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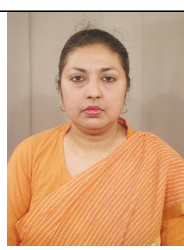
|  |  |  |  |  |  |
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**Title of the paper (PN-31)-**

# Remote Sensing and GIS: Tools for the Prediction of Epidemic for the Intervention Measure

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## Abstract

Kala-azar or Visceral Leishmaniasis is caused by the *Protozoan Parasite* (Genus: *Leishmania donovani)* transmitted to humans by the bite of infected female sandfly, *Phlebotomus argentipes*. Kala-azar is geographically and temporarily limited by variation in environmental factors. Present study focused on disease distribution and its relation between the environmental factors and vector distribution in a Kala-azar endemic region. We used remotely sensed environmental indices and correlated with the vector (*P. argentipes*) abundance to discriminate their habitats. Geo-statistical method was used to identify spatial patterns and directional distribution of disease within the study area. Standard deviation ellipse showed diseases were spread in eastern to western direction for the entire district and more clustered in the western part of the district. Vector density was much higher in the month of June, July and September (MHD >8) whereas low density was found in December and January (MHD <2). Descriptive statistics of Soil **A**djusted Vegetation Index (SAVI) was calculated to measure the vegetation which showed that values varied from -0.42 to 0.69. Minimum and mean SAVI index values showed vulnerabiliy to the distribution of vector abundance. Wetness index values also showed significant relationship with the *P. argentipes* abundance in the study area. The preferences for breeding site by the sandflies appeared to be associated in the zone having LST values varying from 27.0°C – 31.0°C, ($R^2$=0.58). Risk land use/ land cover characteristics showed that settlement, grass/weed cover land, surface waterbody and marshy land, river and sand played crucial role for *P. argentipes* breeding. This information assists an epidemiologist and entomologist in gaining further insight into the relationship or characteristics between the encroachments of a disease.

**Keywords:** Kala-azar, *Phlebotomus argentipes*, Remote Sensing, Environmental indices.

## Introduction

Kala-azar or visceral leishmaniasis (VL) is a family of vector-borne diseases caused by a protozoan parasite *Leishmania donovani*, transmitted by the bite of female phlebotomine sandfly *Ph. argentipes* (Swaminath et al., 1942). VL is the second largest parasitic killer in the world after Malaria (Strom 2006). The parasite attacks internal organs such as the liver, spleen, and bone marrow.

VL exists in 88 countries on five continents; however, the countries mostly affected in the world are India, Bangladesh, Nepal, Sudan, and Brazil (MD 2009). These five countries contain approximately 90% of the estimated 500,000 new cases of VL that occur annually worldwide (Desjeux 1996, 2004). India, Nepal, and Bangladesh account for an estimated 300,000 cases annually and more than 60% of the global burden (Bern et al. 2005). It is estimated that 200 million people worldwide are at risk of contracting the VL disease, with 62 countries being already endemic (Desjeux 2004). There are no vaccines available to prevent infection, thus protection against sandfly bites is regarded as one of the best defenses from contracting the disease. Occurrence of Kala-azar is determined by multiple factors, including environmental dimensions that affect the population biology, development, and behavior of vectors, as well as dimensions that determine the population biology, and even behavior of humans. Meteorological factors (i.e. temperature, rainfall) and environmental factors (i.e. soil temperature and moisture) have been associated with *P. argentipes* monthly abundance in Bihar (Picado *et al.,* 2010) and West Bengal (Ghosh *et al.*, 1999) respectively. In recent times, satellite data are used to obtain a variety of types of geographical and landscape information [Beck *et al.*, 2000; Hay *et al.*, 1996]. Across continental extents and broad areas, environmental factors like humidity, temperature, rainfall and land cover features highly influenced the distribution and development of *Phlebotomous argentipes.* A study of these variables can limit Kala-azar occurrence [Bhunia *et al.*, 2010; Ranjan *et al.*, 2005; Bucheton *et al.*, 2002].

The use of Remote Sensing (RS) and Geographic Information System (GIS) have made new technological developments available for the study of vector borne diseases such as VL based on the fundamental landscape epidemiology (Pavlovsky, 1996). In this study, we demonstrate how GIS, in combination with other geographical technologies, namely remote sensing and geo-statistics, can be used to analyse and manage the vector borne diseases, especially kala-azar, to identify areas favourable for the breeding of the vector, *P. argentipes,* and to assess the risk of this disease to a local population. Previous research on kala-azar has shown how local climate variables such as rainfall and temperature can affect the incidence rate of the disease (Bhunia et al., 2010; Sudhakar et al., 2006). The present study thus focuses on examining disease distribution and its relation with the environmental factors and vector distribution in a Kala-azar endemic region in Bihar, India.

## Materials and Method

### *Study area*

Muzaffarpur district lies in North Bihar (i.e. North of Ganga). It covers a geographical area of 3132 $Km^2$ and falls under 72 F, 72 G and 72 B degree topographical sheets of Survey of India (SOI). It lies between Latitudes 25º54'00"N to 26º23'00"N and Longitudes 84º53'00"E to 85º45'00"E. It is surrounded by the districts of Sitamarhi and East Champaran in North and Vaishali and Saran in south whereas in east it is surrounded by Darbhanga and Samastipur and in west by Saran and Gopalganj district. The district, with it's headquarters at Muzaffarpur, consists of 16 administrative development blocks. The district headquarters as well as all the blocks are well connected with the state capital by road. The total population of the district as per 2001 census is 37.43 lakhs with a density of 1180 persons per $Km^2$ showing a decennial growth of 20%.

The district received an average rainfall of 1280 mm. The monthly rainfall data shows that 85% of rainfall comes during monsoon period. The district experiences a severe winter followed by a very hot summer (40ºC) and then by heavy downpour of monsoon. The summer starts here from April and lasts upto June, and then monsoon starts and continues upto September.

