Devi, Prashanthi.M., B.Manickiam* and S.Balasubramanian "Use Of Remote Sensing And Gis For Monitoring The Environmental Factors Associated With Vector-Borne Disease (Malaria)" in Martin J. Bunch, V. Madha Suresh and T. Vasantha Kumaran, eds., *Proceedings of the Third International Conference on Environment and Health, Chennai, India, 15-17 December, 2003*. Chennai: Department of Geography, University of Madras and Faculty of Environmental Studies, York University. Pages 127 – 137.

USE OF REMOTE SENSING AND GIS FOR MONITORING THE ENVIRONMENTAL FACTORS ASSOCIATED WITH VECTOR-BORNE DISEASE (MALARIA)

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Abstract

An epidemiological and ecological study has been conducted to determine sustenance of malarial incidences in Salem district of Tamil Nadu, India (latitude of 77º 39' - 78º 50' 60" E and longitude of 11º 0' 36" - 11º 58' 48" N). The primary environmental factors like temperature, rainfall and humidity in association with forest cover and water bodies are enumerated to predict malaria incidences. The primary data were collected from The Directorate of Health under the Government of Tamil Nadu Health Ministry. The Survey of India toposheets at 1:250,000 scale and IRS IC LISSIII imagery pictured on February 26th, 1999 were used for digitization of forest cover and water bodies. GIS is used to overlay and analyse parameters contributing to malaria transmission by creating layers on epidemiological, environmental and ecological data. Monthly scale analysis was done using environmental variables and the mosquito incidences to find the optimum temperature, humidity and rainfall patterns contributing to maximum disease incidences.

Multiple Linear Regression method (backward elimination method) was used to analyse the environmental factors related to malarial incidences. The fitted model values are used on geocoded data on GIS. A risk map was prepared. The results showed that temperature, water body and the interaction of rainfall and forest cover played an important role in the spread of the disease. It is observed that even if the environmental conditions do not favour the spread of the disease, other factors such as sociological and health conditions may also play an important role. Precautionary methods and lack of awareness among the public may be another important factor. Epidemic control strategies must be effectively implemented in these areas.

1. INTRODUCTION

The Malaria epidemic is caused by infection with plasmodium viruses transmitted principally by mosquitoes in the tropical and subtropical regions of the world. Epidemics may arise through changes in the ecological equilibrium, mass migration and importation of exotic vector species and abnormal meteorological conditions. Among these factors the commonest possible in malaria epidemics is the change in meteorological environment conditions, which temporarily alter the equilibrium between malaria host(s), vector(s) and parasites(s). This type is termed as a "true epidemic".[1] In contrast, "resurgent outbreaks" result from control failure where inadequate health care infra structure and increasing insecticide drug resistance which will enable a malarial epidemic in regions where it has previously been under control.

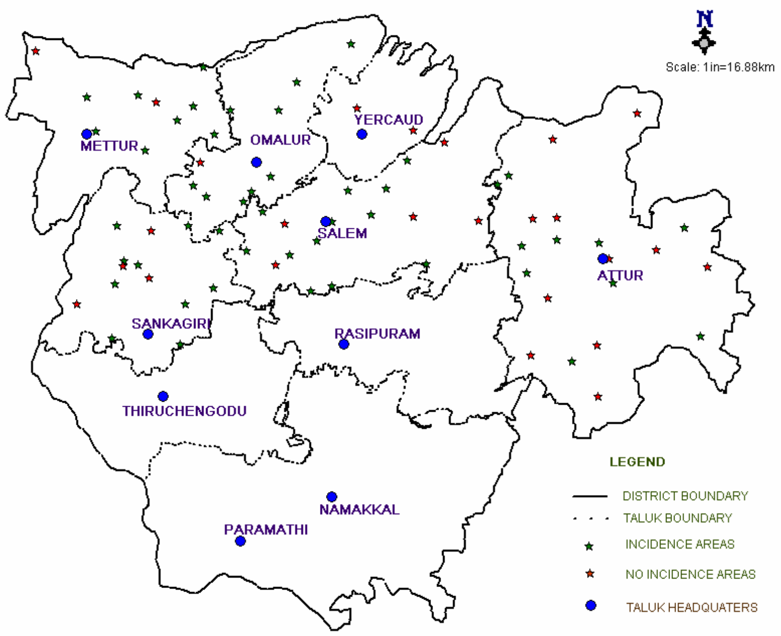
Spatial aspects of the epidemiology of infectious diseases include locational surveillances data, distribution of human animal host and vectors, spatial determinants of disease transmission, landscape constraints, spatial association of risk factors and disease, targeting of control efforts and questions related to the origin of diseases and outbreaks.[2]

