Visceral Leishmaniasis (Kala-Azar) Risk Mapping using Geo-Spatial Tools: A Case Study in Kafta Humera District, North Western Ethiopia

Solomon, N.,[1] Suryabhagavan, K. V.[1*] and Gadisa, E.,[2]
[1]School of Earth Sciences, Addis Ababa University, Addis Ababa, P. O. Box: 1176, Ethiopia
E-mail: drsuryabhagavan@gmail.com*
[2]Armauer Hansen Research Institute, Addis Ababa, P. O. Box: 1005, Ethiopia
* *Corresponding author*: Suryabhagavan

Abstract
Visceral Leishmaniasis (VL) is a severe vector-borne parasitic disease. In Ethiopia, the estimated incidence of VL ranges from 2,000 to 4,500 cases per year. Based on this, the main objective of this research was to develop an area risk map of VL and to estimate the total population at risk in Kafta Humera District, Northwestern Ethiopia. To achieve the stated objective, geospatial tools were used to extract and develop a risk cover map of VL using variables including rainfall, temperature, vegetation cover, soil type, altitude, slope and population data. Multivariate logistic regression analysis was used to assign the weight of influence for the variables in a spatially weighted overlay analysis model. The result revealed that temperature, elevation, soil, slope, rainfall and NDVI were the major predictors of VL presence with percentage influence of 29%, 22%, 15%, 13%, 12%, and 9%, respectively. From the produced risk map, 3453.69 km^2, 2210.38 km^2 and 269.59 km^2 representing 58.21%, 37.25%, and 4.54%, of the total area of Kafta Humera District are at high, medium and low VL risk, respectively. In addition, the estimated population at high, medium and low risk levels are 92,831 (68.98%), 34,864 (25.91 %) and 6,874 (5.11%), respectively. Based on the output, villages such as Bereket, Rawoyan, Baeker, Adebay, May Kadra and Humera town were identified with high population at risk for VL. Identification of "priority Villages" requiring immediate attention from health agencies as well as the local community greatly reduces the cost, time and energy needed for designing effective VL control measures.

1. Introduction

Leishmaniases are vector borne diseases with a broad range of clinical manifestations caused by several species of protozoic parasites belonging to the genus *Leishmania*. There are four major clinical forms of leishmaniasis: Visceral Leishmaniasis (VL), Cutaneous Leishmaniasis (CL), Diffuse Cutaneous Leishmaniasis (DCL) and Mucocutaneous Leishmaniasis (MCL) (WHO, 2010). Visceral Leishmaniasis (VL), also known as Kala-azar or black fever, is a severe form of leishmaniasis (Ahluwalia et al., 2003). It is an important public health issue caused by the species of the *Leishmania* donovani, transmitted to humans through the bite of infected female phlebotomine sandflies. Its incubation period typically ranges from 2 to 6 months, but it can also range from a few weeks to years. It is always fatal in untreated patients. Visceral Leishmaniasis has been a cause of major epidemics, which killed thousands of people. The symptoms of VL include prolonged fever, weight loss, fatigue, weakness, loss of appetite, enlargement of spleen and/or liver (causing abdominal distension) and anemia (FMOH, 2013). Leishmaniasis is spread over a large geographical area across the globe (Arti et al., 2013), and nearly 350 million people are at risk in 98 countries around the world. Currently, an estimated 310 million people are infected, and approximately 0.2 to 0.4 million cases of VL occur every year. Visceral Leishmaniasis causes an estimated 50,000 or more deaths annually (Alvar et al., 2012). It is the world's second deadliest parasitic disease after malaria (Darren et al., 2010). In Ethiopia, the estimated incidence of VL ranges from 2,000 to 4,500 cases per year (FMOH, 2013). It is distributed mainly in the lowlands with varying degree of endemicity. Important endemic foci include the Genale focus at Lake Abaya, the Segen Valley in Konso District, the Omo river plains in the southern part of the rift valley and the Metema and Humera plains in the Northwest of Ethiopia (Hailu and Frommel, 1993). Two sandfly species, *viz., Phlebotomus martini* and *Phlebotomus orientals* are the principal vectors of VL in East Africa (WHO, 2012). As pointed out by

ISSN 1686-6576 / © Geoinformatics International

Thomson et al.(1999) a VL risk-map was developed based on geographical information system for Sudan and the adjacent endemic area of Humera in northwestern Ethiopia; delineating where the vector, *P. orientalis* might be found. Bhunia et al., (2012) also suggested the requirement of environmental conditions such as soil type, climatic condition and topography for the analysis of propagation related vectors stressing the value of Remote Sensing (RS) and Geographic Information System (GIS) in the study of VL. Several studies have used remote sensing imagery and geographic information systems techniques to map the distribution of vector species at different spatial scales such as for the entire world, continent, national, regional and even at village levels (Bhunia et al., 2012). According to Tran et al., (2008) in tropical and subtropical regions, vector maps are designed to improve vector control, which is currently one of the essential methods in limiting the burden of important vector-borne diseases such as malaria, leishmaniasis and dengue fever. In areas where the diseases are found, analyzing the link between the environment and potential vector distribution may help to evaluate the risk of emergence of the disease, and for design of better mitigation and control measures. Therefore, this study was aimed to produce a VL risk-map and estimate the total population at risk of VL, using geospatial tools by assessing environmental factors in Kafta Humera District, Ethiopia. The identification of priority zones requiring immediate attention from health agencies as well as the local community greatly reduces the cost, time and energy required in the VL control and prevention programs.

