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GEOGRAPHIC INFORMATION SYSTEM AND REMOTE SENSING-BASED MALARIA RISK MAPPING: A CASE OF GEDEO ZONE, SOUTHERN NATIONS NATIONALITIES AND PEOPLES' REGIONAL STATE, ETHIOPIA

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Abstract

Geographic Information System and Remote Sensing played an important role in analyzing environmental and socio-economic drivers that created favorable condition for malaria breeding as well as in identifying hazard and risk areas. This study gives great emphasis on mapping malaria hazard and risk areas in Gedio zone of SNNPs using geospatial technology. The study identifies two major drivers like Environmental (physical) factors: which provide for the endurance of mosquitoes and Socio-economic factors. The above data were presented and analyzed quantitatively. The content analysis shows that Malaria hazard prevalence areas were mapped based on the environmental factors which are potential of providing good environmental conditions for mosquito breeding. The hazard map was produced using elevation, slope, proximity to breeding sites, and soil type as the factors for breeding mosquitoes. The malaria hazard analysis of the Gedio zone revealed that from the total area, 9.83%, 35.29% is mapped as a very high and high-risk area, whereas, the remaining 38.73%, a 16.14%, and 0.01% were mapped as moderate, low, very low level of malaria hazard respectively. The total area of the study area more than 1/3rd of the area is identified as a very high and high malaria risk area while the rest 2/3rd of an area is considered as a moderate to very low hazard risk zone. Accordingly, very high malaria risk area is found around towns because of population density. Finally, I recommend that the concerned body should have to expand health center, creating awareness of society, especially around populated areas where the risk is high and environmental and individual sanitation can reduce the risk of malaria.

Keywords: GIS and Remote Sensing, Hazard, Risk, Vulnerable, Gedio zone

1. Background of the Study

Malaria is an ancient disease that has been affecting people since the beginning of recorded time. It poses serious economic, social, and, health burdens in tropical and subtropical countries

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where it is predominantly founded (Mandal *et al*., 2011). Malaria still remains a huge public health issue regardless of how many years of research have been conducted on how to combat this disease. The WHO 2012 report showed that malaria is presently endemic to 104 countries worldwide and is transmitted in 99 of them. Seventy-nine of those countries are classified as being in the control phase, 10 are in the pre-elimination phase, and another 10 are the elimination phase. Another 5 countries do not have ongoing transmission and are classified as being in the prevention of re-introduction phase (WHO, 2012). Although efforts of combating malaria have yielded dramatic decreases in malaria cases and deaths in most endemic regions, in its 2012 World Malaria Report, the WHO reported devastating statistics that in 2010 655,000 people died from this disease, with 86 % of the victims being children under 5 years of age. The vast majority of cases (80%) and 91% of the total deaths of the 216 million cases worldwide occurred in Africa (WHO, 2012).

Malaria is one of the main health problems in Ethiopia in which its cases are one of the highest and it is increasing at an alarming rate. In Ethiopia, malaria affects around 4 to 5 million people annually throughout the country, with morbidity and fatality rates of 13 to 35% and 15 to 17%, respectively (MoH, 2004). Of the four species that infect human beings, *Plasmodium falciparum* and *Plasmodium vivax* are the two most dominant malaria parasites in Ethiopia. They are prevalent in all malarious areas in the country (usually below 2000 meters above sea level) with *P*. *falciparum* representing about 65-75% of the total reported malaria cases, relative frequency varying in time and space within a given geographical ranges. About 75% of the land and 60% of the population is exposed to malaria in Ethiopia.

Ethiopia is generally considered a low- to moderate malaria transmission intensity country. However, the health sector in Ethiopia is greatly affected by climate change which has profound consequences on the transmission cycles of vector-borne infectious diseases like Malaria. Due to the unstable and seasonal transmission of malaria in the country, the protective immunity of the population is generally low and all age groups are at risk. The prevalen of malaria is currently estimated to be 1.3% (Ethiopia Malaria Indicator Survey, 2011).

The advancement of geographic information systems (GIS), the global positioning system (GPS), and remote sensing (RS) technologies has enabled the collection and analysis of field data in ways that were not possible before the advent of the computer (Milla *et al*., 2005).

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

In the study area different researches were conducted in relation to malaria. However, they didn't consider the importance and application of GIS and remote sensing technology in malaria risk mapping and risk level identification. For instance a research conducted by (Mohammed *et al*. 2012), was on paracheck-pf® test versus microscopy in the diagnosis of falciparum malaria. It was focused on diagnostic tests in detecting falciparum malaria. Moreover, the study area is one of populated zone of Ethiopia due to that malaria spreading was highest in the area relative to others, and no any researchers could conducted malaria risk area mapping using environmental and socio-economic factors based analysis in my study area, so that there is also a methodological gaps when compared with the others researched.

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

The main aim of this study is to develop map of malaria risk by using Remote Sensing and GIS techniques in, Gedio Zone, SNNPRs', Ethiopia. The specific objectives of the study area are 1st to identify environmental (topographic) factors which make condition suitable for breeding and outbreak of malaria epidemics, 2nd to map the extent and magnitude of malaria hazard areas in Gedio Zone and 3rd to Generate malaria risk map of the study area

2. Research Methodology

2.1. Description of the Study Area

The Gedeo zone is located 369 km from the capital, Addis Ababa, and Gedio capital town is 90 km from the SNNPs regional capital Hawassa, to the south on the main highway from Addis Ababa to Moyale toward Kenya. Administratively, it lies in South Nation Nationalities and People Regional State (SNNPRS) one of the nine self-administering regions in Ethiopia. Gedeo zone has 6 woredas and 2 administrative towns. Geographically, the zone is located north of the equator from 5°53'N to 6° 27'N latitude and from 38° 8' to 38° 30'E longitude