The potential application of Remote Sensing and GIS to epidemiological studies has been shown by recent studies. GIS is a valuable tool of environmental epidemiology but very few applications have been made, even though epidemiological data clearly have spatial components. GIS also permits analysis of both spatial and non- spatial information and hence is an excellent framework for disease monitoring and control. Clarke *et al.*, have reviewed the use of GIS in surveillance and monitoring of vector borne diseases, water borne diseases, environmental health and modeling exposure to electromagnetic fields, quantifying lead hazards in a neighborhood area, predicting child pedestrian injuries and the analysis of the diseases policy and planning.[3] The present study was taken up to identify potential zones of malaria incidences in Salem district and prepare a risk map.

2. STUDY AREA DESCRIPTION

The present Salem district has a geographic area of 5173 km^2. The geographical location extents from latitude 77º 39' - 78º 50' 60" E and longitude of 11º 0' 36" - 11º 58' 48" N. The climate is tropical monsoon with a rainy season from June to November/December with a normal average of 5837.78 mm/year. The average temperature ranges between 22.5º c and 35.08º c. The study area is presented as figure 1.

Fig 1.Study area and recorded malaria incidences in Salem district



3. DATA USED

The ground data consisted of surveys carried out by Directorate of Health under the Government of Tamil Nadu through a number of Primary Health Centers (PHC) in the district (around 70 distributed in the six Taluks). Monthly malarial incidences survey in both the rural and urban areas was confirmed through microscopic examination. Among the blood smears taken, 1% positive cases were considered as active and 0.5% were considered as passive cases. Systematic recordings were done in ward registers from January 1996 to June 2001 both months inclusive. Case numbers in each area were treated as incidence figures because the population eligible for health care kept varying throughout the period. The data were collected from 70 Primary Health Centers (PHC) randomly distributed in the rural area and in four urban centers viz Salem, Mettur, Attur, and Edappadi.

The Survey of India toposheets at 1:250,000 scale of the study area and IRS IC LISSIII data of February 26th, 1999 were used for the study. The relevant meteorological data were obtained from the Department of Meteorology, Salem Collectorate.

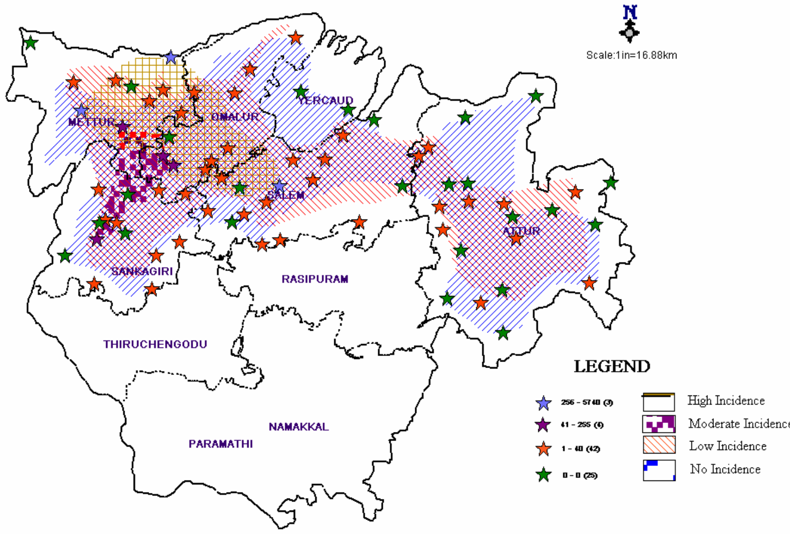
4. RESULTS

Digital thematic layers of forest, water body and rainfall were prepared and were overlaid, integrated and analyzed using GIS software MAPINFO. The incidence cases of both rural and urban areas were collected and recorded in dbase III plus and using MAPINFO a map was created for the incidences of malaria in Salem district (Figure 1).

4.1 Thematic factors

Using the incidence map (Figure 1), a thematic map was prepared to classify the malarial incidences as high, moderate and low and presented as Figure 2. The no incidence areas, as red objects, were also considered for thematic maps. This is used to visually interpret the spread of incidences according to their intensity in the district.

Figure 2. Thematic map of recorded malaria incidences in Salem district



From the above thematic map, it was inferred that no incidences cases were recorded in 25 locations out of the 74 locations present in the district. Three areas of high incidences were recorded at Vellar (MT7), Mettur (MT8) and Salem (SL5). Areas of moderate incidences were recorded at four locations namely Tharamangalam (OM3), Sedapatty (OM5), Kedaiyur (SK5) and Nangava lli (MT2). The remaining 42 locations were designated as low incidence areas.

