ADDIS ABABA UNIVERSITY

COLLEGE OF SOCIAL SCIENCES AND HUMANITIES

DEPARTMENT OF GEOGRAPHY AND ENVIRONMENTAL STUDIES

Geographic Information System and Remote Sensing Based Malaria Risk Mapping Using Environmental Factors: A Case of Arba Minch Zuria Woreda, Southern Nations Nationalities and Peoples' Regional State

By: Mestewat Simeon

ADDIS ABABA, ETHIOPIA

June, 2014

Geographic Information System and Remote Sensing Based Malaria Risk Mapping Using Environmental Factors: A Case of Arba Minch Zuria Woreda, Southern Nations Nationalities and Peoples' Regional State

By: Mestewat Simeon

Advisor: Shimeles Damene (PhD)

A Project Submitted to

The Department of Geography and Environmental Studies

Presented in Partial Fulfillment of the Requirements for the Degree of Master of Art in Geography and Environmental Studies (GIS, Remote Sensing and Digital Cartography)

ADDIS ABABA, ETHIOPIA

June, 2014

ADDIS ABABA UNIVERSITY

COLLEGE OF SOCIAL SCIENCES AND HUMANITIES

This is to certify that a project prepared by Mestewat Simeon entitled: *GIS and Remote sensing based malaria risk mapping using environmental factors in Arba Minch Zuria Woreda, SNNPR,* is submitted in partial fulfillment of the requirements for the degree of Degree of Master of Arts in Geography and Environmental Studies with specialization GIS, Remote Sensing and Digital Cartography compiles with the regulation of the university and meets the accepted standards with respect to originality and quality.

Signed by Examining committee:

External examiner________________________Signature_____________Date________

Internal examiner_________________________Signature______________Date_______

Advisor________________________________Signature_____________Date_________

____

Chair of the department or Graduate program coordinator

ABSTRACT

Malaria is one of the world's serious and complex public health problems and it remains one of the greatest killers of human beings in developing countries. Due to its tropical location and other environmental factors, part of Ethiopia is favorable for mosquito breeding and malaria transmission. The purpose of this project was generating Geographic Information System and Remote Sensing based malaria risk map of Arba Minch Zuria Woreda of the Gamo Gofa Zone, Southern Nations Nationalities and Peoples' Regional State, by using environmental factors. To generate the risk map, seven parameters were selected depending on previous works and based on discussion made with malaria experts. The environmental factors considered for the analysis are temperature, rainfall, elevation, slope, soil, land use land cover and proximity to water bodies. Weight was assigned for these parameters by pairwise comparison method and weighted overlay was used in Arc GIS spatial analyst tools to produce the final malaria risk map of the study area. The final risk map indicates that from the total of the study area 58 % is mapped as high, 35.7 % as moderate and 6.3 % as low malaria risk level. Malaria risk level with kebele wise comparison shows that eight kebeles are fully belong to high malaria risk and other eight kebeles partially mapped in high risk level. Only six kebeles mapped under low malaria risk areas. Other six kebeles fully mapped under moderate malaria risk level and the rest kebeles mapped partially under moderate and high risk level. In general, based on environmental factors the majority of study area fell in high risk level, which is followed by moderate and low malaria risk level, respectively. To make malaria control and eradication program of the Woreda time and cost efficient, it is important to consider the risk level of kebeles.

Key Words: GIS, Malaria, Pairwise comparison, Remote Sensing, Risk map, weighted overlay

Acknowledgements

Above all, I would like to thank 'Almighty God' who made it possible for me, to start and finish my study successfully.
I would like to extend my heartfelt thanks and appreciation to my advisor, Dr. Shimeles Damene for his valuable, unreserved and constructive comments and guidance at each phase of this study.

I would also like to thank those people who are working at National Meteorological Services Agency, Ethiopia Mapping Agency, Arba Minch Zuria Woreda health office and Sikela health center for their cooperation and provision of the required data.

My special thanks go to my father Simeon Tsalke and my mother Worknesh Leye for their encouragement and moral support throughout my study. I am also thankful to my brothers, sisters and friends for their support and follow up the progress of my work.

Last but not least thanks to my classmates for their cooperation and experience sharing during my study.

Table of Contents

List of Figures ix

List of Tables... xi

List of Acronyms xii

Chapter One:Introduction..1

1.1. Back Ground of the Study...1

1. 2. Statement of the Problem...3

1.3. Objective of the study...5

1. 3.1. General Objective...5

1.3.2. Specific Objective..5

1.4. Research Questions...5

1.5. Significance of the Study...5

1.6. Scope of the Study...6

1.7. Limitations of the Study...6

1.8. Organization of the Project..6

Chapter Two:Review of Related Literature...7

2.1. The Concept of Malaria..7

2.2. Global Distribution of Malaria...8

2.3. Distribution of Malaria in Ethiopia..10

2.4. Factors Affecting Malaria Incidence 12
2.4.1. Climatic Factors....................12
2.4.1.1. Temperature 13
2.4.1.2. Rainfall 14
2.4.2. Topographic Factors 15
2.4.2.1. Altitude 15
2.4.2.2. Slope 16
2.4.3. Factors Related to Distance from Water Bodies 16
2.4.3.1. Proximity to Rivers 17
2.4.3.2. Proximity to Lakes 17
2.4.3.3. Proximity to Swamps 17
2.4.4. Land Use Land Cover related Factor....................18
2.4.5. Soil....................19
2.5. Geographic Information System and Remote Sensing....................19
2.5.1. Geographic Information System....................19
2.5.2. Remote Sensing 20
2.6. Application of GIS and RS in Malaria Risk Mapping....................20
Chapter Three:Materials and Methods....................23
3.1. Study Area....................23
3.1.1. Location....................23
3.1.2. Population....................24
3.1.3. Climate 25

3.1.4. Topography of the Study Area 27

3.1.5. Soil 28

3.1.6. Land Use Land Cover of the Study Area 31

3.1.7. Malaria Trend of the Study Area 32

3.2. Types of Data used for Analysis 33

3.3. Software and Materials used in the Project..33

3.4. Methodology 34

3.4.1. Methods used for Analysis of Factors 36

3.4.1.1. Climatic Factors 36

3.4.1.2. Topographic Factors...38

3.4.1.3. Proximity to Water Bodies related Factors...38

3.4.1.4. Land Use Land Cover..40

3.4.1.5. Soil...40

3.4.2. Weight Derivation..41

3.4.2.1. Weight Computation for Proximity to Water Bodies related Factors.......41

3.4.2.2. Weight Derivation for all Environmental Factors under Consideration ...43

Chapter Four:Results and Discussions..46

4.1. The Relationship of Malaria Risk with Climatic Factors 46

4.1.1. Relation of Temperature with Malaria Infestation 46

4.1.2. Rainfall and Malaria Risk Level..47

4.2. Relationship Between Topographic Factors and Malaria Incidence Level 48

4.2.1. Elevation and Malaria Risk Level 48

4.2.2. Relation of Slope and Malaria Incidence 49

4.3. Proximity to Water Bodies and Malaria Risk Level..50
4.3.1. Proximity to Rivers..51
4.3.2. Proximity to Lakes...52
4.3.3. Proximity to Swamps..53
4.4. Land Use Land Cover..54
4.5. Soil Type and Malaria Risk Level...57
4.6. Malaria Risk Map...58
4.7. Comparing Malaria Risk Level with Kebeles...61
Chapter Five:Conclusion and Recommendation...63
5.1. Conclusion..63
5.2. Recommendations...65
References
Appendices

List of Figures

Figure1. Global distribution of malaria transmission risk……………………………..….9

Figure 2: Location map of the study area ……………………….…………………....24

Figure 3: Population density map of the study area………………………..……..….25

Figure 4: Mean monthly: maximum, minimum and mean temperature at Arba Minch station (1999 to 2013)…………………………………………………….…......26

Figure 5: Mean monthly rainfall at Arba Minch station (1999 to 2013)…………..…..…27

Figure 6: Contour map of the study area……..……………………………...……..……28

Figure 7: Soil map of the study area……………………………………..……………31

Figure 8: Malaria cases of Arba Minch zuria woreda from 2004_2013………………....32

Figure 9: Methodological frame work……………………………………………..35

Figure 10: Location map of metrological stations used for the analysis………………...36

Figure 11: AHP weight derivation for proximity to rivers, lakes and swamp………..….42

Figure 12: Module result for weight derivation of proximity to rivers, lakes and swamps……………………………………..……………………...42

Figure 13: AHP weight derivation for elevation, temperature, rainfall, slope, soil, land use land cover and proximity to water bodies ……………………….………...44

Figure 14: Module result for weight derivation of all environmental factors …………...45

Figure 15: Reclassified temperature based malaria risk map …………..……………….47

Figure 16: Reclassified rainfall based malaria risk map ………………..…….………48

Figure 17: Reclassified elevation based malaria risk map …….…………………..…..…49

Figure 18: Reclassified slope based malaria risk map ………………………………..50

Figure 19: Proximity to water bodies based malaria risk level ………………………….51

Figure 20: Reclassified Rivers and Canals based risk map ……………………...……..52

Figure 21: Reclassified proximity to lakes based malaria risk map ………………….....53

Figure 22: Reclassified proximity to Swamps based malaria risk map …………………54

Figure 23: Land use land cover map of the study area...……..55

Figure 24: Reclassified land use land cover type based malaria risk map……………….57

Figure 25: Reclassified soil type and malaria risk level……….……………………..….58

Figure 26: Final Malaria Risk Map…………………….…………………………………..59

Figure 27: Malaria risk level in kebeles………………..………………………………..….62

List of Tables

Table 1: Types of data used and their sources…………………….………………..33

Table 2: Software types and their application areas……………………………………..34

Table 3: Weights assigned for proximity to rivers, lakes and swamps…………………..43

Table 4: Weights assigned for all environmental factors ……………………...………...45

Table 5: Accuracy assessment matrix …………………………………………..…..…56

Table 6: Summary of factors risk level and their area coverage……………….…….…60

List of Acronyms

AHP	Analytic Hierarchy Processes
CSA	Central Statistical Agency
DEM	Digital Elevation Model
EMA	Ethiopia Mapping Agency
ESRI	Environmental Science Research Institute
ERDAS	Earth Resources Data Analysis System
FAO	Food and Agricultural Organization
FMoH	Federal Ministry of Health
GIS	Geographic Information System
GPS	Global Positioning System
HSDP	Health Sector Development Program
ITN	Insecticide Treated Net
Km	Kilometer
m.a.s.l.	Meter above sea level
MOA	Ministry of Agriculture
mm	Millimeter

NMSA	National Meteorological Services Agency
NIAID	National Institute of Allergy and Infectious Diseases
RH	Relative Humidity
RS	Remote Sensing
SNNPR	Southern Nations Nationalities and Peoples Region
SRTM	Shuttle Radar Topography Mission
TM	Thematic Mapper
WHO	World Health Organization

CHAPTER ONE

INTRODUCTION

1.1. Back ground of the study

The threats to human health from vector-borne diseases, especially mosquito borne diseases are like malaria, dengue, elephantiasis, etc. continue to be a global problem (Agarwal et al., 2012). Malaria is a major global health problem. Worldwide, it affects 3.5 to 5.0 billion people and has devastating effects on health and development with at least one million deaths taking place annually (Saxena et al., 2009).

According to Kaya et al. (2002), malaria remains one of the greatest killers of human beings, particularly in the developing countries. The World Health Organization (WHO,2012), estimated over one million malaria cases each year, where more than 80% of the cases are in Sub-Saharan Africa countries. According to the latest WHO estimates, there were about 219 million cases of malaria in 2010 and an estimated 660,000 deaths. Africa is the most affected continent, where about 90% of all malaria deaths occur (WHO, 2012).

Malaria is also a major public health problem in Ethiopia. It is the leading cause of outpatient consultations, admissions and death (Tiruneh, 2010). In most parts of Ethiopia, malaria is seasonal with periodic transmission that lends to the outbreak of an epidemic. The transmission patterns and intensity vary greatly due to the large diversity in altitude, rainfall and population migration. In Ethiopia, areas below 2,000 m.a.s.l. elevation are considered to be malarious or potentially malarious. These areas are home to approximately 68% of the Ethiopian population (MOH, 2008).

Malaria is a Vector borne disease. The vector *Anopheles* mosquitoes are particularly influenced by environmental conditions. Indeed, arthropod vectors in general, and insect vectors in particular are very sensitive to their environments, which in turn determines their presence and development. As a consequence, climatic as well as landscape and land cover factors greatly influence the spatial distribution of vectors and the diseases they transmit (Van der Hoek et al., 2003).

About 70 – 90% malaria risk is associated with environmental factors, which in turn influence the abundance and survival of the vectors. This has motivated the WHO to pursue the development of new techniques and models in which the role of environment is fundamental (Saxena et al., 2009).

In recent years, the rapid development of spatial technologies has made available new tools and capabilities for management of spatial data. In particular, the evolution of geographic information systems (GIS), the global positioning system (GPS), and remote sensing (RS) technologies has enabled the collection and analysis of field data in ways that were not possible before the advent of the computer(Milla et al., 2005).

GIS applications enable the storage, management, and analysis of large quantities of spatially distributed data. These data are associated with their respective geographic features. Its application is recognized to a wide range of disciplines (Milla et al., 2005).

GIS has many applications for the study of vector-borne diseases, as many of the fundamental factors influencing the distribution of disease vectors are spatially heterogeneous. Mosquitoes require stagnant water for breeding and the short flight range of many species limits the adult populations to areas surrounding their breeding sites. Recently, there has been interest in applying GIS to study the continental and global malaria distribution and spatial distribution of malaria transmitting mosquitoes (Omumbo et al., 1998).

Analyzing satellite based remotely sensed environmental data in GIS is one approach that can be utilized to identify geographic areas of suitable mosquito habitat. Exploratory analysis of these habitats can also be employed within GIS to design an effective strategy for determining malaria transmission risk to surrounding human populations (Wilder, 2007).

Therefore, the goal of this study is to identify environmental factors facilitating mosquito breeding conditions and generate malaria risk map of the study area using GIS and remote sensing. The output malaria risk map of the study area could be used for efficient malaria control by giving priority based on the risk level of the areas.

1. 2. Statement of the problem

Due to its tropical location and availability of many rivers and lakes, Ethiopia is favorable for breeding of plasmodium (Womie, 2008). As a result, malaria prevention and control program in Ethiopia is guided by a five-year National Malaria Prevention and Control Strategic Plan developed in line with the goals of the Health Sector Development Program (HSDP). The goal of malaria prevention and control in Ethiopia is to reduce malaria morbidity and malaria related mortality by 75% by the end of 2013. To achieve the aforementioned goal the government has taking different intervention strategies. Such as Insecticide Treated Net (ITNs) provisions, free anti-malarial drugs, free indoor residual spraying of houses, community health education, etc (http://www.moh.gov.et).

Even though, the aforementioned intervention strategies were implementing, malaria is still the major health problem of the study area, affecting children, pregnant women, adults and the society as a whole. It is the major cause for admissions and deaths in the study area. According to Arba Minch Zuria Woreda health office, from year 2004 - 2013 minimum yearly malaria case recorded in 2013, i.e., 7,422 cases and maximum yearly record is 20,382 cases in 2010. Even though it shows a decline since 2011, malaria is a major health problem of the area.

In the study area different researches were conducted in relation to malaria. However, they didn't consider the importance and application of GIS and remote sensing technology in malaria risk mapping and risk level identification. For instance a research conducted by Mohammed et al. (2012), was on paracheck-pf® test versus microscopy in the diagnosis of *falciparum* malaria. It was focused on diagnostic tests in detecting *falciparum malaria.*

As a result, in the study area, the risk level of malaria based on environmental factors is not identified, which could facilitate the malaria prevention and control activities. To feel this gap, this study tried to identify environmental factors facilitating conditions for mosquito breeding and malaria risk map is generated, which will make malaria prevention and control exercise cost and time efficient.

1.3. Objective of the study

1. 3.1. General objective

The main objective of this study is to investigate and generate malaria risk map of Arba Minch Zuria Woreda using key environmental factors which facilitate mosquito breeding conditions using Geographic Information System and Remote Sensing techniques.

1.3.2. Specific objective

The specific objectives are:

- To assess environmental factors facilitating mosquito breeding conditions
- To generate malaria risk map of the study area
- To compare malaria risk level of kebeles in the study area

1.4. Research questions

Basic questions answered by this project work are:

- What are the major environmental factors facilitating mosquito breeding conditions?
- Which parts of the study area have high, moderate and low malaria risk levels?

1.5. Significance of the study

This study is significant in identifying malaria risk level of the study area by producing the risk map. This will enable the Woreda health office to prioritize malaria prevention and controlling actions based on the risk level such as insecticide house spraying, anti-malaria drugs distribution, and bed net distribution. Which means the findings of this study will make malaria prevention and controlling program time and cost efficient.

1.6. Scope of the study

The scope of this study is delimited both in geographical area and issue of concern. Geographically, it is delimited to Arba Minch Zuria Woreda, which is one of the Woredas in Gamo Gofa Zone of the Southern Nation's Nationalities and Peoples Region. Regarding the area of concern, the main focus of the project was developing malaria risk map for the Woreda. Thus, this study is restricted to develop GIS and remote sensing based malaria risk map of Arba Minch Zuria Woreda using environmental factors.

1.7. Limitations of the study

The major limitations of this study include lack of adequate meteorological stations closer to the study area to make accurate interpolation or to reduce generalization in the process of interpolating temperature and rainfall maps, lack of well documented malaria case data for the town of Arba Minch as well as kebele based data. There was also lack of relative humidity data for the study area to include it as one factor.

1.8. Organization of the Project

This study is organized in five chapters. Chapter one provides introduction, problem statement, objectives, significance, scope and limitation of the project. Chapter two presents review of related literatures of concept and distribution of malaria, environmental factors, GIS and remote sensing application on malaria control and risk mapping. Chapter three provides description of the study area and methodology. Chapter four describes results and discussions and finally chapter five is about summary, conclusions and recommendations.

CHAPTER TWO

REVIEW OF RELATED LITERATURE

2.1. The concept of malaria

Malaria is an ancient disease caused by parasites of the genus *Plasmodium* and transmitted by several species of female a*nopheline* mosquitoes. The term 'malaria' originates from mal'aria (Italian) signifying 'bad air' or miasmas arising from marshes (Shumbullo, 2013). More than 100 different species of *Plasmodium* exist. They produce malaria in many types of animals and birds, as well as in humans. Among *plasmodium* species four of them commonly infect humans. These are *Plasmodium falciparum, Plasmodium vivax, Plasmodium ovale* and *Plasmodium malariae*. Each parasite has a distinctive appearance under the microscope, and produces a somewhat different pattern of symptoms (NIAID, 2007). Their description is given below.

Plasmodium falciparum: is responsible for most malaria deaths, especially in Africa. The infection can develop suddenly and produce several life threatening complications. With prompt, effective treatment, however, it is almost always curable (NIAID, 2007).

Plasmodium vivax: the most geographically widespread of the species, produces less severe symptoms. Relapses**,** however, can occur for up to 3 years, and chronic disease is debilitating. Once common in temperate climates, *Plasmodium vivax* is now found mostly in the tropics, especially throughout Asia (NIAID, 2007).

Plasmodium malariae: infections not only produce typical malaria symptoms, but also can persist in the blood for very long periods, possibly decades, without ever producing symptoms. A person asymptomatic (no symptoms) *Plasmodium malariae*, however, can infect others, either through blood donation or mosquito bites. Plasmodium *malariae* has been wiped out from temperate climates, but it persists in Africa (NIAID, 2007).

Plasmodium ovale: is rare, can cause relapses, and generally occurs in West Africa (NIAID, 2007).

2.2. Global distribution of malaria

Malaria, caused by parasites transmitted to humans by mosquitoes, is one of the world's most common and serious tropical diseases. However, on the globe, it extends up to 60° north and 40° south of latitudes. Its distribution in the world is not uniform (Figure 1). Different species of Plasmodium are found in different countries. *Plasmodium falciparum* is predominantly found in the warm and moist parts of Africa, the Middle East, Asia, Haiti, the Caribbean Islands, and Central and South America. *Plasmodium vivax* is dominant in the tropical and subtropical parts of Asia and in Eastern Africa and in some temperate regions such as in the Middle East and Iran. It is not found in the natives of West Africa. Though *Plasmodium malariae* is much less common than *Plasmodium falciparum* and *Plasmodium vivax*, it is widely distributed throughout the tropics. *Plasmodium ovale*, which is uncommon species of malaria, occurs in Africa and South America (Brian, 1989; Whittle and Hensbroek 1994).