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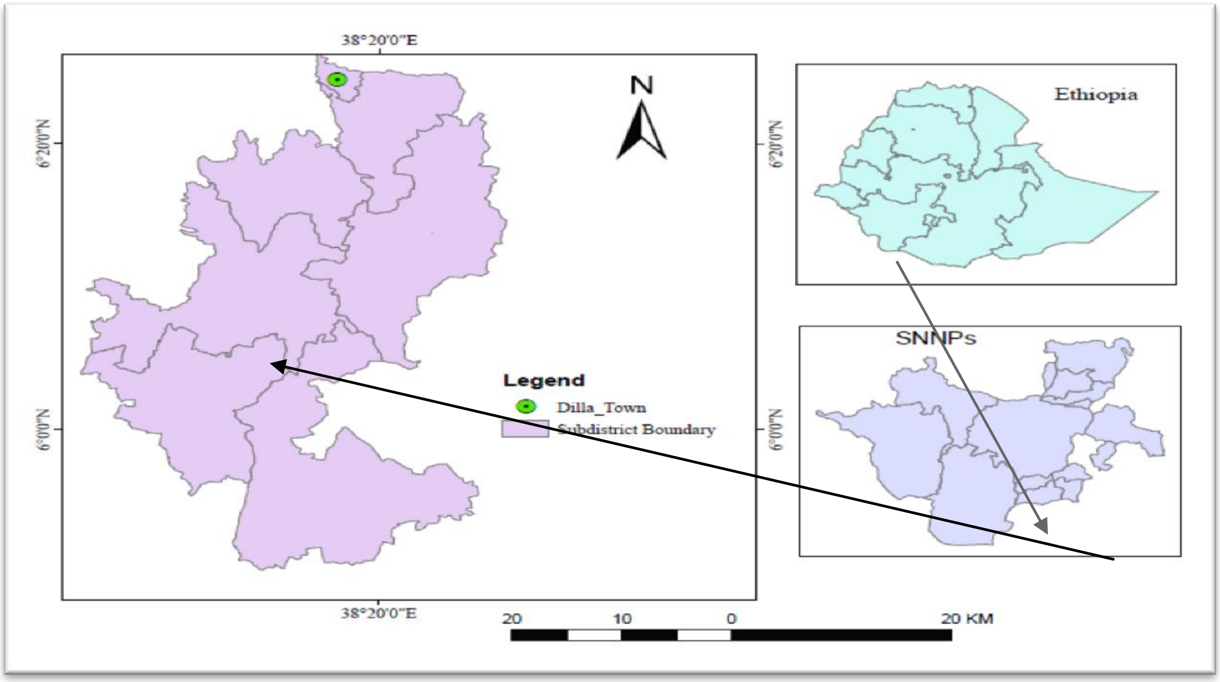

Figure 2. 1: Locational map of the study

2.2 Materials and Methods of Data Collection

2.2.1 Data Collection Methods

As it determines the quality of the research, collecting accurate and reliable data is the most determinant factor for any research. Both primary and secondary data used for malaria risk mapping of the study area, that obtained from field survey and concerned institutions. The data's are GPS points, and topographic information, digital elevation model (DEM data), and remote sensing satellite images (Santinel2 for 2021 year) of the study area. GPS reading as firsthand information used to collected reference points to rectify LULC classes, and to locate the position of health institutions in the study areas. Elevation, slope, soil, and proximity to water body (river, stream etc.) were selected as major environmental factors for malaria incidence.

The data types are used and their sources are described in Table 1 below.

Table 2. 1: Types of data and their sources

No	Types of data	Type	Source of data
1	Santinel2 satellite image	Raster	USGS earth explorer
2	Topographic Map	Raster	Ethiopian Geospatial Institute

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3	Digital Elevation Model	Raster	USGS earth explorer
4	Study area boundary shape file	Vector	Central Statistical Agency (CSA)
5	Ground control points	Vector	Field survey
6	Soil data	Vector	http://www.fao.org/ag/agl/agll/key2soil.stm

2.2.2. Software and materials used in the project

Different software are applying for different types of activities. ERDAS IMAGINE was use for Land use/land cover image classification and for accuracy assessment. Arc Map 10.8 is used for reclassification of each factor, for weighted overlay analysis and generation of risk maps, IDRISI software used for weight derivation of factors and Global Positioning System (GPS) was used for collection of ground control points to prepare accuracy assessment for land use land cover map and collecting health facility.

2.3. Research Methods

This paper was carry out by using dominantly quantitative research approach such as Vulnerability risk analysis. The malaria hazard areas mapping were carried out using Multi Criteria Evaluation (MCE). To carry out the MCE, weight for the factors depending on their suitability for malaria incidence was gave in IDRISI software. Then the overly analysis conducted using IDRISI Software. Finally, the malaria hazard map was produced using similar procedures, the malaria risk map produced by including population density, distance from health facilities, land use/land cover and malaria hazard map.

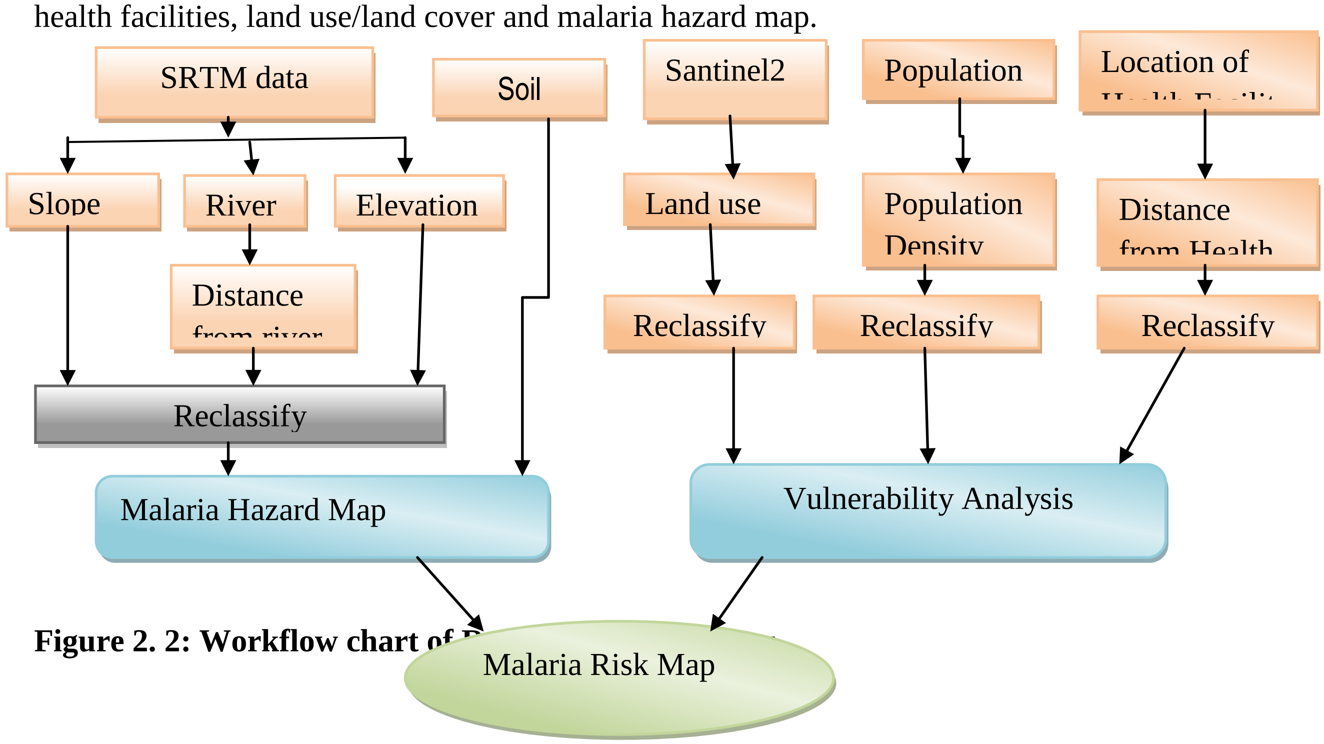

Figure 2. 2: Workflow chart of

2.4. Malaria Hazard Analysis

Malaria transmission is strongly associated with environmental conditions, which control mosquito maturity and parasite development. Accordingly distance from water bodies, slope, soil and elevation were listed in order of importance. To assess malaria hazardous sites the weight for each criterion was development corridor using IDRISI software, Multi-Criteria Evaluation (MCE) is used. MCE is a procedure which needs several criteria to be evaluated to meet a specific objective. 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 techniques 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 (Saaty, 1977). 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 the malaria hazard map was produced in ArcGIS 10.8.

