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Modeling Kenya's Vulnerability to Climate Change – A Multifactor Approach

Kenneth Kemucie Mwangi[1], Felix Mutua[2]

[1, 2]Jomo Kenyatta University of Agriculture and Technology, Department of Geomatic Eng. & Geospatial Information Systems, P.O. Box 62000, 00100 Nairobi, Kenya

Abstract: ***Kenyan landscape has experienced in extremes the impacts of climate change. This study assesses climate change vulnerability and shows its spatial distribution in Kenya in the last thirty years by using geospatial techniques to integrate climate data, land use data and socio-economic data. The measure of vulnerability (vulnerability index) has been used in this study to indicate the combined effects of exposure, sensitivity and adaptive capacity to climate change. Various factors representing exposure, sensitivity, impacts and adaptive capacity were derived from spatial data. Primary data obtained from official sources was used in the assessment. The climate change vulnerability map developed highlights how different regions are vulnerable to climate change with 5.01% of the country was categorized as highest vulnerability, 79.9% as high vulnerable, 14.82% as moderately vulnerable and 0.28% being least vulnerable. These figures are obtained after weighted analysis of exposure, sensitivity and adaptive capacity. Vulnerability index map obtained can be a useful tool to guide decision making in Kenya climate change response planning and the implementation of mitigation measures to the effects of climate change.***

Keywords: Climate Change, GIS, Vulnerability Index

1. Introduction

Climate change is a change in the state of the climate that can be identified by changes in the mean and/or the variability of its properties and that persists for an extended period, typically decades or longer [1]. It has been attributed to natural causes and thought to be accelerated by manmade causes. Among the most manmade cause is the burning of fossil fuel and land use changes which lead to increase in quantities of green house gases; carbon dioxide (CO_2), methane (CH_4) and nitrogen dioxide (N_2O). The rise in these gases has caused a rise in the amount of heat from the sun withheld in the earth's atmosphere which would normally be radiated back to space. This is the green house effect which results in climate change [2]. According to [1], over the last century atmospheric concentration of carbon dioxide increased from a pre-industrial value of 278 parts per million to 379 parts per million in 2005 and the average global temperature rose by 0.74^{o}C. This according to scientists is the largest and fastest warming trend.

For proper observation of climate change, the observations must be based on long term data to eliminate the effect of climate variability. The climate variability is natural and hence is expected. Over the next decades billions of people are predicted to face shortages of water and food and greater risks to health and life as a result of climate change. Concerted global action is needed to enable developing countries to adapt to the effects of climate change that are happening now [1].

Vulnerability is the inability to withstand the effects of a hostile environment in this case climate change. It is the degree to which a system is susceptible to, and unable to cope with adverse effects of climate change, including climate variability and extremes [3]. Several factors make a community vulnerable to the effects of climate change and this study spatially assessed field data and came up with individual maps for the factors. These were then combined to a climate change vulnerability map for Kenya.

2. Study Area

The study area was selected as Kenya, a country in East Africa lying between 34^{o} E and 42^{o} E and 5^{o}N and 4^{o}S with a landmass of about 582,350 km^2 and population of 38.6 million Figure 1. 17% of the land in Kenya is arable while the remaining 83% consists of arid and semi-arid land (ASAL). There are indications according to [4] study that the ASAL is increasing and the country is losing valuable natural assets due to climate change.

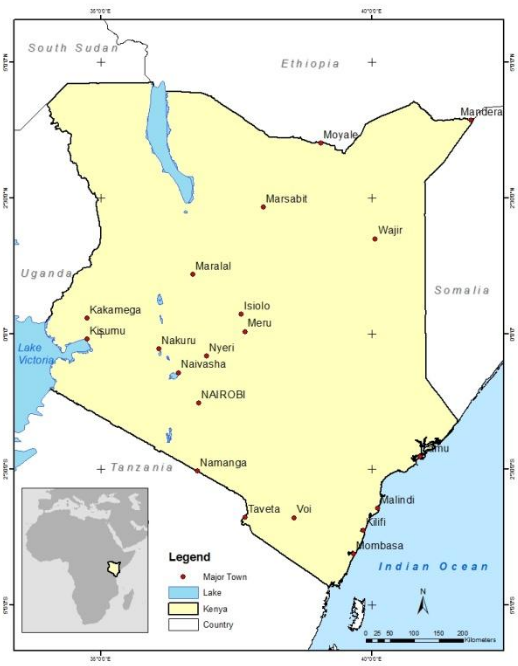

Figure 1: Map of the Study Area

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3. Materials and Methodology

3.1 Vulnerability Assessment

The IPCC's assessment technique that vulnerability depends on exposure, sensitivity and adaptive capacity was adopted [5]. Their interaction can be seen in Figure 2. This vulnerability assessment sought to geographically portray each of the factors by looking at the sub-factors that drive exposure, sensitivity and adaptive capacity.