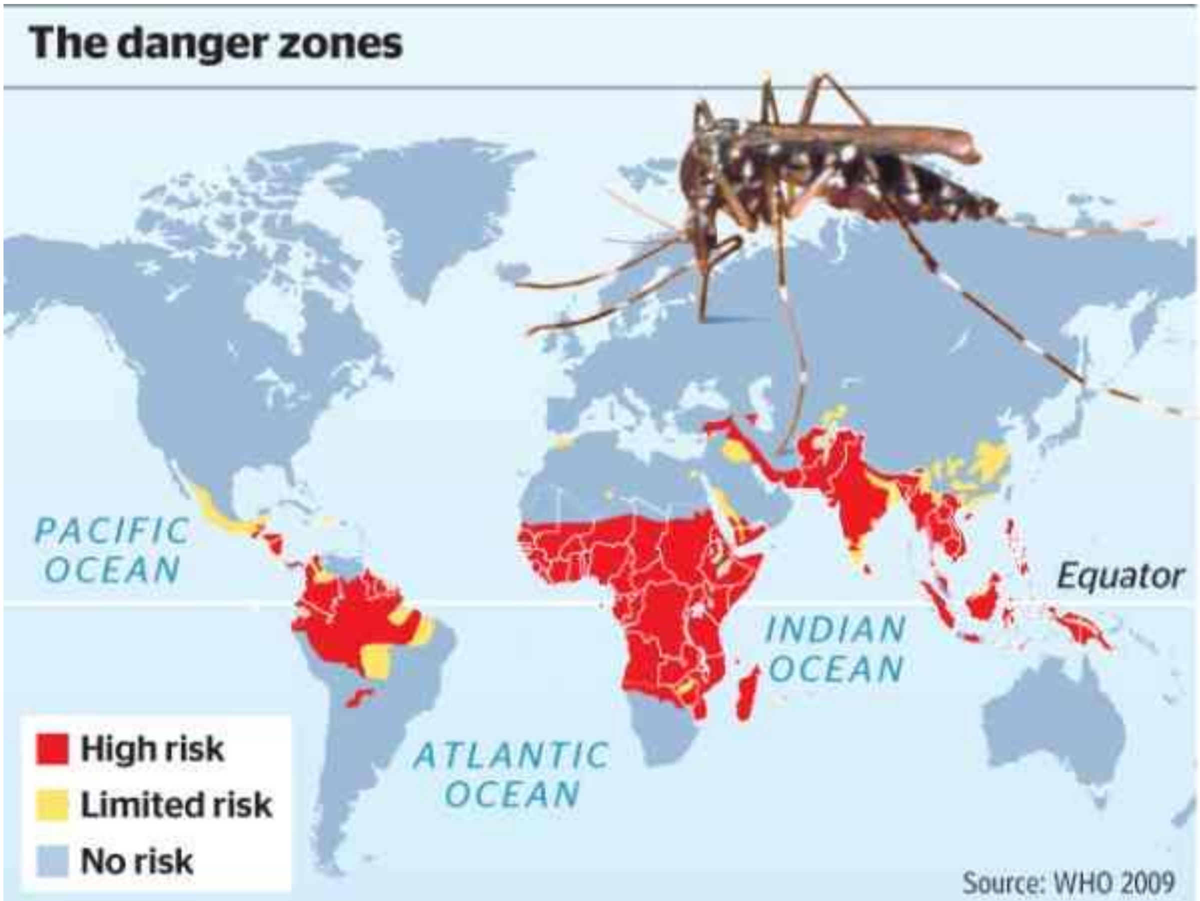

Figure1. Global distribution of malaria transmission risk

Source: WHO, 2009

About 90% of all malaria deaths in the world today occur in Sub Sahara Africa countries. This is because the majority of infections in Africa are caused by *Plasmodium falciparum*, the most dangerous malaria species of the four types. It is the most widespread in Africa and the most difficult to control. About one million people in Africa die from malaria each year, where most of them are children under 5 years old (WHO, 2003).

2.3. Distribution of malaria in Ethiopia

The existence of malaria in Ethiopia is unquestionable due to its tropical location. Besides its tropical location, 75% of the area that lies below 2000 m a.s.l elevation, where about two-third of the population is living on is also provides favorable natural environment for the occurrence of malaria and hence it is malarious (Woime, 2008).

Malaria is one of the major public health challenges in Ethiopia; an estimated 68% of the population is at risk of contracting malaria. Transmission is seasonal and predominantly unstable with frequent and often large-scale epidemics. The impact of malaria, in addition to its health consequences has significant impact on social and economic development in the country. To mention some: it causes loss of work force and time both of the sick and the family members, who provide care, depletion of income and cause school absenteeism/dropout (http://www.moh.gov.et).

Among plasmodium species, *Plasmodium falciparum* and *Plasmodium vivax* are the most dominant malaria parasites in Ethiopia, distributed all over the country and accounting for 60% and 40% of malaria cases, respectively. *Plasmodium malariae* accounts for less than 1% and *Plasmodium ovale* is rarely reported. The parasite is principally transmitted by the major mosquito vector known as *Anopheles arabiensis*. In some areas, *Anopheles pharoensis, Anopheles funestus* and *Anopheles nili* also transmit the disease (Adugna, 2011).

According to MoH (2008), the transmission patterns and epidemiology of malaria in Ethiopia is generally seasonal and highly unstable due to spatial variations in topography and rainfall patterns. Because of this, unstable and seasonal pattern of malaria transmission, the protective immunity of the population is generally low, and all age groups are at risk of infection and disease.

In Ethiopia, altitude and climate (rainfall and temperature) are the most important determinants of malaria transmission. Transmission is seasonal and largely unstable in character. The major transmission of malaria follows the June – September rains and occurs between September and December, while the minor transmission season occurs between April and May following the spring (*belg*) rains, which occurs between February and March. Areas with bimodal pattern of transmission are limited and restricted to a few areas that receive bimodal rainfall, i.e., the small (*Belg)* and main (*Kiremt*) rains. The major transmission season occurs in large part of the country (Adugan, 2011).

In addition to climatic factors, topography is also another factor affecting malaria epidemiology in Ethiopia. There are five main eco-epidemiological strata of malaria in Ethiopia (President's Malaria Initiative, 2012). These are:

- Malaria free highland areas above 2,500 meter altitude
- Arid areas where malaria is only found near semi-permanent water bodies
- Epidemic-prone areas in highland fringes between 1,500 – 2,500 meters
- Seasonal transmission in lowland areas <1,500 meters
- Stable, year round, transmission in the western lowlands and river basin areas

2.4. Factors affecting malaria incidence

The distribution of malaria is governed by a large number of factors relating to the parasite, the vector and the host (human). Predominant among these are climatic and environmental factors, particularly those that affect habitat and breeding sites of the *Anopheles* mosquito vectors such as temperature, precipitation, humidity, presence of stagnant water pools, vegetation, migration and human to vector contact etc. Specifically, temperature and rainfall act as limiting factors on the development of *Anopheles* mosquitoes, which are the intermediate hosts in the transmission of malaria parasites. Additionally, the anthropogenic changes in the environment, in land use, deforestation, in hydraulic network, induce continuous changes in the intensity of malaria transmission (Zacarias & Andersson, 2010). About 70 – 90% malaria risk is associated with environmental factors, which in turn influence the abundance and survival of the vectors (Saxena et al., 2009).

2.4.1. Climatic factors

For the breeding of *Anopheles* mosquito and the development of the *Plasmodium* parasite in the mosquito, most part of Ethiopia provides favorable temperature and moisture conditions. These elements of climate are mainly the result of the country's location and topography. As Ethiopia is located in the tropical region, most parts of the country have high temperature throughout the year. High amount of seasonal rainfall in most parts and year round rainfall in some areas, are mainly related to the tropical location of the country. The seasonal rainfall with high temperature is responsible for the occurrence of unstable and seasonal malaria transmission after the onset of the rainfall in most part of the country (Woime, 2008).

2.4.1.1. Temperature

Researches show that temperature has significant influences on mosquito density and malaria transmission. Climate variability, specifically temperature, impacts the incubation rate and breeding activity of certain species of mosquitoes and is considered as one of the key environmental contributors to mosquito propagation (Wilder, 2007).High temperature speeds up the development of the life cycle of a mosquito and accelerates the length of the development of the life cycle of malaria parasite within the mosquito host (FMoH, 2003).

Different researches suggest that the optimum temperature for development of malaria parasite is between 25°C to 30°C. At lower temperature (16°C), the larval and pupal stages of mosquitoes take longer time to complete sporogony cycle and below 16°C the sporogony ceases. An increase in temperature results in shortened sporogonic period of the *Plasmodium* parasite within the vector up to about 30°C. In addition, at temperatures below 20°C, *Plasmodium falciparum*, which causes severe malaria, cannot complete its life cycle in the Anopheles mosquito, and thus cannot be transmitted. On the other hand, increased temperature above 30°C has negative impact on the survival of the vector (Dutta, 2006; Wilder, 2007; Abeku, 2006; Teklehaimanot et al., 2004; Omumbo et al., 2002).

The development rate of immature mosquitoes is very much temperature dependent. Below 16°C, development of *Anopheles gambiae*, the main malaria vector in most parts of Africa, will completely stop, and the larvae will die in wet temperature below 14°C. In low temperature conditions, mosquito larval development is severely delayed and has high mortality incurs. In the adult stage, increase in ambient temperature accelerate the digestion of blood meals taken by Mosquitoes, leading to increased human biting frequency and malaria transmission (Afrane et al., 2011).

2.4.1.2. Rainfall

Rainfall is considered to be the most important malaria triggering parameter causing soil saturation and a rise in pore-water pressure. So it expands breeding grounds, and in many tropical areas, malaria cases increase during rainy season (Kumar et al., 2012; NIAID, 2007). Excessive rainfall in warm, arid areas can lead to increased transmission due to creation of vector breeding sites (Abeku, 2006). Apart from creating mosquito breeding sites, rainfall also affects malaria transmission through increasing humidity, which in turn will help to increase the longevity of the adult vectors (FMoH, 2003). While increasing precipitation may increase vector populations in many circumstances by increasing available anopheles breeding sites, excessive rains may also have the opposite effect by flushing out small breeding sites, such as ditches or pools or by decreasing the temperature, which in regions of higher altitude can stop malaria transmission (Ceccato et al., 2005).

Areas with annual rainfall amount greater than 1000 mm are malarious and have intense malaria transmission, but areas with rainfall amount between 500 and 1000 mm have seasonal transmission (President's Malaria Initiative, 2012). Since very high rainfall is not suitable for vector immature stages, areas having >1600 mm annual rainfall are unfavorable for mosquito breeding (Srivastava, 1995).

2.4.2. Topographic factors

Topography is an important factor in understanding the malaria epidemiological situation at local scale (Saxena et al., 2009). The most important topographic factors in malaria distribution are altitude and slope.

2.4.2.1. Altitude

The prevalence of malaria parasites in people varies with altitude. People at low lands have significantly higher prevalence of malaria than those in middle and highlands (Kimbi et al., 2013). Therefore, altitude is significant in determining the distribution of malaria and its seasonal impact on many parts of the World.

Based on altitude, traditionally Ethiopia is divided in five agro-ecological climatic zones. These are *Wurich/kur, Dega,Woina Dega, Kola and Bereha* (Hurni,1998). In Ethiopia the *Dega* zone with elevation above 2500 m.a.s.l. is malaria free. In Ethiopia, malaria frequently occurs in areas below 2000 meters elevation and the transmission is very intense in areas below 1500 meters elevation (Adugna, 2011). Now a day due to temperature increase (global warming) and other factors malaria is emerged in high altitude areas of Ethiopia including those above 2000 m.a.s.l, during malaria non-epidemic year (Woyessa et al., 2012). On the other side in Ethiopia lowland deserts (*Bereha*) areas have an altitude < 500 m.a.s.l. and annual rainfall < 900mm (MOA,1998).So, these regions are not suitable for mosquito breeding as a result of low annual rainfall amount and very high temperature above 30^{o}c.

2.4.2.2. Slope

Slope is a measurement of the steepness of the ground surface. The steeper the surface, the greater the slope is. Steeper slope does not favor plant and animal dwelling relative to gentle slopes (Lemessa, 2011). Malaria transmission is affected by slope of the land. Mosquito larvae need stagnant water pools to survive, and these pools are less likely to form in sloped areas. Moreover, larvae developing in water pools in sloped areas are more likely to be washed away during downpours. Thus, sloped areas make poor mosquito breeding ground, reducing the threat of malaria transmission (Burlando, 2012).

Slope is used as a decisive factor of water stagnation. This is because in areas with low slopes, water tends to be dammed because of physical soil properties and slope gradient (Rincón-Romero and Londoño, 2009). According to a study conducted in Estado Sucre (2011), a slope gradient range below 5% showed the highest number of malaria cases (Petrocelli et al., 2011).

2.4.3. Factors related to distance from water bodies

According to Woime (2008), in Ethiopia the existence of permanent water bodies such as rivers, lakes and streams creates favorable environment for the breeding of the mosquito and the transmission of malaria in Ethiopia. As a result of seasonal variation in rainfall, the rivers and lakes of Ethiopia have seasonal characteristics. During the rainy season both the rivers and lakes are full and sometimes they flow over their banks and these lead to flooding. During the dry season their volume is decreased and they create different pockets of water body that is favorable ground for the breeding of different disease vectors such as mosquito. Most Lakes of Ethiopia are found in the rift valley. Due to high temperature, which is favorable for the breeding of different disease vectors and pathogens, the habitats of the Lakes region are highly affected by vector born diseases especially by malaria (Woime, 2008). Water body, particularly not moving is a typical place for mosquito breeding (Lemessa, 2011).

Most Anopheles mosquitoes have a flight range of 2 kilometers from their breeding sites (Jackman and Olson, 1914; Whelan and Warchot, 2009; FMoH, 2003). Depending on this, people living within 2 km distance from rivers, lakes and swamps are in high risk of malaria incidence than peoples living far from rivers, lakes and swamps.

2.4.3.1. Proximity to Rivers

One of important parameter that some time plays important role to increase malaria parasites and malaria disease is the distance to river. The closeness of the populated area to drainage systems is an important parameter for malaria vector breeding source in malaria risky areas (Kumar et al., 2012).

2.4.3.2. Proximity to Lakes

Most lakes of Ethiopia are found in the rift valley area, where the temperature is high throughout the year. These regions are occupied by both rural and urban populations, and high numbers of people are vulnerable to the disease like malaria (Woime, 2008).

2.4.3.3. Proximity to swamps

According to a study in Estado Sucre state of Paria Peninsula (2011), the risk for malaria transmission is reinforced by nearby wetlands constitute ideal vector habitats promoting reproduction and maintenance of stable mosquito populations (Petrocelli et al., 2011).

2.4.4. Land use land cover related factor

Although the terms land cover and land use are often used interchangeably, their actual meanings are quite distinct. Land cover refers to the surface cover on the ground, whether vegetation, urban infrastructure, water, bare soil or other. Land use refers to the purpose the land serves, for example, recreation, wildlife habitat, or agriculture (Amdie, 2007).

Land cover affects the temperature of larval habitats directly and food conditions and other factors indirectly, but the combined effects of these factors may be more significant to larval survivorship (Munga et al., 2006).

A study on Western Kenya highlands indicates the influence of land use and land cover on larval survivorship and adult productivity by affecting the amounts of temperature reaching the place of breeding and their source of food. According to this study, farm lands are more suitable for larval survivorship than forested areas (Zhou et al., 2007). Forest areas or areas with tree canopy reduces the water temperature of larval habitats, as tree canopy cover reduces the amount of solar radiation reaching the larval habitats, the algal contents, one major food source of *Anopheles gambiae* larvae, was considerably lower in forest than in the farmland and the larvae from forested habitats took a much longer time to develop into adults than those from farmland habitats (Zhou et al., 2007). In addition, a study in highland community of Africa indicates the association between land cover type and presence of *anopheline* larvae. The study shows that the highest proportions of *anopheline* positive habitats occurred in pastures and farmlands followed by swamps. Compared to pastures and farm lands, forests contain small number of *anopheline* positive habitats. (Munga et al., 2009).

2.4.5. Soil

According to Srivastava (1995), soils are categorized as poorly drained or well drained. Poorly drained soils facilitate water stagnation and create conducive conditions for mosquito breeding and thus, favor malaria outback. Well drained soil doesn’t allow water stagnation, so it creates unfavorable condition for *anopheline* breeding.

2.5. Geographic Information System and Remote Sensing

2.5.1. Geographic information system

GIS is defined as an information system that is used to input, store, retrieve, manipulate, analyze and output geographically referenced data or spatial data (Saxena et al., 2009). It is also defined as, an organized collection of computer hardware, software, geographical data, and personnel designed to efficiently capture, store, update, manipulate, analyze, and display all forms of geographically referenced information (ESRI, 1990).

GIS is a powerful tool for clarifying spatial patterns and processes and it is able to link spatial and non-spatial data, allowing for a wide range of display and analysis capabilities. It has many applications in numerous fields of study, including marketing, agriculture, forestry, animal ecology, transportation planning and public health (Clarke et al., 1996).

According to Rao (2000), GIS offers an ideal environment for integration of spatial and attribute data on natural resources for formulating the developmental plan of an area taking into account social, cultural and economic needs of the people.

GIS has considerable potential for both policy decisions and resource allocation decisions. Policy decisions are intended to influence the decision behavior of decision makers whilst resource allocation decisions involve decisions that directly affect the utilization of resources. GIS for policy decisions also has potential as a process modeling tool, in which the spatial effects of predicted decision behavior might be simulated. Resource allocation decisions are also prime candidates for analysis with a GIS (Kapetsky and Aguilar-Manjarrez, 2007). In health sector also GIS spatial analysis is the best way to produce valuable information to support decisions against the illness, parasite and vector (Rincón-Romero and Lodono, 2009).

2.5.2. Remote sensing

Remote sensing, in the broadest sense, refers to the acquisition of information of an object or phenomenon, employing either a real-time sensing device that is not in physical or intimate contact with the object itself, e.g. by means of an aircraft or a satellite (Simoonga et al., 2009). Remote sensing technologies are used to gather information about the surface of the earth from a distant platform, usually a satellite or airborne sensor. Most remotely sensed data used for mapping and spatial analysis is collected as reflected electromagnetic radiation, which is processed into a digital image that can be overlaid with other spatial data (Milla et al., 2005).

2.6. Application of GIS and RS in malaria risk mapping

Currently, GIS is being introduced in tropical disease control programs against sleeping sickness, Chagas disease, leishmaniasis, schistosomiasis, guinea worm and malaria. For national health policy makers, cartographic display can indeed facilitate identification of risk areas, their subsequent targeting and monitoring of interventions to these areas (Boelaert et al 1998).

GIS and remote sensing are increasingly used for the study of spatial and temporal patterns of vector borne diseases. The study carried out in central region of Gwalior reveals that RS and GIS techniques are proved to be a significant in larval habitat identification and risk area mapping (Agarwal et al., 2012). For disease epidemiology at an exploratory level, GIS is well suited for the study of associations between location, disease, vector/intermediate host and environment, due to its display capabilities (Simoonga et al., 2009).

The mapping and analysis of the environmental landscape through remote sensing technology and GIS allows for a better understanding of temporal and spatial aspects of infectious disease transmission. Yet, turning infectious disease characterizations into preemptive intelligence for a given geographic area can be challenging due to variability of the environmental landscape (Wilder, 2007).

GIS has also many applications to the study of mosquitoes and mosquito-borne diseases. It used to study the distribution and abundance of mosquitoes, determining risk factors and prediction of risk exposure. It also used to map and analyze the spatial distribution of mosquitoes and to assess the ecological factors that contribute to observed distributions. In addition, GIS technology contribute to the study of mosquitoes and mosquito-borne disease include studies of landscape architecture to assess how elevation, slope and land-use patterns influence the formation of larval breeding sites (Gimnig et al., 2005).

RS data in GIS have been used widely for identification, characterization, monitoring, and surveillance of breeding habitats and mapping of malaria risk. GIS based malaria incidence mapping has been used for risk assessment at national, regional, town and village level. Such mapping is considered crucial for analyzing past as well as present disease trends. Risk maps developed on the basis of mapped malaria incidence are tools for targeted and cost-effective control of disease (Saxena et al., 2009).

According to a study carried out in central region of Gwalior, RS and GIS techniques are proved to be significant in larval habitat identification and risk area mapping. So GIS and remote sensing are increasingly used for the study of spatial and temporal patterns of vector borne diseases (Agarwal et al., 2012)

A study by Rincón-Romero and Lodono (2009), conclude that more research needs to be done in the sense of mapping malaria risk where approaches could be integrated with better resolution in space and time to produce valuable information to support decisions against the illness, parasite and vector. To do so, GIS spatial analysis is the best way to support approaches for mapping malaria risk.

In Ethiopia, a study conducted in Fentale woreda suggests that, GIS and remote sensing based malaria risk mapping considering appropriate mosquito harboring factors is a worthwhile technique to know the risk level associated with each area and it enables to support public health officers in space and time so as to control and predict malaria spread over extensive areas (Lemessa,2011).In addition, according to Tiruneh (2010), application of GIS provided the necessary infrastructure for identifying and combining different variables and for identifying the risk level.