2.5. Malaria Risk Analysis

Identification malaria risk areas are computed by the model developed by Solomon. E, (2018) that states risk is the combined result of hazard, element at risk and vulnerability (Equation 2).

Risk = Hazard * Element at Risk*Vulnerability…………….……………….*equation (2)*

Where:

- Risk in this study refers to is the expected degree of loss due to a particular natural phenomenon. It is expressed as the product of hazard (H), vulnerability (V), and element at risk"
- 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 breading 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 land cover in the study.

Thus, malaria risk mapping for the study area was done using the malaria hazard layer which is based solely on natural conditions and the elements at risk, namely land use/land cover, population density and distance from health services. The malaria hazard layers were computed by overlaying elevation, slope, distance from watery areas and soil types. The element at risk layer were developed by reclassifying land use/ land cover image file on the basis of malaria susceptibility of each land use/ cover classes as well as population density and vulnerability layer was developed by computing distance on the existing health centers distribution point data of the study area.

3. Result and Discussion

3.1 Methods of Environmental and Socio-economic factors Analysis

3.1.1 Environmental Factors

3.1.1.1 Elevation and Malaria risk

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 (Shililu J, et al, 2003). Elevation is a prominent factor for malaria transmission, this is because of elevation highly determines the amount of Temperature, and temperature in turn affect mosquito breeding as the length of immature stage in life cycle. In high temperature, the egg, larval and pupil stages will be shortened so that the turnover will be increased and also affect the length of the saprogenic cycle of the parasite with in the mosquito host i.e. when Temperature increase, the period of the saprogenic cycle will be shorted (Ahmed, 2014). For this study the elevation map was produced by the processing the SRTM DEM (30m resolution), using Arc GIS software Surface Analysis.

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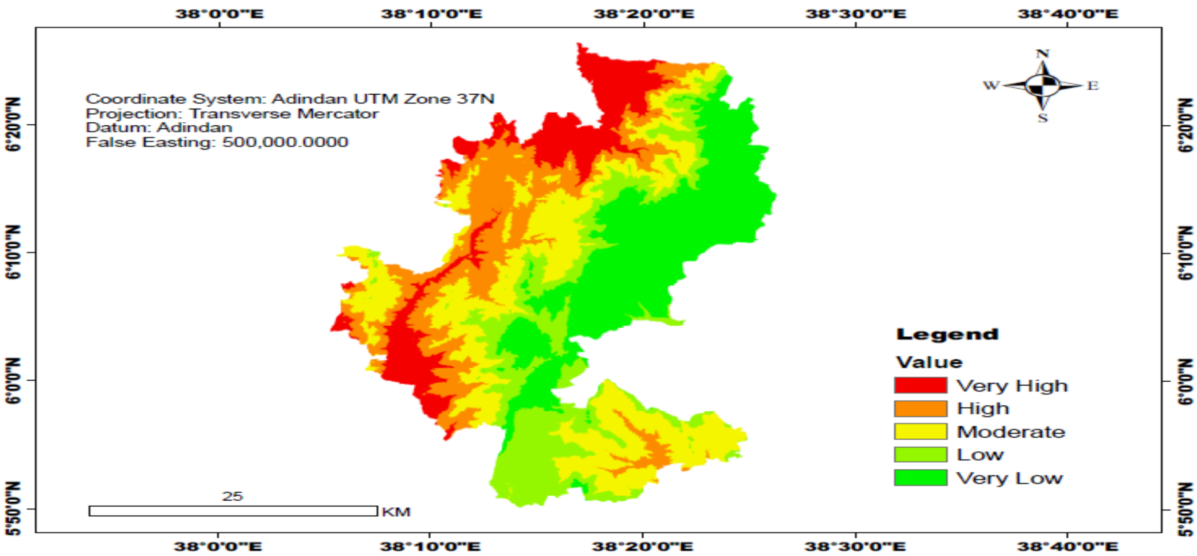

Figure 3. 1: Elevation based malaria hazard map

Table 3. 1: Malaria hazard, elevation rating area coverage and percentage

No	Rating	Elevation Range (m)	Pixel Count	Area in KM^2	Percent %
1	Very High	$\leq$ 1850	181481	226.07	12.66
2	High	1850 - 2000	264280	237.85	18.44
3	Moderate	2000 - 2200	361978	325.78	25.26
4	Low	2200 - 2400	254590	229.13	17.77
5	Very Low	$\geq$ 2400	370674	333.61	25.87
	Total		1433003	1352.44	100

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 and rainfall. Therefore, based on this context malaria breeding sites are negatively related with the altitude, and when temperature decrease and malaria also increase. Different literatures indicate that mosquitoes have typical breed's elevation ranges up to 2000ms for this study the classification was depending on (Solomon E, 2018). Figure 3.1, the reclassified elevation map covering 12.66%, 18.44%, 25.26%, 17.77%,and 25.87% were mapped as areas of very high, high, moderate, low, and very low malaria hazard level, respectively. According to the above elevation map more area of the study area are above 2400m so that 25.87% of the areas is considered as very low. In other way 25.26% of the area is classified as moderate risk elevated between 2000m and 2200m.

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3.1.1.2. Slope and malaria risk level

Slope is other topographic parameter that may be associated with creating suitable condition for mosquito spreading as well as breeding, is the measurement of the rate-change of the land per unit distance which may affect the stability of the aquatic habitat (Stephen, 2000; Ahmed, 2014). Moreover, steeper slopes are areas where surface water flows speedily and not suitable for settlement areas due to that it was accepted as areas where not favorable for malaria spread. On the other hand gentler slopes are slopes where surface water movement is stagnant this creates fertile situation for mosquito breeding and areas where chooser for settlement or agricultural land it turns to create favorable condition for mosquito breeding. Therefore, gentler slopes are accepted as high risk areas it can help for mosquito breeding. The slope map was produced by the processing the SRTM DEM (30m resolution), using Arc GIS software Surface Analysis.