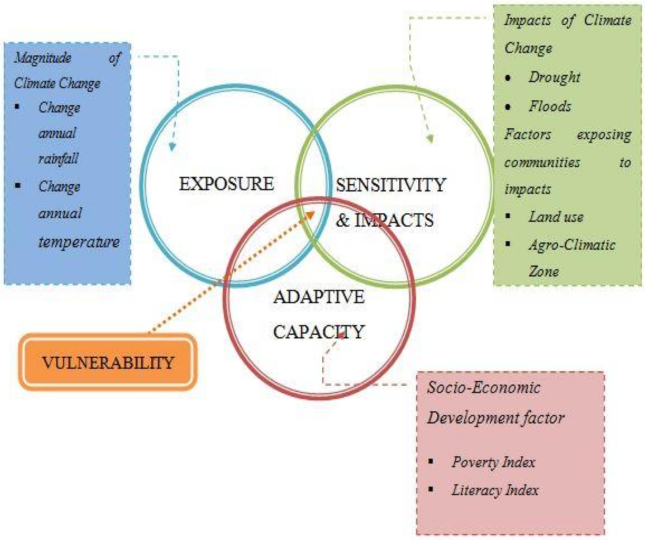

Figure 2: How Exposure, Sensitivity and Impacts, and Adaptive Capacity Interact

Vulnerability index **(VI)** indicates the combined effects of exposure (**e**), impacts (**i**) and sensitivity (**s**) and adaptive capacity (**a**) by the algebraic combination;

$$\boldsymbol{VI} = \boldsymbol{e} \times \boldsymbol{i} \times \boldsymbol{s} \times \boldsymbol{a} \quad (1)$$

Such an index of vulnerability allows the emphasis on some factors more than others. To illustrate, most regions are exposed to climate change equally in terms of magnitude of temperature and rainfall variation; but some communities are able to cope better than others due to their socio-economic setting.

Empirical data of the various factors was represented in raster format such that each attribute was recorded in a separate overlay so that any mathematical operation performed on one or more attributes for the same cell can easily be applied to all cells in the overlay. Map algebra method was used to build a vulnerability model for spatial analysis [6].

3.2 Exposure to Climate Change

Climate change is manifested in the changes in average temperature and rainfall amounts. Exposure to climate change was assessed by the change over-time t of annual-mean temperature $\Delta T\ (t)$ at a country level and change of annual mean rainfall $\Delta P\ (t)$ [7].

3.1.1 Climate Data Gap Filling

Temperature and rainfall were acquired from the Kenya Meteorological Department (KMD). The study period concentrated on the latest 30yrs (1981-2011) due to the fact that it is the period under which satellite records can be obtained and World Metrological Organization (WMO) recommends 30yrs as a reasonable climate normal.

Both minimum temperature and rainfall data had missing data in some months. To fill the data gaps, two techniques were used. In the case of one data gap missing, a technique of moving averages was applied [10] within the particular station. In some cases, missing data was covering more than one month. In such instances data from several years before and years after was used to fill the gaps in a non-linear regression. Each data gap was treated as a specific case with identification of the best set of stations and the period that minimizes the estimated reconstruction error for the gap. The procedure used was similar to that in [11] which entailed the following procedures;

1. Analysis of target station by identification of a period without gaps of sufficient length contiguous to the gap.
2. Identification of stations that can be used for data reconstruction in the neighbourhood of target station through the coefficient of determination R^2. Stations with the highest R^2 were selected in each case.
3. Selection of the period to be considered (before or after the gap)
4. Identification of the station giving the best correlation with the target station for the specific gap to be filled.
5. Identification of the best sampling size or length of period to be used for data coupling
6. Reconstruction of the gap

Exposure to climate change was obtained by mapping variability of current minimum mean temperature from a long term (30 years) mean. Historical annual temperature data was used to derive statistical variation. The minimum temperature was picked for analysis of vulnerability of climate change in Kenya. This is because the minimum temperature (Tmin) as compared to maximum temperature (Tmax) is not sensitive to cloud cover and down dwelling radiation which is observed most during summer months. This was from a study by [14] that investigated the uncertainties in climate sensitivity to model differences in cloud behavior.

The same approach was applied for annual-mean rainfall variation for the different rainfall stations in Kenya. In Both cases rasterization was done by using inverse distance weighting in GIS spatial analysis. Each of the variation raster was classified into 4 classes to represent; High variation, medium variation, low variation and no variation. The two raster were then overlay mathematically in GIS to come up with a climate change exposure map for Kenya.

