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# Biophysical Environment Based Malaria Risk Zoning, and Incidence Relationship in Sidama Zone, Ethiopia

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**Abstract:** Although several attempts were made to control malaria, it is still the leading cause of human mortality and morbidity in Ethiopia. The interpretation of the tie between the spatial landscape dynamics and malaria risk zone and its synchrony to the incidences has great importance in planning the interventions measures to control the spontaneous breakout of the pandemic. The study area, Sidama zone, which extends from the floor of the Great Rift Valley to the south east highlands of Ethiopia, is used to characterize the interpretation of the biophysical environment with malaria risk zoning. GIS and remote sensing technology were applied as a toolkit to manipulate and analyze the given variables for prioritizing areas of intervention to control the pandemic. According to this study more than half of the study area is depicted out as malaria inflicted area, and the high risk zones are situated particularly on the administrative districts of Shebedino, Dalle and Wendogenet. And, as the risk has positive relationship with population density of the area, it has sigmoidal patterns with temperature and elevation and in terms of land use classes; the agroforestry is taken to be the highest cause for malaria risk. The areas of the malaria risk zone and the number of incidences by administrative districts is also highly synchronous. Hence, this result shows that the GIS based malaria risk zoning is helpful to administrative units' in decision making to prioritized areas of interventions.

**Keywords**: Biophysical environment, Malaria risk zoning, Incidence, GIS, Ethiopia

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## I. INTRODUCTION

A great deal of malaria prevention and controlling endeavors have been made in Ethiopia. Though the country has an experience of organizational malaria prevention and control mechanisms for about more than four decades, it has made important paces only very recently to attain better results. From strategizing the problem of malaria Ethiopia has developed the 2011-2015 National Strategic Plan envisioned eliminating in some specific spatial scales, lowering the transmission and a near-zero malaria death rate in the remaining malerious areas of the country by 2015 [1]. And, to act on the problem, and hold the category of second level among African countries, there was success as the trend of reported malaria incidence decreased from 50% - 75% in the years between 2000 -2015 including the projected [2].

However, 75-80% of the country's landmass or about 736 districts [3, 1], which comprises about 68% of the total population of 84.3 million lives at crucial risk of malaria. It is the leading pandemic in Ethiopia and public health and socioeconomic problem, as well as it is responsible for high morbidity and mortality rate of the country [4, 5].

Actually, malaria epidemic outbreak has a dynamic pattern in space and time in Ethiopia. So there is an incidence of the spontaneous outbreak of the epidemics. Several studies have been made on the spatial inferred malaria epidemics in Ethiopia. Moreover GIS and Remote Sensing techniques have also made use, particularly in malaria risk zoning to assist the interventions to prevent and control the pandemic [5, 6, 7 ]. However, the biophysical environment interpretation and incidences synchrony with the malaria risk zones have not yet acquired proper attention particularly in the study area.

Having the stated intention above, the objective of this study is to map out the malaria risk zone of the Sidama Zone, which extends From the Great Rift Valley Floor to South East High Lands of Ethiopia, and thereby to interpret the spatial landscape dynamism of the biophysical environment and incidences synchrony.

The study area was selected for the research because: i) it is typical of the South Highlands of the country in terms of the various environmental attributes such as topography, soils, climate, and the socioeconomic environment, and because ii) no study has been carried out on the issue of mapping out the malaria risk zone based on its spatial landscape dynamism of the biophysical environment and incidences synchrony. The fact that the study is site-specific is believed to make it a valuable contribution to the muchneeded local-level understanding of the problem of malaria alleviation. The following section describes the methodology of the study, followed by the results and discussion in section 3. Section four presents conclusions.

## II. METHODS

Malaria distribution and expansion is highly characterized by the biophysical environmental attributes, as the risk of the epidemic is greatly determined by the local environmental conditions, propensity to accommodate the parasite (plasmodia) and the vector (anopheles mosquito) as well as the infected/ affected people.

### 1.1. The study area

Sidama is one of the administration zones of Southern Nations and Nationalities Peoples Regional State (SNNPRS) of Ethiopia. The administrative capital is Hawassa town located 275 south of Addis Ababa. Hawassa is also the regional administrative capital. Astronomically, Sidama zone is extending from $6^{o}$ 8’38”N to $7^{o}$ 8’55”N and $37^{o}$ 58’31”E to $39^{o}$7’20”E. It has a total area of 6,538 square kilometers. The Zone is currently divided in to 19 woredas (districts). It has also two rapidly growing reform towns Aleta-Wendo and Yirgalem and other immerging towns (see fig 1).