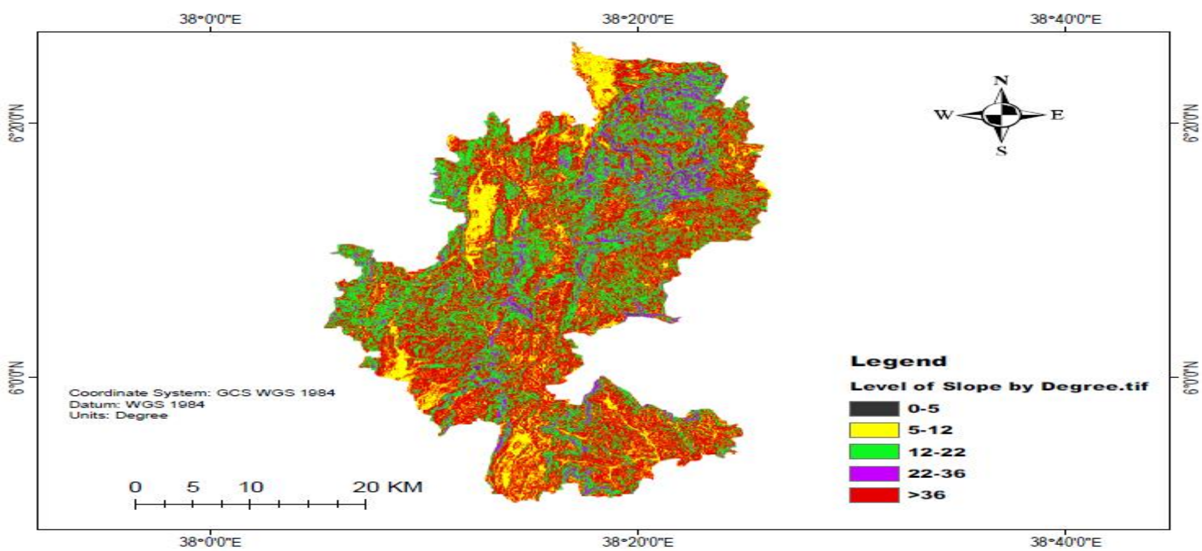

Figure 3. 2: Slope based malaria hazard map

Table 3. 2: Malaria hazard, slope rating area coverage and percentage

No	Rating	Slope Range (degree)	Pixel Count	Area in KM2	Percent %
1	Very High	$\leq 5^0$	210228	260.63	19.27
2	High	5^0 - 12^0	674688	607.22	44.90
3	Moderate	12^0 - 22^0	445845	401.26	29.67
4	Low	22^0 - 36^0	87766	78.99	5.84
5	Very Low	$\geq 36^0$	4828	4.35	0.32
	Total		1423355	1352.44	100

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As indicated in Arega (2009), 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.

As a result based on the suitability of the slope for mosquito breeding, the reclassified slope map shows of the area covered about14.77%, is incorporated in a very high; 47.40%, in high; 31.32%, in moderate; 6.17%, is considered as low; and 0.34%, is also incorporated in very low hazard of malaria incidence. Thus, relatively, more than 60% of the area 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.

3.1.1.3 Distance from Breading Sites and Malaria Risk Level

The most obvious factor influencing the distribution of mosquitoes is the distribution of breeding sites. 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 (FMoH, 2003). Moreover, as Malhotro and Srivastava (2005) stated, the abundance of water in irrigated areas due to seepage, silting, and stagnation, creates innumerable sites for malaria vector breeding.

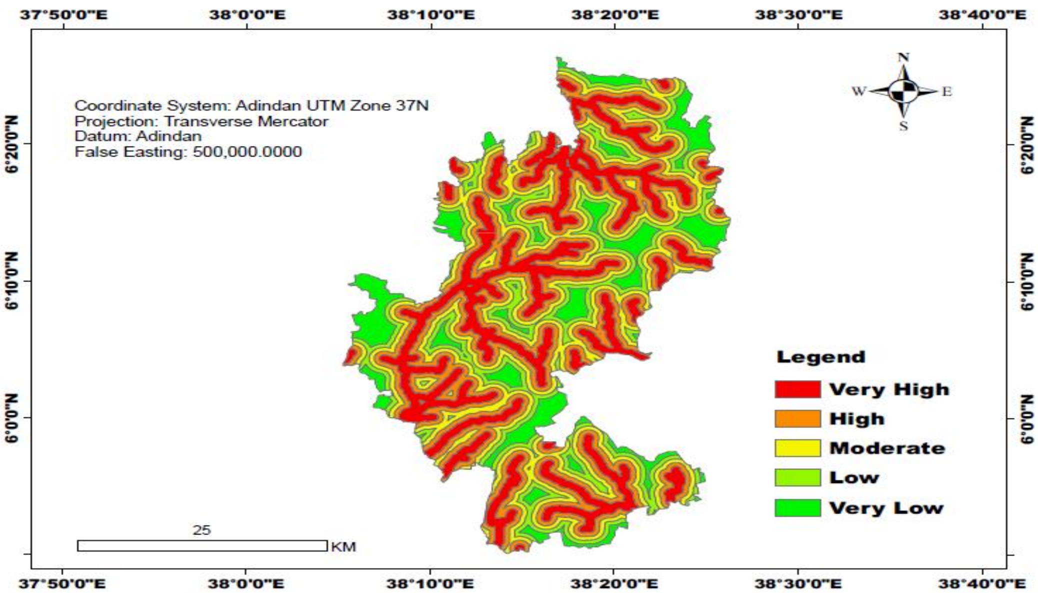

Figure 3. 3: Breading sites based malaria hazard map

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Table 3. 3: Malaria hazard, breading sites rating area coverage and percentage

No	Rating	Distance from breading site (m)	Pixel Count	Area in KM^2	Percent %
1	Very High	$\leq$ 500	407921	367.13	27.15
2	High	500 - 1000	378987	341.09	25.22
3	Moderate	1000 - 1500	319064	280.94	20.77
4	Low	1500 - 2000	214091	192.68	14.25
5	Very Low	$\geq$ 2000	189565	170.61	12.61
	Total		1509628	1352.44	100

In this factor breading sites comprises swamp areas, river and stream, wetland areas and other watery places. For the purpose of identifying the abundance of mosquitoes around rivers, the river network was derived from the 30 meter SRTM DE data. Distance was computed from every river. The computed distance was reclassified based on the maximum distance that mosquitoes can fly.