*Data Sources*

The total number of VL cases reported per year in Muzaffarpur district and information on their origin (i.e. PHC, hospital or NGOs clinic) between 2005 and 2010 were obtained from the Ministry of Health district headquarters at Muzaffarpur. VL diagnosis was similar over the study period. According to the guidelines provided by National Vector borne Disease Control Programme (NVBDCP), Government of India, patients presenting chronic fever, loss of appetite, weight loss, skin pigmentation and abdominal distension were considered VL suspects. After clinical exploration to determine splenomegaly and discard other pathologies VL cases were confirmed by serological tests i.e. aldehyde test or rK39 dipstick.

Adult sandflies were monitored randomly in households and/or cattle sheds from the 30 villages within the entire district between January and December, 2010 using Communicable disease Centre (CDC) light traps placed at 50–70 cm above the ground, and at 1feet distance from the wall. Traps were run (between 18.00 hours and 06.00 hours) once a month, early in (in the first week of) each month. The counts of *P. argentipes* in the traps were used to calculate mean monthly numbers of this sandflies/trap-night, as a measure of the density of the local vector population.

During the ground survey, inside room temperature and relative humidity were also recorded from the relevant sites (e.g. at the time of sandfly collection) by installing the instrument *Polymeter* and was compared with the weather parameter to evaluate the favourable climatic condition for vector habitats.

*Satellite data processing and analysis*

All the satellite data was geo-referenced to the projection: Universal Transverse Mercator (UTM) zone 45 and Datum: World Geodetic Datum (WGS) 84. Geometric correction was made using both topographic maps and ground control points (GCPs) to register the 2010 image. The root mean square error (RMSE) between the 2009 image and other images was within the acceptable limit of 0.5 pixels (Lunetta and Elvidge, 1998).

Land use/land cover maps were generated to identify the different classes of land from Landsat 5 TM imagery (Path/Row-141/42; DOP-22/10/09). A supervised classification technique with Maximum Liklihood (MXL) algorithm was used to assign the pixel into eleven land cover classes for endemic sites and ten classes for non-endemic sites, based on their spectral reflectance characteristics (Richards and Jia, 2006). Using a separability cell array, different spectral signatures in each class were merged together (Jensen, 2004) which evinced better accuracy in the final image classification. Image processing was performed using ERDAS IMAGINE v.9 image processing software. Concentric circles of 500 m radii buffer zone was generated for 30 villages, around the centre of the village.

The SAVI is one of the most widely used indices in the processing of satellite data (Huete, 1988). This index attempts to be a hybrid between the ratio-based indices and the perpendicular indices. In areas where vegetative cover is low (i.e., < 40%) and the soil surface is exposed, the reflectance of light in the red and near-infrared spectra can influence vegetation index values (Treitz and Howarth, 1999). The output of SAVI is a new image layer with values ranging from -1 to +1. The lower the value indicates less amount/cover of green vegetation.

The WI was generated from tasseled-cap transformed (Tcap) TM image. Tcap transformations were used to extract relevant variables related to environmental factors, since it is linear combination of the original sensor bands to interpret the multi-spectral satellite image, and the derived data respond to particular physical scene class characteristics and capture 95% or more of the total data variability in the raw spectral bands (Qiu et al., 1998). The transformation formula for TM scene is defined as Crist and Cicone (1984), used to develop the model in model builder of ERDAS INAGINE software (ERDAS Imagine, version 9.1, Atlanta, Georgia, USA).

LST refers to general index of the apparent environmental temperature (whether soil or vegetation), and radiometric surface temperature ($S_t$) as well defined by Planck's law, including the effects of emissivity (e) and the atmosphere (Li and Becker, 1993; Goetz et al., 1995). The temperature values obtained above are with reference to a blackbody. Therefore, correction for spectral emissivity (e) became necessary according to the nature of land cover. The emissivity corrected land surface temperature (LST) was computed based on the model developed by Sorbino et al., (2004); Artis and Carnahan (1982).

*Statistical analysis*

Data was analyzed using statistical software SPSS v.16. Pearson correlation test was applied to compare the relationship between sandfly density environmental variables. In order to estimate the effect of climatic and environmental variables on sandfly density, multivariate linear regression analysis was carried out using backward step methods thus putting all the observed independent variables into the model at the same time, and removing the most insignificant variable one by one from the model until the final model is achieved. The chi - square test was used to investigate the contribution of independence land cover classes with the presence/absence of sandfly (villages of 500m buffer zone) of the study site.

## Results

*Disease incidence and geo-statistical analysis*

Figure 1 represents the variation in the yearly number of kala-azar cases and deaths of six contiguous years (2005-2010) of the study area. The highest kala-azar incidence was observed in 2007, whereas number of deaths was also higher in this year. The results also illustrated that numbers of cases and deaths are lower in 2009. However, the cases were not concentrated in a particular part of the district; the pattern has changed over time. Monthly distribution of kala-azar cases of the study area for year 2005-2010 show that maximum number of cases has been reported in the month of March (e.g. 11.77%), whereas lowest number of cases was observed in the month of January (e.g., 5.28%).

Disease incidence data were entered into village boundary as attribute data and created as polygon based GIS layers. To analyze the locational information of spatial distribution of disease together with attribute information some geo-statistical measurements were performed. The calculation of mean centre of the case location represented the geometric centre of case location, as expected. By identifying the mean centre of case observations within the districts, ideal location may be allocated to monitor and manage the deadly disease for epidemiological surveillance and control. Figure 2 shows directional distribution of cases in Muzaffarpur district. The X stdDist and YstdDist represents standard distance in X direction and Standard distance in Y direction respectively whereas the angle of rotation illustrated the angle from north clockwise to the axis (Table 1). The directional distribution of case follows western to eastern direction

(Figure 2). Plotting ellipse for disease outbreak overtime may be used to model its spread and mapping the distributional trend might identify a relation to a particular physical feature which has highly influenced the disease pattern and distribution of this area.

