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Malaria Hazard and Risk Mapping Using GIS Based Spatial Multicriteria Evaluation Technique (SMCET) in Tekeze Basin Development Corridor, Amhara Region, Ethiopia

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Abstract
Tekeze Bain Development Corridor (TBDC) is a major river basin that has malaria problems in Ethiopia. Given that malaria is an environmental disease and spatial phenomenon, the application of GIS based Spatial Multicriteria Evaluation Technique (SMCET) are essential to the malaria hazard/risk management process. Malaria hazard and risk map are effective tools to reduce the spread of malaria. The purpose of this study was to assess malaria hazard and risk of TBDC using GIS based SMECT. Malaria causative factors such as distance from water bodies, temperature, drainage, slope and elevation were developed in the GIS environment. The computed Eigen vector was used as a coefficient for the respective factor maps to be combined in weighted overlay in the Arc GIS environment. A model builder in Arc GIS was used to facilitate the overall malaria hazard assessment by combining all impact factors. Malaria risk assessment was done using the malaria hazard layer and the elements at risk/socio-economic factors that determine the level of risk, namely population density, land use, health services and road access. The major finding of the malaria hazard map of TBDC indicated that 397,333.1ha (14%), 1,689,179.68ha (58%), 743,988.96 ha (26%) and 59, 849.41ha (2%) of the area considered in TBDC were subjected respectively to low, moderate, high and very high malaria hazards.
Keywords: Malaria hazard; Malaria Risk; Geographic Information System; Arc Map Model Builder, Spatial Multicriteria Evaluation Technique; Tekeze Basin Development Corridor.

1. Introduction

Malaria is a serious vector-borne disease affecting a greater proportion of the world's population. It is a life-threatening caused by Plasmodium parasite infection (Ayele et al., 2012). Ethiopia, one of the sub-Saharan countries in Africa is the victim of malaria epidemic and it's far reaching negative impacts. Malaria is one of the main health problems in Ethiopia in which its cases are one of the highest and it is increasing in 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 (Ministry of Health, 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 as 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, protective immunity of the population is generally low and all age groups are at risk. Prevalence of malaria is currently estimated to be 1.3% (Ethiopia Malaria Indicator Survey, 2011). However, exposure to malaria varies markedly by location and season. Ethiopians live at altitudes ranging from −100 to >4220 m, the topography made a fertile ground for the reproduction of the epidemic. More than 50 million (68%) of the population live in areas below 2000 m above sea level are at risk of malaria. With consequent variation in minimum and maximum temperatures. In general, the main reasons given for the increment are ecological and climatic changes. The peak of malaria incidence follows the main rainfall season in July, August, September, October and November each year. (Negassi, 2008).

Malaria is essentially an environmental disease since the vectors require specific habitats with surface water for reproduction, humidity for adult mosquito survival and the development rates of both the vector and parasite populations are influenced by temperature (Ashenafi, 2003). Although improved hydraulic infrastructure holds potential for alleviating poverty, promoting economic growth, improving food security and mitigating floods, adverse health effects may undermine these objectives. The malaria burden may indeed rise after impoundment of large bodies of water in Africa (Lautze et al., 2007).Past experience shows that inadequate consideration of both environmental and public health impacts can seriously undermine the envisioned benefits of investments in large dams. Key among the potential negative effects of large dams is intensified malaria transmission, resulting from changes in environmental conditions that increase vector (i.e. *Anopheles* mosquito) abundance (Keiser et al., 2005). In our study area, Tekeze Dam is a hydropower reservoir constructed in 2009 over the Tekeze River, the major river in Ethiopia. It has maximum length of 75 km, maximum width of 6 km, covering an area of about 160.4 km^2 and situated at an elevation of 1107 masl (Tsegay et al., 2016) and other small irrigation dams were also constructed in TBDC.

Thus, mapping malaria cases can help health authorities to understand more about spatial distribution of the disease in their area as well as its temporal occurrence. Hazard/Risk maps have proven to be important tools for public health decision making and priority-setting for vector-borne diseases because they assist with the targeting of prevention and control efforts. The spatial information obtained from mapping malaria hazard and risk will provide a guideline for control programs and preparing health facilities based on the requirement of each area. GIS have been continuously used for the analysis of spatial health related data. It can be a useful tool for analyzing the spread of diseases in both developed and developing countries. This tool is useful for management strategy to allocate resources for preparing the needs for control of disease in high risk areas of disease. GIS also enable us to generate revised maps as soon as new data are available (Srivastava et al., 2009; Hanafi-Bojd et al., 2012).Geographic information systems (GIS), which have already been widely applied to vector-borne disease risk mapping, have been used in conjunction with MCDA, sometimes referred to as GIS-MCDA or spatial MCDA to gain insights on the effects of spatial constraints such as zoning, land use or demography on policy-making problems in public health and other disciplines(Hongoh et al., 2011).

The study was conducted in TBDC, Amhara National Regional state, Ethiopia with the objective developing map of malaria hazard and risk, which identify and integrates environmental factors that make condition suitable for breeding, outbreak malaria incidence and identification of habitat site for mosquito in the study area, develop land use/land cover map and different factors map for malaria hazard and risk analysis finally compute Eigen vector for the developed factors and conduct weighted overlay Analysis in Arc GIS by integrating information derived to develop a malaria risk map showing malaria risk areas using GIS based SMCET.

