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**ADDIS ABABA UNIVERSITY
SCHOOL OF GRADUATE STUDIES
DEPARTMENT OF EARTH SCIENCES**

**VULNERABILITY ANALYSIS AND MALARIA RISK MAPPING IN AWASSA
AND WONDOGENET WOREDAS.**

**A THESIS SUBMITTED TO THE SCHOOL OF GRADUATE STUDIES OF ADDIS
ABABA UNIVERSITY IN PARTIAL FULFILLMENT OF THE
REQUIREMENTS FOR THE DEGREE OF *MASTER OF SCIENCE (M.SC)* IN
REMOTE SENSING AND GIS.**

AREGA DEGIFE GURMU

JUNE 2009

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JUNE 2009

To

The late *Dadhi Lugo* and *Askalech Mergiya*

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ABSTRACT

Malaria is one of the high priority tropical diseases in Tropical Countries. Although, there have been many efforts to eradicate malaria from the world over a long period of time, yet it remains a complex disease. Among the efforts made so far, the main intervention area has been targeting at the ecology of the Mosquito. This study is aimed at first mapping malaria hazard areas and then the malaria risk areas at Awassa and Wondongenet Woredas. For mapping malaria hazard areas five parameters were selected. The parameters include elevation, slope, distance from rivers, distance from wetlands and drainage density. The elevation, slope, and river net works were derived from SRTM satellite data and the wet land layer was extracted from land use/land cover map. These layers were combined by using weighted multi criteria evaluation. Similarly, risk map was developed depending on the malaria hazard layer, land use/land cover, distance from health stations layer and population density layer of the study area. The landuse/ landcover layer was obtained from Landsat ETM+ imagery of the year 2005. The resulting malaria hazard map depicts that 184.7Km², 76.3 Km², 37.4 Km², 26.9 Km², and 24.1 Km² representing 48.6%, 19.9%, 9.7%, 7%, and 6.3%, of the total area is subject to very high, high, moderate, low, and very low level of malaria hazard. The remaining 32.0 Km² (8.4%) of the total area is free from malaria. Yuwa, Aruma, Edo, Busa, Chuko, Entaye, Kela, Wetera, Shasha Kakale, Gotu Anuma, Abaye and Baja Fabrica kebeles were found to be under high malaria hazard. The risk map produced from the overlay analysis of the four parameters also showed that 122Km²(32%), 117Km²(30.7%), 60Km²(15.7%), 31Km²(8.1%) 19Km² (5%), and 32Km²(8.4%) of the total area is subject to very high, high, moderate, low, very low and is free from malaria risk respectively. Part of Abaye, Yuwo, Aruma, Tllu, Chefe Kotegebesa, Swampy area, Shashsa Kakalo, Washa Soyama, and Gamato are subject to very high risk of malaria. In conclusion, 68% of the total area is highly exposed to malaria hazard and more than 60% is under high risk of malaria. It is also suggested that it will be cost effective and time as well as energy saving if the results of this study will be incorporated into the ongoing malaria eradication programs.

Key words: GIS, Remote Sensing, MCE, malaria hazard, malaria risk

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List of Abbreviations

AAU	Addis Ababa University
AVHRR	Advanced Very High Resolution Radiometer
BOFED	Bureau of Finance and Economic Development
CDC	Centers for Disease Control and Prevention
DEM	Digital Elevation Model
ERDAS	Earth Resources Data Analysis System
ETM+	Enhanced Thematic Mapper Plus
FAO	Food and Agricultural Organization
GIS	Geographic Information System
GFATM	Global Fund to Fight AIDS, Tuberculosis and Malaria
GPS	Global Positioning System
m.a.s.l	meter above sea level
MCE	Multi Criteria Evaluation
MDGs	Millennium Development Goals
MFI	Malaria Foundation International
MOWR	Ministry Of Water Resources
MSS	Multispectral Scanner
NDVI	Normalized Difference Vegetation Index
NMA	National Meteorological Agency
NOAA	National Oceanic and Atmospheric Administration
RBM	Roll Back Malaria
RS	Remote Sensing
SNNPR	Southern Nations, Nationalities and Peoples Region
SRTM	Shuttle Radar Thematic Mapper
SWIR	Short Wave Infrared
TM	Thematic Mapper
WHO	World Health Organization
WMR	World Malaria Record

1. INTRODUCTION

1.1. Background and Problem Statement

Malaria is one of the high priority tropical diseases in Tropical Countries. Although, there have been many efforts to eradicate malaria from the world over a long period of time, yet it remains a complex disease. It affects human health and continues to be one of the most serious vector-borne diseases world-wide. Malaria transmits through 3 possible mediums; malaria parasite, human hosts, and *Anopheles* mosquito. The way to solve the malaria problem is to intervene these mediums. One of the interventions mechanisms includes identifying possible potential malaria prone areas. The suitable environmental conditions for various behaviors of *Anopheles* mosquito such as resting, swarming, oviposition, biting, and feeding can easily be examined by first predicting and analyzing potential mosquito reproduction areas. The characteristic of heterogeneous space is an important factor to predict the mosquito densities. The heterogeneous space is called “land cover” (Abose et al., 2003).

Every year nearly 350-500 million clinical disease episodes are caused by malaria parasites and 3.2 billion people in the world are living under the risk of malaria (WHO, 2005). Malaria is essentially an environmental disease since the vectors require specific habitats with surface water for reproduction, humidity for adult mosquito survival and the development rates of both the vector and parasite populations are influenced by temperature (Ashenafi, 2003). Although it is preventable, Malaria is a leading cause of morbidity and mortality in the developing world, especially sub-Saharan Africa where the transmission rates are highest and where it is considered to be a major impediment to economic development (Robert et al., 2003).

In Sub-Saharan Africa the pattern of malaria transmission varies markedly from region to region, depending on climate and biogeography, and broad ecological categories have been widely used to describe variations in the observed epidemiological patterns (MFI, 1997). One of the new approaches to better understand the variability in the epidemiology of the disease depends on knowledge of biodiversity. Specifically, the distribution and ecology of the vectors and the parasites are considered within a context of a climatic and anthropogenic environment which is in perpetual evolution.

This biodiversity is determined by many factors:

- Environmental: rainfall, temperature, vegetation;
- Biological: competence of the vectors (transmission), biology of each species of *Plasmodium*; and susceptibility of the host to disease;
- Anthropogenic: deforestation, irrigation, urbanization, movements of populations and economic changes.

During the last twenty years, the development of Geographical Information Systems (GIS) and satellites for earth observation have made it possible to make important progress in the monitoring of the environmental and anthropogenic factors which influence the reduction or the re-emergence of the disease. Analyses resulting from the combination of GIS and Remote Sensing (RS) have improved knowledge of the biodiversity influencing malaria. This knowledge can help decision-makers to better allocate limited resources in the fight against the disease (Robert *et al.*, 2003).

Thus, remote sensing and geographic information systems (GIS) technologies have been used to describe local and landscape-level features that influence the patterns and prevalence of disease and then model the occurrence of the health event in space and time (Ashenafi, 2003; Bose, 2003). In the study area although malaria is prevalent, risk analysis is not yet done and potentially prone areas are not delineated based on environmental factors. This has created a problem to target at high risk areas and has substantial increased costs of prevention.

This study therefore apply the combined use of GIS and remote sensing which provides a strong tool for monitoring environmental conditions that are conducive to malaria and mapping the disease risk. GIS and remote sensing tools are used to analyze and integrate the spatial component of vector-borne disease situation in the study.

1.2 Objectives

- **General Objective**

The objective of this study is to use GIS and Remote Sensing to investigate the area that is suitable for the breeding of malaria vectors and map malaria risk areas.

- **Specific Objectives**

The specific objectives of the study include:

1. To identify environmental factors that contribute for malaria incidence in the study area;
2. To investigate malaria hazard;
3. To identify priority areas for taking mitigation measures against the problem by mapping areas of population at risk of malaria;
4. To compare the malaria risk map with kebeles which were labeled as malarious so as to verify study results based on health bureau data;

1.3 Organization of the Thesis

This thesis is organized in five chapters. Chapter one provides research background, problem statement, Objectives and the like. Chapter two provides a literature review of application of RS/GIS technology to the study and control of malaria, including the environmental factors like climate, temperature, humidity, land cover, etc. Chapter three provides the background of the study area and describes methodology. Chapter four describes analysis, result and discussion and finally chapter five is about conclusion and Recommendations.

1.4 Significance of the Study

This research is aimed at using GIS and RS tools for identification of malaria prone areas. The ability of identifying risk areas will greatly enhance the effectiveness of prevention efforts and will substantially reduce costs of prevention with efficient targeting of high risk areas. Applying GIS and RS for visualizing and analyzing epidemiological data, revealing trends, dependencies and interrelationships will provide valuable information for evaluation and monitoring.

1.5 Limitation of the Study

The main limitation of the study was the unavailability of well documented monthly medical data at kebele level over extended years, and lack of a detailed population distribution data of the study area. There was also lack of satellite images taken at different seasons for some years which can help to map seasonal variation of climatic variables in relation with malaria epidemics.

2 REVIEW OF RELATED LITERATURE

2.1. Some Concepts: Malaria and its Behavior

Malaria is a mosquito-borne disease caused by a parasite. The geographic distribution of malaria depends mainly on climatic factors such as temperature, humidity, and rainfall. It is transmitted in tropical and subtropical areas. Malaria is responsible for over 300 to 500 million clinical cases and more than one million deaths each year. Approximately 20% of the world population is living under risk of malaria, mainly in tropical areas and in the poorest countries of the world (CDC report, 2007). Scientists have observed significant correlations between malaria epidemics and seasonally warm semi-arid and highland areas. Several tools, such as, GIS, GPS, remote sensing and spatial statistics were used for malaria surveillance and malaria control programs.

2.2. Using RS and GIS Technology to Study and Control Malaria

Historically several attempts have been done to study and control malaria by using different technologies and ideas that the body of knowledge has produced. Satellite sensors developed in US, Europe, Canada, and India have contributed to a better understanding of malaria vector ecology. The history of RS and its application to malaria and other vector-borne diseases has been recorded over time in a series of review papers (Hay *et al.*, 2000). Yet, despite 30 years of research on the potential applicability of remote sensing technologies to malaria control, these tools are only now beginning to have an impact on policy and practice in operational control of malaria in affected countries.

In 1971, NASA scientists first identified larva habitat sites using CIR photography. Manually they identified forest coverage, open wetlands, marshy lands and residential areas from CIR photography and, by calculating mosquito flight range from settlements, produced a risk map for malaria control. Pope *et al.* (1992) used Landsat TM imagery over the Pacific coastal plain of Chiapas, Mexico and by integrating GIS, RS and field research tried to predict *Anopheles* mosquito population dynamics.

TM proved its usefulness by identifying *Anopheles* larva habitat sites in California (Wood et al., 1992) and mapping rift valley fever vectors in Kenya, East Africa (Pope et al., 1992). In that study, they classified TM image and identified roads, water and vegetation. They also colour coded the homogeneous vegetation types and water bodies on classified TM images. Their study result revealed that habitat types were divided in low, medium and high larva producing groups. Many disease vectors cannot be observed directly.

Wood et al. (1992) identified high mosquito producing fields in California using GIS and Landsat TM imagery. They also detected the reflectance of canopy growth in early season and correlated with *Anopheles* larva density. Distances between rice fields and source of blood meal for mosquitoes, i.e. pastures with livestock, were measured using GIS. Their study result revealed that rice fields situated very close near pastures had more larva production compare with rice fields far from pastures.

Rahman *et al.* (2006) carried out another study in Bangladeshi. They used GIS technology to understand the spatial distribution of houses and incidence rates. In that study, GIS was used to generate the nearest distance between houses, water bodies and forest edges, and to create a buffer zone around water bodies. Finally, the findings were used to estimate the impact of malaria risk reducing interventions. In order to identify the environmental risk factors associated with malaria risk, a study was carried out by Kaya *et al.* (2001) in coastal Kenya. In that study risk areas were identified based on the highest mosquito flight carrying capacity from breeding sites. Wetlands were considered suitable for larva breeding sites and a two-kilometer buffer zone was created around mosquito breeding sites. With that information a risk map was generated that showed which settlements were situated very close and within the buffer zones. That study demonstrated the potential of using SAR images for identification of land cover types that may be associated with malaria carrying mosquito breeding.

2.3 Importance of Landuse / Landcover Classification for Malaria Study

In different parts of the world different landscape elements were identified for different types of malaria breeding. Beck et al. (1997) demonstrated how landscape elements can be used to predict mosquito availability and subsequently malaria outbreaks in Mexico. Land cover maps were produced from Landsat imagery to identify different classes of land. Land type was then

correlated with malaria incidence to identify the landscape elements that are most suitable for mosquito breeding.

Research was carried out by Bian et al. (2003) in the Kenyan highlands to understand mosquito larval habitats. Remote sensing images were classified for land cover types using a supervised classification method. A total of seven land cover classes were used: farmland, pasture, natural swamp, forest, river/stream, road and suburbs. DEM was used to investigate topographic parameters that can be related with mosquito larva habitat sites such as elevation, wetness index, and distance from stream, land surface and curvature. They used Landsat TM images and their study results revealed that transitional swamps and unmanaged pastures were the most suitable land types for mosquito larva breeding.

To see the spatial distribution of Plasmodium Vivax in Afghanistan a study was carried out by Broker et al. (2002). Afghanistan is divided into four ecologic zones on the basis of differences in elevation, temperature and land cover type. Epidemiologic data were obtained from a nation wide survey of 269 villages. They used logistic regression analysis to investigate the relationship between environmental variables and the probability of transmission. No transmission occurred in those villages higher than 2000 meter above sea level because of variation of temperature. Prevalence rate was higher in river valleys and no transmission occurred in settlements farther than 10 km away from rivers.

2.4 The relationship Between Major Climatic Variables and Malaria Incidence

Rainfall in tropical areas creates an opportunity for *anopheles* mosquitoes to lay eggs, which can reach adulthood. 9-12 days are needed for that process. The *anopheles* mosquito transmits the causative agent, plasmodium species, when the environmental parameters (such as water availability, temperature and humidity) permit. In many parts of the world where temperature is not a limiting factor, seasonal malaria transmission takes place during peak rainfall periods (Daniel, 1999). It is already established that vector abundance, distribution and pattern of vector behaviours changes because of climate change. In order to develop malaria early warnings based on seasonal climate forecasts in Botswana, research was carried out in 1996. Malaria incidence data, precipitation data, DEMETER (Development of European Multi-Model Ensemble System

for Seasonal to Interannual Climate Prediction) climate predictions were used for probability forecasts. Study result revealed that high incidence malaria years were associated with above average precipitation, while the lowest malaria years were associated with below average precipitation (Thomson et al., 2006).

To understand climate change and its relation to vector borne disease a review was carried out by Githeko et al. (2000) on the whole world. Literature suggests inter-annual and interdecadal climate variability has a direct influence on vector-borne disease epidemics. Broker et al. (2001) studied to see the spatial distributions of Helminthes (one type of parasites) in Cameroon. They collected epidemiological and population data. Land surface temperature was derived from NOAA-AVHRR. They used a Logistic regression model to identify significant environmental variables which affect the transmission of infection. The variables used in the regression analysis were mean, minimum and maximum land surface temperature; total annual rainfall and altitude. The result revealed that maximum temperature was an important variable in determining Helminthes distribution.

2.5 Factors Affecting the Emergence of Malaria

The severity of malaria is a function of the interaction between the **parasite**, the *Anopheles mosquito vector*, the **human host** and the **environment**. Vector abundance, duration of the extrinsic incubation period and survival rate of the vector, combined with the probability of the vector feeding off a susceptible human host determine the risk of malaria infection, the stability of disease transmission, and seasonal patterns. Many factors are involved in determining the evolution of the parasite, the vector, the human and the environment (WHO, 2005). Hackett wrote 'Everything about malaria is so molded by local conditions that it becomes a thousand epidemiological puzzles'. Like chess, it is played with few pieces, but is capable of an infinite variety of situations'. If we are to see order within the chaos we must consider that most of the factors are interrelated and it is necessary to take into account these inter-relationships in a holistic approach to understand the components which influence the development of malaria; we must also understand the differing scales at which each factor play out its influence on the overall game. According to many researchers including WHO (2005), Githeko et al. (2000), and

Broker (2002), the natural principle that govern malaria emanate from the natural conditions that are favorable to it.