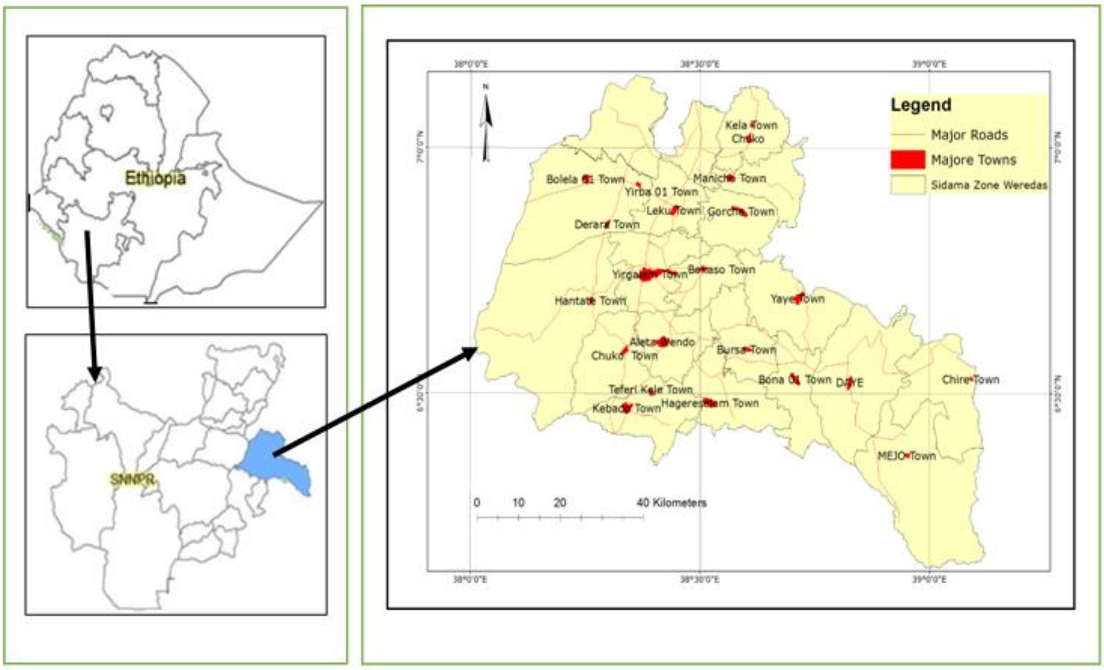


**Figure 1.** The study area location map

According to the 2007 census conducted by Central Statics Agency **[8],** the zone has a total population of 2,954,136, of whom 1,491,248 (50.48%) are men and 1,462,888 (49.52%) women. Of the above total population 5 .51% are urban dwellers while 0.18% pastoralist and the remaining 94.31% are rural inhabitant whose life is attached to agriculture. On the average the zone has 4.99 persons per household and a total of 592,539 households resulting in a population density of 451.83/km sq. and on average each district has a population of 100,000. The district level density of population is shown in fig. 2a.

The physiography of the study area is highly dominated by the Great Rift Valley and the south east volcanic highlands in the country’s physiographical category. The elevation of the area gradually increases from the wider lowland areas of the western districts and south eastern stripes of valleys which rise up to about 1150m.asl. The height increases more towards the high volcanic mountainous region of eastern central parts up to around 3350m.asl. The region includes the escarpment of the rift valley. The drainage basis also follows the physiographic patterns of the area. Hence, most of the major streams and rivers drained to south western lowland areas of the region towards the floor rift valley (see fig 2b).

The land use and the land cover distribution of the study area, as it is shown in fig. 2c; is the reflection of the physiographic characteristics of the area. The dominant land cover type is cultivated land which can be seen in every part of the study area. And, the agroforestry, eastern and central high mountain regions of the study area is highly dominated by high and moderate density of forest and wood land vegetation. The bare surface on the other hand, is located in the western end of the study area and around the Hawassa Lake near the city of Hawassa. The city Hawassa and the built environment surrounding Hawassa Lake, the urban and other major settlements were dispersed throughout the zone.

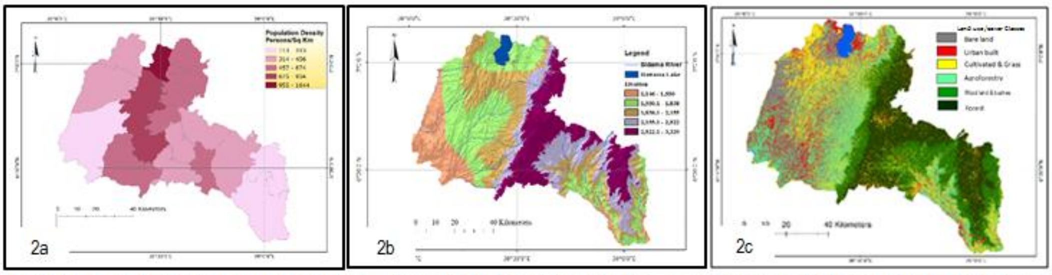


**Figure 2. 2a)** The pattern of population density **b)** the physiographic, drainage pattern& land use **c)** Land cover distribution of the study area

Land use /cover Classes

### 1.2. Methods of data processing and analysis

The study mainly applied GIS and remote sensing techniques that requires substantial spatial and attribute data. The main data type and sources of this study is presented in table 1.