2. Methods

2.1 Study Area Description

TBDC is located in the northern part of Amhara National Regional state. Geographically, it is located between North latitude 1289271-1507588m and East longitude 341299 up to 545604m.The development corridor's elevation ranges 845- 4539 meter above sea level with its total area of 2,890,352.11hectares.The study area includes partially or totally 27 districts or Woredas (Farta, Libokemkem, Ebinat, Laygayint, Meket, Wadla, Gubalafto, Gidan, Raya kobo, L, Bugna, Gazgibla, Sekota, Dahina, Ziquala, Abergelie, Sahelaseyent, Telemet, Adarkay, Debark, Dabat, Wogera, Gondar Zuria, East Belesa, west Belesa, Beyeda, Janamora and 3 town administrative (Debark, Lalibela and Sekota).

The mean annual rainfall within the basin varied from 272 to 1737mm. The maximum temperature varied in the study area from 4.4 to 37.69^{0}C and the annual minimum temperature from -2.2 to 19.95^{0}C. TBDC has been divided in to eight different agro-climatic zones namely, sub moist hot, sub moist warm, sub moist cool, sub moist tepid, moist warm, moist tepid, moist cool, moist cold, moist very cold, sub-humid cool and sub-humid cold, sub-humid very cold and sub-humid warm. The soils of TBDC have been identified into around nine reference soil groups or major soils (Alisols, Arenosols, Calcisols, Chernozems, Fluvisol, Leptosol, Luvisols, Regosols and Vertisols).

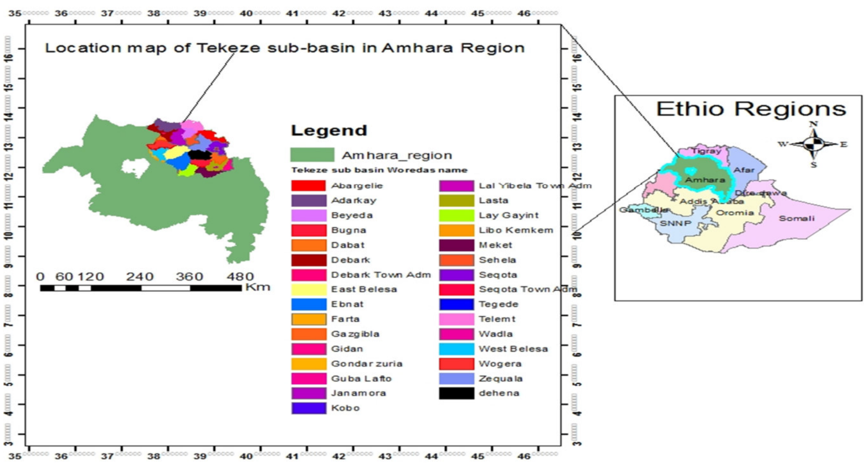

Figure 1. Location map of Tekeze Basin Development Corridor

2.2 Methods

2.2.1 Malaria Hazard Analysis

Malaria transmission is strongly associated with environmental conditions, which control mosquito maturity and parasite development. Accordingly distance from water bodies, temperature, drainage and slope, and elevation are listed in order of importance. To assess malaria risk of the development corridor using GIS and Remote Sensing, Multi-Criteria Evaluation was used. SMCE is a procedure which needs several criteria to be evaluated to meet a specific objective.

2.2.1.1 Factor Development

A. Distance from Water Bodies Factor: Taking heed of the maximum flying distance of anopheles mosquito from the distance to stream is 2 km as a basis for reclassification distance to the stream layer. Distance to water bodies was calculated using Spatial Analyst Tool, Distance, Euclidean Distance. Then river distance raster layer was further reclassified using natural break standard reclassification method in ARC GIS 10.1 software in to four subgroups and the reclassified subgroups of stream distance raster layer were ranked according to mosquitoes flying distance threshold value, which means areas out of the flaying distance threshold were considered as less malaria risk level. And new values re-assigned in order of Malaria hazard rating. Distance from water bodies of TBDC ranged 0-72.7km.

B. Temperature Factor: Temperature can 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 (ministry of health, Ethiopia.1999; Ahmed, 2014). Average temperature values of TBDC ranged between 3.39 -29.25 c ^{0}.

C. Drainage Factor: Drainage status of the development corridor can affect the availability of mosquito in a given area. Drainage factor contribute for malaria hazard, as the wetness of the land increase water holding capacity of the land increases and that would create a breeding site for the mosquito. The drainage type of the study Area was derived from soil data base (soil textural type, major soil type and slope) of the Tekeze development corridor which was produced by soil survey team of Tekeze Integrated Land Use Plan.

D. Elevation Factor: 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 (ministry of health,1999;Ahmed, 2014). The elevation map was produced by the processing the DEM (30m resolution), using Arc GIS software, Spatial Analysis Tool, Surface Analysis. The elevation raster layer, which was reclassified in five sub-group using standard classification schemes namely quantiles. This classification scheme divides the range of attribute values into equal-sized sub ranges, allowing you to specify the number of intervals while Arc Map determining where the breaks should be. Finally, the elevation was reclassified into continuous scale in order of malaria hazard rating. The elevation in the development corridor ranges from 858 to 4529 meter.

E. Slope Factor: Slope is other topographic parameter that may be associated with mosquito larval habitat formation, 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).

The slope map was produced by the processing the DEM (90m resolution), using Arc GIS software, Spatial Analysis Tool, Surface Analysis, Slope. The slope raster layer, which was reclassified in five sub-group using standard classification schemes namely quantiles. This classification scheme divides the range of attribute values into equal-sized sub ranges, allowing you to specify the number of intervals while Arc Map determining where the breaks should be. Finally, the slope was reclassified into continuous scale in order of flood hazard rating. The slope in the sub-basin ranges from 858 to 4529 meter. Slope values of TBDC ranged between 0 up to 497%.