According to Arega (2009), areas range up to 2 kms are favorable for mosquito spreading and breeding, for this study distance from breading sites, the suitability map of malaria was reclassified into five classes depending on Arega (2009). The reclassified map shows the area less than 500m is very suitable for mosquito breeding and this area covered 27.15% out of total area of the study. 25.22%, 20.77%, 14.25%, and 12.61% of the area were considered as high, moderate, low and very low suitable for mosquito breading respectively. Verdoschot, (2013) reviewed article about anopheles mosquito flight distance and found average flight distance for anopheles was around 2000m (2km). However the flight distance depends on the habitats of the species and some species have a stronger dispersal capacity than others. As a result according to Gedio zone more than half of the area was considered as very high and high suitable for mosquito breeding.

3.1.1.4. Soil and Malarial risk level

Soil is defined by Davidson (1992) 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. Injury is usually most severe in light-textured soils that are low in nutrients (e.g., nitrogen, potassium, or calcium) and in organic matter. Plants under moisture and high-temperature stress are most likely to suffer damage (Balaji A., 2019).

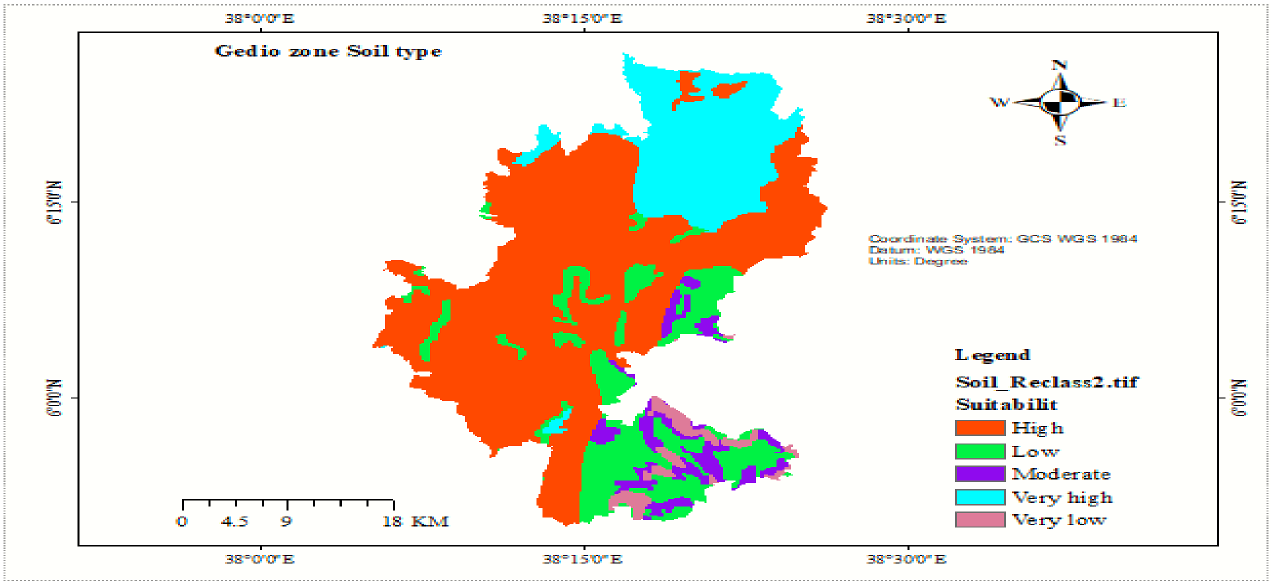

Figure 3. 4: Soil based malaria hazard map

Table 3. 4: Malaria hazard, Soil rating area coverage and percentage

No	Rating	Soil Name	Pixel Count	Area in KM^2	%
1	Very high	Vertisols, cambisols	10033	256.96	19
2	High	Nitosols, gleysols	30491	780.17	57.69
3	Moderate	Xerosols	2629	67.09	4.96
4	Low	Solonchaks, acrisols	8371	214.67	15.87
5	Very Low	Leptosols	1308	33.55	2.48
	Total		52832	1352.44	100

The major types of soil found in the study area are Nitosols, vertisols, luvisols, Cambisols, gleysols, Xerosols, solonchaks, acrisols, and Leptosols. Luvisols, vertisols and cambisols are classified as very high suitability which was recorded 19% out of the total study area. Nitosols and gleysols are found relatively in higher altitude with low infiltration rate. Majority of the study area was covered by Nitosols, which was 57.69% this analyses identifies the area was higher altitude with low infiltration rate so that it can drain water fast. The rest 4.96, 15.87, and 2.48 percent are medium, low and very low suitable respectively. The area was abundantly covered by Nitosols, which is 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.

3.1.2 Socio-Economic Factors

3.1.2.1 Population Density and Malaria Risk Level

Certain human activities have unintentionally worsened the spread of malaria. Settlement areas, for example, can create new places for mosquito larvae to develop and can increase mosquito breeding sites (NIAID, 2007). 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 (Packard R, 2007).

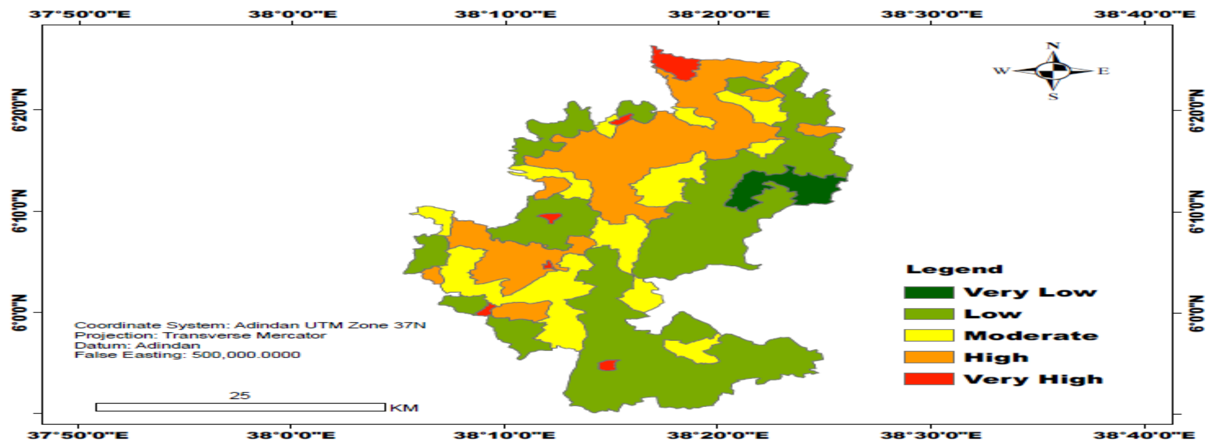

Figure 3. 5: Population Density based malaria risk level map

Table 3. 5: Malaria Risk Level based on population density and area coverage

No	Rating	Level of Vulnerability of Population	Area in KM^2	Percent %
1	Very low	< 358	41.68	3.08
2	Low	359 – 748	679.57	50.25
3	Moderate	749 – 1061	254.07	18.79
4	High	1062 – 1752	352.74	26.08
5	Very high	> 1753	24.38	1.80
	Total		1352.44	100.00

When population densities are low, the transmission of malaria will be less intense (Packard R., 2007). Population data was taken from the Gedio Zone Plan and Development (GZPD) office, the aforementioned office projected the population data depending on the past conducted census according to CSA standardization projection system. In this study some of the study area with very high and high population density covers together almost 377.12 km^2 and further

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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 41.68 km^2, 679.57 km^2 and 254.07 km^2 area consecutively. Thus, as compared to others towns of woreda's and, areas surrounded zone town including zone town are inhabited by relatively large number of population than others sub-district due to migration of rural to urban areas and productivity of the land. Moreover, around urban areas or densely populated there is highly accumulation of unmanageable liquid waste disposal this condition facilitates expansion of malaria in terms of creating favorable conditions for mosquito breeding.