**Table1**. Main Data Sources and Uses

| Data type andmaterials | Data source | Method of data collection and uses |
|---|---|---|
| Topographical sheet | EMA | Purchase (with 1:50000) |
| Landsat OLI 2015 | USGS online | Download (with row and path number of 168 by 54 & 53) |
| DEM | USGS online | 30m resolution for the region elevation and slope map |
| Major roads & major rivers and protected areas feature data | Southern Nation Nationalities and Peoples Region (SNNPR), Finance & Economic development Bureau | Edited and rasterize to develop proximity map |
| The Sidama Zone District boundary | SNNPR Finance & Economic development Bureau | Gathered from concerned offices |
| Ground survey field attributes (Training) | Field measurement and observation | GPS measurement, and checklist |
| Ancillary data | | |
| Sidama zone Malaria incidence Data by districts | SNNPR Health Bureau | Corrected and edited |

Based on the major biophysical and some anthropogenic variables, and with the help of GIS and remote sensing technologies, it is possible to make malaria risk zoning. As to **[9]**, the technology enables researchers to identify multi temporal and spatial environmental realities that determine the human health risk intensity. **[9]** also extends his idea by capitalizing the significance of it in defining the epidemiology of the disease with reference to the environmental variables which delineate the risk zones by using pertinent variables that determine the distribution of the risk.

As far as the malaria epidemiology is concerned it is a complex disease that links the parasite, the vector, the human host and the environment. Malaria is essentially an environmental disease since the vectors require specific habitats with surface water for reproduction and humidity. Adult mosquito survival and the development rates of both the vector and parasite populations are influenced by temperature **[10].** So it is necessary to handle the possible factors that determine the cause of malaria incidence. Hence, the GIS and remote sensing technologies can help researchers to identify and prioritizing areas by their vulnerability of the parasite and the prevention mechanisms. It also helps to discern the relationship between disease occurrence indexes and environmental characteristics, and to observe the geographic locations of the prevalent determinant physical variables that affect the incidence, prevalence and the mechanisms to control the disease.

The methodological structure of the this study (Fig 3) portrays the major variables that determine the malaria risk area delineation, generated the data from metrological, topographic, land use, land cover, demographic as well as proximity dependent risk variables (includes the buffered distances from major water bodies and wet surfaces and from health canters).

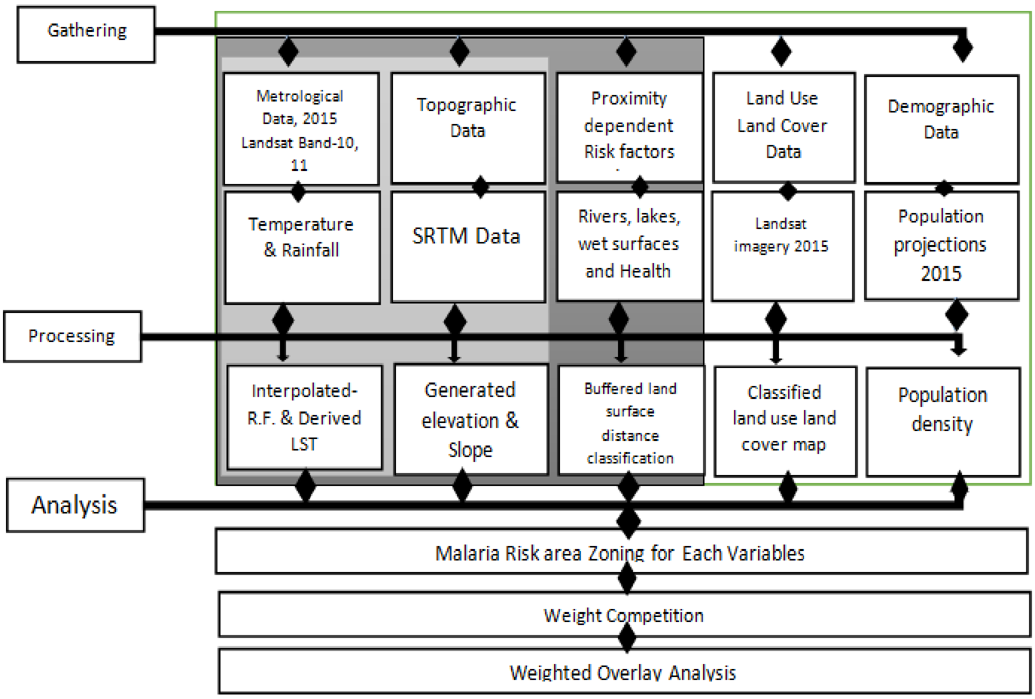


**Figure3.** Methodological structure of the study

### 1.3. Malaria Risk Mapping Criteria Erection

Risk is actually a product of the probability of occurrence of potential malaria outbreak, the presence and exposure of the human being with a given determining factors at a given spatial and temporal dimension. It means risk is a function of hazard, elements at risk and vulnerability.