4.2 Analysis of Meteorological factors

4.2 a) Temperature and Humidity

Cross *et al.*, have studied that the temperature and relative humidity pattern of incidence location are considered to have high probability of occurrences.[4] Mosquito species have different threshold levels of temperature. In this study, the day temperature ranges from 30^0C to 36^0C, where the occurrences of incidences were noted. In areas of lower temperature (Nagalur, Valavanthi and Pachamalai) around 20^0C, malarial incidences were not reported. the related humidity data were collected for Salem district to correlate with the malaria incidences. In this study, the average relative humidity was recorded as 74 % for the years 1996 to 2001.

4.2 b) Rainfall

As mosquito species are temperature bound they are also rainfall dependent. For most species, the number of breeding sites is proportional to the amount of rainfall and its pattern. Extreme conditions restrict mosquito proliferation, low rainfall creates less number of breeding habitats and high rainfall flushes mosquito eggs. The average rainfall was recorded as

506.36mm in the district. Rainfall was categorized into four classes ranging from 15-25, 51-59, 59-96 and 96-134 accordingly.

4.3 Analysis of Environmental factors

4.3 (a) Forest and Vegetation cover

Malaria vector is reported to be found in evergreen forest favorably. Out of all the climatic conditions, rainfall is a major contributor to the forested areas and hence the classification of forest mainly depends upon the intensity of rainfall.[5] From the layers derived from the toposheets, the vegetation cover is mainly classified into mixed jungle, scrublands, plantations and unclassified reserve forests. The overall area of forest cover was 1196.68 sq.kms.

4.3 (b) Water Body

Malarial larva is aquatic and need relatively quiet water to grow. Perennial water bodies were digitized from the IRS 1C LISS III imagery. A digitized layer from the imagery was overlaid on the toposheet to present a common map for forest cover and water bodies.

With an overlay of the created thematic maps of incidences and rainfall, the results were observed that in areas of High incidences the average rainfall is 71.55 mm/year with a temperature and relative humidity of 33.71º C and 78.34% respectively. The total area of forest cover is 316.86 sq.kms and the total area of water body is 467.09 sq.kms. In areas of moderate incidences the average rainfall is 75.55 mm/year having a mean temperature of 33.78º C and a relative humidity of 77.50%. The total forest area is 246.74 sq.kms having a water body of 150.69 sq.kms. The low incidence areas recorded an average rainfall of 70.66 mm/year having a mean temperature of 33.84º C and a relative humidity of 78.25%. The areas of the total forest cover and total water bodies are 942.95 sq.kms and 172.66 sq.kms, respectively. In areas where no incidence cases occurred the average rainfall, mean temperature and relative humidity were recorded as 84.42 mm/year, 29º C and 74% respectively. The forest covers an area of 1196.68 sq.kms and the water body has an area of 173.98 sq.kms.

4.4 Malaria Incidence Seasonality

Mapping of malaria seasonality is an important goal because the distribution of the vector (Mosquito) depends on the seasons. India is a resources constrained country and has diversified environment conditions and seasonality. Such infrastructures are useful for optimizing the timing of insecticide spraying, for restricted distribution of anti malaria drugs to periods of known disease risk and to reduce the time required to provide logically and financially demanding chemo prophylaxis.

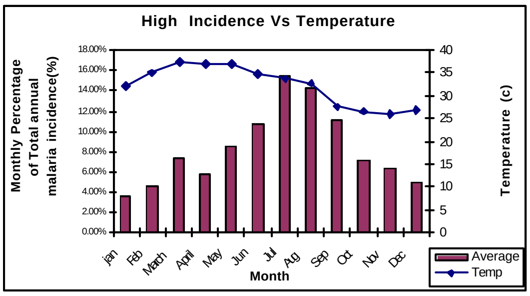
Based on this information reported by Hay *et al.*, for Gambia, a temporal variability analysis for Salem District of Tamil Nadu was done.[6] The correspondence between the mean maximum day temperature, rainfall, humidity and malaria incidences is illustrated in Figure 3 for high, moderate and low incidence areas detected from the incidence thematic map of Salem District.

