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# Modelling of malaria hotspot sites using geospatial technology in the north-western highlands of Ethiopia

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### Abstract

The study focused on mapping risk areas in *Fogera* plain, North-Western Highland of Ethiopia. Environmental and socio-economic factors were considered, after assigning their own valuable weight in IDRISI software using Pairwise Comparison Technique. Malaria hazard map was developed combining environmental factors like altitude, slope, soil, and distance from breeding sites by using Weighted Overlay Model in Arc GIS. Finally, the risk map was generated by employing risk model that uses hazard, element at risk (population density layer) and vulnerability (land cover layer and distance from health center layer) as input. Hence, very high and high-risk areas constitute 5.51% and 58.12% of the total area respectively. Moderately risk land comprises 30.51% share of the total area. Very low and low risky areas together account below 6% of the total land in the study area. Thus, integrating GIS and remote sensing-based modeling for malaria risk mapping is a worthy technique. Especially, this method can contribute lot to more informed decision and policy making process in terms of planning for intervention and controlling malaria. Hence, it is suggested that it will be effective if the results of this study will be incorporated into ongoing malaria eradication programs at national level in general and in the study area in particular.

**Keywords:** Hotspot, hazard, risk, malaria, weighted overlay model

### 1. Introduction

Malaria is parasitic disease transmitted from one person to another through the bites of infected female anopheles' mosquitoes that live and feed on human blood and liver cells. It is mainly caused by genus plasmodium species that have different characteristics such as physical forms, growth courses and life orders <sup>[1, 2]</sup>. Malaria is the most challenging communicable disease that kills the lives of many people across the globe. As reports reveal that approximately 350 to 500 million cases of malaria occur worldwide yearly. Among these cases, more than 1 million of its sufferers, frequently young age groups, lost their lives each year. Geographically, it commonly distributes in the tropical areas of Asia, Africa, and Central and South America <sup>[3]</sup>.

In Africa, the plateaus of the eastern and southern portions of the landmass is typically affected by malaria. For example, malaria is seriously prevalent in Ethiopia, Eritrea, Western Kenya, and Southwestern Uganda, the highlands of Tanzania, Rwanda and Burundi <sup>[4]</sup>. Malaria remains one the of the common disease that causes of illness and death in Ethiopia. About 75% of the nation is expected as malarias, and neary 68% of the total population live in areas at risk of malaria <sup>[5]</sup>. Similarly, malaria is one of the major communal health issues in Amhara region. For instance, between July, 2013 and July, 2014, the total of 659,149 malaria cases were diagnosed and treated in the region, which accounts for 12.1% of the total out patients registered at all health facilities. Plasmodium falciparum and Plasmodium vivax accounted for 55.8% and 38.6% of the infection respectively in this year, and they were responsible for almost all malaria outpatient cases in the region <sup>[6]</sup>.

Such situation also severe in the study area, malaria is the leading causes of illness and death among top ten diseases. For example, in 2015, 78, 655 patients were treated in different health institutions in Fogera District in all cases of diagnosis. Of these malaria cases were 43,345 (51.11%) of all patients. During the study periods, malaria cases were seen in all months, but the highest number was recorded after the main rain season in September and October <sup>[7]</sup>.

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Hence, malaria in Fogera District is great public challenge and concern, with large spatial and temporal disparity in transmission and distribution. It is the most common and serious vector borne disease which affects the rural community in general and children under five years' age and pregnant women in particular. Topographic nature, climatic condition, severity of flood, availability of swamp areas, and limited health services and facilities are the major factors for the prevalence of malaria in the study area.

There are numerous studies done so far regarding malaria and related issues in Ethiopia. To mention some recent one [8-13] are well-known. Most of these gave due attention on status and transmission, prevalence and associated risk factors affecting malaria mainly using regression model in their studies. Unfortunately, studies related to malaria risk area modeling using GIS and remote sensing is rare in Amhara region in general and, yet not investigated in the study area, Fogera District, in particular.

Thus, this research may serve as a means in identifying, categorizing, and mapping malaria risk areas by considering various environmental and socio-economic factors using Geospatial techniques such as GIS and remote sensing. The study may also fill the gaps in the area of health in Ethiopia in general and malaria in particular by using these technologies

as a tool. Furthermore, the study may help the efforts made to plan and take control measures such as preventing and eradicating campaign in high malaria risk areas effectively. Therefore, this study aimed at modelling the spatial distribution of malaria using geospatial technology in Fogera District. Specifically, the study tried to answered the following specific objectives: to investigate the effect of hazard and risk causative factors of malaria in Fogera District. to map the extent and magnitude of malaria hazardous sites in Fogera District; and to map the spatial distribution and scale of malaria risk areas in Fogera District.

## 2. Materials and Methods

### 2.1. Description of Study Area

The study area, Fogera District, is located in South Gondar Zone in the North West of the Amhara National Regional State in Northwestern Ethiopia. It is situated at 11°58' latitude and 37°41' longitude [14]. The District is bordered by Libo Kemkem District in the North, Dera District in the South, Lake Tana in the West and Farta District in the East. The District is divided into 29 rural peasant sub-districts and 5 urban sub-districts [15]. The total land area of the district is 1075 Square kilometer [16].

