



**VISCERAL LEISHMANIASIS (KALA-AZAR) RISK
MAPPING USING GEO-SPATIAL TOOLS, A CASE
STUDY IN KAFTA HUMERA WOREDA, NORTH
WESTERN ETHIOPIA**

By

Negussie Solomon

**A Thesis Submitted to the School of Earth Sciences Presented
in Partial Fulfillment of the Requirements for the Degree of
Master of Science in Remote Sensing and Geographic
Information Systems**

**Addis Ababa University
Addis Ababa, Ethiopia
May 2014**

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Under the guidance of

**Dr. K.V. Suryabhagavan
Assistant Professor, School of Earth Sciences
Addis Ababa University, Addis Ababa**

And

**Dr. Endalamaw Gadisa
Postdoctoral Scientist
Armauer Hansen Research Institute, Addis Ababa**

**Addis Ababa University
Addis Ababa, Ethiopia
May 2014**

Addis Ababa University
School of Graduate Studies

This is to certify that the thesis prepared by **Negussie Solomon Abrha**, entitled: *Visceral Leishmaniasis (Kala-azar) Risk Mapping Using Geo-spatial Tools, A Case Study in Kafta Humera Woreda, Northwestern Ethiopia* and submitted in partial fulfillment of the requirements for the Degree of Master of Science (Remote Sensing and Geographic Information Systems) complies with the regulations of the University and meets the accepted standards with respect to originality and quality.

Signed by the Examining Committee:

Advisor Dr. K.V. Suryabhagavan Signature _____ Date ____/____/____

Co-Advisor Dr. Endalamaw Gadisa Signature _____ Date ____/____/____

Examiner Prof. M. Balakrishnan Signature _____ Date ____/____/____

Examiner Dr. Getachew Berhan Signature _____ Date ____/____/____

Chair of Department or Graduate Program Coordinator

ABSTRACT

Visceral Leishmaniasis (Kala-azar) Risk Mapping Using Geo-Spatial Tools; A Case Study in Kafta Humera Woreda, North Western Ethiopia

Negussie Solomon
Addis Ababa University, 2014

Visceral Leishmaniasis (VL) is a severe vector-borne parasitic disease. In Ethiopia, the estimated incidence of VL ranges from 2,000 to 4500 cases per year. Based on this, the main objective of this research was to develop a risk map of VL and to estimate the total population at risk in Kafta Humera Woreda (District), Northwestern Ethiopia. To achieve the stated objectives, geospatial tools were used to extract and develop 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 weight of influence for the variables in spatial 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 km², 2210.38 km² and 269.59 km² representing 58.21%, 37.25%, and 4.54%, of the total area of Kafta Humera were at high, medium and low VL risk, respectively. In addition, the estimated population at high, medium and low risk level were 92,831 (68.98%), 34,864 (25.91 %) and 6,874 (5.11%), respectively. Based on the output, Kebeles (the lowest administrative unit) such as Bereket, Rawoyan, Baeker, Adebay, May Kadra and Humera town were identified with high population at risk for VL. Identification of priority Kebeles requiring immediate attention from health agencies as well as the local community greatly reduces the cost, time and energy for designing efficient VL control and program.

Keywords: geospatial tools, GIS, Kafta Humera, remote sensing, Visceral leishmaniasis.

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Dedication

**To the memory of my late brother, Muluaem Solomon, who lost his life
by Visceral Leishmaniasis.**

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Acronyms

AHRI	Armauer Hansen Research Institute
CL	Cutaneous Leishmaniasis
CSA	Central Statistics Agency
EMA	Ethiopian Mapping Agency
FAO	Food and Agricultural Organization
GCP	Ground Control Point
GIS	Geographical Information Systems
GPS	Global Positioning System
KHWSAO	Kafta-Humera Woreda Social Affair Office
<i>L. Donovanii</i>	<i>Leishmania Donovanii</i>
MSF	Medicines Sans Frontiers
NDVI	Normalized Difference Vegetation Index
NMA	National Metrological Agency
<i>P. orientalis</i>	<i>Phlotobomus Orientals</i>
<i>P.celiae</i>	<i>Phlotobomus celiae</i>
<i>P.martini</i>	<i>Phlotobomus Martini</i>
RF	Rainfall
SPOT	Satellite Pour l'Observation de la Terre
SRTM	Shuttle Radar Topography Mission
USGS	United States Geological Survey

UTM Universal Transverse Mercator

VL Visceral Leishmaniasis

CHAPTER ONE

INTRODUCTION

1.1 Background of the Study

The leishmaniasis 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 species of the *Leishmania donovani* complex, which are 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 epidemic, which killed thousands of people. The symptoms of VL include prolonged fever, weight loss, fatigue, weakness, loss of appetite, an enlarged spleen and/ or liver (causing abdominal distension) and anemia (Palate 1.1) (MoH, 2013).

Leishmaniasis is spread over a large geographical area across the globe (Arti *et al.*, 2013). 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 each year. Visceral Leishmaniasis causes an estimated over 50,000 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 4500 cases per year (MoH, 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 Northwest Ethiopia (Hailu and Frommel, 1993).



Plate 1.1 Visceral Leishmaniasis infected child.

(Source: <https://www.google.com.et/search?q=phlebotomine+sandfly+leishmaniasis>)

Two sandfly species; *Phlebotomus martini* and *Phlebotomus orientalis* are the principal vectors of VL in East Africa (WHO, 2012). As pointed out by Thomson *et al.* (1999) a VL risk-map was developed based on a 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 such environmental conditions (soil type, climatic condition and topography) for the vector propagation underlining the value of Remote Sensing (RS) and Geographic Information System (GIS) in the study of VL.

Geographical information systems, computer-based spatial techniques used to input, store, retrieve, manipulate, analyze, integrate and output geographically referenced or spatial data, are becoming important tools for understanding the epidemiology of leishmaniasis. Such systems integrate a wide range of data from different sources, including remote sensing and global positioning systems. Furthermore, GIS can be flexibly adapted to the needs of endemic countries and geographical regions. When used properly, these systems can facilitate decision-making and support strategic planning for

resource allocation and effective control (Bhunia *et al.*, 2012). Combined with good data from surveillance activities, GIS can be used routinely to generate base maps, delineate the distribution of vectors and reservoir hosts and prepare maps based on leishmaniasis prevalence or incidence. After proper analysis of environmental factors obtained through remote sensing and ground-based surveys, GIS based models can be used to produce risk maps that can predict the probability of the presence of vectors and reservoir hosts and the presence or incidence of leishmaniasis in locations not covered by ground-based surveys (WHO, 2010).

Furthermore, 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 the entire world, continent, national, regional and even at village levels (Bhunia *et al.*, 2012). According to Tran *et al.* (2008) in endemic areas, mainly 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 lead to better mitigation and control measures.

Therefore, this study aimed to produce VL risk-map and estimate the total population at risk of VL, using geospatial tools by assessing environmental factors in Kafta Humera District. The identification of priority zones requiring immediate attention from health agencies as well as the local community greatly increases the cost, time and energy efficiency in the VL control and prevention programs.

The main reason why this research selected by the researcher was based on the ever growing fatality rate of VL during his stay in Kafta Humera District for a long period of time; and his interest in the application of GIS and RS.

1.2 Statement of the Problem

It has been about 60 years since VL was reported for the first time in Ethiopia. Since then it has been recognized as an endemic disease with a patchy distribution in the southern, northwestern low-lands and arid regions of the country. The main foci of VL includes the Metema and Humera low lands in the northwest and the Segen, Woyto and Omo Valleys in the southern part of the area at Rift Valley (Meshesha *et al.*, 2002).

According to Tadesse Fesseha (2005) Tigray Province, the endemic region in the northwest Ethiopia, has historically reported sporadic cases. Until the 1960s, the Humera and Metema areas were mostly uninhabited, because of VL. Since 1997, the number of cases of VL increased which appears to correspond to the extensive program of large agricultural developments in the area.

The study area is one of the agriculture surplus areas in Ethiopia known for producing sorghum and exportable products like sesame and cotton which makes it a net contributor to the national economy. It is believed that there are about 515 investors engaged in a number of large scale farming activities. Due to this, huge labor force estimated in the range 300,000–400,000 migrates to Kafta Humera every year, many of this from VL non-endemic areas of the country (KHWSAO, 2012). Thus, the influxes of migrant workers have increased the population at risk of exposure to VL. In the District Hospital 9,269 patients of VL were treated during this period 1998-2012 (Kahsay Abera Hospital, 2012).

Analyzing the location, identification and standardization of leishmaniasis along with monitoring environmental variables with conventional, ground surveys is time consuming, laborious and expensive. With increasing accessibility to new technologies, such as RS, it is possible to monitor landscape features on the earth's surface over various time intervals to develop methods for rapid stratification of highly susceptible areas and to design remedial measures (Bhunias *et al.*, 2010). Another recent development is the use of satellite data to acquire increasing amounts of geographical data available in conjunction with GIS to assist with interpretation of ecosystems and environmental parameters related to sandfly conditions (Bhunias *et al.*, 2011). With increasingly widespread and combined implementation of RS and GIS technology, professionals have been provided with efficient and accurate tools for mapping, maintaining and managing information on

landscape features to further understand the epidemiology for the purpose of controlling of VL (Kesari *et al.*, 2011). Thus, RS and GIS technologies have been used to describe local and landscape-level features that influence the patterns and prevalence of disease and then analyze the occurrence of the health event in space and time (Ashenafi madebo, 2003).

In addition, GIS have been used in a number of studies on leishmaniasis, including mapping of important species of sandflies such as *P. orientalis* and *P. martini* in Ethiopia, Kenya, Somalia and the Sudan and *P. papatasi* in south-east Asia. Similarly, they were used to map the incidence of VL in eastern Sudan and the northwestern Bahia area of Brazil and the incidence of Cutaneous Leishmaniasis (CL) in Colombia and Tunisia. Furthermore, systematic use of such systems and standardized case-reports is improved the gathering of epidemiological data on Leishmania/HIV co-infection in southwestern Europe and allowed visualization, analysis and monitoring of the spatial distribution of these cases (WHO, 2010).

The study area is identified as VL-risk area in previous VL study in Ethiopia (Tsegaw *et al.*, 2013). However, the authors have not incorporated the NDVI factor in their study, which is included in this study. Furthermore, risk-mapping and estimation of the Kebele level population at risk and delineation of potentially prone areas were not done, which created a gap in targeting at high risk Kebeles and has substantial in increased costs of prevention. Therefore, this study was designed to fill the gaps using geospatial tools and statistical approach to provide a strong tool for monitoring environmental conditions that are conducive to VL and Kebeles level risk-mapping.

1.3 Objectives of the Study

1.3.1 General Objective

The main objective of this study was to develop a Kebeles level risk map of Visceral leishmaniasis and to estimate the population at risk of Visceral leishmaniasis in the study area.

1.3.1.1 Specific Objectives

The specific objectives of the study were:

1. To identify major environmental variables contributing for the presence of visceral leishmaniasis transmission in the study area.
2. To analyze Visceral Leishmaniasis incidence in relation to major environmental variables.
3. To develop a Kebele level risk map of Visceral leishmaniasis based on the identified environmental parameters.
4. To estimate the population at risk of Visceral leishmaniasis.

1.4 Significance of the study

The Kebele VL risk-map obtained from this is expected to enable decision makers, public health officers and different stake holders in the field of public health to make focused decision and ensure the wise use of scarce resources in mitigation and prevention programs. Moreover, the risk-map will be beneficial for public warning and awareness programmes. Finally, the outcome of this research can be used as a baseline for further scientific research in the coming years.

1.5 Limitation of the Study

During the process of carrying out this study, the researcher encountered lack of better spatial and temporal resolution satellite images; lack of climate data (relative humidity and soil moisture) and lack of well documented monthly VL patient statistics for extended years. Therefore the researcher was forced to use different duration of time series data.

1.6 Organization of the Research

This thesis contains five chapters. Chapter one includes the research background, statement of the problem, objectives, significance, limitation and organization of the research. Chapter two deals with literature review of basic concepts and factors influencing VL incidence, and application of GIS and RS in the study of VL. The third chapter focuses on the study area and analysis and interpretation of the data. Chapter four contains results and discussion. Finally, Chapter five deals with conclusion and recommendations.

CHAPTER TWO

LITERATURE REVIEW

2.1 Historical Background

The parasite causing VL was first described in 1903 by Sir William Leishman, who examined the spleen of a British soldier stationed at Dumdum near Calcutta, India. Subsequently, Charles Donovan verified this finding. Thereafter, the parasite was known as Leishman-Donovan (LD) body (Chulay, 1991). In the same year, the genus *Leishmania* was created by Ross to include *Leishmania donovani*. In India, VL is also called kala-azar, meaning “black sickness or fever” as it turns the color (pigmentation) of the skin black. The word ‘kala’ means ‘black’ and ‘azar’ means ‘deadly’, thereby signifying a fatal illness (Chatterjee, 1982). In 1904, Roger observed the conversion of amastigotes to promastigotes in culture (Chulay, 1991). Also Nicolle in 1908 documented in children from the Mediterranean countries and proposed the name of infantile kala-azar for this disease and designated the parasite as *L. infantum* (Chatterjee, 1982). The parasite of South American kala-azar was originally named as *L. chagasi* in 1937, was also found to belong to the *L. donovani* species complex. Promastigotes were found in sandflies by Alder and Theodor in 1925 (Chulay, 1991).

2.2 World’s Situation of Visceral Leishmaniasis

Visceral leishmaniasis is one of the worlds most neglected diseases, affecting the poorest people in developing countries associated with malnutrition, VL/HIV co-infection, displacement, poor housing, illiteracy and lack of resources (WHO, 2012). Also, VL is a re-emerging serious public health problem in different parts of the world. As it has been discussed in the background of this study currently an estimated 0.2 to 0.4 million cases occur annually. It also causes an estimated over 50,000 deaths annually. Though, it is endemic in over 80 countries of the tropical and sub-tropical regions of Africa, Asia, the Mediterranean, southern Europe, South and central America, more than 90% of global VL burden occur in six countries: India, Bangladesh, Sudan, South Sudan, Ethiopia and Brazil (Fig 2.1) (Alvar *et al.*, 2012).

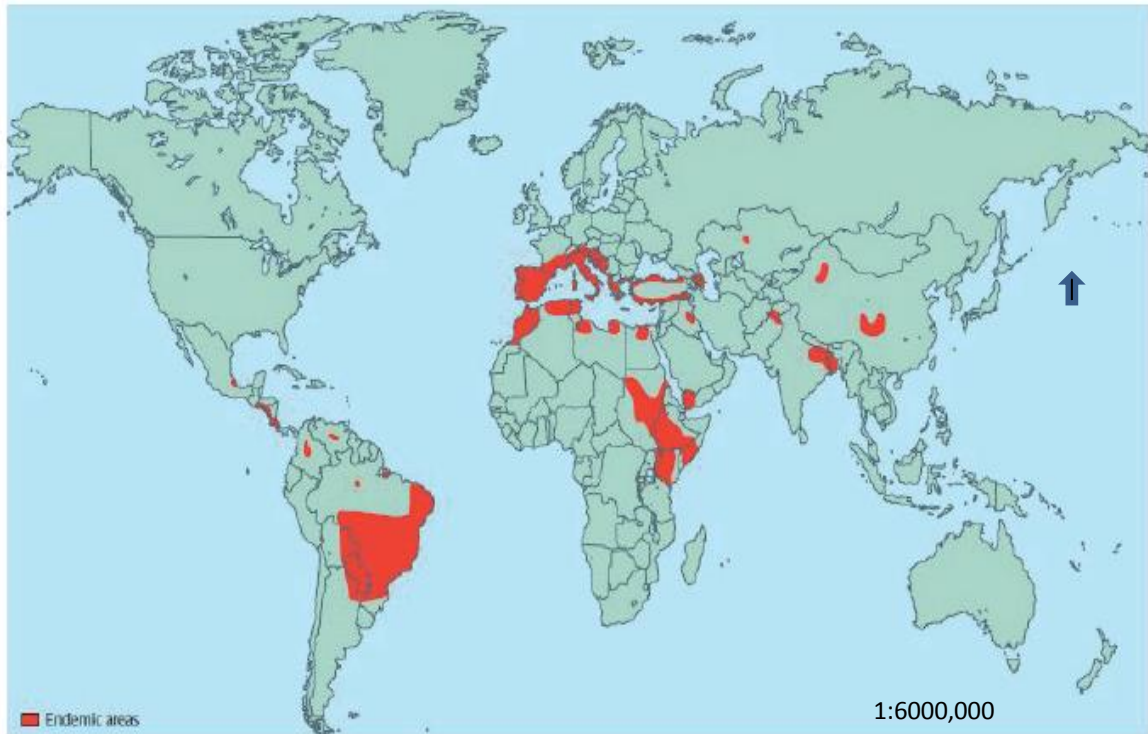


Figure 2.1 Geographical distribution of endemic area of Visceral Leishmaniasis. (Source: WHO 2012).

In India VL is endemic in the states of Bihar, Uttar Pradesh and West Bengal. One of the largest epidemics occurred in 1978 in North Bihar where over half a million people fell victim of kala-azar. In the first eight months of 1982, 7500 cases were reported and in one year alone, between 1987 and 1988, 22,000 cases of VL were registered (WHO, 1991).

In Bangladesh, in 1970, due to the sandfly vector populations increased the cases of VL appeared at a rate in excess of 15,000 per year (Al-Masum *et al.*, 1995). In Brazil, VL is distributed widely in the south, east and the central regions of the country. The disease is highly endemic in the states of Bahia and Ceara, which together accounts for 70% of the total cases of VL in Brazil Up to 1989, 15,000 cases of VL was recorded in multiple states (WHO, 1991). During 1993 and 1994, approximately 3000 cases per year were recorded (Arias *et al.*, 1996).