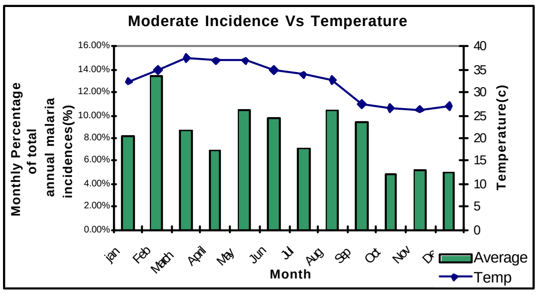
The collected environmental data such as rainfall, temperature and humidity were used for mapping malarial seasonality (Figure 3). The collected monthly malarial incidences (in percentage) at 49 PHC wards were used to correlate the environmental variable. The high, moderate and low incidences lies between 3.6% to 15.63%, 4.9% to 10.5%, and 5.1% to 13.8% respectively for 6 years total cases. The total cases were taken from the thematic map of malarial incidences (Figure 2) and the PHC areas under which it covers.

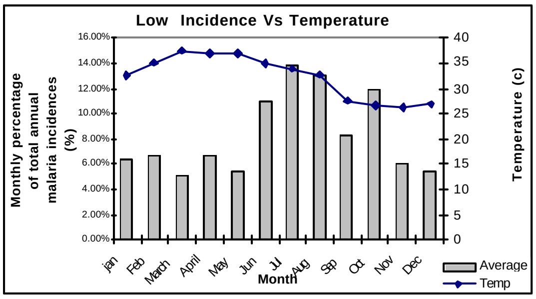
In low and high incidence areas, the maximum malarial incidences occurs in July and August. In the moderate incidences areas, the maximum percentage of incidences occurs in February. The temperature ranges between 32°C and 34°C in the high, moderate and low incidence areas. The rainfall ranges from 8.48 mm to 236.78 mm in high incidence areas, 11.23 mm to 489.0 mm in moderate areas and 18.18 mm to 794.51 mm in low incidence areas. The relative humidity of all the three areas ranges from 68.16% to 84.5%. From the above results, it is inferred that moderate rainfall with optimum temperature and relative humidity is most favorable for the prevalence of malaria. From the figures it is inferred that

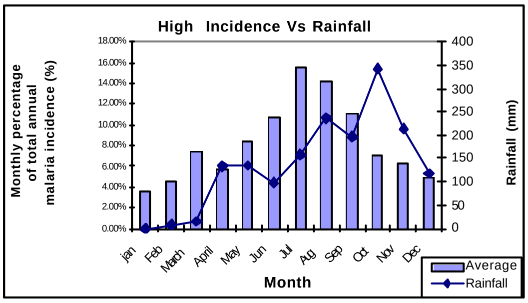
i) If the temperature is optimum the incidence is high
ii) In high rainfall the incidence is low but increases in the subsequent months
iii) With respect to the humidity, high humidity is a favorable condition for increasing mosquito incidences.

From these results, it is concluded that the environmental variables are acting more or less similar in all the three derived incidences. It is understood that in addition to this information some other factors like vegetation cover and water body may play an important role in the increase of incidences. It is well understood that the interaction of the factors influencing the mosquito incidences has a formidable complexity.