3.3 Sensitivity to Climate Change

In climate change setting sensitivity is the degree to which a system is affected either adversely or beneficially, by climate-related stimuli. Climate-related stimuli encompass all the elements of climate change, including mean climate characteristics, climate variability, and the frequency and magnitude of extremes [5]. Sensitivity to climate change is determined by the bio-physical factors of an area and hence the uses of land use map and agro-climatic zones.

Kenya's land use was extracted from GlobCover 2009 land use and 26 classes merged to march the IPCC land use classification system for analysis [8]. Using literature and similar assessments the various land uses were ranked into 4 classes according to their sensitivity to climate change. The classes are; most sensitive, moderately sensitive, least sensitive and not sensitive.

Impacts of climate change are often manifested on the bio-physical environment. Thus to be included in the mapping of vulnerability of climate change impacts will be assessed on the land use types. Different Kenya land uses were ranked according to the observed impacts of climate change over the years. The ranking was based on supporting literature and expert-based opinion. As an example, deciduous forest cover is less severely affected by climate change as compared to forests occurring in the ASALS. Thus impacts were ranked from 1 to 4 with 1 being the least impacted by climate change and 4 most impacted.

According to [9], the current climate in East Africa is characterized by large variability in rainfall with occurrence of extreme events in terms of *droughts* and *floods*. These are the most visible impacts of climate change in Kenya. Certain sectors are most impacted by climate change with the most impact in Kenya being on the rain-fed agriculture sector. These means areas where rain-fed agriculture is practiced suffer most when drought or floods occur. In the Kenya vulnerability index model, rain-fed agriculture land use gets the highest ranking 4, since the impact of climate change are most/highest in that. Other land uses are assessed in the same approach based on how drought and floods affect them.

3.4 Impacts of Climate Change in Kenya

3.4.1 Drought Occurrence

For this study, monthly rainfall datasets were acquired from the Kenya Meteorological Department (KMD) for the period 1981-2011. This data was used to compute Standardized Precipitation Index (SPI). Standardized Precipitation Index (SPI) was developed by [12] for the purpose of defining and monitoring drought. It is based in cumulative probability of a given rainfall event occurring at a station. Historic rainfall data is fitted in a Gamma distribution and transformed into a standard normal variable Z with a mean of zero and standard deviation of one. The SPI is thus a representation of the number of standard deviations from the mean at which an event occurs often called a 'z-score' [12].

SPI was used in drought assessment by identifying the drought occurrence and severity by how much the value varies from the historical mean. A threshold value indicating drought severity of SPI values between -3 to -1.5 representing severe dry to extreme dry was used derive a frequency of drought occurrence of each station in Kenya. The droughts frequency SPI was then interpolated using Inverse Distant Weighting (IDW) to obtain a drought frequency distribution map. For the stations, the number of drought occurrences range from 3 to 25 occurrences. The raster values obtained were then classified into four classes representing areas of different drought frequency in 30 year period to result in Figure 3 below.

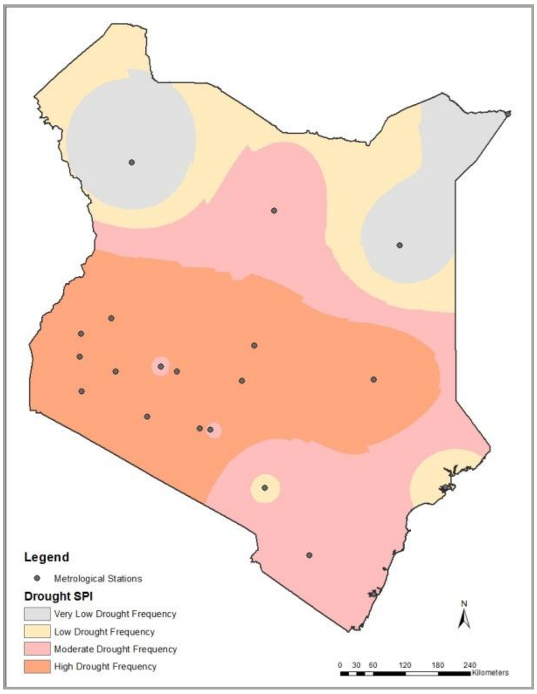

Figure 3: Drought Frequency in Kenya 1981-2011 based on SPI

3.4.2 Flood Frequency

As an impact of climate change, floods have come as El-Nino in Kenya and in the East African region [9]. Due to the variation in climate zones influenced by altitude and land formation, floods impact different areas differently in terms of magnitude and frequency.

