IOSR Journal of Environmental Science, Toxicology and Food Technology (IOSR-JESTFT)
e-ISSN: 2319-2402,p- ISSN: 2319-2399.Volume 10, Issue 4 Ver. I (Apr. 2016), PP 104-112
www.iosrjournals.org

Malaria Risk and Vulnerability Assessment GIS Approach. Case Study of Busia County, Kenya.

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***Abstract**:Malaria is one of the vector borne diseases that is usually common in regions where environmental and climatic conditions allow the survival of the anopheles mosquitoes. Some of the climatic and environmental factors that influence malaria transmission include amongst others temperature, rainfall, relative humidity and landuse/cover type. The social economic factors such as population density and poverty levels together with development factors and control measures like use of insecticide treated mosquito nets and distribution of health facilities also greatly contribute to levels of malaria risk.The purpose of this research was therefore to employ geospatial technologies in identifying possible mosquito breeding sites and thereafter model them together with vulnerability factors using weighted multi-criteria decision analysis to determine the risk levels within the county and to compute the population at risk of malaria. The results from the research showed over 60% of the entire county being areas at risk of malaria with risk levels varying from sub-county to sub-county. The comparative analysis of the results was carried out by comparing the ratios of estimated population at risk of malaria to the actual reported malaria cases per sub-county and this gave a close correlation.*

***Keywords:**Hazard, Malaria risk, vulnerability, weighted multi-criteria decision analysis.*

I. Introduction

Malaria is a highly killer disease that affects majority of the world's populations especially those people living in African continent and part of Asia. Based on 2008 and 2010 WHO reports, significant progress has been achieved in control of malaria prevalence, but still disease mortality rate is estimated at over one million people per year with nearly 247 million new infections cases of malaria being reported every year [1]. However of great concern is that most of the mortality and morbidity cases of malaria occur among children below five years of age and pregnant women in sub-Saharan Africa. Kenya being no exception.

Countries around the world together with the support of the donor community continues to mobilize huge amount of resources in an effort to eliminate malaria around the globe, but despite all these efforts, the disease still continues to be a major health challenge in a number of societies especially in developing countries. The limited success in control of malaria in Kenya and other developing countries around the world could be attributed to lack of adequate resources, poorly coordinated preventative measures and lack of integrated research agenda.

Political instability mainly in Africa that results in large-scale displacement of people has even complicated the situation and therefore one of the major challenges to reduction or eradication of malaria [2, 3]. The other major factors that have led to lack of good progress in eliminating and control of malaria is lack of cooperation between biomedical and, social and behavioural research approaches [4, 5].

Therefore by employing geospatial technologies in collaboration with biomedical approaches and social economic researches can greatly improve the understanding of malaria models, distribution patterns and population likely to be at risk of malaria and thereby enable the health service providers especially in developing countries to try and offer quality and effective health services to the rural population. Thus as the global community continues to scale up the fight on HIV/AIDS and TB interventions, it is vital to also to map out other common vector borne diseases such as malaria and other emerging diseases that are also rampant. With the health sector now being devolved to county governments in Kenya, provision of quality health services will require a good understanding by county management team of disease distribution pattern and risk levels especially malaria for counties in Nyanza and western regions of Kenya.

Thus Malaria asa vector borne disease whose transmission and risk levels depend on environmental and anthropogenic factors, any changes in temperature, rainfall, relative humidity, vegetation cover types amongst others factors results in major impact on malaria transmission [6]. Temperature for instance affects mosquito development rate and final survival of the adult mosquitoes. Vegetation types, population density, poverty levels together with other development and social economic factors also greatly influence malaria risk levels in a given locality. Non-forested areas for example have higher temperatures and relative humidity that leads to higher malaria infection rates than the forested areas [7].

Hence to efficiently manage and control malaria menace, its important use models that incorporates not only environmental and anthropogenic factors but consider also social economic factors and existingcontrol measures. The research therefore employs weighted multi-criteria analysis procedures using various ArcGIS Tools to determine possible mosquito breeding sites (hazards) within the study area and combine this with vulnerability factors to identify malaria risk areas.