First case of VL in Sudan was reported in 1938. Since then, the disease has become widespread and endemic in south and eastern parts of the White Nile and Upper Nile states (Hashim *et al.*, 1995). Other sporadic areas include the provinces of Kasala, Jonglei

and Kapoeta in the south, El Fasher and El Nahud in the west and also north of Khartoum (WHO, 1991). The recorded annual incidence was 38.4 per 1000 population between 1991 and 1992 (Zijlstra *et al.*, 1994).

The first case of VL in Ethiopia was documented in 1942 in the southern parts of the country. Then after the disease was known to be endemic in the Segen, Woito, Gelana river valleys in the south and Metema and Humera, in the lowlands of north western Ethiopia. The highest incidence of VL was recorded in Aba Roba area (WHO, 1991).

2.3 Visceral Leishmaniasis in Ethiopia

According to MoH (2013) VL is a growing public health problem in Ethiopia, with endemic areas continually spreading. It is caused by *L. donovani* with an anthroponotic transmission. At least three species of sandflies: *P. orientalis*, *P. martini* and *P. celiae* are confirmed to be involved in the transmission. So far, no confirmed animal reservoir is identified.

Visceral Leishmaniasis is fatal in untreated patients, and has been a cause of major epidemic which killed thousands of people. The endemicity of VL has widened recently in at least five administrative regions, viz, Amhara, Tigray, Southern Nations Nationalities Peoples Region, Oromia and Somali. However, its exact burden and factors determining its distribution are poorly known (MoH, 2013).

Tekle *et al.* (1970) diagnosed VL in migrant workers of the agricultural schemes at Metema and Humera, adjoining the vast VL endemic area of Sudan. Based on clinical, serological and leishmanin skin test survey conducted in June 1995, overall proportion of leishmanin test positives in different settlements in Humera varied from 12.5% to 28.5%, with an average estimate of 20%. The proportion of leishmanin skin test positives among farm laborers who emigrated from the Sudan was 63.2% (Berhe *et al.*, 1995). In Humera lowlands, leishmanin skin test rates of up to 43% have been reported among a study on 530 farm laborers (Fuller *et al.*, 1976).

The incidence of VL in Ethiopia has dramatically increased over the last 10 years, coinciding with the advent of HIV pandemic (Hailu and Berhe, 2002). In the northern foci, the most affected population are mainly male seasonal migrant workers that travel in

the harvesting season from non-endemic highlands to the cotton, sesame and sorghum fields of Humera and Metema. In Humera, the proportion of VL patients co-infected with HIV was 40% (Alvar *et al.*, 2012).

Between 2005 and 2008, an outbreak of VL occurred in Amhara region (Libo Kemkem and Fogera districts), where VL had not been reported before, with 2,500 cases and initially a very high mortality. It was suggested that probably it was spread from the endemic areas of Humera and Metema. A total of 2,500 and 1,500 VL cases were received treatment at the Addis Zemen Treatment Center in 2007 and 2008, respectively. In 2010, 30 cases of VL formed the beginning of an outbreak in a formerly non-endemic area in Tigray region (Shiraro district), and 40 VL cases, were diagnosed in east Imey, a district in Somali region, previously non-endemic. In the northern VL foci, the vector is associated with Red *Acacia* and *Balanites* trees, while in the south with termite hills (Alvar *et al.*, 2012).

2.4 Causative Agents of Leishmaniasis

Seven species complexes consisting of seventeen *Leishmania* species i.e. *Leishmania donovani* complex, *Leishmania tropica* complex, *Leishmania major* complex, *Leishmania aethiopica* complex, *Leishmania mexicana* complex, *Leishmania braziliensis* complex and *Leishmania guyanensis* complex have been identified as causative agents of leishmaniasis all over the world (WHO, 1990).

Visceral Leishmaniasis is caused by the *Leishmania donovani* complex which includes *Leishmania donovani donovani*, *L.d. infantum* and *L.d. chagasi*. Some undefined or unspecified species belonging to the *Leishmania donovani complex* has been isolated from VL patients in Kenya, Ethiopia and Somalia (Pearson and Sousa, 1990).

Anthroponotic VL is caused by *L.d. donovani* in India, Bangladesh, Nepal parts of China and East Africa. Zoonotic VL in Mediterranean region, China, the Middle East and parts of Sub-Saharan Africa is caused by *L. d. infantum* with dog being the principal reservoir. New World zoonotic VL is caused by *L.d. chagasi* and *L. d. infantum*, here as well; dogs are the main reservoir (Mirza, 2010).

2.5 Vectors of *Leishmania*

The species and subspecies of *Phlebotomus* in the Old World (Asia, Africa and Europe) and *Lutzomyia* in the New World (Central and South America) are the only proven vectors of *Leishmania* (WHO, 1990). In the Central and South America *Lutzomyia longipalpis* is the main vector for transmission of VL. In the Mediterranean region, *Phlebotomus perniciosus* and *P. ariasi* are important vectors, while in China, *P. chinensis* and *P. alexandri* are the proven vectors. In East Africa including Sudan, South Sudan and Ethiopia, *P. martini* and *P. orientalis* are as the known vectors of VL. In India, the proven vector is *P. argentipes* (WHO, 1990).

2.6 Mode of Transmission

As discussed in the background of this study Leishmaniasis is transmitted by the bite of infected female sandfly of the genera *Phlebotomus* and *Lutzomyia*. Sandflies feed on man and a variety of warm and cold-blooded animals, which is an important factor in spreading of VL. A sandfly become infected 14-18 days after the ingestion of infected blood meal and remains infected for life, and are capable of infecting several persons (Cheesbrough, 1999). In addition, rare, accidental inoculation of parasites during laboratory work, blood transfusion, during coitus and congenital transmissions are documented (Bahr and Bell, 1987).

2.7 Life Cycle

Leishmania is a digenetic parasite that needs two hosts, the sandfly and a mammalian host, to complete their life cycle. The transmission is either zoonotic, involving animal reservoir hosts, mainly (dogs), or anthroponotic in which humans are the only source of infection for the vector. Moreover, different species of *phlebotomine* sandflies require different ecological niche to survive and have different biting preferences (indoor/outdoor, forest/village, day/night). This has direct implication in the transmission dynamics and control measures to be applied (MoH, 2013).

2.8 Spatiotemporal Factors Influencing Visceral Leishmaniasis Incidence

2.8.1 Temperature

Visceral Leishmaniasis is transmitted by an insect vector i.e. Phlebotomine sandfly that lives in warmer places where humidity and temperature are present at regular intervals in a day (humidity during night and temperature during day time). These conditions are essential for parasite development and distribution. Sandflies are mainly active during night, and the highest risk for contracting the infection from sandfly bites is thus between dusk and dawn (Rajesh and Sanjay, 2013).

The distribution of sandflies is considered to be confined to areas that have at least one month with a mean temperature of 20°C (Rajesh and Sanjay, 2013). Furthermore, a research in anthroponotic foci in Bangladesh, India and Nepal showed that the general conditions that favor transmission is at a maximum temperature of 38°C and a minimum of 15°C (WHO, 2010). Sandflies were also found to inhabit a climate space of mean maximum daily temperature of ~34–38°C (Elnaiem *et al.*, 2003).

In relation with its growth, the eggs, larvae and pupae develop in moist microhabitats rich in organic matter. Precise periods for the development of the stages cannot be given for they are affected by ambient temperature, while low temperatures lengthen and high temperatures shorten the times (WHO, 2010). Because sandflies are sensitive to sudden temperature changes; they usually prefer those regions where maximum and minimum temperatures slightly differ. Sandfly survival can be reduced if the climate gets too hot and dry, even though the fly may rest in cold, humid places during the daytime (Rajesh and Sanjay, 2013). Furthermore, mean annual temperatures of 26°C–31°C is the best for their survival in Ethiopia (Tsegaw *et al.*, 2013) and 25°C–30°C in India (Bhunja *et al.*, 2012).

2.8.2 Rainfall

Precipitation has very important role in the spread of VL. Flooding may spread not only the sandfly but also the larvae of fly to distant and non-affected areas (Rajesh and Sanjay, 2013). An annual mean rainfall of 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). The sandflies were found to inhabit areas with annual rainfall between 180 and 1050 mm (Gebere-Michael *et al.*, 2004). In Sudan Gedarif, mean annual rainfall is found to be one of the most important predictive variables for both the probability of presence and the actual incidence of VL (Thomson *et al.*, 1999). On the other hand, high amount of rainfall may affect the sandfly and the reservoir hosts by affecting the vegetation, temperature and relative humidity (Elnaiem *et al.*, 2003).

2.8.3 Vegetation

In East Africa, VL occurs in two distinct ecological settings: the savannah regions with Red *Acacia* or *Acacia balanites* trees and savanna grass (Ethiopia and Sudan) (Palate 2.1); and the savannah and forest areas (WHO, 2012). The local vegetation is important as resting sites and sugar sources for sandflies (Rajesh and Sanjay, 2013). Hence, people settling in forest areas or moving near sandflies habitat; and sleeping outside under *Acacia* trees appear to increase the VL-risk (WHO, 2012).

Application of remote sensing techniques can quantify the amount of vegetation by Normal Difference Vegetation Index (NDVI) (Yazoume *et al.*, 2008). A study conducted in Gedaref State, Sudan, which is adjacent to Kafta Humera District showed that minimum NDVI is the main environmental variable associated with the distribution and incidence of VL. For such kind of environment, *P. orientalis*, is known to thrive in habitats characterized by presence of *Acacia* trees. It is also interesting that VL incidence is positively correlated with the mean and minimum NDVI and did not appear to have an association with maximum NDVI. The minimum NDVI in this region generally coincides with the sandfly season and should reflect the density of trees because most grasses of the area are highly seasonal, flourishing after the start of the rains (Elnaiem *et al.*, 2003). According to Gebere-Michael *et al.* (2004) the annual composite NDVI value range of (0.05–0.28) was the best fit for distribution of *P.orientalis* in east Africa.



Plate 2.1 Red *Acacia* habitat in the study area.

2.8.4 Topography

Elevation is known to define VL transmission through area of temperature gradient. At certain altitudes, VL transmission does not occur because of extreme temperatures that inhibit sandflies. A study in Gedaref State, using a probabilistic model, revealed that altitude is one of the best predictors for the presence of VL (Elnaiem *et al.*, 2003). Another study in India showed that VL was more likely to be present in areas where the elevation is >436 m amsl (Nieto, 2001). The long known endemic foci established through epidemiological surveys and self-reported cases of VL in Ethiopia are from the lowlands and the recently reported highland foci range from 1,800 to 2,000 m (Sordo *et al.*, 2012). It is probable that due to global climate changes and temperature increases, which support the high degree of sand fly growth, the transmission of VL has increased manifold (Rajesh and Sanjay, 2013).

2.8.5 Soil type

According to FAO data, among soil types, Vertisol has a high content of the expanding clay type known as montmorillonite that forms cracks (Palate 2.2), when dried but which absorbs water and swells causing self-mulching during the rainy season. The deep cracks provide sand flies essential microhabitat suitable for breeding and resting (Elnaiem *et al.*, 2003). This soil type is associated with the *Acacia* and *P. orientalis*, which are common in areas endemic for *L. donovani* transmission. Influence of VL with this type of ecological situations are found in areas of northwest Ethiopia, and much of the areas of Sudan except perhaps in the extreme southeast (Gebre-Michael *et al.*, 2010).

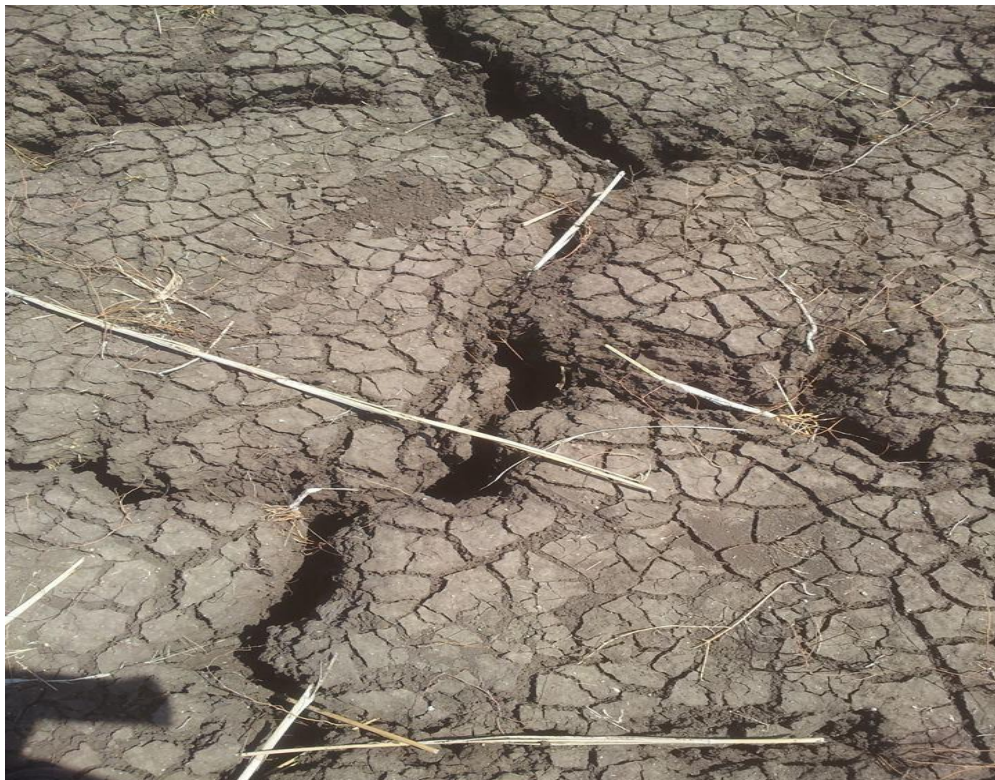


Plate 2.2 Vertisol soil type of the study area.

2.8.6 Slope

Slope has a significant role for the existence and distribution of VL. A study conducted to compare slope with presence/absence of VL cases indicated an inverse relationship between slope and presence of VL. This indicates that the presence of VL cases is more related to areas with less slope values (<1.53 degree) (Tsegaw *et al.*, 2013).

2.8.7 Humidity

Humidity plays an important role in survival of sand-fly, development and its activity. Few species of sand-flies live in tree holes and trunks. Peridomestic species rest on walls and, at hot times of the day, retreat into cracks and crevices. The rise in temperature in day time and humidity level during night time greatly influences the growth of sandflies and the distribution of VL. However on the contrary to these, in the cold climatic countries the prevalence is limited because the growth of sand-fly is limited and not able to suck the blood in night (Rajesh and Sanjay, 2013). In anthroponotic foci in Bangladesh, India and Nepal (with the exception of Bhutan; and Kashmir, Himachal Pradesh and Uttarakhand in India) the general conditions that favor transmission of VL is a mean humidity above 70% (WHO, 2012).

2.9 Application of Remote Sensing (RS) and Geographic Information System (GIS) in Visceral Leishmaniasis Studies

Recent advances in remote sensing techniques and computer-based geographic information systems enabled scientists to map vector-borne diseases and analyze environmental factors affecting their spatiotemporal distribution. These techniques have been used to map and monitor several vector-borne diseases, including leishmaniasis, malaria, trypanosomiasis, onchocerciasis, and schistosomiasis (Elnaiem *et al.*, 2003).

Previous studies using geographic information systems for risk assessment of schistosomiasis, leishmaniasis, malaria and other diseases indicated that climatic and environmental variables, such as NDVI, temperature, elevation, rainfall and humidity are important factors influencing the presence and potential transmission. Similar approaches by RS technology have been used to map potential distribution and risk for leishmaniasis and schistosomiasis (Gebere-Michael *et al.*, 2004). If we understand these factors and their relation to the sand-fly survival, and if RS data containing these elements are available in digital format, GIS can help identify human populations at risk of infection. This approach can adapted to help to target VL control much more cheaply and efficiently than older manual field methodologies (Alen, 2002).

The geographic information systems can be used to integrate and manipulate multiple layers or themes of spatial data for a large area and from different sources at different scales. The data source can be paper maps, aerial photographs, satellite images, geographical positioning systems as well as census data, epidemiological surveys data, environmental data, health data and any other data with spatial components (Yazoume *et al.*, 2008).

In addition, geographic information system is characterized by the strict link between feature's, geographical position or coordinate and its attribute data. It permits dynamic link between databases and maps so that data updates are automatically reflected on the maps. It can also help to generate thematic maps, ranged color maps or proportional symbol maps to denote intensity. In comparison with tables and charts, maps developed using GIS are more effective means for communicating messages clearly even to those who are not familiar with the technology (WHO, 2010). Geographic information systems makes the manipulation and possible combination of several data layers from the different data sources easy, and it allows rapid display and analysis of multivariate spatial data. For this combined display layers, data are to be registered geographically to a common coordinate system (Bhunia *et al.*, 2012). Therefore, it is a powerful tool for epidemiology, in mapping diseases and their determinants, quantifying risk, linking diseases and their potential risk factors, and creating databases for further statistical and epidemiological analyses. For leishmaniasis research and control it has been intensively used to examine the link between environmental factors and leishmaniasis transmission risk (Yazoume *et al.*, 2008). Regression statistical analysis has been used to model geographic distribution of leishmaniasis vectors. Moreover, GIS based model has been used to predict potential risk of Leishmaniasis, Schistosomiasis and malaria (Peterson *et al.*, 2004 and Tsegaw *et al.*, 2013).