- ***Rainfall***

Different malaria vectors use a variety of sites in which to lay their eggs (irrigation canals, tire ruts, mangrove swamps, pools, etc.) as long as the water is clean, not too shaded and, for most species, relatively still. In many semi-arid areas these sites are only widely available with the onset of the seasonal rains unless dry season irrigation is undertaken. The association between rainfall and malaria epidemics has been recognized for many decades (WHO, 2005) but 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 (Fox, 1957) or by decreasing the temperature, which in regions of higher altitude can stop malaria transmission.

- ***Temperature***

Temperature has an effect on both the vector and the parasite. For the vector, it affects the juvenile development rates, the length of the gonotrophic cycle and survivorship of both juvenile and adult stages with an optimal temperature and upper and lower lethal boundaries. For the parasite it effects the extrinsic incubation period (Lactin *et al.*, 1995). *Plasmodium falciparum* (the dominant malaria parasite in Africa) requires warmer minimum temperatures than *Plasmodium vivax*. This helps account for the geographic limits of falciparum malaria transmission in Africa (Bruce and Chwatt, 1991). At 26°C the extrinsic incubation period of this malaria species is about 9-10 days whereas at 20- 22°C it may take as long as 15-20 days. In highland areas, where cold temperatures preclude vector and/or parasite development during part/or all of the year, increased prevalence rates may be closely associated with higher than average minimum temperatures (Bouma *et al.*, 1994).

- ***Humidity***

The survival rate of adult insects is often thought to increase or decrease in relation to a factor called saturation deficit. Saturation deficit is derived by subtracting the actual water vapor pressure from the maximum possible vapor pressure at a given temperature. Evidence for other

vectors (tsetse, ticks, culicoides) suggests that saturation deficit is an important environmental variable in larval and adult survivorship.

- ***Surface Water***

Surface water provides the habitat for the juvenile stages (egg, larvae, and pupae) of malaria vectors. Monitoring the state of small water bodies and wetlands using satellite data is therefore very useful to identify the source of malaria vectors. The Short Wave Infrared (SWIR) is a wavelength (1.55-1.75 μm) absorbed by water and therefore can be used to retrieve information on the presence of water bodies and vegetation water content (Gond *et al.*, 2004)

- ***Vegetation***

Vegetation type and growth stage may play an important role in determining vector abundance irrespective of their association with rainfall. The type of vegetation which surrounds the breeding sites, and thereby provides potential resting, sugar feeding supplies for adult mosquitoes, and protection from climatic conditions, may also be important in determining the abundance of mosquitoes associated with the breeding site (Broker 2002). Furthermore, vegetation type may influence mosquito abundance by affecting the presence or absence of animal or human hosts and thereby affecting the availability of blood meals.

- ***Seasonality of Climate***

The combined influence of rainfall, temperature and humidity, re-grouped underneath weather (short-term) and climate (long-term) on malaria is very complex, especially for extreme weather conditions. Direct effects of climate on vector and parasite development are easy to see but indirect effects may also be important such as the effects of previous exposure (related to direct effects), nutritional status, and co-infection may help determine the disease outcome. Just as climate is one of the determinants of malaria endemicity, climate variability is one of the main factors behind inter-annual fluctuations of malaria. Literature abounds with examples of how unusual, anomalous or extreme weather conditions have led directly and indirectly (through destructive crop pests and diseases) to human malnutrition and in turn to health problems or to both at the same time (Ashenafi, 2003).

In recent years there have been significant scientific advances in our ability to predict climate on the seasonal timescale (Goddard *et al.*, 2001). The skill associated with these predictions varies from region to region, but is generally higher within the tropics. The World Health Organizations Technical Support Network for Malaria Epidemic Prevention and Control has suggested that such forecasts may be relevant to malaria early warning (WHO, 2005). Recently, the information provided by regional forecasters in Southern Africa has been presented and used by decision-makers to forecast an increase in malaria risk in epidemic prone areas during seasonal Outlook Forums (Daniel, 1999). The importance of the factors influencing malaria is not only limited to climatic factors. Anthropogenic changes in the environment, in land use, deforestation, in hydraulic network, also induce continuous changes in the intensity of malaria transmission.

2.6 . Anthropogenic Factors Affecting Malaria Transmission

Consequences of demographic and technological developments during the last century have considerably modified the environment. Forest and swamp regions were shifted to agriculture to feed an ever-increasing population. Water requirements for many crops have led to modifications of surface waters. Development of urban areas has also modified the spatial distribution of populations and lead to high concentrations of population in restricted areas. Already more than 50% of the total global population lives in cities. These demographic changes in cities can impact malaria, either by increasing the potential for malaria transmission where the development of irrigated cultures surrounding the city increases the vector population or by decreasing it, if adequate measures are taken to reduce the vector and parasite population in the cities. In some countries, and in particular in Africa, movements of population for political or economical reasons create another risk factor to the spread of malaria.

Migrants and refugees may bring new parasites (including drug resistant parasites) to an area and increase transmission in the settled population, or because they come from a low, no transmission area migrants and refugees may be highly vulnerable to severe disease when they enter a malaria endemic area (Giada *et al.*, 2003). Development of urban cities (Small, 2003) can be monitored with high spatial resolution images such as Ikonos and QuickBird (respectively, 1m and 0.61m for the panchromatic channel).

2.7 Global Malaria Distribution and Burden

Malaria has been recorded as far North 64°N latitude and as far South 32°S latitude and in altitude ranges of 400m below sea level up to 2800m above sea level. Within these limits of latitude and altitude, there are large areas free of malaria (figure: 1), which is essentially a focal disease, since the transmission of malaria depends greatly on local environment and other conditions (Gilles and Warrell, 1993). The World Health Organization estimates that 300 to 500 million people are diagnosed with malaria annually, causing 1.1 to 2.7 million deaths (WHO, 2000; WHO, 2003).

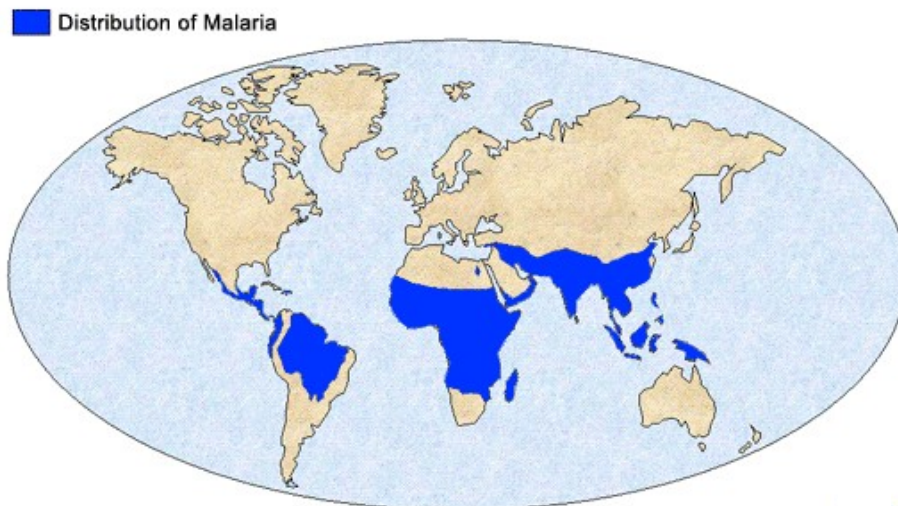


Fig 2.1. The Malaria Belt of the world

Source: WHO, 2005

Malaria has a major place among the endemic tropical diseases (Gilles and Warrell, 1993). Reports as for 2004 indicate that 107 countries and territories have reported as areas at risk of transmission. This number is considered less than the 1950s report where 140 endemic countries and territories were accounted, but still in these 107 countries there are 3.2 billion people at risk of infection (WMR, 2005). Around 60 % of the cases of clinical malaria and over 80% of deaths occur in Africa, south of the Sahara. In addition to acute disease episode and deaths in Africa, malaria also contributes significantly to anemia in children and pregnant women, adverse birth outcome and overall child mortality. Financially, it is estimated to be responsible for 3% in

average annual reduction of economic growth in countries with high disease burden (WMR, 2005).

Malaria extracts an enormous toll in lives, medical costs, and days of labor lost. Educational systems also suffer as large numbers of children miss several weeks of school each year in endemic regions (MFI, 1997). In addition to the direct economic cost of malaria such as costs related to transportation to health service facility, consultation fee, laboratory test fee, and more importantly, drug cost, malaria mortality and morbidity sluggish economic growth by reducing the capacity, and efficiency of the labor force. The economic loss due to malaria is very high, with an annual loss of growth estimated at 1.3% and loss of approximately 12 billion US dollars every year in Africa (WHO, 2005).

The wide variation seen in the burden of malaria between different regions of the world is driven by several factors (WMR, 2005). The presence of the most serious parasite, accompanied by the potent vector species and vulnerable human population (Parasitevector- human transmission dynamics) is the one amongst the factors that favor or limit the transmission of malaria and the associated risk of disease and death (Gilles and Warrell, 1993; Konradsen *et al.*, 1990; cited by Joshi *et al.*, 2005). The severe malaria parasite *P. falciparum* and the most efficient malaria vector mosquitoes *Anopheles gambiae* occur exclusively in tropical and sub tropical part of the world, especially in Africa (Gilles and Warrell, 1993; WMR, 2005). Tropical areas of the world have the best combination of adequate rainfall, temperature and human host allowing for breeding and survival of malaria vector mosquitoes (WMR, 2005).

The other major factor contributing to regional and local variability in malaria burden is differences in level of socio-economic development. Determinants include general poverty, quality of housing and access to health care and health education, as well as existence of active malaria control programmes providing access to malaria prevention and treatment measures (Gilles and Warrell, 1993; WMR, 2005). The poorest nations generally have the least resource for adequate control efforts (WMR, 2005). The combination of all these factors put down a heavy toll on malaria burden in Africa. In fact, the population groups at risk of malaria also differ between regions. The majority of death in tropical Africa occurs in areas of stable transmission of *falciparum* malaria (WMR, 2005). In these areas the two groups at high risk are

the very young children, who have not yet acquired clinical immunity (Gilles and Warrell, 1993), and pregnant women, whose immunity to malaria is temporarily impaired (WMR, 2005). Whereas in areas of unstable or highly seasonal *falciparum* malaria transmission, which is mostly common outside Africa, the lack of frequent exposure to malaria infection early in life delay the acquisition of clinical immunity, and thus older age groups remain at relatively higher risk for malaria disease when exposed (WMR, 2005).

More recently, there is evidence that compared with the 1980's, the burden of malaria increased during the 1990s in several areas in terms of population at risk, the severity of infection and the number of deaths (WMR, 2005). Malaria re-emerged in several countries of central Asia with an increased frequency of epidemics and with the re-establishment of stable endemic transmission. Factors contributing to the increase in malaria include (i) resistance of parasite to commonly used anti-malaria drugs; (ii) breakdown of control programs; (iii) complex emergencies; (iv) collapse of local primary health services; (v) resistance of mosquito vectors to insecticides (WMR, 2005). In addition, there are other variables that expand malaria endemicity such as, deforestation, introduction of different irrigation schemes, swamp drainage and specific crop intensification (Patz and Lindsay, 1999; Boelee *et al*, 2002; ICMR, 2002; Kebede *et al*, 2005). Within the same period, however, malaria was well controlled in the five northern African countries and elimination or a very low level of transmission was maintained in some of the islands of the cost of Africa. Throughout the decades, malaria was generally less intense in central and South America than in Africa and South East Asia (WMR, 2005).

From the available information, it is not yet possible to determine with sufficient confidence whether the global burden of malaria has changed substantially, for better or worse, since 2000 when Roll Back Malaria (RBM) implementation began in many countries. In some areas, fluctuations in malaria transmission from year to year potentially confound evaluation of broader trends. Therefore, a final conclusion typically requires analysis of epidemiological data over multiple years. For the high burden in Africa, reliable data will only become available after a time lag of several years. Nevertheless, for some countries and areas throughout the world, there is evidence that successful control has got an impact on malaria disease burden (WMR, 2005).

2.8 .The Situation of Malaria in Ethiopia

Malaria is a major public health problem in Ethiopia (Abose *et al.*, 1998). Its occurrence in most parts of the country is unstable mainly due to the country's topographical and climatic features (Abose *et al.*, 2003). Although the two epidemiologically important malaria parasite species in the country are *P. falciparum* and *P. vivax*, the other two species, *P. malariae* and *P. ovale*, are also reported to occur. *Anopheles arabiensis* is the major malaria vector; *An. pharoensis*, *An. funestus* and *An. nili* are deemed as secondary vectors (Abose *et al.*, 1998). Approximately 4-5 million cases of malaria are reported annually in Ethiopia (in a normal transmission year) (WHO, 2005). Malaria is found in about 75% of the total area of the country, and 40-50 million (>65%) of the total population is at risk of infection (Tulu, 1993; WHO, 2005). Malaria accounts for seven per cent of outpatient visits and represents the largest single cause of morbidity. It is estimated that only 20 per cent of children less than five years of age that contract malaria are treated at existing health facilities. Large-scale epidemics occur every 5-8 years in certain areas due to climatic fluctuations and drought-related nutritional emergencies. There are also areas of stable transmission in some low-lying western regions of the country (WHO, 2005).

Transmission usually occurs at altitudes <2000 meters above sea level. The two main seasons for transmissions of malaria in Ethiopia are September–December, after the heavy summer rains, and March–May, after the light rains. *P. falciparum* and *P. vivax* are the dominant human malaria parasites, which account for about 60% and 40% of cases, respectively (Tulu, 1993). Malaria epidemics are frequent and widespread in the country. Most of the areas affected by epidemics are highland or highland fringe areas (mainly areas 1000–2000m above sea level), in which the population lacks immunity to malaria (Tulu, 1993). Occasionally, transmission of malaria occurs in areas previously free of malaria, including areas >2000m above sea level, in which the microclimate and weather conditions are favorable for malaria. According to Negash *et al.* (2005) true explosive epidemic malaria was recorded at exceptionally high altitude (around 2500 m above sea level). Resulting from human activities, aggravated transmission in the country was also observed (Negatu *et al.*, 1992).

2.9. Potential Applications of GIS in Public Health:

The recognition and employ of GIS technology in public health is significantly growing. GIS is gradually being accepted & used by public health administrators & professionals, including policy makers, statisticians, epidemiologists, regional & district medical officers. Some of its potential applications in public health are listed below:

1. Determine the geographical distribution & variation of diseases.
2. Analyze spatial & temporal trends of diseases.
3. Identify gaps in immunizations.
4. Map populations at risk & stratify risk factors.
5. Document community health care needs & assess resource allocations.
6. Forest epidemics.
7. Plan & target interventions.
8. Monitor diseases & interventions over time.
9. Manage patient care environments, materials, supplies & human resources.
10. Monitor the utilization of health centers.
11. Route health workers, equipments & supplies to service locations.
12. Publish health information maps on the internet.
13. Locate the nearest health facility.

(Negash et al., 2005; Tulu, 1993)

3. METHODOLOGY

3.1. Description of the Study Area

3.1.1. Location, Size and Accessibility

The study area is found in the main Ethiopian rift extending up to the eastern escarpment. It is located in SNNPR, South Ethiopia, in and around Awassa town, which is located at 275 Km south of Addis Ababa. The study area includes Kebeles which are found under the administration of Awassa and Wondo Genet Weredas. Most of these kebeles were labeled as malarious. The total area of these study kebeles is 381.1296km² (see figure 3.1). The surrounding area is accessible by all weather road and seasonal gravel roads (Awassa Town Municipality, 2009).