2. The Study Area and Methods

2.1 Study Area

Kafta Humera District is located in the western Tigray region along the border of Ethiopia, Sudan and Eritrea about 991 km northwest of Addis Ababa, the capital city of Ethiopia. A large part the western side of the District coincides with the Sudanese border while the northern part is adjacent to the Eritrean border. Most of the area on the south the Welkayit and partially with the Tsegede Districts. On the eastern side, it borders Tahtai Adiabo District. Its geographical location extends between latitudes 13° 41′ 25″–14° 26′ 44″ N and longitudes 36° 26′ 33″–37° 31′ 18″ E, covering a total area of 5,933.66 km^2, which is about 50 percent of the western Tigray Zone (Figure 1). Kafta Humera District, in general has tropical and sub-tropical climates. Accordingly, it is characterized with high temperature throughout the year, especially during the dry season (February–June). It has a uni-modal rainfall pattern with 80–85% of the rainfall during June – September. The remaining months, are dry and hot. The reconstructed temperature and rainfall data from station observations and satellite records for 20 consecutive years (1993–2012) showed that the mean monthly temperature varies from 24.3°C in August to 28.9°C in May, and the mean monthly rainfall ranges from 2.3 mm in January to 227.8 mm in August.

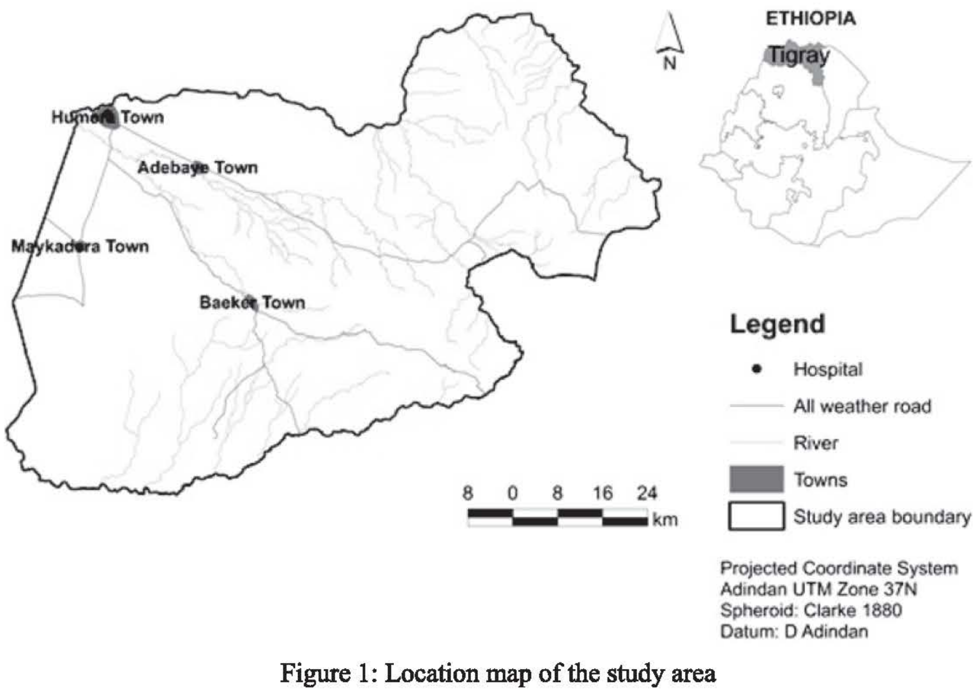

Figure 1: Location map of the study area

2.2 Methods

The collected variables from different sources include mean annual temperature, mean annual rainfall, elevation, slope, soil type, mean Normalized Difference Vegetation Index (NDVI), Ground Control Point (GCP) of VL cases, VL cases statistics and population data. The variables were derived and analyzed using different geospatial and statistical techniques. All the input data sets were projected to the Universal Transverse Mercator (UTM) projection system, Zone 37N and datum of Adindan ensuring consistency between datasets. All the input spatial data sets were geometrically checked through the 1:50,000 scale topographic map of the study area. Altitude and slope of the study area were derived from the Digital Elevation Model (DEM) of Shuttle Radar Topography Mission (SRTM) with 30 meter spatial resolution. A slope surface (in degrees) was subsequently generated using the ArcGIS Spatial Analysis tool. Multi-year meteorological data were used in the analysis. For this, the reconstructed monthly temperature and rainfall data from station observations and satellite records for 20 consecutive years (1993–2012) for 91 grid points with 10.1 km distance in the study were taken from Ethiopian National Meteorology Agency (NMA). Mean annual temperature and rainfall were calculated for all grid points, and a gausian semivariogram model using the ordinary kriging method was applied to obtain an interpolated continuous surface temperature and rainfall using the ArcGIS spatial analysis tool. Average temperature and rainfall were also computed for each month in order to correlate with the monthly record of VL cases. The vegetation coverage status was considered as an input to run VL risk analysis. In this regard, the SPOT VEGETATION(VGT), which was launched in March 1998 on board of the SPOT 4 satellite, to monitor surface parameters with a frequency of about once a day on a global basis at a spatial resolution of 1 km was selected for NDVI derivation. The decadal SPOT VEGETATION (VGT) image synthesized (S) for 10 days from the first of January 2003 to December 2012 was downloaded from (http://www.vito-eodata.be/PDF/portal/Application.html). This data set consists of several Hierarchical Data Format (HDF) layers joined in one zipped file which was extracted using VGT Extract software. As radiometric correction of the dataset is a pre-requisite for using time series of remote