Geographic information systems and remote sensing technologies enable health workers to evaluate the relationship between the environment and disease agents as well as to define risk in areas where surveillance data are not readily available to design appropriate control and prevention strategies (Yazoume *et al.*, 2008).

Moreover, as it was discussed in the background of the study, potential benefits of geographic information systems in public health (Negash *et al.*, 2005) are to:

- Determine the geographical distribution and variation of diseases.
- Analyze spatial and temporal trends of diseases.
- Identify gaps in immunizations.
- Map populations at risk and stratify risk factors.
- Document community health care needs and assess resource allocations.
- Forecasting epidemics.
- Plan and target interventions.
- Monitor diseases and interventions over time.
- Manage patient care environments, materials, supplies and human resources.
- Monitor the utilization of health centers.
- Route health workers, equipments and supplies to service locations.
- Publish health information maps.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Description of the Study Area

3.1.1 Location

Kafta Humera District is located in the western Tigray region along the border of Ethiopia, Sudan and Eritrea at 991 km northwest of Addis Ababa the capital city of Addis Ababa. Large part on the western side of the District coincides with the Sudanese border while the northern part is fully covered by the Eritrean border. Most part on the south is attached with Welkayit and partially with Tsegede District. On the eastern side, it coincides with 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 5933.66 km², which is about 50 percent of the western Tigray Zone. The location of the study area is shown in Figure 3.1.

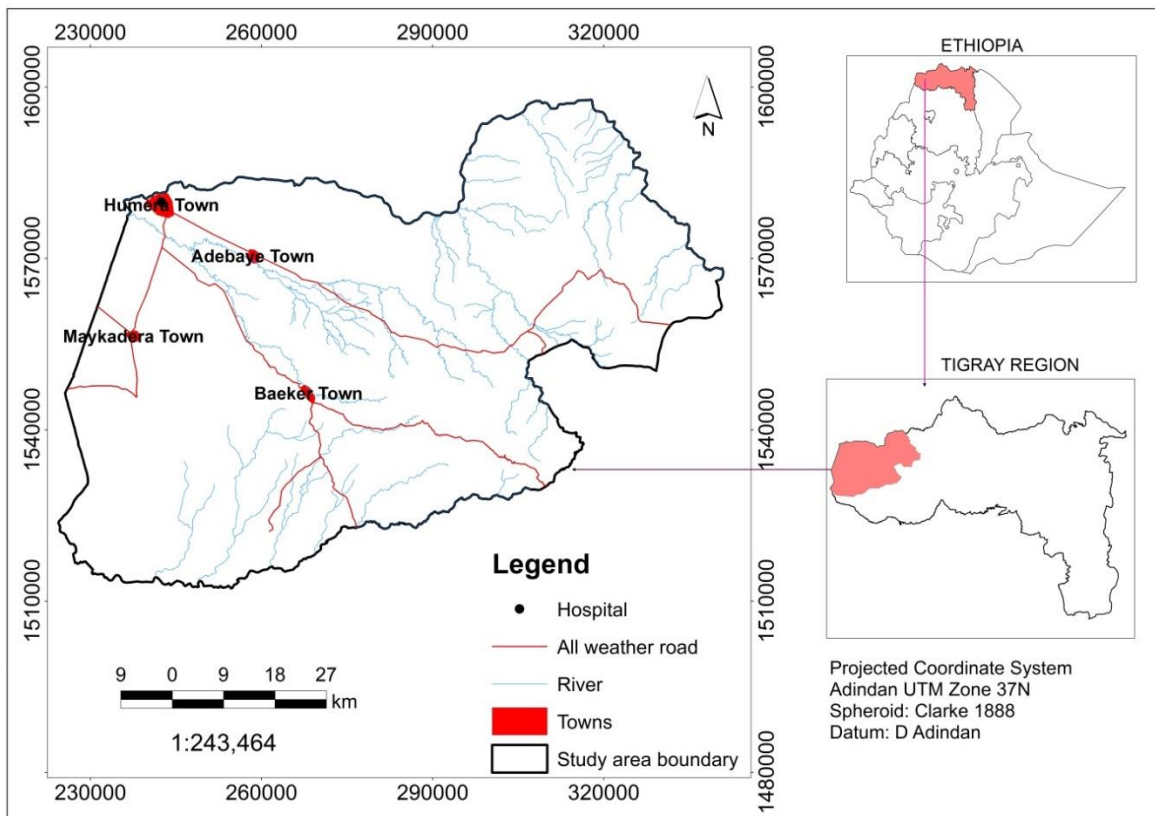


Figure 3.1 Location map of the study area.

3.1.2 Topography

The altitude of Kafta Humera District ranges from 515–1863 m amsl. According to Haile Fesseha (2007) the landform of the study area is heterogeneous in nature and consists of flat plains, undulating to rolling, some isolated hills and ridges, chain of mountains, valleys and gorges. The western, north-western and south-western parts of the study area are characterized by flat lying topography with some scattered hills, where as the eastern and north eastern parts are characterized by mountain, valleys and Gorges (Fig. 3.2).

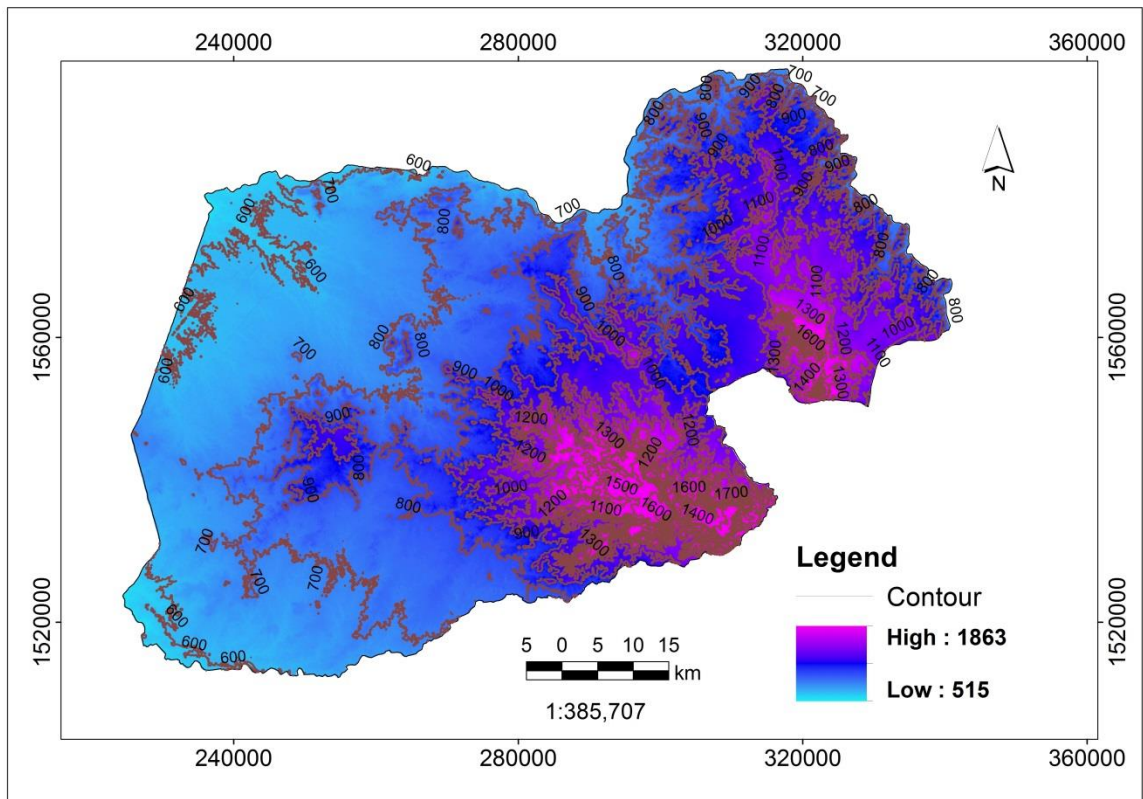


Figure 3.2 Topography map of the study area.

3.1.3 Population

Administratively the Kafta Humera District comprises 21 Kebeles of which four are semi-urban towns and others are rural. According to the 2012 projected population of Central Statistics Agency (CSA), the District has a total population of 134,569 (CSA, 2014). Humera town, Maykadra, Adi hirdi, Adebaye, Habesha Adigoshu, Baeker, Rawyan and Adi Tsetser Kebeles are highly populated with more than 5,000 to 27,412

inhabitants per Kebele (Fig. 3.3). Other area are located along with the boundary of the study area with a moderate and lesser population size.

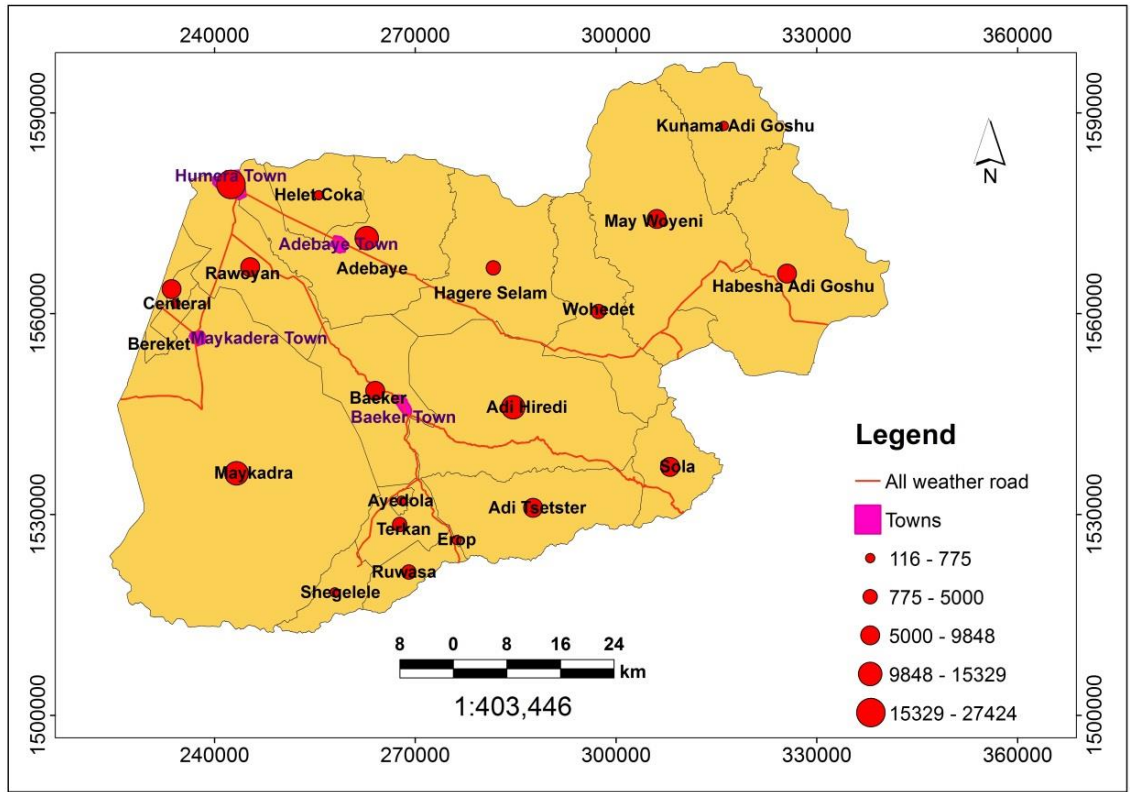


Figure 3.3 Population distribution map of the study area.

3.1.3.1 Population Density

Kafta Humera District is characterized by less population density of 23 people per km², where people live in clusters over a wide range of areas. On Kebele level the population density ranges from 3 to 2030 inhabitants per km². Humera town, Bereket and Erop Kebele are the most densely populated with 115, 135 and 2030 people per km², respectively. The majority of the Kebeles are with lesser population density.

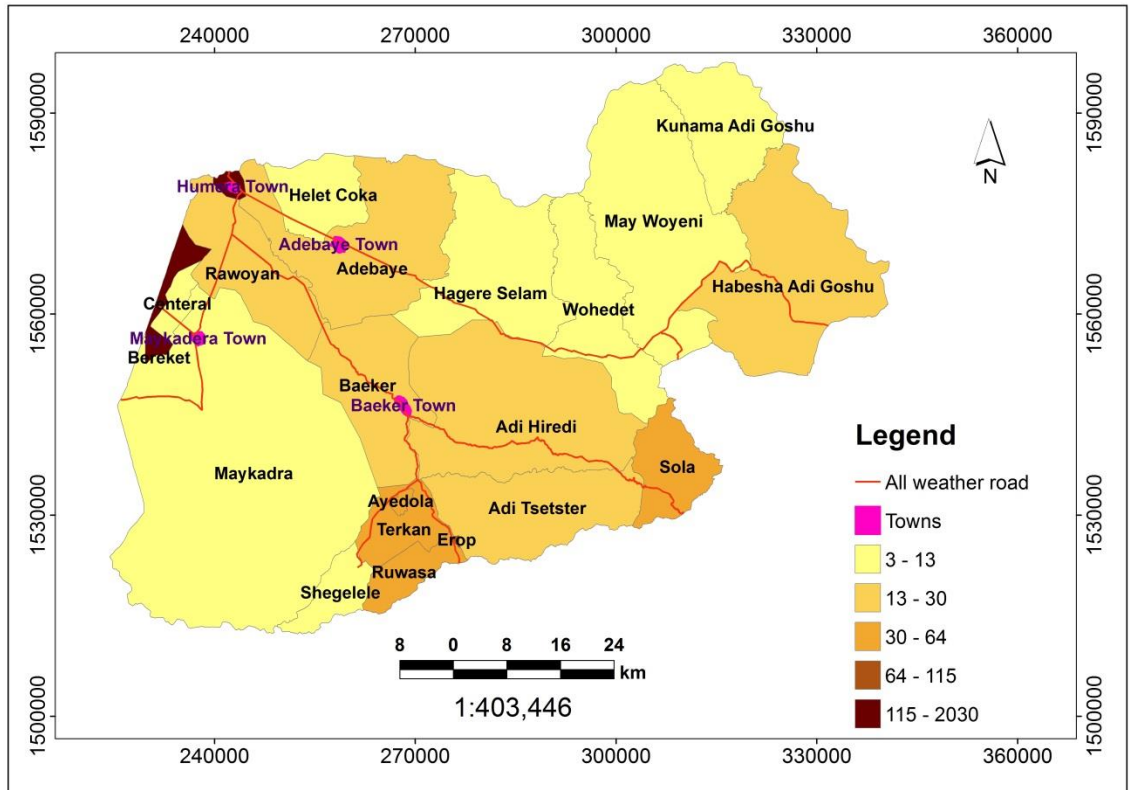


Figure 3.4 Population density map of the study area.

3.1.4 Temperature and Rainfall

Kafta Humera District, in general has a tropical (*kola*) and sub-tropical (*woina dega*) climates. Accordingly, it is characterized with high a temperature throughout the year especially during the dry season in February–June. It has a uni-modal rainfall pattern 80 to 85% of the rainfall in the wet season from June to September. The remaining 8-9 months are dry and hot (Haile Fisseha, 2007). The reconstructed temperature and rainfall data from station observations and satellite record for consecutive 20 years (1993–2012) showed that mean monthly temperature vary from 24.3°C in August to 28.9°C in May; and the mean monthly rainfall pattern ranges from 2.3 mm in January to 227.8 mm in August (Fig. 3.5).

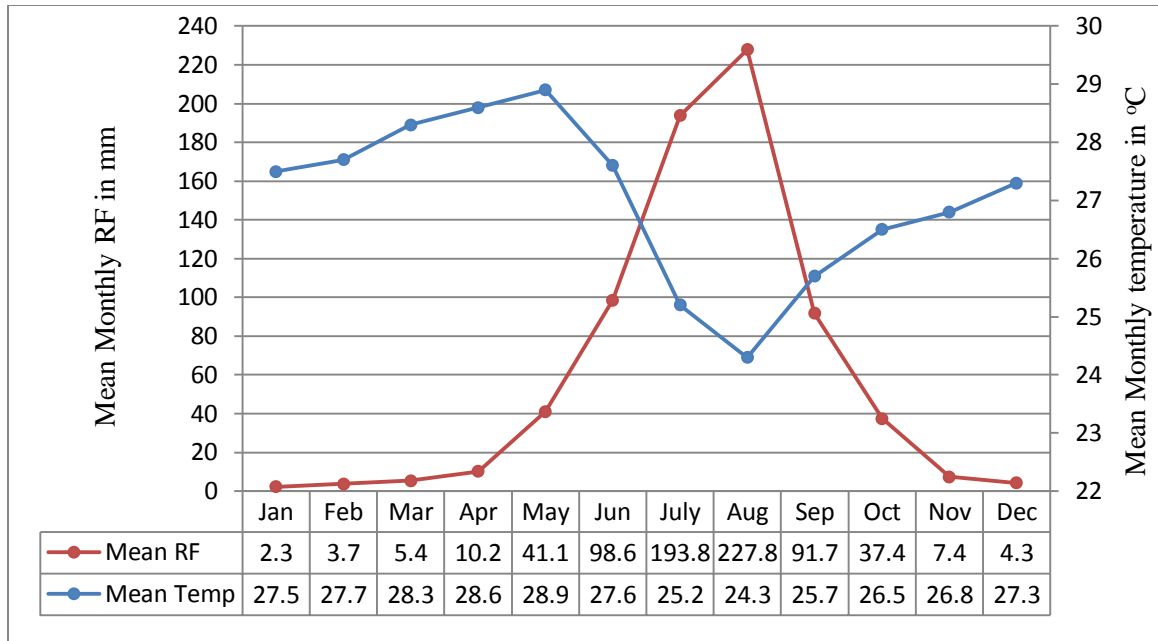


Figure 3.5 Mean monthly rainfall and temperature (1993-2012) of the study area.