1.1. Study Area

The research project covers Busiacountythat comprises of Teso North, Teso South, Nambale, Butula,Bunyala (Bundalangi),Samia (Funyula) and Matayossub-county administrative units. Busia County together with Kakamega, Bungoma and Vihiga counties constitute the western region of Kenya. The Republic of Uganda lies to the North, Siaya, Kakamega and Bungoma counties to the South, East and North East respectively see Figure 1below. The County covers an area of approximately 1,683 sq.km and islocated between latitudes 00° 01' and 00° 47' North of Equator and longitudes 33° 57' and 34° 26' East of Greenwich Meridian.The area has moderate climatic conditions with average temperatures ranging between 20 to 28 degrees Celsius. The Main economic activities in the county isAgriculture practiced at both small and large scale, Fishing in areas bordering Lake Victoria in Bunyala and Samiasub-counties, Dairy farming and livestock keeping at a small scale and Hotel industry that is slowly coming up.

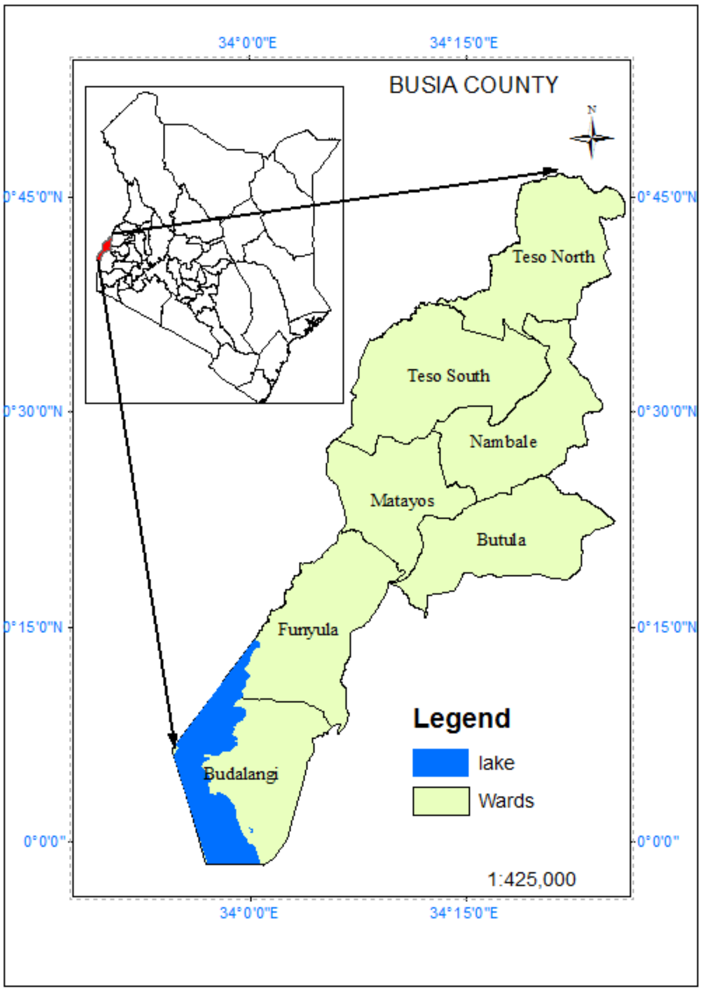

Figure 1: Area of study: Busia County

1.2. GIS And Malaria Risk Mapping

Studies and developments on malaria risk mapping has been ongoing in different parts of the world, for instance [8] mapped malaria high risk areas based on environmental and human population data using participatory multi-criteria decision analysis in which expert opinions was solicited to determine weights of the key environmental and population data. The factors considered were elevation, wetland, distance from roads and river, urban areas and population density.[9] also carried out malaria risk analysis based on land and water use patterns, socio-economic factors and data on malaria interventions using multi-variant analysis with main factors in this study being rainfall, forest cover, Agricultural activities, abandoned irrigation reservoirs and poor social-economic status.Similarly[10] in his research developed a malaria risk map of Bashagarddistrict of Iran using evidencebased weighting method of transmission risks by considering temperature, relative humidity, altitude, slope and distance from rivers that were combined by other factors such as land use/cover, population density, reported cases,development level through weighted multi-criteria procedures.