For this study, existing analysis in frequency and distribution of floods as a hazard was used. The data was obtained from [13]. The analysis period was 1985 and 2003 which slightly varies from the study period of the other factors considered in this vulnerability assessment. The flood frequency raster was reclassified into four classes ranked according to increasing severity in flood as shown in Figure 4 below.

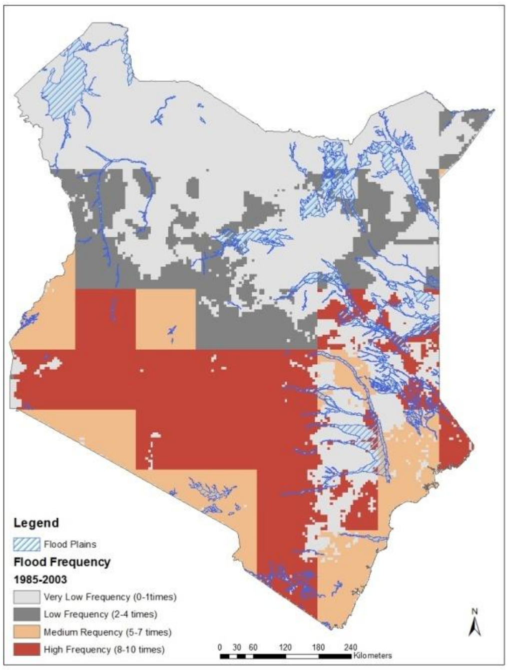

Figure 4: Flood Frequency in Kenya

Floods and Droughts in Kenya cause different impacts according to their extents and frequency of occurrence. Thus to develop an impact map, the recorded frequency of occurrence was used to assign weights. Data from the *International Disaster Database* published by [16] was obtained for Kenya. The data enumerates disasters occurrence, numbers affected and estimated economic damage. From the data, flood events in Kenya for the period of study number at 13 while flood events at 33 events [16]. This gives a total occurrence of 46. From this, the combine impact of climate change was derived to give the formula of;

Combined Impacts = 0.3Drought + 0.7Flood (2)

3.5 Adaptive Capacity

Adaptation refers to an adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects that moderate, harm or exploit beneficial opportunities [7].

The challenge of using secondary data to develop socio-economic development indices is that the data comes at varied and course resolution. For example in this study, some data were obtained at a provincial scale and others at a district administrative level. Such data was re-sampled to a common spatial resolution to allow integration with other datasets and represented in a raster format as seen in Figure 5

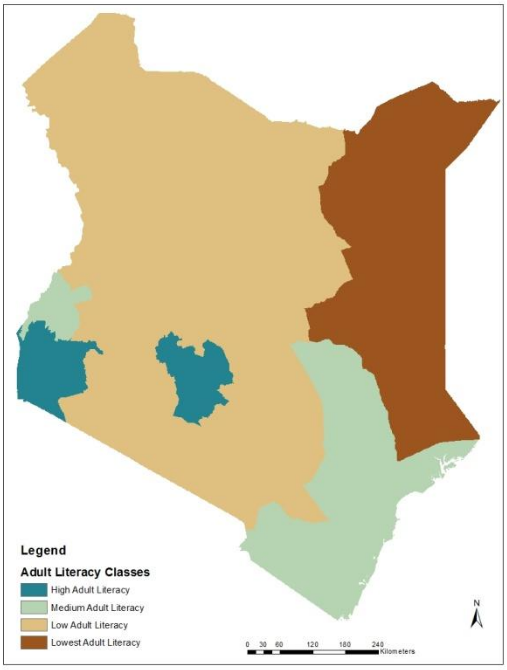

Figure 5: Classified adult literacy rates in Kenya

Each of the socio-economic indicators was ranked into four classes according to their adaptive capacity to climate change. The classes are; highly adaptive, moderately adaptive, least adaptive and not adaptive. An overlay in GIS was done such that some factors received higher weights according to their inability to adapt to climate change.

4. Results

From the minimum temperature analysis in the years 1981 to 2011 all stations reported a positive slope trend except fours stations. This indicates an overall increase in the average monthly minimum temperature for the period under study as seen in Figure 6. This correlates with the studies done in [3].