Hence, the risk mapping criteria is also erected based on the intrinsic relationship between the biophysical variables characteristics and the behaviour and habitability of the parasite plasmodium, the vector mosquito, and the host human being. Variables specified in TABLE 1, which were based on literature reviews and interviews with health sector experts, greatly influence on malaria prevalence in the study area. And these variables aggregated in ArcGIS modeling using spatial analyst tool after each factor was given the appropriate weight. Reclassed layers of the variables were ordered according to their degree of impact. Pair wise comparison of each variable was executed to develop their weights as it is presented in TABLE 2. Assumptions were also set up for precise criteria erection to execute malaria risk zoning by their magnitude. The spatial distribution of malaria related environmental and socio-demographic variables, and buffered distances of proximity variables were reclassed. Euclidean distances and map algebra of a raster maps are also applied to produce required spatial information that determine malaria risk zoning. The weighted overlay algorism or model was used in order to process the outlined data further analyzed in relation to population density and Land use-land cover patterns.

**Table 2**. Variables of Malaria Risk Zoning, Weight and Assumptions Related to Each Variable

| Variables | Input Data | Variables Measurement | Variables weight | Control Points | Rank | Risk Level | Assumptions |
|---|---|---|---|---|---|---|---|
| ***Variables of Risk Zoning by Terrain structures and Major Climatic Elements*** | | | | | | | |
| Elevation | SRTM 30m | Elevation | 32 | 1000-2000<br>2000-2200<br>2200- 2500<br>>2500 | 4<br>3<br>2<br>1 | V. High<br>High<br>Medium<br>Low | The epidemic is endemic b/n 1000-2000, [11, 12, 13]. |
| Temperature | Landsat 2013 Band6 | Land surface temperature | 38 | $18^0$c-$28^0$c<br>$28^0$c -$32^0$c<br>>$32^0$c<br>< $18^0$c | 4<br>3<br>2<br>1 | V. High<br>High<br>Medium<br>Low | Temperature below 15°C is too cold for mosquito development [14]. |
| Slope | Derived from SRTM 30m | Slope | 13 | < $5^0$<br>$5^0$- $10^0$<br>$10^0$-$15^0$<br>>$15^0$ | 4<br>3<br>2<br>1 | V. High<br>High<br>Medium<br>Low | Slope determines the potential water holding of the land surface. as the slope of a given land is gently sloped the it has higher potential to hold water. [15] |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Rain Fall | Metrological data | Rain Fall intensity | 17 | < 950<br>950- 1150<br>1150-1250<br>>1250 | 4<br>3<br>2<br>1 | V. High<br>High<br>Medium<br>Low | An area of high RF create larger swampy surface and helps the air to hold more humidity which support the development of the vector [16,17 ] put a maximum limit of 950mm annual R.F. |
| ***Variables of Risk Zoning by Proximity to related Variables*** | | | | | | | |
| Water Bodies and any wet lands<br>• **Rivers**<br>• **Lakes** | Vector data SNNPR FEDB | Euclidean Distance | <br><br><br>30<br>23 | < 1500m<br>1500-3000<br>3000-5000<br>>5000 | 4<br>3<br>2<br>1 | V. High<br>High<br>Medium<br>Low | Vectors found within 3 km of rivers and streams [18].<br>Malaria cases associated with proximity to the water bodies; as the distance from the wet lands increase the intensity of malaria incidence increases [19]. |
| Urban centres | Vector data SNNPR FEDB | Euclidean Distance | 28 | < 1500<br>1500- 3000<br>3000-5000<br>>5000 | 4<br>3<br>2<br>1 | V. High<br>High<br>Medium<br>Low | Urban centres have better health service facilities. So the proximity of urban centres determine the population and areas those which under 5000 m radius is taken as they have good access to health centres.<br>[ 20 ]also puts a radius of 3000m as a less risky area. |
| **Major Roads** | Vector data SNNPR FEDB | Euclidean Distance | 19 | < 1500<br>1500- 3000<br>3000-5000<br>>5000 | 4<br>3<br>2<br>1 | V. High<br>High<br>Medium<br>Low | Distance to road refers to access for mobilization and access to the main health institution [17]. |
| ***Overlaid Variables of Malaria Risk Zoning by Land use-Land cover and Population Density*** | | | | | | | |
| Population | Census | Population Density | 28 | < 313<br>314- 454<br>454-631<br>> 631 | 1<br>2<br>3<br>4 | Low<br>Medium<br>High<br>V. High | As population density of an area gets higher, the no of persons under the risk of malaria also appears to be higher. [21] |
| Land use, land cover | Landsat TM8 | Land use, land cover classes | 9 | *Wet Lnd<br>VegtativeLd<br>AgFost-Cultiv<br>Bare&Urban | 4<br>3<br>2<br>1 | V. High<br>High<br>Medium<br>Low | Regarding LULC malaria risk: Bare soil; Forest and bush land; rain fed farm land and water body; and irrigated farm land show risk levels low, medium , high, and very highrespectively (Dambach et al. 2009 as cited in [5]. |
| Risk level by Terrain structures and Major Climatic Elements | Weighted Overlay output | | 48 | | 1<br>2<br>3<br>4 | Low<br>Medium<br>High<br>V. High | |
| Risk level by Proximity to related Variables | Weighted Overlay output | | 15 | | 1<br>2<br>3<br>4 | Low<br>Medium<br>High<br>V. High | |