sensing data for any application, atmospheric corrections were done on the images before they were delivered to users (Xiao et al., 2002). However, other preprocesses were carried out like extracting region of interest and analyzed time series imagery using Spirit software (Eerens et al., 2014). Thus, to reduce the effect of variations of climate through the years, an annual composite of 10 consecutive years of decadal NDVI data from January 2003 to December 2012 were combined to create average annual composite NDVI using the ArcGIS spatial Analysis tool. The NDVI product was scaled to positive values (49–209). Finally, the data were converted to real NDVI values which ranged from 0.09 to 0.68 using the ArcGIS Spatial Analysis tool.

$$\text{Real NDVI (VGT)} = (\text{VGT value} * 0.004) - 0.1$$

Equation 1

Where, Real NDVI (VGT) = NDVI values between 0.09 and 0.68, VGT value = SPOT VGT NDVI values between 49–209.

Mean monthly NDVI values for each month of the above mentioned years were also computed to correlate with the monthly records of VL cases. Food and Agricultural Organization (FAO, 1998) soil type data were taken from the Ethiopian Ministry of Agriculture to analyze its contribution for the existence of VL sandfly in the study area. The vector soil database was changed into raster format using ArcGIS conversion tool for further analysis. Well recorded and documented VL cases have a significant role to identify the temporal pattern of VL occurrence and transmission. Due to this, fifteen years (1998–2012) of monthly VL case records were taken from Kahsay Abera hospital to correlate with the computed mean monthly temperature, rainfall and NDVI values. This was used to identify favorable months for the incidence and transmission of VL in the study area. Ground truth data were used as an important approach to integrate all the input data sets and to produce the necessary VL-risk map. A total of 82 GPS points (46 marking VL presence and 36 marking VL absence) data were collected on the ground from Armauer Hansen Research Institute (AHRI) for the study area. These points were collected by AHRI GIS experts in December 2012 on site using a hand-held GPS device from VL endemic and non-endemic villages of the district. For this reported VL data, case information and address were gathered from the medical records in Kahsay Abera Hospital and used a purposive non-random sampling technique to collect the VL cases. This sampling technique was selected because one VL case GPS point can represents areas with the range of elevation ≤100m in places with the same soil type (Tsegaw et al., 2013).

For the collected global positioning system points of VL absence/presence data, extraction of values from each the above identified parameters was done using the spatial analysis tool. These GPS points with extracted values were used to run multivariate logistic regression in order to assess the relative importance of each environmental parameter for the presence of VL using Stata/SE version 12 software. The relative importance was determined by their respective Odds Ratio (OR) if $P \leq 0.05$. This indicates that the desired confidence level is 95% and the desired precision error tolerance is 5%. The parameters considered in the analysis revealed significant P-values. Hence, in order to get the percentage influence of each factor in the overlay analysis and to avoid biased and subjective judgment in assigning weight of influence, the OR value of each variable was divided by the total OR value and multiplied by 100 (Tsegaw et al., 2013). The 2012 projected village population data of the study area was taken from CSA. The total population of each village was divided in to their total area and population density of each village was extracted in km^2. The overall procedure of the methodology were given in Figure 2.