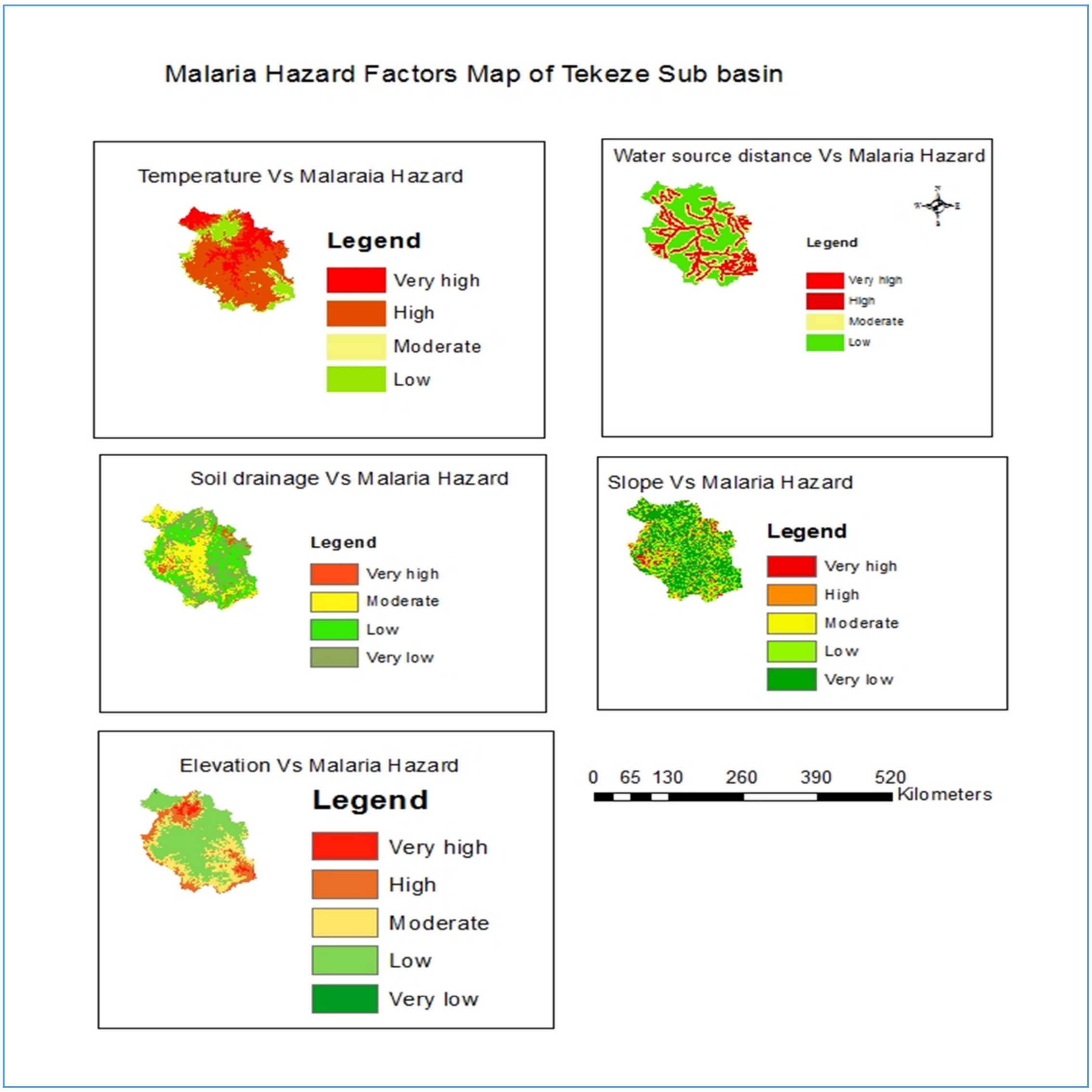

Figure 2: Map of Factors developed for Malaria Hazard Mapping

2.2.1.2 Malaria Hazard Mapping

Hazard is the probability of the occurrence of mosquitoes infective with malaria in a certain area. It was approached by assessing the suitability of environmental condition for malaria transmission based on environmental and physical factors. Malaria hazard analysis was computed by Weighted Sum Overlay of distance from water bodies, temperature, drainage, elevation, and slope developed factors.

The technique used in this study and implemented in IDRISI GIS software is that of pair wise comparisons developed by Saaty's (1977) in the context of a decision-making process known as the Analytical Hierarchy Process (AHP) (Eastman, 2001). It is one of the multi-criteria decision-making techniques. In the procedure for Multi-Criteria Evaluation using a weighted linear combination, it is necessary that the weights sum to one. In Saaty's technique, weights of this nature can be derived by taking the principal Eigen Vector of a square reciprocal matrix of pair wise comparisons between the criteria. Eigen vectors are a special set of vectors associated with a linear system of equations (i.e., a matrix equation) that are sometimes also known as characteristic vectors, proper vectors, or latent vectors (Marcus and Minc, 1988).The standardized raster layers were weighted using Eigen Vector that is important to show the importance of each factor as compared to other in the contribution of flood hazard.

Accordingly; the Eigen Vector of the weight of the factor was computed in IDRISI 32 Software in

Analysis menu of the decision support/weight module based on the given pair-wise comparison. The weighted module was fed with the pair wise comparison 9 point continous scale. Then the principal Eigen Vector of the pair wise comparison matrix using the factors affecting flood hazard was calculated. A consistency ratio values less than 0.1 is acceptable. The consistency ratio of the calculated Eigen Vector was 0.02 that shows that the given pair-wise weights are accepted.