3.1.2.2 Malaria Risk Level and Health Facility

Distance based analysis is one of the most fundamental functionalities of the GIS. Euclidean or straight-line distance function measures distance from one point, line or polygon to another on a plane. The applications of GIS based distance parameter have been substantiated by different studies depicting the growing importance of this parameter in malaria study (Solomon, 2018). Malaria vulnerability can be reduced by the advancement of vector control mechanisms.

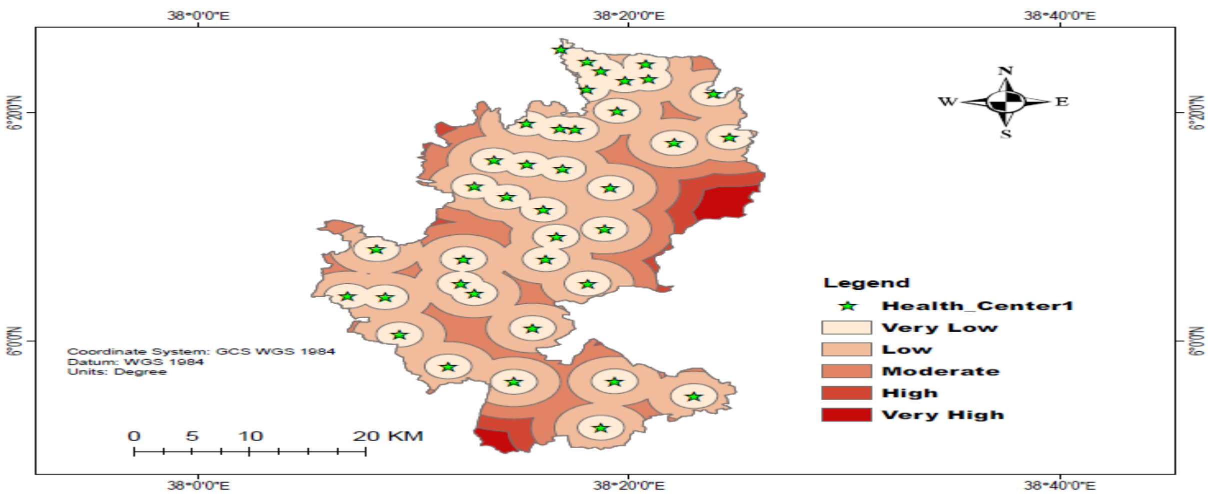

Figure 3. 6: Health facility based malaria risk level map

Table 3. 6: Malaria Risk Level based on distance from health facility

No	Rating	Distance from Health Center	Area in KM^2	Percent %
1	Very High	>8KM	30.75	2.27
2	High	6-8KM	50.50	3.73
3	Moderate	4-6KM	219.09	16.20
4	Low	2-4KM	640.01	47.32
5	Very Low	<2KM	412.09	30.47

Total	1352.44	100.00

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. 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.

According to WHO (2003), the result of distance analysis from health centers reveals that 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, less than 4km, and 6km, range of land respectively. For this study distance from healthy center was set depending on *'WHO'* aforementioned, therefore the above result of distance analysis from health centers reveals that 412.09km^2 areas, which are found within range of 2km distance from the health centers, were distinguished as very low risk of malaria. Low risk, and moderate risk areas on, on the other hand, accounted for 640 km^2 and 219 km^2 area of land respectively. Almost 81.25 km^2 areas were subjected to malaria. Of these, 50.50 km^2 were high-risk areas, and 30.75 km^2 were very high risky ones.

3.1.2.3 Malaria Risk Level and Land Use/Cover Type

The LULC is directly related to the malaria burden through its impact on breeding sites and on the adult mosquito survival rate and dispersal. In Ethiopia, malaria mosquito prefers for breeding mainly water collections from rains. However, the mosquito breeds also in intermittent rivers and streams, around ponds, swamps, and marshy areas, slowly running shallow irrigation waters and around shallow dams (FMoH, 2003).

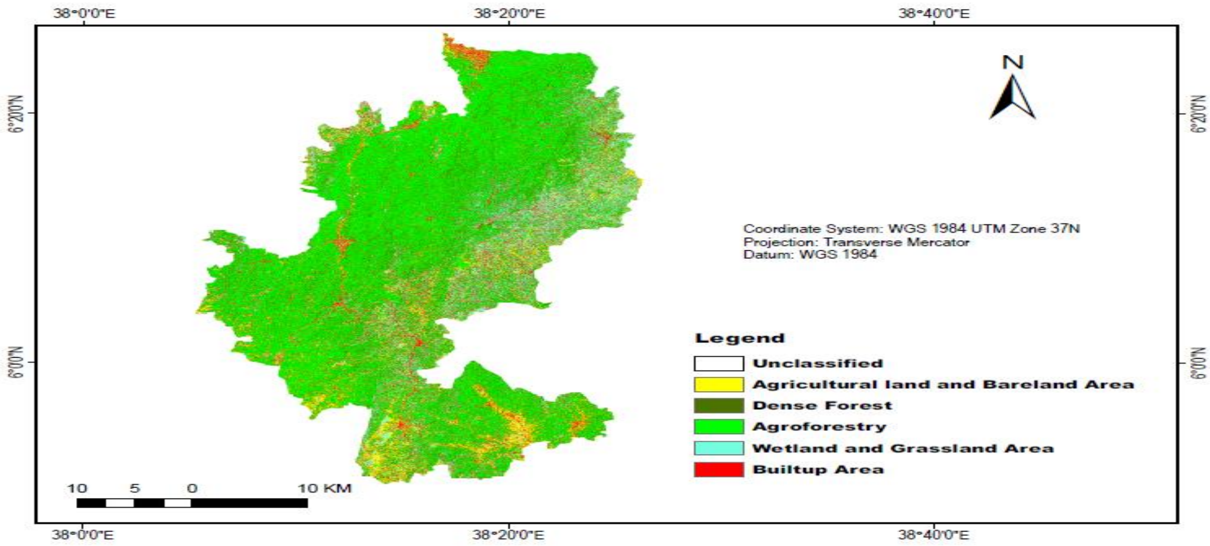

Figure 3. 7: Land use/cover based malaria risk level map

Table 3. 7: Malaria Risk Level based on LULC

No	Rating	LULC type	Pixel Count	Area in km^2	Percent
1	Very Low	Agricultural land and Bare land Area	55720825	125.4	9.27
2	Low	Dense Forest	6159447	193.8	14.33
3	Moderate	Agroforestry	318053750	715.6	52.91
4	High	Built-up Area	72447705	163	12.05
5	Very High	Wetland and Grassland Area	68807067	154.64	11.43
	Total		532381727	1352.44	100