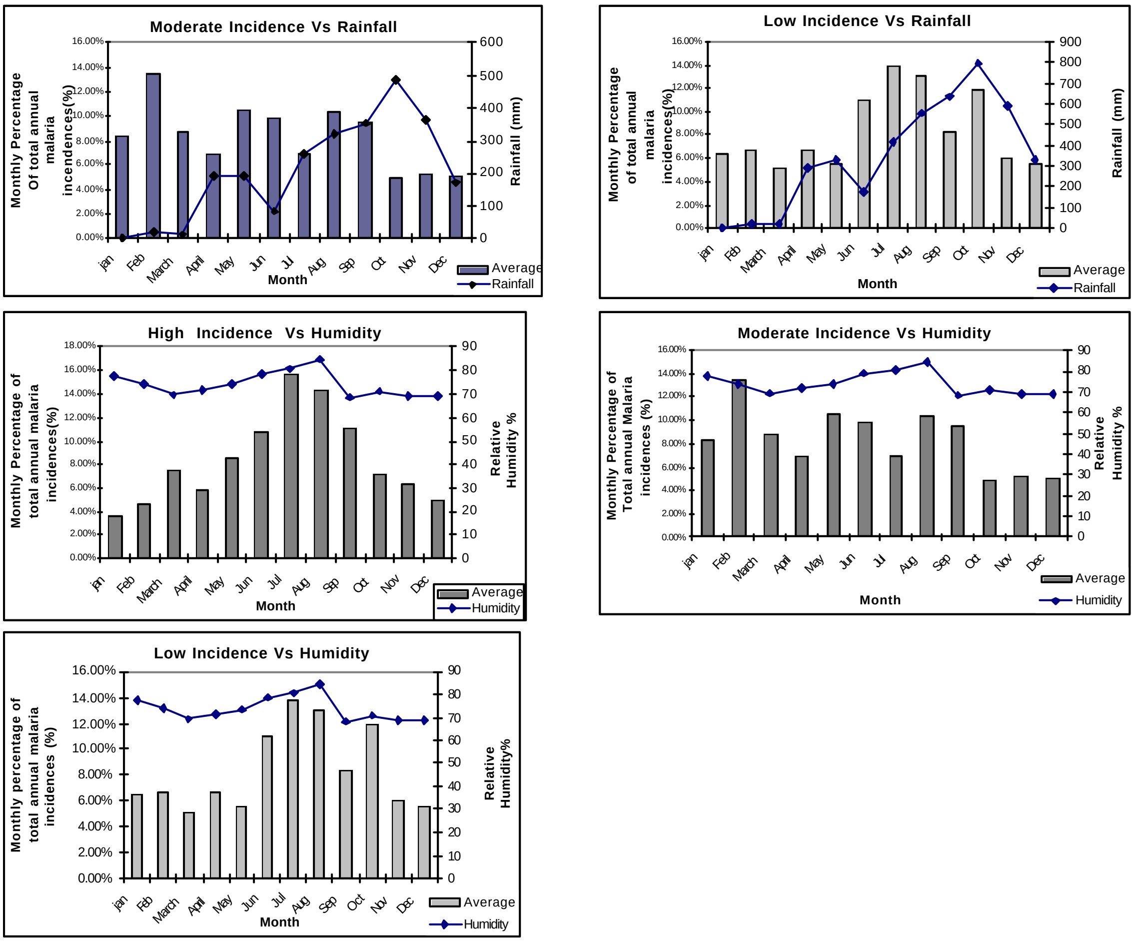


Fig 3. Graphs show the monthly mean percentage of malarial incidences (bars) for the High, Moderate and Low incidence areas of Salem District along with the environmental factors Temperature, Rainfall and Humidity.

4.5 Incidence Prediction Model

A number of models have been proposed by Klienbaum *et al.*, to predict the vector-borne diseases.[7]

Backward elimination method of Multiple Linear Regression Model (MLR) was applied to interpret the incidence of mosquito in the form of

$$Y=\beta o+\beta_1 X_1+\beta_2 X_2+\ldots\ldots\ldots+\beta_k X_k+E \qquad \ldots\ldots\ldots\ldots\ldots (1)$$

Where Y is the total malarial incidences, X1- X_k are predictors, β_0 is a constant and β_1 - β_k are coefficients.

Confounding and interactions are two methodological concepts relevant to attaining this goal. Kleinbaum *et.al.*, describes the context of epidemiological research, which typically address the ethological question involving the goal.[8] In general *confounding exist if meaningfully different interrelations of the relationship of interest results in a exogenous variable is ignored are included in the data analysis.* Whereas *interaction is the condition where the relationship of interest is different at different levels (values of the extraneous variable(s)*[7].

Mathematically the interaction effects will represent in one way as:

$$Yy/X1\ldots Xk = \beta o + \beta_1 X_1 + \beta_2 X_2 \ldots\ldots \beta_k X_k \ + \beta X_1 X_k \qquad \ldots\ldots\ldots\ldots\ (2)$$

The proposed model to interpret the relationship between malarial incidences and the related environmental factors such as vegetation cover, rainfall, water body, temperature and humidity is

$$Y=\beta o+\beta_1 X_1+\beta_2 X_2+\beta_3 X_3+\beta_4 X_4+\beta_5 X_5 +\beta_6 X_6 +\beta_7 X_7 +\beta_8 X_8+\beta_9 X_9+\beta_{10} X_{10}+E \qquad \ldots\ldots\ldots\ldots\ (3)$$

Where Y is the Total incidences, X_1 is the Rainfall in mms, X_2 is the Temperature in Celsius, X_3 is the Humidity in %, X_4 is the extent of Vegetation cover in sq.kms, X_5 is the extent of Water body in sq.kms, X_6 is the Interaction of Rainfall * Temperature, X_7 is the Interaction of Rainfall * Humidity, X_8 is the Interaction of Rainfall * Vegetation cover, X_9 is the Interaction of Vegetation cover * Water Body, X_{10} is the Interaction of Rainfall * Vegetation cover * Water Body.