* Wet Lnd refers Wet land, VegtativeLd refers to Natural Vegetation Cover, AgFost-Cultiv refers to Agroforestry cultivated land, Bare &Urban Bare land and Urban settlements

## III. RESULTS AND DISCUSSION

As it is seen in the methodology stepwise procedure, the analysis is followed. Hence, the study first develops the malaria risk zones by using the spatial configuration of the terrain structures and major climatic elements of the study area. Accordingly, the malaria risk zoning have been developed with the help of the proximity variables such as rivers, lakes and swampy areas, as well as urban centres and major all-weather roads of the zone. The final malaria risk zone map was produced using the overlaid map of terrain structure and climatic variables, proximity parameters, the land use-land cover map, and the population density map of the study area.

## IV. RESULTS

The malaria risk by terrain structure and major climatic elements in this study represent elevation; slope, temperature and rain fall. The relationship between malaria and elevation and slope is generally linear inverse. As elevation and slope increase the malaria incidence declines. Whereas the malaria relationship with temperature and rain fall is somehow an inverted U shaped. As temperature and rain fall increase the malaria incidence increases up to some optimum level then it starts to decline as the value continues to grow. Having this basic is considered, the multi criteria overlay analysis of malaria risk by major climatic elements and terrain structures depicts that the higher risk of malaria is predominantly located in the western half of the study area (see Fig. 4a).

As far as the malaria risk zoning by proximity to related variables is concerned, it relays on the buffered Euclidian distances from major rivers, lakes, urban centres and major roads by taking the following basics. Malaria incidence has a linear inverse relationship with wet surfaces, such as rivers and lakes, since malaria risk is getting higher with proximity to these wet surfaces. There is of linear direct relationship with urban centres and major roads; malaria incidence increases with increasing distance from urban centres and major roads. Proximity to urban centres and major roads provides an area to better access, improved health services and facilities. As it is shown in fig. 4b, a very high risk zone, with very small proportion which looks a small tick mark, have been at the northern tip of the study area, while high, medium and low risk zones were found somehow everywhere throughout the study area with varying level of extent.

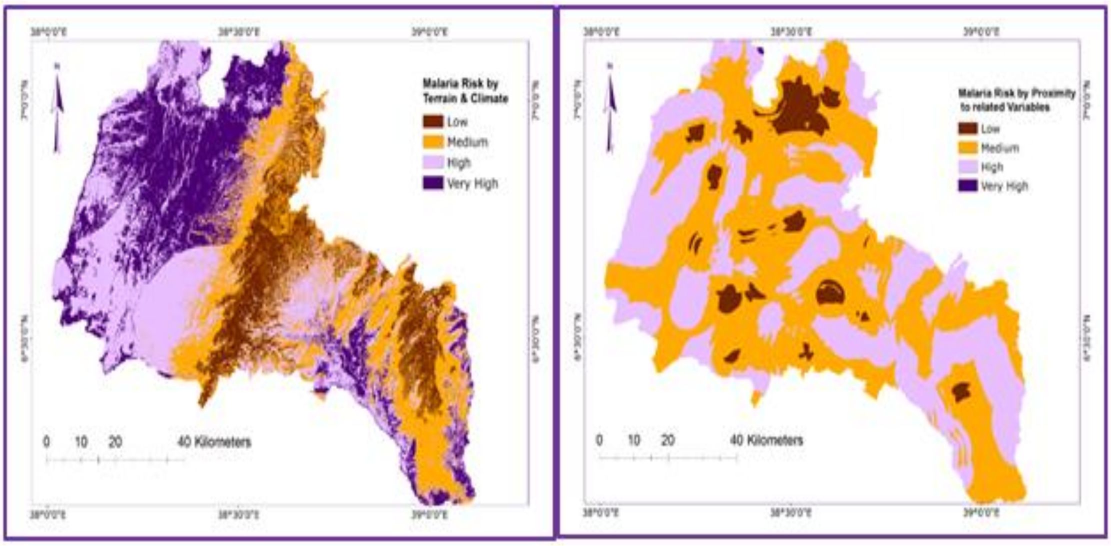


**Figure 4. a)** Malaria risk zoning map by terrain structure and major climatic variables**, b)** Malaria risk zoning map by proximity to related variables

And, for the purpose of producing the final malaria risk zoning map, the risk zoning generated by terrain structure and major climatic variables, and proximity to related variables overlaid with land use- land cover and population density map. And then, the risk zone map aligned with the administrative district of the zone.