CHAPTER THREE

MATERIALS AND METHODS

3.1. Study area

3.1.1. Location

Arbaminch Zuria Woreda is one of Woreda's found in Gammo Gofa zone of the Southern Nation's Nationalities and Peoples Regional State (SNNPR). The Woreda is located at a distance of 275 and 505 km from the regional city, Hawassa and the country capital, Addis Ababa, respectively. Geographically, the Woreda is located between 5°42´ and 6°13´north latitude and 37°19´ and 37°41´ east longitude (Figure 2). It is bordered on the south by the Dirashe special Woreda, on the west by Bonke, on the north by Dita and Chencha, on the northeast by Mirab Abaya Woredas, on the east by the Oromia National Regional State, and on the southeast by the Amaro special Woreda. The Woreda covers 1001 km² and has twenty nine rural kebeles and one Woreda town.

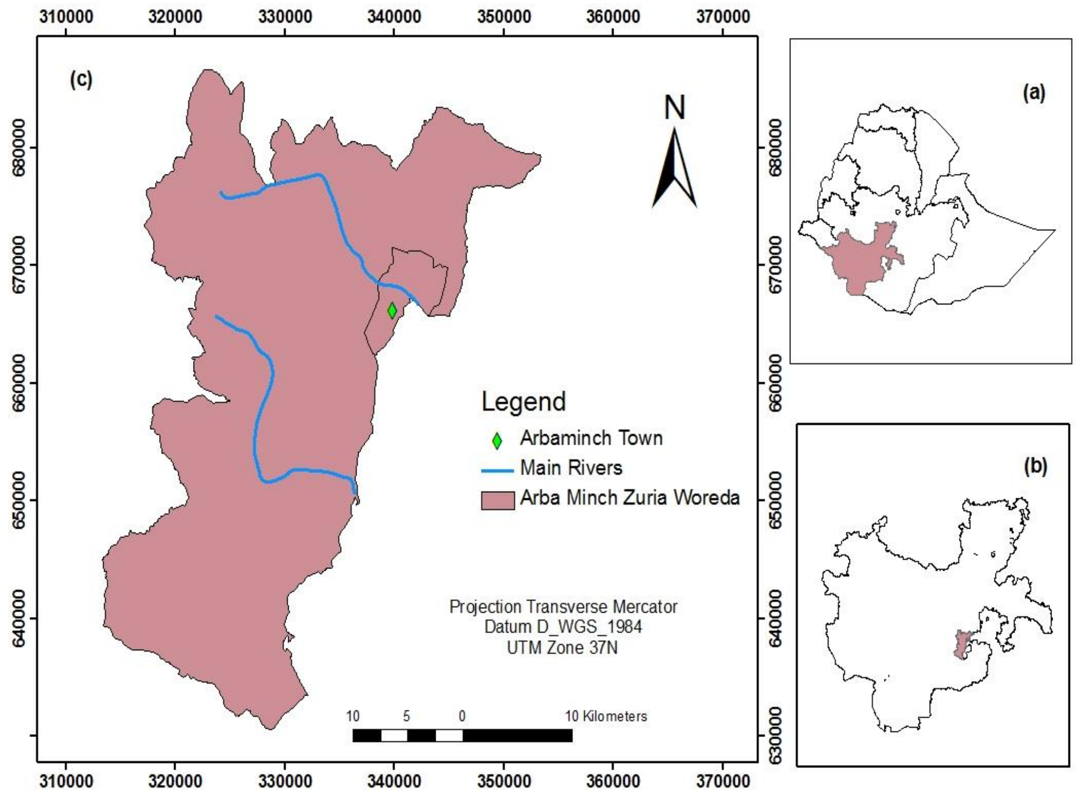

Figure 2: Location map of the study area: (a) SNNPR in Ethiopia, (b) Arba Minch Zuria Woreda in SNNPR and (c) Arba Minch Zuria Woreda

3.1.2. Population

Based on 2007 population census, Arba Minch Zuria Woreda has a total population of 164,529 of whom 82,199 are men and 82,330 are women (CSA, 2008). And the town of Arba Minch has a total population of 74,843 of whom 39,192 are men and 35,651 are women. The population density of the study area varies from172 person/km^2 to 2268 person/km^2. As shown in figure 3 dark colored areas have high population density. These areas are dense because they include the town of Arba Minch and other rural town settlements.

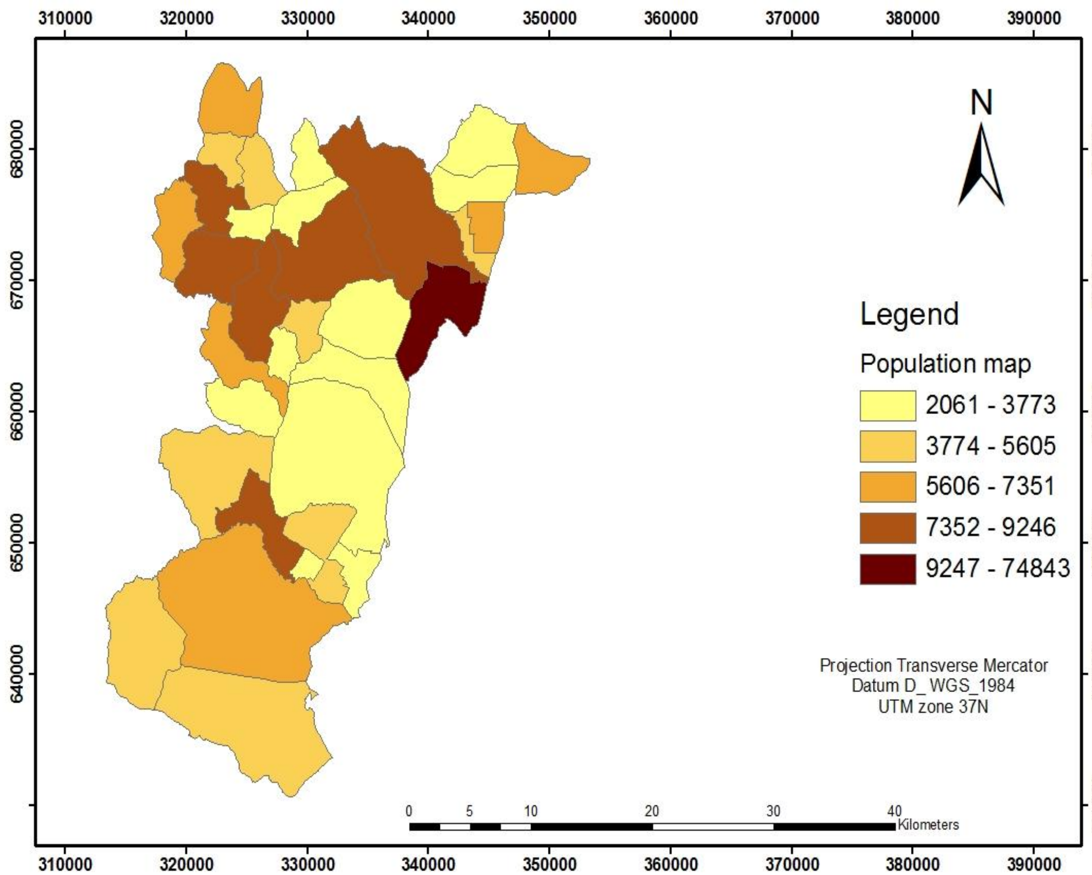

Figure 3: Population density map of the study area

Source: CSA, 2007

3.1.3. Climate

According to the fifteen years climatic data, particularly temperature and rainfall which was obtained from National Meteorological Services Agency (NMSA), the average monthly temperature of the study area ranges between 25.8°C in March to 23°C in July. The mean monthly maximum and mean monthly minimum temperature of the study area ranges between 33.8°C in February to 28.1°C in July and 18.2°C in April to 15.3°C in December, respectively (Figure 4).

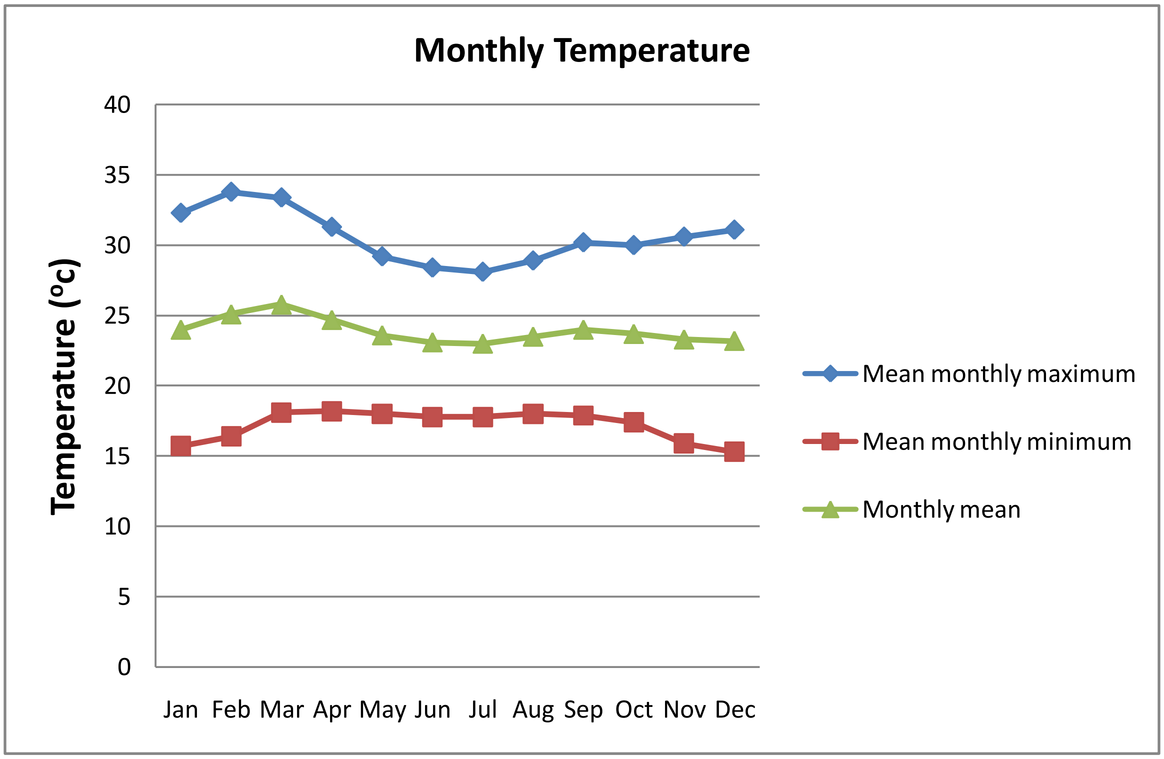

Figure 4: Mean monthly: maximum, minimum and mean temperature at Arba Minch station (1999 to 2013)

Source: National Meteorological Services Agency

Regarding the rainfall pattern, it ranges from 26.45 mm in February to 164.6 mm in April. The mean annual total rainfall of the study area is about 963.3 mm. According to the data collected from NMSA, the study area has two rain seasons. The main rain season is March, April and May which have 172.35 mm and 129.13 mm mean monthly rainfall in April and May, respectively. The second highest monthly rainfall is recorded in September and October, 126.6 mm and 133.05 mm respectively (Figure 5).

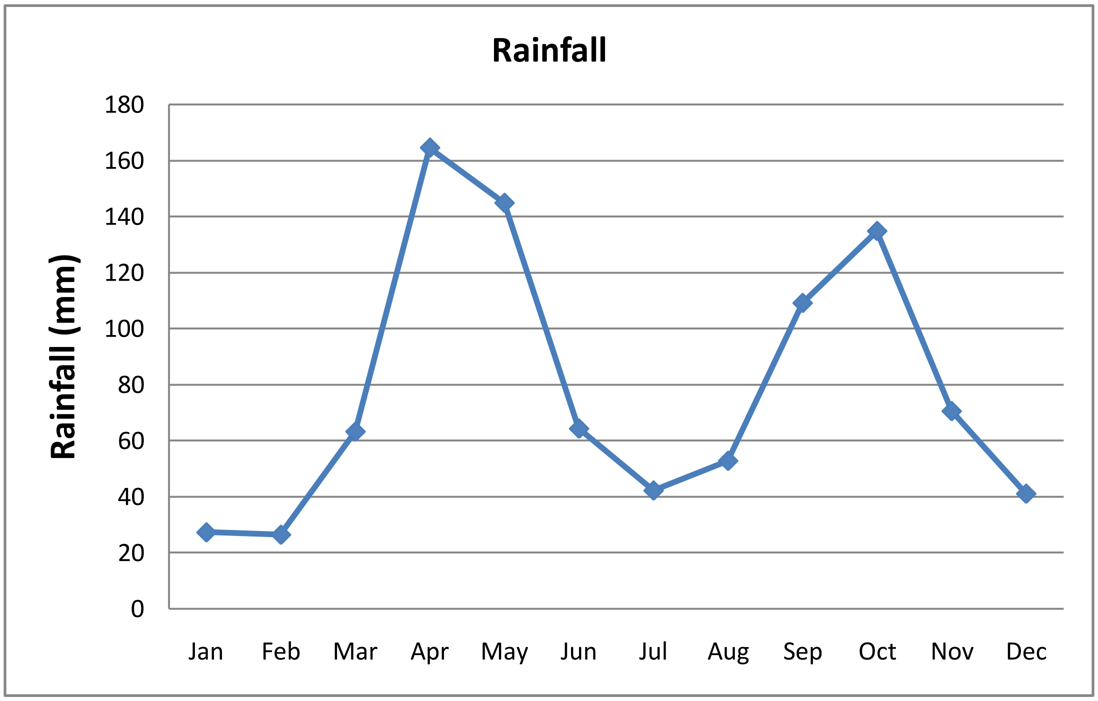

Figure 5: Mean monthly rainfall at Arba Minch station (1999 to 2013)

Source: National Meteorological Services Agency

3.1.4. Topography of the study area

Topography of the study area constitutes plain, gentle sloppy lands and mountains. Its elevation ranges from 1200 meters above sea level around eastern part to 3000 meter above sea level in north western part. Eastern part of the study area is dominated by flat lying topography, while the northern and north western parts constitute areas with high altitude (Figure 6).

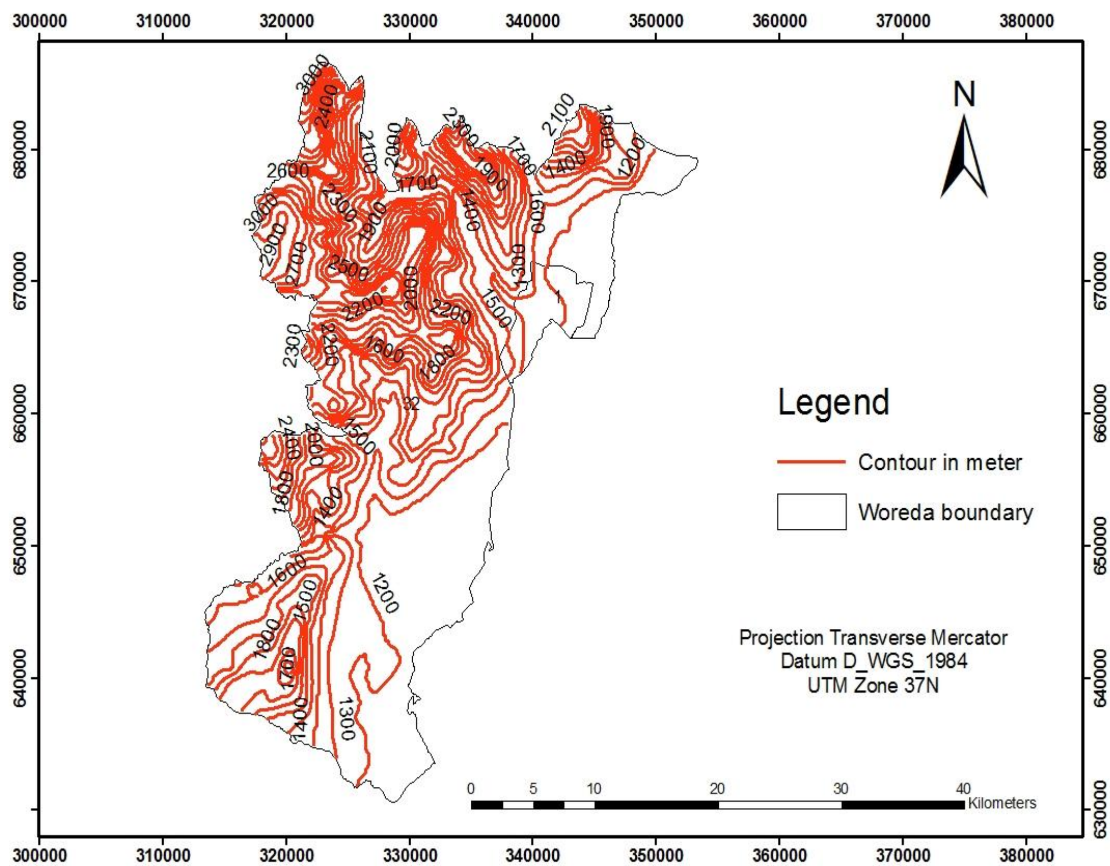

Figure 6: Contour map of the study area

3.1.5. Soil

On the basis of Food and Agricultural Organization (FAO) soil classification system, the study area consists of seven soil types. These are Xerosols, Vertisols, Fluvisols, Nitosols, Leptosols, Acrisols and Solonchaks (Figure 7). Figure 7 illustrates types of soils and their distribution in the study area (FAO, 1984). Description of the soil types based on FAO (2006) is given below.

Acrisols

Acrisols are soils that have higher clay content in the subsoil. They are strongly weathered acid soils with low base saturation at some depth. The soils are yellowish brown and well drained.

Fluvisols

Fluvisols are genetically young soils. They are zonal soils in alluvial deposits, which found in alluvial plains, river fans, valleys and tidal marshes on all continents and in all climate zones. Many Fluvisols under natural conditions are flooded periodically. Most Fluvisols are wet in all or part of the profile due to stagnating groundwater and/or flood water from rivers or tides. So they are poorly drained soils.

Leptosols

Leptosols are very shallow soils less than 30 cm thick over continuous rock or conglomeratic materials (which have over 75% coarse fragments). Due to high gravelly/stony and/or contact with lithic material at shallower depth, they have high water drainage/percolation. Leptosols are zonal soils and particularly common in mountainous regions.

Nitosols

Nitisols are deep, well-drained, red, tropical soils. Nitisols have high moisture storage capacity. They are finely textured weathering products of intermediate to basic parent rock. Nitisols are predominantly found in level to hilly land under tropical rain forest or savannah vegetation.

Solonchaks

Solonchaks are soils that have a high concentration of soluble salts at some time in a year and are poorly drained. Solonchaks are largely confined to the arid and semi-arid climate conditions and to coastal regions in all climates. They are named as *saline soils* and *salt-affected soils* and found in arid and semi-arid regions, notably in areas where ascending groundwater reaches the solum, with vegetation of grasses and/or halophytic herbs, and in inadequately managed irrigation areas.

Vertisols

Vertisols are churning, heavy clay soils with a high proportion of swelling and shrinking clays. These soils form deep wide cracks from the surface downward when they dry out, which happens in most years. They are almost impermeable, when saturated and very plastic and sticky when wet. Vertisols allow water stagnation during rainy season and found around depressions and level to undulating areas, mainly in tropical, subtropical, semi-arid to sub humid and humid climates with an alternation of distinct wet and dry seasons. The climax vegetation is savannah, natural grassland and/or woodland.

Xerosols

Are arid desert soils containing low organic matter; the top layer is of a light color, and underlying layers may contain clayish and/or salt minerals such as carbonates and sulphates. They have low water storage capacity, thus they have good drainage.