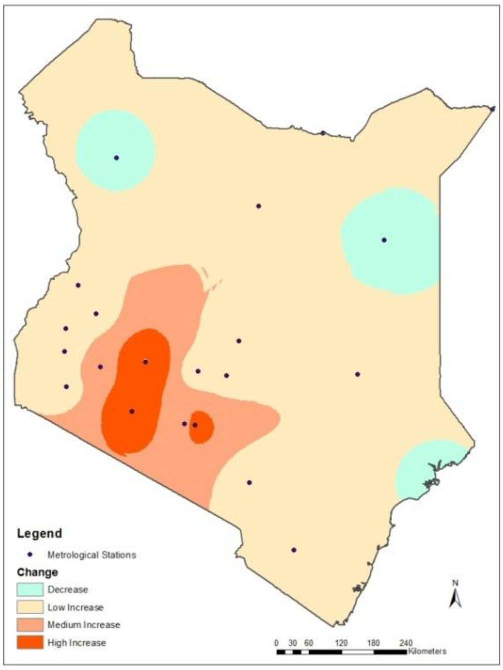

Figure 6: Minimum temperature trend in Kenya 1981-2011

The monthly rainfall amounts analyzed using trend analysis slope function yielded a raster where negative slope meant a decrease in long term rainfall while a positive slope an increase in long term rainfall. The magnitude of the slope represents a magnitude of change in monthly precipitation over the 30years analyzed as seen in Figure 7 below.

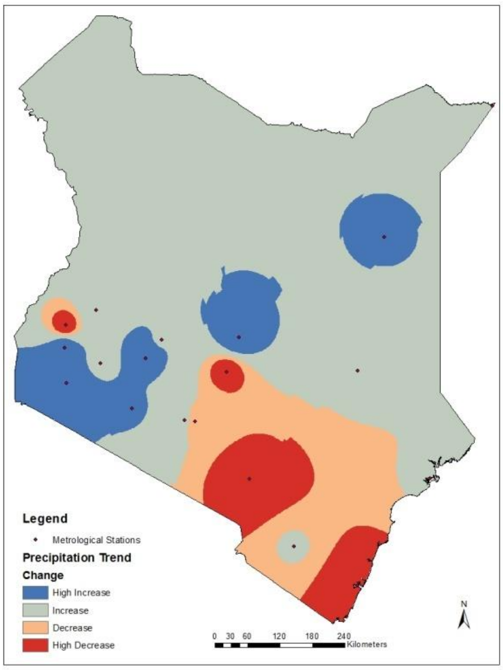

Figure 7: Precipitation trend in Kenya for the years 1981-2011

Long term minimum temperature and rainfall trend combined yielded the *climate change exposure indicator.* According to the results obtained least exposure to climate change happened in the north eastern area in a unique zone. This area had the least changes in temperature and rainfall amounts in the 30year period analyzed. Highest exposure happened in a zone near Kenya's capital and a curved stretch as seen in the marked red class in Figure 8.

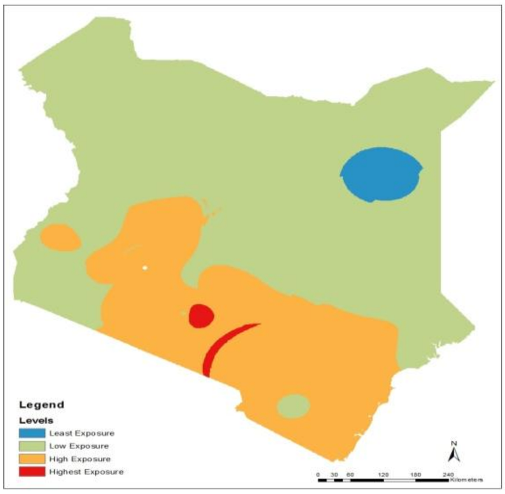

Figure 8: Climate change exposure map of Kenya

Using this analysis, majority of Kenya falls under low exposure and high exposure. High exposure is characteristically around the agricultural areas of Kenya.

The results of the land cover sensitivity assessment shows the areas of Northwestern as having the highest sensitivity to climate change Figure 9. This is mainly due to their having sparse vegetation which is easily affected by a change in climate. Forests and irrigated croplands are some of the land cover classes that are least affected by climate change. This is because of their ability to withstand a high threshold of climate change effects namely floods and droughts as compared to other land cover types.

The idea of thresholds to climate change has been discussed in which some levels are tolerable and must be exceeded before significant impacts occur [15]. In the same way the idea that some land cover classes are able to withstand a higher level of climate change that others has been accounted for in this study.