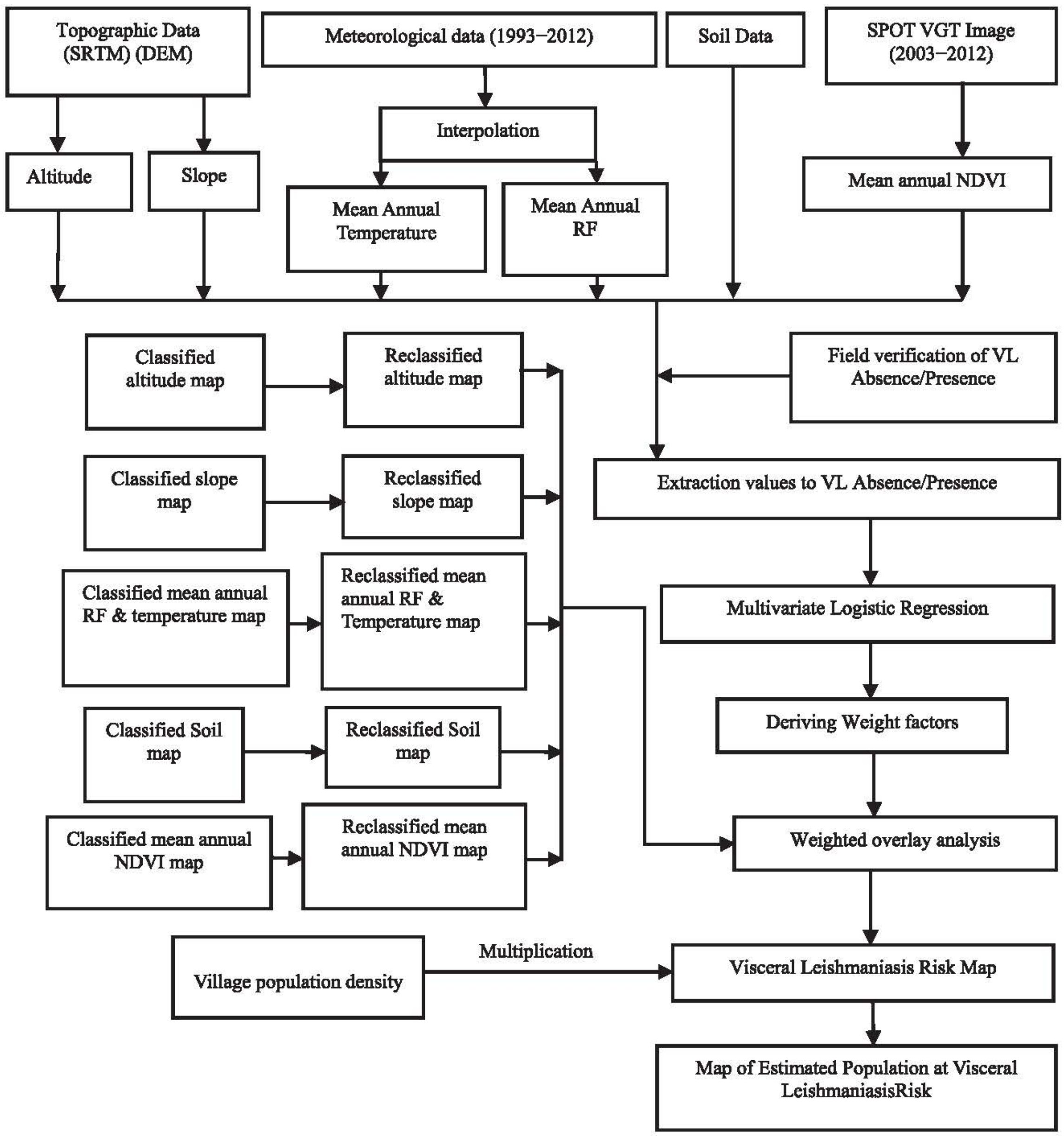

Figure 2: Schematic diagram of the methodology

3. Results

Environmental factors such as, rainfall, temperature, altitude, soil type, NDVI and slope were identified as major factors for VL occurrence and transmission in the study area. The findings showed that VL incidence and transmission was directly related with temperature and presence of vertisol soil type. On the other hand, VL incidence and transmission was inversely related with altitude, rainfall, slope, and mean NDVI.

3.1 Visceral Leishmaniasis Cases vs Temperature

The computed mean monthly temperature and VL cases recorded showed a positive relationship from September to December (Figure 3). It was observed that the peak transmission of VL with 1,478 cases was in December. There was also direct relationship from June to August, as the VL cases decreased along with the dawn mean monthly temperature due to the seasonal rainfall which affects survival of the vector. On the contrary, from January to May as temperature increased, the number of VL cases decreased, as the temperature of the area gets too hot and dry and this condition affects the survival of the vector.

3.2 Visceral Leishmaniasis Cases vs Rainfall

The mean monthly rainfall received was higher in July and August with 193.8mm and 227.8mm, respectively (Figure 4). It was also shown that during these months, there were low number of VL cases (351 and 375, respectively). This is due to the high rainfall which affects the sandfly and the reservoir hosts. Similarly the peak VL transmission was recorded in November, December and January with total VL cases of 1,037, 1,478 and 1,098, persons, respectively. The indirect relationship of VL cases and mean monthly rainfall was also observed from January–June, as the high temperature of the season makes the condition arid and warm and not suitable for the survival of the vector.