The computed Eigen vector was used as a coefficient for the respective factor maps to be combined in weighted Overlay in the Arc GIS environment using the following equation:

Malaria hazard*=0.40* × [Distance from water bodies] +0.35× [Temperature] +0.10× *[Slope] +0.10*× *[*Drainage]+0.05× */*Elevation]

Table 1.Weighted Malaria Hazard Ranking for Tekeze Basin Development Corridor

No	Factors including units	Weight	Class	Ranks/ Rating	Naming /Degree of Vulnerability
1	Distance from water bodies(meter)	0.4	0–1000 m	5	Very high
			1000–2000 m	4	High
			2000–5000 m	3	Moderate
			>5000 m	2	Low
2	Temperature(c 0)	0.35	24–30◦C	5	Very high
			18–24◦C	4	High
			16–18◦C	3	Moderate
			<16◦C	2	Low
3	Slope (%)	0.1	0-5%	5	Very high
			5–8%	4	High
			8-15%	3	Moderate
			15-30%	2	Low
			>30%	1	Very Low
4	Drainage (drainage class of the soil)	0.1	Poorly drained/slow	5	Very high
			Moderate	3	Moderate
			Rapid	2	Low
			Very rapid	1	Very low
5	Elevation(meter)	0.05	845–1000 m	5	Very high
			1000–2000 m	4	High
			2000–2500 m	3	Moderate
			2500-3500 m	2	Low
			>3500 m	1	Very low

A model builder in Arc GIS was used to facilitate the overall malaria hazard assessment by combining all impact factors.It is a visual programming language for building geo-processing workflows. Geo-processing models automate and document our spatial analysis and data management processes. We create and modify geo-processing models in Model Builder, where a model is represented as a diagram that chains together sequences of processes and geo-processing tools, using the output of one process as the input to another process.

The following procedures were followed to create, add data/tools and running Malaria Hazard Mapping Model in Arc Map Model Builder:

1. First, Malaria Hazard Mapping Model in ARC Map was created: In order to create the model, Arc Toolbox window should be open by clicking on the Arc Toolbox window button. Right-click somewhere on the empty area inside the Arc Toolbox window -> Add Toolbox. The Add Toolbox window appears. In the Add Toolbox window, navigate to the location where you created your new toolbox, select it and click Open. The toolbox will appear alphabetically in the Arc Toolbox window. To create a new model, right-click the toolbox we just added to open its contextual menu->New->Model. The Model Builder window opens. Inside the Model Builder window, click on the Model menu->Model.
2. Secondly, adding data, tools and running a model: First we have to make sure that the Model Builder window for our model is open in edit mode (right-click the model ->Edit) and that we can see both the Model Builder window and the Arc Toolbox window. To add data and tools to our model, In Arc Toolbox, locate the tool which you would like to use (e.g. Spatial Analyst Tools ->Overlay->Weighted Overlay), drag and drop it in the Model Builder window. The white rectangle is connected to a white ellipse through a connector. The ellipse indicates the output. The white colour means that the parameters have not been set yet. Double-click the tool (the white rectangle). A tool-specific dialog window will open, where we set the parameters for the operation. Once we have specified the input file(s) that we will use in our model, it will appear as a blue ellipse, connected to the rectangle tool. The output will be indicated through a green ellipse. Once all parameters are set, the white rectangle will turn yellow. Double-click the white rectangle of the tool to active its tool-specific dialog window. Before we run the model, right-click on the green ellipse indicating the output, and select Add to Display. The output file containing our results from the model will now be added to the Table of Contents in Arc Map.
3. Thirdly, run the model, click on the Model menu, where we will see two options: Run and Run Entire Model. Run will only run the parts of the model that have not been ran previously, while Run Entire

Model will execute all operations from start to end.

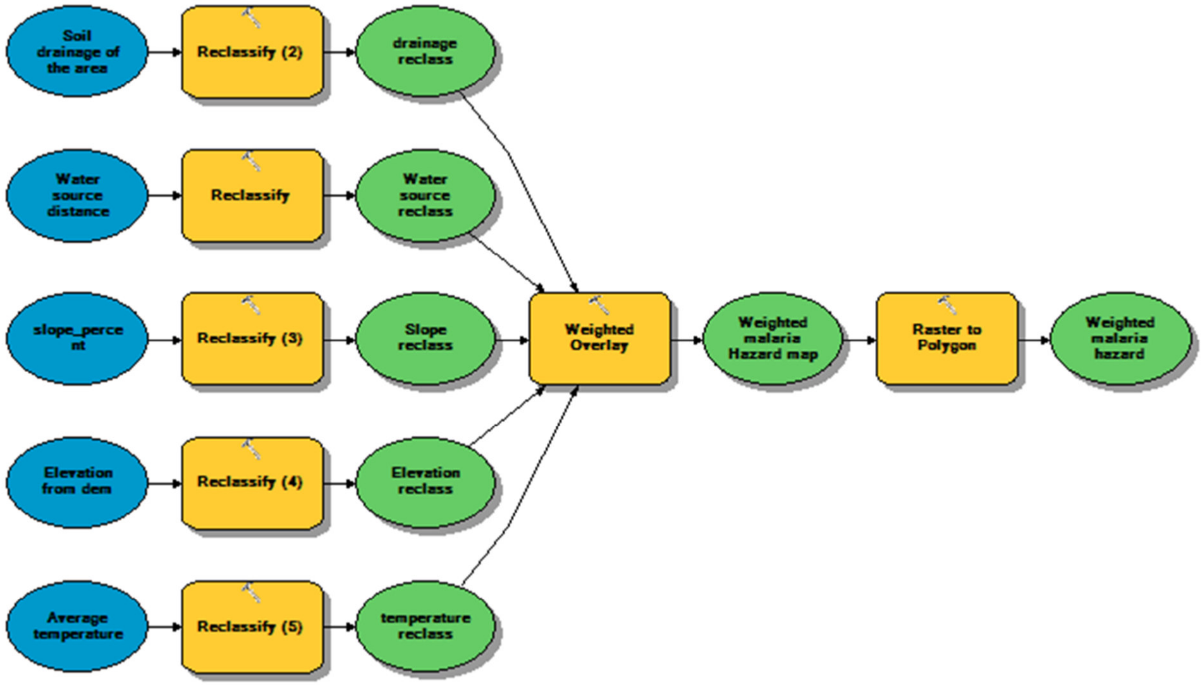

Figure 3: Malaria Hazard Analysis workflow using Model Builder in Arc GIS environment