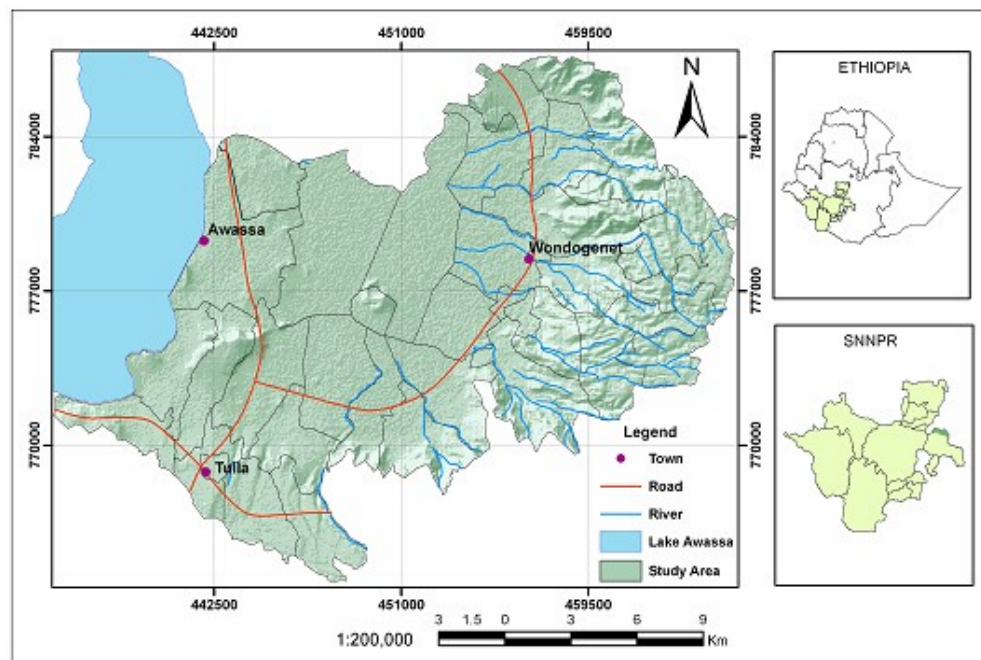


Fig 3.1. Location of the Study Area

3.1.2. Topography

The study area is situated in a large volcano-tectonic collapse at the eastern margin of the Main Ethiopian Rift, Woldegabriel *et al.*, (1986). As it is indicated in figure 3.2, the area is characterized by flat lying topography with some scattered hills, like Mount Tabor (1800m), and

Mount Alamura (2019m). The depression is bounded by remnants of the caldera wall and some regional and local faults. The eastern scarp forms the edge of the rift whose average throw is about 500 m, whereas the southern and western scarps of the caldera which roughly form an arc of a circle are relatively lower with a 250 m elevation difference from the floor.

Water bodies, swampy areas and small volcanic hills such as Lake Awassa, Chefe, and Mt. Tabor and Mt. Alamura characterize the floor of the depression, (Awassa Town Municipality, 2009).

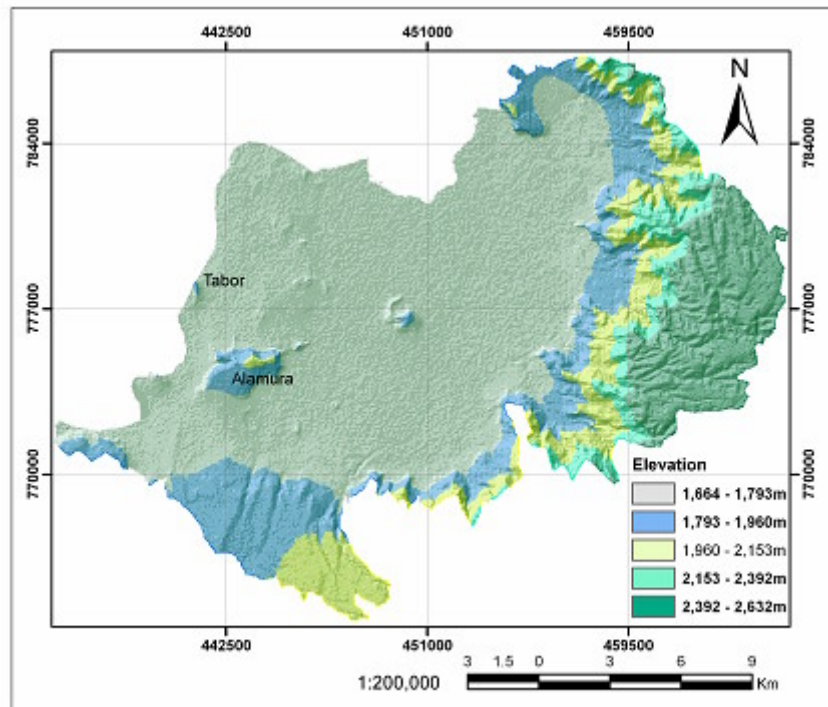


Fig.3.2. Topographic Structure and Elevation of the Study Area

3.1.3. Drainage Pattern

The study area is found in a poorly drained catchment. It is drained by ephemeral and perennial rivers radiating from the eastern escarpment of the rift valley, flowing to the swampy area and then to lake Awassa (Figure 3.3). The former Lake Cheleleka is now converted to swamp since sediments that are coming from the eastern side of the scarp are partly deposited in this area.

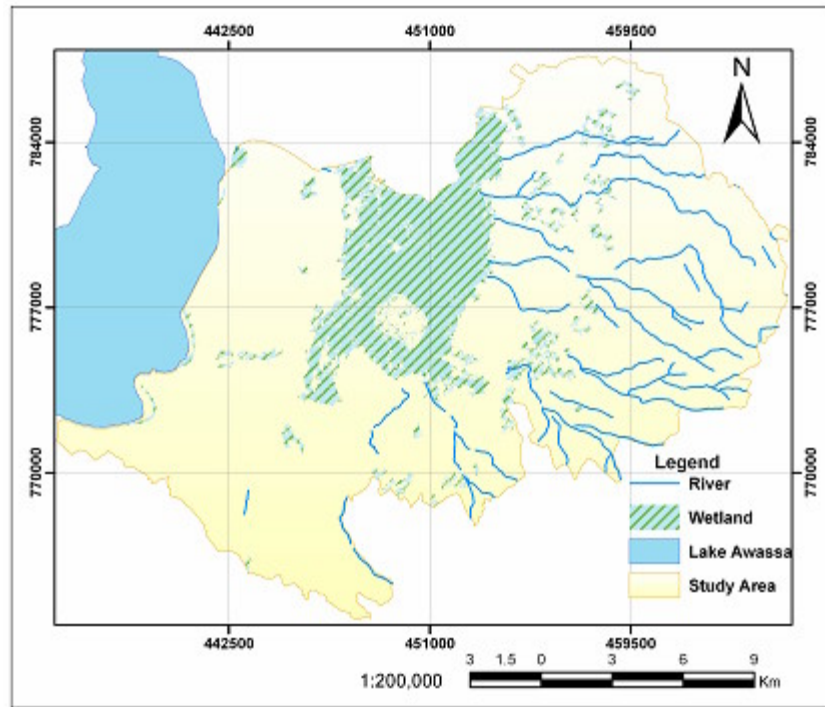


Fig.3.3. Drainage Pattern of the Study Area

3.1.4. Landuse/ Landcover

As far as the land use is concerned, as it is indicated in figure 3.4 and figure 3.5, the main land use of the area is dominated by rain fed agriculture and irrigation based agro-forestry practices like coffee, enset, avocado and banana, sugarcane and chat plantations. The escarpment on the eastern part of the area is covered by agro forestry and the lower flat lands are used for mechanized farms, although these farms are shrinking due to urban expansion. Private small holding farms also occupy a considerable large portion on this area. A swampy area is found and serves as a very important grazing land. Since, the capital town of the SNNPR is found within this area, settlement areas are found to be another significant land use type. At higher altitudes especially in the north east side of the area dense forests on which the Wondogenet Forestry College depends is found.

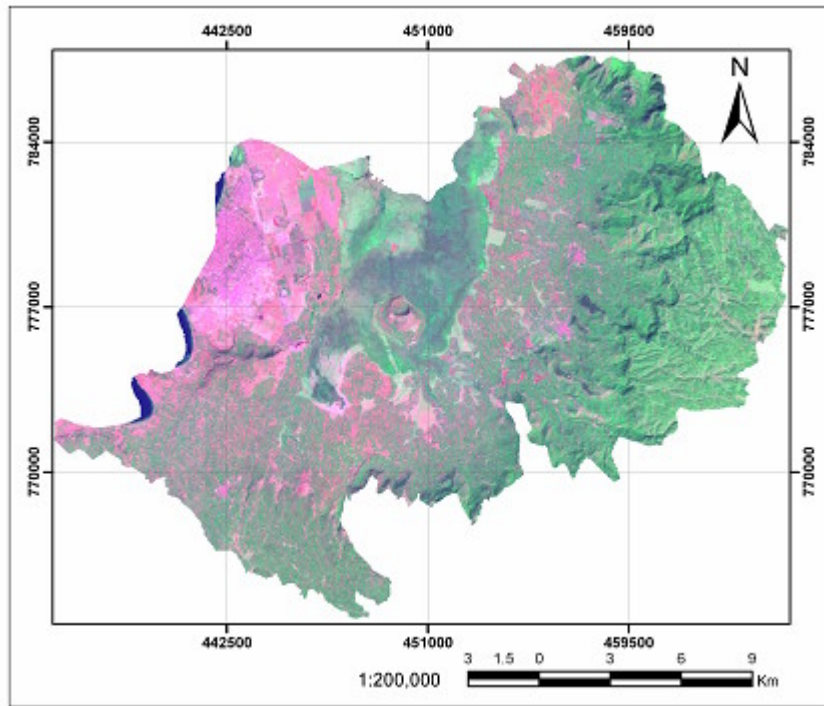


Fig.3.4. True Color Composite Landsat ETM+ Image of the year 2005 at Bands 6, 4 and 2.

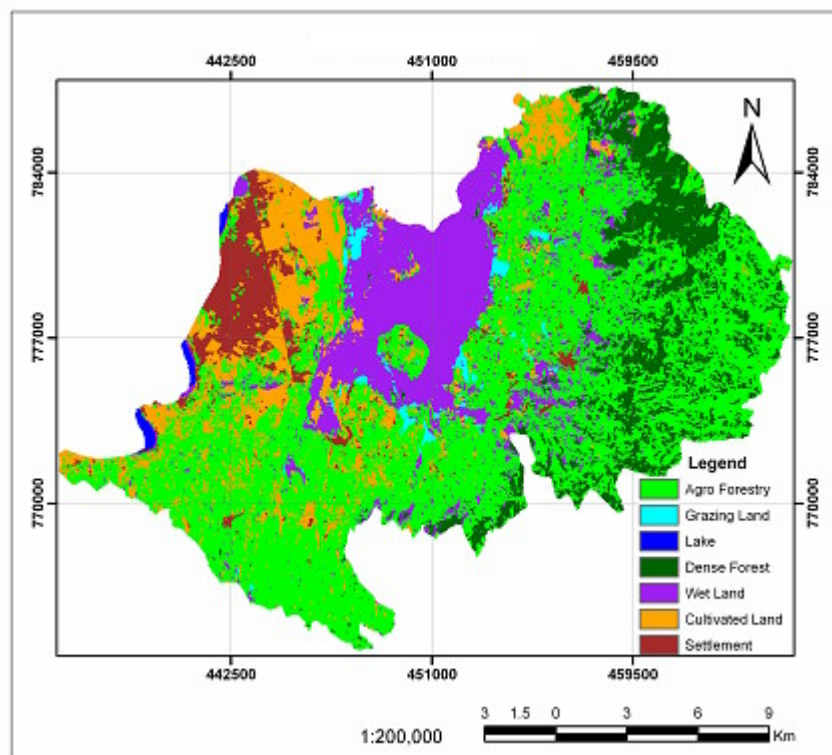


Fig.3.5. Landuse/ Landcover of the Study Area

3.1.5. Population Distribution

The population data used for this study area is the 2009's population data which is obtained from BOFED. As it is indicated in figure 3.6, areas colored red are areas of high population density. These areas are dense because they are areas of urban settlement. The second dense areas are areas surrounding the urban areas. The next dense areas are areas of agro forestry and areas where irrigation practices are conducted. Finally, areas of higher altitude where there is dense forest coverage and areas of wet lands are very sparsely populated (see figure 3.5 and figure 3.6).

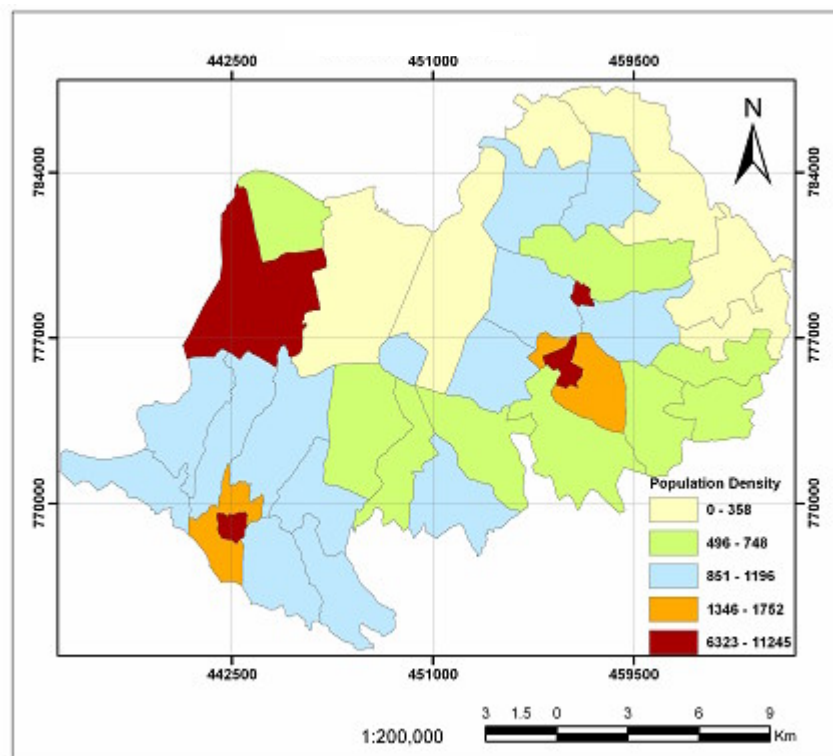


Fig.3.6. Population Density of the Study Area

3.1.6. Climate (Temperature and Rainfall)

Awassa area is affected by the north-south movement of ITCZ (Inter Tropical Convergence Zone) almost through out the year, MOWR, (2000). The area has a sub-humid climate, FAO, (1984). Awassa area, according to table 3.2, has a mean annual precipitation of about 1062mm. The mean minimum precipitation is 21 mm in December during the dry season and the mean

maximum precipitation is 128mm in July, during the rainy season. Temperatures vary between 19°C in July and 22°C in April as it is indicated in table 3.1. The daily sunshine hours ranges between 4 hours during the rainy season and 9 hours during the dry season and the relative humidity varies between 48% and 73% over the year at 1800 local station. The average wind speed recorded is between 0.7 and 1.3m/second at 2m elevation with dominant direction from northeast to southwest (NMA, 2009). Regarding Wondogenet area, the mean annual precipitation is about 1122mm. The mean minimum precipitation is 15 mm in December during the dry season and the mean maximum precipitation is 144mm in July, during the rainy season.

Table 3.1. Average Monthly Temperature Values of Awassa (1993-2001)

Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Awassa	20.0	20.65	21.22	20.98	20.35	19.75	19.05	19.40	19.39	19.43	19.27	19.4

Table 3.2. Average Monthly Rainfall Values of Awassa and Wondogenet (1993-2001)

Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Awassa	39.07	54.25	73.58	97.66	96.36	113.51	128.43	112.58	105.65	101.80	35.86	21.62
W /G	22.26	32.98	110.48	137.62	123.47	112.21	144.20	138.66	136.22	115.68	33.73	15.20

3.1.7. Malaria Trend and Major Climatic Variables

3.1.7.1. Malaria and Temperature

Temperature is an important factor that determines the distribution of mosquitoes. It has an effect on both the vector and the parasite. For the vector, it affects the juvenile development rates, and survivorship of both juvenile and adult stages. For the parasite it affects the extrinsic incubation period (Lactin *et al.*, 1995).

