture of the impact of determinant variables on the filariasis transmission risk zones in the country. The results show that spatial agreement was existed and it was appropriately describe the variation in disease occurrence in the regional scale [1, 5, 7, 16]. Spearman's correlation coefficient was applied for analyzing the qualitative in nature of variables (vegetation and land use / land cover), filarial endemicity were found significant with these measured variables [11-15]. While the above methods were used to measure the association between the filariasis and the individual variable separately, the multivariate analysis was applied to fit the model and the results obtained that the spatial agreement was statistically significant when the variables are analyzed simultaneously.

The most significant variables that could be associated with the presence or absence of filarial endemicity were identified using multivariate linear regression analysis, with the results the rank value is ranging from 1 to 7. Based on the rank value, the rank score value was calculated for each grid cell, which was ranging from 10 to 100. The data analyzed in the present study confirmed that the range of values of the variables (altitude 0 m – 600 m MSL, temperature from 16 to 30 ^{0}C, average annual rainfall from 300 mm to 1200 mm and relative humidity from 40 to 90) are statistically significant with filariasis transmission risk. The rank score value are carryover to the further analysis with geo-statistics for calculating the Filariasis Transmission Risk Index (FTRI). FTRI was developed for mapping filariasis transmission risk for the entire country. Accordingly, it was classified into three spatial categories, the red colour shows that the FTRI (66-100) is highly risk zones, the blue colour region shows that the FTRI (33–66) is moderately risk zones and the white colour region with FTRI (<33) is free from risk of filariasis. The FTRI is perfectly fit on the observed endemicity level over the region and mapping of filariasis transmission risk zone is statistically significance (Fig 7.).

8. Conclusion

The filariasis transmission risk is mainly controlled by the climate, landscape, and environmental variables. The level of agreement between the determinant variables and the filariasis transmission risk is statistically significant and spatially important .Thus, the delineation of the areas and categorization of filariasis transmission risk zones using geo-statistical modeling was highly reliable, accurate, quick, cost benefit and predictable for replacing the conventional methods of predicting and mapping of filariasis in India having a vast geographical area. It is obviously uncomplicated to stratification of the area under highly risk zone, moderately risk zone, and 'no risk' zone of filariasis transmission with correct spatial classification of area with 93.4% accuracy and 100% sensitivity. Thus, the application of GIS to the study of geo-statistical modeling approach for stratification of filariasis transmission risk zones could be useful for preparing control program towards the achievement of filariasis transmission control at the gross root level in the country.

9. Acknowledgement
The author is grateful to the Director, Vector Control Research Centre, (ICMR), Indira Nagar, Pondicherry – 605 006, India for providing the facilities, and also appreciates the Director General, Indian Council of Medical Research, Ministry of Health & Family Welfare, Government of India, New Delhi, for the funding support towards the study.

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