1.3. Malaria And Poverty

The relationship between poverty and malaria especially in developing countries continues to be a major debate among researchers, with the main issue being whether poverty is the cause of malaria or malaria is the cause of poverty [5, 11–14]. Inequalities in development levels both locally and globally influence the status of people's health and also the persistence of malaria in certain regions of the world and in particular certain communities within countries that are highly malaria prone is an indication of this complex relationship [5, 12, 14].

These inequalities may include weak local public heath infrastructure, high health costs, extreme poverty, poor sanitary condition, and lack of public education amongst others. Malaria also affects economic development resulting in poverty in many different pathways[13]. The overall cost of malaria treatment and prevention in developing countries such as Kenya is fairly high and thus negatively affects the level of investment in infrastructure development resulting in poor economic development and a debilitated workforce due to high medical costs and days lost to illness.

Studies on the link between malaria and poverty in several African countries show mixed results [15]. For instance, [16] in their research in Tanzania, shows that among 50 randomly selected households there is a positive association between income poverty and malaria experience. A study by [17] work on bed net use in Mwea division found that social and economic factors affect use in that low-income individuals are less likely to use bed netting. However, a study by [18]showed a negative relationship between income and malaria experience.

Despite the noted inconsistency it can generally be agreed that there is a close relationship between malaria and poverty.

II. Methodology

The challenges facing the county government of Busia in the health sector are not only related to spatial distribution of the existing health facilities and lack of balance between demand and supply in the provision of health service but also challenges in effective management and utilization of the resources. The study tries to solve some of these challenges through mapping of possible mosquito breeding sites (hazards), Malaria risk areas and distribution pattern in the county, computation of population at risk of malaria, analysis of the social economic and development factors that can make people vulnerable to malaria infections and consideration of the control measure put in place especially use of insecticide treated mosquito nets (ITN). Inventory mapping of existing health facilities within the county together with the road networks is also done to support the study

Hazard areas were mapped via analysis of climatic and environmental factors namely temperature, temperature suitability index, precipitation, altitude, slope and distances to water bodies through weighted multi-criteria decision analysis using ArcGIS model builder tool. To identify the malaria risk areas, the generated hazard map was analyzed together with vulnerability factors namely poverty levels, population density, land use /cover, development and control measures (ITN) again through weighted multi-criteria decision analysis using ArcGIS model builder tool. The computation of the population at risk was achieved using the risk maps and respective population density in such areas.

2.1. Materials

The data used in this research included temperature and rainfall exracted from Global (land) precipitation and temperatures and FEW-NET respectively using 68 fishnet points for the period 2002 to 2013 and this was compared with data from Kenya meteorological department of three ground station two within the study area and one in the neighbouring kakamega county and gave a close correlation.Temperature suitability index (TSI) covering the entire African continent was obtained from Malaria Atlas project and area of interest extracted using extract by mask spatial analyst tool. TSI considers many factors including relative humidity that are key for survival of mosquitoes.

The scanned topographical maps, administrative plans and hospital locations and road networks were also used as obtained from relevant government agencies. The satellite dataLandsatETM+ of June 2011 was obtained from Regional centre for mapping of Resources for Development (RCMRD) and this was processed using Erdas Imagine software and classified using hybrid method of classification into five classes water bodies, built up area, Farm lands, Vegetation and bare land. The demographic data of the county and poverty levels were collected from KNBS for the year 2009 and were used together with similar data from AfriPOPproject for 2014.