The result of land use land cover was reclassified by considering classes which are favorable to breeding and transition of malaria. Therefore, the mosquito breeds also in intermittent rivers and streams, around ponds, swampy and marshy areas, slowly running shallow irrigation waters and around shallow dams (FMoH, 2003). According to Solomon, E, (2018) land classes were that are create favorable conditions for malaria breeding classified; Bare Land, Forest/Built-up area, Grazing Land, Crop Land and Water areas as very Low, low, moderate, high, and very high respectively.

In the study area, the researchers reclassified the LULC class in to five major classes considering their suitability for malaria; wetland and built-up land use land cover areas are accepted as very high and high risk area. Agroforestry, dense forest and bare land or agricultural areas considered as moderate, low and very low for malaria expansion. As seen from the above LULC result watery areas covered 11.43% out of the total areas of the Gedio

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zone and also it is considered as very high for malaria transmission. The rest built-up, agroforestry, dense forest, and agricultural or bare land areas were accounted 12.05%, 52.91%, 14.33% and 9.27% for malaria transmission respectively.

4.2 Malaria Hazard Area Identification

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 3. 8: Weight of Malaria Hazard Factors

Factors	Weight	Class	Level of Suitability	Ranking	References
Elevation	0.52	≤ 1850m 1850m-2000m 2000m-2200m 2200m-2400m ≥2400m	Very high High Moderate Low Very low	5 4 3 2 1	Solomon, E (2018) UNICEF (2008)
Slope	0.1	≤ 5^0 5^0 - 12^0 12^0 - 22^0 22^0 - 36^0 ≥ 36^0	Very high High Moderate Low Very low	5 4 3 2 1	Arega (2009)
Distance from breading sites	0.3	≤ 500m 500m – 1000m 1000m – 1500m 1500m – 2000m ≥ 2000m	Very high High Moderate Low Very low	5 4 3 2 1	Amare. S. M and Kalkidan. A (2018)
Soil	0.08	➧ Vertisols, luvisols, &cambisols ➧ Nitosols, and gleysols ➧ Calcic xerosols ➧ solonchaks and acrisols ➧ Leptosols	Very high High Moderate Low Very low	5 4 3 2 1	FAO, (1993)

For the purpose of identifying areas of malaria hazard, this study focused on elevation, slope, distance from breading sites, and soil type as the factors of malaria incidence in the study area.

Table 2. 9: Malaria hazard area coverage and percent

No	Rating	Pixel Count	Area in km^2	Percent %
1	Very High	4903	132.91	9.83
2	High	19877	477.26	35.29
3	Moderate	21811	523.86	38.73
4	Low	9166	218.25	16.14
5	Very Low	8	0.15	0.01
	Total	55765	1352.44	100

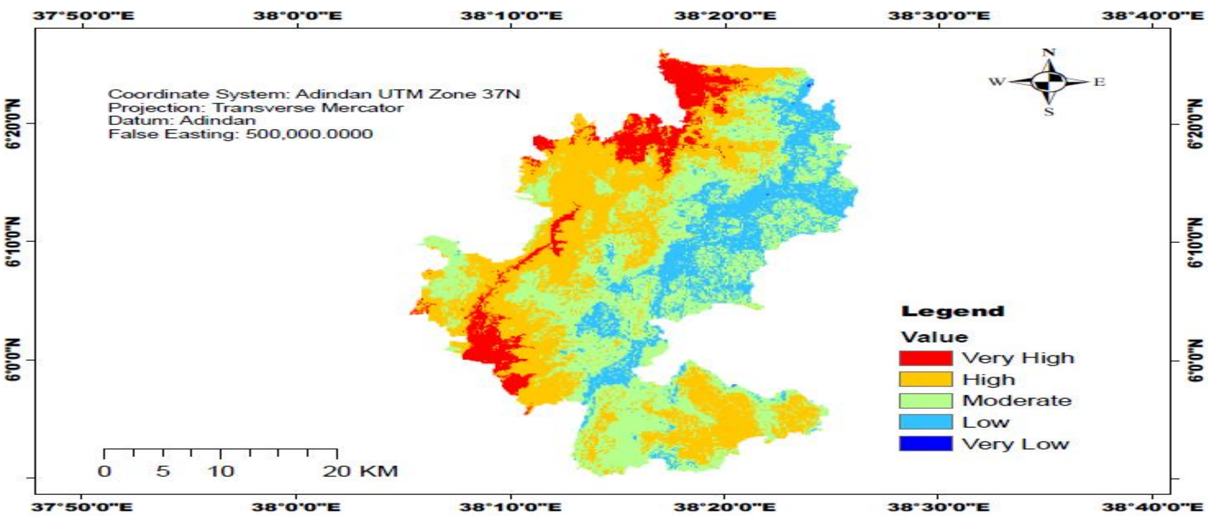

Figure 3. 8: Malaria Hazard Map

The above malaria hazard map portrays that, 9.83% and 35.29% were considered as very high and high vulnerable respectively. Moreover, these areas are located around the north western, south western and southern tip of the Gedio zone. The other part of the study area 38.73%, 16.14% and 0.01% shows that moderate, low and very low vulnerable to spread of malaria respectively. Therefore, north eastern and south eastern parts of the zone were moderate and low vulnerable areas.

3.3 Malaria Risk Area Identification

Malaria hazard mapping which is only based on natural or environmental conditions is not sufficient but socio-economic factors, such as population density, distance from health centers, and land use land cover should have to be included. Accordingly in this study malaria risk area identification was conducted using both environmental and socio-economic factors evaluations. Therefore, the weight of each factor has been given depending on the weight of variables that they make good conditions for malaria breeding and also by reviewing the previous related research conducted on the similar areas.