*Sandfly trapping and density measurement*

A total of 504 sandflies were collected from 30 villages, belonging to three species of the genus *Phlebotomus* and *Sergentomiya* (Table 2). Of the collected total, *P. argentipes* was found to be the most abundant species, the proven vector of visceral leishmaniasis (VL) in Bihar, India. It accounted for (67.66%) of sandflies while *Sergentomiya*, (29.37%), identified within the districts. *Phlebotomus papatasi* was very rare (2.98%) in Muzaffarpur district. The detail of the sandfly characteristics is shown in Table 1. During the study period, aggregate population of sandflies was found to the lowest at December and January. Population size rose during June to July, with highest peak in September to October, and decreased during mid-November to February (figure 3).

*Climate data analysis*

From the climatic data, it was found that the room temperature of the study area ranged from 23°C - 29°C (X=26, SD=±1.76); whereas, relative humidity (RH) varied from 66%-84% (X=72.4, SD=±0.99). Highest temperature was recorded in the month of May (e.g., 29°C) and the lowest temperature recorded in the month of January (e.g. 23°C). On the contrary, highest RH was recorded in the month of July (e.g., 84%), and the lowest in the month of January (e.g., 66%).

The result of the multivariate linear regression analysis was carried out to determine the predictor variables affecting sandfly density. It showed significant effect of climatic variables such as inside room temperature, RH on vector density (Table 3). The final model used for predicting sandfly density is given by the following equation:

$$Y= - 87.26 + (1.42 \times \text{temperature}) + (0.84 \times \text{RH})$$

Where, Y is the estimated sandfly density (trap/night)

The final model was highly significant (F=48.96, p-value= <0.0000). It means that these two variables when considered together are significant predictors of sandfly density, and also the adjusted $R^2$ = 0.80, indicating that nearly 80% of the variance of sandfly density could be explained by these two predictor variables.

*Vegetation density and its relation between kala-azar endemic areas*

A SAVI index map of the study area was derived from the Landsat image. The SAVI values estimated are in the range of -0.320 to 0.66, having a mean value of 0.22 with a standard deviation of 0.23. It is seen that lower SAVI value (dark area) corresponds to high dense waterbody and built up area within the study site. Higher SAVI values (bright areas) are observed in the central and western part (plantation land) of the image. Medium SAVI values (grey areas to bright areas) are observed over agricultural and croplands, in the central and southern part of the image. A significant relationship was shown with maximum, minimum and mean SAVI value with sandfly density (figure 4).

*Surface wetness and its relation between kala-azar endemic areas*

A wetness index (WI) map was prepared to investigate the dampness of the surface of study area (figure 5). The WI values of the study area varied from -57.74 to 33.76. The minimum value of WI indicates the dryness (e.g. sandy area), whereas, the maximum value indicates wetness (e.g. waterbody / river) within the study site. Maximum, minimum and mean WI index value was calculated for each buffer zone. Pearson correlation test showed that there is a significant positive relationship with minimum and maximum WI value with the sandfly density (r=0.70 and 0.65 respectively). However, no significant relation was found with the mean WI value (r=0.12).

*Land surface temperature (LST) and its relation between kala-azar endemic areas*

Figure 6 shows the spatial distribution of LST of Landsat- 5 TM, ranged from 19.61°C to 36.51°C (X=28.67°C, SD- 5.49°C). It was observed from the image that central part exhibits high temperature mainly due to waste land, bare soil and fallow land. Some parts of the image also show high temperature i.e. in the south and south-west, mainly due to waste and fallow land. The surface temperature difference average values (LST) were calculated from 500m distance for 30 villages. Based on statistically demonstrated the importance of the LST values in comparison with the vector density, LST values (27.50℃ to 29.50℃), was considered to be indicative of the areas with highest transmission risk of kala-azar prevalence, LST values (26.50°C – 27.50℃ and 29.50 – 31.50°C), to be areas of low-middle risk, and LST values (<25.00°C and >31.00°C) to be areas with the lowest risk. A simple correlation was made between vector density and minimum, maximum and mean LST values. Results showed that there is a very strong relationship between minimum and mean LST values, e.g., $r$= 0.76 and 0.69 respectively. Maximum LST values showed moderate linear relationship with the vector density ($r$= 0.49).

*Multivariate regression analysis based on environmental variables to predict sandfly*

Multivariate linear regression analysis was used to indicate that environmental variables were significant parameters in the study area for vector abundance. Backward stepwise technique of Multivariate linear regression analysis (Table 4) was used, as the derivation of a common model to predict the vector density. SPSS 16.0 software was used to find the correlation and Multivariate linear regression analysis. The final model was highly significant (F=27.34, p-value= <0.001). It means that these five variables when considered together are significant predictor of sandfly density, and also the adjusted $R^2$ = 0.85, indicating that nearly 85% of the variance of sandfly density could be explained by these five predictor variables.

*Relationships between land use/land cover (LULC) and vector density*

The LULC maps of the study sites are presented in figure 7 for the study area. Following land use classes were considered in image classification: settlement, marshy land, wet fallow, river, sand, surface water body, vegetation and agricultural/crop land. In the study site marshy land, moist fallow and agricultural/crop land covered 80.94% of the whole area. The results also illustrated that remaining 19.06% were covered by the other LULC classes, viz., river (1.48%), settlement (6.10%), sand (0.88%), surface waterbody (2.69%) and vegetation (7.90%).

In chi-square test analysis, we considered the variables responsible for *P. argentipes* presence and different land cover variables: settlement, marshy land, sand, surface waterbody, river, moist fallow, vegetation and agricultural/crop land of the study site (Table 6). From this analysis, we found that variables having a significant response with *P. argentipes* were presence of settlement, surface waterbody, sand, river and vegetation. However, in this analysis, we did not find any significant response to moist fallow and agricultural/crop land due to small sample size.