As it is portrayed fig. 5, a very high risk area was intense in central and north eastern part of the study area. High malaria risk zone is distributed widely whereas dominating the western half and south eastern part of the study area. On the other hand, as low malaria risk zone is localized in the eastern central parts and spotted at the central part of the region; the moderate malaria risk zone inhabits substantial areas of eastern, central, eastern fringes and some south western parts of the study area.

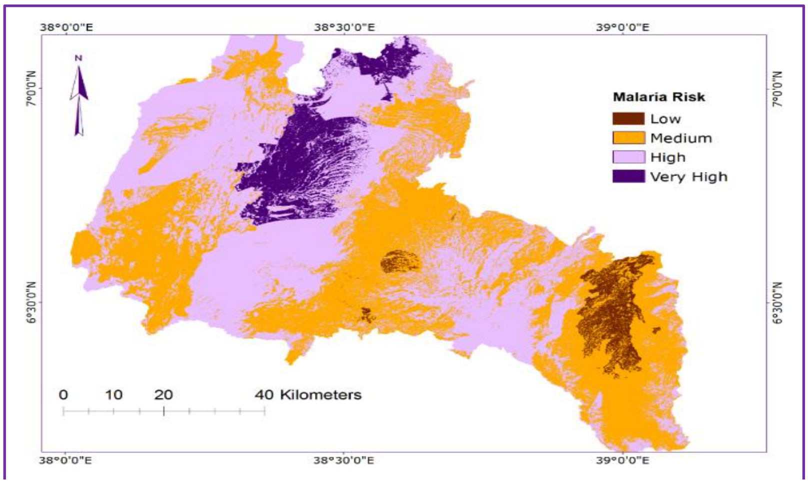


**Figure 5.** Malaria risk zoning map of the study area

As to the areal distribution of malaria risks by its levels, as about half of the study area (49%) is categorized under high malaria risk zone; the next higher proportion (about 41%) of the study area fall under medium malaria risk zone. And the two extreme very high and low risk zone of malaria covers very small proportions which represents about 7% and 3% of the total area respectively.

Concerning the malaria risk level analysis by district, while seven of the twenty districts were of low malaria risk areas; part and parcel of the twelve districts were at a very high malaria risk zone. However, almost all of the districts of the study area were experiencing high and medium level of malaria risk (see fig. 6)

Particularly Shebedino, Dalle, Wendogenet districts and Hawassa city administration enclose a relatively higher percentage of an area which is at a very high risk zone representing about 77%, 63%, 27%, and 23% of their total area, respectively.

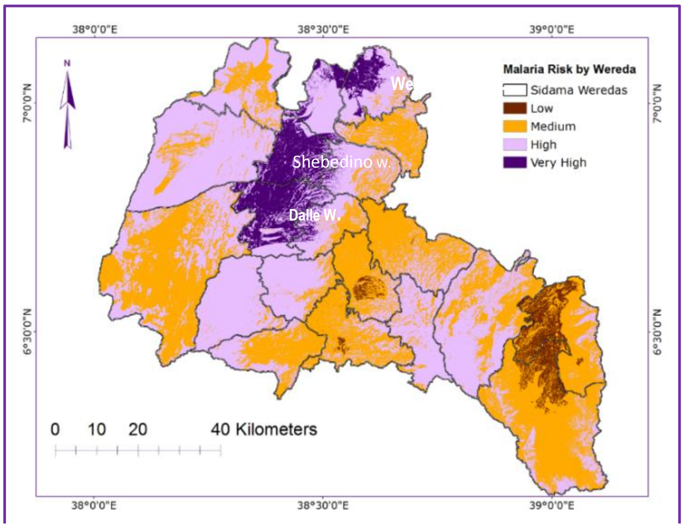


**Figure 6.** Malaria risk zoning map by districts

In the cross-tabulation (TABLE 3) the major biophysical characteristics of malaria risk zoning correlated with malaria risk levels in this study area. The inverse relationships of malaria risk levels elevation is depicted in this study again. As the propensity of the lower risk zones (low and medium) is at a higher altitude greater than 2000m asl, the high risk zones (high and very high) tend to appear at the lower altitude less than 2000m.asl.

As it is seen in the second lane of the variable column in TABLE 3, an inverted U shaped relationship of malaria risk and temperature is confirmed in this study. The higher risk zones are perpetuated in areas experiencing an average temperature of $18^0$c-$32^0$c. The remaining other areas which are experiencing an average temperature of <$18^0$c and >$32^0$c are subject to a lower risk zone.

On the other hand malaria risk has direct linear relationship with population density. Areas with higher population density correspond to higher risk of malaria. As it is seen on TABLE.5, at population density row of almost all areas which have a population densities of 670/$km^2$ and above lied in a very high risk zone.