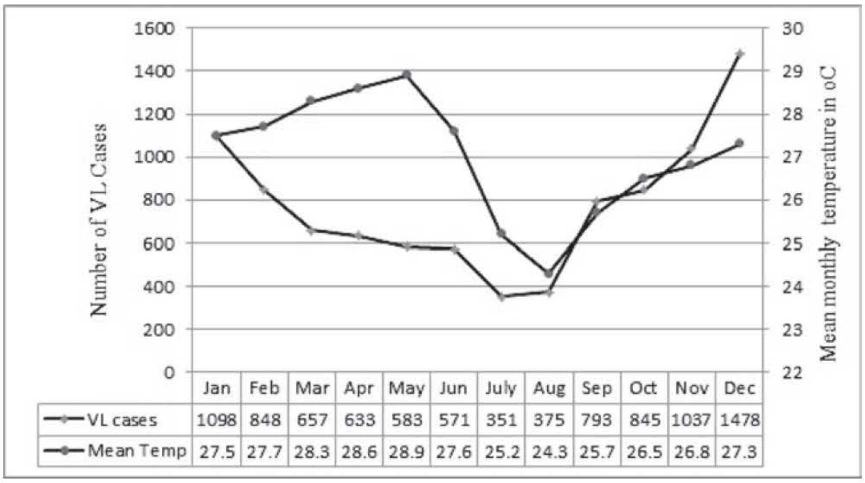

Figure 3: Number of visceral leishmaniasis cases (1998–2012) vs mean monthly temperature (1993–2012)

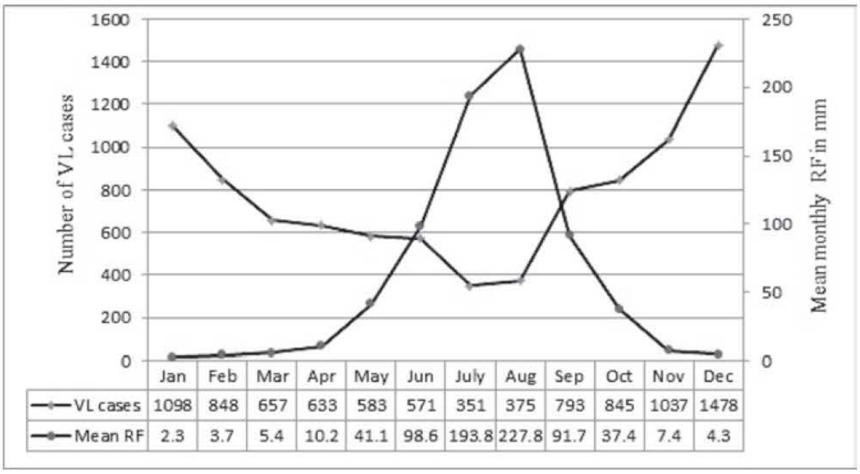

Figure 4: Number of Visceral leishmaniasis cases (1998–2012) vs mean monthly rainfall (1993–2012)

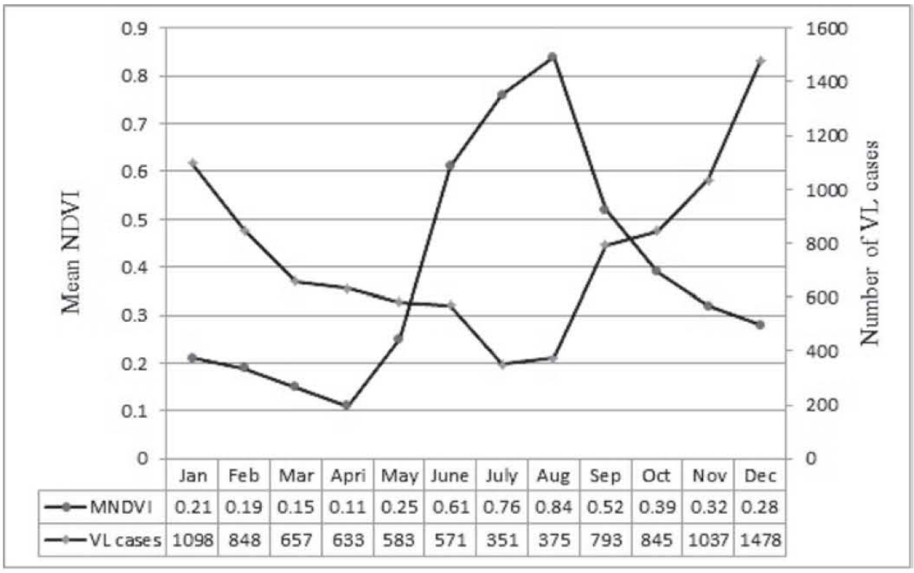

Figure 5: Number of Visceral leishmaniasis cases (1998–2012) vs mean monthly NDVI (2003–2012)

Table 1: Weight of visceral leishmaniasis risk factors

Factors	Weight (%)	Odds Ratio	P-value
Soil	15	6.57	0.043
Rainfall	12	5.20	0.024
Temperature	29	13.10	0.030
Altitude	22	10.05	0.027
Slope	13	5.89	0.015
NDVI	9	4.00	0.041
Total	100	44.81	–

3.3 Visceral Leishmaniasis Cases vs NDVI

The lowest number of VL cases between 351 and 375 were recorded during the highly rainy months of July and August with 0.76 and 0.84 NDVI values, respectively (Figure 5). This is the season the vegetation becomes green and the temperature becomes low. Furthermore, negative temporal patterns of VL cases and mean monthly NDVI values were observed from September to December with the highest VL cases of 1,478 recorded in December. It is believed due to, the high amount of rainfall is starting to decline and the temperature to increase. On the other hand, from January to May, VL cases decreased with mean monthly NDVI, as a result of the high temperatures recorded during these months, which make it difficult for the survival of the sandfly.