Temperature also increases transmission of malaria by increasing the frequency with which the vector takes blood meals, which increases the growth rate of vector populations through shortening of the generation time. However, the temperature should be combined with the

availability of rainfall for this to be effective. The following graphs illustrate the relationship between malaria incidence and temperature of the study area.

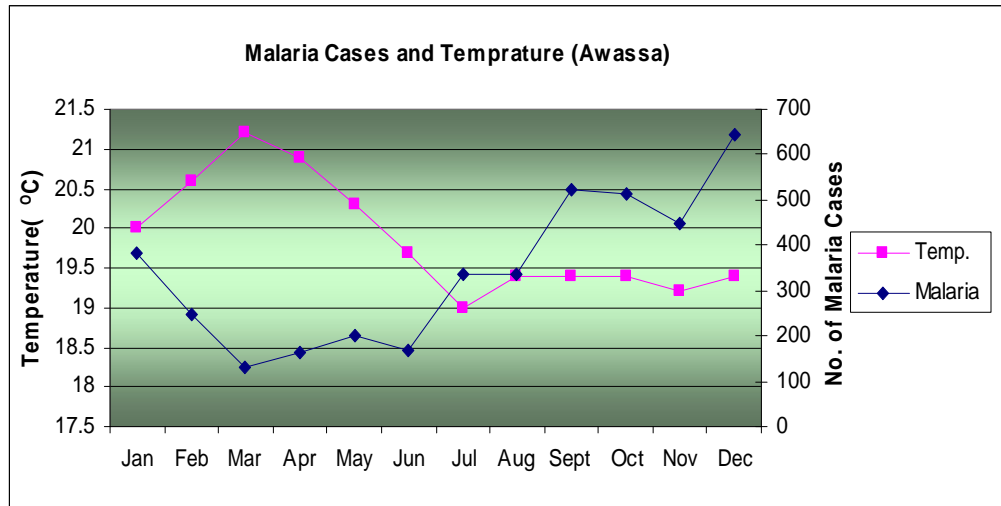


Fig.3.7. Temporal Patterns of Malaria Cases and Temperature at Awassa Health Center (1993-2001)

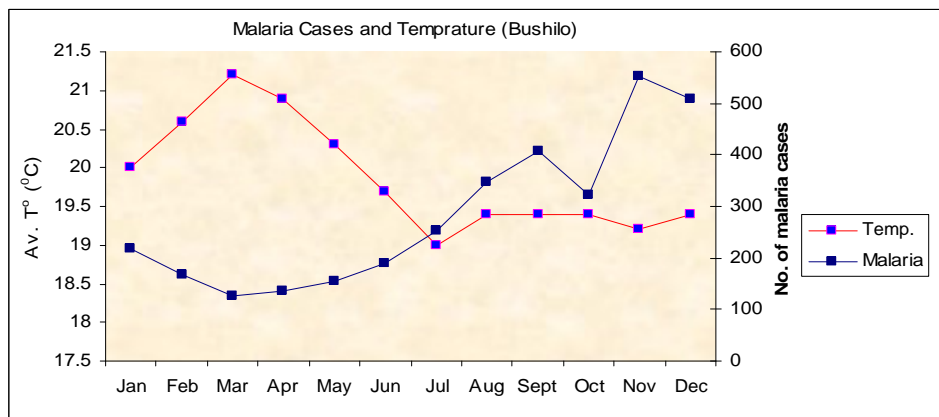


Fig.3.8. Temporal Patterns of Malaria Cases and Temperature at Bushilo Health Center (1993-2001)

Bushilo and Awassa health centers are found in Awassa town. They have similar climatic situation. As the above graphs in figure 3.7 and figure 3.8 show that, there is negative relationship between malaria case and temperature for most months except during and immediately after the main rainy season of the area. During and immediately after the rainy

season the temperature is relatively constant. However, the malaria case showed increment and become the highest at the month of November. This implies that temperature alone is not a sufficient condition for the occurrence of malaria epidemics. It means that the seasonality of temperature should be combined with other climatic variables especially with rainfall as most of the time malaria epidemics are related to the seasonal pattern of rainfall in Ethiopia.

3.1.7.2 Malaria and Rainfall

Preliminary data analysis of 11-woredas in Ethiopia showed a strong seasonal pattern of malaria transmission rate being related to the seasonal pattern of rainfall with a lag time varying from a few weeks at the beginning of the rainy season to more than a month at the end of the rainy season. In most of the 11 Woredas, the malaria transmission rate peaks occurs in May/June at the beginning of the “kiremet” rainy season and in October /November after the “kiremet” rains have stopped in mid September.

Concerning the relationship between rainfall and malaria epidemics of the study area, the following graphs in figure 3.9 and figure 3.10 show the monthly average rainfall and malaria cases of Awassa, and Bushilo health centers for the years between 1993 and 2001.

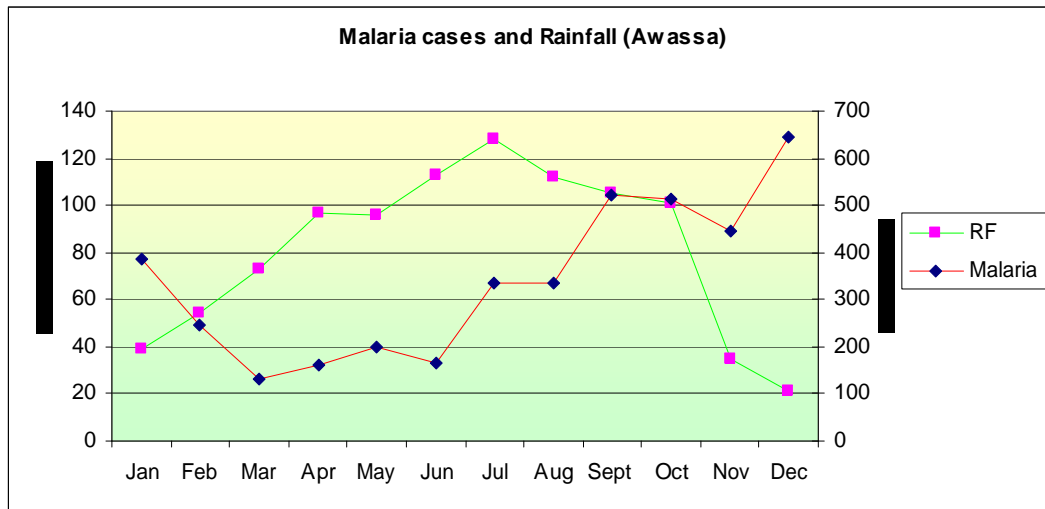


Fig.3.9.Temporal Patterns of Malaria Cases and Rainfall at Awassa Health Center (1993-2001)

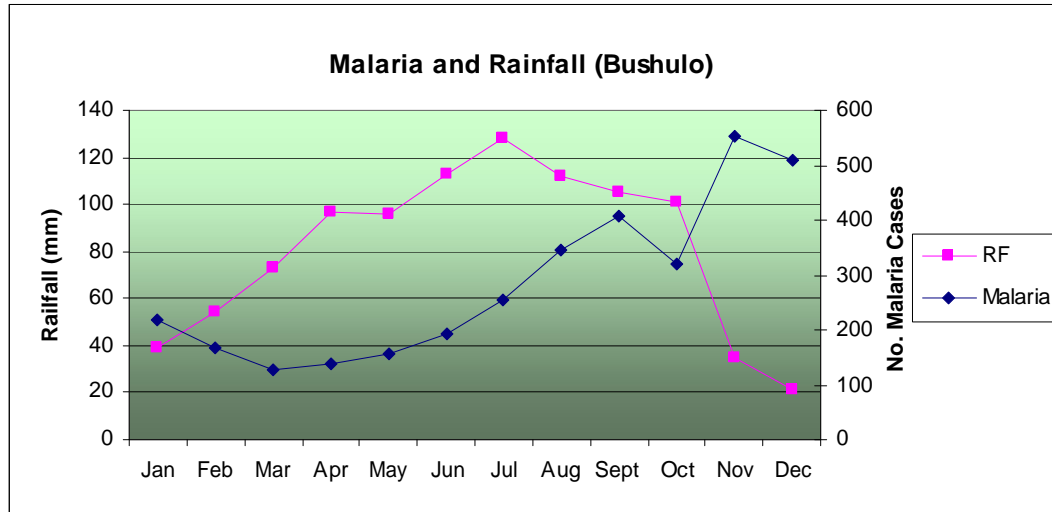


Fig.3.10. Temporal Patterns of Malaria Cases and Rainfall at Bushulo Health Center (1993-2001)

Figure 3.9 and 3.10 Show similar temporal patterns of malaria cases in relation with rainfall as the two areas are located at the same city. There is positive relationship between rainfall and malaria case from March up to October. However, the relationship becomes negative between November and February. There is a peak malaria epidemic immediately after rainy season at November. Once the main rainy season declines in intensity and frequency in November, the increasing average daily temperature and progressive dryness beginning mid-October creates a conducive environment for mosquito breeding in areas where water has been accumulating from the main rain season. The lag time between the end of the main rainy season and peak malaria transmission can be explained by the inherent lag time in mosquito breeding and parasite life cycle inside the mosquito, which are dependent on air temperature and humidity (Zucker, 1996, Malakooti et al, 1998). In addition, the appearance of a malaria patient to the clinic will play role in the observed lag time.

The case of malaria seasonality of Wondogenet area is relatively different from Awassa area. It shows lower seasonal variation as it is indicated in the following figure 3.11.

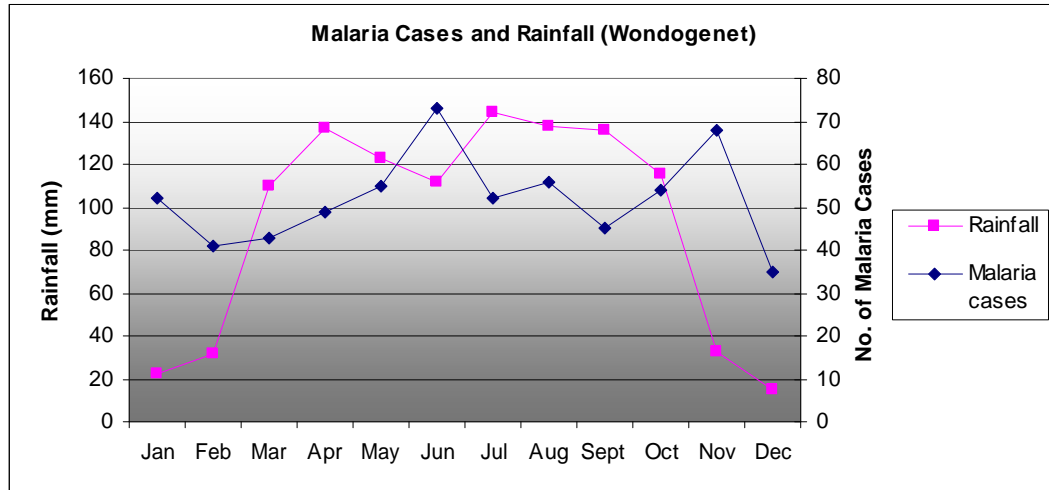


Fig.3.11. Temporal Patterns of Malaria Cases and Rainfall at Wondogenet Health Center (1993-2001)

Figure 3.11 indicates the presence of a lower seasonal variation of malaria epidemics as compared to Awassa area. However, there is some increment of malaria cases after the two rainfall seasons in May and November. The lower seasonal variability of malaria epidemics might be due to the availability of irrigation practices around Wondogenet area. Irrigation structures in the area might have provided suitable breeding sites for mosquitoes during the dry season. Since mosquito-breeding sites are equally available both in the dry and rainy season, such a very high increase in malaria prevalence was not observed during and after the rainy season. The humid environment, which is created through irrigation during the dry season, might have enhanced vector longevity and resulted in lower seasonal variation of malaria epidemics. Likewise, Robert (2004) observed, the increase in the density of foliage of plants will provide more shelter and sites for resting for adult mosquitoes, extending their longevity. This can explain the higher adult density of mosquito in irrigated areas during the dry season (Abose *et al.* 1998).

3.2. Data Sources and Methodology

3.2.1. Data Sources

The input data were taken from various offices where relevant information was expected to be available. Accordingly, the following data shown in table 3.3 were obtained from the respective offices.

Table 3.3. Data used for Analysis

Item	Data type	Source	Remarks
1	SRTM data	GSOE	30m
2	Land Sat ETM+	AAU GIS Stream	2005 data
3	T°, RF	NMA	10 Years Data
4	Medical Data	Health Bureau	10 Years Data
5	Health Facility Location	BOFED	Shapefile
6	Study Woredas Boundary	BOFED	Shapefile

Data about malaria patient cases were collected from the health bureau of Awassa and Wondogenet Weredas. Patient cases of 3 health centers were included for the study. In addition, the point location of 6 health facilities was obtained from the SNNPR BOFED. Detailed information about the land use/cover was extracted from the Landsat ETM+ of the year 2005 imagery by using the supervised classification technique. The topography patterns were extracted from 30m SRTM data. Besides, population data of each kebele within the study area was obtained from BOFED of SNNPR. Moreover, rainfall and temperature data were received from NMA and included for analyzing the relationships between malaria epidemics and rainfall and temperature. Finally, for limiting the area extent of the study, a shape file showing the administrative boundary of the study area was received from the BOFED of SNNPR.

3.2.2. Research Methodology

The study is aimed at first identifying malaria hazard (infected) areas and then malaria risk areas. For mapping malaria hazard five parameters were selected by consulting a malaria expert and depending on related previous works. The factors include elevation, slope, distance from rivers, distance from wetlands, and drainage density. The malaria hazard areas mapping was done using MCE. To carry out the MCE, weight for the factors depending on their suitability for malaria incidence was given in IDRISI software. Then the overlay analysis was conducted using ArcGIS 9.2 spatial analyst extension. Finally, the malaria hazard map was produced. Using similar procedures, the malaria risk map was produced by including population density, distance from health facilities, land use/land cover and malaria hazard layer. For the purpose of depicting the

trend of malaria epidemics and climatic variables, graphs showing the patterns of malaria cases and rainfall and temperature were produced (see figure 3.12).

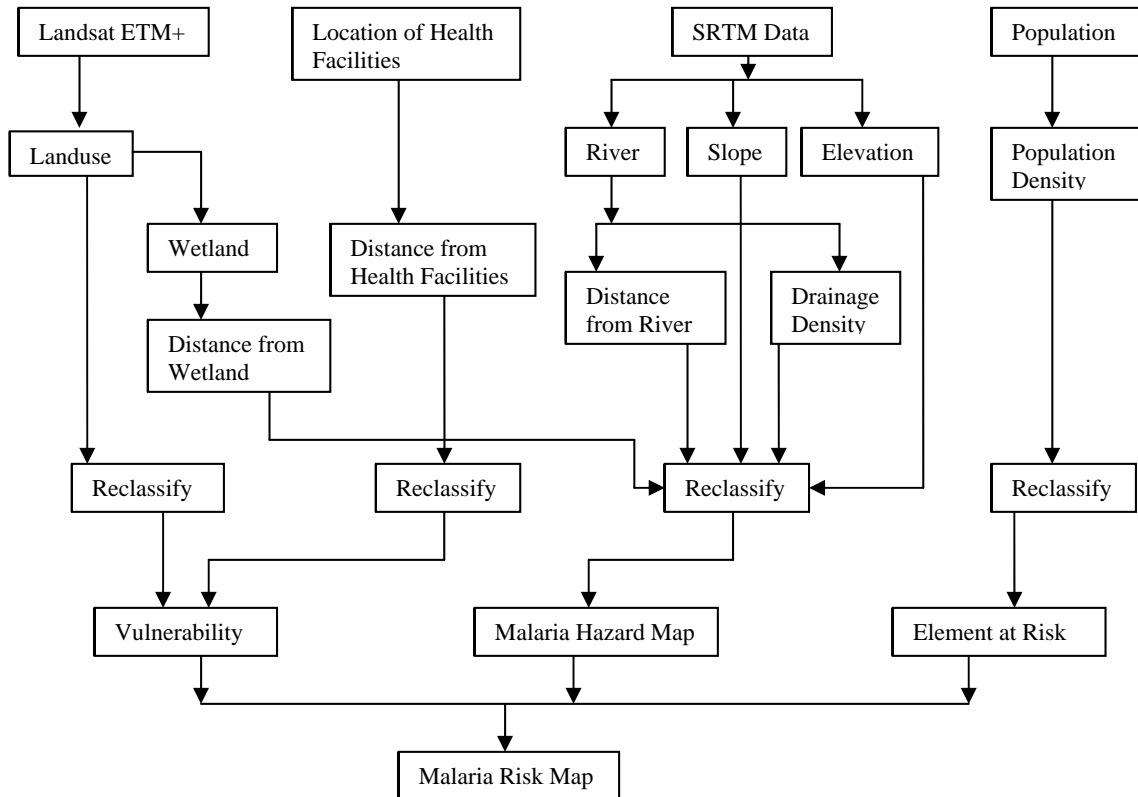


Fig.3.12. Procedural Flow chart of Methodology

3.2.3. Mapping Parameters

From the collected data, relevant parameters which can be used for mapping malaria prone areas were extracted. Their relevance for the mapping is described in table 3.4.