**Table 3.** Relationship of the Malaria Risk Level with Prominent Risk Zoning Variables

| | Level of Risk / Area sq km | | | | |
|---|---|---|---|---|---|
| Variables | Value | Low | Medium | High | Very High |
| Elevation | <2000 | 0 | 0 | 0.1 | 190.9 |
| | 2000-2200 | 1098.3 | 192.0 | 481.5 | 979.4 |
| | 2200-2500 | 2267.4 | 373.1 | 403.6 | 255.2 |
| | > 2500 | 445.8 | 12.5 | 0 | 0 |
| Temperature | < 18 | 190.9 | 0 | 0 | 0 |
| | 18-28 | 1701.2 | 327.5 | 530.3 | 192.2 |
| | 28-32 | 600.0 | 1984.6 | 573.4 | 141.2 |
| | >32 | 0 | 449.9 | 8.4 | 0 |
| Population Density | < 423 | 172.8 | 18.1 | 0 | 0 |
| | 424 – 546 | 1270.9 | 783.2 | 542.3 | 154.8 |
| | 547 -669 | 481.1 | 944.1 | 1003.7 | 870.4 |
| | > 670 | 0 | 0 | 0.005 | 458.3 |
| Land Use- Land Cover | Urban/Settlement | 1.7 | 226.5 | 343.3 | 52.6 |
| | Agroforestry | 0.1 | 428.9 | 861.0 | 185.1 |
| | Wet Surfaces | 0.001 | 3.4 | 14.7 | 0.2 |
| | Cultivated Land | 14.4 | 284.6 | 845.2 | 165.3 |
| | Forest | 174.7 | 1561.7 | 838.9 | 5.0 |
| | Bare Land | 0.005 | 246.1 | 396.2 | 50.2 |

As far as the land use land cover and malaria risk relationship is concerned, as it is seen in TABLE 5-lane 4, agroforestry, cultivated land and forest lands were the riskiest of all land cover types (based on an aggregate result of very high and high risk zones).

In order to see the synchrony of the incidences with the amounts of malaria risk area of each district, it is necessary to understand the distribution of the incidence. Hence, malaria is still one of the leading causes of morbidity in Sidama zone, though great deals of malaria control and protection attempts were made. According to the last four years record of SNNPR health Bureau (2014) report, out of the 21 districts of the zone malaria is in the top five lists in 14 districts, and it is in the top ten lists in 17 districts. Fig.7 also displayed that malaria at the upper strip is and one of the widely distributed case followed by Pneumonia and Acute febrile illness (AFI). Rift Valley Fever (RVF) conversely is high in more localized pattern. It is high only in the two districts of Bensa and Dera.

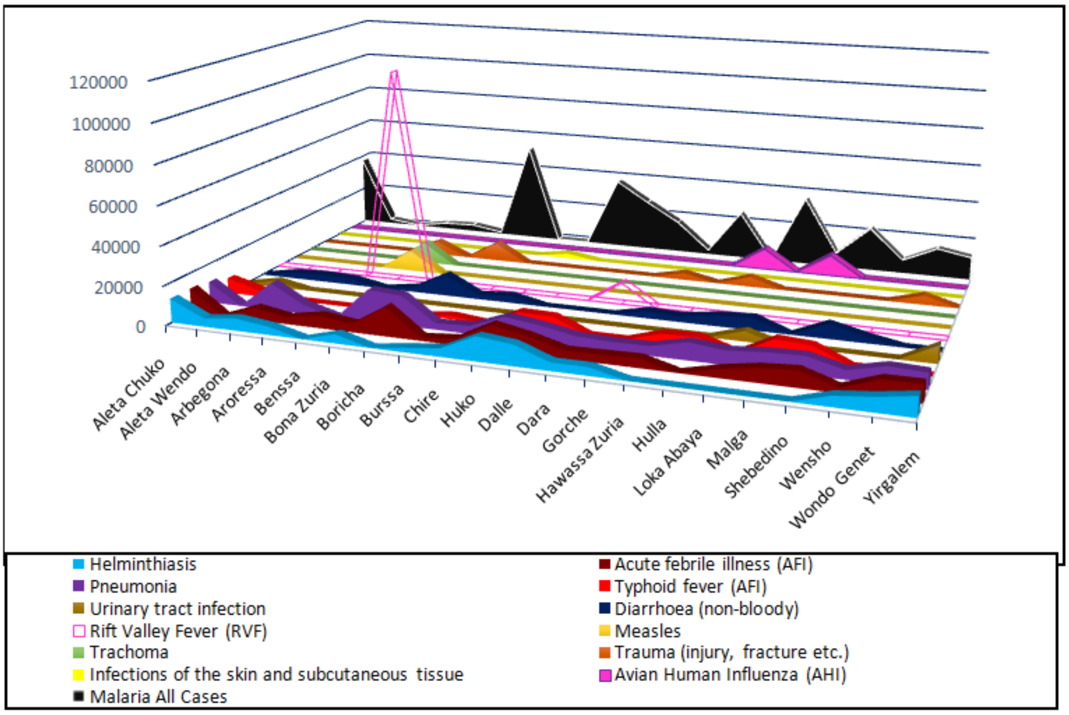


**Figure 7.**The pattern of malaria cases in relation to other epidemics by Sidama zone districts

As to the comparison of percentage of malaria risk zones of each district with the recorded malaria cases, Fig.8 depicted strong synchrony of a percentage of recorded malaria cases of the district and the percentage of malarious area what each district has comprised. That entails districts which have largest percentage share of areas of very high and high malaria risk zones also have higher records of malaria cases registered for the last five years, as they are picky in the line graph of fig.8. Conversely districts like Arbegona, Bonazuria, Burssa, Chire, Gorche, Hula, Malga and Wensho have both lower area of very high and high risk zones and records of malaria cases.