Intervention Measures considered in the study was data on use of insecticide treated mosquito nets (ITN) across the county was obtained from Malaria Atlas project, University of Oxford, department of Zoology for year 2014. The index ranged between 0.52 to 0.72 implying usage of ITN across all parts of county being well above 50% andin agreement with the MOH report of 2014 that puts usage of treated mosquito nets in the study area at about 56%.The data on monthly malaria reported positive cases in various hospitals within the county ranging from January 2011 toJuly 2015 was obtained from the county records database and covered the total annual malaria treated cases including repeated cases for children below five years of age and also those people above five years at sub county level.

The work involved use of nine topographical map at a scale of 1:50,000 covers the county of Busia The nine topographical maps were then scanned and geo-referenced in Arc 1960 datum and later converted to WGS 1984 reference spheroid to allow harmonization with other spatial data From these scanned maps, information as such rivers, streams, contours, road networks and swamps were extracted through on-screen digitizing and stored as feature classes in a geo-database. Digitized classes features were then cleaned to remove errorsand used as base-map elements in the County health facility map. Using the contours digitized from scanned topographical maps, the digital elevation model and slope rasters were generated and used in the analysis to determine hazard areasThe software used in the processing and analysis of most of the data in this research to generate hazard and malaria risk areas was ArcGIS 10.2. Hazard map was created using temperature/temperaturesuitability index, precipitation, slope, altitude and proximity to water bodies and swamps. The malaria risk map was on the other hand generated by considering the hazard map together with population density, poverty levels, Landuse/cover,development factors and control measures (ITN). All the factors were classified, ranked and weighted as can be seen in Table 1 and Table 2

Table 1: Classification, ranking and weighting of hazard factors

Factor	Weight	Reclass	rank	Degree of influence
Temperature	0.3	29-31	5	Very high
		25-29	4	high
		21-25	3	moderate
		19-21	2	low
		<19	1	Very low
Distance to rivers	0.2	0-1.5km	5	Very high
		1.5-3.0	4	high
		3.0-4.0	3	moderate
		4.0-5.0	2	low
		>5.0	1	Very low
Altitude	0.15	0- 600m	5	Very high
		600-900m	4	high
		900-1100m	3	moderate
		1100-1500	2	low
		>1500m	1	Very low
Slope	0.15	0-4%	5	Very high
		4-8%	4	high
		8-12%	3	moderate
		12-15%	2	low
		>15	1	Very low
Rainfall	0.2	>2100mm	5	Very high
		2100-1900mm	4	high
		1900-1600mm	3	moderate
		1600-1300	2	low
		<1300mm	1	Very low

Table 2: Classification, ranking and weighting of risk factors

Factor	Weight	Reclass	Rank	Degree of influence
Potential breeding sites	0.4	>4.5	5	Very high
		4.5-3.5	4	high
		3.5-3.0	3	moderate
		3.0-2.5	2	low
		<2.5	1	Very low
Population Density	0.2	564-480	5	very high
		480-400	4	high
		400-380	3	moderate
		380-350	2	low
		<350	1	Very low
Land use/cover classes	0.1	Built up areas	5	Very high
		Farm lands	4	high
		Rivers and swamps	3	moderate
		Bare lands	2	low
		vegetation	1	Very low
Poverty levels	0.1	0-1	5	Very high
		1-5	4	high
		5-7	3	moderate
		7-10	2	low
		>10	1	Very low
Distance to hospitals	0.05	>5000	5	Very high
		4000-5000	4	high
		3000-4000	3	moderate
		1500-3000	2	low
		0-1500	1	Very low
Distance to roads	0.05	>5000	5	Very high
		4000-5000	4	high
		3000-4000	3	moderate
		1500-3000	2	low
		0-1500	1	Very low
Control Measures Use ITN	0.1	0.52 - 56	5	Very high
		0.56 – 0.61	4	high
		0.61- 0.65	3	Moderate
		0.65 -0.70	2	low
		0.70 -0.74	1	Very low

The weighting of the various factors used in this study was generally relied on work of previous researchers on malaria risk and vulnerability studies. To ascertain the reliability of the weights assigned to various factor, a rigorous process of sensitivity analysis was carried out on each factor to test impact of varying weight of each factor on the resultant out for both hazard map and malaria risk map. From the derived malaria risk map and population density raster, the population at risk of malaria infection in the county was computed and this was compared with the actual malaria reported cases at sub county level.