3.1.5 Soil Types

The soils of Kafta Humera District are classified based on the FAO soil classification as Vertisol, Lixisol, Luvisol, Alisol, Cambisol and Nitosol. The dominant soil type in the area is Vertisol (Fig. 3.6) (Haile Fisseha, 2007).

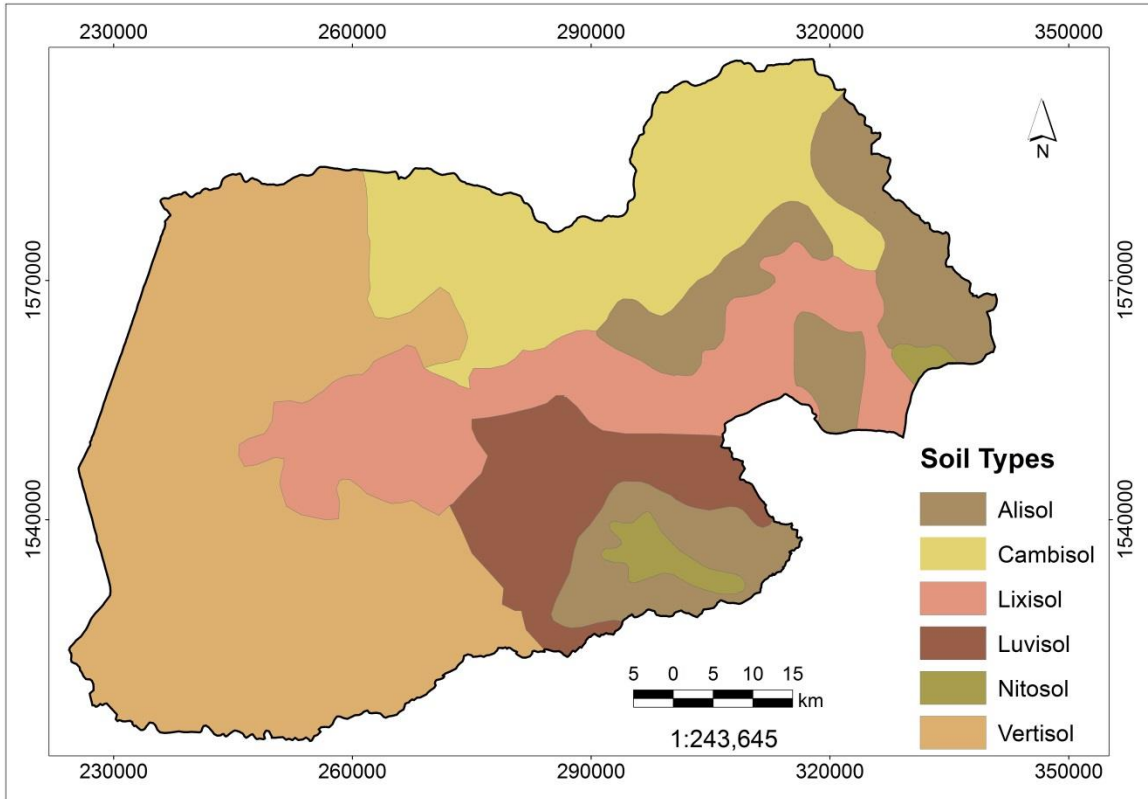


Figure 3.6 Soil type map of the study area.
(Source: FAO 1998).

3.2 Materials

3.2.1 Data Types and Sources

Selected weather and environmental factors were collected from different sources (Table 3.1). In addition, published and unpublished materials from, journals, books reports and electronic web sites were collected. Mapping, graphing and Photographing were also incorporated as supplement sources.

Table 3.1 Data types and sources.

S.N	Data types	Source
1	GCP of VL cases (2012)	AHRI
2	VL patient statistics (1998–2012)	Kahsay Abera Hospital
3	Rainfall and temperature data (1993–2012)	NMA
4	Altitude (SRTM 30 m)	EMA
5	FAO Soil data (1998)	Ministry of Agriculture
6	Literature	Journals, books and websites
7	Population data	CSA
8	Administrative boundary	EMA
9	SPOT VEGETATION (VGT) 1 km (2003–2012)	http://www.vito-eodata.be/PDF/portal/Application.html
10	Topography map (1:50,000) scale 1336 A2, A4, B1, B2, B3, B4, 1337 A1, A2, 1436 D1, D2, D3, D4, 1437 C1, C2, C3 and C4 sheet number.	EMA

3.2.2 Software and Hardware Utility

Table 3.2 shows the software and hardware used for this study.

Table 3.2 Software and Hardware used for the study.

Type	Name	Utility
Software	ArcGIS 10	Database creation, Contour generation, overlay analysis, map and lay out preparation
	SPIRIT	Extracting region of interest
	VGT Extract	Extraction of the NDVI product
	Global Mapper	For 3D visualization
	MS Office 2010	Documentation, statistical analysis and presentation
	Stata/SE version 12	Multivariate logistic regression
Hardware	Computer	For storage, software installation and internet support
	GPS	For GCP collection

3.3 Methodology

The collected variables from different sources include mean annual temperature, mean annual rainfall, elevation, slope, soil type, mean NDVI, 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 topography 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) 30 meter spatial resolution. A slope surface (in degrees) was subsequently generated using ArcGIS Spatial Analysis tool.

Multi-year meteorological data was used in the analysis. For this, the reconstructed monthly temperature and rainfall data from station observations and satellite record for consecutive 20 years (1993–2012) for 91 grid points with 10.1 km distance in the study taken from Ethiopian National Meteorology Agency (NMA). Mean annual temperature and rainfall was calculated for all grid points (Appendix I), and gaussian semivariogram model of ordinary kriging method was applied to obtain an interpolated continuous surface temperature and rainfall using 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.

In addition, 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 is 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 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 are 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 years, annual composite of 10 consecutive years decadal NDVI data from January 2003 to December 2012 were combined to create average annual composite NDVI using ArcGIS spatial Analysis tool. The NDVI product is scaled to positive values (49-209). Finally, the data were converted to real NDVI values which ranged from 0.09 to 0.68 using ArcGIS spatial Analysis tool (Sawasawa, 2003).

$$\text{Real NDVI (VGT)} = (\text{VGT value} \times 0.004) - 0.1 \dots \dots \dots \text{Equation 3.1}$$

Where, Real NDVI (VGT) = NDVI value between 0.09 and 0.68

$$\text{VGT value} = \text{SPOT VGT NDVI values between 49-209}$$

Mean monthly NDVI values for each month of the above mentioned years were also computed to correlate with the monthly record of VL cases.

Food and Agricultural Organization of the United Nations (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) 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.

Having all the above data, 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 (Appendix II). 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 Kebeles of the District. For this reported VL cases information and address were gathered from the medical records in Kahsay Abera Hospital (Appendix III) and used purposive non-random sampling technique to collect the VL cases. This sampling technique was selected because one VL case GPS point can represent areas with the range of elevation $\leq 100\text{m}$ in places with the same soil type (Tsegaw *et al.*, 2013). Therefore, the collected points were well enough to represent the VL situation in the study area and to use for further analysis and to conduct the research.

For the collected global positioning system points of VL absence/presence data, extraction of values from each the above identified parameters was done using 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 $P \leq 0.05$ (Appendix IV). This indicates that the desired confident 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).

All the derived datasets of mean annual temperature, rainfall, elevation, slope, soil type and mean NDVI were classified in to different suitability classes based on the range of measurement scales for the presence of VL in the study area. Reclassification was also done and new values 4, 3, 2 and 1 were assigned. Subsequently, the classes were labeled as high, medium, low and very low suitable, respectively as per the standard given in Table 3.3. This standard is accepted by Federal Ministry of Health, and other researchers used as a guideline for VL risk analysis in Ethiopia.

Finally, after each parameter and weights were standardized the method of aggregation was performed to produce VL-risk map of the study area. Consequently, from the produced VL risk map, the risk of VL category in terms of area coverage (km^2) and the

corresponding percentages were calculated. In addition, by superimposing Kebele boundaries on the final VL risk-map it was possible to identify VL risk at Kebele levels.

The 2012 projected Kebele population data of the study area was taken from CSA. The total population of each Kebele was divided in to their total area and population density of each Kebele was extracted in km². Accordingly, each was multiplied by their respective spatial coverage risk. Finally population under the different VL risk level was summed up based on their category and calculated in percentages. In addition, Kebeles with high population at risk of VL were identified. The overall procedure of the methodology is depicted in Figure 3.7.

Table 3.3 Summary of influential factors for visceral leishmaniasis in Ethiopia.

Factors	Class	Ranking	Susceptibility	References
Soil	Vertisol	4	High	Gebere-Michael <i>et al.</i> (2004).
	Lixisol	3	Medium	
	Cambisol	2	Low	Tsegaw <i>et al.</i> (2013)
	Luvisol	2	Low	
	Nitosol	1	Very Low	
	Alisol	1	Very Low	
Average annual rainfall	<766	3	Medium	Gebere-Michael <i>et al.</i> (2004)
	766–1,057	2	Low	
	1,057–1142	4	High	Tsegaw <i>et al.</i> (2013)
	>1,142	1	Very Low	
Average annual temperature	<16	1	Very Low	Gebere-Michael <i>et al.</i> (2004)
	16–21	2	Low	
	21–26	3	Medium	Tsegaw <i>et al.</i> (2013)
	26–31	4	High	
	>31	1	Very Low	
Altitude	>2,305	1	Very Low	Gebere-Michael <i>et al.</i> (2004)
	1,872–2305	2	Low	
	1,794–1872	3	Medium	Tsegaw <i>et al.</i> (2013)
	<1,794	4	High	
Slope	>3.78	1	Very Low	Tsegaw <i>et al.</i> (2013)
	1.53–3.78	2	Low	
	0.56–1.53	3	Medium	
	<0.56	4	High	
Mean annual NDVI	<0.05	1	Low	Gebere-Michael <i>et al.</i> (2004)
	0.05–0.28	4	High	
	0.28–0.36	3	Medium	
	>0.36	2	Low	

(Source: Gebere-Michael *et al.* 2004, Tsegaw *et al.* 2013).

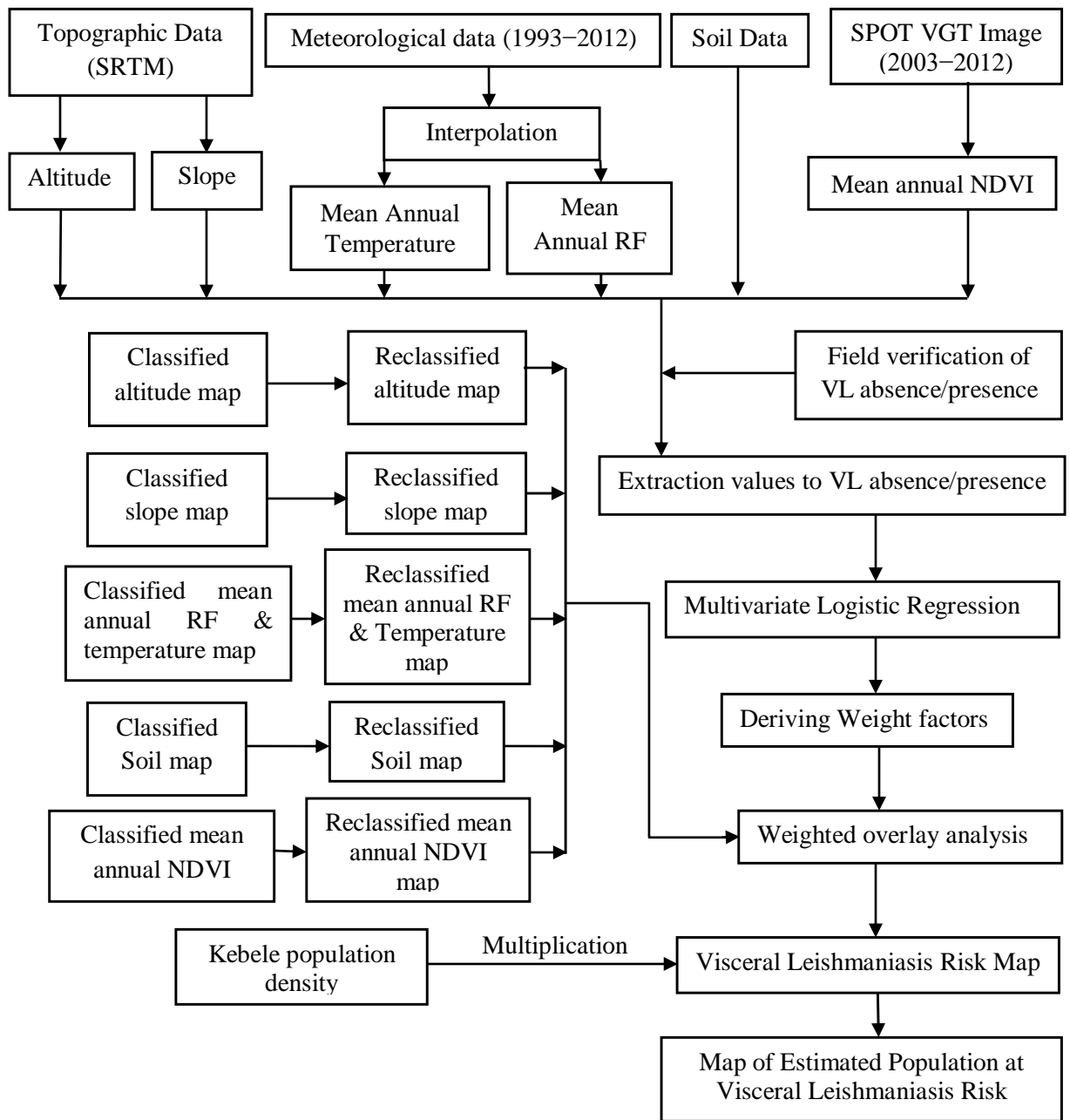


Figure 3.7 Schematic diagram of the methodology.

3.4 Data Analysis and Interpretation

The obtained influential environmental factors were analyzed and interpreted using ArcGIS spatial analyst tool.

3.4.1 Rainfall

The annual rainfall of the study area ranges from 576 to 884mm. The data were categorized in to two class ranges 576–766 mm and 766–884 mm (Fig. 3.8). The categorized data were further reclassified based on the standard and assigned values 3 and 2. Accordingly, the classes were labeled as medium and low degree of suitability to VL presence, respectively, using spatial analyst tool (Fig. 3.9). Thus, the output map indicated most of the study area is under moderately suitable rainfall for the presence VL. In addition, when the amount of annual average rainfall increased, the likelihood of presence of VL decreased.

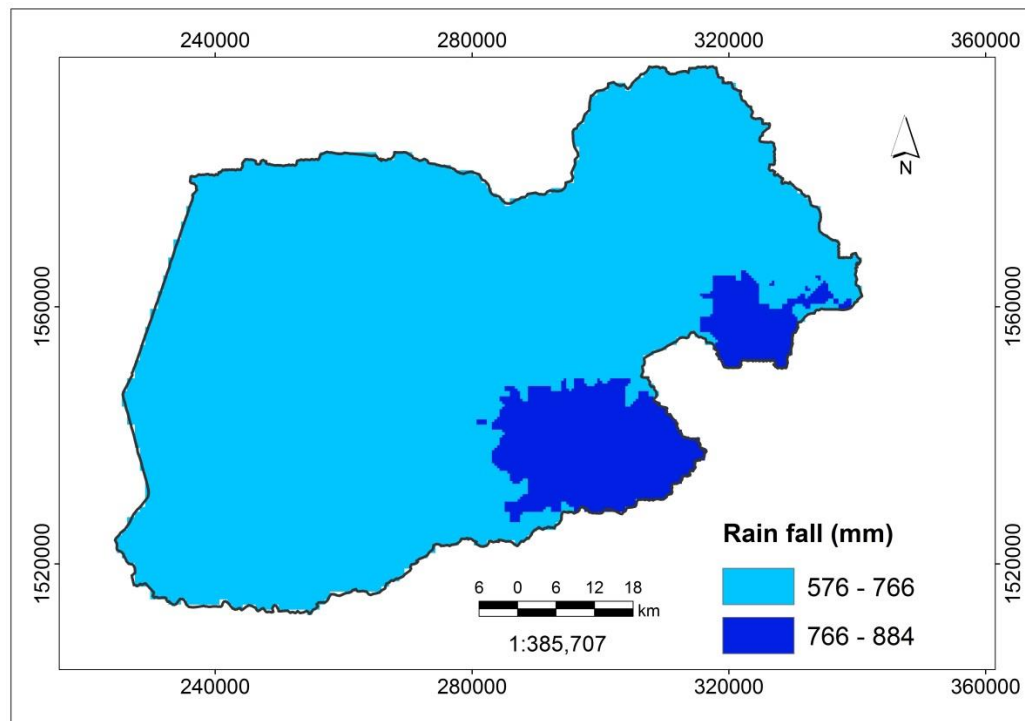


Figure 3.8 Classified mean annual rainfall map.