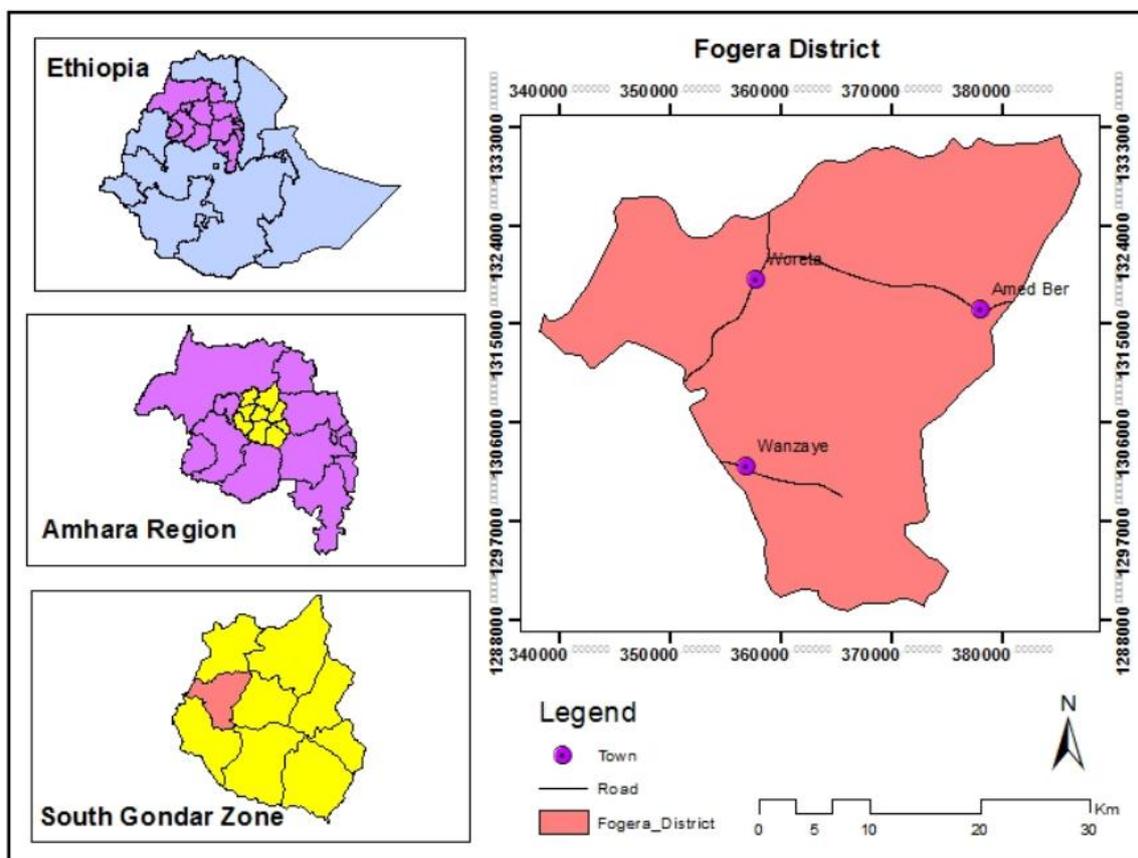


Fig 1: Location of Fogera District

### 2.2. Methods of Data Collection

Both primary and secondary data sources were used in the study. GPS reading as firsthand information was collected to rectify LULC classes, and to locate the position of health institutions in the study areas. Accordingly, representative points supposed to represent the various land cover classes were marked using Garmin GPS during the field visit for the

accessible places. Hence, 250 sample points were taken randomly for various land use and landcover classes. The sample points were selected based on the background experience of the study area, nature, type and width of land use land cover classes. These points were used as sample representative signatures for the different land cover types identified during image classification. Furthermore, among

fifty-one governmental health institutions including health posts and health centers, GPS reading was taken from all (nine) health centers that were operating fully malaria treatment and diagnosis in Fogera District in the study year. The primary data was also collected from Interview of Malaria Team Experts who have been working in selected health institutions for long period of time and with good exposure of the area as well. A total twenty-seven (27) and three experts from each of the nine health institutions were involved in the discussion.

Whereas land use land cover, digital elevation model (DEM), digital soil map, distance from breeding sites, distance from health institutions and population data were the most important secondary sources that were considered in the study too. LULC for the year 2015 was downloaded from the USGS Website with Path 169 and row 052. Digital Elevation Model, and soil data were obtained from Ethio-GIS (II) database. Distance from breeding sites were derived from Topographic Map of Fogera District (2005) with scale of 1:50,000, which was gained from Ethiopian Mapping Agency, and distance from health institutions were computed from data sets collected from GPS sources. Finally, population data for the year 1984, 1994, and 2007 of the study areas was obtained from national censuses results from Central Statistics Agency (CSA).

### 2.3. Methods of Data Analysis

Digital Elevation Model of South Gondar Zone with a spatial resolution of 90meter was employed to generate elevation and slope of the study area. The DEM was used to set and categorize the elevation and slope of the study area in to different classes based on the work of [1,17]. Elevation generally correlates positively with precipitation and negatively with temperature and can be used as surrogate indicator [18]. So, the study only consider elevation rather than temperature and rainfall for modelling risk areas. Reclassify algorithm in the spatial analyst tools in Arc GIS was used to reclassify and to set the values of elevation. The elevation of Fogera District ranges from 1782 m.a.s.l. to 2248 m.a.s.l, then it was reclassified in to five classes using natural break standard reclassification technique and new values were assigned to each class. So, these classes were at the ranges of 1782-1846m, 1846-1937m, 1937-2029m, 2029 -2132m, and 2132-2248m, and labeled as very high, high, moderate and low, and very low risk areas of malaria incidence respectively See Fig. 2(a).

As elevation, the slope of the study area was further processed in Arc GIS 10.3, in spatial analyst tools in surface analysis and slope operation, and reclassified based on Arega [19] in to five classes using natural break standard reclassification technique. Five new slope classes (0-1.5°, 1.5-3°, 3-5.5°, 5.5-9°, and 9-18°) were produced and labeled as very high, high, moderate, low, and very low respectively based on the relative degree of suitability for malaria incidence in Arc GIS (Fig. 2(b)).

The four major classes of digital soils as identified by FAO was used to generate the soil of the study area. It was clipped by Fogera District in analysis tools in Arc Toolbox using Extract by Mask. The criterion [18] and Interview of Experts (2015) were considered to classify the soil data as very high risk (Vertisols), moderate risk (Nitrosols), low risk (Luvisols), and very low risk (Liptosols). For the sake of analysis, all vector soil layers were changed in to raster for further analysis

in Arc GIS 10.3 (Fig. 2(c)).

The Topographic map of (2015) was employed to digitize malaria breeding sites in the study area. Malaria mosquitoes breeding site such as swamp areas, streams and rivers layers were digitized from Topographic map (2015) of the study area, and the layer was changed in raster layer for further processing. Distance to breeding sites was calculated in Euclidian Distance Tool and reclassified using Arc GIS environment as it stated in [20] as criterion. As a result, the breeding site layer was reclassified in to five classes. Thus, these classes were 0-1.5km, 1.5-4 km, 4-6.5km, 6.5-10km and > 10 km, and reassigned as very high, high, moderate, low, and very low susceptibility to malaria respectively (Fig. 2(d)).

Population data of the National Census from Central Statistics Agency (1984, 1999 and 2007), and projected population results were taken in to account to compute the population density in the study area. Since, there was no census results after 2007 at national level, population data of the study area from 2007 and on wards was projected using the following exponential growth rate relationship recommended by the Ethiopian Central Statistical Agency:

$$P_t = P_0 e^{r \times t} \quad (1)$$

where  $P_t$  is the population projected at a given time,  $P_0$  is the population size of a base year,  $e$  is the natural logarithm base,  $r$  is annual population growth rate (2.8% for rural areas and 4.6% for urban areas), and  $t$  is the time interval between the base year and the projected year (Equation1). The present annual growth rate of population varies from rural to urban areas in Ethiopia. According to ANRS [21], the present annual rural growth rate is estimated at 2.8 percent and the population will double in 32 years. Where as in urban areas, growth rate of increase is 4.55 percent per annum, and will double in 17 years. Therefore, for the purpose of mapping the population at risk of malaria, population density of each sub-districts was computed. The population density at sub-district level was considered because sub-district is the smallest administrative unit in the country. The population data from CSA (1984-2007), and projected population data (2007-2015), which was computed by Equation (1), was used to compute population density of the study area. Lastly, rasterization of population density was carried out in Arc GIS 10.3 to make it suit for modelling hazard and risk areas. Therefore, the population density layer was reclassified into five classes as 117-114, 144-182, 182-230, 230-306, and above 306. These classes were labeled as very low, low, moderate, high and very high respectively (Fig. 3(a)).