III. Results And Analysis

3.1 Hazard Map

The final hazard map/potential mosquito breeding sites shows that much of the county falls within the very high and high potential breeding areas Three sub-counties Matayos,Nambale and Samia appears to be almost entirely in high potential mosquito breeding areas. Much of North TesoSubCountyhowever falls in low potential mosquito breeding areas. See hazard map Figure 2 below. The percentage area of the county classified as hazard based on this analysis is well above 70% of the entire county. .Implying that mosquitoes can survive in almost every part of the county. See also Figure 3 below.

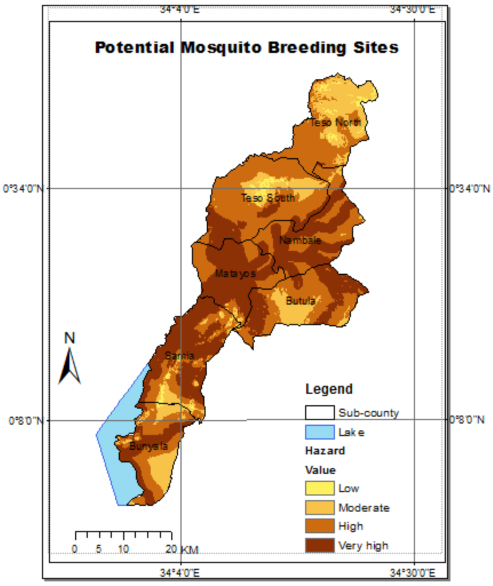

Figure 2: Hazard Map

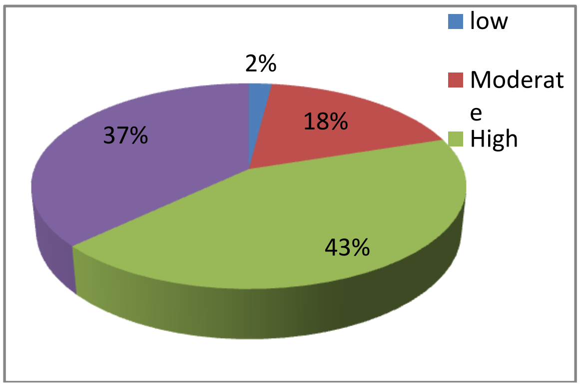

Figure 3: Percentage hazard area in the county

3.2 Cartographic Visualization Of Malaria Risk Area

The malaria risk map Figure 4 below was generated using ArcGIS model builder tool after weighting, reclassifying and ranking of the potential mosquito breeding sites, population density, landuse/cover raster, development factors (access to hospitals and motor able roads) and intervention measures(use of treated mosquito nets) and was reclassified into four categories based on the degree of risk for each class as very high, high, moderate and low risk areas. The very high and high risk areas are considered in this research as the actual Mosquito risk areas and this constitutes approximately 63% of the entire county. Moderate and low risk areas were taken as non-malaria risk areas.