## Discussion

Like many other diseases VL or kala-azar is a communicable and infectious disease and its distribution, incidence and prevalence are greatly influenced by local environmental factors. Our main aim was to find land surface temperature (LST), vegetation index (SAVI) and wetness index (WI) associated with saturation deficit responding to kala-azar vector breeding habitats determinants, using remotely sensed imagery. In a previous study, it was shown that the sandfly started building up in pre and post monsoon season, when mean temperature ranged from 27.5°C to 31°C and relative humidity 73% - 93% (Bhunia et al., 2010; Raina *et al.,* 2009; Sharma and Singh, 2008). During the warmer months the density is minimum (Napier, 1926; Ranjan et al., 2005), as the temperature in the area ranges between 40°C to 46°C; and the species also disappeared during the winter months (Smith, 1959A). The predictive value of this remote sensing map based on LST, SAVI and WI indices data appears to be better for the forecast of the disease risk areas. The predictive models can differentiate between transmission and non-transmission zones, so that areas mapped as non-transmission zones appear to accurately fit the real situation. Such a study will help control kala-azar cases vis-à-vis vector in Indian sub-continent. Determination of spatial and temporal variability in LST for example, may be used as correlative index of vector abundance (Malone et al., 1994; Rogers et al., 1996). Land surface temperature (LST) is computed from a combination of spectral thermal channels. In epidemiology and more generally, vegetation type may be most relevant in that it reflects and modifies land surface processes such as energy or materials exchange modeling, for example, it towards de-emphasis of species composition and a focus on rate-limiting factors associated with nutrient availability, resource scaling, and carbon allocation (Goetz and Prince, 1999; Bavia et al., 2005; Carneiro *et al*., 2004). This study also found that the usage of environmental indices plays a major role towards the collection of vector vis-à-vis the development of kala-azar risk map.

Analysis of land use/land cover features revealed that adult sand fly density was significantly associated with land cover variables (e.g., settlement, surface water body, moist fallow, vegetation, sand and river**).** The importance of surface water bodies lie in the fact that these contribute to maintain soil moisture conditions at soil/sub-soil level, which in turn suits breeding propagation of immature stages of sandfly as well as adult resting habitats. In a previous study, Sudhakar et al., (2006) demonstrated a significant correlation of vector density with variables like temperature; humidity and land use/land cover characteristics, which strongly, supported our study. Likewise, settlement has also been responsible with the presence of vector, because humans play a role in feeding of their preferred host and also act as a reservoir (Rahman et al., 2010). Bhunia et al., (2011) scrutinized that the presence of streams and other water bodies plays an important role in the distribution of vector as well as affect the Kala-azar incidence. It may be due to the increased surface humidity associated with river bank enhances the generation suitable breeding areas and host seeking behavior. Thus, we expect that the dynamics of infection vis-à-vis abundance of vector comprising only certain critical value of environmental indices. This information assists an epidemiologist and entomologist in gaining further insight into the relationship or characteristics between the encroachments of a disease. However, our study suggests that these environmental factors are important for the successful determinants of Kala-azar vector vis-à-vis cases in Indian sub-continent.


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**Table 1:** Location of mean centre and details of the directional distribution in different years.

| Year | Mean Centre | Directional distribution | | |
|---|---|---|---|---|
| | | X stdDist | YstdDist | Rotation |
| 2005 | 85°13'1.961"E 26°8'50.079"N | 31069.639 | 15804.3939 | 103.224241 |
| 2006 | 85°13'55.268"E 26°8'50.066"N | 29911.454 | 16487.827 | 100.942721 |
| 2007 | 85°12'35.815"E 26°9'14.123"N | 29401.1004 | 15839.5034 | 97.813479 |
| 2008 | 85°14'26.656"E 26°8'34.286"N | 31413.5138 | 15542.5772 | 97.206117 |
| 2009 | 85°16'5.763"E 26°8'25.861"N | 32396.3968 | 15575.1497 | 101.976689 |
| 2010 | 85°16'49.898"E 26°8'42.872"N | 33954.8853 | 15718.1063 | 99.344004 |

**Table 2:** Sandfly characteristics of the study area

| | *P. argentipes* | Percent | *Sergentomiya* | Percent | *P. papatasi* | Percent |
|---|---|---|---|---|---|---|
| Male (M) | 126 | 36.95 | 80 | 54.05 | 9 | 60.00 |
| Female (F) | 215 | 63.05 | 68 | 45.95 | 6 | 40.00 |
| Total | 341 | 100% | 148 | 100% | 15 | 100% |
| Relative abundance (%) | 67.66 | | 29.37 | | 2.98 | |
| M:F Ratio | 1:1.59 | | 1:1.18 | | 1:1.50 | |

**Table 3:** Significant predictor variables of sand fly density

| Predictor Variables | Coefficients (95% CI) | SE(ßs) | T-statistic | p-value |
|---|---|---|---|---|
| Intercept | -87.26 (-108.88 - -66.33) | 10.09 | -8.65 | <0.0000 |
| Room temperature | 1.42 (2.25 – 0.62) | 0.39 | 3.69 | 0.0012 |
| Room relative humidity (RH) | 0.84 (1.13 – 0.56) | 0.13 | 6.19 | <0.0000 |

**Table 4:** Sandfly prediction based on environmental variables derived from remote sensing technology

| **Predictor Variables** | **Standard Error** | **(ßs)** | **T-statistic** | **p-value** |
|---|---|---|---|---|
| Intercept | 6.283 | | -1.746 | 0.096 |
| Minimum SAVI | 1.986 | 0.175 | 2.02 | 0.056 |
| Mean SAVI | 3.284 | 0.228 | 2.636 | 0.015 |
| Mean LST | 0.198 | 0.251 | 1.965 | 0.063 |
| Minimum WI | 0.052 | 0.423 | 4.282 | 0.000 |
| Maximum WI | 0.041 | 0.301 | 2.825 | 0.010 |

**Table 5:** Association between land use/land cover classes with the presence/absence of sandfly.

| Variables | Presence of LULC classes | Chi-square test ($X^2$) | *P-value* |
|---|---|---|---|
| Settlement | 10 | 9.44 | 0.002 |
| Marshy land | 16 | 3.92 | 0.048 |
| Moist fallow | 23 | 0.75 | 0.384 |
| River | 2 | 18.47 | 0.000 |
| Sand | 3 | 6.63 | 0.010 |
| Surface waterbody | 16 | 9.93 | 0.002 |
| Vegetation | 9 | 4.33 | 0.040 |
| Agricultural/crop land | 24 | 0.00 | 1.00 |