Table 3.4. Mapping parameters and their use in the analysis

Parameter/Map	Relevance for mapping
Distance from rivers, and wet lands	For identifying surface waters and swamps as they are related to vector breeding.
Slope, and Drainage Density	For identifying of areas receptive to water logging
Landuse/ Landcover	For identifying vulnerable and receptive areas for malaria
Location of health facilities	To determine areas that are far away from health service
Elevation	To stratify the elevation according to its suitability to malaria
Population Density	To determine the degree of proneness of the population to malaria risk

3.3. Data Analysis

3.3.1 Environmental Factors for Identifying Malaria Hazard Areas

Malaria transmission is strongly associated with environmental conditions, which control mosquito maturity and parasite development. According to a study conducted in Kenyan highlands, malaria is associated with ecological risk factors. Higher elevation, increased distance from swamp and increased population density were associated with decreased malaria risk (Kaya *et al.*, (2001); Bose, 2003 and Negasi, 2007).

Based on literature search, previous works, and interviews with malaria experts; the following environmental factors that greatly influence on malaria prevalence were identified.

3.3.1.1 Altitude

Altitude has long been recognized as an important determinant of malaria endemicity. It affects various transmission factors which are epidemiologically significant. Probably the most important of these factors is temperature, which affects longevity of vectors and the process of parasite development. In simple terms, the duration of sporogony increases hyperbolically with

decreasing environmental temperatures to a point where parasite development ceases altogether. (Bouma *et al.*, 1994).

Temperature affects malaria transmission for two reasons: either the minimum temperature is so low that it prevents parasite and vector development or else the temperature is too high resulting in increased mortality of the vector. A minimum temperature of 16⁰C restricts parasite development and also prevents the development of the vector in its aquatic stages. At 17⁰C parasites develop but not rapidly enough to cause an epidemic (Lindsay *et al.*, 1998). Maximum temperatures in the neighborhood of 40⁰C have been found to seriously reduce the daily survival probability of the mosquito (Martens *et al.*, 1995). Temperature is an important factor when determining the distribution of mosquitoes since research has made it quite apparent that regions with temperatures dropping to 16⁰C are rarely at risk for malaria epidemics and can be disregarded.

In Ethiopia malaria epidemics tend to occur in areas which are found below 2,200m a.m.s.l. Areas above 2,200 m were considered to be malaria free (UNICEF, 2008). However, most of the areas affected by epidemics are areas located between 1000–2000 m. (Tulu, 1993). Now, transmission of malaria is expanding in to areas which were previously free of malaria. It was revealed that the limit has moved up to 2,500 m. (Negash *et al.*, 2005). In this study, altitude of up to 2,500 m, above which due to low temperature mosquito survival is greatly reduced and malaria transmission does not occur, is taken for the analysis.

The elevation layer was reclassified based on the extent of malaria prevalence at different altitudes given by UNICEF (2008) and Tulu (1993). The layer was reclassified in to five classes and new values were assigned to each class and based on this classification, 5, 4, and 3, values were given to elevation ranges of 1664-2000m, 2000-2200m, and 2200-2500m, respectively and the elevation above 2500m was given no value as malaria can not survive beyond this elevation. Accordingly, the classes were labeled in the figure 3.14 as very high, moderate, very low and malaria free based on the level of vulnerability of those areas to malaria incidence.

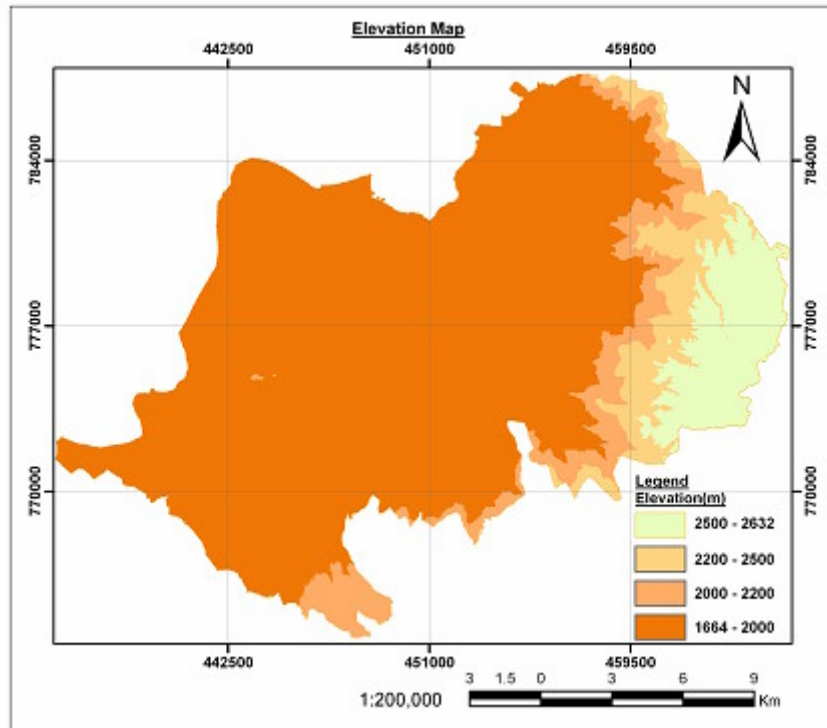


Fig.3.13. Elevation

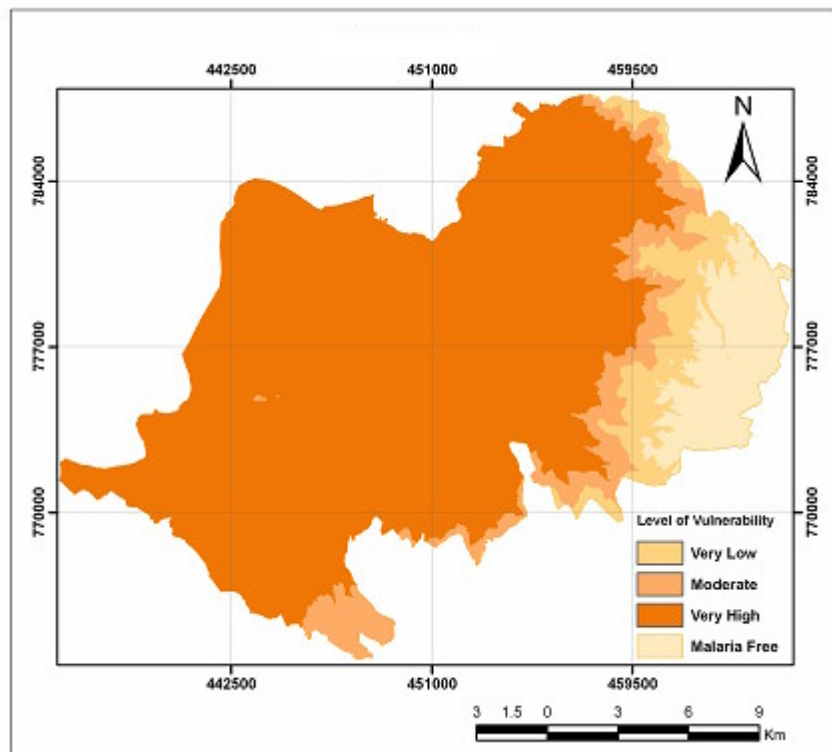


Fig.3.14. Reclassified Elevation

3.3.1.2. Slope

Slope is also one of the topographic parameters that can determine the existence of mosquito larval habitat. It is the measurement of the rate of change of elevation of the land per unit distance. It affects the stability of aquatic habitats (Munga, 2000) as steeper slopes are slopes that allow the fast movement of water. Hence, they restrain the development of stagnant aquatic bodies which can be conducive for breeding of mosquito. Relative to steeper slopes, gentler slopes are slopes where surface water movement is stagnant and this creates fertile situation for mosquito breeding. Therefore, identifying gentler slopes can help to detect the relative importance of areas for mosquito breeding.

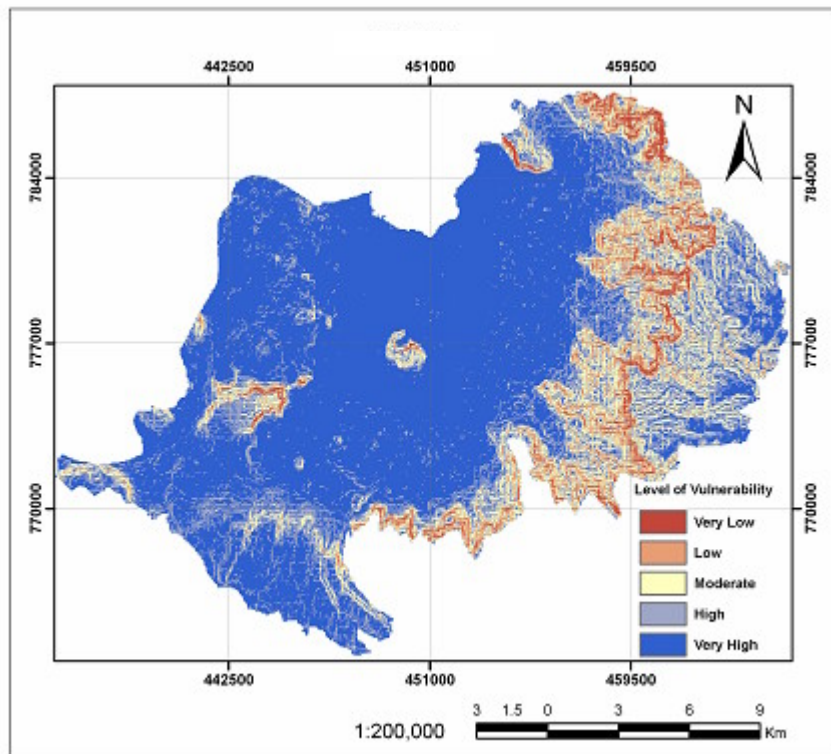


Fig.3.15 Reclassified Slope

The slope of the study Area was derived from 30 meter SRTM data and reclassified in to five classes like the other parameters using natural break standard reclassification technique. The new classes (0-5°, 5-12°, 12-22°, 22-36°, 36-69°) in the reclassified slop layer shown in figure 3.15

were ranked to 5, 4, 3, 2, and 1 and described as very high, high, moderate, low, and very low respectively based on the relative degree of suitability of the slope class for malaria incidence. This means that relatively, gentler slopes are better suitable for malaria incidence and steeper slopes are less suitable.

3.3.1.3 Distance from Wetlands

Wetlands provide habitats for the juvenile (immature) stages (egg, larvae, pupae) of malaria vectors. Monitoring the state of small water bodies and wetlands using satellite data is therefore very useful to identify the source of malaria vectors. Since the fly range of mosquitoes is limited and breeding should be done in water, the abundance of mosquitoes can be found around the places where there are patches of still waters and wetlands (Gond *et al.*, 2004). The premise for assessing areas at risk of malaria infection is based on the maximum distance a malaria-carrying mosquito can travel from its breeding ground to infect human hosts. For this study, the wetland factor was considered to be the most conducive to mosquito larval breeding. A two-kilometer distance around wetlands larval breeding grounds were taken as an area with high malaria transmission with increasing transmission near wetlands. According to Kaya *et al.* (2001) a two-kilometer distance around wetlands is considered to be the maximum flying distance for mosquito. With this information, new classes of the wet land layer were generated to show the highest mosquito density near wetlands.

The wetlands layer was extracted from land use land cover map of the study area. Then, distance calculation and reclassification was done on the layer. The reclassified sub groups of distance from wetlands were ranked according to mosquitoes flying distance threshold value. Areas out of the maximum flying distance threshold were considered to be less malaria prone. Areas found within the two kilometer distance was reclassified in two four classes as all the area can not have equal and uniform distribution of mosquitoes. Hence, new values as it is indicated in figure 3.16. were re-assigned as 5, 4, 3, 2, and 1 in order to show the relative susceptibility of the class ranges of 0-500m, 500-1000m, 1000m-1500m, 1500m-2000m and > 2000m which indicate very high, high, moderate, low, and very low susceptibility to malaria respectively.

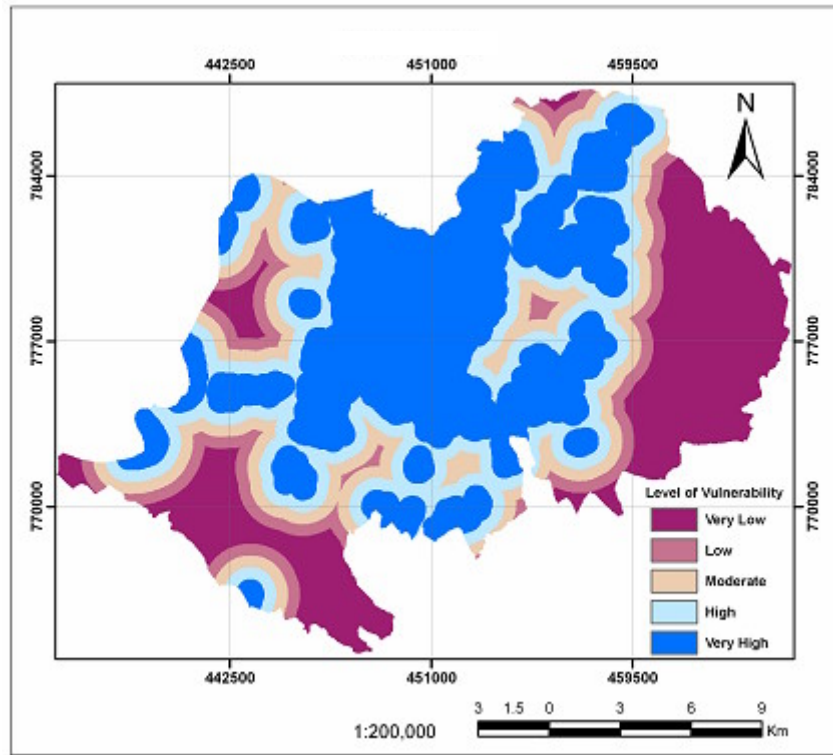


Fig.3.16. Reclassified Distance from Wetlands

3.3.1.4 Distance from River

Breeding and early prevalence of anopheles mosquito is done in water basins. Since the fly range of mosquitoes is limited, the abundance of mosquitoes can be found around rivers where there are still waters. Conducting irrigation practices and developing agricultural projects around rivers can produce still water and as a result, the changing ecosystem can cause an increase in abundance of mosquitoes. As to Bradley (1995) cited in Boelee (2003), irrigation often facilitates double or even triple cropping of crops; here the irrigation system can lead to continuous availability of surface water where vectors can breed without restraint. In the irrigated fields mosquito abundance will increase and if these mosquitoes have enough food source in the breeding sites, the resulting adults may live longer and allow malaria parasites to complete their developmental cycle so that they can be passed on to another host. This allows year round transmission of disease. Moreover, according to Maihotro and Srivastave (2005), the abundance of water in irrigated areas due to seepage, silting, and stagnation, creates innumerable sites for malaria vector breeding. In the study area, specifically around Wondogenet area, small scale

irrigation practices are conducted by farmers. According to Malaria expert of the area, it is these practices and the abundance of wet lands that makes malaria to be prevalent through out the year in the area.