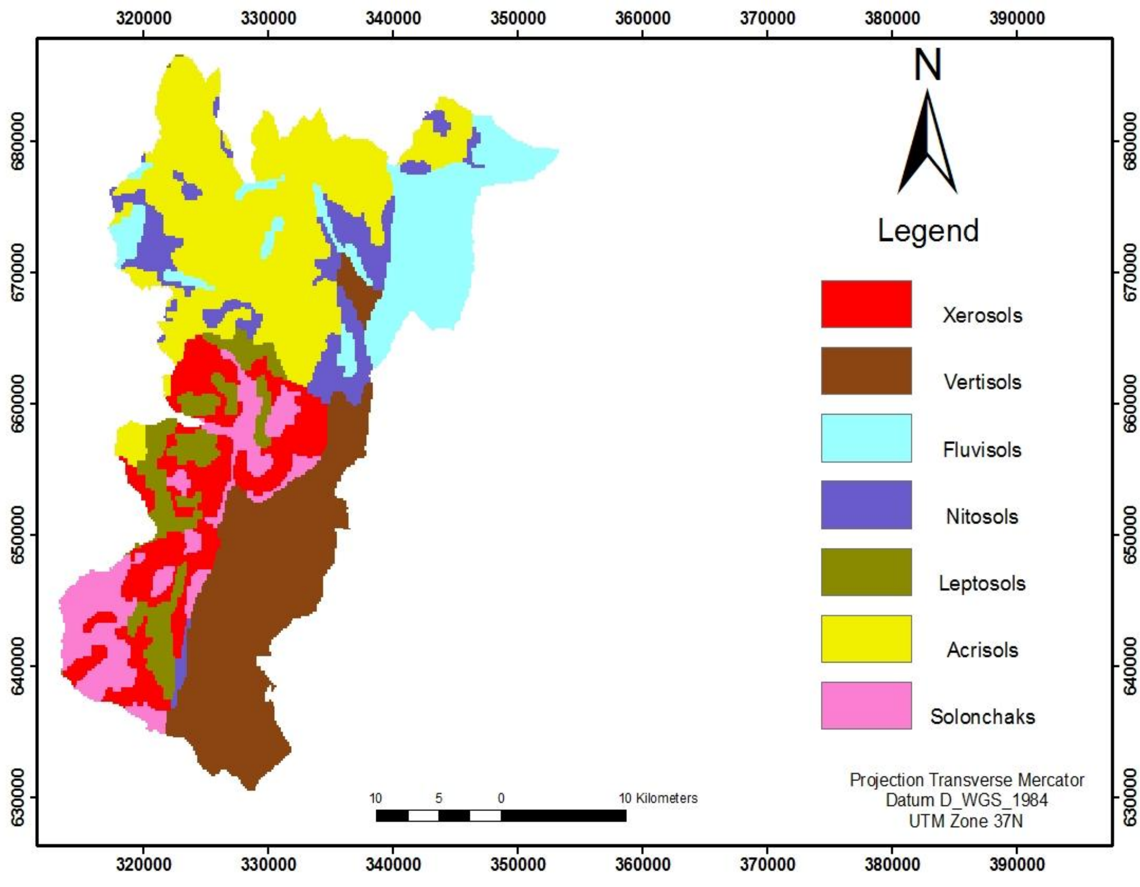

Figure 7: Soil map of study area

Sources: Ministry of Agriculture (FAO, 1984)

3.1.6. Land use land cover of the study area

The study area involves six major types of land use/ land cover. These are settlement, farm land, water bodies, forest, bush lands and bare lands. It is dominated by farm lands account 46% of the total area, including two state owned farm lands (Arba Minch Ersha Limat and Sille Ersha Limat) and wide farmers owned farm lands. The second dominant land use land cover type is bush land area 34.1%, which includes short trees and shrubs found in different parts of the study area. The study area also includes settlement areas account 12.5%, which are the town of Arba Minch and small Kebele settlements, dense forest 5.7% of the total area found around the two lakes, water bodies 0.85%, part of two lakes and major rivers in the study area and bare lands account 0.85% found in different parts of the Woreda, which left fallow.

3.1.7. Malaria trend of the study area

Based on ten years data obtained from Arba Minch Zuria Woreda health office, the number of malaria cases in the Woreda is very high. The trend of malaria in Arba Minch Zuria Woreda is irregular showed decrease between 2004 and 2006 and increased between 2007 and 2010. But since 2011, it showed decreasing trend due to several preventive actions taken by the Woreda health office and other concerned bodies. Even though, these actions have been undertaking, malaria is still major health problem in the study area. The following graph shows malaria trend of the Woreda in the last 10 years, i.e., between 2004 and 2013 (Figure 8).

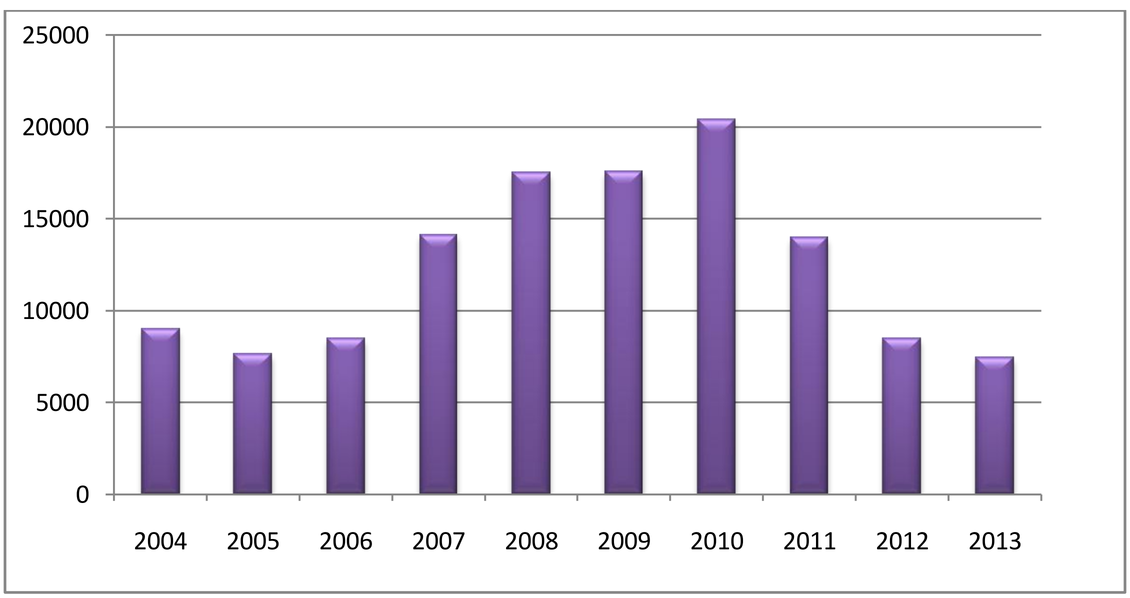

Figure 8: Malaria cases of Arba Minch Zuria Woreda from 2004 - 2013

Source: Arba Minch Zuria Woreda health office

3.2. Types of data used for analysis

Both primary and secondary data were used for the malaria risk mapping of the study area, which were obtained from field survey and concerned institutions. The data and materials used include satellite imagery Landsat Thematic Mapper (TM), climatic data (rainfall and temperature), Shuttle Radar Topography Mission (SRTM) 30 m resolution data, topographic map (1:50,000 scale), soil map and clinical data (malaria cases) of the study area. Types of data used and their sources are described in Table 1 below.

Table 1: Types of data used and their sources

No	Types of data	Source of data
1	Land Sat satellite image	Ethiopian Mapping Authority
2	Topographic Map	Ethiopian Mapping Authority
3	Digital Elevation Model	Internet (SRTM)
4	Rainfall and temperature data	National Meteorological Services Agency
5	Study area boundary shapefile	Central Statistical Agency
6	Ground control points	Field survey
7	Clinical data(malaria cases)	Woreda health office
8	Soil map	Ministry of Agriculture (FAO, 1984)

3.3. Software and materials used in the project

The software types used for different types of activities in the process of generating malaria risk map include: ERDAS IMAGINE 2010, Arc Map 9.3 and IDRISI 32. Global Positioning System was used for collection of ground control points to prepare accuracy assessment for land use land cover map.

Table 2: Software types and their application areas

No	Software and material Used	Major application areas in the project
1	Arc Map 9.3	Reclassification of factors, for weighted overlay analysis and generation of risk maps
2	ERDAS IMAGINE 2010	Land use/land cover image classification and for accuracy assessment matrix preparation
3	GPS	For collection of ground control points
4	IDRISI 32	For weight derivation of factors

3.4. Methodology

The main objective of this project work is to generate malaria risk map of Arba Minch Zuria Woreda based on environmental factors responsible for malaria incidence. These environmental factors were selected depending on previous research works and by collecting information from malaria experts of the Woreda. According to this elevation, temperature, slope, soil, rainfall, land use land cove type and proximity to water bodies and swamps are selected as major environmental factors for malaria incidence.

For each environmental factors mentioned above maps were generated and then reclassified depending on their suitability for mosquito breeding. In the process of reclassification, new values 1, 2, 3, 4 and 5 were assigned and they represent very low, low, moderate, high and very high malaria risk level, respectively. To see the influence of each factor, weight computation was done by pair wise comparison matrix. And finally weighted overlay carried out using Arc Map 9.3 to generate the final malaria risk map of the study area. The overall work flow (methodology) used to accomplish the project is presented figure 9.

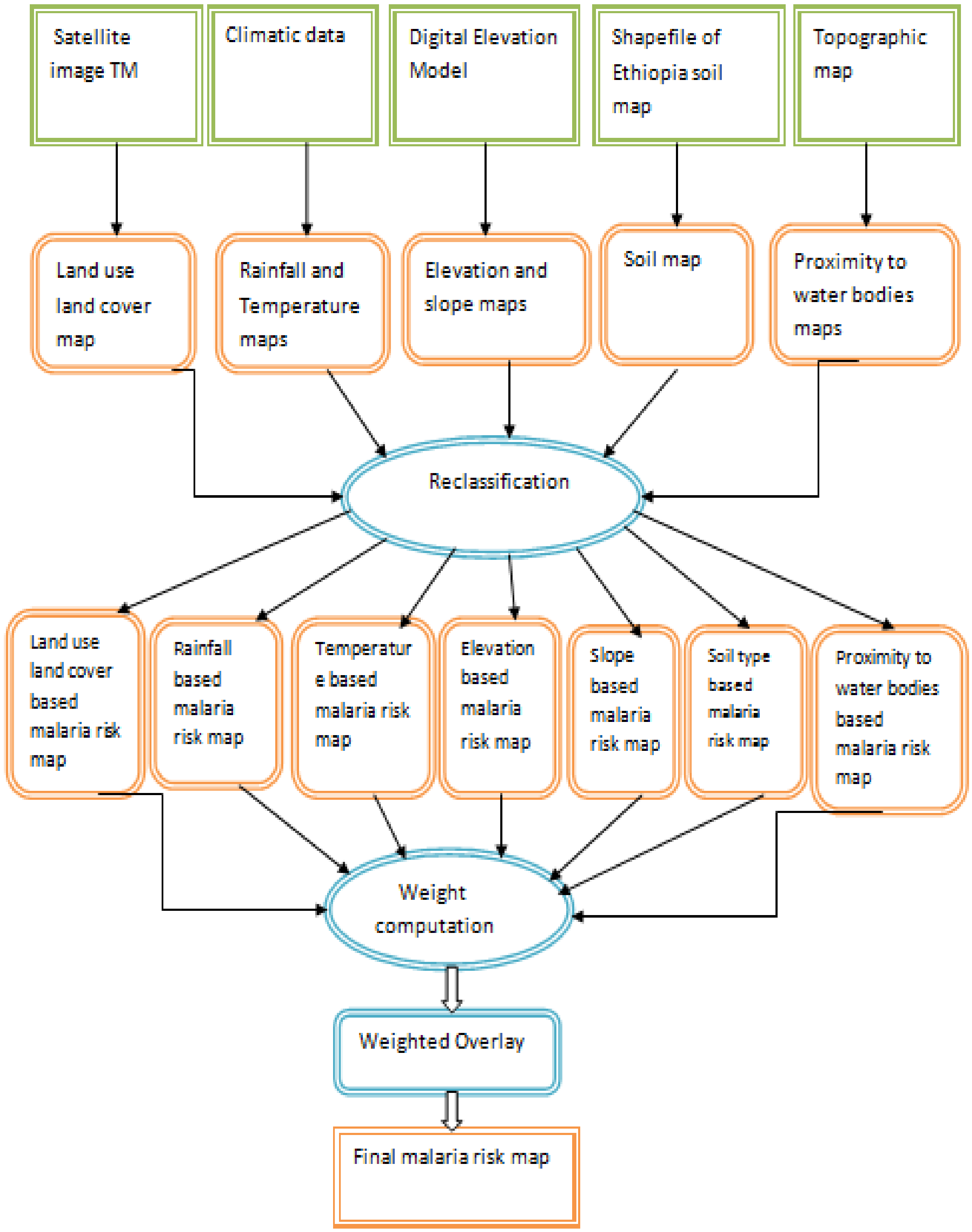

Figure 9: Methodological frame work

3.4.1. Methods used for analysis of factors

3.4.1.1. Climatic factors

The temperature and rainfall maps of the study area generated from fifteen years mean monthly temperature and mean annual rainfall data collected from the national meteorological services agency. The data was collected from thirteen stations, one of them is found in the study area and the rest twelve stations are surrounding the study area. The data was collected with the geographical location of stations as a point data. These stations are Arba Minch, Mirab Abaya, Wajifo, Morka, Beto, Gerese, Gidole, Amaro Kelle, Gato, Chencha,Wolayta, Boditi school and Konso. The geographical distribution of the metrological station used for the analysis is given in figure 10 below.

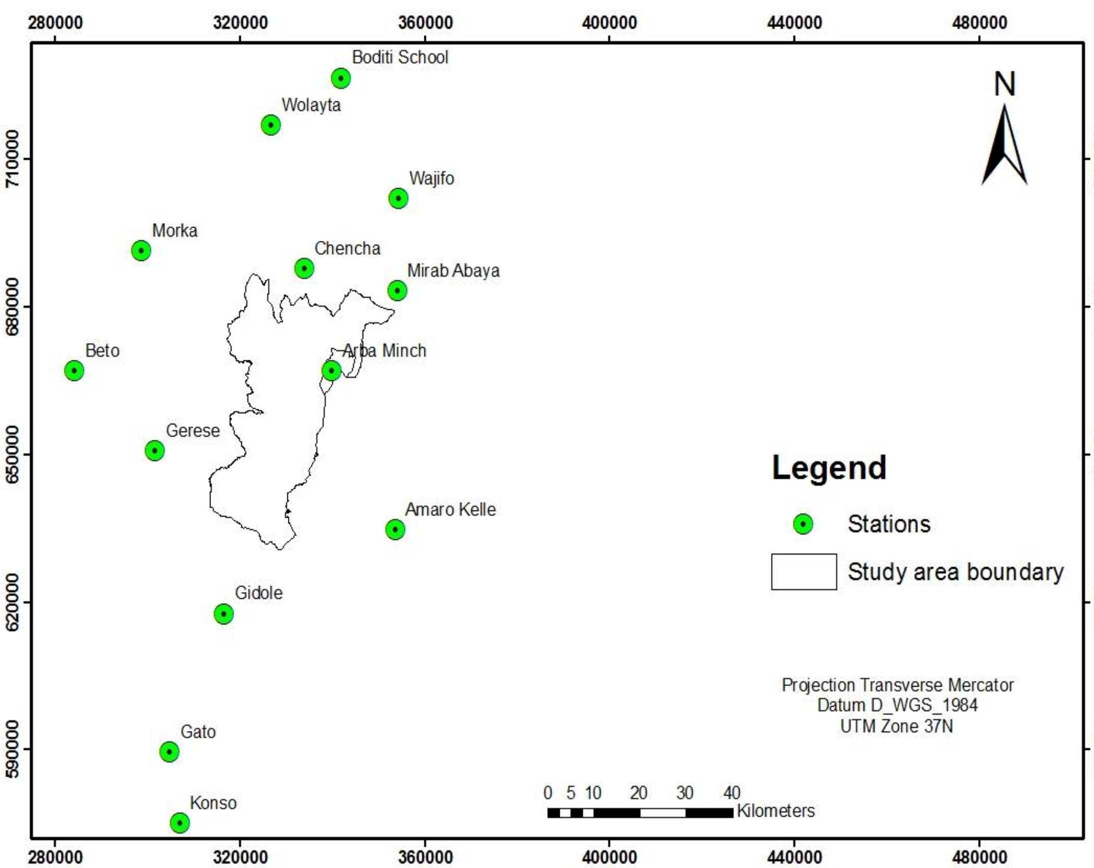

Figure 10: Location map of metrological stations used for the analysis

Temperature

To generate temperature map, fifteen years mean monthly maximum and mean monthly minimum temperature data of thirteen stations were analyzed. From the mean monthly maximum and minimum temperature of the stations, mean monthly temperature of each stations were calculated. Then, a single average value is computed for fifteen years. Finally, a single average value of each station used for surface interpolation in Arc GIS spatial analyst tools. The technique used to interpolate the data was kriging interpolation technique.

The temperature map was reclassified by spatial analyst tools in Arc GIS. The study area is reclassified in to three classes based on its suitability to mosquito breeding. New values 2, 4, and 5 were assigned to temperature from 16 to 19, 20 to 22 and 23 to 24, respectively. Then, the classes were labeled as low, high and very high malaria risk level, respectively.

Rainfall

The rainfall map was also generated from fifteen years monthly rainfall data of thirteen stations. Annual rainfall of each station calculated from monthly rainfall data and the average annual rainfall computed for each station. In the same fashion as temperature map, by using kriging interpolation technique continuous surface was created. The reclassification of rainfall map of the study area was done in Arc map spatial analyst tools. Accordingly, the rainfall map of the study area was reclassified in to two classes on the basis of the rainfall amount suitability for mosquito breeding. The rainfall amount of

820 to 1000 mm and 1000 to1600 mm are given new values 4 and 5, respectively and leveled as high and very high malaria risk level.

3.4.1.2. Topographic Factors

Elevation

Elevation map was generated from SRTM 30 meter resolution Digital Elevation Model (DEM). The elevation map was reclassified on the basis of the relationship between elevation and malaria incidence that is based on previous research works and literatures. Then, the elevation of study area classified in to three classes as 1149 to 1500 m, 1500 to 2000 m and > 2000 m.a.s.l. and new values were assigned for each class as 5, 4, and 2, respectively. Finally elevation based malaria risk level is leveled as very high, high and low, respectively.

Slope

Slope map of the study area was generated from SRTM 30 meter resolution Digital Elevation Model. Then, the slope map was reclassified based on suitability of the slope for mosquito breeding by using spatial analyst tools in Arc GIS. The slope is classified in to five classes as: 0 - 5%, 5 - 8%, 8 - 15%, 15 - 30% and >30% and assigned new values as 5, 4, 3, 2, and 1, respectively. Slope based malaria risk level is described as very high, high, moderate, low and very low, respectively.

3.4.1.3. Proximity to water bodies related factors

The map which shows proximity of the study area to water bodies such as rivers, lakes and swamps generated from 1:50,000 scale topographic map of the area (EMA, 1980). The scanned topographic map was geo-referenced and rivers, lakes and swamps are digitized by Arc GIS. The distance calculation from water bodies and the reclassification processes was also done in Arc GIS.

Proximity to Rivers

The map showing proximity to rivers and canals is generated by using Euclidean distance in spatial analyst tools of Arc Map from digitized rivers and canals. The reclassification of rivers map is based on flight range of mosquito. Areas found < 1 km, 1 - 2 km and above 2 km from rivers and canals assigned new values as 5, 4 and 2 and classified as very high, high and low malaria risk level, respectively.

Proximity to Lakes

Proximity to lakes map is generated and reclassified in Arc GIS by using Euclidean distance calculation in spatial analyst tools. New values were assigned for regions located within < 1 km, 1 - 2 km and above 2 km as 5, 4 and 2.Then reclassified as very high, high and low malaria risk areas, respectively.

Proximity to swamps

As it was mentioned above, swamps are digitized from1:50,000 scale topographic maps obtained from Ethiopia Mapping Agency (EMA) and the map was generated in Arc GIS environment by using Euclidean distance calculation. The reclassification was done on the basis of mosquito flight range. Areas found below1 km, 1 - 2 km and above 2 km distances are given new values 5, 4, and 2 and reclassified as very high, high and low malaria risk level, respectively.

3.4.1.4. Land use land cover

The land use land cover map was produced from Land Sat (TM) image of the year 2010, which is obtained from EMA. Supervised classification technique was used to classify the image in ERDAS IMAGINE 2010. The land use land cover classification was verified by ground truth data (ground control points) collected for each land use land cover types by field survey. From all land use land cover types, a total of 203 ground control points were collected from the field by GARMIN GPS and simple random sampling technique was used for collection of ground control points. By using ground control points collected from the field, accuracy assessment for the algorithm/computer based classification was conducted for the classified image.

The land use land cover map was reclassified in to four classes depending on its suitability to mosquito breeding. According to literatures and previous works, farmlands are most suitable for mosquito breeding so, they classified as very high, forests and water bodies as high, because wet lands around the lakes create favorable conditions, settlement areas and bush lands are classified as moderate and bare lands are classified as low malaria risk level. Assigned new values for farmlands, forests and water bodies, settlement and bush lands and bare lands are 5, 4, 3 and 2 respectively.

3.4.1.5. Soil

Soil types of the study area reclassified based on their ability to hold moisture or based on being permeable or impermeable. As it was mentioned above in description part, Vertisols are very sticky poorly drained soils and Fluvisols are found along tidal marshes and alluvial plains allow water stagnation. So they reclassified as very high malaria risk level and assigned new value 5. Nitosols, those have also high moisture storage capacity are given new value 4 and reclassified as high malaria risk level. Solonchaks poorly drained soils are given new value 3 and classified as moderate risk level. Leptosols, Xerosols and Acrisols those have good drainage leveled as low malaria risk level and assigned new value 2.

3.4.2. Weight derivation

Environmental factors mentioned above are rated based on the level of their influence on mosquito breeding and their suitability for mosquito habitat. Since the aforementioned factors vary spatially, discussion was made with malaria experts of the Woreda to give weight for the factors. So the rating or assigning weights for the factors depends on previous works and literatures and the influence of the factors in the study area. Weights are assigned by pairwise comparison 9 point continuous rating scale in IDRISI 32. Factor weights are calculated by comparing two factors at a time depending on their importance.