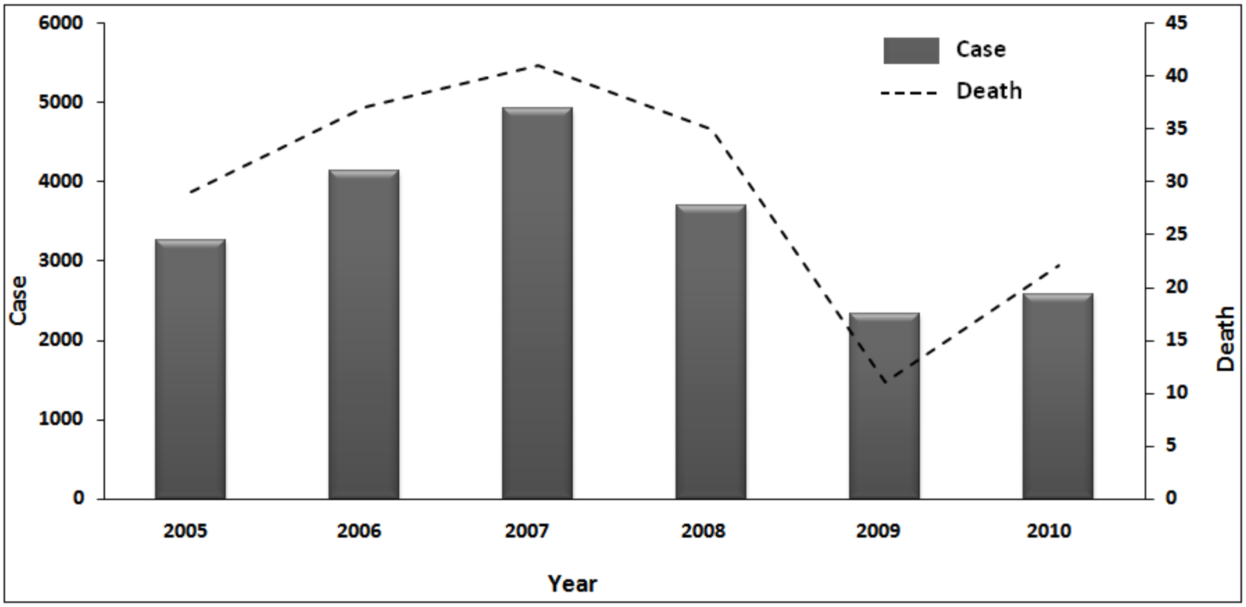


**Figure 1:** Temporal distribution of cases and deaths of the study area.

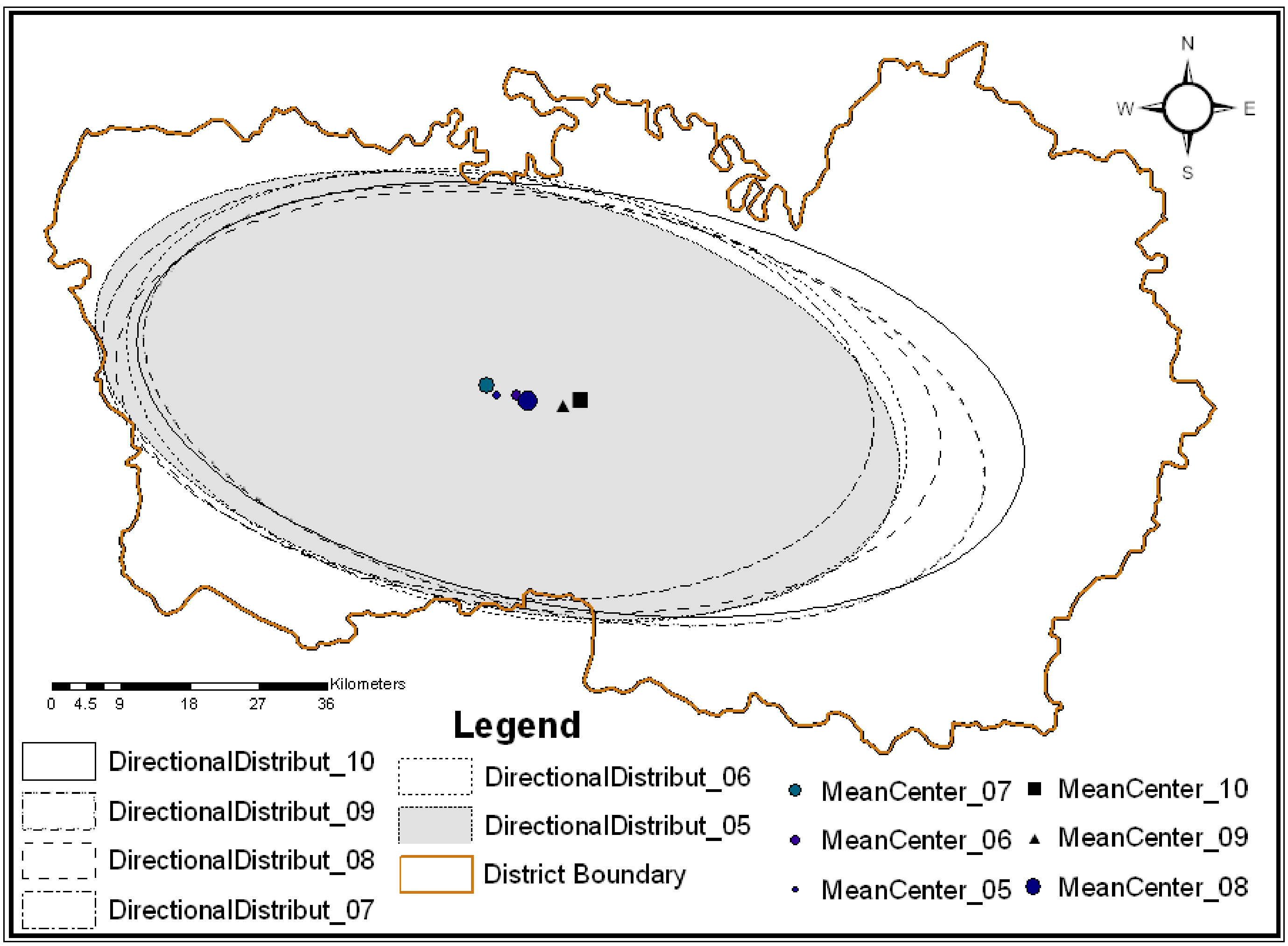


**Figure 2:** Calculation of mean centre and directional