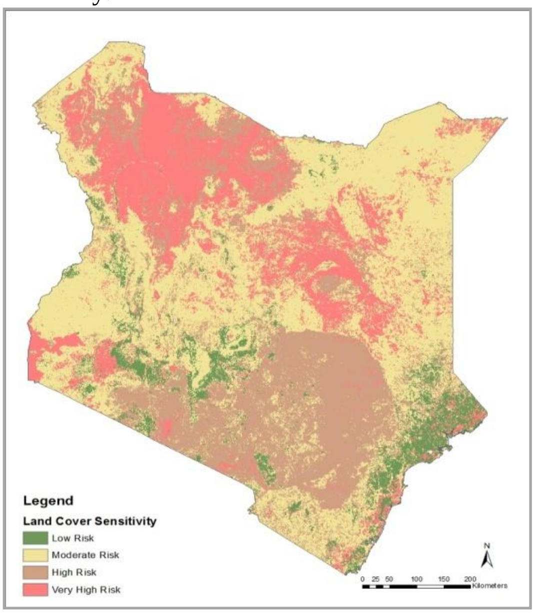

Figure 9: Land cover sensitivity classfication derived form Globcover classes for Kenya

The classification of Agro-Climatic zones yielded Figure 10 below. Notably, the largest area of Kenya has been classified as highest risk zones and falling in the classes 3 and 4 as seen in

Table 1. This is because majority of the country is classified as ASAL-Arid and Semi Arid Land.

Table 1: Agro Climatic Zones of Kenya reclassification according to climate change risk

ACZ Description	*Ranking/ Classification*
Humid	1
Semi-Humid to Semi-Arid, Semi-Humid	2
Semi Arid	3
Very Arid, Arid	4

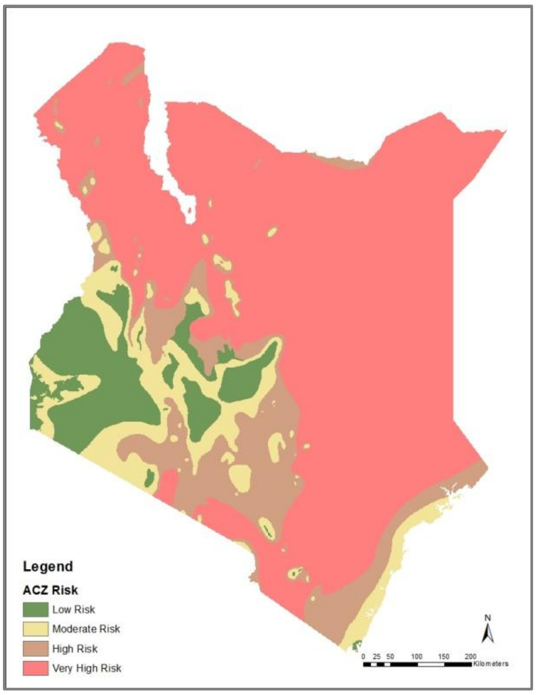

Figure 10: ACZ of Kenya classified to show climate change effects risk

The result of the climate change sensitivity index map obtained by combining land cover sensitivity and agro-climatic zone risk is shown in Figure 11.

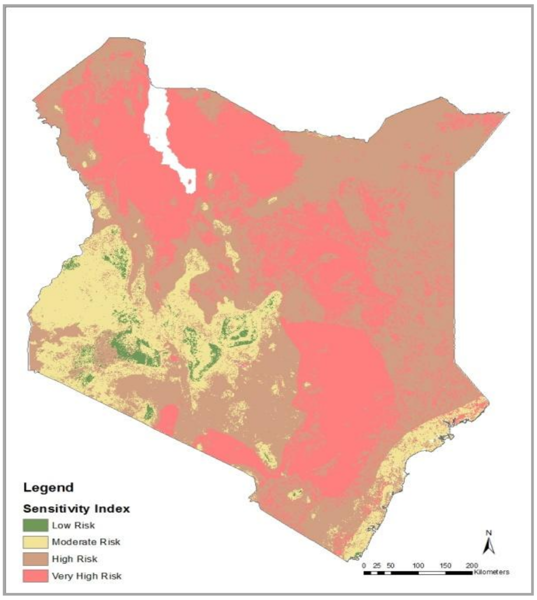

Figure 11: Climate change sensitivity map of Kenya

Due to the factors considered in the analysis, areas in the high moisture climatic zones and have land covers that are forests, urban or irrigated agriculture have the sensitivity to the effects of climate change.

Majority of Kenya (47.36%) has been found to be high risk and 36.11% very high risk sensitivity to climate change as shown in Figure 12. This means that these areas have a low threshold to the effects of climate change and would suffer most to the effects if no adaptation mechanisms are in place. Areas with lowest risk would have a higher threshold to withstand or cope with the effects of climate change and compose the smallest area of 1.65% in Kenya.