3.4.2.1. Weight computation for proximity to water bodies related factors

Proximity to rivers, lakes and swamps rated based on their level of influence. Weight is calculated by pairwise comparison 9 point continuous rating scale in IDRISI 32. Since water body, particularly not moving is a typical place for mosquito breeding, swamps which provides best vector habitats are given high weight followed by lakes. Rivers, which are not stagnant and able to wash away mosquito habitats, are given less weight. Figure 11 and 12 show weight derivation of proximity to rivers, lakes and swamps and consistency ratio.

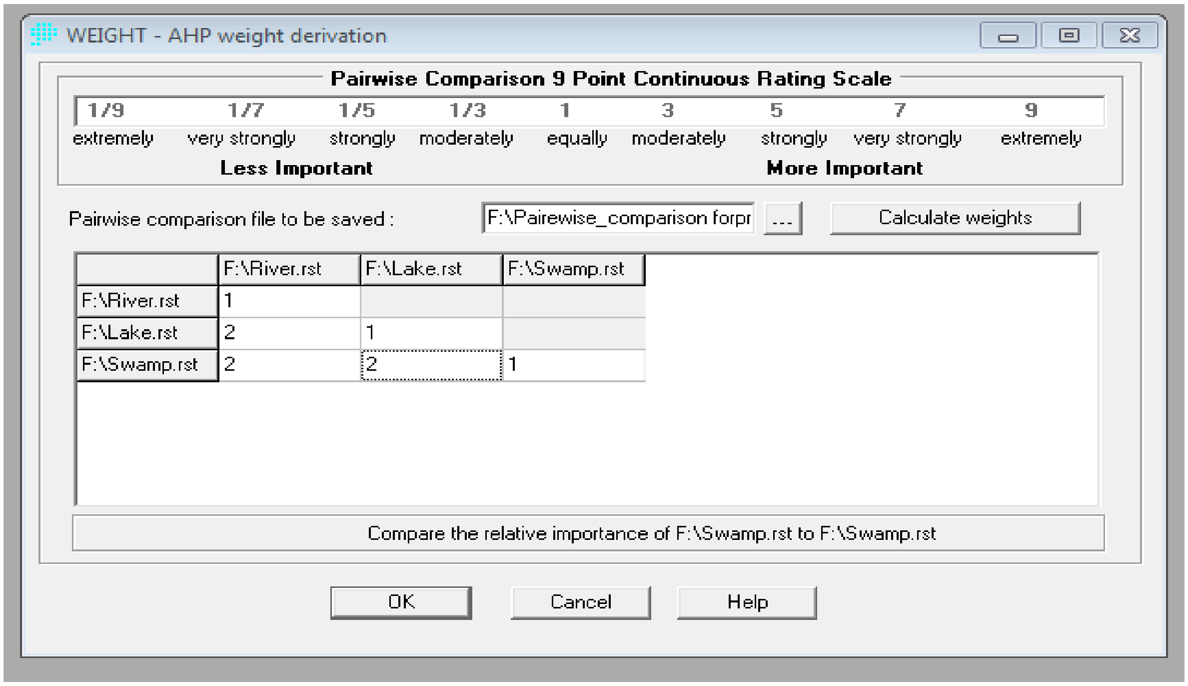

Figure 11: AHP weight derivation for proximity to rivers, lakes and swamps

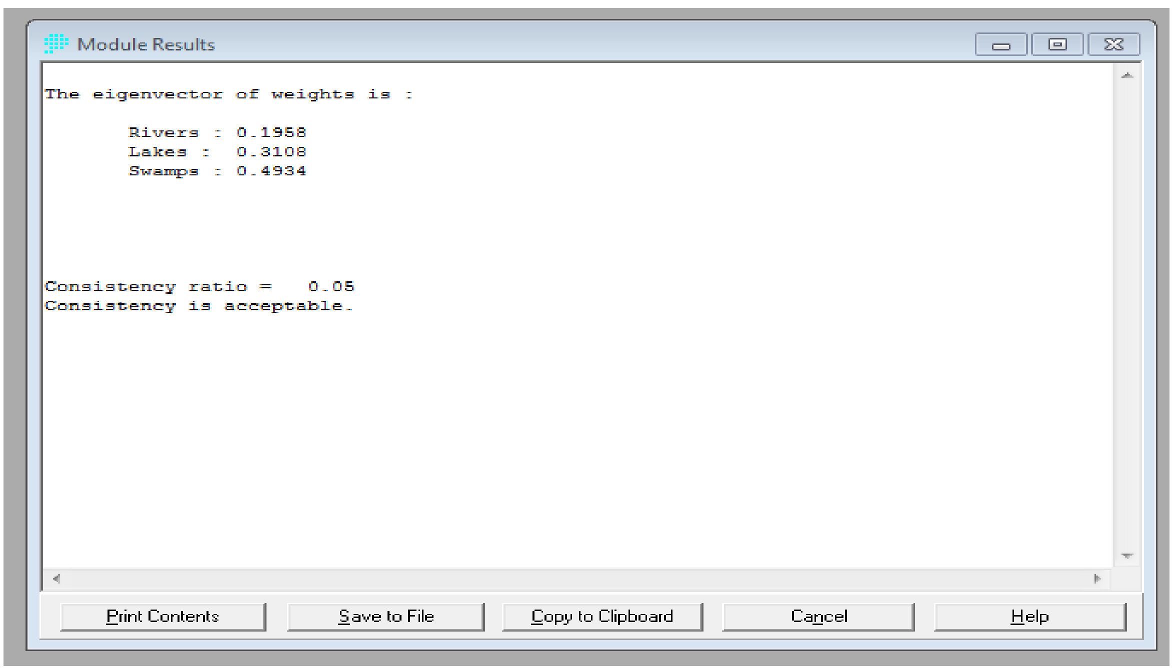

Figure 12: Module result for weight derivation of proximity to rivers, lakes and swamps

Proximity to water bodies based malaria risk map was developed by using weighted overlay tool in Arc GIS spatial analyst tools. Then proximity to rivers, lakes and swamp maps were overlaid depending on their assigned weights. Weights assigned for proximity to rivers, lakes and swamps described in table 3.

Table 3: Weights assigned for proximity to rivers, lakes and swamps

NO.	Proximity to water bodies Related factors	The Eigenvector of Weights	Percentage of Weights (%)
1	Rivers	0.1958	19.58
2	Lakes	0.3108	31.08
3	Swamps	0.4934	49.34
	Total	1	100

3.4.2.2. Weight derivation for all environmental factors under consideration

Malaria risk level of the study area is finally identified by assigning weights for previously discussed seven environmental factors. These are temperature, elevation, rainfall, slope, soil, land use land cover and proximity to water bodies. The importance of these factors for malaria incidence was discussed in chapter two, in the literature review part. These factors are rated based on their degree of importance that they have in mosquito breeding and malaria incidence. Weight is calculated by pairwise comparison 9 point continuous rating scale in IDRISI 32.

Regarding the weights assigned for the factors previous researches and local condition of the study area were taken in to consideration. As it was mentioned above to consider local condition, discussion was made with malaria experts of the Woreda. Depending on this temperature which determines the incubation rate and breeding activity of mosquito given the highest weight followed by elevation. Rainfall which provides *anopheles* breeding sites by causing soil saturation is given the third weight. Since the study area consists of two lakes, swamps, rivers and canals, proximity to water body related factors leveled as fourth factors and followed by slope, land use land cover and soil as fifth, sixth and seventh factors, respectively (Wilder, 2007; Afrane et al., 2011; Kumar et al., 2012; Burlando, 2012; Woime, 2008; Munga et al., 2006; Srivastava, 1995). Figure 13 and 14 show weight derivation of environmental factors and its consistency ratio.

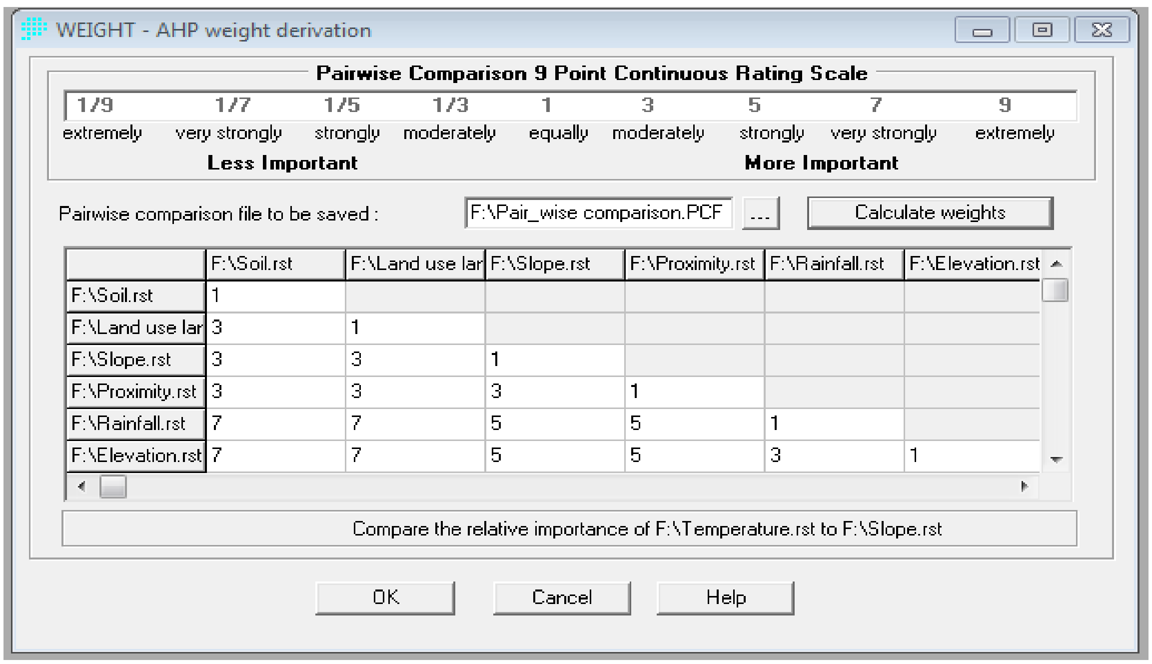

Figure 13: AHP weight derivation for elevation, temperature, rainfall, slope, soil, land use land cover and proximity to water bodies

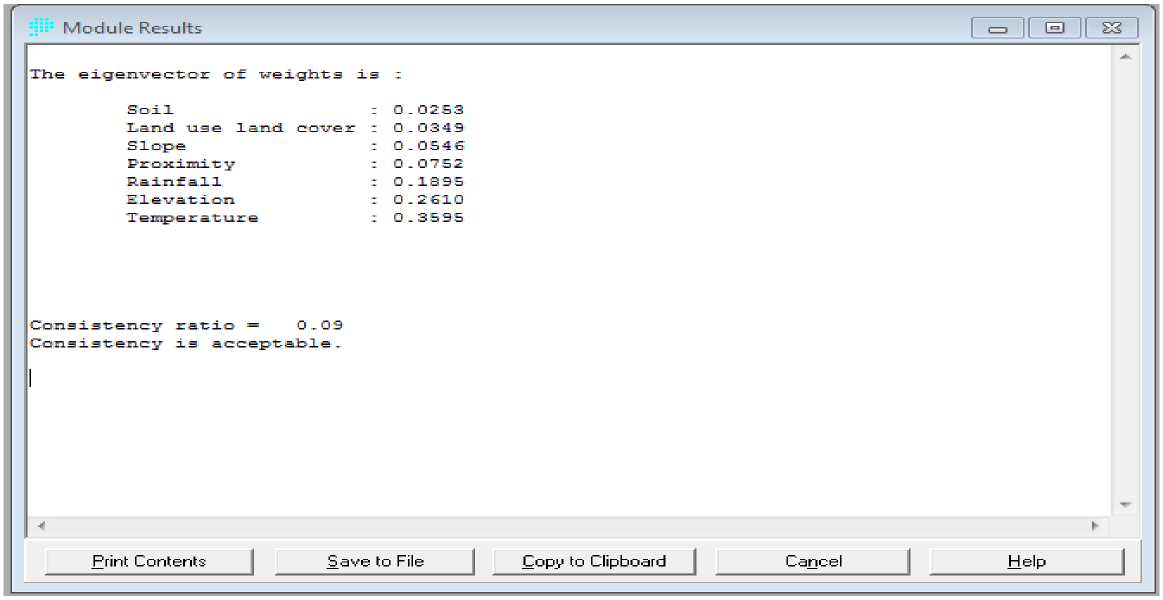

Figure 14: Module result for weight derivation of all environmental factors

Weights assigned for all environmental factors mentioned above described in the following table.

Table 4: Weights assigned for all environmental factors

No	Factors	The Eigenvector of Weights	Percentage of Weights (%)
1	Temperature	0.3595	35.95
2	Rainfall	0.1895	18.95
3	Elevation	0.2610	26.10
4	Slope	0.0546	5.46
5	Soil	0.0253	2.53
6	Land use land cover	0.0349	3.49
7	Proximity to water bodies	0.0752	7.52
	Total	1	100

The final malaria risk map was generated by using weighted overlay tool in Arc GIS. All factors mentioned above, temperature, rainfall, elevation, slope, soil, land use land cover and proximity to water bodies overlaid based on their weights.

CHAPTER FOUR

RESULTS AND DISCUSSIONS

4.1. The relationship of malaria risk with climatic factors

4.1.1. Relation of temperature with malaria infestation

As presented in figure 15, the reclassified temperature map, 62.2 km², 746.8 km² and 192 km² mapped as low, high and very high malaria risk level, respectively, which is based on suitability of the amount of temperature for mosquito breeding. As the figure shows most of the study area (93.8%) is in the temperature range between 20°C to 24°C, which is suitable for mosquito breeding. In the area where temperature amount is less than 20°C *Plasmodium falciparum* that causes severe malaria, cannot complete its life cycle in the Anopheles mosquito. On the other side, places with temperature amount >30°C are difficult for larval survivorship (Afrane et al., 2011). So the average temperature between 20°C to 24°C is suitable for malaria incidence thus leveled as high and very high risk level of malaria.

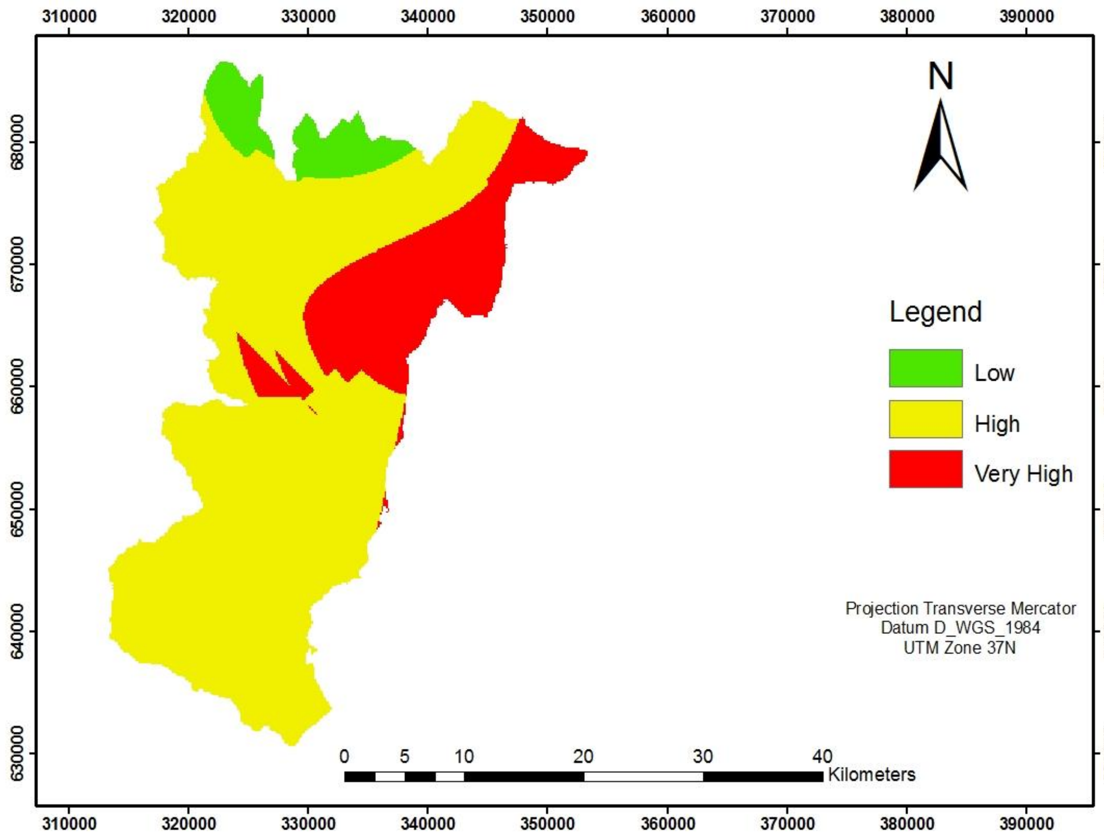

Figure 15: Reclassified temperature based malaria risk map

4.1.2. Rainfall and malaria risk level

The reclassified rainfall map (Figure 16) shows that 118 km^2 areas have high risk of malaria and the rest 883 km^2 areas have very high risk of malaria depending on the amount of rainfall. Based on the amount of rainfall, the whole study area is in very high and high risk of malaria. This is due to the annual rainfall amount, ranges between 820 mm to 1600 mm conducive for mosquito breeding. The following figure shows rainfall based malaria risk level of the study area.

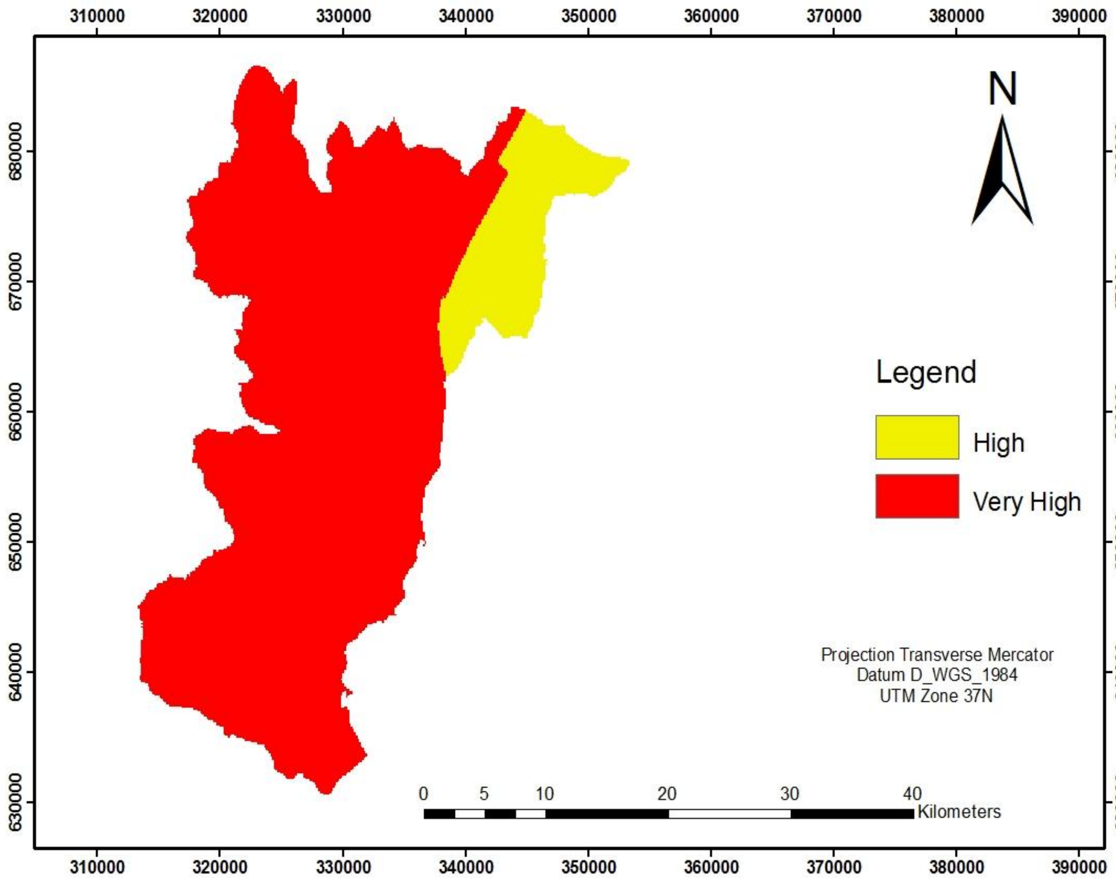

Figure 16: Reclassified rainfall based malaria risk map

4.2. Relationship between topographic factors and malaria incidence level

4.2.1. Elevation and malaria risk level

Figure 17, the reclassified elevation map covering 207.5 km^2, 289.5 km^2 and 504 km^2 were mapped as areas of low, high and very high malaria risk level, respectively. From this figure, it is possible to deduce that 79.3% of the study area is in high and very high malaria risk. In Ethiopia malaria frequently occurs in areas with elevation below 2000 m above sea level and its transmission is very intense below 1500 m. So, 79.3% area's elevation ranges between 1149 to 2000 m above sea level, which is potentially malariuos.