A log transformation was used to stabilize the variance of Y (Total incidences) to normalize the dependant variable. A summary of the backward elimination method of multiple linear regression analysis was presented in Table 1 where six models were presented. The R (multiple correlation) value is decreased from model 1 to model 6 and the contribution of the 4 predictors is significant in model 6. Therefore model 6 is used for predicting the malarial incidences. The selected final model is

$$Y = -4.98 + 0.14\ (\text{Temperature}) - 3.44 \times 10^{-3}\ (\text{Water body}) - 1.40 \times 10^{-5}\ (\text{Interaction of Rainfall and Forest cover}) + 1.33\ (Z) \qquad \ldots\ldots\ldots\ldots\ (4)$$

Model		Unstandardized Coefficients		Std. Coefficients	t	Sig.	95% Confidence Interval for B		Correlations			Collinearity Statistics	
		B	Std. Error	Beta			Lower Bound	Upper Bound	Zero-order	Partial	Part	Tolerance	VIF
1	(Constant)	-13.861	7.473		-1.855	.071	-28.976	1.254					
	TEMP_MA	.231	.207	.285	1.119	.270	-.187	.649	.111	.176	.089	.097	10.305
	HUMID_MA	.319E-02	.092	.074	.794	.432	-.113	.260	.064	.126	.063	.726	1.377
	WATERBO	9.95E-03	.017	-.594	-.591	.558	-.044	.024	.154	-.094	-.047	.006	60.769
	FOREST	.583E-04	.005	.091	.099	.921	-.009	.010	-.230	.016	.008	.008	31.665
	X6	1.85E-03	.002	-1.232	-.744	.461	-.007	.003	-.025	-.118	-.059	.002	35.452
	X7	.173E-04	.001	1.305	.786	.437	-.001	.003	-.025	.125	.062	.002	38.032
	X8	3.47E-05	.000	-.395	-.473	.639	.000	.000	-.241	-.076	-.038	.009	10.673
	X10	.511E-07	.000	.395	.397	.694	.000	.000	.020	.063	.031	.006	57.416
	Z7	1.367	.184	.891	7.416	.000	.994	1.740	.818	.765	.588	.436	2.292
2	(Constant)	-13.723	7.252		-1.892	.066	-28.380	.933					
	TEMP_MA	.230	.204	.284	1.130	.265	-.182	.642	.111	.176	.089	.097	10.289
	HUMID_MA	.241E-02	.091	.073	.798	.430	-.111	.256	.064	.125	.063	.731	1.367
	WATERBO	1.06E-02	.015	-.636	-.703	.486	-.041	.020	.154	-.110	-.055	.008	33.271
	X6	1.86E-03	.002	-1.236	-.756	.454	-.007	.003	-.025	-.119	-.059	.002	35.240
	X7	.077E-04	.001	1.290	.790	.434	-.001	.003	-.025	.124	.062	.002	34.247
	X8	2.80E-05	.000	-.319	-.958	.344	.000	.000	-.241	-.150	-.075	.055	18.075
	X10	.444E-07	.000	.438	.496	.623	.000	.000	.020	.078	.039	.008	27.256
	Z7	1.372	.175	.894	7.820	.000	1.018	1.727	.818	.778	.613	.470	2.128
3	(Constant)	-14.708	6.910		-2.128	.039	-28.664	-.752					
	TEMP_MA	.278	.178	.343	1.564	.126	-.081	.637	.111	.237	.121	.125	7.987
	HUMID_MA	.672E-02	.089	.067	.748	.459	-.113	.247	.064	.116	.058	.743	1.345
	WATERBO	3.17E-03	.001	-.189	-2.139	.038	-.006	.000	.154	-.317	-.166	.769	1.300
	X6	2.40E-03	.002	-1.598	-1.103	.276	-.007	.002	-.025	-.170	-.086	.003	48.200
	X7	.002E-03	.001	1.600	1.071	.290	-.001	.003	-.025	.165	.083	.003	70.385
	X8	1.40E-05	.000	-.159	-1.933	.060	.000	.000	-.241	-.289	-.150	.888	1.126
	Z7	1.316	.132	.857	9.983	.000	1.049	1.582	.818	.842	.775	.818	1.223
4	(Constant)	-11.473	5.362		-2.140	.038	-22.294	-.652					
	TEMP_MA	.337	.159	.415	2.119	.040	.016	.657	.111	.311	.164	.155	6.442
	WATERBO	3.18E-03	.001	-.190	-2.160	.037	-.006	.000	.154	-.316	-.167	.769	1.300
	X6	2.92E-03	.002	-1.940	-1.419	.163	-.007	.001	-.025	-.214	-.110	.003	13.504
	X7	.226E-03	.001	1.957	1.390	.172	-.001	.003	-.025	.210	.107	.003	32.624
	X8	1.36E-05	.000	-.155	-1.893	.065	.000	.000	-.241	-.280	-.146	.893	1.120
	Z7	1.305	.130	.850	10.012	.000	1.042	1.568	.818	.839	.773	.827	1.209
5	(Constant)	-4.690	2.243		-2.091	.042	-9.213	-.167					
	TEMP_MA	.134	.065	.166	2.082	.043	.004	.265	.111	.303	.163	.960	1.042
	WATERBO	3.57E-03	.001	-.213	-2.440	.019	-.007	-.001	.154	-.349	-.190	.798	1.254
	X6	6.56E-05	.000	-.044	-.534	.596	.000	.000	-.025	-.081	-.042	.914	1.094
	X8	1.33E-05	.000	-.152	-1.837	.073	.000	.000	-.241	-.270	-.143	.894	1.119
	Z7	1.341	.129	.874	10.380	.000	1.080	1.601	.818	.845	.810	.861	1.162
6	(Constant)	-4.984	2.157		-2.311	.026	-9.330	-.637					
	TEMP_MA	.139	.064	.171	2.187	.034	.011	.267	.111	.313	.169	.976	1.024
	WATERBO	3.44E-03	.001	-.206	-2.404	.020	-.006	-.001	.154	-.341	-.186	.819	1.221
	X8	1.40E-05	.000	-.159	-1.966	.056	.000	.000	-.241	-.284	-.152	.918	1.089
	Z7	1.333	.127	.868	10.472	.000	1.076	1.590	.818	.845	.811	.872	1.147