2.2.2 Malaria Risk Analysis

Elements at risk indicators specify the amount of social, economic or ecological units which are at risk of being affected regarding all kinds of hazards in a specific area e.g. persons, economic production, buildings, public infrastructure, cultural assets, ecological species and landscapes located in a hazardous area on connected to it. Thus, Malaria risk mapping for Tekeze development corridor was done using the malaria hazard layer which is based solely on natural conditions and the elements at risk, namely population density, land use, health services and road access as indicated in the table below and factor development description.

2.2.2.1 Factor Development and Description

A. Population Density: Gross population density calculation method is used to calculate the number of person per square kilometers. Then population shape file was converted to raster layer using Conversion Tools/Feature to Raster. Then further the data layer was reclassified into five sub-factors which are classified using equal interval method. And new values re-assigned in order of increasing number of population that is more susceptible to malaria hazard. The population density was reclassified in the assumption that the denser the population, the more vulnerable it will be to malaria hazard.

B. Land use land cover factor: The land use land cover was taken as element at risk that affect by malaria incidence. Land use is the way in which and the purpose for which human beings employ the land and its resources. Land cover by contrast the physical state of the land surface as in as in cropland, mountains or forests (Ahmed,2014).The land use /land cover classes of TBDC had been classified using Land sat ETM+ satellite image with a spatial resolution 30m. The land use/cover types of the basin were reclassified into a common scale in order of sensitivity for the malaria risk analysis.

C. Heath Centers: Distance from the house to the nearest health center or facility was another risk factor for malaria incidence. The study area has 7 hospitals, 119 health centers and 449 health posts. The number of health institutions in the study area varies from woreda to woreda. Spatially the location of these health facilities in the study area were indicated on a map and distance from the nearest health institution (Euclidian distance) was generated in arc GIS environment.

D. Road Access: The distance of a place from roads affects or determines the effectiveness of measures to be taken to control the risk of malaria infestation. When the distance from the road is short, the probability of malaria risk on a community is lower. Therefore, Euclidian distance was generated in arc GIS environment from the existing road in the study area, and classified as having the lowest risk of malaria infections when the distance from road access is less than 6 kilometer.