The GPS points collected for health institution location and LULC rectification were processed in Microsoft office 2016 excel operation and changed in to database file. In Arc GIS, the data base file was brought and changed in to shape file, and finally it derived as health center layer. Then, distance from the existed each health center was calculated in Euclidian Distance Tool, and reclassified in to five classes on the lowest easily accessible distance set by WHO [22] in Arc GIS 10.3. So, taking this in to consideration, the WHO [22] criterion, distance was calculated from each health center. Hence, classes of distances; 0-2.8km, 2.8- 4.6 km, 4.6- 6.6 km, 6.6- 8.9 km and > 9.8 km were computed. These classes were scaled as very low risk, low, moderate, high, and very

high-risk areas respectively based on the degree of vulnerability to malaria (Fig. 3(b)).

Land sat image of 2015 with path 169, and row 52 which was downloaded in January from Global Land Cover Facility was used to classify land use land cover of the study area. Georeferencing, layer stack, sub setting, and image enhancement were the main techniques used before land use land cover classification of the study area. Both unsupervised and supervised image classifications techniques were applied in this stage. Unsupervised classification was done before field work. Then supervised classification technique was used to categorize the image in to six different land use/ land cover categories such as built up, forest, crop, bare land, water and grazing land. Furthermore, the land uses or covers were also reclassified in to five classes based on their susceptibility and suitability for malaria (Interview of Malaria Experts, 2015) (Fig.3(c)). Both supervised and unsupervised land use / land cover image classification has been carried out using in

ERDAS Imagine 10 software on Landsat satellite image of 2015. At the end accuracy assessment for LULC features using GPS sample points was carried out to see the effectiveness of the land use land cover classification in the study.

Finally, as it is shown in (Figure 7), Weighted-overlay Model was applied to identified malaria risk areas in the study. Identification malaria risk areas is computed by using Shook [23] model that states risk is the combined result of hazard, element at risk and vulnerability (Equation 2). Necessary weight values for the variables were computed using Multi Criterion Evaluation (MCE) in IDRISI software (Table 1). First, malaria hazard areas were identified by using elevation, slope, soil and distance from breeding sites layers. Subsequently, using similar procedures, the malaria risk map was produced by including malaria hazard layers, population density, distance from health center and land use/land cover layers in Arc GIS 10.3.

**Table 1:** Weight of malaria factors as computed by IDRISI Pairwise comparison method

Factors	Weight	Class	Rank	Susceptibility
Slope	25	0-4%	5	Very High
		4-12%	4	High
		12-22%	3	Moderate
		22-37%	2	Low
		37-109%	1	Very Low
Elevation	22	1776-1850	5	Very High
		1850-1945	4	High
		1945-2045	3	Moderate
		2045-2155	2	Low
		2155-2465	1	Very Low
Distance from Breeding Sites	15	0-1km	5	Very High
		1-2km	4	High
		2-3km	3	Moderate
		3km-4m	2	Low
		> 4km	1	Very Low
Population Density	14	510	5	Very High
		365	4	High
		190	3	Moderate
		50	2	Low
		15	1	Very Low
Distance from Health Centers	12	0-1km	1	Very Low
		1-2km	2	Low
		2-3km	3	Moderate
		3km-4m	4	High
		> 4km	5	Very High
Land Use Land Cover	9	Bare Land	1	Very Low
		Forest/Built-up area	2	Low
		Grazing Land	3	Moderate
		Crop Land	4	High
		Water	5	Very High
Soil	3	Liptosols	1	Very Low
		Nitosols	2	Low
		Vertisols	4	Moderate
		Luvisols	5	Very High

### 3. Results and Discussion

Malaria transmission is strongly associated with environmental conditions, which control mosquito maturity and parasite development. Based on literature search, previous works, and interviews with malaria experts, the following environmental and scio-economic factors that greatly influence malaria incidence and prevalence were presented.

#### 3.1. Environmental Factors

##### 3.1.1. Topographic (Elevation) Factor

Topography generally has a great influence on mosquito replication and thus affects the rate of malaria cases. Higher topographies results in cooler temperatures, which limits the reproduction rate of the parasite [24]. As stated Cohen et.al [25] in their study of topography-derived wetness indices and household-level malaria risk in two communities in the

western Kenyan highlands, indicated the transmission of *Plasmodium falciparum* generally decreases with increasing topography. Throughout most Sub-Saharan Africa, malaria shows a high endemicity with average altitude of 1400m [16]. The distribution and transmission of malaria in Ethiopia varies from place to place. For example, the distribution of malaria in Ethiopia is largely determined by altitude. Altitude affects the pattern of malaria distribution in Ethiopia through its effect on temperature [26]. In Ethiopia, generally low land and temperate areas below 2000 meters' altitude are considered Malarious. Occasionally, malaria transmission also occurs in previously non-malarious areas including areas having above 2500 meters' altitude when micro-climate and weather conditions favorable for the breeding of mosquitoes prevail [1].

Very high and high-risk areas cover 350km<sup>2</sup> and 234km<sup>2</sup> of land respectively. Almost 308 km<sup>2</sup> and 88 km<sup>2</sup> areas of land were identified as moderately risk and low risk consecutively. Malaria free or low risky areas accounts 94 km<sup>2</sup> area of land. Thus, very high and high malaria incident are observed in the North, North West and South part, occupying the low land areas, and relatively free or low incident areas are identified in North East and South part stretching along the highland territory of the study area (Fig. 2 (a))

### 3.1.2. Slope Factor

As indicated in Arega [19], steeper slopes allow the fast movement of water and they have less chance to accumulate stagnant water. Hence, it is unlikely to attract mosquito. Relative to steeper slopes, gentler slopes are slopes where surface water movement is stagnant creates favorable situation for mosquito breeding.

Therefore, slope analysis result reveal that, the majority of the study area falls under the slope class of 0-1.5<sup>0</sup>, which covers 551 km<sup>2</sup> of the total study area, and 316 km<sup>2</sup>, 143km<sup>2</sup>, 51km<sup>2</sup> and 13 km<sup>2</sup> of the study areas were covered by slope classes of 1.5-3<sup>0</sup>, 3-5.5<sup>0</sup>, 5.5-9<sup>0</sup> and 9-18<sup>0</sup> respectively. Thus, relatively, gentler slopes are more favorable for malaria mosquitos breeding than steeper slopes due to their high capacity of accumulating stagnant water as heavy rainfall showers the area (Fig.2 (b))

### 3.1.3. Soil Factor

Soil is defined by Davidson [27] as a natural body consisting of layers or horizons of mineral and or organic constituents of variable thickness, which differ from the parent material in their morphological, physical, and chemical properties and their biological characteristics.

The major types of soil found in the study area are Vertisols, Luvisols, Nitisols and Leptosols. Vertisols soils are characterized by their high clay content. In most cases, it is distributed along low sloppy area with sticky and plastic, often impassable character and high water holding capacity when wet. Luvisols with a high silt content are susceptible to structure deterioration when wet. Nitisols and Leptosols are found relatively in higher altitude with low infiltration rate [28].