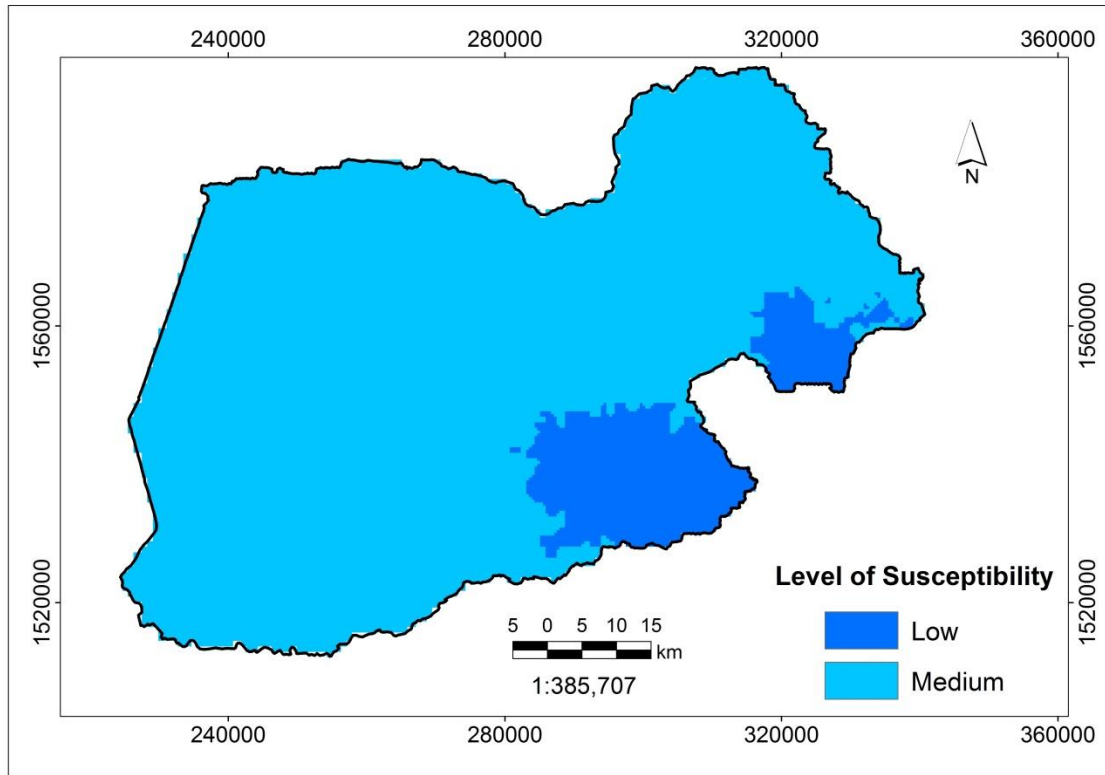


Figure 3.9 Susceptibility mean annual rainfall map.

3.4.2 Temperature

The computed mean annual temperature of the study area ranges from a minimum of 20°C to a maximum of 31°C. This range was further classified into three sub classes (20–21°C, 21–26°C and 26–31°C), that can be support the final overlay process (Fig. 3.10). Furthermore, the classified layer was reclassified and assigned values 2, 3 and 4, respectively. Then, each class was labeled as low, medium and high to VL susceptibility as depicts in figure 3.11. The aforementioned fact shows that VL increases with the average temperature. In addition, being the majority of the study area is with high temperature, this condition in turn promotes for the existence of VL.

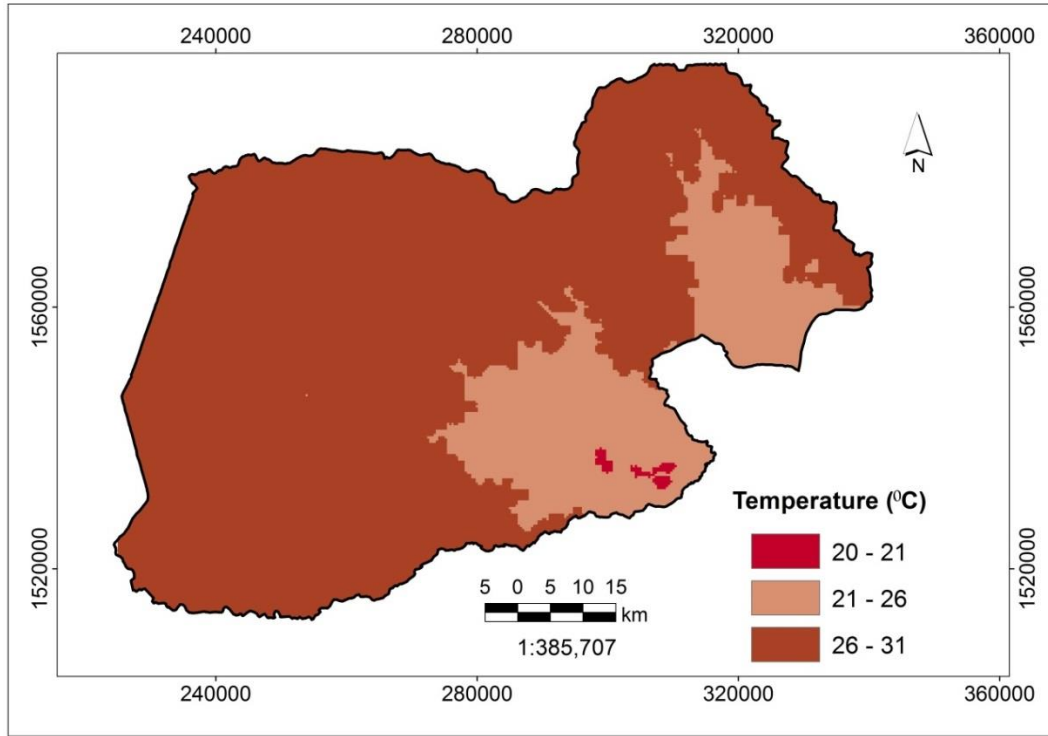


Figure 3.10 Classified mean annual temperature map.

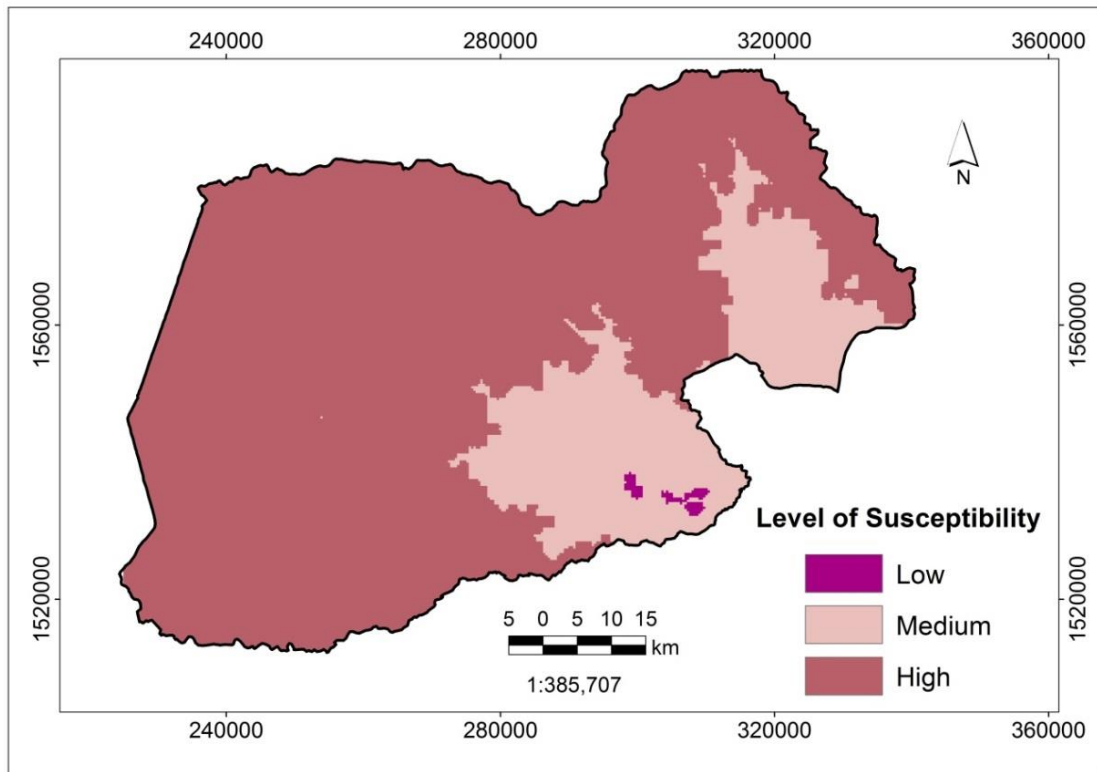


Figure 3.11 Susceptibility mean annual temperature map.

3.4.3 Altitude

Altitude has been recognized as an important determinant of VL endemicity. Hence, the elevation layer of the study area was classified in to two based on the standards 515–1794 m and 1794–1863 m (Fig 3.12). Then the layer was further reclassified in to two classes and new values 4 and 3 were assigned to each class. Accordingly, the classes were labeled as high and medium suitability for the presence of VL (Fig. 3.13). From this it was possible to understand VL increases with low altitude and also majority of the study area is found highly suitable for the presence of VL.

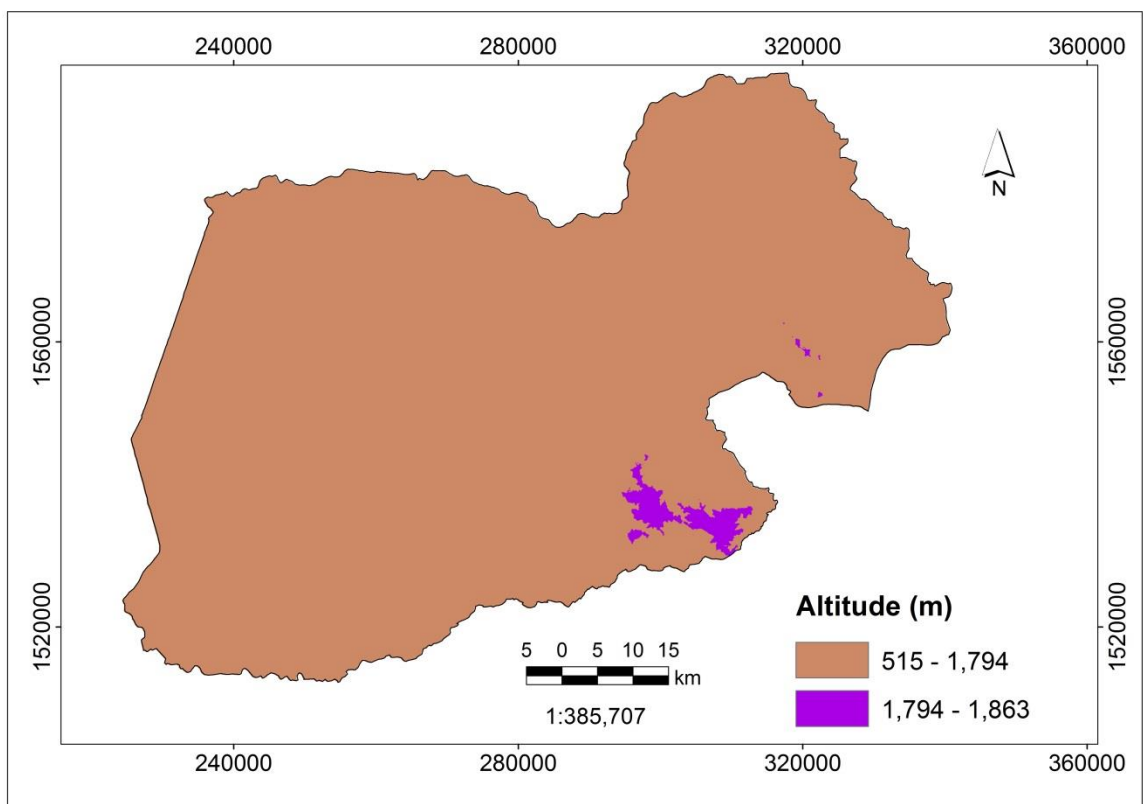


Figure 3.12 Classified altitude map.

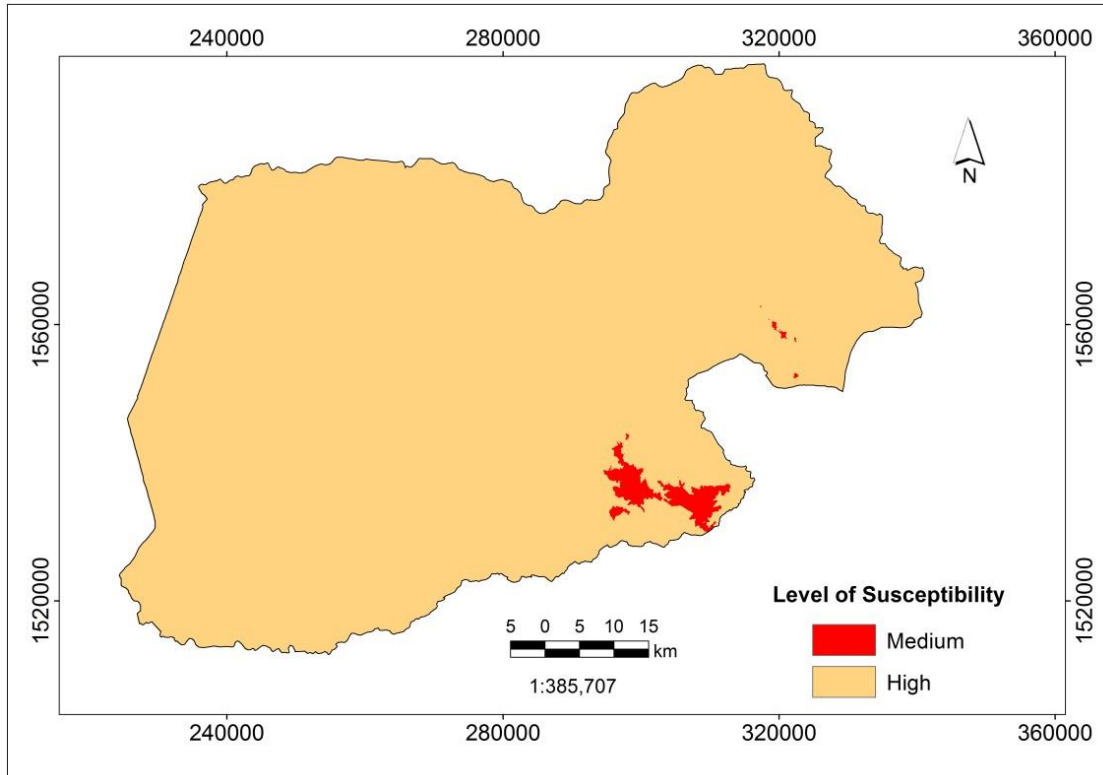


Figure 3.13 Susceptibility altitude map.

3.4.4 Slope

The slope data of the study area was calculated in percentage and its slope ranges from 0 to 74%. Based on its susceptibility for VL incidence it was classified in to four: 0–0.56%, 0.56–1.53%, 1.53–3.78 and 3.78–74% (Fig. 3.14). Then, the layer was further reclassified and new values 4, 3, 2 and 1 were assigned to each class, respectively. Accordingly, each class beginning from the low to high value were labeled as high, medium, low and very low (Fig. 3.15). This showed that the incidence of VL increases as slope decreases.

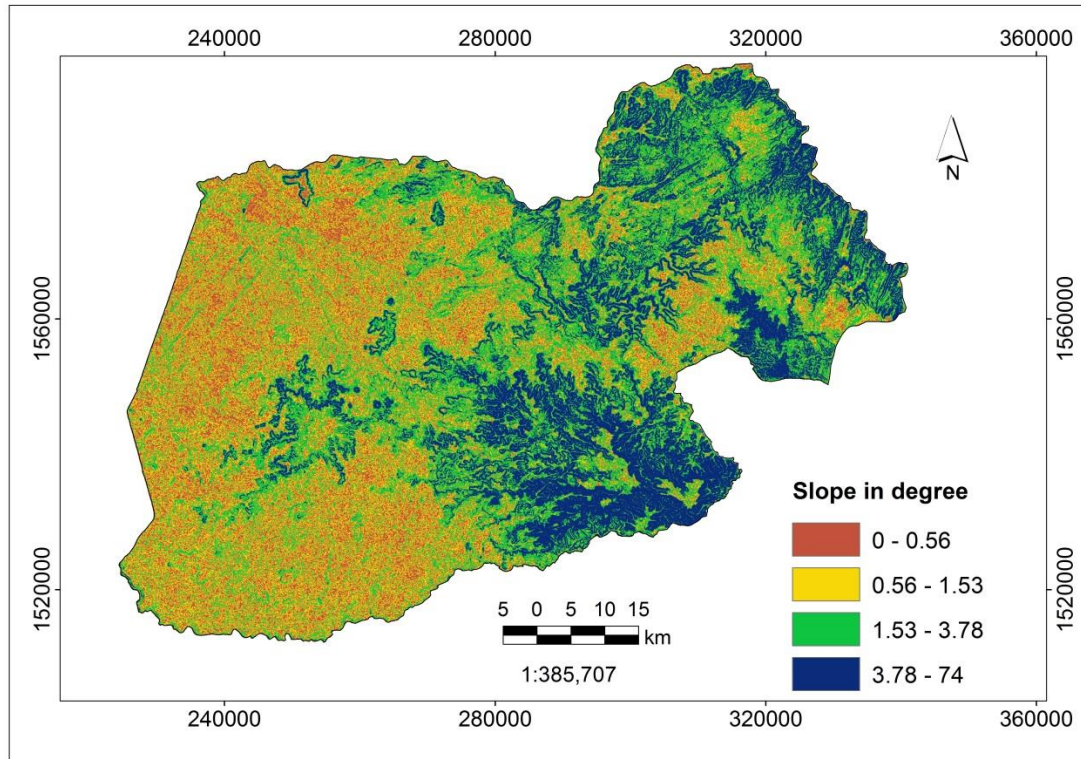


Figure 3.14 Classified slope map.