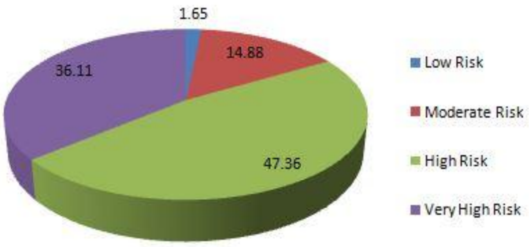

Figure 12: Percentage of land by area representing sensitivity to climate change in Kenya

In the analysis of impacts of climate change the results showed that areas with low drought occurrence based on SPI analysis and low floods frequency based on the floods occurrence experienced the lowest impacts of climate change, and vice versa. This is observed in the Northeastern and Northwestern areas of the country as shown in Figure 13.

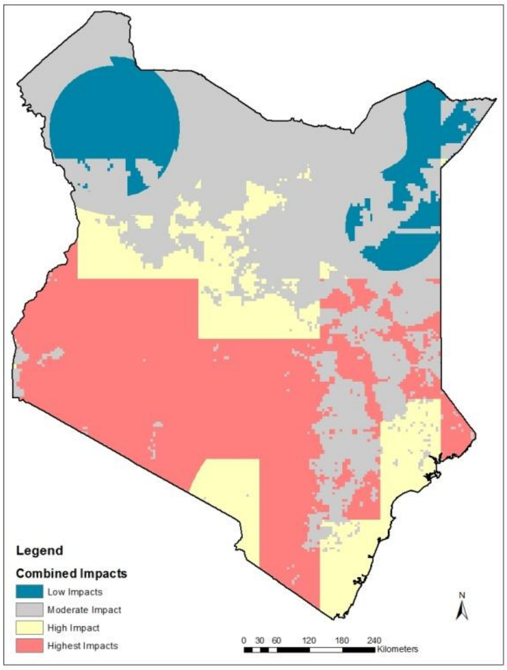

Figure 13: Impacts of climate change showing combined effects of drought and flood frequencies

For this vulnerability study, wealth levels in Kenya were derived from level of poverty as studied in [17]. The poverty figures used were at District level for the period 2005-2006. Four classes were used that ranks poverty percentages into quartiles (0-25%, 25-50%, 50-75% and Greater than 75%) as seen in Figure 14.

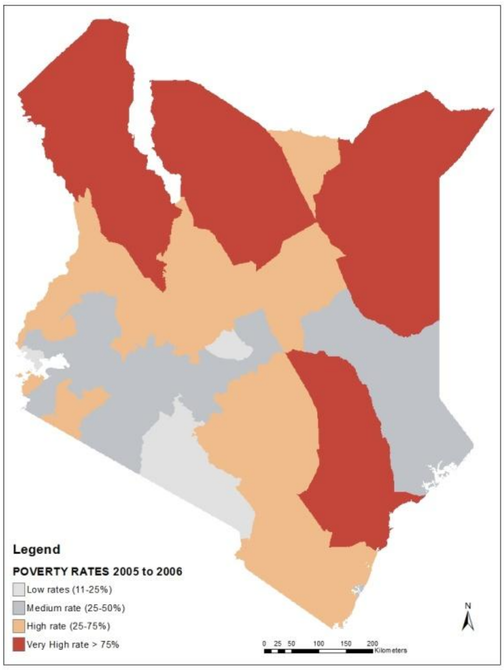

Figure 14: Poverty rates in Kenya

The adaptive capacity developed showed that the areas with high adult literacy and low poverty rates are considered to be the ones with the highest adaptive capacity as seen in Figure 15. This means they have best coping mechanisms.

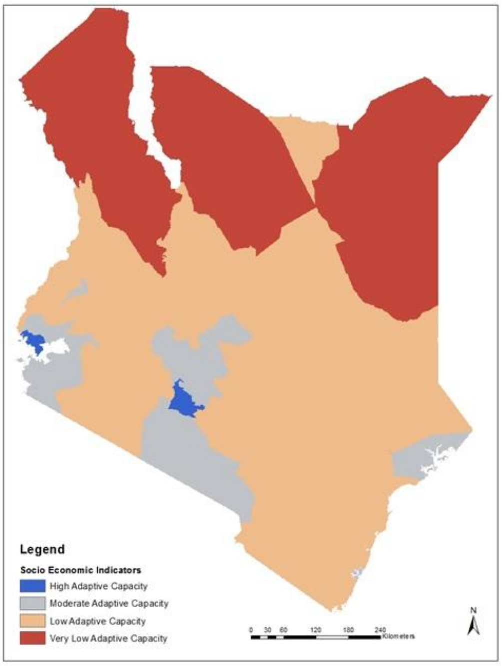

Figure 15: Combined socio economic indicators adult literacy and poverty rates representing climate change adaptation in Kenya

The results of vulnerability index map Figure 16 show different vulnerability classes from low vulnerable to highest vulnerable.