distribution of disease in different year of the study site

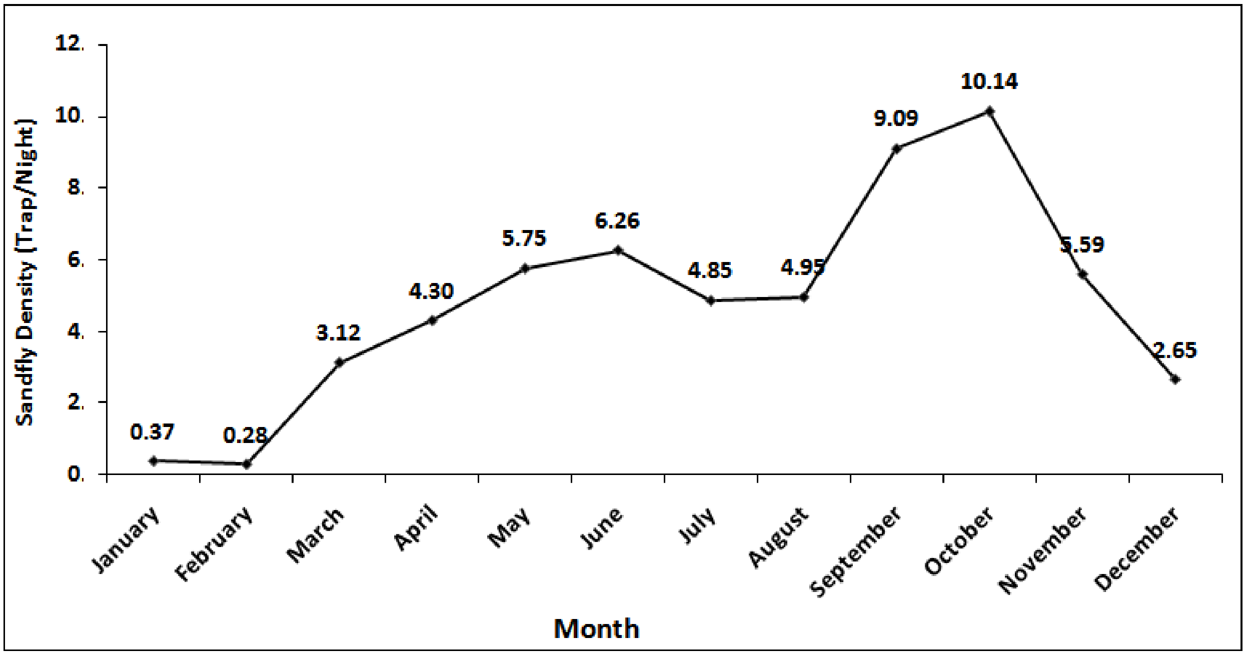


**Figure 3:** Monthly distribution of sandfly density in the study site

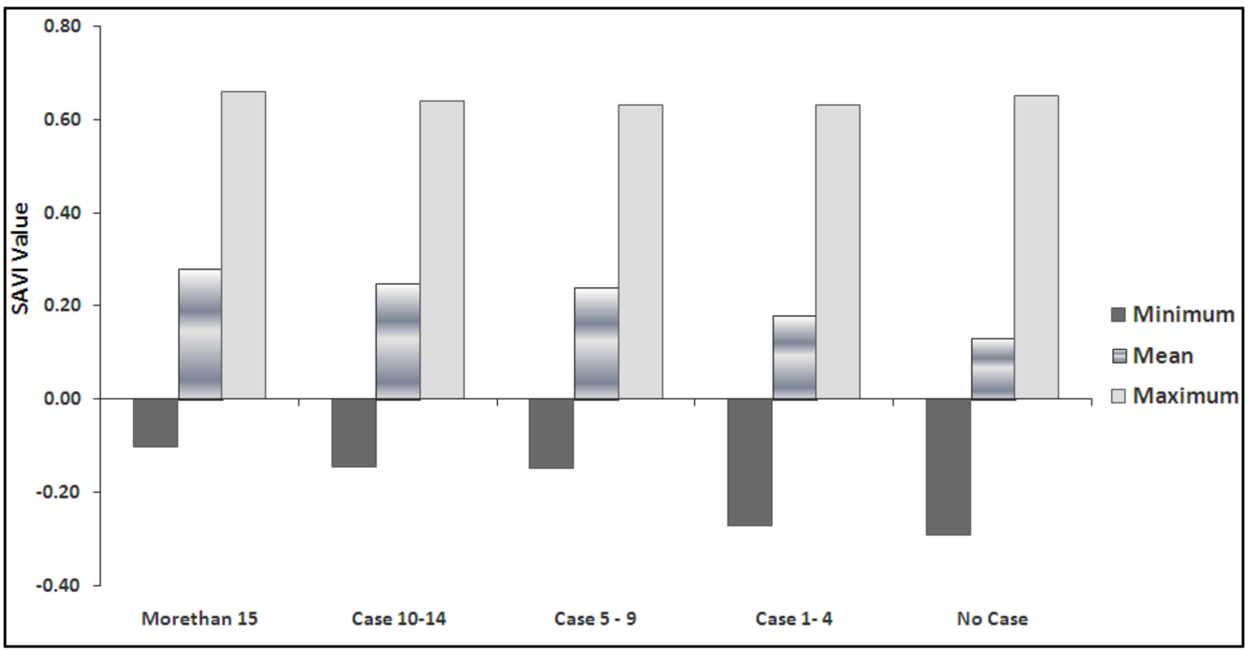