3.4 Identifying Visceral Leishmaniasis Risk Areas

The multivariate logistic regression model result revealed that temperature, altitude, soil, slope, rainfall and NDVI datasets had respectively a 29%, 22%, 15%, 13%, 12% and 9% weight of influence for the existence of VL, (Table 1). Temperature, altitude and soil were the dominant factors for the existence of VL in the study area. The VL risk map was produced in (Figure 6). The points of VL cases represents by black pins indicates that all 46 (100%) of the VL presence were overlaid and coincided geographically on the high VL risk areas, whereas 24 (66.7%) and 12 (33.3%) of the VL absence points displayed by blue pins were on low and medium VL risk category areas, respectively. When compare the result of the analysis with the GPS data collected for absence/presence of VL cases, it was revealed that areas which were identified as high risk by the analysis covers 100% of the VL presence cases collected from the field. The risk-map illustrates that 3,453.69 km^2, 2,210.38 km^2 and 269.59 km^2 representing 58.21%, 37.25%, and 4.54%, of the total area were high, medium and low VL risk areas, respectively (Table 2). Thus, more than half of the District is under high VL risk. Accordingly, the risk levels of VL presence in terms of area coverage and the corresponding percentages are presented in Table 2.

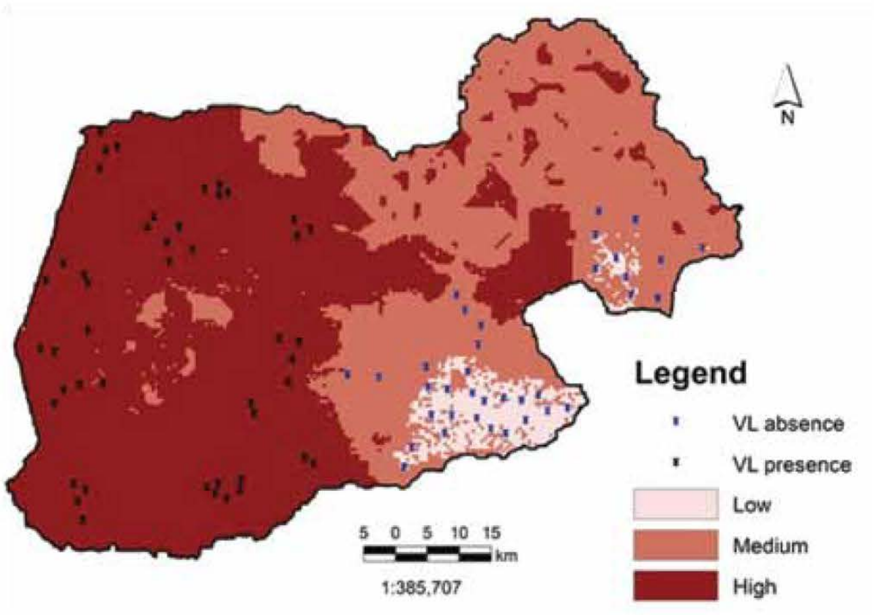

Figure 6: Visceral leishmaniasis risk-map for the study area

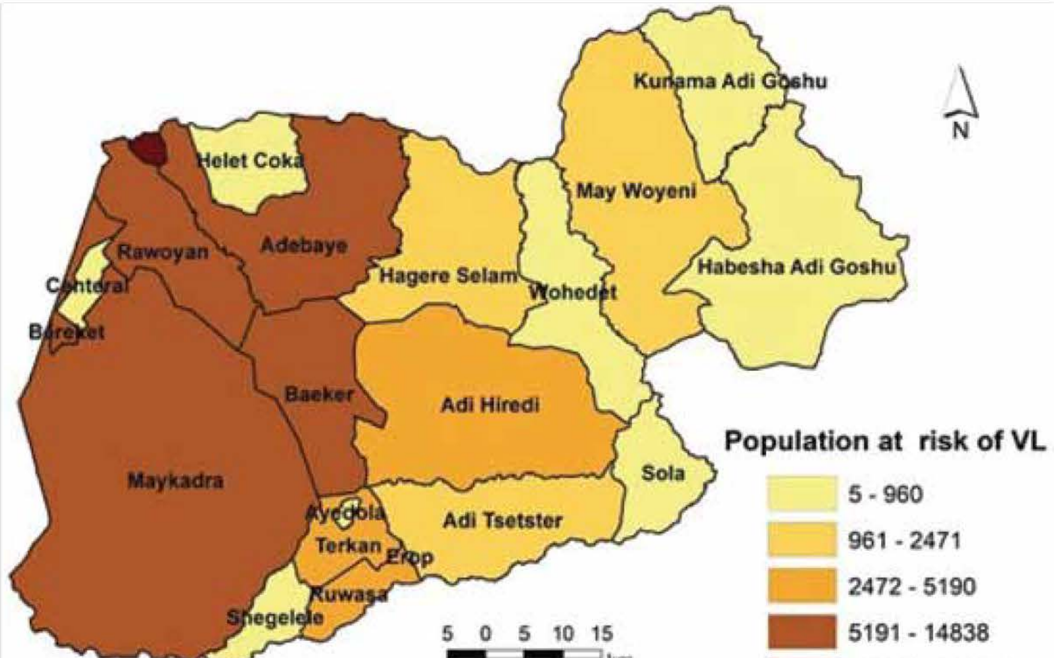

Figure 7: Visceral leishmaniasis risk-map showing estimated population

Table 2: Visceral leishmaniasis risk level and population at risk of the disease

Risk Level	Area in (km^2)	Area in (%)	Population at risk	Population risk in (%)
High	3,453.69	58.21	92,831.00	68.98
Medium	2,210.38	37.25	34,864.00	25.91
Low	269.59	4.54	6,874.00	5.11
Total	5,933.66	100	13,4569	100