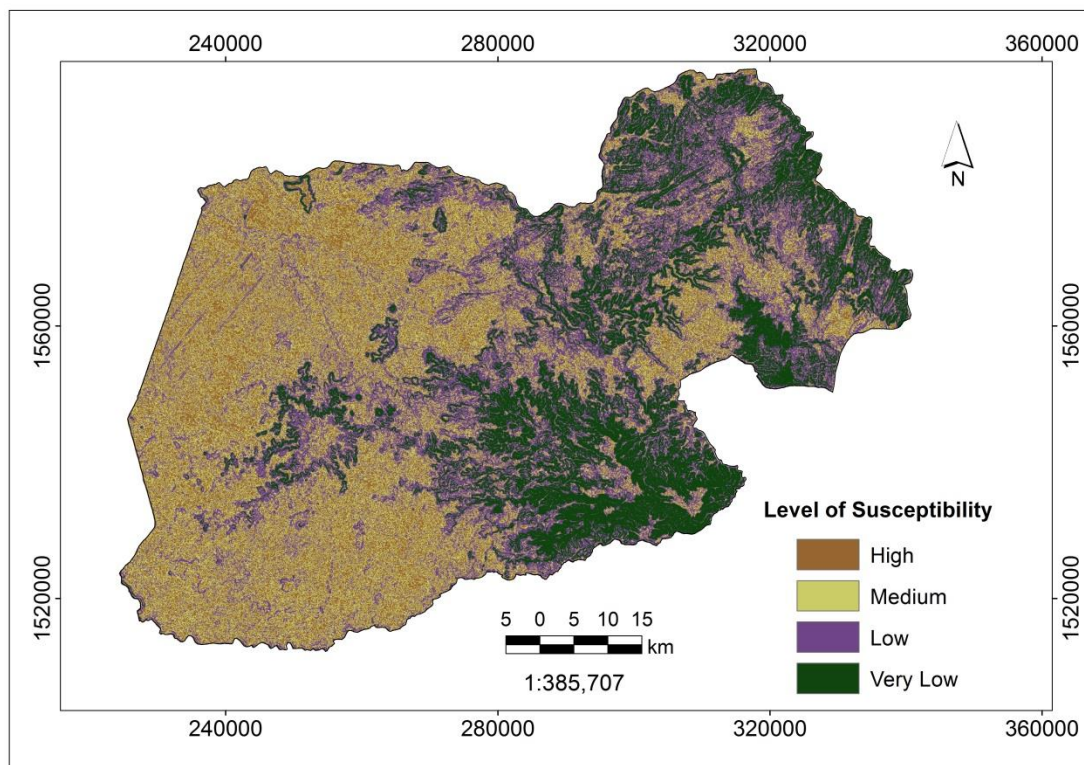


Figure 3.15 Susceptibility slope map.

3.4.5 Vegetation/NDVI

The calculated NDVI value of the study area ranges from 0.09 to 0.68. Accordingly, in order to fit to the standard, it was classified in to three sub classes: 0.09–0.28, 0.28–0.36 and 0.36–0.68 (Fig. 3.16). Then after the classes were further reclassified and new values 4, 3 and 2 were assigned, respectively. Accordingly, they were labeled as high, medium and low suitability of the NDVI value for the existence of VL (Fig. 3.17). The result showed that the prevalence of VL increased as the NDVI value decrease.

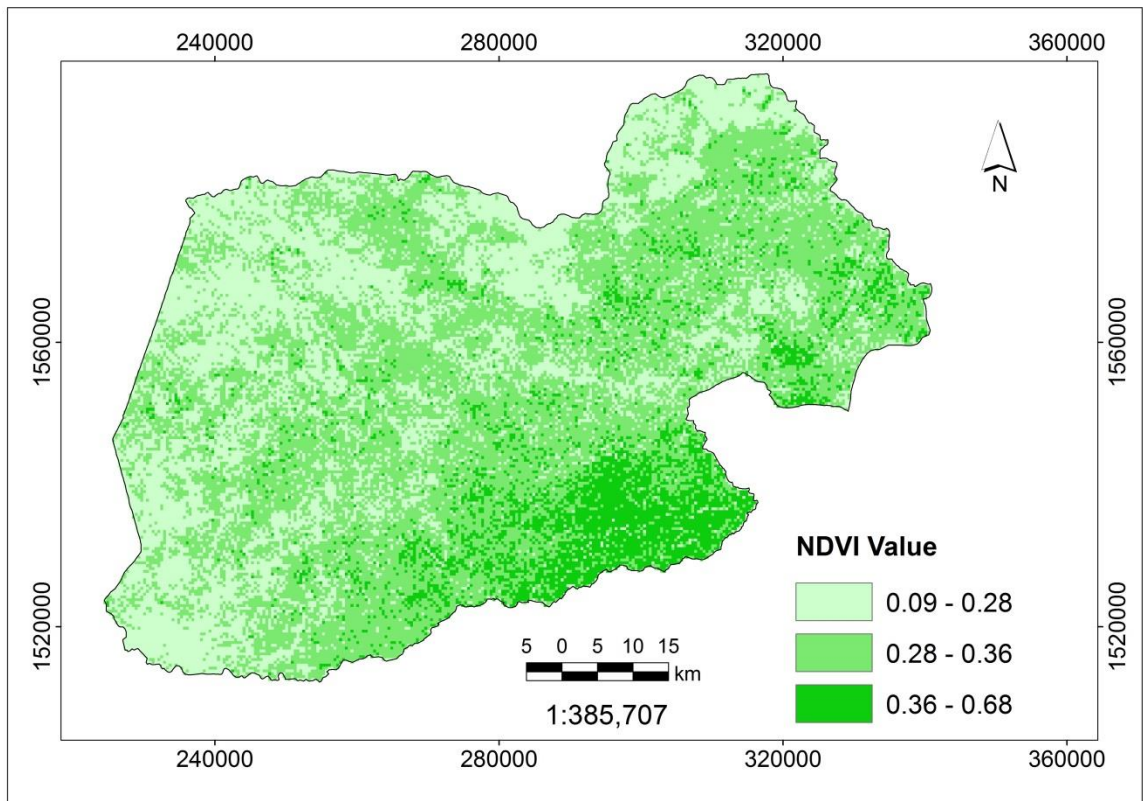


Figure 3.16 Classified mean NDVI value map.

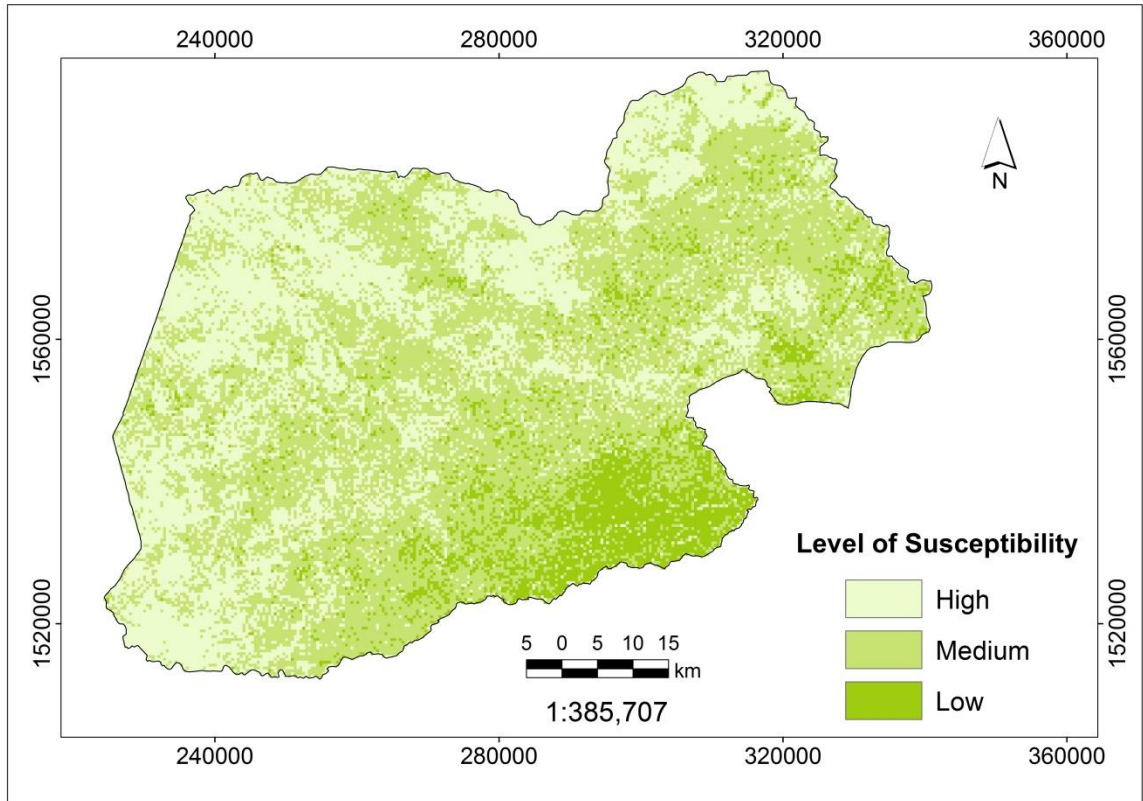


Figure 3.17 Susceptibility mean NDVI map.

3.4.6 Soil Type

The classified soil data were changed in to raster format and reclassified in to four classes. Then, new values 4 for Vertisol, 3 for Lixisol, 2 for Cambisol and Luvisol, and 1 for Nitosol and Alisol were assigned. Accordingly, they were labeled as high, medium, low and very low suitable for the presence of VL, respectively (Fig. 3.18). From this it was possible to understand that Vertisol was significantly associated with the presence of VL in the study area.

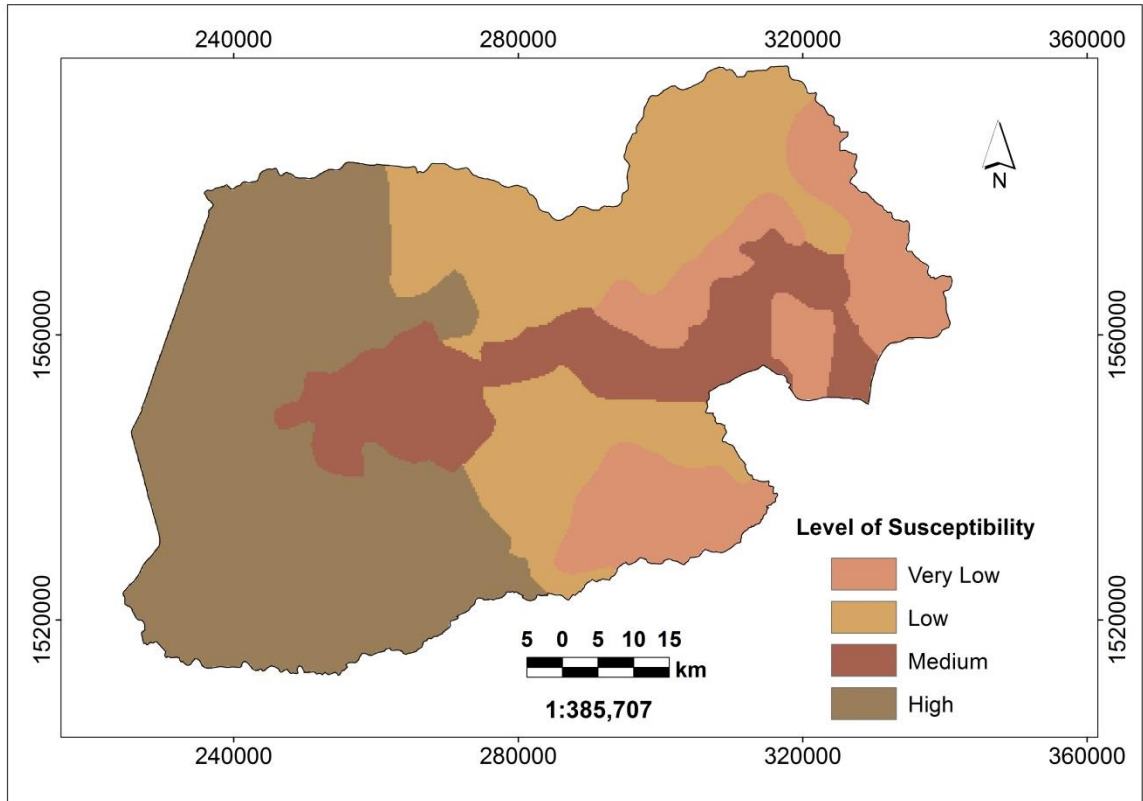


Figure 3.18 Susceptibility soil type map.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Results

Environmental factors such as, rainfall, temperature, altitude, soil type, NDVI and slope are identified as major factors for VL occurrence and transmission in the study area. Hence, 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 is inversely related with altitude, rainfall, slope, and mean NDVI.

4.1.1 Visceral Leishmaniasis Cases vs Temperature

The computed mean monthly temperature and VL cases recorded showed a positive relationship from September to December (Fig. 4.1). Moreover, from the graphs, one can observe that the peak transmission of VL with 1478 cases in December, after the end of lower temperature season in the study area. 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 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.

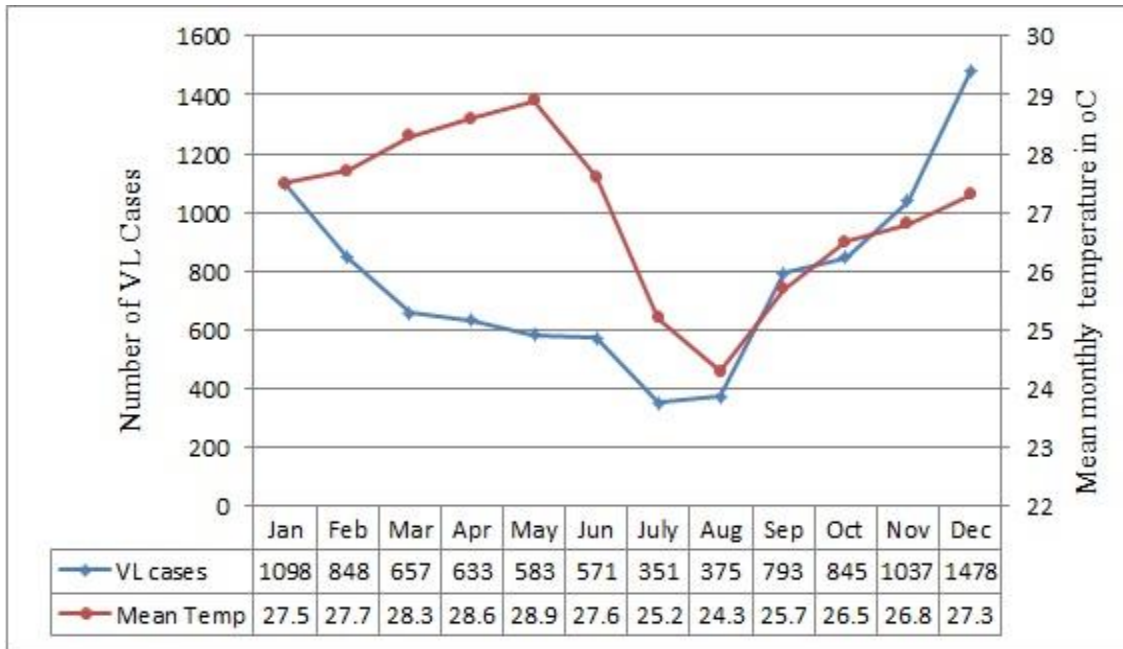


Figure 4.1 Number of Visceral leishmaniasis cases (1998–2012) vs mean monthly temperature (1993–2012).

4.1.2 Visceral Leishmaniasis Cases vs Rainfall

The mean monthly rainfall received was higher in July and August with 193.8 mm and 227.8 mm, respectively (Fig. 4.2). 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 1037, 1478 and 1098, persons respectively when the rainfall received was minimum. 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.

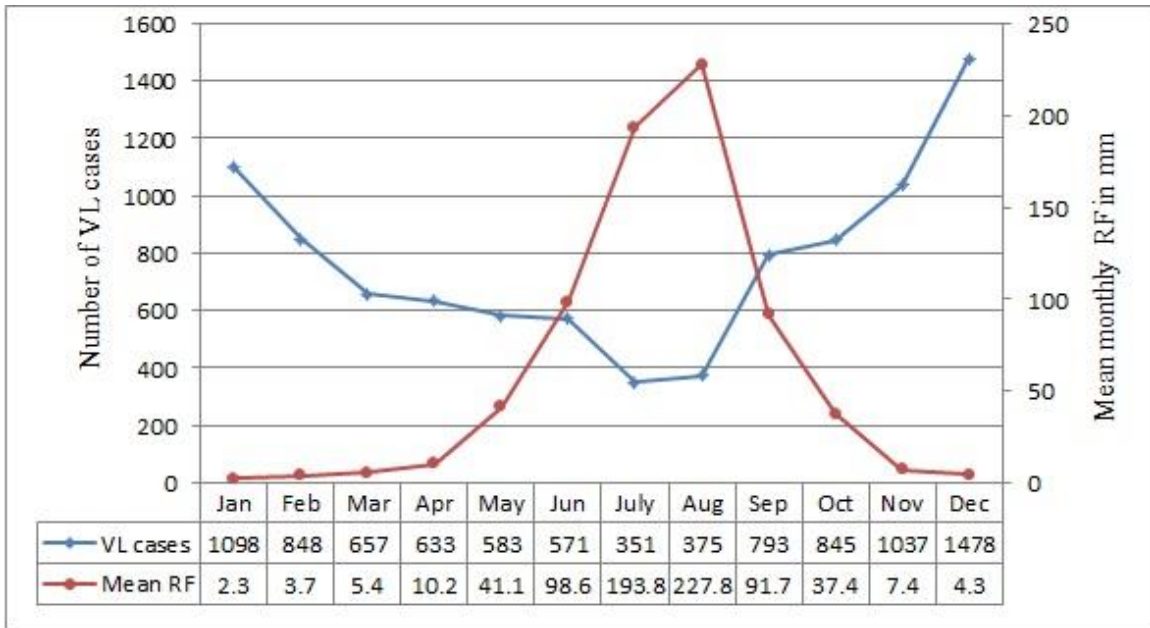


Figure 4.2 Number of Visceral leishmaniasis cases (1998–2012) vs mean monthly rainfall (1993–2012).