The fitted regression model (the fitted equation 4) is diagnostically checked to assess the accuracy of the computations. For this model we have focused the residual analysis method as a diagnostic tool.

The correlation coefficient of this is 0.858 and the percentage of R is around 76%. From the results of the correlation analysis and the significance of the correlation coefficient, the prediction is nearly accurate. The predicted values are used for preparing a predicted visualization map.

A thematic map of the predicted values was created whereby malarial intensity was zoned as high, moderate and low areas (Figure 4). From this thematic map, it was observed that high incidence areas were recorded at 4 areas where the cases ranged from 256 to 5740, moderate incidences were recorded at 3 areas ranging from 41 to 255 and low incidences recorded at 42 locations ranging from 1 to 40. These results were compared with that of the thematic map of incidence.

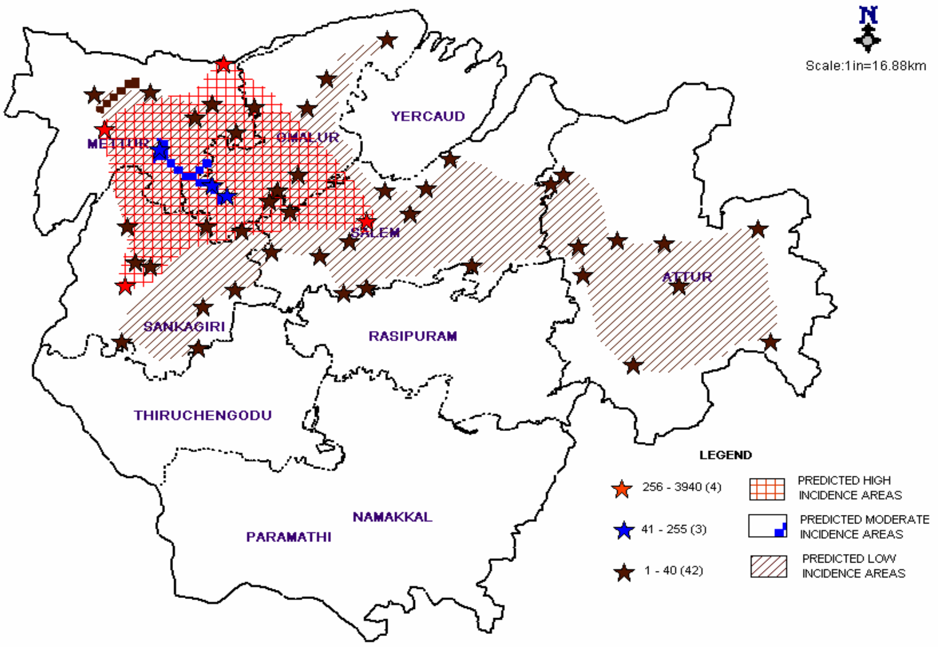


Fig 4. Thematic map of Predicted Malarial Incidences of Salem district

1) While comparing the Figure (2) and Figure (4), we have dissipated 3 zones:
- The environmental variables are favorable for the malaria distribution in the area
- The environmental variables are not favorable for the malaria in the area.
- Both may or may not be in favor of the distribution.