Vertisols which cover 537 km<sup>2</sup> are impermeable especially

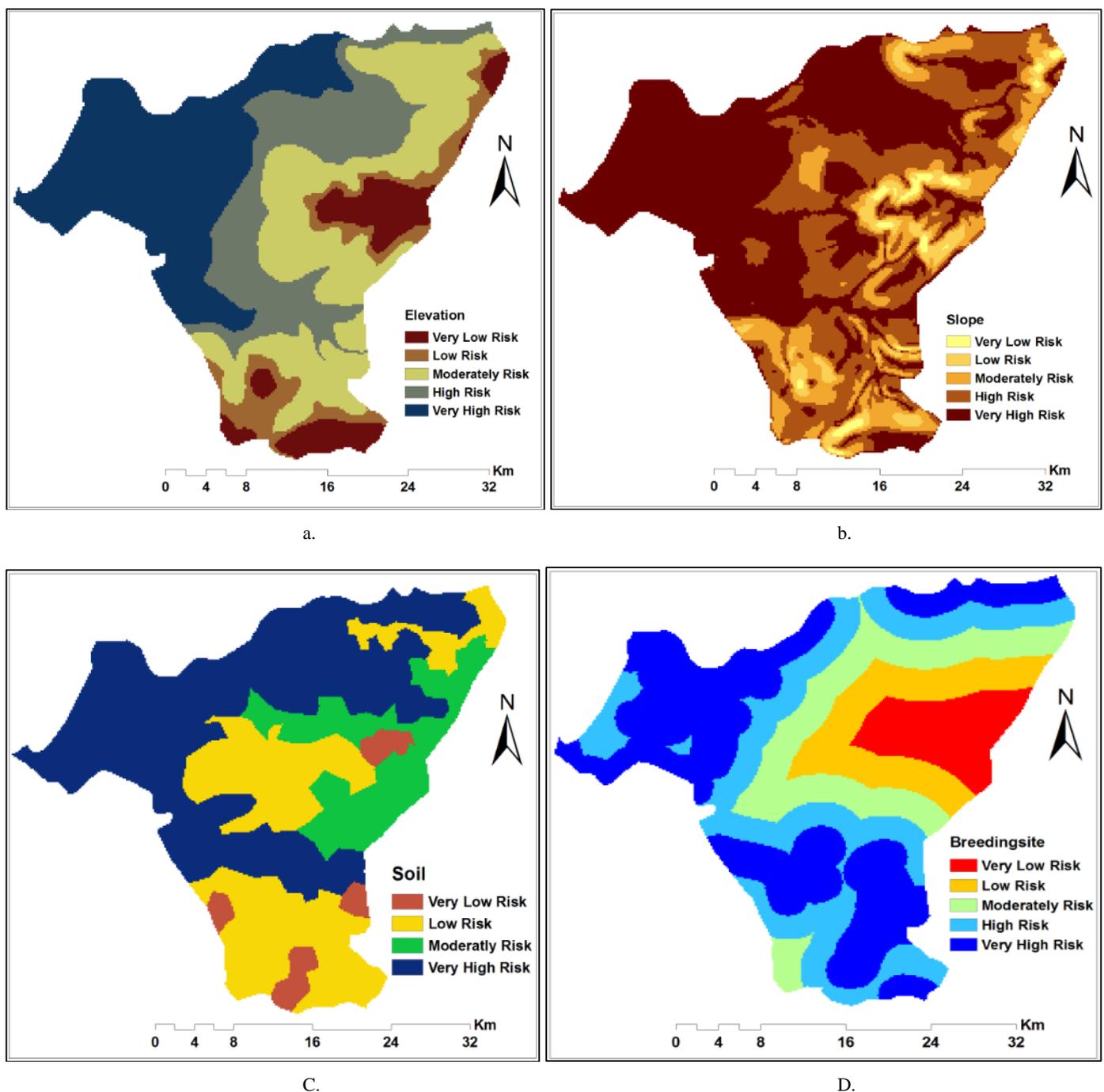
when they are wet, and hence it accommodates water and creates suitable grounds for mosquito breeding site. Nitisols constitute 166 km<sup>2</sup> area mainly in the high land parts of the study area so that it can drain water fast. On the other hand, Luvisols that composes 326 km<sup>2</sup> land relatively more porous, allows water to pass easily and create unfavorable condition for mosquito larva development. Finally, 46km<sup>2</sup> areas are Liptosols at very high elevation than the others considered as very low risk areas (Fig. 2 (c)). As it claimed in interview of experts, much of the vertisols are distributed in low land areas stretching in the north, north-west and west directions of the study area. Thus, due to its distribution, its nature of sticky and high water holding capacity, this soil type is more suitable for malaria mosquito's prevalence than others. The rest soil types like Nitisols, Luvisols, and Liptosols are progressively situated in the highland parts of the study area so that they can drain water quickly, and hence have less chance to accumulate stagnant water for long period of time due topographic influence during the rainy periods, and therefore, mosquitoes could not breed as expected in areas covered by these soils.

### 3.1.4. Distance Factor

The most obvious factor influencing the distribution of mosquitoes is the distribution of breeding sites. Larval mosquitoes are usually highly aggregated in pools of waters with specific characteristics [29]. In Ethiopia, malaria mosquito prefers for breeding mainly water collections from rains. However, the mosquito breeds also in intermittent rivers and streams, around ponds, swampy and marshy areas, slowly running shallow irrigation waters and around shallow dams [1]. Moreover, as Malhotro and Srivastava [30] stated, the abundance of water in irrigated areas due to seepage, silting, and stagnation, creates innumerable sites for malaria vector breeding.

In the study area, Fogera District, the farmers commonly practice small scale irrigation by using rivers and streams nearby them. According to Malaria experts of the area, in addition to topography, these practices and the abundance of wet lands and marsh areas increase malaria to be prevalent throughout the year in the district. Until they dry up after a few months, much of these areas can be used as a seasonal or temporary breeding site for vector mosquitoes.

The maximum flight range of the vector mosquito can be considered to be 2 km [1]. This indicates that areas within 2km range are risky areas and risky decrease as one goes away from breeding sites. Thus, breeding site area with very high and high risk of malaria covers 389 km<sup>2</sup> and 273 km<sup>2</sup> areas of land. Moderate, low and very low malaria risk areas account 183 km<sup>2</sup>, 133 km<sup>2</sup> and 97 km<sup>2</sup> correspondingly. Spatially, most of the risky areas breeding site are concentrated in the West, Northwest and Southern part of the study area due to low topography, numerous rivers, streams and ponds, Relatively the north and extreme of Northeast show little coverage. In the Eastern territory is no breeding sites as a result of very high landscape (Fig.2 (d)).



**Fig 2:** Environmental factors that greatly influence malaria incidence and prevalence in the study. a) Reclassified elevation. b) Reclassified slope. c) Reclassified soil. d) Reclassified distance from breeding sites

### 3.2. Socio-Economic Factors

Risk assessment based on environmental factors alone is not more effective unless and otherwise socio-economic factors included with it. So, the socio-economic factors that were essential to map malaria risk areas in the study were taken in to account. These were population distribution, distance from health facility distribution, and land use land cover.