**Figure 4:** Relationship between maximum, minimum and mean SAVI value with sandfly density

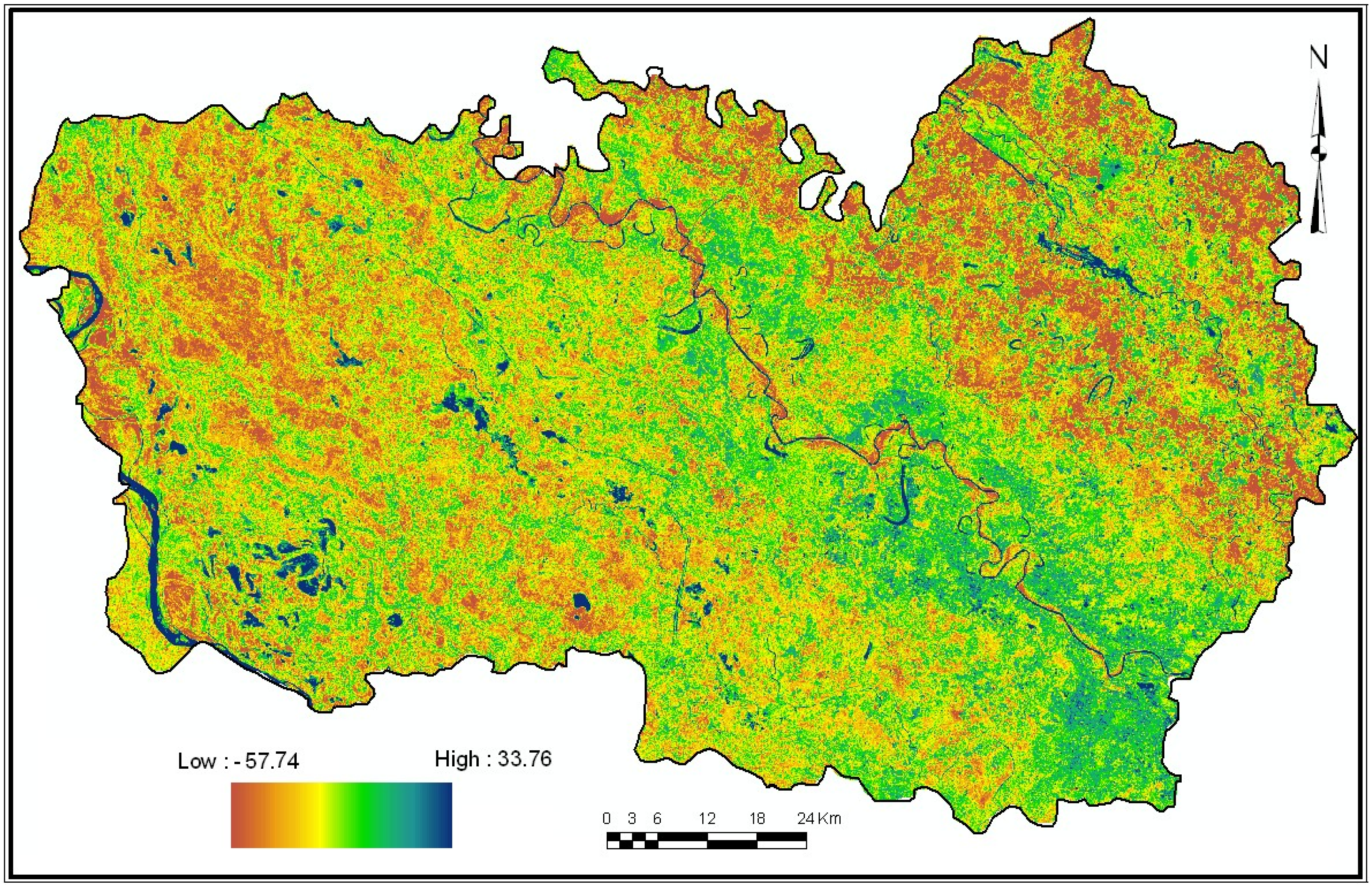


**Figure 5:** Wetness Index (WI) map of the Muzaffarpur district

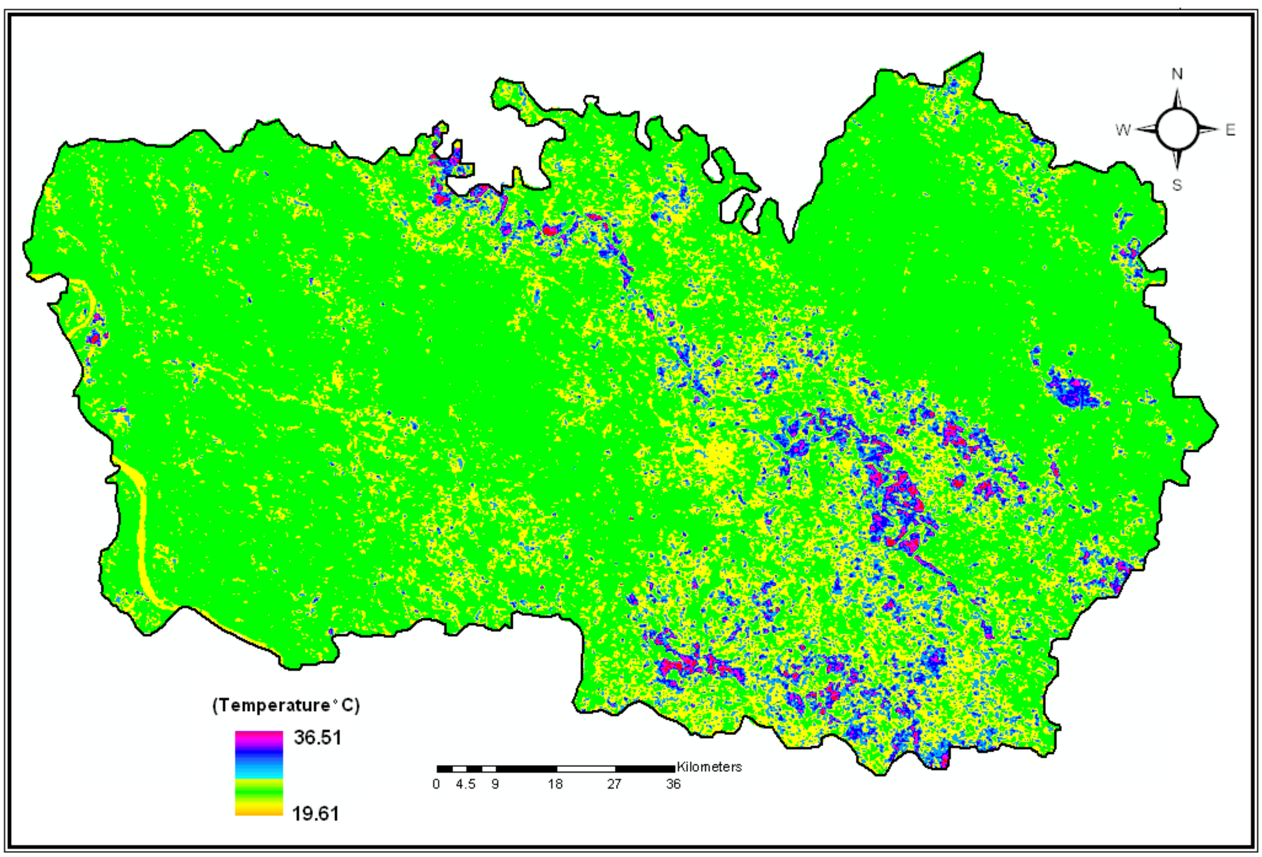