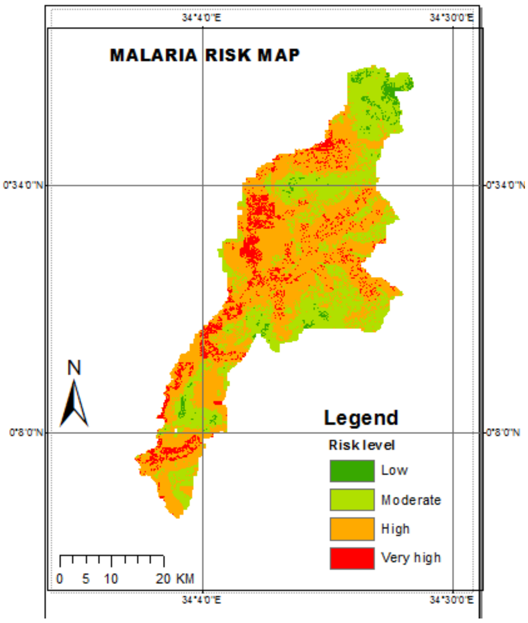

Figure 4: Final Malaria Risk Map

3.4. Estimation Of Population At Risk Of Malaria

To estimate population at risk of Malaria in the county, the study multiplied the derived Malaria risk map raster and the county population density raster for the year 2009, KNBS using zonal statistics in ArcGIS, Arcmap environment to determine population vulnerable to malaria infections in the county.To get a clear distribution of the malaria risk, the computation was also done at sub-county level . The results shows that over five hundred thousand (500,000) people in the county are actually at risk of malaria infections, translating to 63% of the entire county population as illustrated in Table 3 and Figure 5. From the results,Teso south and

Matayos sub-counties have the highest number of population categorized as being at very high and high risk of malaria infections at approximately 102,523 and 95,075 persons respectively while Butula and Teso North are on the other hand, the sub-counties with least number of population at risk of malaria with estimates of 44,284 and 63,042 persons for Teso North and Butula respectively categorized as either being at very high or high risk of malaria.

3.5. Comparison Of Estimated Population At Risk With Actual Malaria Reported Cases

This was achieved by comparing the malaria reported incidence ratios at each sub county to the estimated vulnerable population.The vulnerable rations were computed by determining the average reported cases for period 2011 to 2014 and dividing by the total population projected for 2014 from Afripop project. Table 4 gives the comparison of the estimated population vulnerable to malaria and the actual reported malaria cases as obtained from county data base. The results indicate a good correlation between the research findings per sub-county and reported hospital data for majority of the sub-counties see also Figures 6.

Table 3: Estimate of malaria risk population at sub-county

Subcounty	Very high	High	Moderate	Low
Bunyala	16,412	45,788	14,870	341
Samia	15,780	62,870	25,957	1,655
Matayos	17,422	77,653	18,075	505
Nambale	6,633	65,654	28,055	0
Butula	4,295	58,747	74,003	2,134
Teso South	20,159	82,364	43,974	718
Teso North	16,717	28,125	56,458	10,976
TOTALS	**97,418**	**423,201**	**261,392**	**16,329**