#### 3.2.1. Population Density

Certain human activities have unintentionally worsened the spread of malaria. Agricultural practices, for example, can create new places for mosquito larvae to develop and can increase mosquito breeding sites [3]. There is a positive correlation between the number of people and *Anopheles* mosquitoes living in a particular region, and the intensity in

which the disease can be transmitted. When population densities are high, there is a greater likelihood malaria will be transmitted. When population densities are low, the transmission of malaria will be less intense [31]. Some of the study area with very high and high population density covers together almost 20km<sup>2</sup> and further labelled as very high and high malaria risky areas respectively. Whereas areas with very low, low, and moderate population density labelled as very low, low, and moderate risky areas, and covered 500 km<sup>2</sup>, 365 km<sup>2</sup> and 190 km<sup>2</sup> area consecutively (See Fig.3 (a)). Thus, as compared to others Western, and North western extreme areas are inhabited by relatively large number of population than others due to high fertility and productivity of the land.

### 3.2.2. Distance from Health Facilities

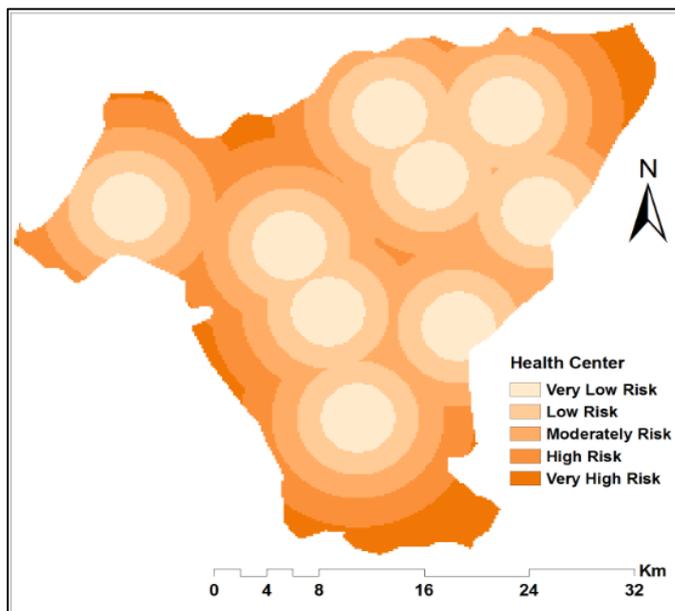
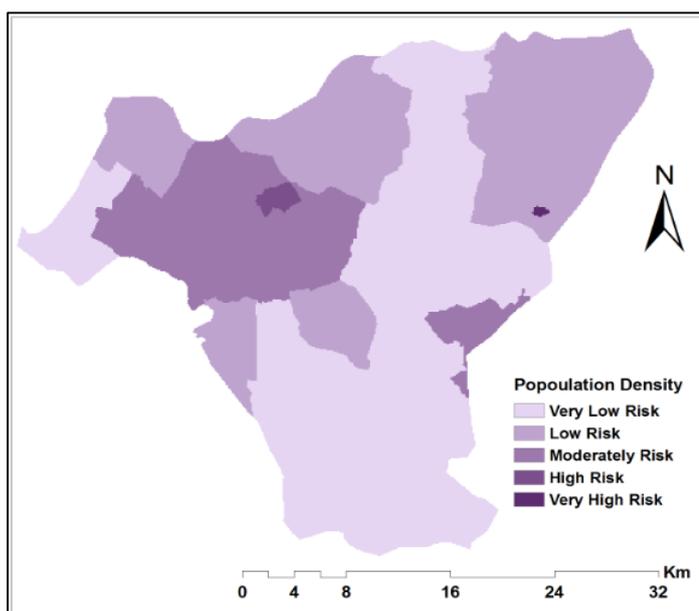
Measuring distance is one of the most fundamental functionalities of the GIS. Euclidean or straight-line distance function measures distance from one point to another on a plane. The applications of GIS-distance parameter have been substantiated by different studies depicting the growing importance of this parameter in malaria study [32]. According to WHO [22], areas found within 3 Km radius from a health facility is assumed to be less risky than areas found beyond this distance. Therefore, assessing the location of health facilities is important in order to map risky areas, evaluating the location of existing health services and uncover potential demands; which in turn assist the provision of the new facilities quickly and effectively. Even though areas with longer distance from the health centers can be covered by transport facilities, road networks and transport mechanisms are inadequate in the study area. In addition, sub-districts in the study area are not interconnected through all-weather roads (Interview of Malaria Experts (2015)). According to WHO [22], the result of distance analysis from health centers reveals that 223km<sup>2</sup> areas, which are found within range of 2.8km distance from the health centers, were distinguished as very low risk of malaria. Low risk, and moderately risk areas on the other hand, accounted 320 km<sup>2</sup> and 291 km<sup>2</sup> area of land respectively. Almost 241 km<sup>2</sup> area were subjected to malarias. Of these, 164 km<sup>2</sup> were high risky areas, and 77 km<sup>2</sup> were very high risky ones (Fig. 3 (b)). Therefore, as it was raised in Interview of Malaria Experts (2015), the existed health facilities are unevenly distributed

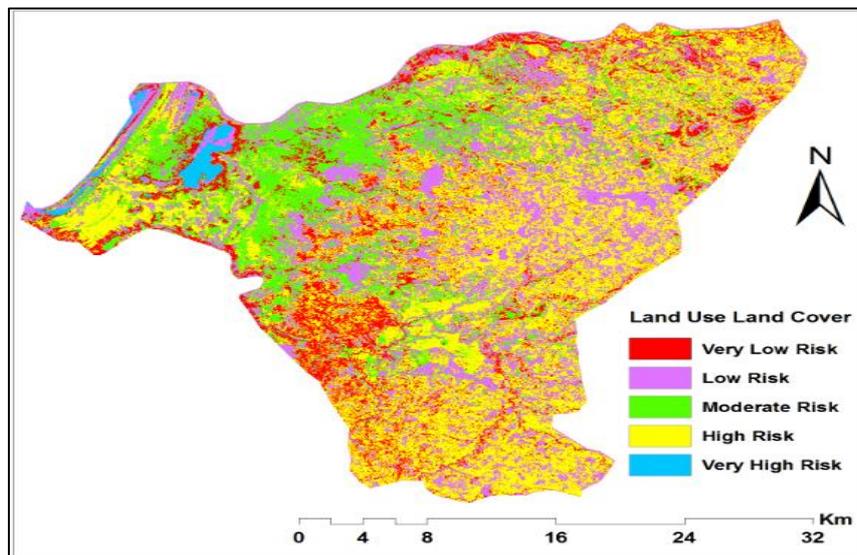
and have little coverage. Thus, new additional health facilities are needed in very high risky areas or sub-districts in order to reduce the burden and effect of the disease in these areas.