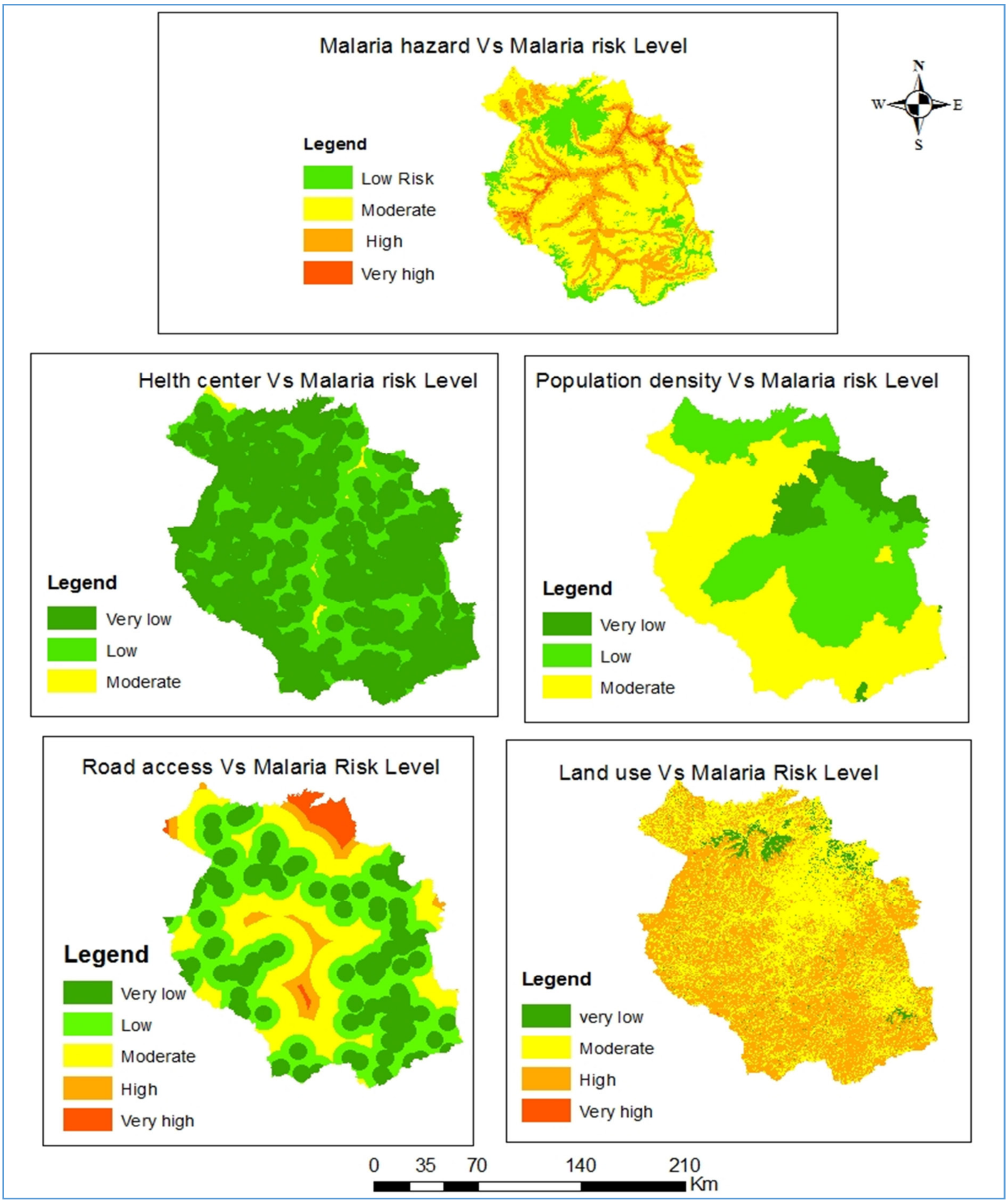

Figure 4. Map of Factors developed for Malaria Hazard Mapping

2.2.2.2 Malaria Risk Mapping

Malaria risk assessment and mapping was done for TBDC by taking population density, land use/cover, health center and road access elements that are at risk as well as socio-economic factors that determine the risk level combined with the degree of malaria hazards of TBDC.

Malaria Risk *=0.40* × [Malaria Hazard Level] +0.20× [Population Density] +0.15× *[Land use/cover] +0.15*× /[Health Center] +0.10× /[Road Access]

Table 2. Weighted Malaria Risk Ranking for Tekeze Basin Development Corridor

No	Factors including units	Weight	Class	Ranks/ Rating	Naming /Degree of Vulnerability
1	Malaria Hazard	0.40	Very high hazard areas	5	Very high
			High hazard areas	4	High
			Moderate hazard areas	3	Moderate
			Low hazard areas	2	Low
			Very low hazard areas	1	Very low
2	Population density	0.20	>901	5	Very high
			301-901	4	High
			101-301	3	Moderate
			31-101	2	Low
			<30	1	Very low
3	Land use/cover	0.15	Built up	5	Very high
			Cultivated land	4	High
			Water body, grass land, forest, shrub	3	Moderate
			Afro-alpine	1	Very Low
4	Distance from Health Facilities (kilometer)	0.15	>30 km	5	Very high
			24–30km	4	High
			12–24km	3	Moderate
			6-12km	2	Low
			0–6 km	1	Very low
5	Distance from Roads (kilometer)	0.10	>30 km	5	Very high
			24–30km	4	High
			12–24km	3	Moderate
			6-12km	2	Low
			0–6 km	1	Very low

A model builder in Arc GIS was used to facilitate the overall malaria hazard assessment by combining all impact factors. Procedures that were used for Malaria Hazard Mapping Model in Arc Map Model Builder were also applied for Malaria Risk Mapping Model Builder.

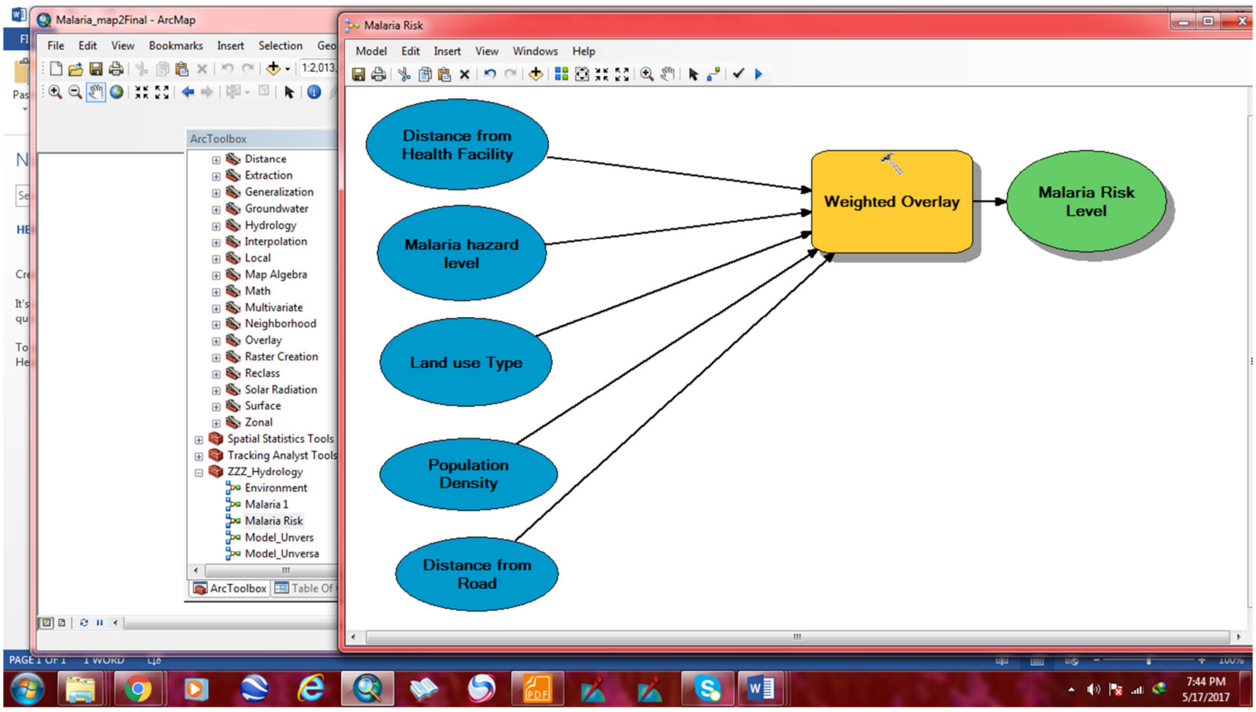

Figure 5. Malaria Risk Analysis workflow using Model Builder in Arc GIS environment