3.5 Estimation of Population at Risk of Visceral Leishmaniasis

The estimated population at high, medium and low risk were 92,831 (68.98%), 34,864 (25.91%) and 6,874 (5.11%), respectively. This shows that more than two third of the population in the study area are under high risk of VL. The population at high risk of VL is found mainly in Bereket, Rawoyan, Baeker, Adebay, May Kadra villages and Humera town ranging from 5,191 to 27,424 people per village. Adihirdi, Terkan, Ruwassa and Hagere Selam villages are located with medium level of population at VL risk ranging from 2471 to 5191 people per village. The remaining villages are with lesser population at VL risk (Figure 7).

4. Discussion

Visceral Leishmaniasis is among the growing public health problems in the study area, where its spatial distribution and environmental determinants are poorly understood. Identification of high-risk villages and estimate of population at risk are important for designing prevention programs that are effective and for efficient implementation. In this study, annual average temperature was found the highest contributor for the occurrence of VL which accounts for 29%. An increase in temperature increased the incidence of VL. Mean annual temperatures 26–31°C were suitable for the survival of the sandfly. This result matches with previous studies in Ethiopia by Tsegaw et al., 2013 in Gedaref State Sudan by Elnaiem et al., (2003) and in the district of Vaishali in Bihar (India) by Picado et al., (2010). Altitude was found as a determinant variable for the prevalence of VL in the study area with a percentage share of 22%. An altitude category of <1,794 m is the most favorable elevation range for VL in this study, which is similar with the finding of Tsegaw et al., (2013). This is supported by Elnaiem et al., (2003) in their study in Gedaref State of Sudan, which concluded that altitude is one of the best predictors for the presence of VL in a village. Soil type is identified as another important factor for the presence of VL with 15% share. Among the soil types in Kafta Humera District, vertisol was found to be significantly associated with the presence of VL. This is in conformity with the view of Elnaiem et al., (2003) that the black-cotton soil type has a high content of the expanding clay type known as montmorillonite that forms cracks when dried, but which absorbs water and swells causing self-mulching during the rainy season. The deep cracking properties of this type of soil provide sandfly microhabitat suitable for breeding and resting. As pointed out by Gebere-Michael et al., (2004), this soil type is associated with the red *Acacia* and *P. orientalis*, which are common in areas endemic for *L. donovani* transmission. Slope was another determinant parameter for VL occurrence with a percentage influence of 13%. Lower slope seemed to be the most favorable slope category for VL. This is highly related with a study conducted by Tsegaw et al., (2013), whose conclusion was slope value of <0.56 degrees have high influence for the occurrence of VL. Rainfall produced a relative percentage of influence of 12%. Rainfall of less than 766mm per year showed medium influence for VL presence. A study in East Africa indicated that annual rainfall of 180–1050 mm was the best fit for the distribution of *P. orientalis* (Gebere-Michael et al., 2004). Another study in Sudan of VL foci on the influence of annual average rainfall on VL distribution documented that up to 1,200 mm is suitable for the growth of red *Acacia* trees known to be preferred by sandflies associated with *L. donovani* (Thomson et al., 1999). NDVI was also identified as one of the determinant variables for the occurrence of VL in the study area with a 9% influence. It is obvious from the NDVI results that low density vegetation (minimum mean NDVI) was associated with a high incidence rate of VL. As suggested by Elnaiem et al., (2003), most grasses in the area are highly seasonal, flourishing after the start of the rains. Similarly, Gebere-Michael et al., (2004) have shown that, NDVI value of 0.05–0.28 was the best fit for the distribution of *P. orientalis* in east Africa. It is associated with the *Acacia* and *P. orientalis,* which are common in areas endemic for *L. donovani* transmission and with the vertisol soil types. In general, the above discussed variables were found to be the most determinant spatio-temporal factors for the presence of VL in this study and in other similar works done previously.

Acknowledgements

We would like to thank School of Earth Sciences, Addis Ababa University for facilities and funds. We are also extremely grateful to Armauer Hansen Research Institute, Ethiopian Metrology Service Agency, Kafta Humera District Health Bureau, and Kahsay Abera Hospital in Humera for data and for their support. We also thank the anonymous reviewers for their valuable comments and suggestions.

References

Ahluwalia, I. B., Bern, C., Costa, C., Akter, T., Chowdhury, R. and Ali, M., 2003, Visceral Leishmaniasis: Consequences of a Neglected Disease in a Bangladeshi Community. *The*

American Journal of Tropical Medicine and Hygiene, 69, 624–638.