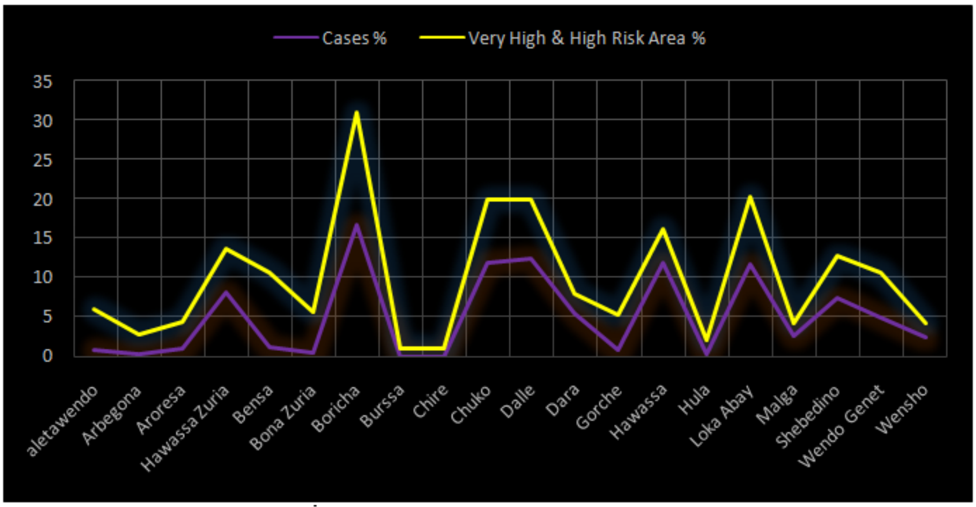


**Figure 8.** Comparisons of district area at risk by recorded malaria cases (2009-2013)

## V. DISCUSSION

The result of this research was based on the GIS multi-criteria overlay analysis. The maps also give a picture of spatial patterns of events distribution throughout the study area. As it is evidenced by this investigation, larger areas about 49.2% of the area was depicted as high risk zone. The additional 6.8% of the study area was also identified as a very high risk zone. This areal coverage comprises about 67.4% of the population in the administrative zone. This may denote about more than 1.9 million people of the administrative zone. Hence, the administrative program unit may require roughly 1.2 million Insecticide Treated Net at list to address 80% of the need, or the program unit may supply 3.5 ITN per household. The result again confirmed the regional administration Health Bureau's last five year disease surveillance data which makes malaria at the summit of the top five prioritized diseases of the region and the zone too. The synchrony of the malaria risk area proportion and the recorded malaria cases of each districts reflects how good area coverage represented well the condition of malaria disease distribution in the study area.

In terms of land use and land cover patterns, agroforestry, cultivated land and forest covers contributed larger proportion of the risk zones. This is somehow related to the population distribution pattern. Those areas which are highly dependent on agroforestry have a highest population density than other areas. The wide spread agro-forest type in the study area is enset (*Ensete ventricosum*). So the highest population density actually typifies the Enset culture region of the south central high lands of Ethiopia. As the researcher himself personally observed, the selected households in agroforestry lands mostly grew enset around their homestead, a situation suitable for the vector breeding. Some studies also confirmed that the effect of some ecosystem condition and land use land cover characters increased the exposure of areas for malaria epidemics. [22] confirmed that irrigated drained lowland areas contributed for malaria incidence. Similarly, other writers like [23] related malaria epidemics to coffee and cacao farm expansion and [24] linked it with Maize production.

## VI. CONCLUSION

Environmental factors determine the conditions of malaria vector breeding and the level of epidemic outbreak. It was, thus, necessary to assess the biophysical environment based malaria risk mapping to address the problem. As a result this study identified high risk areas and districts of the administration zone. Besides, it showed a high relationship between the level of the districts vulnerability level and the actual incidence of the malaria cases records.

A number of plans and programs were developed and huge amount of resource has been expended to control malaria pandemic throughout the country. Government and nongovernmental organizations have not been assisted by this kind of research works. GIS and remote sensing based multi criteria overlay analysis result in more effective allotment of available budget for the proposed intervention measures. The result of this study can help to prioritize areas by their vulnerability level and estimate the necessary resources. Therefore it can be used as an instrument to make a decisions more effective than the usual. The biophysical based GIS and remote sensing analysis was helpful to visualize and analyze the epidemiological data in most tropical developing countries health related decision making in general and the study area in particular.

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