For the purpose of identifying the abundance of mosquitoes around rivers, the river network was derived from the 30 meter SRTM satellite data. Distance was computed from every river. The computed distance was reclassified based on the maximum distance that mosquitoes can fly. Different literatures indicate that mosquitoes have typical flight ranges up to 2 kms depending upon species (Kaya *et al.*, 2001). Therefore, for this study, similar to the distance calculated around wetlands, new classes of 0-500m, 500-1000m, 1000-1500m, 1500-2000m, and above2000m were computed and assigned values of 5, 4, 3, 2, and 1 respectively. Then, each class shown in figure 3.17, beginning from the class with the highest value, was labeled as very high, high, moderate, low, and very low based on the degree of vulnerability of the area to malaria. In other words, this means that areas near to river(s) are highly vulnerable to malaria and those areas far from river(s) are less vulnerable.

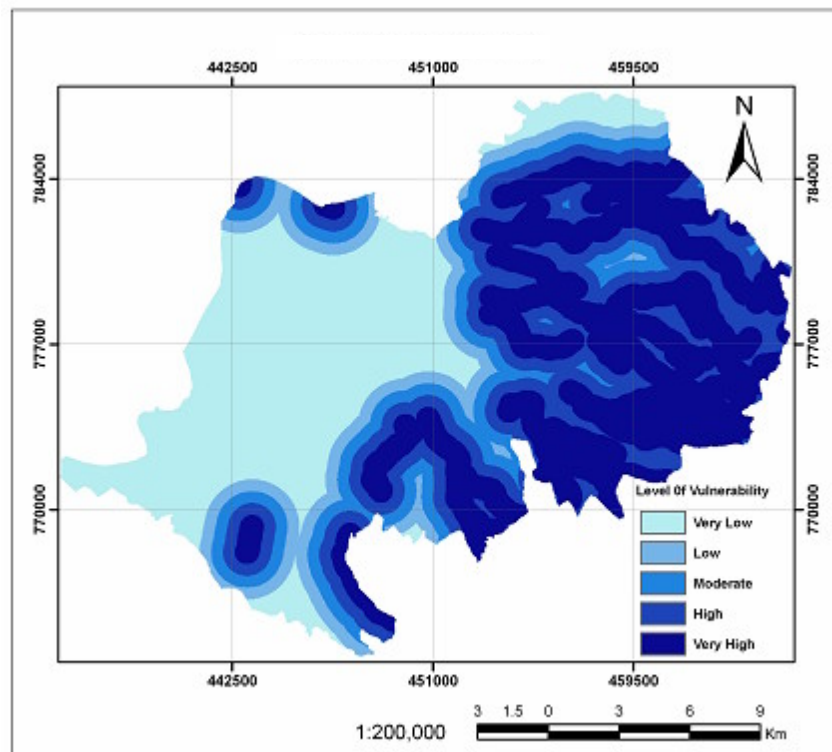


Fig.3.17 Reclassified Distance from Rivers

3.3.1.5 Drainage Density

Drainage density refers to the average length of streams within each unit area. A number of factors influence drainage density. It tends to be highest in areas where the land surface is impermeable, where slopes are steep, and where rainfall is heavy and prolonged (Waugh, 1996). Steeper slopes inhibit the development of still aquatic body; thereby inhibiting mosquito breeding habitats. In addition, heavy rains may have a flushing effect, cleaning breeding sites of mosquitoes. Therefore, calculating drainage density helps to identify the potential areas for mosquito breeding by identifying areas of water-logging. A.W. Sweeney (1999) stated that, there is a negative correlation between mosquito habitat and drainage density. This means that the lower the drainage density, the higher an area is suitable for water logging and the better suitable the area is for mosquito breeding. To this effect, classes of 0-0.28, 0.28-0.56, 0.56-0.84, 0.84-1.12, and 1.12-1.40 were formed and ranked as 5, 4, 3, 2, and 1 respectively. The values were described in figure 3.18 as very high, high, moderate, low, and very low in correspondence with the values beginning from the highest value representing degree of malaria proneness.

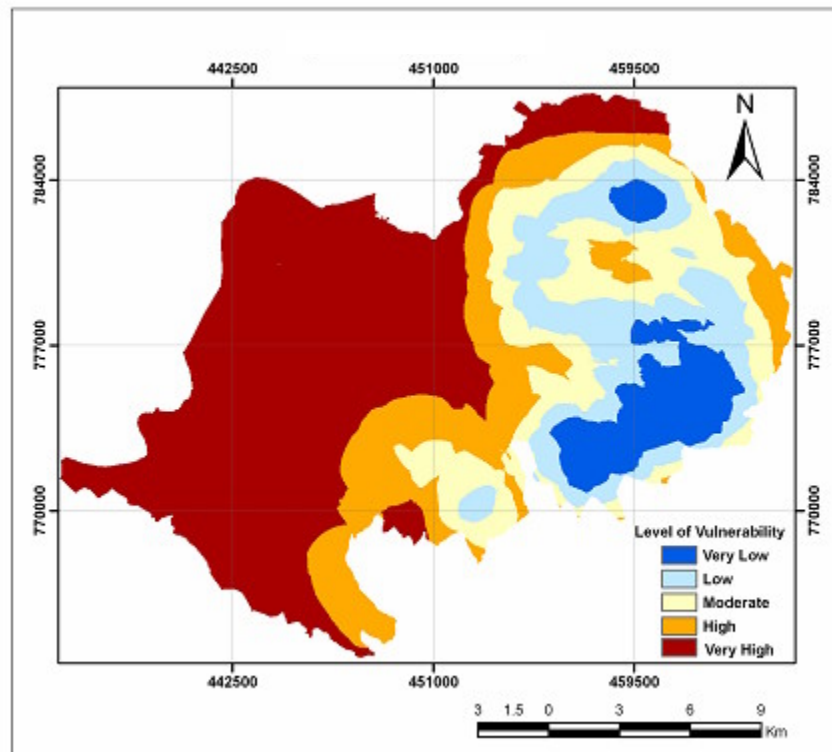


Fig.3.18. Reclassified Drainage Density

3.3.2. Socio-Economic Factors for Identifying Malaria Risk Areas

In assessing an the area in urgent need of attention to fight against malaria, mapping which is based solely on natural conditions is not sufficient but socio-economic factors, such as population distribution, health facility distribution and land use should also be included. Because it is then that one can better site the area where there is high risk of Malaria and can at the same time locate people at risk.

3.3.2.1. Distance from Medical Facilities

Assessing the location of health facilities is important, because it is necessary not only to map risky areas but also to uncover the potential needs and the location of existing medical facilities so that allocation of the new facilities can be done effectively.

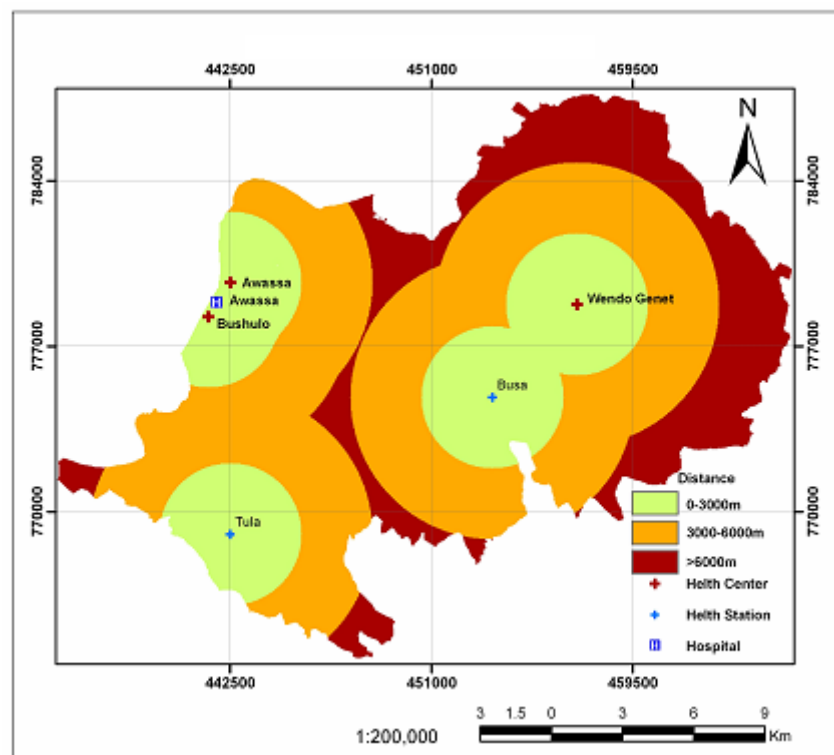


Fig.3.19. Reclassified Distance from Health Facilities

The location map of medical facilities of the study area is obtained from SNNPR BOFED. The map below illustrates the sphere of influence of medical facilities in the study area. This was

done by calculating distance from each health facility and by reclassifying the distances into 5 classes based on the lowest easily accessible distance set by WHO.

According to WHO (2003), areas found within 3 Km radius from a health facility is assumed to be less risky than areas found beyond this distance. Hence, classes of distances; 0-3000m, 3000-6000m, and >6000m were computed in figure 3.19. The classes were given values of 1, 3, and 5 and scaled as low, moderate and very high respectively based on the degree of vulnerability to the risk of malaria.

3.3.2.2 Landuse/ Landcover

Ecological disturbances are unavoidable as humans are changing the environment in which they and other biological systems exist. The creation of new habitat for mosquitoes is observed when changes in landuse, such as forest clearance and irrigation agriculture are part of a region. Irrigated areas are ideal places for mass production of mosquitoes (Beck et al., 1997). As to Bradley (1995) cited in Boelee (2003), irrigation system can lead to continuous availability of surface water where vectors can breed without restraint. In the irrigated fields mosquito abundance will increase and if these mosquitoes have enough food source in the breeding sites. The resulting adult mosquitoes may live longer and allow malaria parasites to complete their developmental cycle so that they can be passed on to another host. As a result, there can be more human-vector interactions, which cause an increase in malaria incidence in the human population there by allowing year round transmission of disease.

Curran *et al.* (2005), provide an excellent overview of the use of remote sensing data for health applications. They indicate that a complex set of inter-relationships exist between land surface characteristics, as perceived by remote sensing, and disease risk spatially distributed on the earth's surface. In the malaria-mosquito disease-vector combination, there is a link between land cover and vector density on the one hand, and vector density and disease risk on the other. In the case of the landcover and mosquito population, it is generally understood that proximity to water is important, particularly in the breeding phase. However, there are many other factors that intervene, such as internal vector population dynamics, interrelations between the vector and vertebrate populations, and environmental influences such as microclimate.

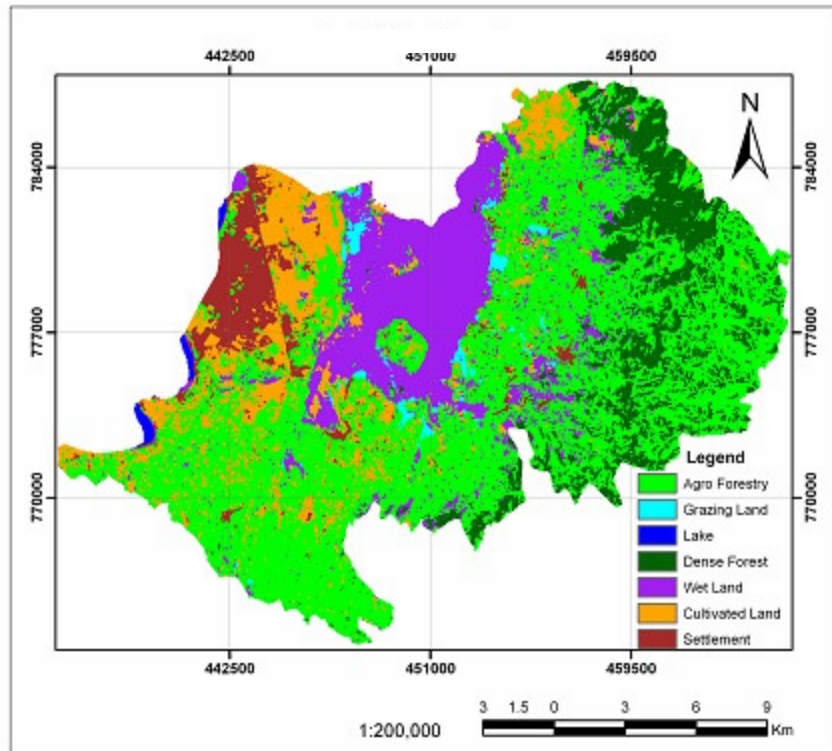


Fig.3.20. Landuse/Landcover

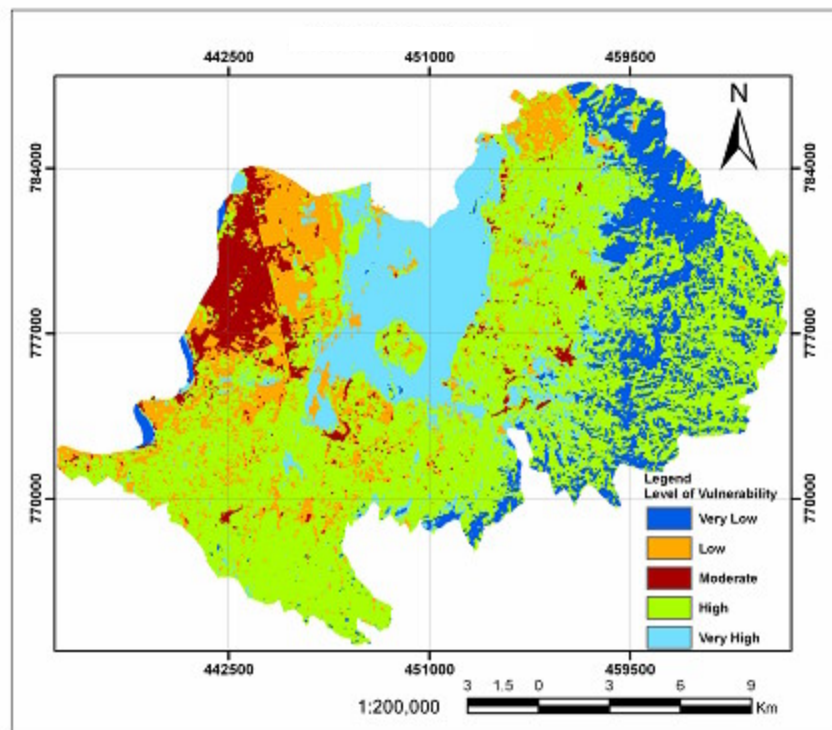


Fig.3.21. Reclassified Landuse/ Landcover

In the study area, in order to identify aquatic habitats and landcover types that affect the survivorship of anopheline mosquito, Landsat ETM+ satellite image of the year 2005 was classified using a supervised classification method. A total of seven land-cover classes were identified: farmland; grazing land, natural swamp, dense forest, settlement, lake, and agro-forestry. Ground truthing was conducted by direct field inspection of 50 points randomly, which assesses the accuracy of landuse and landcover classification. Moreover, the landuse/ landcover map in figure 3.20 was reclassified in to five sub-groups in order of susceptibility and suitability for malaria risk. Thus, the reclassified version in figure 3.21 implies 1 to 5 values, where 1 stands for less prone land use land cover and 5 for highly prone landuse / landcover for malaria.

Due to their suitability for malaria, wetland & agro-forestry landuse/ landcovers were considered as high risk in terms of malaria breeding and resting sites. Robert (2004) observed that the increase in the density of foliage of plants provide more shelter for adult mosquitoes. The irrigated farming in the study area, where different crops were grown and other trees planted for fencing, provided ideal sites for resting and enhancing longevity of vectors. In addition, settlement areas open doors to new habitats for the malaria vector, because not only are there more people in the city, but also there are more places to breed in the city as well (Broker *et al.*, 2005).