4.1.3 Visceral Leishmaniasis Cases vs NDVI

Figure 4.3 showed the lowest number of 351 and 375 VL cases recorded during the high rainy months of July and August with 0.76 and 0.84 NDVI values, respectively, this is the season the vegetation becomes green and the temperature becomes low. Furthermore, opposite temporal patterns of VL cases and mean monthly NDVI values were observed from September to December with the highest VL cases of 1478 recorded (December). It is believed due to, the high amount of rainfall start to reduce and the temperature increase. On the other hand, from January to May, VL cases decreased with mean monthly NDVI, as a result of the high temperature recorded during these months, which make it difficult the survival of the sandfly.

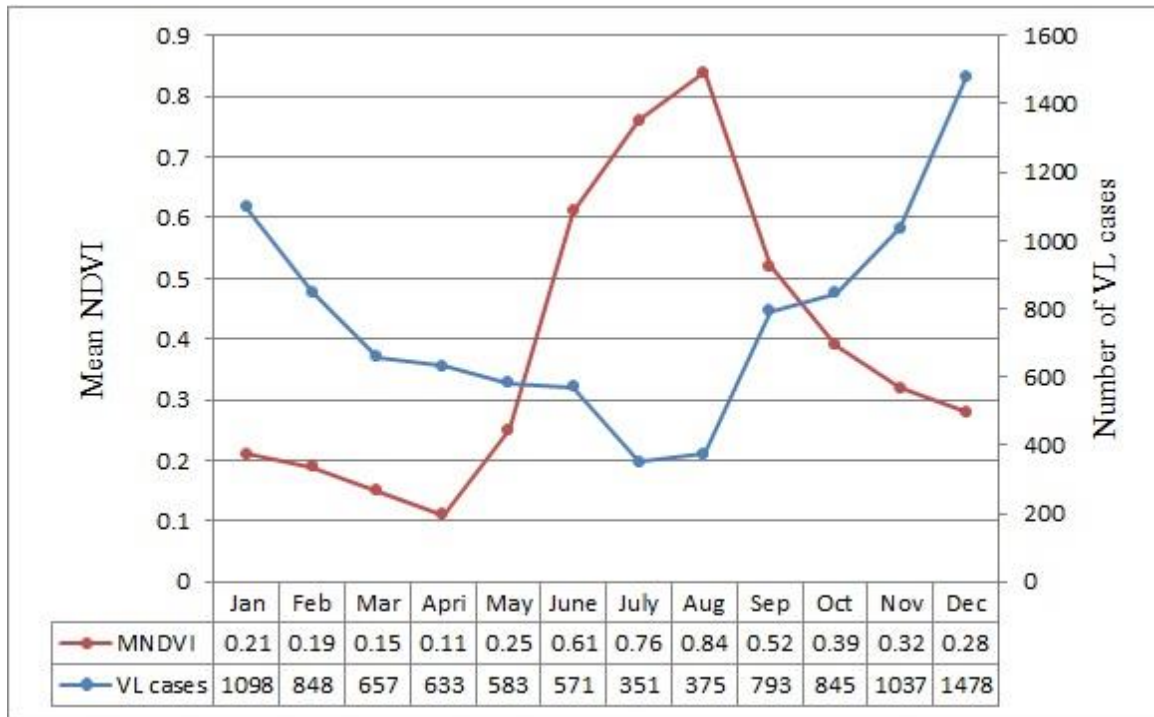


Figure 4.3 Number of Visceral leishmaniasis cases (1998–2012) vs Mean monthly NDVI (2003–2012).

4.1.4 Identifying Visceral Leishmaniasis Risk Areas

The multivariate logistic regression model result revealed that temperature, altitude, soil, slope, rainfall and NDVI datasets were shared 29%, 22%, 15%, 13%, 12% and 9% weight of influence for the existence of VL, respectively (Table 4.1). The result showed that temperature, altitude and soil were the dominant factors for the existence of VL in the study area. Finally VL risk map was produced (Fig. 4.4).

Table 4.1 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	–

The produced VL risk-map was validated by super imposing the VL presence/absence GPS points over the risk-map (Fig. 4.4.). 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, respectively. When we 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.

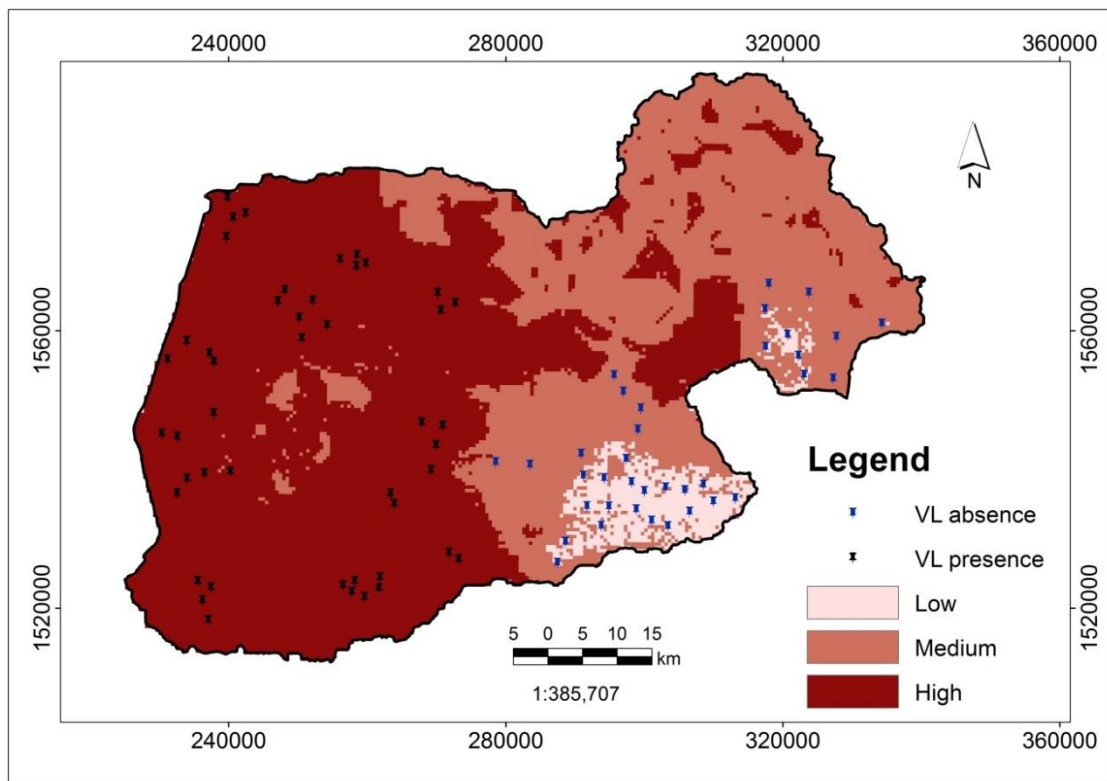


Figure 4.4 Visceral leishmaniasis risk-map with Visceral leishmaniasis absence/presence points.

The risk-map illustrates that 3453.69 km², 2210.38 km² and 269.59 km² representing 58.21%, 37.25%, and 4.54%, of the total area were high, medium and low VL risk areas, respectively (Fig 4.4). 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 4.2 and 4.3.

Table 4.2 Visceral leishmaniasis risk level and population at risk of the disease.

Risk Level	Area in (km ²)	Area in (%)	Number of Population at risk	Population risk in (%)
High	3453.69	58.21	92831.00	68.98
Medium	2210.38	37.25	34864.00	25.91
Low	269.59	4.54	6874.00	5.11
Total	5933.66	100	134569	100

The overlaid Kebele boundary of the study area over the VL risk-map illustrates the whole part of Ayedola, Bereket, Central, Erop, Helet Coka, Ruwassa, Shegelele, Rawoyan, Terkan Kebeles and Humera town fell in the high; and May Kadra, Adebay, Baeker and Hagere Selam Kebeles were widely under high; and also majority areas of Adihirdi, Habesha Adigoshu, Kunama Adigoshu, May Woyeni and Wohedet Kebeles were in medium risk categories; and majority areas of Aditsetser and Sola Kebeles fell under low VL risk (Fig 4.5 and Table 4.3).

4.1.5 Estimation of Population at Risk of Visceral Leishmaniasis

The estimated number of people at high, medium and low risk were 92,831 (68.98%), 34,864 (25.91%) and 6,874 (5.11%) respectively, (Table 4.2 and 4.3). This revealed that more than two third population of the study area were under high risk of VL. Accordingly, population at high risk were found mainly in Bereket, Rawoyan, Baeker, Adebay, May Kadra Kebeles and Humera town ranging from 5,191 to 27,424 people per Kebele. In addition Adihirdi, Terkan, Ruwassa and Hagere Selam Kebeles were located with medium number of population at VL risk ranging from 2471 to 5191 people per Kebele. The remaining Kebeles were with lesser population at VL risk (Fig. 4.6).

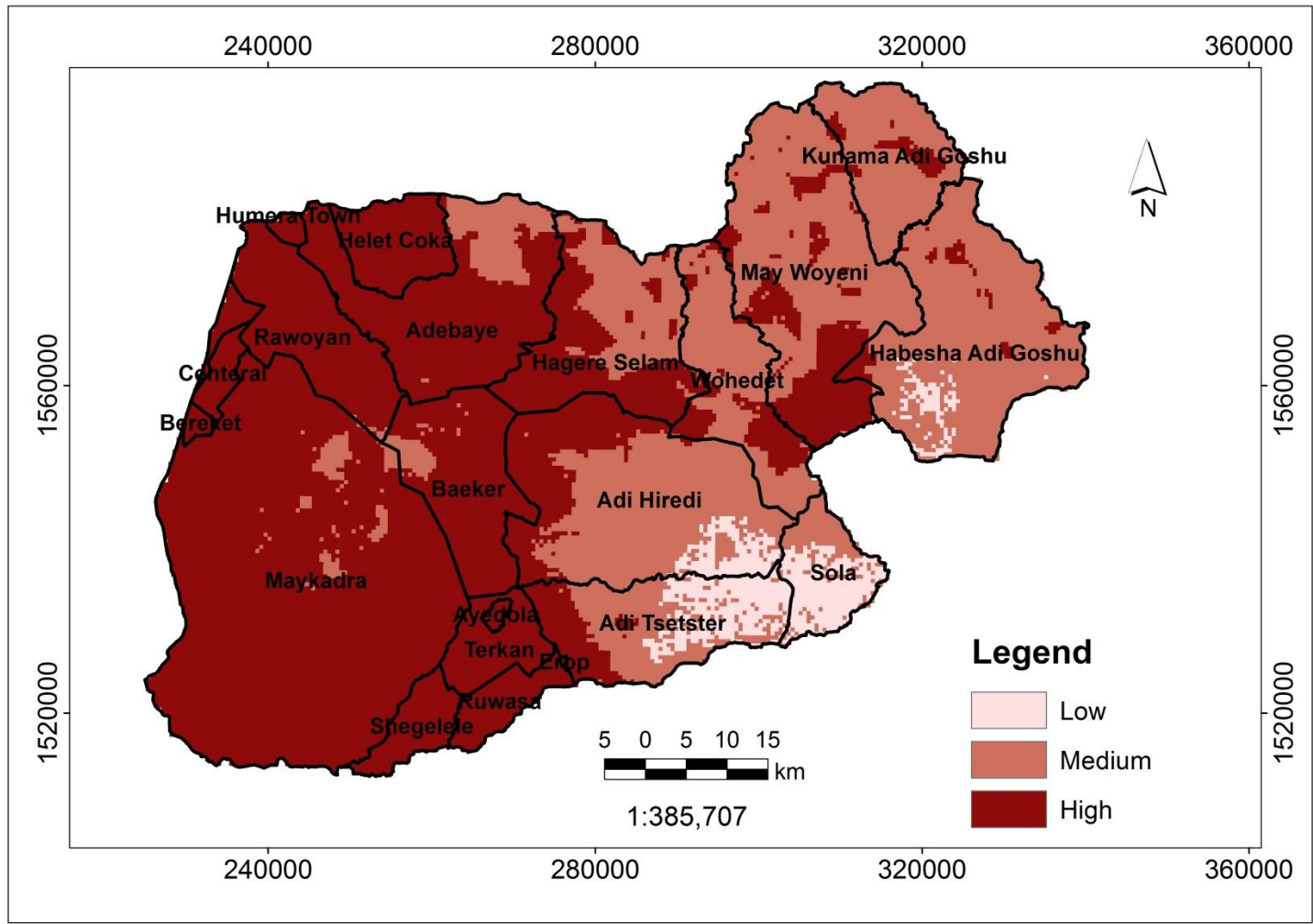


Figure 4.5 Visceral leishmaniasis risk-map in Kebele level.

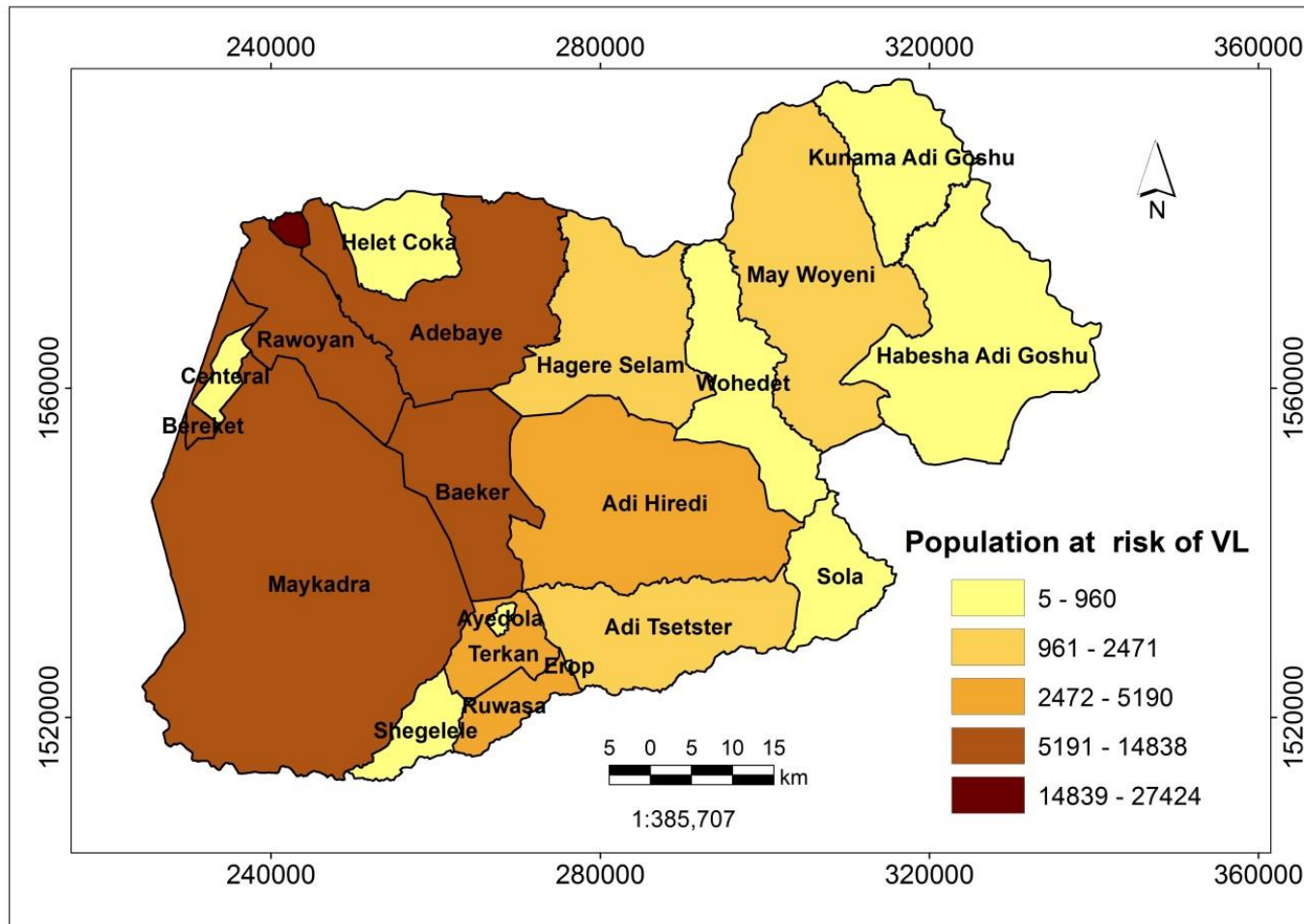


Figure 4.6 Risk-map of estimated population with visceral leishmaniasis.

Table 4.3 Population distribution in Kebele and risk of Visceral leishmaniasis.