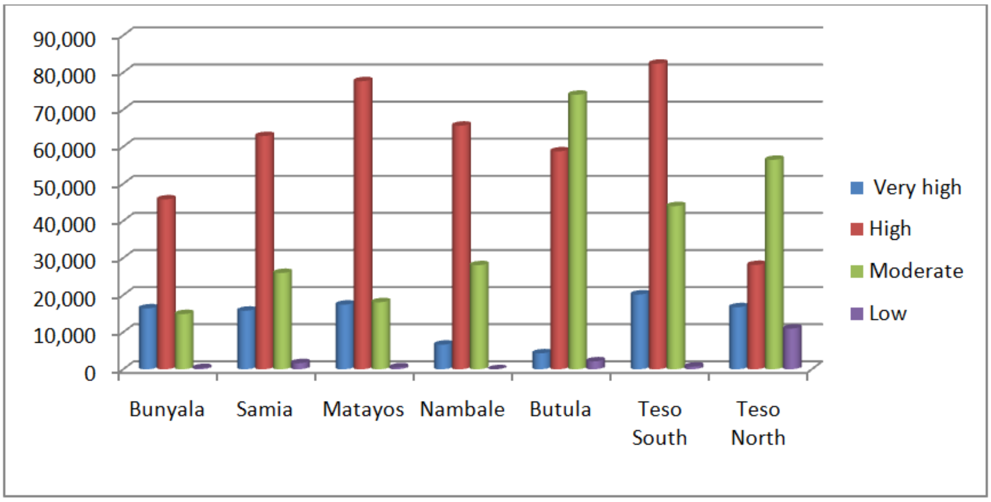

Figure 5: Graph of Risk at sub county

Table 4: Comparison of actual Hospital Reports to estimated population at risk

Sub-County	Total population	Average reported cases	Estimated vulnerable pop	Ratio Reported to pop	Ratio of Estimated vulnerable to pop
Teso North	117,947	77,469	44,842	7	4
Teso South	137,922	60,230	102,523	4	7
Matayos	111,345	86,327	95,075	8	9
Nambale	94,634	36,449	72,287	4	8
Butula	121,870	67,116	63,042	6	5
Samia	93,500	53,141	78,650	6	8
Bunyala	66,723	46,773	62,200	7	9

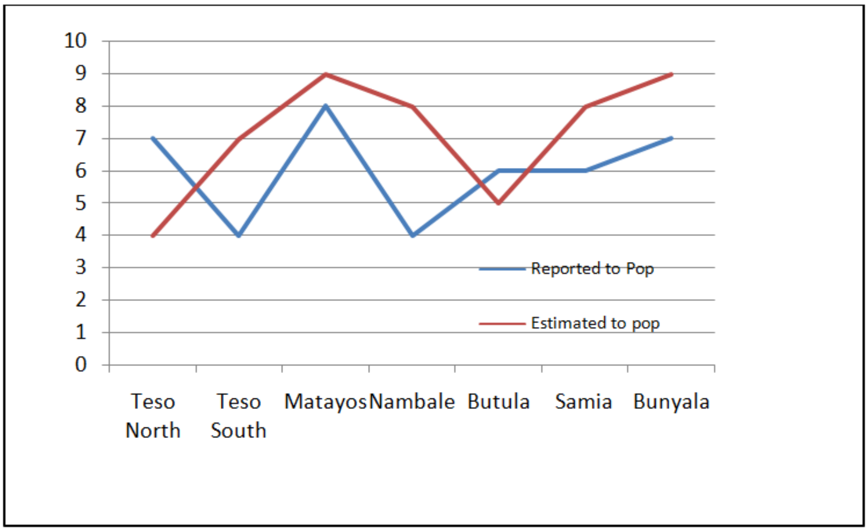

Figure 6: Comparative Analysis

IV. Conclusions

By using weighted multicriteria analysis guided by outputs from sensitivity analysis of individual factor influence and taking intoconsiderationweighting of factors by previous researchers, a GIS raster based model was generated producing malaria risk map of Busia county. The Malaria risk map was validated usinggeoreferenced data representing actual reported malaria cases in hospitals within the county as obtained from the county data base covering the period January 2011 to July 2015.

This method of mapping malaria risk areas by identifying the hazard areas and combining it with other risk and vulnerability factors can also be replicated for other counties in western and Nyanza regions where cases of malaria and other vector borne diseases are still rampant since most of the environmental data used in deriving hazard map and vulnerability data are publicly available through online sources.

This results will not only help the county health management team to adequately understand the scope and the likely trend of the disease in the county, also guide in planning the control measures such as distribution of insecticide mosquito treated nets and distribution of malaria related drugs based on demand per health facility.

Future directions to refine this research on malaria risk mapping can include testing the results against individual hospital data in various localities instead of consolidated sub county data, taking into considerattion specific land use factors such, irrigation, mining,logging, type of housing units and specific and vegetation and crop types. Also more development factors such as access to electricity, educational levels as cultural beliefs can be incorporated in future studies to enrich the findings.

Acknowledgements

This paper is a part of the results of the first author's research project for fulfillment of Msc degree in GIS and Remote Sensing from Department of Geomatic Engineering and Geospatial Information Systems,Jomo Kenyatta University of Agriculture and Technology, Kenya.The authors are quite grateful to the Kenya meterological department ,Kenya National bureau of statistics,The Survey of Kenya, Regional Centre for Mapping of Resources for Development,Busia county hospital records department and the department of Geomatic Engineering and Geospatial Information systems of JKUAT for their support in providing data used in this research.

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