3.3.2.3 Population Density

The growth of population and urbanization is another factor in the determination of health events such as epidemics of malaria. Issues related with urbanization include open water storage and the inadequate disposal of water (Reiter, 2001). When population is rapidly expanding, it opens doors to new habitats for the malaria vector, because not only are there more people in the city, but there are more places to breed in the city as well. Also of importance is the movement of people, infected people traveling to non-endemic areas can introduce disease where it would not normally occur. Conversely non-immune people are at a high risk if they move to a region where transmission is high.

Malaria as a disease is closely bound to conditions which favour the survival of the anopheles mosquito. For malaria to occur in a person, *Anopheles* mosquitoes must be present, which are in contact with humans, and in which the parasites can complete the "invertebrate host" half of their

life cycle. In addition, humans must be present, who are in contact with *Anopheles* mosquitoes, and in whom the parasites can complete the "vertebrate host" half of their life cycle. Finally, malaria parasites must be present.

For *Anopheles* mosquito to survive, it has to feed on human blood. The frequency with which the vector takes blood meals is directly related with rising temperature at optimal range of temperature (20-30⁰c) and the presence of people exposed to *Anopheles* mosquitoes. The larger the population, the greater it is exposed to the risk of malaria in areas where malaria hazard is prevalent. Because, it increases the human-vector interactions, and enhances transmission by increasing the frequency with which the vector takes blood meals. This causes an increase in malaria incidence in the human population.

Therefore, for the purpose of mapping the population at risk of malaria, population density of each kebele was computed. The population density at kebele level was used because there is no detail population data or map that can depict the detail spatial distribution of the population in an area less than kebele level. Then, the population density map is reclassified in to 5 classes and the densely populated areas were labeled as highly susceptible in figure 3.22.

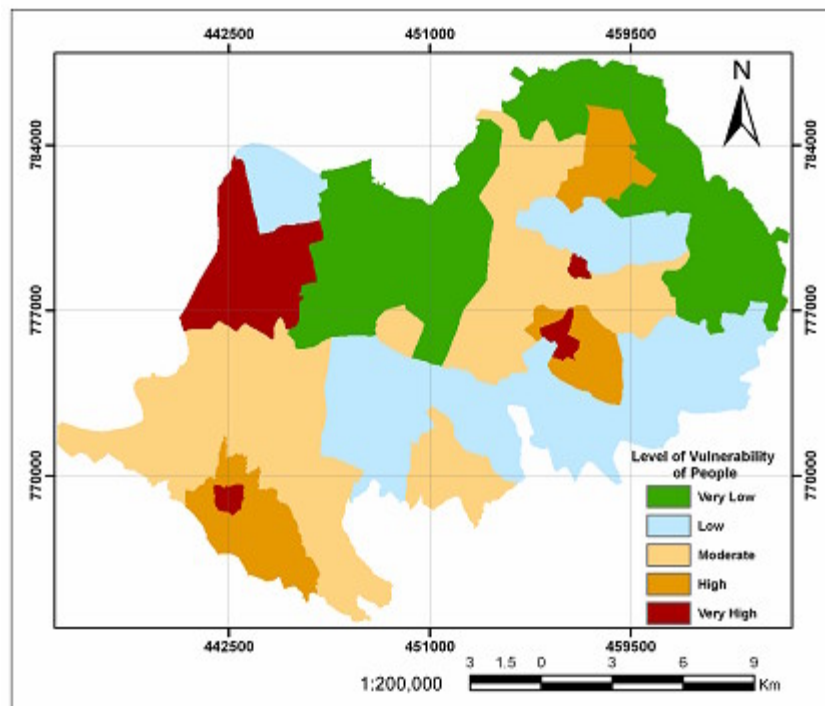


Fig.3.22. Reclassified Population Density

4. RESULTS AND DISCUSSION

4.1. Identifying Areas of Malaria Hazard

Hazard is the probability of occurrence of damaging natural phenomenon within specified period of time. As a hazard, malaria incidence is mapped by depending on some of the environmental factors which contribute for the survival of *Anopheles* mosquitoes.

Table 4.1. Weight of Malaria Hazard Factors

<i>Factors</i>	<i>Weight</i>	<i>Class</i>	<i>Ranking</i>	<i>Susceptibility</i>	<i>References</i>
Altitude	0.50	1664-2000m	5	Very High	UNICEF (2008) Tulu (1993)
		2000-2200m	3	Moderate	
		2200-2500m	1	Very Low	
		>2500m		Malaria Free	
Distance from wet lands	0.30	0-500m	5	Very High	Kaya <i>et al.</i> (2001) Gond <i>et al.</i> (2004)
		500-1000m	4	High	
		1000-1500m	3	Moderate	
		1500-2000m	2	Low	
		> 2000m	1	Very Low	
Slope	0.10	0-5°	5	Very High	Munga (2000) Negasi (2007)
		5-12°	4	High	
		12-22°	3	Moderate	
		22-36°	2	Low	
		36-69°	1	Very Low	
Distance from river	0.04	0-500m	5	Very High	Kaya <i>et al.</i> (2001) Negasi (2007)
		500-1000m	4	High	
		1000-1500m	3	Moderate	
		1500-2000m	2	Low	
		> 2000m	1	Very Low	
Drainage Density	0.06	0-0.28	5	Very High	Sweeney (1999) Negasi (2007)
		0.28-0.56	4	High	
		0.56-0.84	3	Moderate	
		0.84-1.12	2	Low	
		1.12-1.40	1	Very Low	

For the purpose of identifying areas of malaria hazard, this study focused on elevation, slope, distance from rivers, distance from wetlands, and drainage density as the factors of malaria

incidence in the study area. The malaria incidence and transmission requires the environment with lower elevation (higher temperature), abundance of wet lands, occurrence of gentle slopes, availability of still waters around rivers, and areas of lower drainage density (Kaya *et al.*, (2001); Bose, 2003 and Negasi, 2007). It is by overlaying these factors that areas vulnerable to malaria were identified. The overlay analysis was done after each factor was given the appropriate weight. The factors were ranked in Table 4.1, according to the degree of importance that they have for the incidence of malaria in this research. This was done based on the previous studies, by consulting the malaria expert of Wondogenet woreda, and by using weighted linear combination method in IDRISI software. Pair wise Comparison of the five parameters was carried out to develop the pair wise comparison matrix. Accordingly, the above weights of factors in table 4.1. was computed.

After the overlay analysis of the five factors namely; elevation, slope, distance from rivers, distance from wetlands, and drainage density, the following malaria hazard map in figure 4.1 was produced.

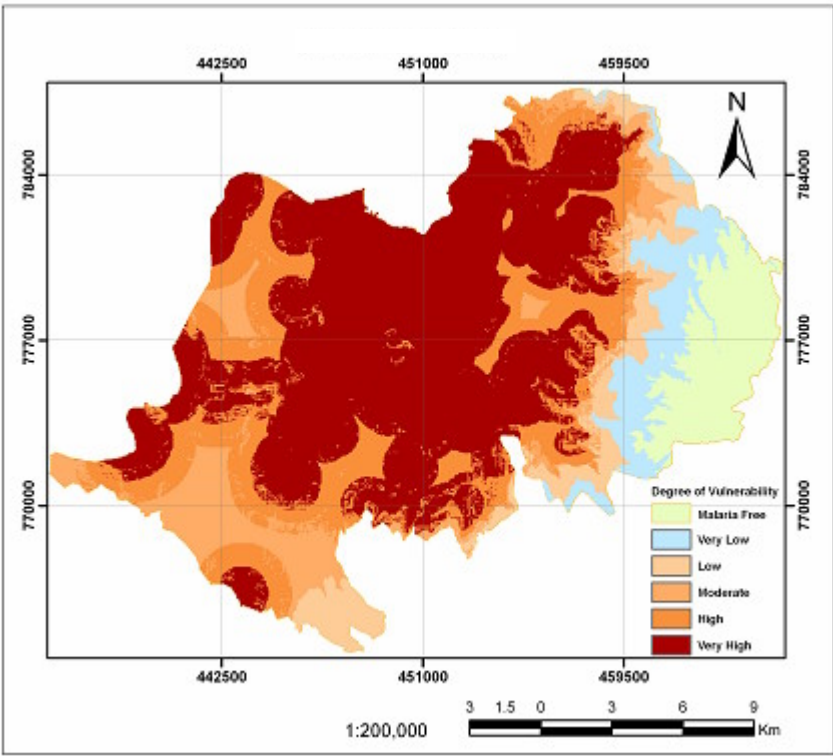


Fig.4.1. Malaria Hazard

The Malaria hazard map in Figure.4.1 depicts that 184.7Km², 76.3 Km², 37.4 Km², 26.9 Km², and 24.1 Km² representing 48.6%, 19.9%, 9.7%, 7%, and 6.3%, of the total area is subject to very high, high, moderate, low, and very low level of malaria vulnerability. The remaining 32.0 Km² (8.4%) of the total area is a free from malaria. Hence, from these figures it is possible to conclude that about 68% of the total area is highly exposed to malaria hazard. This is mainly due to the excessive availability of aquatic bodies and irrigation practices in the study area.

4.2. Identifying Areas of Malaria Risk

In assessing the area in urgent need of attention to fight against Malaria, hazard mapping which is based solely on natural conditions is not sufficient but socio-economic factors, such as population density, distribution of health facilities, and land use land cover should also be included. Because, it is only then that one can site the area where there's high risk of malaria. The malaria hazard map, Population distribution map, health facilities map, and land use land cover map were multiplied and malaria risk indicator map which is shown in figure 4.2 was created. The basis for the calculation of the map was the risk computation model developed by shook (1999). According to (shook, 1999):

$$\text{Risk} = \text{Hazard} * \text{Element at Risk} * \text{Vulnerability}$$

“**Hazard (H)** is the probability of occurrence of a potential damaging phenomenon within a specified period of time and within a given area”

“**Vulnerability (V)** is the degree of loss to a given element or set of elements at risk resulting from the occurrence of a damaging phenomenon of a given magnitude”

“**Element at risk (E)** includes the population, buildings, and civil engineering works, economic activities, public services, utilities and infrastructures, etc., at a given area.”

“**Risk (R)** is the expected degree of loss due to a particular natural phenomenon. It may be expressed as the product of hazard (H), vulnerability (V), and element at risk”

As it is indicated above, the mapping of malaria risk includes hazard, element at risk, and vulnerability. The malaria hazard layer was computed by overlaying the five selected causative factors which includes wet lands, elevation, slope, drainage density and distance to streams. The element at risk layer was developed by reclassifying population density layer. Moreover, vulnerability layer was developed by reclassifying land use/ land cover layer on the basis of the degree of susceptibility of each landuse/ landcover to malaria and by computing and reclassifying distance from the existing health facilities layers. The layers were prioritized according to their degree of influence. Pair wise comparison of the four parameters was carried out to develop the following weights in Table 4.2. Based on these weights, the map in Figure 4.2 showing areas of malaria risk was produced.

Table 4.2. Weight of Malaria Risk Factors

Factor	Class	Rank	Susceptibility	Weight
Malaria Hazard		5	Very High	40%
		4	High	
		3	Moderate	
		2	Low	
		1	Very Low	
Land Use	Wet Land	5	Very High	30%
	Agro forest & Grazing	4	High	
	Settlement	3	Moderate	
	Cultivated Land	2	Low	
	Dense Forest & Lake	1	Very Low	
Health Facility	0-3000m	5	Very High	20%
	3000-6000m	4	High	
	>6000m	1	Very Low	
Population Density	0-358	1	Very Low	10%
	358-748	2	Low	
	748-1061	3	Moderate	
	1061-1752	4	High	
	1752-11245	5	Very High	

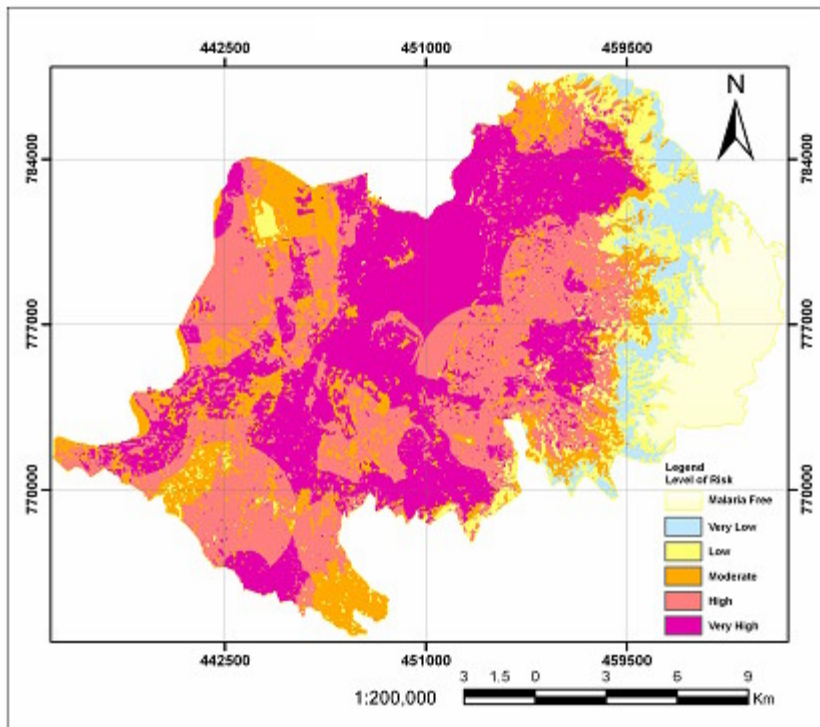


Fig.4.2. Malaria Risk

In this study, for the purpose of identifying areas of malaria risk; population density, distribution of health facilities, malaria hazard and land use land cover were used as input factors for malaria risk mapping. As a result, the risk map in figure 4.2 showed 122Km²(32%), 117Km²(30.7%), 60Km²(15.7%), 31Km²(8.1%) 19Km²(5%), and 32Km²(8.4%) of the total area is subject to very high, high, moderate, low, very low and is free from malaria risk respectively. Hence, it is possible to conclude that the majority of the area (more than 60%) is under high risk of malaria. Part of Abaye, Yuwo, Aruma, Tllu, Chefe Kotegebesa, Swampy area, Shasha Kakalo, Washa Soyama, and Gamato are subject to very high risk of malaria. This seems due to the humid environment, which is created by irrigation and the wet land, and the availability of large number of people with lower health facility. Moreover, the existence of the agroforestry might have provided more shelter and sites for resting for adult mosquitoes, which extends their longevity and density.

4.3. Comparing Malaria Hazard Map with Kebeles Which Were Labeled as Malarious

The entire kebeles under Awassa woreda and part of kebeles under Wondogenet woreda (Yuwa, Aruma, Edo, Busa, Chuko, Entaye, Kela, Wetera, Shasha Kakale, Gotu Anuma, Abaye and Baja Fabrica) were labeled as malarious by health bureaus of the respective woredas. Similarly, these kebeles were labeled and mapped under high and moderate hazard areas in the hazard map (see fig 4.3). The main difference is that Kebeles under Awassa woreda are labeled as areas of seasonal malaria prevalence and malarious kebeles of Wondogenet woreda are labeled as areas of permanent malaria prevalence. This is mainly attributed to the presence of wet lands, rivers, agro forests and irrigation practices around Wondogenet area.