### 3.2.3. Land Use Land Cover

The LULC is directly related to the malaria burden through its impact on breeding sites and on the adult mosquito survival rate and dispersal [17]. In Ethiopia, malaria mosquito prefers for breeding mainly water collections from rains. However, the mosquito breeds also in intermittent rivers and streams, around ponds, swampy and marshy areas, slowly running shallow irrigation waters and around shallow dams [1].

Built up area and forest were merged as one class and covered 282 km<sup>2</sup> area. Bare land accounted 150 km<sup>2</sup>. The crop land with 436 km<sup>2</sup> covered the largest area of all land use land cover. Grazing land and water bodies constituted 196 k m<sup>2</sup>, and 11 k m<sup>2</sup> respectively (Fig. 3 (c)). As a result, the crop farm lands labeled as high risky areas. Due to their suitability for malaria proliferation, water bodies, suitable place for malaria breeding and resting sites, were considered as very high-risk areas. The irrigation farming practices in the study area, where different crops in particular vegetables and fruits were grown along rivers and streams, provided ideal sites and increasing longevity of vector mosquitoes ((Interview of Malaria Experts, 2015)). Moreover, grazing land, built up areas and forests, and bare lands were identified as moderate, low and very low risk land use cover respectively (Fig. 3 (c)).





**Fig 3:** Socio-economic factors that affect malaria occurrence and distribution in the study. a) Reclassified population density. b) Reclassified distance from health facilities. c) Reclassified land uses

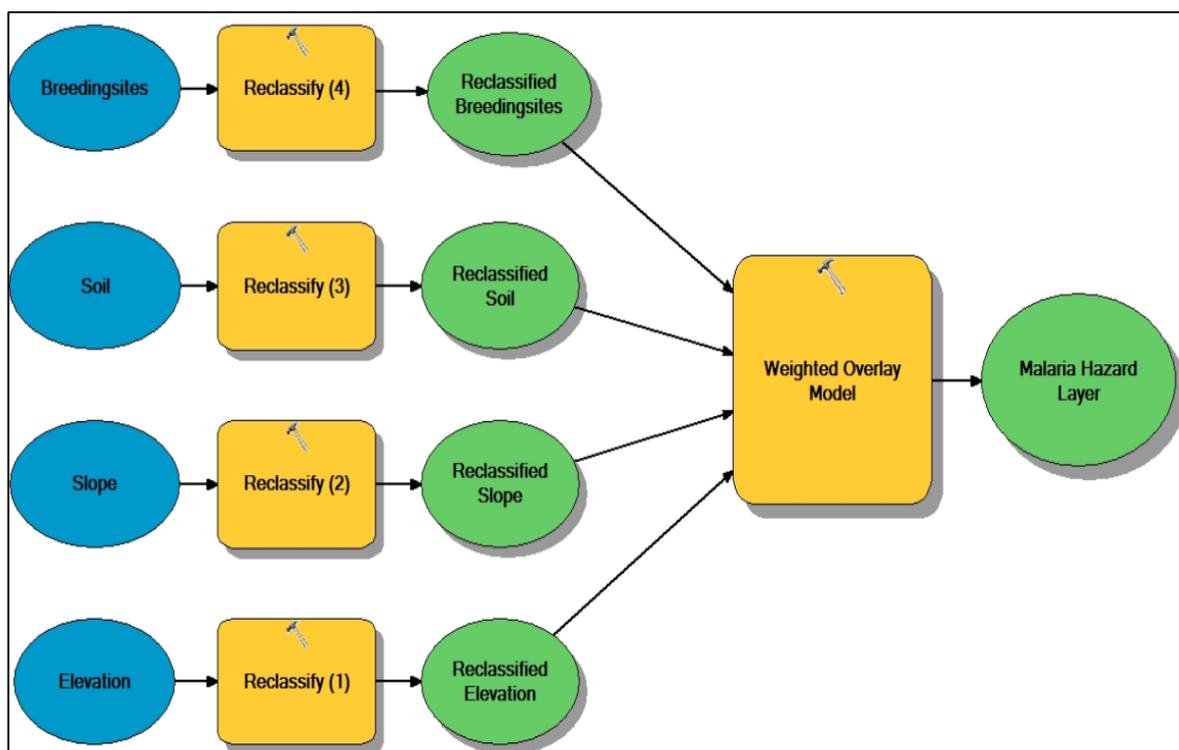
### 3.3. Mapping Malaria Hazard Areas

Environmental factors such as elevation, slope, soil, and distance from breeding sites were considered as factors for malaria hazard areas in this study (Fig. 2). As a hazard, malaria incidence is mapped by taking in to account these environmental factors that create favorable condition for the survival of the vector *Anopheles* mosquitoes. The variables were computed in ArcGIS 10.3 using spatial analyst tool. This was done after each factor was given the appropriate weight in IDRISI software (Table 1). The weight for each factor was assigned by consulting Malaria Experts in the study area, and various researches conducted before in the area.

A wide variety of technique exist for the development of weights including pairwise comparison technique. A pairwise comparison technique which is implemented in IDRISI

software as a decision-making process known as the Analytical Hierarchy Process (AHP). In this technique the weights of the criteria can be derived by taking the principal eigenvector of a square reciprocal matrix of pairwise comparison between the criteria<sup>[33]</sup>.

For the purpose of identifying malaria hazard areas, the above-mentioned environmental variables were taken as the factors of malaria incidence. The process of weighting each factor was performed in IDRISI software in order to control the consistency of weighting. The comparison of these four environmental variables was carried out to develop the pair wise comparison matrix in IDRISI software. After the overlay analysis of factors like elevation, slope, soil, and distance from breeding sites using Weighted Overlay Model (Fig. 4), the malaria hazard map was produced (Fig. 5) in ArcGIS 10.3



**Fig 4:** Malaria Hazard Layer developed in Arc GIS software

The Malaria hazard map in Figure 5 portrays that 348 Km<sup>2</sup>, 383 Km<sup>2</sup>, 228 Km<sup>2</sup>, 103 Km<sup>2</sup>, and 13 Km<sup>2</sup> of the total area is exposed to very high, high, moderate, low, and very low level of malaria vulnerability respectively. Very high and high hazardous areas share 32.37% and 35.63% of the total area. Moderately hazardous land comprises 21.21% of the total area. Low and very low account 9.58% and 1.21% of area

subsequently. This show that except few areas, all others are under the exposure of malaria. As it was stated by Interview of Malaria Experts (2015) the prevalence of such fact is mainly due to the excessive availability of water bodies with high temperature, temporary swamp areas and irrigation practices in the study area.