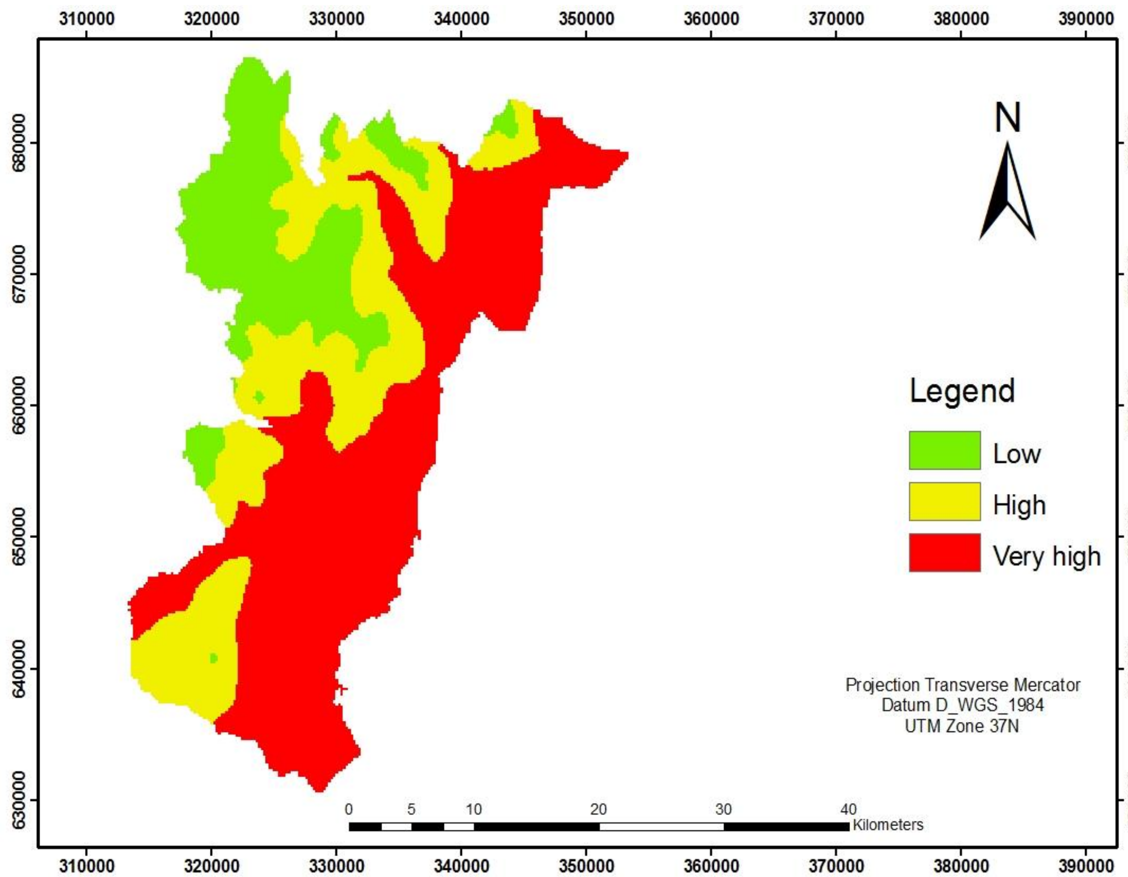

Figure 17: Reclassified elevation based malaria risk map

4.2.2. Relation of Slope and malaria incidence

Based on the suitability of the slope for mosquito breeding, the reclassified slope map shows 93 km² area is in very low, 278 km² in low, 221 km² in moderate, 107 km² in high and 302 km² in very high risk of malaria incidence. Of the total area, 40.9% is in high and very high malaria risk level, while the rest (59.1%) area is in moderate, low and very low risk level. Areas leveled as high and very high risk level have, slope less than 5% and 5 - 8% that allow water stagnation and create suitable conditions for mosquito breeding. The following figure shows slope based malaria risk level (Figure 18).

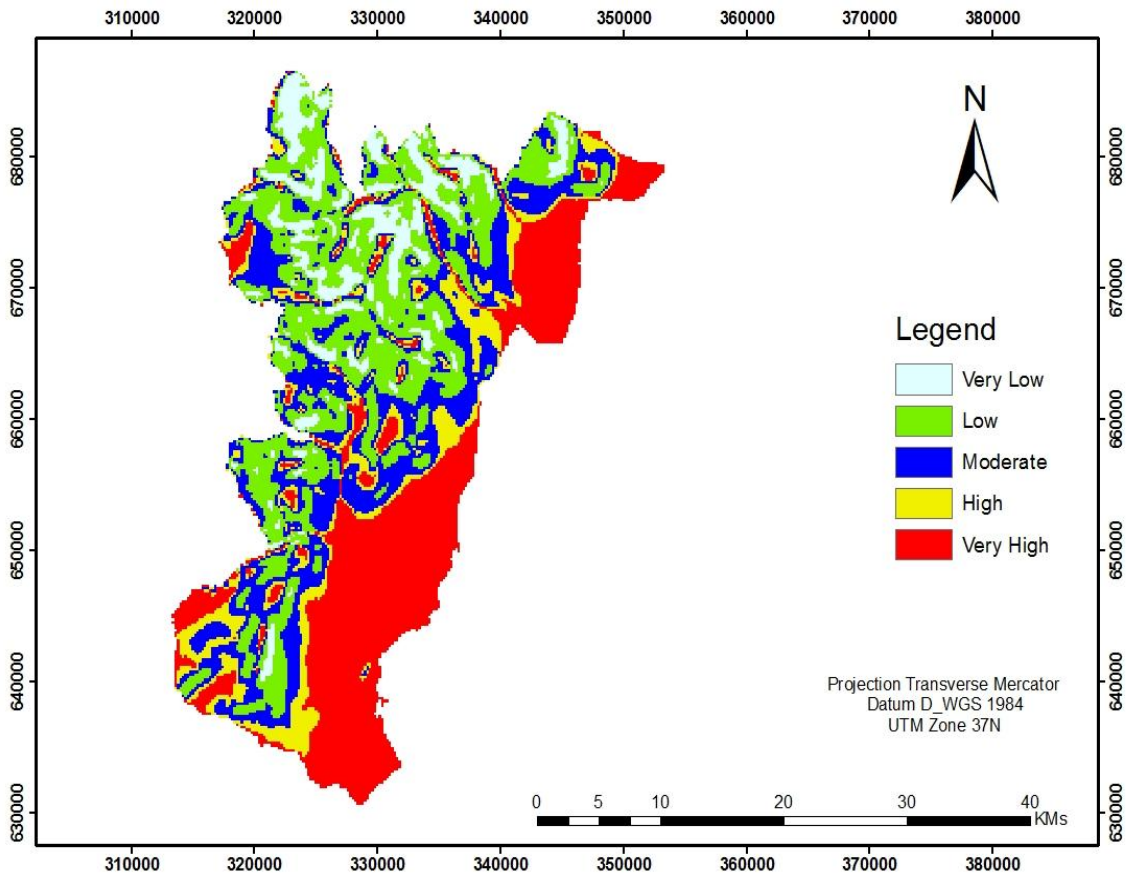

Figure 18: Reclassified slope based malaria risk map

4.3. Proximity to water bodies and malaria risk level

The proximity to water bodies map is the result of overlaid proximity to rivers, lakes and swamp maps. This shows that 477 km^2 have low, 488 km^2 have moderate, while the remaining 29km^2 and 7km^2 have high and very high malaria risk level, respectively. This implies that very high and high malaria risk level cover only 3.59% of the study area. This is the result of small area coverage of swamps and lakes, those are given higher weights. Very high and high malaria risk observed in few areas located within 1 km and 2 km distance from lakes and swamps. Since rivers are given less weight compared to swamps and lakes due to their non-stagnant characteristics, areas located closer to rivers are mapped as moderate risk level. Areas located above 2 km distance from rivers, lakes and swamps are mapped as low malaria risk level. This shows the same result to study conducted in Fentale Woreda, concluded that areas located closer to (< 2000 meters) rivers, irrigation canals and lakes are in high risk of malaria than areas further away (Lemessa,2011). Figure 19 portrays proximity to water bodies based malaria risk level.

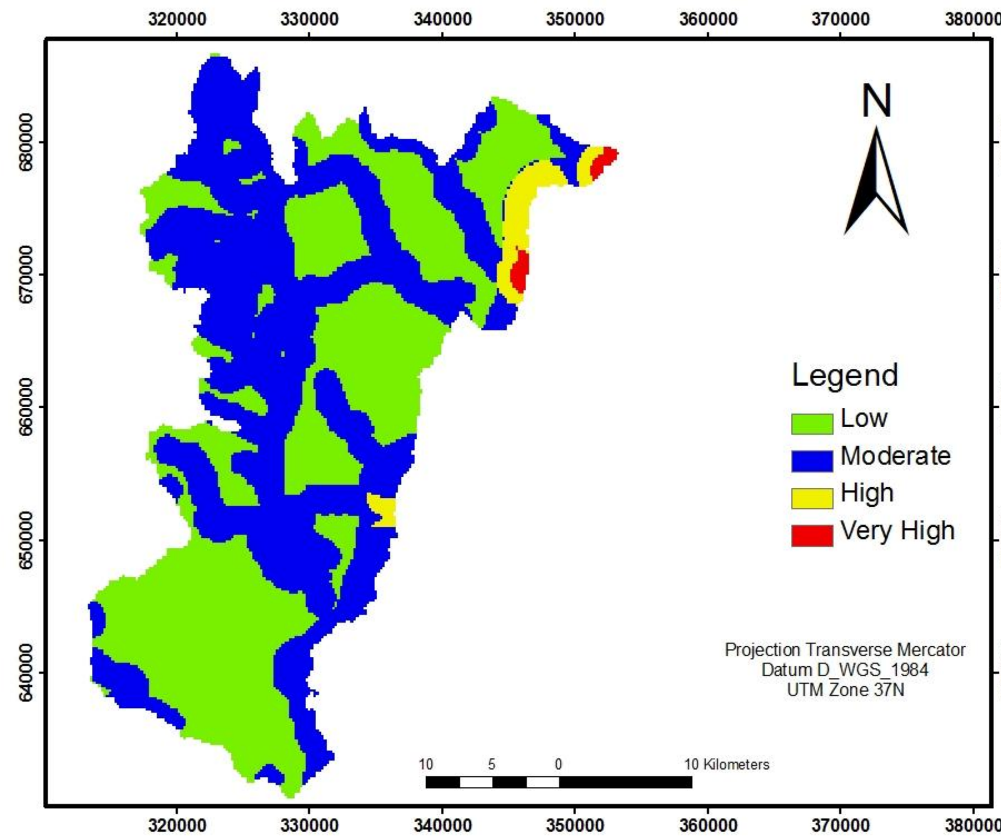

Figure 19: Proximity to water bodies based malaria risk level

4.3.1. Proximity to Rivers

The reclassified map which shows distance to rivers indicates that low malaria risk covers 326 km², high malaria risk covers 239 km² and very high risk 436 km² area. This is based on flight range of mosquito. Since mosquito can fly 2 km from its breeding site, areas mapped as very high, high and low malaria risk located < 1 km, 1 - 2 km and > 2 km distance, respectively. Figure 20 shows proximity to rivers based malaria risk level of the study area.

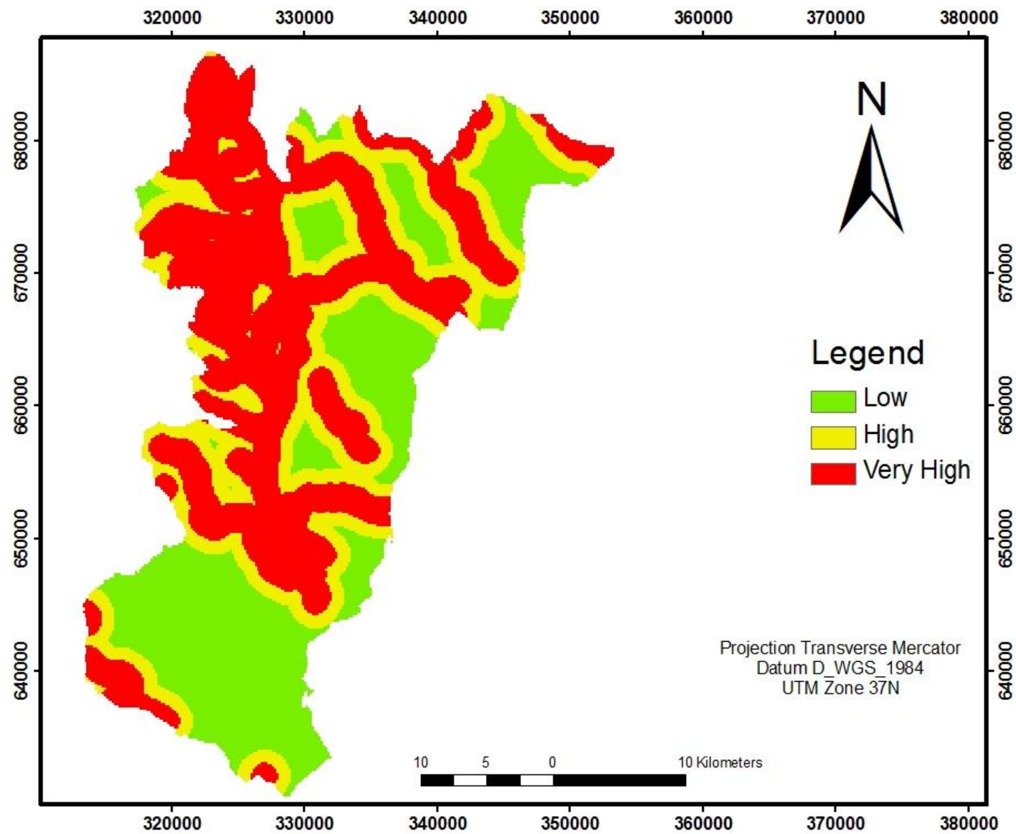

Figure 20: Reclassified proximity to rivers and canals based risk map

4.3.2. Proximity to Lakes

The study area comprises two lakes namely: Lake Abaya and Lake Chamo. During rainy seasons, these lakes get over flooded and create suitable environment for mosquito breeding. Since mosquito can fly 2 km from its breeding site, people living closer to lakes are under high malaria risk.

Since the boundary of the study area is restricted, it doesn't include the whole portion of the lakes. It includes very small portion of the lakes. So, few Kebeles are bordered by the lakes. Figure 21 shows that, based on the proximity to the lakes 898.4 km^2 has low, 50.9 km^2 has high and 51.7 km^2 has very high risk of malaria incidence. From this figure, it is possible to deduce that most of the study area is far from the lakes. Hence, only 10.3% of the total area falls in high and very high malaria risks level.

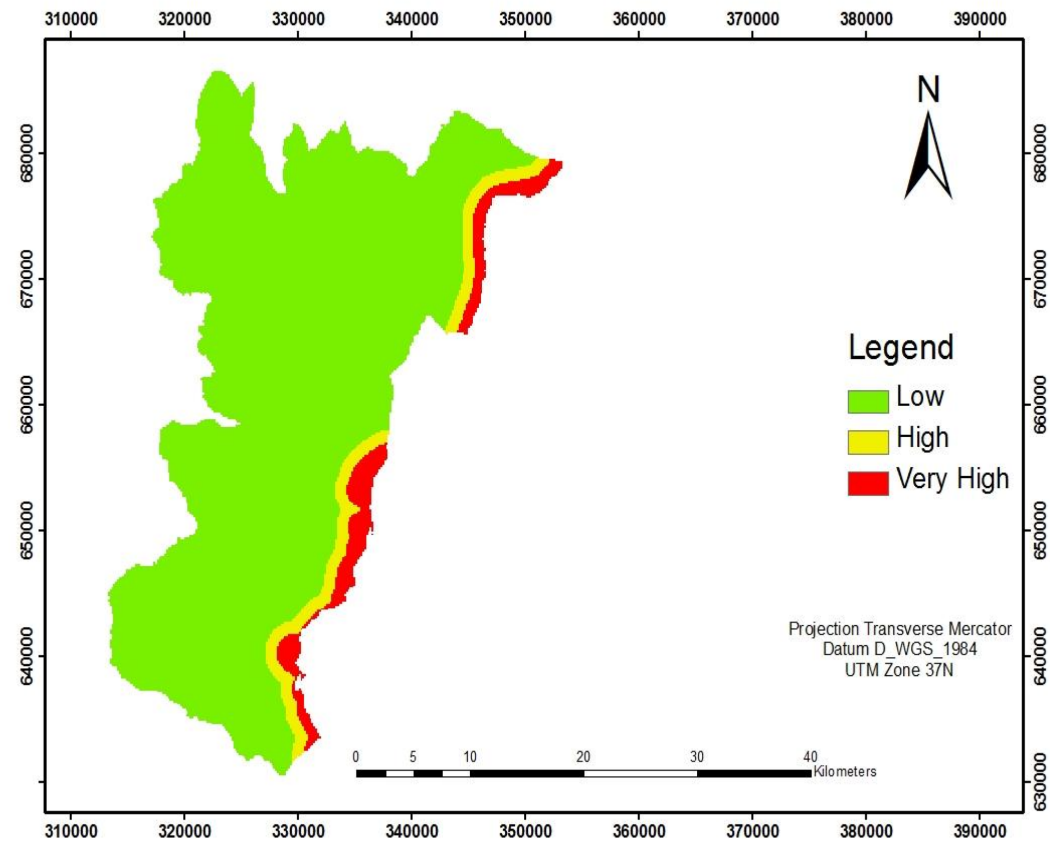

Figure 21: Reclassified proximity to lakes based malaria risk map

4.3.3. Proximity to Swamps

In the study area, swamps are located along Lake Abaya. Swampy areas are suitable for mosquito breeding because they promote reproduction and maintenance of stable mosquito population. Based on the proximity to swamps, the majority of study area is in low risk of malaria that cover 971 km^2. High and very high risk level areas account for 17.9 km^2 and 12.1 km², respectively. Since swamps cover very small area, regions fell in high and very high risk level become small. Figure 22 portrays proximity to swamps based malaria risk level.

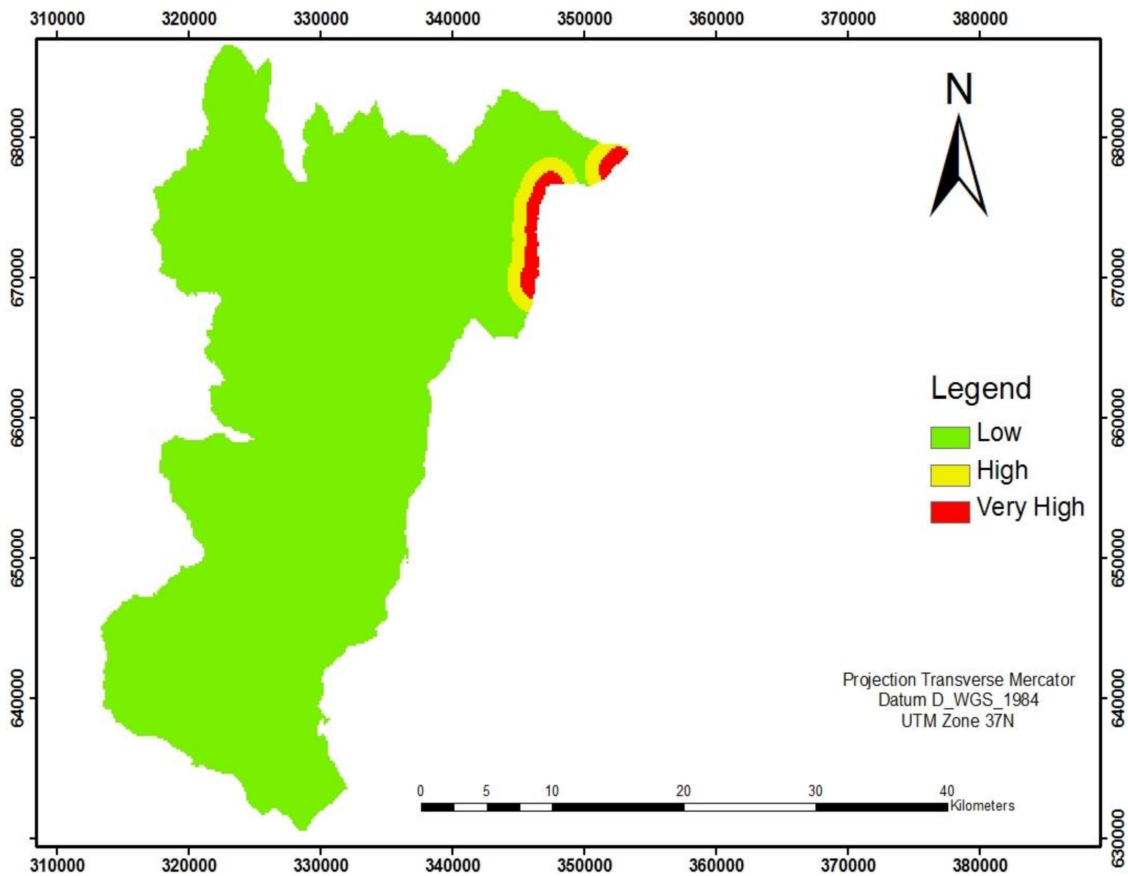

Figure 22: Reclassified proximity to Swamps based malaria risk map

4.4. Land use land cover

Based on the supervised classification done for the satellite image, the study area has six major land use land cover types. Such as settlement, farmland, water body, bare land, forest and bush land. From the total area coverage they account 125km^2, 461km^2, 8.5km^2, 8.5km^2, 57km^2 and 341km^2 respectively. Figure 23 shows the major land use land cover types of the study area.