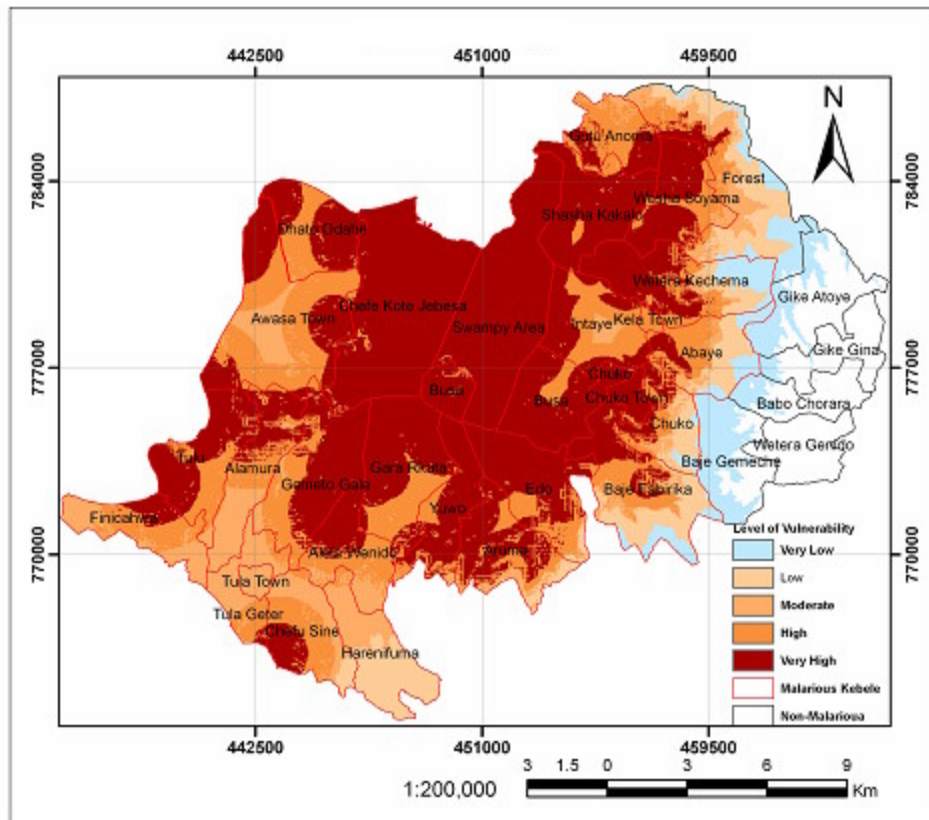


Fig.4.3. Malaria Hazard Map Showing Malarious and Non-Malarious Kebeles

5. CONCLUSIONS AND RECOMMENDATIONS

5.1. Conclusions

This study was aimed at producing malaria hazard and risk maps of Awassa and Wondogenet Weredas so that it can help to improve the management and control of malaria vector. Although the environmental drivers that determine the life cycles of both the vector and the parasite are complex, they can be monitored and analyzed using newly available technologies of RS and GIS. This research has shown that GIS and remote sensing is important to create operational maps which could help the vector control agencies to identify hazard and priority areas for disease control.

The hazard map was produced depending upon the physical parameters which are capable of providing fertile environmental situations for mosquito breeding. The study focused on elevation, slope, distance from rivers, distance from wetlands, and drainage density as the factors of malaria incidence having 50%, 10%, 4%, 30% and 6% weights respectively in the overlay analysis. The malaria incidence and transmission requires the environment with lower elevation (higher temperature), abundance of wet lands, occurrence of gentle slopes, availability of still waters around rivers, and areas of lower drainage density. Hence, from the result of the overlay analysis of the physical parameters, it is possible to conclude that about 68% of the total area is highly exposed to malaria hazard. In addition, Yuwa, Aruma, Edo, Busa, Chuko, Entaye, Kela, Wetera, Shasha Kakale, Gotu Anuma, Abaye and Baja Fabrica kebeles were highly found to be under malaria hazard. This is mainly due to the greater availability of aquatic bodies and irrigation practices in the study area.

Similarly, the malaria risk map was produced depending upon the overlay analysis of the malaria hazard map and some socio-economic parameters like landuse/ landcover, distance from health facility services location and population density. The factors had 40%, 30%, 20% and 10% weights in the overlay analysis respectively. The result indicated that the majority of the area (more than 60%) is under high risk of malaria. Part of Abaye, Yuwo, Aruma, Tllu, Chefe Kotegebesa, Swampy area, Shashsa Kakalo, Washa Soyama, and Gamato are subject to very

high risk of malaria. This is not only due to the physical parameters but also the poor health facility for the existing large number of people in the study area and the existence of suitable landuses and landcovers for mosquito breeding.

Hence, the maps were constructed to allow targeting intervention within kebeles according to the risk gradient. Thus, vector control mechanisms like indoor insecticide spraying could be limited to these priority zones.

Recommendations

Based the findings of this study the following recommendations were given as follows:

1. The Woredas should develop the capacity to use GIS and remote sensing technology for the effective identification of ecologies of mosquito and other vector borne diseases;
2. It will be cost effective if the woredas will incorporate the malaria hazard and malaria risk maps of the results of this study in the current ongoing health development activates so as to target on the priority areas identified by the study;
3. The establishment of health centers should be made at high and very high risk areas at reasonable distance away from the existing health facilities so that people at a distance can easily access the service.
4. Proper data bases about detail patient data, the seasonal incidence of epidemics and about other related aspects of the malarious kebeles should be made using GIS ;

References

- Abose, T., Yeebiyo, Y., Olana, D., Alamirew, D., Beyene, Y., Regassa, L. and Mengesha, A. (1998). Re-orientation and Definition of the Role of Malaria Vector Control in Ethiopia. (WHO/MAL/98.1085) WHO, Geneva, pp.1-37.
- Abose, T., Garrit, J. V., Bosboom, G., Sakr, J. and Habbema, J.D. (2003). Spatial and temporal variation of malaria epidemic risk in Ethiopia: factor involved an implication. *Acta Trop.* **87**: 331-340.
- Ashenafi, M. (2003). Design and water management of irrigation systems to control breeding of *Anopheles* mosquitoes. Case study: Hara irrigation project, Arba Minch, Ethiopia. M.Sc. Thesis. Wageningen University, Wageningen. The Netherlands.
- Awassa Town Municipality. (2009). Landuse Information of Awassa Town, Awassa.
- Bian L, Mushinzimana, E., Munga S., Minakawa N. and Feng C. (2006). Landscape determinants and remote sensing of anopheline mosquito larval habitats in the western Kenya highlands. *Malaria journal* 5:13.
- Boelee, E., Konradsen, F. and Wim Vander Hek. (2002). Malaria in irrigated agriculture, papers and abstracts for the SIMA special seminar at the ICID 18th International congress on irrigation and Drainage, Montreal, 23 July 2002. IWMI, working paper 47. SIMA Document 2.Colombo, Sri Lanka.
- Boelee, E. (2003). Water and Health in irrigated agriculture .In: Mc Cornick, P. G., Kamara, A. B. and Girma, T. (eds). International water and land management research and capacity building priority of Ethiopia. Proceeding of a MoWR/EARI/IWMI/ILRI/ international workshop held at ILRI, Addis Ababa, Ethiopia.2-4Dec.2002.Pp.121-129.IWMI, Colombo Sri Lanka, and ILRI Nairobi, Kenya.267P.
- Brooker S, Hay SI, Tchuem Tchuenté LA, Ratard R (2002). Using NOAA AVHRR data to model human helminth distributions in planning disease control in Cameroon, West Africa. *Photogram Eng Rem S68* (2): 175-179.
- Bziava, J. and Kruashvili, L. (2002). Ecological changes of malaria mosquito larvae at the rehabilitation of irrigation and drainage systems. In: Boelee, E., Konradsen, F., Van der Hoek W, (eds). Malaria in irrigated agriculture: papers and abstracts for the SIMA Special Seminar at the ICID 18th International Congress on Irrigation and Drainage, Montreal, 23 July 2002. IWMI Working Paper 47 SIMA Document 2, Colombo, Sri Lanka.

- Carrara ,C., Petrarca, V., Niang, M. and Coluzzi, M. (1990). *Anopheles pharoensis* and transmission of *Plasmodium falciparum* in the Senegal River delta. West Africa. Med. Vet. Entomol. **4**:421-424.
- CDC. (2004). Centers for Disease Control and Prevention. Department of Health and Human Services. [http://www.cdc.gov/malaria/biology/. On 12 Feb 2005 25:27:24].
- CDC. (2006). Centers for Disease Control and Prevention. Department of Health and Human Services. Schema of the Life Cycle of Malaria. [http://www.cdc.gov/malaria/biology/life_cycle.htm. On 16 May 2006 20:30:24.
- Coetzee, M., Craig, M. and Sauer, D. (2000). Distribution of Africa malaria mosquitoes belonging the *Anopheles gambiae* complex. Parasitol. Today. **16**: 74-77.
- Daniel, E. (1999). Malaria: Failure, Puzzle, & Challenge. Perspectives in health. Media center press release megazine.No.1. 74
- Deirdre, A.J., Xiaorong, F., Jianbing, M., Tetsuya, F., Kesinee, C., Antoniana, U. K., May, H., Alex, W., Nicolas, J.W., Edward, S., Peter, B. and Xin-zhun, S. (2003). Early Origin and Resent Expansion of *Plasmodium falciparum*.Science.**300**: 318- 20.
- Dessie Nadaw (1997) Hydrogeology of Awassa area, M. Sc. Thesis, AAU, Addis Ababa.
- Githeko, K., Ndong, C.M. and Atieli, K. (2000). Climate change and vector-borne diseases: a regional analysis. WHO Bulletin, 78(9): 1136-1146.
- Gilles, H.M. and Warrell, D.A. (1993). Bruce- Chewatt's Essential malariology. 3rd edition. Arnold. London.
- Glass, G.E., Check, J.E., Patz, J.A., Shields, T.M., Doyle, T.J., Thoroughman, D.A., Hunt, D.K., Ensore, R.E., Gage, K.L., Irland, C., Peters, C.J. and Bryan, R. (2000). Using remotely sensed data to identify areas at risk for hantavirus pulmonary syndrome. Emerging Infectious Diseases **6**, 238–247.
- Hay, S.I., Omumbo, J.A., Craig, M.H. and Snow, R.W. (2000). Earth observation, geographic information systems and *Plasmodium falciparum* malaria in sub-saharan Africa. Book chapter: Remote Sensing and GIS in Public Health. Advances in Parasitology. Eds. Hay, Randolph, Rogers, D. Academic Press, 47: 173-215.
- Hunt, R., Coetzee, M. and Fettene, M. (1998).The *Anopheles gambiae* complex: a new species from Ethiopia. Trans. Roy. Soc. Trop. Med. Hyg.**92**:231-235.
- Hunter, J., Rey, L., Chu, K., Adekolu-John, E., and Mott, K. (1993). Parasitic diseases in water resources development. The need for intersectoral negotiation. World Health Organization,

- Geneva.ICMR. (2002). Chemical Insecticides in malaria vector control in India. Indian Council of Medical Research Bulletin (ICMR). Bulletin. **32**. October 2002.
- Ijumba, N.J. and Lindsay, S.W. (2001). Impact of irrigation in malaria in Africa: Paddies Paradox. *Med. Vet. Entomol.***15**: 1-11.
- IWMI. (2004). Malaria and water management. International Water Management Institute. [<http://www.iwmi.cgiar.org/health/>].
- Joshi, V., Sharma, R.C., Singhi, M., Singh, H., Sharma, K., Sharma, Y. and Adha, S. (2005). Entomological studies on malaria in irrigated and non-irrigated areas of Thar desert, Rajasthan, India. *J. Vect. Borne Dis.* **4**:25–29.
- 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. IGARSS, Toronto, June 24-28. Submitted to the International Geoscience and Remote Sensing Symposium (IGARSS '02), Toronto, June 24-28, 2002.
- Kebede, A., McCann, C. J., Kiszewski, E. A. and Ye Beiyo, Y. (2005). New evidence of the effect of agro-ecologic change on malaria transmission. *Am. J. Trop. Med. Hyg.***73**:676-680.
- Konradsen, F., Wim Vander Hoek, Felix, P. A., Mutero, C. and Boelee, E. (2002). Engineering and Malaria control: Learning from the past 100 years. In: Malaria in Irrigated agriculture, papers and Abstracts for the SIMA special Seminar at the ICID 18th International congress on irrigated and Drainage, Montreal, 213 July2002. IWMI working paper 47. SIMA document 2. Colombo, Sri Lanka.
- Konradsen, F., Amerasinghe, Wim Van Der Hoek, Amerasinghe, P. F., Perera, D. and Maldeniya, P. (2003). Strong association between house characteristics and malaria vector in Sri Lanka. *Am. J. Trop. Med. Hyg.* **68**: 177-181.
- Lindsay, S.W. and Bayoh, N. M. (2004). Mapping member of the *Anopheles gambiae* complex using climatic data. *Physiol. Entomol.* **29**: 204-209.
- Maihotro and Srivastava, A. (2005). Diagnostic features of malaria transmission in Nadiadd using remote sensing and GIS: India.[<http://www.web.idrc.ca/en/ev>. On 22 Feb 2005 23:31:24 GMT].
- MFI. (1997). Embracing Humanity Worldwide. Malaria foundation international. Fact Pact. 12 August 1997.

- Ministry of Water Resources (MoWR). (2002). Water sector development programme 2002-2016, Volume II: Main Report. Ministry of Water Resource, Federal Democratic Republic of Ethiopia, October 2002. Addis Ababa.
- Munga, S.(2006). Landscape determinants and Remoter sensing of Mosquito Larva habitats in the islands of Kenya, malaria Journal.
- Negash, K., Kebede, A., Medhen, A., Aragaw, D., Babaniyi, J., Guintaran, O. J. and Delacollette, C. (2005). Malaria epidemics in the highlands of Ethiopia. East Arf. Med. J. **82** : 186-192.
- Negasi, F (2007). Identification, Mapping and Evaluating Environmental factors Affecting Malaria Transmission Using GIS and RS in Selected Kebeles of Adama Woreda, Oromia Region. MSC Thesis, AAU.
- Negatu, W., Abebe, M. and Dejene, A. (1992). *Plasmodium vivax* and *P. falciparum* epidemiology in Gambela, South-West Ethiopia. Trop. Med.Parasitol.**43** : 181- 185.
- Negatu, W., Petros, B., Lulu, M., Adugna, N. and Wirtz, R. (1994). Species composition, feeding and resting behavior of the common antropophilic anopheline mosquitoes in relation to malaria transmission in Gambela, South West Ethiopia. *Insect Sci. Applic.***15**: 371-377.
- Pope KO, et al (1994) Remote sensing of tropical wetlands for malaria control in Chipas, Mexico. Ecological Applications, 4(1): 81-90.
- Pope, K.O., Sheffner, E.J. and Linthicum, K.J. (1992). Identification of central Kenyan Rift Valley fever virus vector habitats with Landsat TM and evaluation of their flooding status with airborne imaging radar. Remote Sens Environ; 40: 185-96.
- Robert, V., Macintyre, K., Keating, J., Trape, J. F., Duchemin, J.B., Warren, M. (2003) Malaria transmission in urban sub-Saharan Africa. Am. J. Trop. Med. Hyg.**68**:169–176.
- Robert, W. S. (2004). Global change and human vulnerability to vector borne-diseases Clin. Microbiol. Prev.**17**: 136-173.
- Shook, G (1997). An assessment of disaster risk and its management in Thailand, Disasters 21(1): 77-88
- Sweney, AW. (1999). The application of GIS in Malaria control program. 10th Colloquium of spatial information research center, Newzeland.
- Tulu, A. (1993). Malaria In: Kloos, H and Zein, Z.A (Eds).The Ecology of Health and Disease in Ethiopia, pp 341-352, .West view Press, Boulder.
- Van der Hoek, W., Feenstra, S.G. and Konradsen, F. (2002). Availability of irrigation water for domestic use in Pakistan: Its impact on prevalence of diarrhoea and

nutritional status of children. *J. Health Popul. Nutrit.* **20**:77–84.

WHO. (2000). WHO Expert Committee on Malaria. WHO. *Tech. Rep. Ser.* No. **892**. 74 pp.

WHO. (2003). Africa Malaria Report. 112 pp.

WHO. (2005). Roll back malaria report. Ethiopia, country profile. 6 pp.

World Malaria Report. (2005). Global malaria situation. In: World Malaria Report /WMR/.
[<http://rbm.wmr2005/htm/1-1.htm>].

Woldegabriel. G.and Aronson,J.L.. (1986). Volcanotectonic history of the central Sector of the Main Ethiopian Rift (Abs.), International Volcanological Congress, Auckland, New Zealand.

Declaration

I, the undersigned declare that this thesis is my work and that all sources of material used for the thesis have been correctly acknowledged.

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