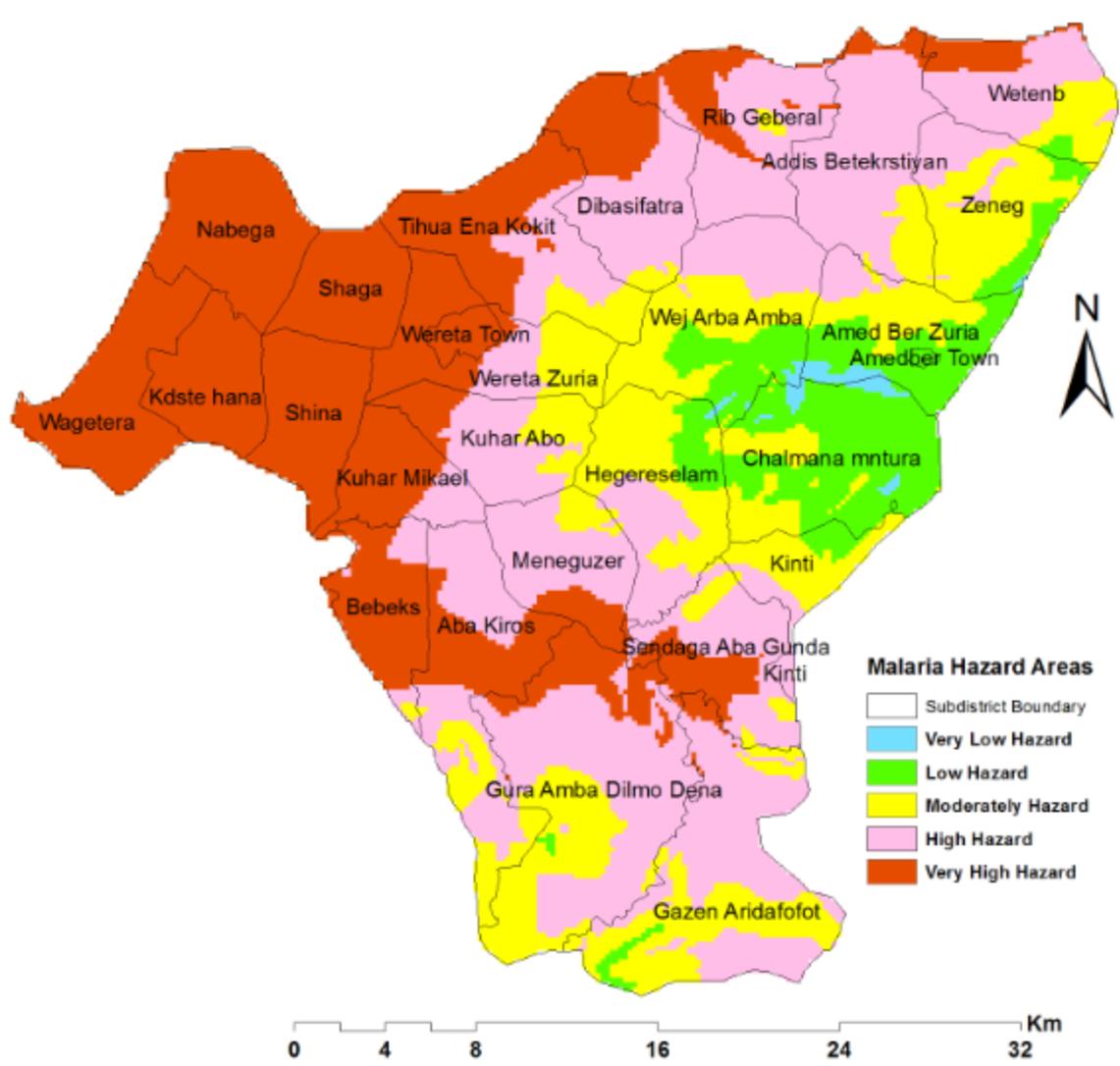


Fig 5: Malaria hazard areas mapped using weighted overlay Model in Arc GIS

### 3.4. Malaria Risk Areas Identification

Identification malaria risk areas is computed by the model developed by Saaty [33] that states risk is the combined result of hazard, element at risk and vulnerability (Equation 2).

$$\text{Risk} = \text{Hazard} * \text{Element at Risk} * \text{Vulnerability} \quad (2)$$

Where:

**Risk** in this study refers to is the expected degree of loss due to a particular natural phenomenon.

**Hazard** is the probability of occurrence of a potential damaging natural phenomenon within a specified period of time and within a given area. It includes elevation, slope, soil, and distance from breeding sites.

**Element at risk** includes the population at risk in a given area.

**Vulnerability** is the exposure of a given element or set of

elements at risk resulting from the occurrence of a damaging phenomenon of a given magnitude, and it denotes land use landcover in the study.

Mapping of malaria risk includes hazard, element at risk, and vulnerability. Element at risk layer was developed by reclassifying population density layer. Moreover, vulnerability layer was developed by reclassifying land use land cover layer and by computing and reclassifying distance from the existing health centers layers (Fig. 6). Based on these weights given (Table 1), malaria risk map was produced using Weighted Overlay Model in Arc GIS (Figure 6). As a result, the risk map in Figure 7 displayed that 12.86Km<sup>2</sup>, 102.37Km<sup>2</sup>, 412.14Km<sup>2</sup>, 516.49Km<sup>2</sup> and 31.14 Km<sup>2</sup> of the total area is subjected to very low, low, moderate, high, and very high risk of malaria respectively.