Alvar, J., Velez, I. D., Bern, C., Herrero, M., Desjeux, P., Cano, J., Jannin, J. and Boer, M. D., 2012, Leishmaniasis Worldwide and Global Estimates of Its Incidence. Available: http://www.plosone.org/article/info:doi/10.1371/journal.pone.0035671.

Arti, G., Mukesh, N., Sidharth, S. M. and Chandrakant, L., 2013, Visceral Leishmaniasis (Kala Azar) Elimination from Indian Sub-continent by 2015. *International Journal of Tropical Disease & Health,* 3, 73–81.

Bhunia, G. S., Chatterjee, N., Kumar, V., Siddiqui, N. A., Mandal, R., Das, P. and Kesari, S., 2012, Delimitation of Kala-Azar Risk Areas in the District of Vaishali in Bihar (India) using a Geo-Environmental Approach. *Mem. Inst. Oswaldo Cruz, Rio de Janeiro,* 107, 609–620.

Darren, S., Anuj, M. and Hristo, V. K., 2010, Impact of Socio-Economic Conditions on the Incidence of Visceral Leishmaniasis in Bihar, India. *International Journal of Environmental Health Research,* 20, 415–430.

Eerens, H., Haesen D., Rembold, F., Urbano, F., Tote, C. and Bydekerke, L., 2014. Image Time Series Processing for Agriculture Monitoring. *Environmental Modelling and Software,* 53, 154–162.

Elnaiem, D. E., Schorscher, J., Bendall, A., Obsomer, V., Osman, M. E., Mekkawi, A. M., Connor, S. J., Ashford, R. W. and Thomson, M. C., 2003, Risk Mapping of Visceral Leishmaniasis: the Role of Local Variation in Rainfall and Altitude on the Presence and Incidence of Kala-azar in Eastern Sudan. *The American Journal of Tropical Medicine and Hygiene,* 68, 10–17.

FAO, 1998, Land and Water Development Division. Food and Agricultural Organization of the United Nations, Rome, Italy.

Gebere-Michael, T., Malone, J. B., Balkew, M., Ali, A., Berhe, N., Hailu, A. and Herzi, A. A., 2004, Mapping the Potential Distribution of *Phlebotomus Martini* and *P. Orientalis* (Diptera: Psychodidae), Vectors of Kala-Azar in East Africa by use of Geographic Information Systems. *Acta Tropica,* 90, 73–86.

Hailu, A. and Frommel, D., 1993, Leishmaniasis in Ethiopia. In: The Ecology of Health and Disease in Ethiopia. Eds, H. Kloos and Z.A. Zein. Westview press, Boulder, Colorado, USA, 375–388.

FMOH, 2013, *Guidelines for diagnosis, treatmentand prevention of leishmaniasis in Ethiopia*, 2nd edition. Federal Ministry of Health, Addis Ababa, Ethiopia.

Picado, A., Murari, L. D., Vijay, K., Diwakar, S. D., Suman, R., Shri, P. S., Pradeep, D., Marc, C., Marleen, B. and Clive, D., 2010, Phlebotomus Argentipes Seasonal Patterns in India and Nepal. *Journal of Medical Entomology,* 47, 283–286.

Tsegaw, T., Gadisa, E., Seid, A., Abera, A., Teshome, A., Mulugeta, A., Herrero, M., Argaw, D., Jorge, A. and Aseffa, A., 2013, Identification of Environmental Parameters and Risk Mapping of Visceral Leishmaniasis in Ethiopia by using Geographical Information Systems and a Statistical Approach. *Geospat. Health,* 7, 299–308.

Thomson, M. C., Elnaiem, D. A.., Ashford, R. W. and Connor, S. J., 1999, Towards a Kala-Azar Risk Map for Sudan: Mapping the Potential Distribution of Phlebotomus Orientalis using Digital Data of Environmental Variables. *Tropical Medicine and International of Health Geographics, BioMed Central Ltd, Franmce,* 4, 105–113.

Tran, A., Nicolas, P., Céline, T., Catherine, L., Helene, G., Jean, B., Ferre, D. L .S., Francois R., Stephane, d.R., Didier, F. and Thierry, B., 2008, Research using Remote Sensing to Map Larval and Adult Populations of Anopheles Hyrcanus (Diptera: Culicidae) a Potential Malaria Vector in Southern France. *International Journal Health.*102, 356–358.

WHO, 2010, *Control of the Leishmaniasis*, Technical Report Series 949. (World Health Organization), Geneva, Switzerland.

WHO, 2012, Post-Kala-Azar Dermal Leishmaniasis: A Manual for Case Management and Control, (World Health Organization) Geneva, Switzerland.

Xiao, X., Boles, S., Frolking, S., Salas, W., Moore, I. and Li, C., 2002, Observation of Flooding and Rice Transplanting of Puddy Rice Fields at the Site to Landscape Scales in China using Vegetation sensor data. *International Journal of Remote sensing,* 23, 3009–3022.