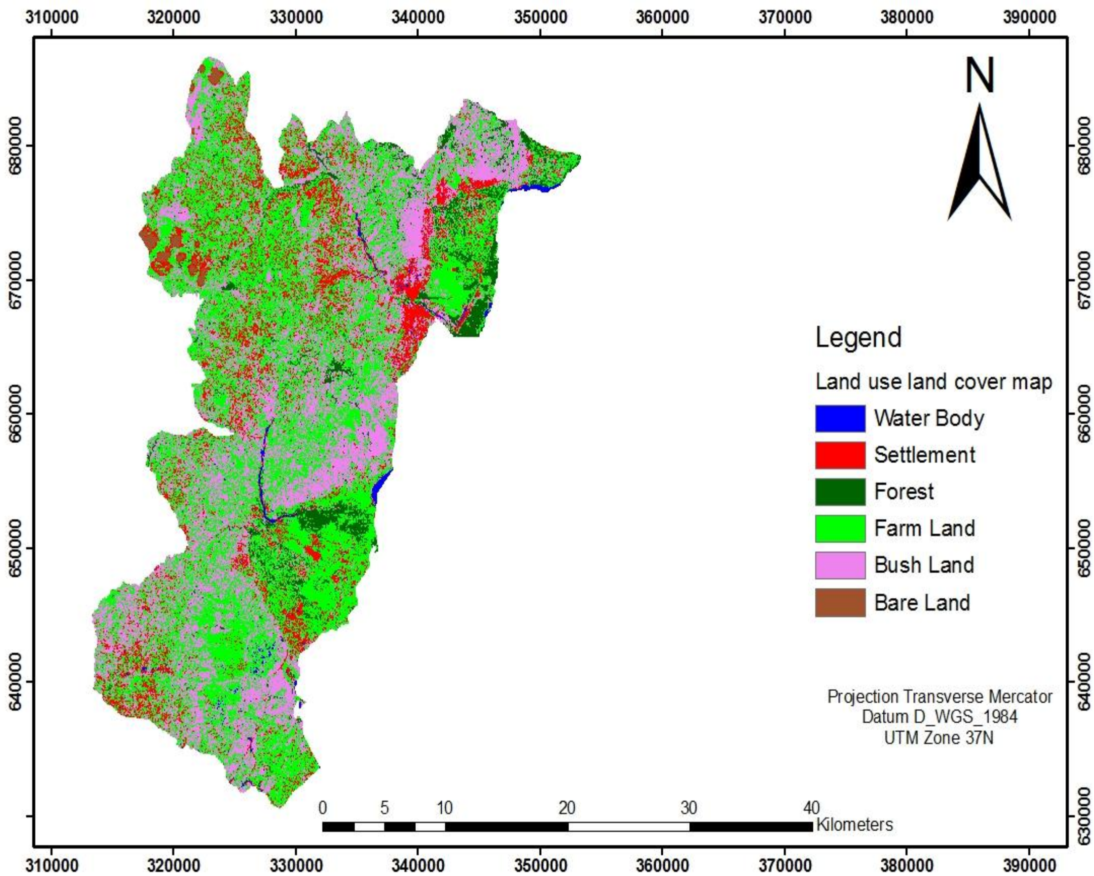

Figure 23: Land use land cover map of the study area

Based on accuracy assessment done for land use land cover map, the overall classification accuracy is 78.82% and an overall kappa statistics is 0.736. The kappa coefficient shows that 73.6% errors were avoided that could be generated by simple random classification. According to Landis and Koch (as cited in Cunningham, 2009), the values of kappa can ranges from +1 to -1.The agreement between the remotely sensed classification and the reference data is poor when the kappa value is < 0, slight between 0 – 0.2, fair 0.21 – 0.4, moderate between 0.41 – 0.6, substantial 0.61 – 0.8 and almost perfect from 0.81 to 1.Thus, the kappa coefficient of 0.736 is in substantial agreement range. The producers and users accuracy of the classification ranges between 62.5% -

95.12% and 60.71% - 94.44% respectively. Table 5 shows the classification accuracy assessment of land use land cover map.

Table 5: Accuracy assessment matrix

Classified Data	Water Body	Farm Land	Forest	Bare Land	Settlement	Bush Land	Row Total	Producers Accuracy	Users Accuracy	Kappa Coefficient
Water Body	17	0	0	0	1	0	18	80.9%	94.44%	0.9380
Farm Land	1	39	2	1	5	0	48	76.4%	81.25%	0.7496
Forest	3	8	17	0	0	0	28	77.2%	60.71%	0.5594
Bare Land	0	0	0	10	1	0	11	62.5%	90.91%	0.9013
Settlement	0	2	1	2	38	2	45	73.0%	84.44%	0.7909
Bush Land	0	2	2	3	7	39	53	95.1%	73.58%	0.6690
Column Total	21	51	22	16	52	41	203			

The overall classification accuracy is 78.82%

The overall kappa statistics is 0.736

Figure 24 shows land use land cover based malaria risk level. From the total area, 461 km^2 leveled as very high risk of malaria, 65.5 km^2 as high, 466 km^2 as moderate and 8.5 km^2 as low risk of malaria incidence based on the suitability of land use land cover types for mosquito breeding. The area reclassified as very high and high malaria risk level covered by farmlands, water bodies and forests. A similar result with a study conducted in highland community of Africa, which discussed that the highest proportions of *anopheline* positive habitats occurred in pastures and farmlands followed by swamps

(Munga et al.,2009). Thus areas covered by farmlands leveled as very high risk level followed by water bodies and forests as high risk level. Bare land which lacks moisture content and food source for larva leveled as low malaria risk level.

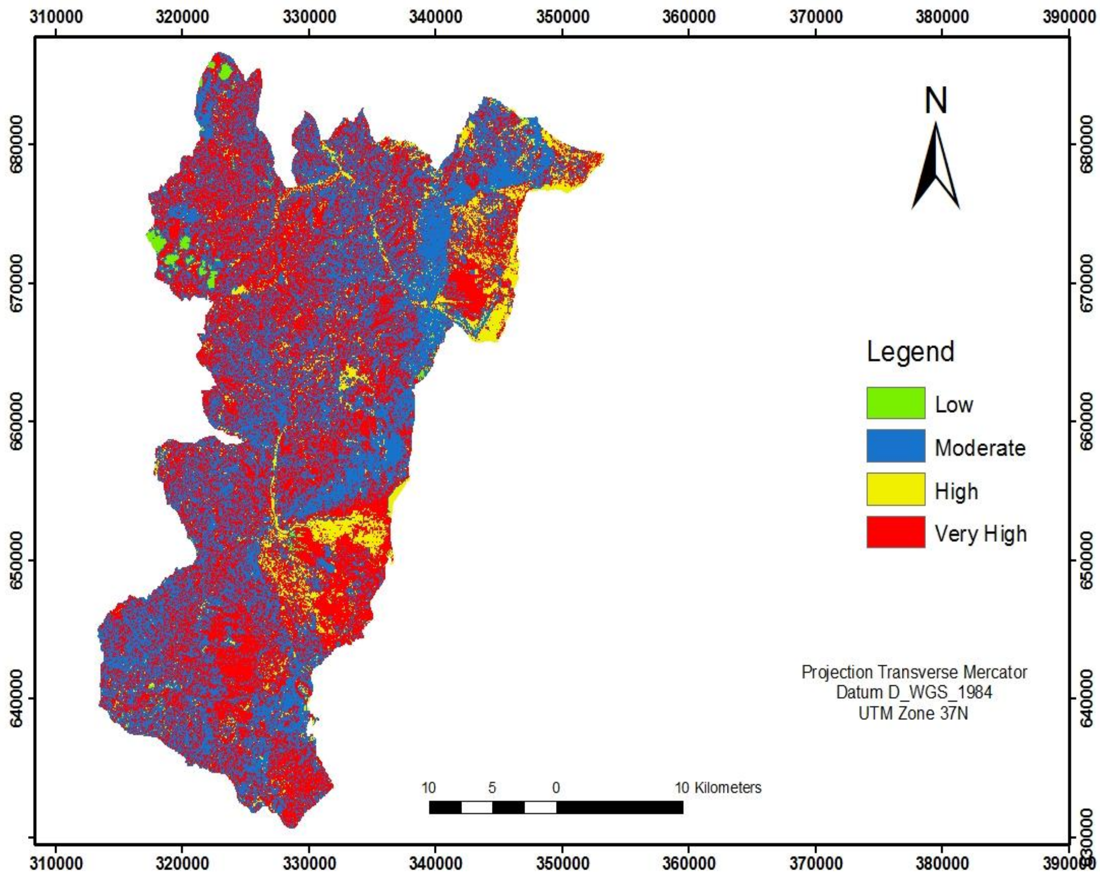

Figure 24: Reclassified land use land cover type based malaria risk map

4.5. Soil type and malaria risk level

The reclassified soil map shows that 358.6 km^2 area mapped have very high, 80 km^2 high, 85 km^2 moderate and 477.4 km^2 areas have low risk of malaria. The reclassification was based on water storage capacity of soils, which determines their suitability for mosquito breeding. Vertisols and Fluvisols, those are poorly drained soils leveled as very high risk level, cover 358.6 km^2. Nitosols cover 80 km^2 have good water storage capacity and mapped as high malaria risk level followed by Solonchaks as moderate and Xerosols, Leptosols and Acrisols as low malaria risk level (Figure 25).

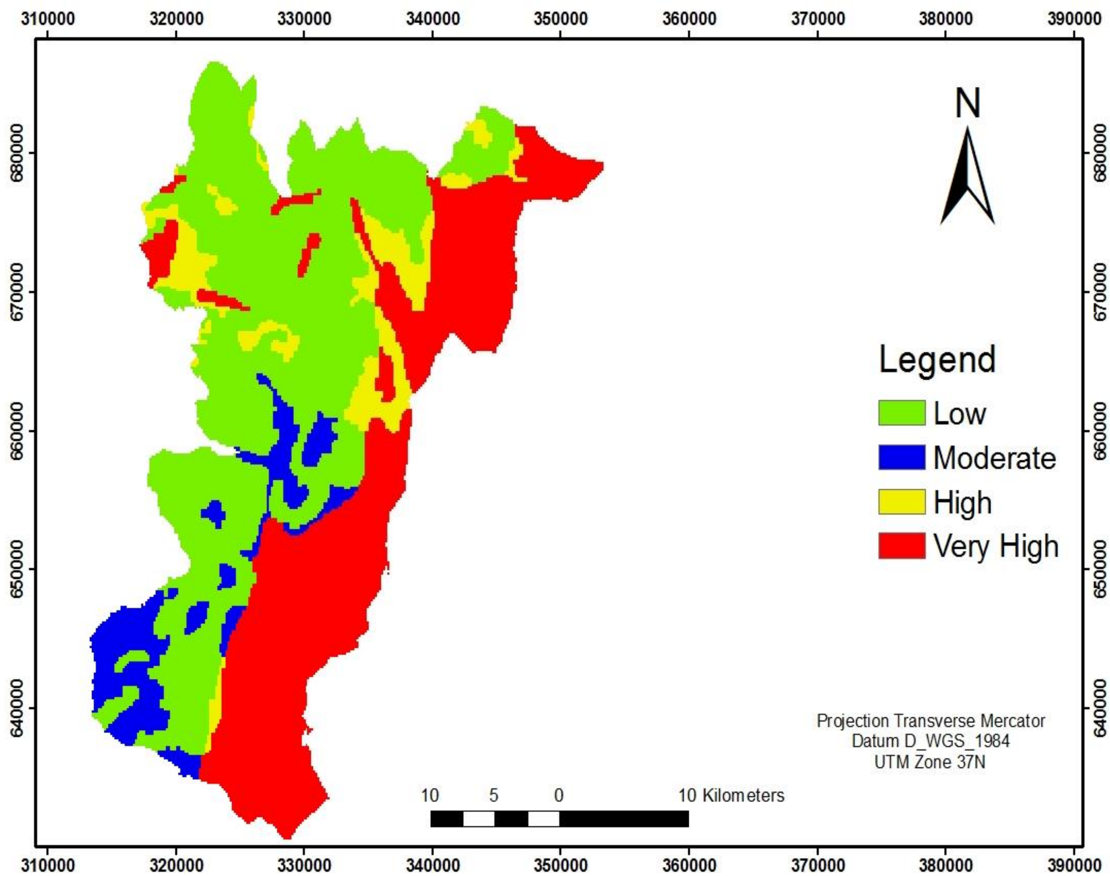

Figure 25: Reclassified soil type and malaria risk level

4.6. Malaria risk map

The final malaria risk map produced by overlaying all environmental factors mentioned above displays that from the total area coverage of the study area 580 km^2 in high, 357 km^2 moderate and 64 km^2 low level of malaria incidence. This shows that the majority of study area fell in high risk level (58 %) and followed by moderate risk level (35.7%). Low malaria risk level is found in very small area, which occupies only 6.3 % of the total area coverage. Figure 26 shows malaria risk map of the study area.

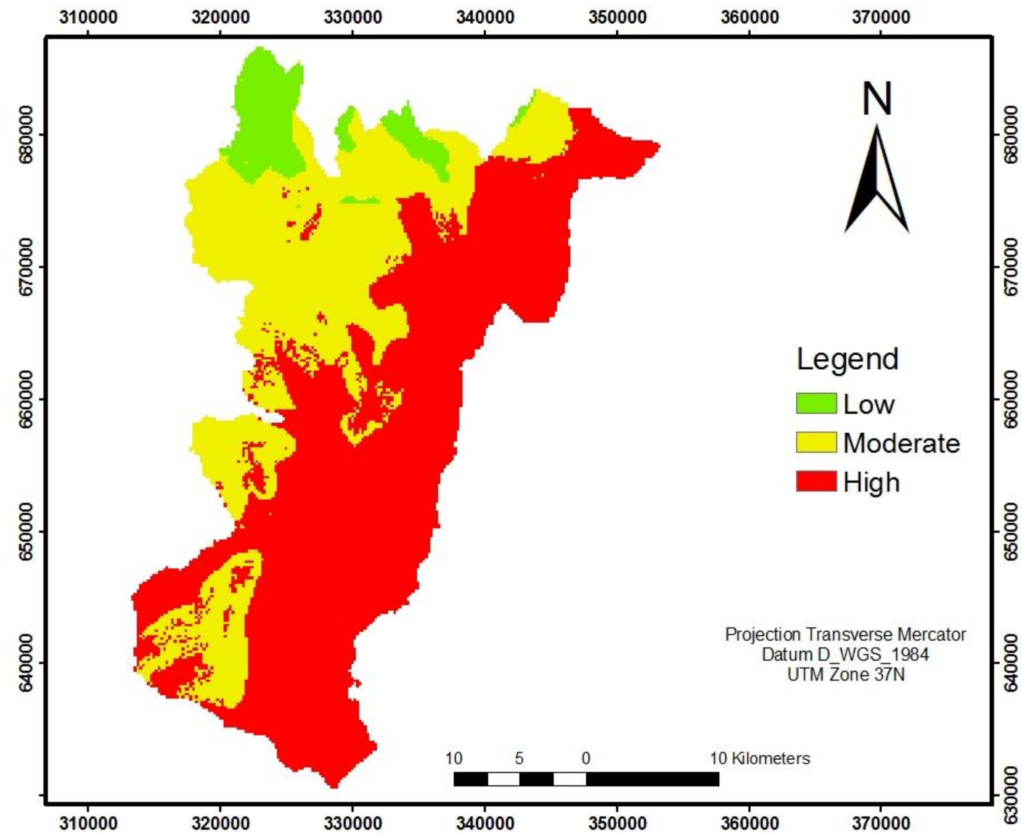

Figure 26: Final Malaria Risk Map

Table 6: Summary of factors risk level and their area coverage

NO.	Factors	Area(Km^2)	Percentage (%)	Risk Level	Assigned Value
1.	Temperature	62.2	6.2	Low	2
		746.8	74.6	High	4
		192	19.2	Very High	5
2.	Rainfall	118	11.8	High	4
		883	88.2	Very High	5
3.	Elevation	207.5	20.7	Low	2
		289.5	29	High	4
		504	50.3	Very High	5
4.	Slope	93	9.3	Very Low	1
		278	27.8	Low	2
		221	22	Moderate	3
		107	10.7	High	4
		302	30.2	Very High	5
5.	Land use land cover	8.5	0.85	Low	2
		466	46.55	Moderate	3
		65.5	6.54	High	4
		461	46.06	Very High	5
6.	Soil	477.4	47.7	Low	2
		85	8.5	Moderate	3
		80	8	High	4
		358.6	35.8	Very High	5
7.	Proximity to water bodies	477	47.65	Low	2
		488	48.76	Moderate	3
		29	2.9	High	4
		7	0.69	Very High	5
8.	Final Malaria Risk Map	64	6.3	Low	2
		357	35.7	Moderate	3
		580	58	High	4

4.7. Comparing malaria risk level with kebeles

The malaria risk level of different Kebeles was observed by overlaying the malaria risk level analysis map and Kebeles boundary map. Accordingly, among all Kebeles in the study area, Arba Minch town, Lante, Chano Mille, Chano Chaliba, Chano Doriga, Shelle Mella, Kola Shelle, and Sille Ersha Limat are fully fall in high risk of malaria incidence. Kolla Shara, Genta Meyche, Genta Ocholle, Genita Kanchema, Zeyse Eligo,Garibansa Koyra, Zeyise Dembile and Wozeqa Kebeles are mapped partially in high malaria risk level. This is the result of suitable climatic conditions, topography and proximity to swamps and lakes. Few Kebeles, such as Mazo Doysa, Kuyle, Dega Shara and partial Sule, Tsayti, and Wisamo are mapped in low malaria risk level. The areas mapped as low malaria risk are due to high elevation (above 2000 meters above sea level), cold climatic conditions and other factors which does not support mosquito breeding. The rest Kebeles located in the north western part of high risk areas and in south eastern part of low malaria risk areas have moderate level of malaria incidence. Figure 27 reveals comparison of malaria risk level with Kebeles.

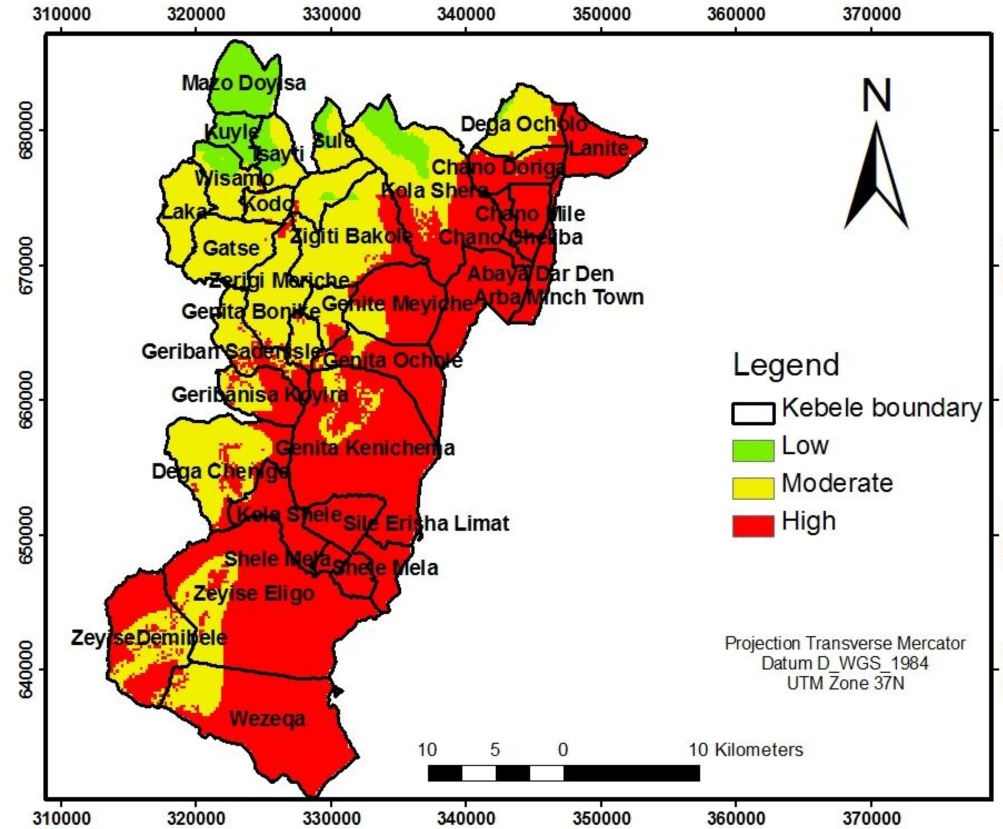

Figure 27: Malaria risk level in Kebeles

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

5.1. Conclusion

The main objective of this study was to generate malaria risk map of Arba Minch Zuria Woreda including the town of Arba Minch by using environmental factors. It was also intended to identify the risk level of Kebeles found in the study area.