Kebele Name	Total Population	Total area in (km ²)	Population density (per km ²)	Risk level in (km ²)			Population at risk		
				High	Medium	Low	High	Medium	Low
Adebay	11937	444.33	26.87	356.39	87.96	–	9574.48	2363.06	–
Adi Herdi	13417	609.28	22.02	180.13	380.11	49.05	3966.66	8370.43	1080.13
Adi tsetser	6388	320.3	19.94	70.85	144.71	104.74	1413.02	2886.07	2088.91
Ayedola	532	8.27	64.33	8.27	–	–	532.00	–	–
Baeker	8272	273.1	30.29	252.45	20.66	–	7646.53	625.78	–
Bereket	5191	38.5	134.83	38.5	–	–	5191.00	–	–
Central	417	36.89	11.30	36.89	–	–	417.00	–	–
Erop	116	1.01	114.85	1.01	–	–	116.00	–	–
Habesha Adi Goshu	9848	543.49	18.12	26.79	488.64	28.07	485.43	8854.12	508.63
Hagere Selam	4368	384.19	11.37	217.32	166.87	–	2470.79	1897.21	–
Helet Coka	775	132.64	5.84	132.63	0.1	–	774.94	0.58	–
Humera Town	27424	13.51	2029.90	13.51	–	–	27424.00	–	–
Kunama Adi Goshu	635	224.7	2.83	23.91	200.86	–	67.57	567.63	–
May Woyeni	5790	601.13	9.63	180.93	420.2	–	1742.69	4047.31	–
May Kadra	15329	1376.67	11.13	1332.6	44.07	–	14838.29	490.71	–
Rawoyan	7647	250.52	30.52	248.43	2.09	–	7583.20	63.80	–
Ruwassa	3162	77.25	40.93	77.25	–	–	3162.00	–	–
Shegelele	677	80.74	8.38	80.74	–	–	677.00	–	–
Sola	5167	141.81	36.44	0.13	53.95	87.73	4.74	1965.73	3196.54
Terkan	3785	104.66	36.16	104.66	–	–	3785.00	–	–
Wohdet	3692	270.46	13.65	70.3	200.16	–	959.65	2732.35	–
Total	134569	5933.66	23.00	3453.69	2210.38	269.59	92831.00	34864.00	6874.00

4.2 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 Kebeles and estimation of population at risk are important for designing prevention programs and their effective and efficient implementation.

In this study annual average temperature was found the highest contributor for the occurrence of VL which accounts 29%. The result confirmed that as temperature increase the incidence of VL also increases. Also a mean annual temperature of 26-31°C is the best 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 sharing 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 highly supported by Elnaiem *et al.* (2003) in their study 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 in a Kebele. This is in conformity with the view of Elnaiem *et al.* (2003), 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 a sandfly microhabitat suitable for breeding and resting. As pointed out by Gebere-Michael *et al.* (2004), this soil type is found 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 766 mm 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 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 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 according to the level of vegetation cover. As suggested by Elnaiem *et.al* (2003), most grasses in the area are highly seasonal, flourishing after the start of the rains. Similarly, a study conducted by Gebere-Michael *et al.* (2004), NDVI value of 0.05–0.28 was found as 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.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

Based on the finding the following conclusions were drawn:

- Temperature, altitude, and soil type were found to be best determinants for the presence of VL in the study area. It is also recognized that susceptibility to VL is directly related with temperature and presence of vertisol soil type; whereas, it is inversely related with altitude, rainfall, slope and NDVI.
- It is evident that a larger number of inhabitants are living in Kebeles such as, Bereket, Rawoyan, Baeker, Adebay, May Kadra Kebeles and Humera town where highly susceptible to VL. Accordingly, the estimated number of people at high VL risk was 92,831 (68.98%) of the total population of the District.
- The finding enables decision makers: public health officers and different stake holders in the field of public health to prioritize at high risk Kebeles and make focused decision: to ensure the wise, use of their resource in mitigation of VL in the study area up to Kebele level.
- The method can be adapted to other vector-borne diseases in Ethiopia and could improve control planning through integrated approach. This would facilitate implementation of evidence-based integrated disease control activities.

5.2 Recommendations

Since majority area and population of the District are found under high VL risk, this research would like to recommend the following points:

- The establishment strong early warning system and targeted intervention within the District by the concerned authorities' body according to the risk gradient.
- More than half of the area and two third of the District population is identified as under high VL risk; thus there is a need for special attention by all concerned groups.
- Attention is needed for proper patient data management: the seasonal incidence of epidemics and related aspects of VL.
- The District should give emphasis for the development spatiotemporal VL variation for the effective identification of ecology of sandflies and mapping for planning mitigation strategies.
- Further research is needed to incorporate soil moisture, relative humidity, high spatial resolution image and the socio-economic factors of VL to more clearly define deriving factors within each of the risk factors.

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Appendixes

Appendix I

Mean annual temperature and rainfall data of the study area from 1983–2012.

S.No	Easting	Northing	Mean annual temperature in °C	Mean annual rainfall in mm
1	213299	1510449	31	705
2	224125	1510333	31	706
3	234949	1510222	29	710
4	245773	1510115	27	716
5	256597	1510012	27	720
6	267419	1509914	27	726
7	278241	1509820	26	740
8	213421	1521518	31	671
9	224241	1521402	28	680
10	235061	1521289	27	704
11	245881	1521181	27	711
12	256700	1521078	27	723
13	267517	1520979	27	733
14	278335	1520885	26	735
15	289152	1520795	25	773
16	299968	1520710	25	781
17	213543	1532587	31	669
18	224359	1532470	31	671
19	235174	1532357	27	688
20	245989	1532248	27	700
21	256803	1532144	27	710
22	267617	1532045	26	722
23	278429	1531950	26	738
24	289241	1531859	25	779
25	300053	1531774	24	801
26	310864	1531692	22	838
27	321675	1531615	20	841
28	224477	1543538	30	631
29	235288	1543424	27	669
30	246098	1543315	27	685
31	256908	1543210	26	711
32	267716	1543110	26	713
33	278524	1543015	25	737
34	289332	1542924	24	794
35	300139	1542837	24	793

S.No	Easting	Northing	Mean annual temperature in °C	Mean annual rainfall in mm
36	310945	1542755	25	772
37	321751	1542678	20	852
38	332557	1542605	19	852
39	224597	1554606	31	631
40	235403	1554492	27	644
41	246208	1554382	27	659
42	257013	1554276	27	669
43	267817	1554176	27	682
44	278620	1554080	26	709
45	289423	1553988	25	734
46	300225	1553901	26	739
47	311027	1553819	26	751
48	321828	1553741	23	799
49	332629	1553667	21	879
50	343429	1553599	22	890
51	224717	1565675	32	556
52	235518	1565559	30	588
53	246319	1565449	27	635
54	257119	1565343	27	649
55	267918	1565241	27	663
56	278717	1565144	27	678
57	289515	1565052	26	694
58	300312	1564965	27	708
59	311109	1564882	26	733
60	321906	1564803	24	771
61	332702	1564730	26	756
62	343497	1564661	22	762
63	224838	1576743	31	541
64	235634	1576627	30	556
65	246430	1576516	27	613
66	257225	1576409	27	629
67	268020	1576307	27	646
68	278814	1576210	27	658
69	289607	1576117	27	662
70	300400	1576029	27	686
71	311192	1575945	26	725
72	321984	1575866	25	735
73	332775	1575792	27	749
74	343566	1575723	23	771
75	224959	1587812	31	541

S.No	Easting	Northing	Mean annual temperature in °C	Mean annual rainfall in mm
76	235751	1587695	31	554
77	246542	1587583	29	609
78	257333	1587475	30	623
79	268123	1587373	27	640
80	278912	1587275	28	639
81	289700	1587181	26	642
82	300488	1587093	26	670
83	311276	1587009	26	690
84	322063	1586929	26	701
85	332849	1586855	27	712
86	343635	1586785	28	723
87	289794	1598246	27	632
88	300577	1598157	27	641
89	311360	1598072	27	680
90	322142	1597992	26	690
91	332924	1597917	27	698

Appendix II

Comparison of visceral leishmaniasis absence/ presence cases with visceral leishmaniasis risk map result.

S.No	Easting	Northing	District	Kebele	VL absence/presence	VL risk map Result
1	256127	1570223	K/Humera	Adebay	1	High
2	270636	1562852	K/Humera	Adebay	1	High
3	270164	1565405	K/Humera	Adebay	1	High
4	258442	1569218	K/Humera	Adebay	1	High
5	259802	1569636	K/Humera	Adebay	1	High
6	258539	1570858	K/Humera	Adebay	1	High
7	269914	1543440	K/Humera	Adi Hiredi	1	High
8	298143	1538030	K/Humera	Adi Hiredi	0	Low
9	294220	1538623	K/Humera	Adi Hiredi	0	Low
10	291190	1539002	K/Humera	Adi Hiredi	0	Low
11	297387	1541407	K/Humera	Adi Hiredi	0	Low
12	296982	1551088	K/Humera	Adi Hiredi	0	Medium
13	299495	1548681	K/Humera	Adi Hiredi	0	Medium
14	283498	1540568	K/Humera	Adi Hiredi	0	Medium
15	299081	1545641	K/Humera	Adi Hiredi	0	Medium
16	290868	1542145	K/Humera	Adi Hiredi	0	Medium
17	278538	1540939	K/Humera	Adi Hiredi	0	Medium
18	287454	1526426	K/Humera	Adi Tsetser	0	Low
19	288634	1529445	K/Humera	Adi Tsetser	0	Low
20	294881	1534537	K/Humera	Adi Tsetser	0	Low
21	291736	1534573	K/Humera	Adi Tsetser	0	Low
22	301074	1532506	K/Humera	Adi Tsetser	0	Low
23	298845	1534119	K/Humera	Adi Tsetser	0	Low
24	300026	1536781	K/Humera	Adi Tsetser	0	Low
25	303413	1531711	K/Humera	Adi Tsetser	0	Low
26	293768	1531743	K/Humera	Adi Tsetser	0	Low
27	269200	1539848	K/Humera	Baeker	1	High
28	270913	1546230	K/Humera	Baeker	1	High
29	267860	1546680	K/Humera	Baeker	1	High
30	231182	1555796	K/Humera	Bereket	1	High
31	233934	1558444	K/Humera	Centeral	1	High
32	327267	1553002	K/Humera	Habesha Adi Goshu	0	Medium
33	323076	1553545	K/Humera	Habesha Adi Goshu	0	Low
34	322255	1556283	K/Humera	Habesha Adi Goshu	0	Low
35	320676	1559332	K/Humera	Habesha Adi Goshu	0	Low

S.No	Easting	Northing	District	Kebele	VL absence/presence	VL risk map Result
36	317430	1563002	K/Humera	Habesha Adi Goshu	0	Low
37	327718	1559034	K/Humera	Habesha Adi Goshu	0	Medium
38	317520	1557574	K/Humera	Habesha Adi Goshu	0	Low
39	334289	1560922	K/Humera	Habesha Adi Goshu	0	Medium
40	323738	1565394	K/Humera	Habesha Adi Goshu	0	Medium
41	272711	1563931	K/Humera	Hagere Selam	1	High
42	256492	1523237	K/Humera	May Kadra	1	High
43	237438	1522883	K/Humera	May Kadra	1	High
44	236216	1521022	K/Humera	May Kadra	1	High
45	237048	1518211	K/Humera	May Kadra	1	High
46	235546	1523812	K/Humera	May Kadra	1	High
47	232591	1536436	K/Humera	May Kadra	1	High
48	263925	1534955	K/Humera	May Kadra	1	High
49	233968	1538596	K/Humera	May Kadra	1	High
50	240246	1539601	K/Humera	May Kadra	1	High
51	236496	1539391	K/Humera	May Kadra	1	High
52	232591	1544648	K/Humera	May Kadra	1	High
53	230352	1545089	K/Humera	May Kadra	1	High
54	237851	1555427	K/Humera	May Kadra	1	High
55	237831	1548043	K/Humera	May Kadra	1	High
56	237244	1556690	K/Humera	May Kadra	1	High
57	263355	1536455	K/Humera	May Kadra	1	High
58	317956	1566680	K/Humera	May Woyeni	0	Medium
59	250569	1558847	K/Humera	Rawoyan	1	High
60	239660	1573417	K/Humera	Rawoyan	1	High
61	254216	1560723	K/Humera	Rawoyan	1	High
62	250175	1561822	K/Humera	Rawoyan	1	High
63	252134	1564278	K/Humera	Rawoyan	1	High
64	239823	1579142	K/Humera	Rawoyan	1	High
65	247097	1564166	K/Humera	Rawoyan	1	High
66	248128	1565779	K/Humera	Rawoyan	1	High
67	240653	1576218	K/Humera	Rawoyan	1	High
68	242423	1576844	K/Humera	Rawoyan	1	High
69	257776	1522238	K/Humera	Shegelel	1	High
70	259604	1521507	K/Humera	Shegelel	1	High
71	261700	1522800	K/Humera	Shegelel	1	High
72	258204	1523808	K/Humera	Shegelel	1	High
73	313155	1535738	K/Humera	Sola	0	Low
74	308536	1537668	K/Humera	Sola	0	Low

S.No	Easting	Northing	District	Kebele	VL absence/presence	VL risk map Result
75	309977	1535261	K/Humera	Sola	0	Low
76	306553	1533806	K/Humera	Sola	0	Low
77	305859	1536913	K/Humera	Sola	0	Low
78	303098	1537296	K/Humera	Sola	0	Low
79	261843	1524370	K/Humera	Terkan	1	High
80	273230	1526981	K/Humera	Terkan	1	High
81	271821	1527918	K/Humera	Terkan	1	High
82	295636	1553486	K/Humera	Wohedet	0	Medium

Where,

1 = represents the presence of Visceral leishmaniasis

0 = represents the absence of Visceral leishmaniasis

Appendix III

GPS Point Data collection Form for Visceral Leishmaniasis

Part I Basic Data

1. Regional State _____
2. Zone _____
3. District _____
4. Kebele _____
5. Gott _____

Part II Case data (point Data)

1. Name _____
2. Sex 1. Male 2. Female
3. Age in years
4. Occupation 1. Farmer
 2. Trader
 3. Civil servant
 4. Laborer
 5. Driver
 6. Others

If other, specify _____

Part III VL assessment

3.1 Treatment History

1. Treated 2. Not treated 3. Unknown

3.1.1. If treated where

1. Traditional healer 2. Modern medical care

3.1.2. If untreated; did he/she know that VL is treatable?

1. Yes, knows it is treatable 2. No, did not know that it is treatable 3. Unknown

3.1.3. If traditionally treated what type of treatment did she/he received

3.2 What is the local name of VL _____

Filled by

Name _____ Signature _____ Date ____/____/____

Checked by

Name _____ signature _____ date: ____/____/____

Appendix IV

Odds Ratio of the Multivariate logistic regression on the basis of Visceral Leishmaniasis presence/absence data and environmental factors.

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-----
StataCorp. (R)
Statistics/Data Analysis 12.0
Special Edition

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Notes:
  1. (/v# option or -set maxvar-) 5000 maximum variables

. insheet using "D:\Leishmiasis\aaaaa\1_4_2014\rf_tem_elv_rhh_slop_ndvii_soill_3cat2soil_82p
> oints_all3.csv"
(34 vars, 82 obs)

. logistic leish_code soil_categ rf_categ temp_categ elevn_categ slop_categ ndvi_categ

. logistic leish_code soil_categ

Logistic regression
Log likelihood = -41.061437
Number of obs = 82
LR chi2(1) = 31.36
Prob > chi2 = 0.0000
Pseudo R2 = 0.2763
-----
leish_code | Odds Ratio   Std. Err.      z    P>|z|     [95% Conf. Interval]
-----+-----
Soil       | 6.576996    2.699424     4.59  0.043    2.942154   14.70245
Rainfall   | 5.20062     1.79763     4.77  0.024    2.641384   10.2395
Temperature| 13.10588    6.874494     4.91  0.030    4.687929   36.63964
Elevation  | 10.05594    4.729512     4.91  0.027    4.000231    25.279
Slope      | 5.892703    2.2584      4.63  0.015    2.78028    12.48937
NDVI       | 4.006414    1.352718     4.11  0.041    2.067082    7.765224
_cons      | .0558414    .0407602    -3.95  0.000    .0133549    .2334924
-----

```

D E C L A R A T I O N

I hereby declare that the dissertation entitled “Visceral Leishmaniasis (Kala-azar) Risk Mapping Using Geo-spatial Tools A Case Study in Kafta Humera Woreda, Northwestern Ethiopia” has been carried out by me under the supervision of Dr. K. V. Suryabhagavan, School of Earth Sciences, Addis Ababa University, Addis Ababa and Dr. Endalamaw Gadissa, Armauer Hansen Research Institute, Addis Ababa during the year 2013-2014 as a part of Master of Science programme in Remote Sensing and Geographic Information Systems. I further declare that this work has not been submitted to any other University or Institution for the award of any degree or diploma.

Place: Addis Ababa
Date: May 30, 2014

Signature_____
(Negussie Solomon)

C E R T I F I C A T E

This is to certify that the dissertation entitled “Visceral Leishmaniasis (Kala-azar) Risk Mapping using Geo-spatial tools a case study in Kafta Humera Woreda, Northwestern Ethiopia” is a bonafied work carried out by Negussie Solomon under our guidance and supervision. This is his original work done by Negussie Solomon for the partial fulfillment of the award of the Degree of Master of Science in Remote Sensing and Geographic Information Systems from Addis Ababa University. Addis Ababa.

Dr. K. V. Suryabhagavan
Assistant Professor
School of Earth Sciences
Addis Ababa University
Addis Ababa.

And

Dr. Endalamaw Gadisa
Postdoctoral Scientist
Armauer Hansen Research Institute
Addis Ababa.