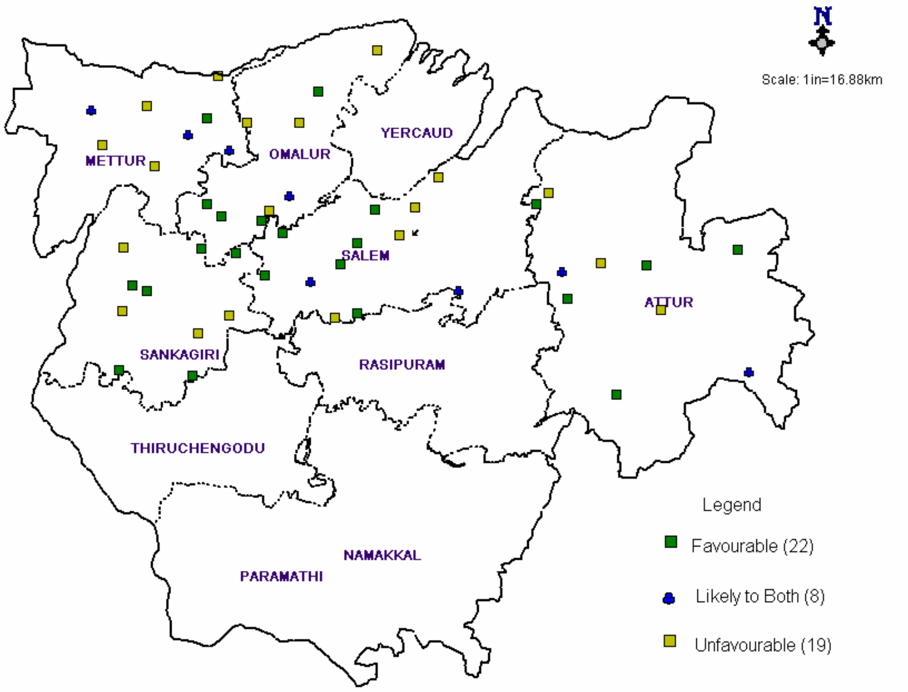
2) If the conditions of the environmental factors are in favour/restricted, in relation to the distribution of the malaria vector, the same may be implemented in other areas to decrease the malarial distribution.

5. DISCUSSION

The malarial incidences collected and partitioned into three intensity areas (High, Moderate and Low incidences) naturally depend on the vector abundance. The scrutinized results reveal that a temperature range of 31.5°c to 33.5°c with the rainfall intensity of 220 – 240 mm and 76-78% relative humidity is suitable for increased malarial incidences. In the low incidence areas, even though the temperature and humidity are favorable for malarial transmission, the increased rainfall intensity decreased the malarial incidences. This is clearly seen from the maximum rainfall of the three incidence areas. The maximum rainfall is 400, 600, 900 mm in High, moderate and Low incidence areas, respectively. It is inferred that the temperature, water body and the interaction of rainfall and forest cover played a major role in the prediction of incidences along with the existing areas of intensity.

Using the predicted values, a map of favourable, unfavourable and likely occurance of malarial incidences in Salem district was presented to implement control strategies (Figure 5).

Fig 5. Areas that are favourable, unfavourable and likely to be affected by malaria in Salem District



In the predicted map (Figure 4), the same 42 locations were observed in the low incidence areas. Out of the 42 locations 15 areas were predicted to be unfavorable for future malarial incidences. In 8 areas, conditions were likely to occur for both favorable and unfavorable conditions. These areas were likely to switch over either of the two. Favorable conditions for malarial incidences were predicted to occur at 19 locations. In these areas, the environmental factors most favor the occurrence of malarial incidences. Similarly in moderate incidence areas, two locations namely Sedapatty (OM5) and Tharamangalam (OM3) were favorable and Nangavalli (MT2) was unfavorable for malarial occurrences.

In high incidence areas, the locations namely Kedaiyur (SK5), Mettur (MT8) and Vellar (MT7) were unfavorable and Salem (SL5) was highly favorable with a predicted value of 3932 cases of malarial incidences in contrast with the observed value of 5737.

From the above study, it is concluded that even if the environmental conditions do not favor the spread of the disease, other factors such as sociological and health conditions may also play an important role. Precautionary methods and lack of awareness among the public may be another important factor. Hence, management strategies must be very effectively implemented in these areas.

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