3. Results and Discussion

3.1 Identified Areas of Malaria Hazard

According to the malaria hazard map it was estimated that 59, 849.41ha (2%), 743,988.96 ha (26%), 1,689,179.68ha (58%) and 397,333.1ha (14%) of TBDC were subjected to very high, high, moderate and low malaria hazard area respectively. As it can be seen from malaria hazard map, areas in the very high malaria hazard zones are mainly parts of the development corridor within or close to the major rivers that are found within the sub-moist hot and sub-moist warm agro-climatic zones of TBDC. The final Malaria Hazard map of TBDC also revealed that distance from water bodies and temperature are the most important factor for malaria hazard in TBDC. While drainage, elevation, and slope were relatively the least important factors.

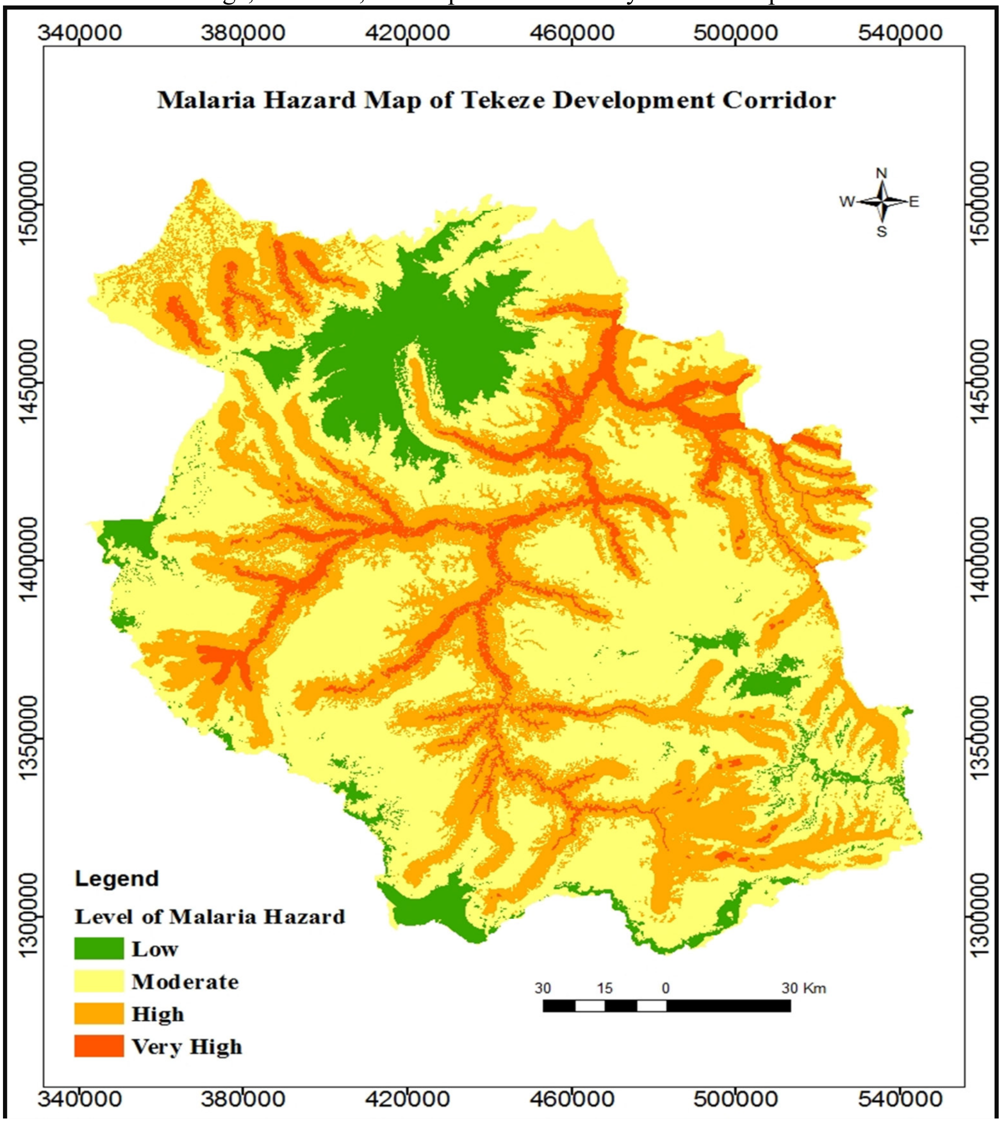

Figure 6. Map of Malaria Hazard Map of Tekeze Development Corridor

Table 3. Area Coverage in ha and Percentage Share of Malaria Hazard of Tekeze Development Corridor

No	Level of Malaria Hazard	Area in ha	%
	Low	397,333.1	14
	Moderate	1,689,179.68	58
	High	743,988.96	26
	Very High	59, 849.41	2

3.2 Identified Areas of Malaria Risk

In assessing the area in urgent need of attention to fight against Malaria, hazard mapping which is based solely on natural conditions is not sufficient but socio-economic factors, such as population density, distribution of health facilities, road access and land use land cover should also be included. Because, it is only then that one can site the area where there's high risk of malaria. According to the malaria risk map, it was estimated that 26383.42ha (0.91%), 1994678ha (69.01%), and 864971.9ha (29.93%) of the Development Corridor were respectively subjected to high, moderate and low malaria risk areas.