Table 3. 10: Weight of Malaria Risk Factors

Factor	Class	Weight	Level of Suitability	Rank
Distance from health centers	> 8KM 6-8KM 4-6KM 2-4KM < 2KM	0.2	Very High High Moderate Low Very Low	1 2 3 4 5
Land use/cover	Wetland and grassland area Built-up Area Agroforestry Dense forest Bare land and Agricultural Area	0.2	Very High High Moderate Low Very Low	1 2 3 4 5
Population density	>1753 1062 – 1752 749 – 1061 359 – 748 < 358	0.3	Very High High Moderate Low Very Low	1 2 3 4 5
Malaria Hazard	1 2 3 4 5	0.3	Very High High Moderate Low Very Low	1 2 3 4 5

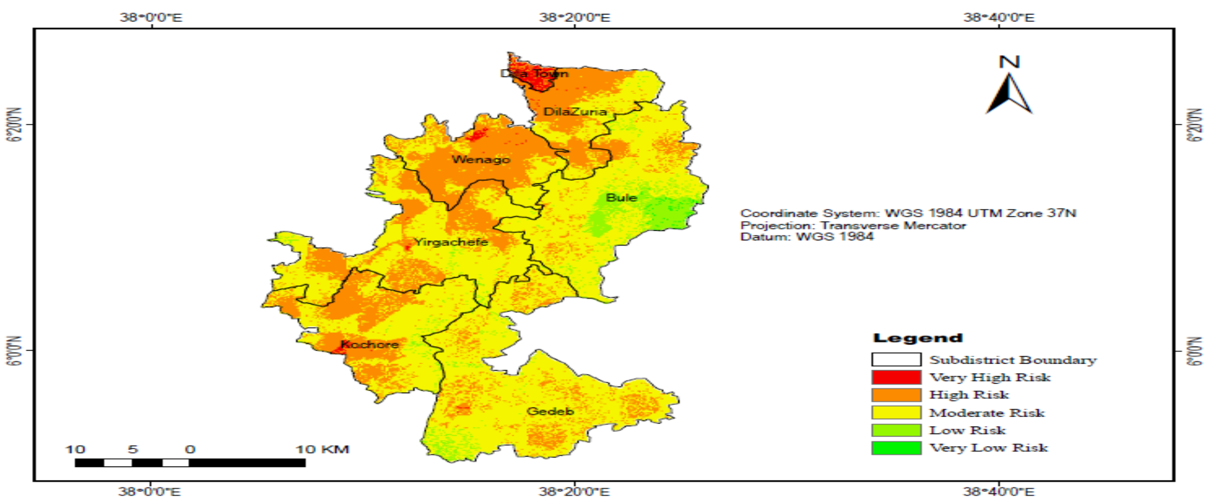

Figure 3. 9: Malaria Risk Areas identified using Weighted overlay Model in Arc GIS

Table 3. 11: Malaria risk area percent and coverage

No	Rating	Pixel count	Area M^2	Area in Km^2	Percent
1	Very High	14395	12955.5	16.74	1.24
2	High	455362	409825.8	409.6	30.29
3	Moderate	929841	836856.9	837.1	61.90
4	Low	73195	65875.5	66	4.88
5	Very Low	2525	2272.5	23	1.70

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Total			1352.44	100.00

Malaria risk map computed by overlaying hazard map and vulnerability maps like land use/cover, population density and distance from health facility. According to the above table 4.11 majority of the area included in the high and moderate risk which are accounts 409.6km^2 and 837.1km^2, the rest 16.74km^2, 66km^2 and 23km^2 also very high, low, and very low risk areas respectively.

As showed spatially on the above figure 4.9 specifically the very high and high malaria risk areas were located around densely settlement and sloppy areas, this identifies as it's known many people lives in the towns and around suitable slope and landscape. Therefore, all tows of Gedio zone including Dilla town are incorporated under malaria risk areas.

Conclusions

This study has the aim of mapping malaria hazard and risk areas in Gedio zone of SNNPs using GIS and Remote Sensing techniques. Geographic Information System and Remote Sensing played an important role in analyzing of environmental and socio-economic drivers that created favorable condition for malaria breeding as well as to identify malaria hazard and risk areas.

The environmental (physical) factors which provide for the endurance of mosquitoes such as; elevation, slope, distance to breeding sites, and soil type. More than 31.1% of elevated areas considered as areas that highly create favorable condition for malaria breeding, around 2/3rd of the areas were gentler slope whereas good for malaria spreading system, half of the study area is close to river areas as such they considered as highly suitable areas for breeding system and there are only two types of soil Eutric Nitosols and Eutric Cambisols, out of this nitosols shares more than 95% and due to its low infiltration rate it has been taken as high risk areas. Similarly, socio-economic factors like; distance from health centers, land use/cover and population density were analyzed independently. Depending on the analysis of population density 1/3rd of the area incorporated under high risk areas, approximately half of Gedio zone is covered by agroforestry and its considered as moderately risk and 1/3rd of the area also considered as highly risk areas.

Malaria hazard prevalence areas were mapped based on the environmental factors which are potential of providing good environmental conditions for mosquito breeding. The hazard map was produced using elevation, slope, proximity to breeding sites, and soil type as the factors for breeding of mosquitos having 0.52%, 0.1%, 0.3%, and 0.08% weights respectively. For malaria breeding lower elevation areas, gentler slope and areas that are closest to watery areas like; swap, wetland, river and stream were highly vulnerable. The malaria hazard analysis of Gedio zone revealed that from the total area, 9.83%, 35.29% is mapped as very high and high risk area, whereas, the remaining 38.73%, 16.14%, and 0.01% were mapped as moderate, low, very low level of malaria hazard respectively.

Malaria risk map was produced depending upon the overlay analysis of the malaria hazard map and malaria suitability maps like; land use/ cover, distance from health facility and population density, using 0.3%, 0.2%, 0.2% and 0.3% weights in the overlay analysis respectively. Risk maps are essential for predicting the scale of the risk, and for this reason the results needed to fight malaria. The results of the study showed that out of the total area of the study area more than 1/3rd of the area was identified as very high and high malaria risk area while the rest 2/3rd of an area was considered as moderate to very low hazard risk zone. According to the result very high malaria risk area was found around tows because of population density.

Recommendation

The following recommendations are proposed by the researcher.

The result of the study identifies malaria risk areas was highly associated with population density, as a result highly risky areas were around towns and cities to overcome this problem the concerned body should have to work to minimize the unmanageable liquid waste that create favorable condition for mosquito spreading.

Gedio zone administration and different stakeholders like NGOs should have to expand health centers like hospital, clinic and others for the areas incorporated in very high and high risk areas those are far from health centers.

Gedio zone health officers should also make awareness concerning the ways of malaria spreading and transmissions as well as the negative impacts of the disease on socio-economic of the area and on the country as the whole.

Lowland areas of the Gedio zone creates good conditions for malaria spreading according to the results of the research so that the government, NGOs, other concerned bodies have to give attention for lowland areas of the zone.

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