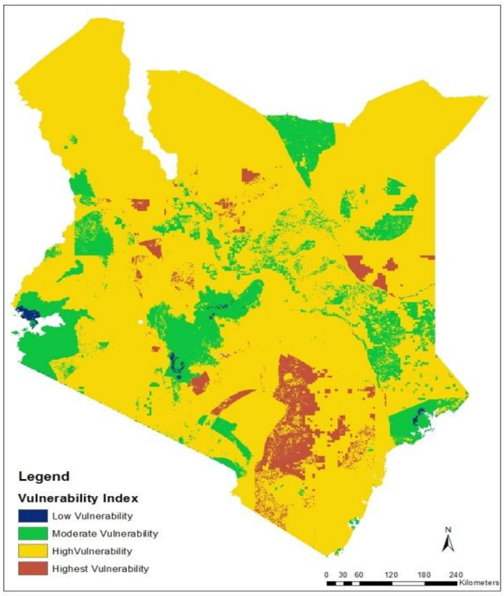

Figure 16: Developed climate change vulnerability map of Kenya

In addition, when the area of classes were computed over Kenya's total area, 5.01% was found to be highest vulnerability, 79.9% high vulnerable, 14.82% moderately vulnerable and 0.28% being least vulnerable as seen in the chart in Figure 17 .

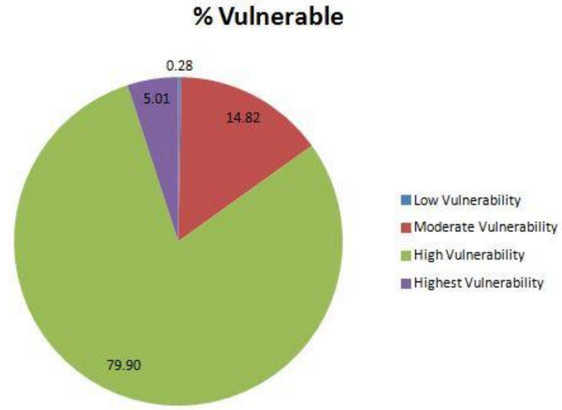

Figure 17: Chart showing percent of land area in the different vulnerability to climate change classes

5. Conclusion

No particular pattern or trend was found in the occurrence of different vulnerability classification in this case. Majority of the country falls under the high vulnerability class (79.9%). This means that when the allowable threshold of climate change has occurred, majority of Kenya's communities would suffer the effects of climate change.

Global studies of a similar approach of integrating information about climate-change exposure, sensitivity and adaptive capacity have classified countries according to the impacts and their ability to adapt to the effects of climate change. Such a study has been done is the Global Distributions of Vulnerability to Climate Change [7] Kenya was classified as extremely vulnerable in the different emissions scenarios and moderately vulnerable when mitigation measures are considered.

6. Recommendations

Interventions measures to combat climate change can be based on such a systematic study to know where exactly and which interventions would enhance adaption to climate change. Scaling down such a study to county level would enable interventions to be community specific. In turn, the overall effect would be effective intervention with a contribution to the overall climate change adaption strategy for Kenya

Most of the factors are obtained from data from different sources, spatial and temporal resolutions. This posed the challenge on accuracy of the final results since error is propagated through the climate change vulnerability model. To minimize on this in future studies, primary studies or pilot studies can be done in smaller scale representative of larger areas and all the data collected for the specific area.

This particular vulnerability study due to lack of specific socio-economic data, considered limited adaptation measures. While literacy levels and poverty index were taken as a good indication of adaptive capacity, community specific climate adaption data could give a more accurate indication of vulnerability to climate change.

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Author Profile

Kenneth Kemucie Mwangi received his BSc. in Soil, Water and Environmental Engineering from Jomo Kenyatta University of Agriculture and Technology in 2010 and is currently pursuing his MSc. Degree in the same university. He has worked in Regional Centre for Mapping of Resources for Development, Nokia-Navteq and now works for IGAD Climate Prediction and Applications Centre. Kenneth's interest is in development and use of satellite products and geo-information for environment applications, agriculture and climate change assessment.

Felix Mutua received his BSc. in Geomatic Engineering from Jomo Kenyatta University of Agriculture and Technology, Kenya with honors in 2006. He continued his studies at the same university where he obtained his MSc. in Environmental Information Systems in 2009. He acquired a Ph.D. in Civil Engineering from The University of Tokyo, Japan in 2013. Felix Mutua's current interests involve GIS and applications of satellite products in monitoring water resources, land use and land cover as well as applications of microwave remote sensing for extreme weather and climate change impact assessment.