**Figure 6:** Land Surface Temperature (LST) of the study area, derived from Landsat- 5 TM

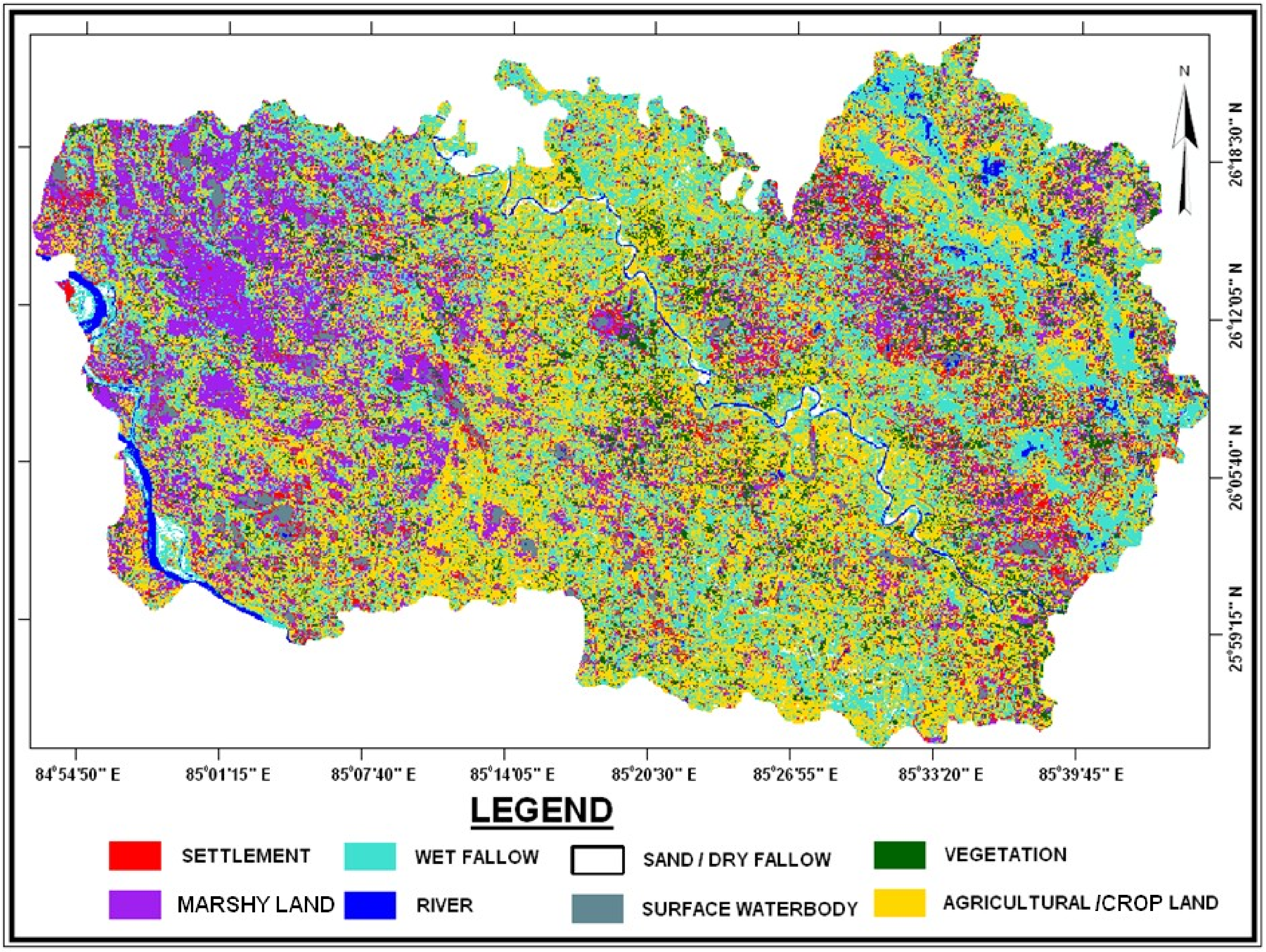


**Figure 7:** Land use/land cover (LULC) map of the study area