Environmental factors used to generate malaria risk map of the study area include temperature, rainfall, elevation, slope, land use/land cover, soil and proximity to rivers, lakes and swamps. Maps were generated for all environmental factors and then reclassified based on their suitability for mosquito breeding and malaria incidence. Depending on the influence of factors, weight was computed by using pairwise comparison 9 point continuous rating scale. Then weighted overlay was undertaken to produce the final malaria risk map.

The final malaria risk map of the study area shows that from the total area, 58 % is mapped in high, 35.7% in moderate and 6.3 % in low level of malaria risk. The majority of study area fall in high risk level (58 %) which is followed by moderate risk level (35.7 %).

Based on Kebele wise comparison, eight kebeles including the town of Arba Minch which located in the eastern part are fully mapped in high malaria risk level and another eight Kebeles which are adjacent to high malaria risk level Kebeles partially located in high malaria risk level. Six kebeles which are bordering high risk level areas mapped under moderate malaria risk level. Other six Kebeles located in the northern parts of the study area are fully or partially mapped as low malaria risk level.

For the presence of high level malaria risk, the existence of suitable climatic condition and topography particularly elevation for mosquito breeding play major role. The role of proximity to water bodies is negligible since the location of lakes and swamps is restricted to very few Kebeles. Low malaria risk level is confined to areas with high elevation above 2000 m.a.s.l. and cold climatic condition, which is not favorable for mosquito breeding.

Finally, this project work confirmed that GIS and remote sensing technology is very important for analysis of spatial data. In this study GIS played great role in the generation of maps for environmental factors, reclassification, overlaying and identification of risk level. Remote sensing also played an important role by providing environmental information. Therefore, GIS and remote sensing technology is vital tool for health sector, particularly to facilitate vector born disease control and prevention program.

5.2. Recommendations

This project is classified the study area in to three malaria risk level, high, moderate and low based on environmental factors those create conducive environment for mosquito breeding and malaria incidence. Hence the followings are recommended by the researcher.

- The Woreda health office could make malaria prevention and control program like, anti – malaria drug provision, bed net distribution and house spraying by prioritizing based on the risk level of areas.
- GIS and Remote Sensing technology makes vector born diseases prevention and control program easy by enabling to map the breeding habitat, risk level and to make prediction to establish early warning system for impending epidemics. So, if possible the Woreda health office could use GIS and Remote Sensing technology for vector born disease prevention and control programs.
- Even though the role of swamps and other water bodies in the study area is insignificant, as compared to the climatic and topographic factors, to reduce the level of exposure to malaria in areas closer to swamps, the community and other concerned bodies should design appropriate facilities to drain swamps and stagnant water.
- Further studies could made by using the already identified environmental factors in this project and by integrating additional parameters beyond environmental factors those may contribute for malaria incidence and transmission like population migration, housing style, health facilities and so on for more accuracy.

References

Abeku,T.A.(2006). Malaria epidemics in Africa prediction, detection and response. (Unpublished doctoral dissertation).Erasmus University Rotterdam.

Afrane,Y.A., Githeko, A.K., and Yan, G. (2011). Malaria transmission in the African highlands in a changing climate situation: Perspective from Kenyan highlands, global warming impacts:- case studies on the economy, human health, and on urban and natural environments, Stefano Casalegno (Ed.), ISBN: 978-953-307-785-7.

Agarwal,S.A., Sikarwar, S.S., and Sukumaran, D. (2012). Application of RS & GIS in risk area assessment for mosquito borne diseases:- A case study in a part of Gwalior City (M.P.) *International Journal of Advanced Technology & Engineering Research, 2 (1), 2250-3536.*

Amdie, Z. (2007). Land use/ land cover dynamics and vegetation vulnerability analysis: A case study of Arsi Negele Woreda. (Unpublished master's thesis).Addis Ababa University, Ethiopia

Boelaert,M., Arbyn,M., and Van der Stuyft,P.(1998). Geographical Information Systems (GIS), gimmick or tool for health district management? *Tropical Medicine and International Health, 3 (3), 163–165*

Brian,M.(1989). Malaria. In Adams M. and Brian, M. eds. Clinical tropical diseases, 9th ed. Blackwell Scientific ed., London

Burlando, A. (2012). The impact of malaria on education: Evidence from Ethiopia. (Unpublished research paper). University of Oregon

Ceccato,P., Connor, S.J., Jeanne, I., and Thomson, M.C. (2005). Application of geographical information systems and remote sensing technologies for assessing and monitoring malaria risk. *Parassitologia, 47, 81-96.*

Clarke,K.C.,McLafferty, S.L., and Tempalski, B.J. (1996). On epidemiology and geographic information systems: a review and discussion of future directions. *Emerging Infectious Diseases, 2 (2), 85-92*

CSA. (2008). Central statistical agency of Ethiopia population and housing census report. Addis Ababa, Ethiopia

Cunningham.(2009).More than just the Kappa coefficient: A program to fully characterize inter-rater reliability between two raters.SAS Global Forum, paper 242.University of Pittsburgh, Pittsburgh, PA.

Dutta,S.(2006). Malaria epidemiology on Jalapaigur district applying remote sensing and Geographic information system. (Unpublished dissertation paper). University of North Bengal

EMA. (1980).1:50,000 scale topographic map of Arba Minch area .Addis Ababa

ESRI.(1990). Understanding GIS: - The Arc/Info method. Environmental systems research institute, Redlands, CA, USA

FAO.(1984). Ethiopian geomorphology and soils (1:1,000,000 scales). Assistance to land use planning, Addis Ababa, Ethiopia.

FAO.(2006). World reference base for soil resources. A framework for international classification, correlation and communication. Rome: Italy

FMoH. (2003).Malaria prevention and control extension package. Addis Ababa, Ethiopia

FMoH. (2008). Ethiopian national malaria indicator survey 2007: Technical summary. Addis Ababa, Ethiopia

Gimnig, J.E.,Hightower,A.W., and Hawley, W.A. (2005). Application of geographic information systems to the study of the ecology of mosquitoes and mosquito-borne diseases. Centers for Disease Control and Prevention, Division of Parasitic Diseases, Atlanta.

Hurni, H. (1998). Agro-ecological belts of Ethiopia: Explanatory notes on three maps at a scale of 1:1,000,000.Research report, Soil Conservation Research Program. Addis Ababa, Ethiopia

Jackman,J.A., and Olson,J.K. (1914). Mosquitoes and the diseases they transmit. Texas Cooperative Extension, the Texas A & M University System.

Kapetsky,J.M.D., and Aguilar-Manjarrez,J.(2007). Geographic information systems, remote sensing and mapping for the development and management of marine aquaculture. FAO fisheries technical paper 458. Rome, Italy.

Kaya,S., Pultz, T.J., Mbogo, C.M., Beier, J.C., and Mushinzimana, E. (2002). The use of radar remote sensing for identifying environmental factors associated with malaria risk in Coastal Kenya. A research submitted to the international Geoscience and Remote Sensing Symposium (IGARSS ’02).Toronto.

Kimbi,H.K., Sumbele,I.U., Nweboh,M., Anchang,J.K., Lum,E., Nana,Y., Ndip,L.M., Njom,H., and Lehman,L.G.(2013). Malaria and haematologic parameters of pupils at different altitudes along the slope of Mount Cameroon: - A cross-sectional study. *Malaria Journal, 12,193.*

Kumar Ra, P., Nathawat, M.S., and Onagh, M. (2012). Application of multiple linear regression model through GIS and remote sensing for malaria mapping in Varanasi District, INDIA *Health science Journal, 6 (4), 731-749*

Lemassa, A. (2011). GIS and remote sensing based malaria risk mapping in Fentale woreda, East Shoa zone, Ethiopia. (Unpublished master's thesis). Addis Ababa University, Ethiopia

Milla,K.A., Lorenzo,A., and Brown,C.(2005). GIS, GPS, and Remote Sensing Technologies in Extension Services: Where to Start, What to Know. *Journal of Extension, 3, 43*

MOA.(1998).National livestock development project working paper 1 – 4.Addis Ababa, Ethiopia

Mohammed,H., Kassa,M., Kebede,A., and Endeshaw.,T.(2012). Paracheck-pf® test versus microscopy in the diagnosis of *falciparum* malaria in Arba Minch Zuria Woreda of South Ethiopia .*Ethiop J Health Science, 22(2), 93-98*

Munga, S.,Minakawa, N., Zhou, G., Mushinzimana, E., Barrack, J., Githeko, K., and Yan, G. (2006). Association between land cover and habitat productivity of malaria vectors in Western Kenyan highlands. *American Journal of Tropical Medicine and Hygiene 74, 69-75.*

Munga,S.,Yakob,L.,Mushinzimana,E.,Zhou,G.,Ouna,T.,Minakawa,N.,Githeko,A.,andYan,G. (2009). Land use and land cover changes and spatiotemporal dynamics of *Anopheline* larval habitats during a four year period in a highland community of Africa. *American Journal of Tropical Medicine and Hygiene, 81(6), 1079–1084.*

NIAID. (2007). Understanding Malaria: Fighting an ancient scourge. National Institute of Health U.S.A.

Omumbo,J.,Ouma,J.,Rapuoda,B.,Craig,M.H.,LeSueur,D.,andSnow,R.W.(1998).Mapping malaria transmission intensity using geographical information systems (GIS): an example from Kenya. *Annals of Tropical Medicine & Parasitology, 92(1), 7- 21*

Omumbo,J.A., Hay, S.I., Goetz, S.J., Snow, R.W., and Rogers, D.J. (2002).Malaria transmission intensity in East Africa using Remote Sensing. *Photogrammetric Engineering & Remote Sensing, 68(2), 161-166.*

Petrocelli,L.D.,Camardiel,A.,Aguilar,V.H.,Martinez,N.,Córdova,K., and Ramos,S.(2011). Geospatial tools for the identification of a malaria corridor in Estado Sucre, a Venezuelan north-eastern state. *Geospatial Health, 5(2), 169-176*

President’s Malaria Initiative. (2012).Malaria operational plan (MOP) of Ethiopia FY 2012

Rincón-Romero,M.E.,andLondoño,J.E.(2009). Mapping malaria risk using environmental and anthropic variables in Buenaventura, Colombia. *Rev Bras Epidemiol, 12(3), 338 - 354*

Saxena,R., Nagpal, B.N., Srivastava, A., Gupta, S.K., and Dash, A.P. (2009). Application of spatial technology in malaria research & control: some new insights, *Indian J Med Res, 130,125- 132*

Shumbullo, E.L. (2013). Variation in malaria transmission in Southern Ethiopia. The impact of prevention strategies and a need for targeted intervention. (Unpublished doctoral dissertation). University of Bergen, Norway

Simoonga, C., Utzinger, J., Brooker, S., Vounatsou, P., Appleton, C.C., Stensgaard, A.S.,Olesen, A., and Kristensen, T.K. (2009). Remote sensing, geographical information system and spatial analysis for schistosomiasis epidemiology and ecology in Africa. *Parasitology, 136, 1683–1693*

Sipe,N.G., and Dale, P. (2003).Challenges in using geographic information systems (GIS) to understand and control malaria in Indonesia. *Malaria Journal, 2, 36*

Teklehaimanot,H.D., Lipsitch,M., Teklehaimanot,A., and Schwartz,J. (2004).Weather based prediction of *Plasmodium falciparum* malaria in epidemic-prone regions of Ethiopia I. Patterns of lagged weather effects reflect biological mechanisms. *Malaria Journal, 3, 41*

Tiruneh, A. (2010). GIS and remote sensing based assessment of malaria risk mapping for Boricha Woreda, Ethiopia. (Unpublished master's thesis). Addis Ababa University, Ethiopia

Van der Hoek, W., Konradsen, F., Amerasinghe, P.H., Perera, D., Piyaratne, M.K., and Amerasinghe, F.P. (2003). Towards a risk map of malaria for Sri Lanka: The importance of house location relative to vector breeding sites. *International Journal of Epidemiology, 32,280 –285*

Whelan,P., and Warchot,A.(2009). Mosquito breeding and sewage pond treatment in the Northern Territory. Medical entomology center for disease control department of health and families Northern Territory government.

Whittle, H., and Bole van Hemsbroek, M. (1994). Malaria, In: Lankinen, K. S., Bergström,S. Mäkelä, P. H. and Peltomaa, M. eds. Health and disease in developing countries, The Macmillan Press limited, London, pp. 147-162

WHO. (2003).The burden of malaria in Africa. The Africa malaria report, Geneva, Switzerland.

Wilder, J. (2007). Modeling malaria transmission risk using satellite based remote sensing imagery: fife year data analysis in Democratic People's Republic of Korea. (Unpublished master's thesis).Northwest Missouri State University Maryville, Missouri

Woime, A.W. (2008). Changes in the spread of malaria in Ethiopia: case study from Awassa and Hossana area 2006-2007. (Unpublished master's thesis).Telemark University College, Norway

Woyessa,A., Deressa,W., Ali,A.,and Lindtjørn,B.(2012). Prevalence of malaria infection in Butajira area, south-central Ethiopia. *Malaria Journal, 11, 84.*

Zacarias,O.P., and Andersson,M.(2010). Mapping malaria incidence distribution that accounts for environmental factors in Maputo Province, Mozambique. *Malaria Journal, 9, 79.*

Zhou,G., Munga,S., Minakawa,N., Githeko,A.K., and Yan,G.(2007). Spatial relationship between adult malaria vector abundance and environmental factors in western Kenya highlands. *American Journal of Tropical Medicine and Hygiene, 77(1), 29 –35*

Web Pages

Adugna, A. (2011).Malaria in Ethiopia. Ethiopian Demography and Health http://www:EthioDemographyAndHealth.org/MedVectoredDiseaseMalaria.pdf (Accessed February, 2014)

http://www.moh.gov.et/English/Information/Pages/MalariaPreventionControlProgram.aspx. (Accessed February, 2014)

Srivastava,A.(1995)Mapping Malaria http://www.gisdevelopment.net/application/health/planning/healthp0002.htm. (Accessed March, 2014)

WHO. (2012).World malaria report fact sheet http://www.who.int/malaria/publications/world-malaria-report-2012/wmr2012-factsheet.pdf (Accessed January, 2014)

Appendices

1. Factors weight calculated by AHP in IDRISI

1.1. Weights for proximity to water bodies

Factors	**Rivers**	**Lakes**	**Swamps**	**Eigenvector of Weights**	**Weights in %**
Rivers	1			0.1958	19.58
Lakes	2	1		0.3108	31.08
Swamps	2	2	1	0.4934	49.34
Total				1	100

1.2. Weights for all environmental factors

Factors	**Soil**	**Land use land cover**	**Slope**	**Proximity to water bodies**	**Rainfall**	**Elevation**	**Temperature**	**Eigenvector of Weights**	**Weights in %**
Soil	1							0.0253	2.53
Land use land cover	3	1						0.0349	3.49
Slope	3	3	1					0.0546	5.46
Proximity to water bodies	3	3	3	1				0.0752	7.52
Rainfall	7	7	5	5	1			0.1895	18.95
Elevation	7	7	5	5	3	1		0.2610	26.10
Temperature	7	7	5	5	3	3	1	0.3595	35.95
Total								1	100

2. GPS Readings used for land use land cover map accuracy assessment

Longitude	Latitude	Land use/land cover
328295	650758	Farm land
328329	650740	Farm land
328377	650702	Farm land
328430	650664	Farm land
328547	650643	Farm land
328600	650649	Farm land
328637	650638	Farm land
328782	650616	Farm land
328864	650591	Farm land
328961	650637	Farm land
329018	650628	Farm land
329077	650612	Farm land
329139	650593	Farm land
329172	650578	Farm land
329194	650551	Farm land
329245	650518	Farm land
329340	650536	Farm land
329396	650544	Farm land
329464	650570	Farm land
329524	650586	Farm land
329653	650557	Farm land
329704	650529	Farm land
329758	650417	Farm land
329752	650346	Farm land
329781	650276	Farm land
329790	650186	Farm land
329809	650087	Farm land
329842	650021	Farm land
329836	649931	Farm land
329833	649881	Farm land
329818	649753	Farm land
330356	646551	Farm land
330399	646545	Farm land
330459	646517	Farm land
330515	646442	Farm land
330567	646374	Farm land
330639	646276	Farm land
330714	646311	Farm land
330760	646381	Farm land
330807	646464	Farm land
330779	646510	Farm land
341572	671293	Farm land
342964	670812	Farm land
342267	670406	Farm land
341031	669559	Farm land
342360	669186	Farm land
343092	668382	Farm land
342101	672556	Farm land
343401	672359	Farm land
341542	672852	Farm land
342455	667728	Farm land
336613	654472	Water body
336925	654936	Water body
348630	677094	Water body
348922	677127	Water body
349939	677098	Water body
349647	677088	Water body
348087	676813	Water body
348244	676834	Water body
348449	676910	Water body
348688	677125	Water body
348898	677076	Water body
349037	677072	Water body
338918	668459	Water body
338747	668498	Water body
339397	668339	Water body
328128	651943	Water body
328735	652336	Water body
348941	677149	Water body
348869	677119	Water body
349218	677090	Water body
344825	667993	Forest
344641	667225	Forest
344067	666771	Forest
343753	666652	Forest
344212	666455	Forest
344711	665807	Forest

344249	665782	Forest
344338	666799	Forest
344694	666532	Forest
343357	665995	Forest
343876	665828	Forest
344356	666285	Forest
345634	669656	Forest
344842	669687	Forest
345856	669451	Forest
345271	668983	Forest
344862	668538	Forest
345226	668350	Forest
345613	668109	Forest
344961	667611	Forest
344578	667306	Forest
344930	667071	Forest
338598	666478	Bush Land
338556	666543	Bush Land
338525	666625	Bush Land
338531	666689	Bush Land
338568	666760	Bush Land
338619	666831	Bush Land
338605	666920	Bush Land
338619	667011	Bush Land
338616	667144	Bush Land
338625	667205	Bush Land
338616	667266	Bush Land
338640	667326	Bush Land
338687	667373	Bush Land
338684	667417	Bush Land
338691	667439	Bush Land
338689	667471	Bush Land
338682	667505	Bush Land
338690	667532	Bush Land
338698	667548	Bush Land
338695	667583	Bush Land
338685	667632	Bush Land
338679	667686	Bush Land
338686	667704	Bush Land
338709	667722	Bush Land
338748	667689	Bush Land

338778	667662	Bush Land
339797	672590	Bush Land
339776	672465	Bush Land
339991	672312	Bush Land
339411	672300	Bush Land
339540	672222	Bush Land
339758	672140	Bush Land
339944	672112	Bush Land
340142	672038	Bush Land
340002	671920	Bush Land
339589	672505	Bush Land
339268	672315	Bush Land
339188	672233	Bush Land
339401	672185	Bush Land
339872	671917	Bush Land
340264	671861	Bush Land
339444	666907	Settlement
339433	666866	Settlement
340634	666554	Settlement
340397	666581	Settlement
340356	666621	Settlement
340326	666721	Settlement
340290	666826	Settlement
340265	666948	Settlement
340320	667099	Settlement
340156	667086	Settlement
339961	667071	Settlement
339816	667022	Settlement
340549	666786	Settlement
340615	666738	Settlement
340519	667169	Settlement
340491	667231	Settlement
340483	667339	Settlement
340474	667442	Settlement
340462	667572	Settlement
340097	665439	Settlement
339395	666937	Settlement
339378	666974	Settlement
339274	666976	Settlement
339145	667009	Settlement
339105	667069	Settlement

339114	667164	Settlement
339152	667287	Settlement
339082	667342	Settlement
339101	667400	Settlement
340097	665403	Settlement
340145	665387	Settlement
340192	665466	Settlement
340252	665476	Settlement
340307	665561	Settlement
340398	665615	Settlement
340388	665670	Settlement
340299	665628	Settlement
340229	665531	Settlement
340140	665536	Settlement
340059	665450	Settlement
338945	667530	Settlement
339063	667488	Settlement
338422	664081	Settlement
338438	664298	Settlement
338821	664325	Settlement
339142	664572	Settlement
339308	664420	Settlement
339488	664275	Settlement
339390	664040	Settlement
339157	664135	Settlement
338904	664177	Settlement
338808	664174	Settlement
338805	663389	Bare Land
339003	663715	Bare Land
339057	663503	Bare Land
339127	663760	Bare Land
339831	664222	Bare Land
339004	663335	Bare Land
338872	663331	Bare Land
338974	663330	Bare Land
339064	663357	Bare Land
339235	663820	Bare Land
339310	663776	Bare Land
339349	663853	Bare Land
350122	678909	Bare Land
346548	677542	Bare Land
346697	677501	Bare Land
346874	677494	Bare Land
339822	664212	Bare Land

DECLARATION

I, the undersigned declare that this project is my original work and has not been presented for a degree in any other university and that all sources of material used for this project have been correctly acknowledged.

Mestewat Simeon

Signature__________________________ Date ____________________________