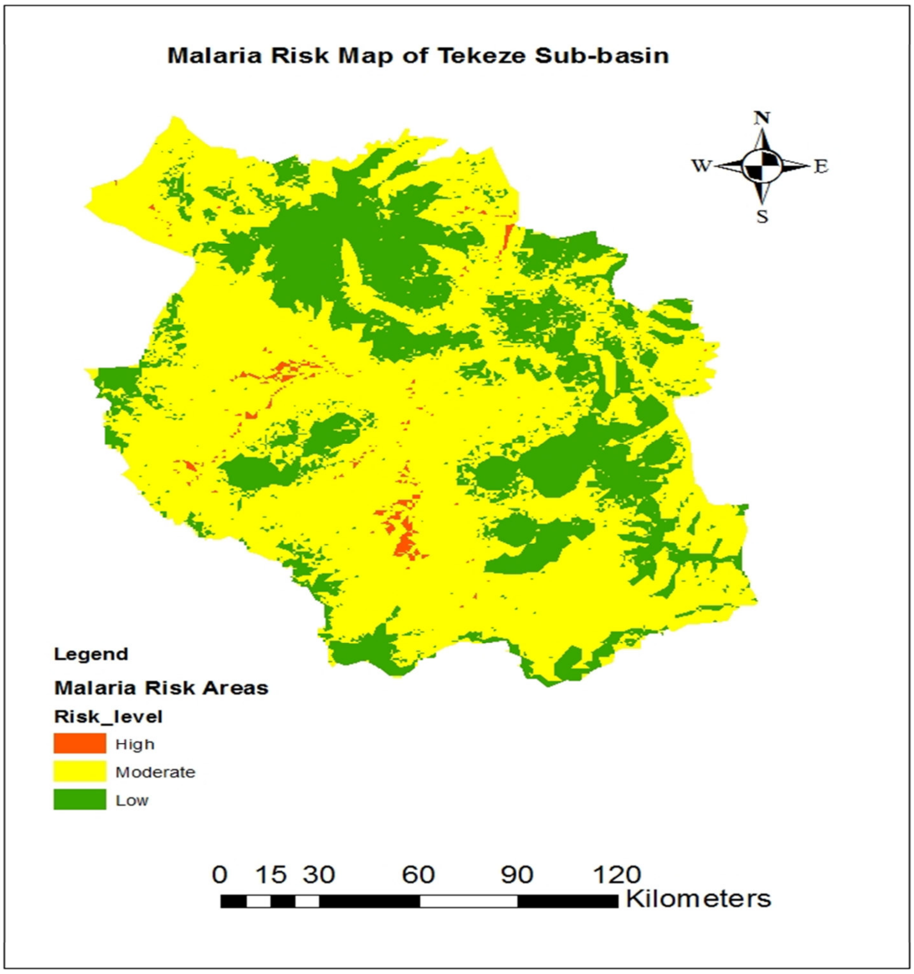

Figure 7. Map of Malaria Risk Map of Tekeze Development Corridor

Table 4.Area Coverage in ha and Percentage Share of Malaria Risk of Tekeze Development Corridor

Malaria Risk level	Area in Hectare	Percent
High	26383.42	0.91
Moderate	1994678	69.01
Low	864971.9	29.93

4. Concluding Remarks

In this study, different factors were considered for malaria hazard and risk mapping. Distance from water bodies, temperature, drainage, elevation, and slope were considered as factors. Then a MCA model in Arc Map Model Builder was built to analyze all factor maps by giving them different weights, and to get the final malaria hazard map. Generally, the most important factor for malaria hazard in TBDC are distance from water bodies, and temperature while drainage, elevation, and slope were relatively the least important factors.

From this GIS based SMCET application for malaria hazard and risk mapping in TBDC, Amhara Region, Ethiopia, it is possible to conclude that GIS tools facilitate a systematic and comprehensive malaria hazard and risk mapping in a more effective and scientific way by combining and spatially assessing multiple factors. This study also indicates that GIS based SMCET developed in Arc Map Model Builder can serve as a support tool to facilitate the overall malaria hazard assessment by combining all impact factors, automate and document our spatial analysis and data management processes, output of one process as the input to another process, and Run and Run Entire Model.

The malaria hazard analysis of TBDC revealed that mainly parts of the development corridor within or close to the major rivers that are found within the sub-moist hot and sub-moist warm agro-climatic zones of TBDC were within very high malaria hazard zones. Even though large areas of the development corridor are subjected to high and very high malaria hazard area, relatively less areas of the development corridor are subjected to high malaria risk (0.91%) and no areas at very high malaria risk. Therefore, it is possible to conclude that elements at risk particularly persons to malaria risk located in malaria hazardous areas or connected to it is relatively low as compare to the malaria hazard.

Currently Tekeze Hydropower Dam is found in the TBDC. Besides it is one of the corridor among other in Amhara Region selected for water resource harvesting development activities and integrated rural land use plan to ensure food security of the local communities of the Basin. Therefore, malaria health impacts will be expected from water resource harvesting development activities and implementation of rural land use plan particularly crop cultivation under irrigation. Although water resource harvesting development activities and integrated rural land use plan hold potential for alleviating poverty, promoting economic growth, improving food security and mitigating floods, adverse malaria health impacts may undermine these objectives. Therefore, malaria hazard and risk maps should be integrated with water resource harvesting development activities and rural land use plan of TBDC. The following mitigation measures should be considered while implementing water resource harvesting development activities and crop cultivation using irrigation at high or very high malaria hazard areas:(a)avoid excess application of water,(b) implement environmental management measures such as filling and leveling of borrow pits, cleared vegetation from the pools or drained to prevent mosquito breeding and resting sites and (c) implement sprinkler irrigation system instead of flood irrigation system which speeds up the spread of malaria.

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