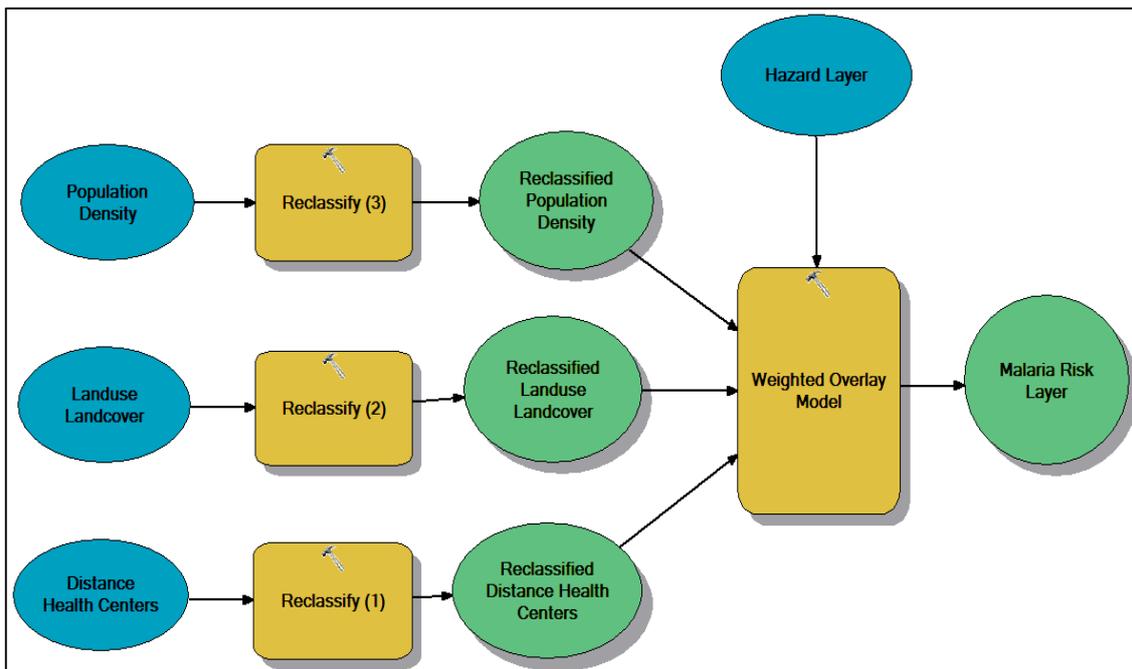


Fig 6: Malaria Risk layer developed in Arc GIS software

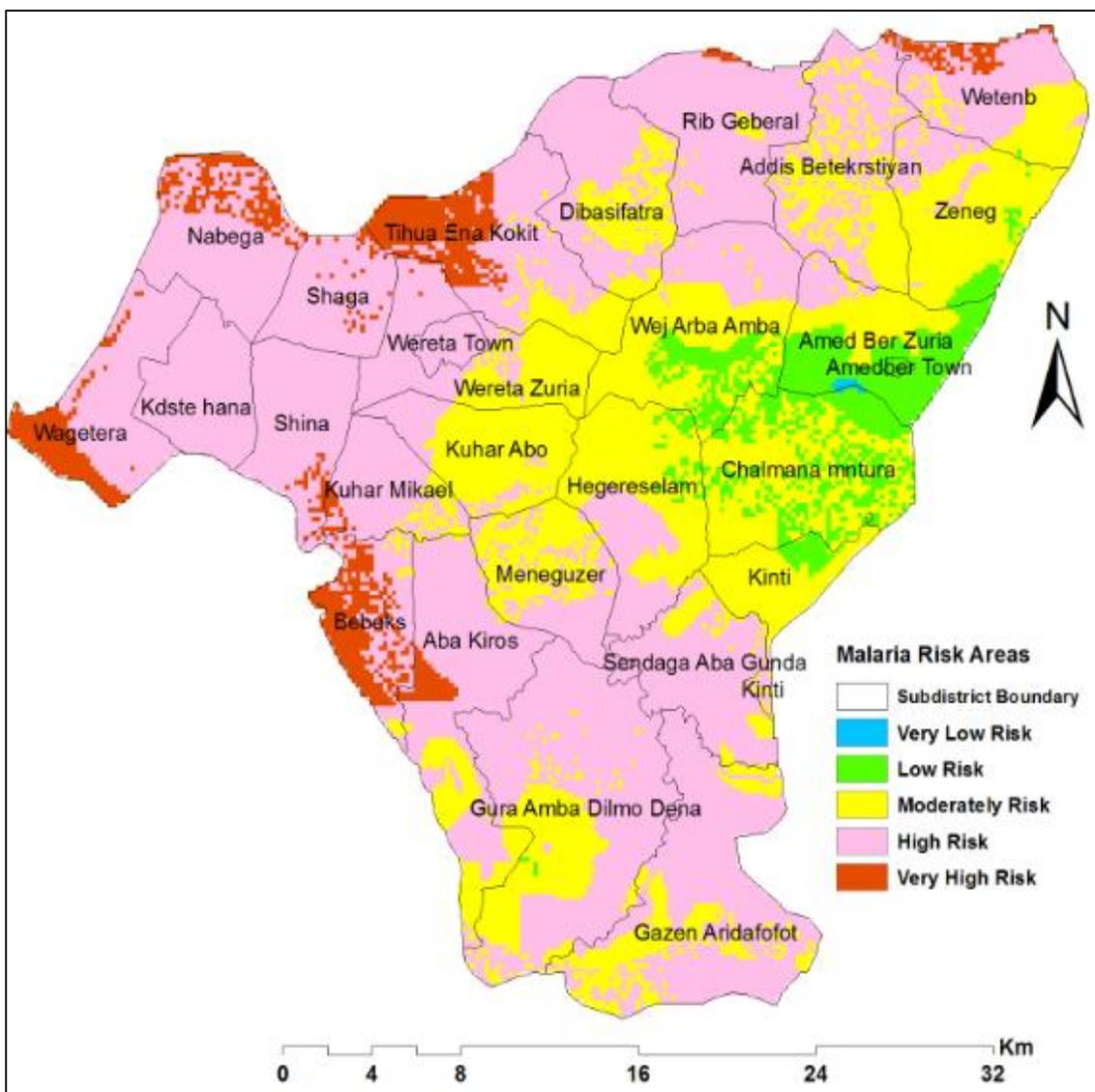


Fig 7: Malaria Risk Areas identified using Weighted overlay Model in Arc GIS

Moreover, at subdistrict level as the risk map reveals, portion Wetemb, Rib Geberal, Shina, Shaga and Wagetea Sub-districts are identified as very high risk of malaria, whereas Sub-districts with almost very high risk of malaria include Nabega, Bebekes and Tihuna Kokit. Most of the Sub-districts in the study area are subjected to highly risk of malaria. The reason behind this seems due to the availability of favorable condition to the vector mosquito such as the gentleness of topography, presence of swamps and ponds, and high irrigation farming practices in the study area. Moderate malaria risky areas were situated in the center, North extreme, South and Eastern part of the study area. In contrast, low risk areas are found in some part of Hagereselam Kinti, and Zeng Sub-districts. Almost the entire of Woji-Arbaamba, Amed-ber, Amed-ber Zuria, and Chalema na Mintura Sub-districts were characterized as low risk of malaria. The existence unsuitable breeding site in general and relatively cold climatic condition, the absence of ponds and swamps, and the presence of low population number in particular attributed to the existence low risk of malaria incidence in these areas.

#### 4. Conclusion

This study has the aim of mapping malaria risk areas in Fogera Districts Using GIS and Remote Sensing. The malaria risk mapping in the study area considered both environmental and socio-economic factors which aggravate malaria breeding and spreading.

The role played by Geographical Information System (GIS) and Remote Sensing in malaria risk mapping is enormous. GIS serve as an important platform for preparing, mapping and modelling various variables related to malaria. Remote Sensing also plays an important role by providing environmental information such as timely satellite image, DEM and LULC data of the study area.

Thus, the research has shown that GIS and remote sensing is important to create operational maps which could help the concerned bodies to identify hazard and risk areas for disease management. Risk maps are fundamental for estimating the scale of the risk, and hence the resources needed to combat malaria. They provide benchmarks for assessing the progress of control and indicate which geographic areas should be prioritized. According to the result of the findings, large area of the Districts is located on high and very high-risk area for malaria. In this study pair wise comparison method of malaria hazard map generation is a good approach to deduce a sound decision for a forthcoming malaria campaign. This research confirmed the method used was capable to integrate all the malaria hazard causative factors and the components of malaria risk factors in a GIS environment. One of the Multi Criteria Evaluation technique which is known as Weighted Overlay in GIS environment was shown to be useful for delineating areas at different rating in terms of malaria hazard and malaria risk.

Therefore, it has been shown that MCE GIS based model has potentiality to provide persuasive approach in making decisions in such kind of investigation. So that it is worthy effective if the government, NGOs and other stakeholders employ GIS and Remote sensing-based malaria assessment in other similar malaria areas.

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