Modelling Land Degradation in Migori County

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Abstract

Land degradation is a complex environmental problem which results from different factors. Identification of areas vulnerable to degradation over different times is important in the development of natural resource management and to safeguard the environment. The objective of this study was to model land degradation vulnerability in Migori County for over 30 year period, through the integration of GIS, RS and multicriteria analysis. Land degradation variables identified through previous literatures and opinion from expert groups were, soil erosivity, soil erodibility, slope length, vegetation cover, and population density. The County was classified into 6 land use land cover classes, open water, wetlands, wooded grassland, open grassland, crop land and other land, using supervised classification. Change detection was carried out and expansion of crop land by 11.15% observed. To model land degradation, multicriteria analysis was used and the weights of the indicators were calculated through pairwise comparison and combined using the weighted overlay tool in ArcGIS. The result shows that land degradation was classified into very low, low, moderate and high degradation, with moderate degradation being dominant. Given the worsening degradation trends, there is need for strengthening local institutions that effectively monitor and manage natural resources in order to curb land degradation

Keywords

AHP, GIS& RS, Land degradation, LULC, Modelling

I. INTRODUCTION

Land degradation is a critical issue worldwide, especially in the developing countries. For sustainable development of human society and a health land ecosystems there is need to curb land degradation. Land degradation means a significant reduction of the productive capacity of land. And it involves various factors, including climate changes, land use/cover changes, and human dominated land management [1]

The 2007 Review Report on Drought and Desertification in Africa stated that LD affected at least 485 million people or 65 per cent of the entire African population, and is increasing in severity in many parts of the world, with more than 20% of all cultivated areas, 30% of forests and 10% of grasslands undergoing degradation [2]. He also identified degradation as a potential precursor to widespread desertification, where approximately 30 per cent of Kenya was affected by very severe to severe land degradation.

Studies by [3] indicate that over 20 per cent of all cultivated areas, 30 per cent of forests, and 10 per cent of grasslands have been subjected to degradation where expansion of crop land into marginal lands accounts for much of this degradation [4] identified the marginal cropland in the Lake Victoria basin region as the areas of sharpest decline.

Increasing demands on land for economic development, expanding towns and growing rural populations leads to land use land cover changes and in turn to land degradation. This is a global development and environmental issue, but there have not been serious authoritative measures of land degradation in Migori County

There is the pressing need for mapping land degradation trends to support policy informed decisions for developing food and water security strategies, environmental integrity in sub-counties, counties and national strategies for economic development and resource conservation.The recent development of remote sensing techniques (RS) and geographic information system (GIS) techniques has enhanced the capabilities to obtain and handle spatial information on the heterogeneities of land surface characteristics and hence land degradation.

Land degradation is a long-term process indicating the loss of ecosystem function and productivity and it is happening in Migori County, where, clearing of vegetation for firewood and logging deprives the soil of organic matter and low levels of macronutrients and soil fertility necessary for plant growth and crop production. Forest land being transformed into bare land, crop land and grassland means that farming is affected and hence less food production and degraded land. Population density is increasing rapidly exerting pressure on land resources. The majority of the people in the county are small scale farmers located in the rural areas. These farmers depend on the already degraded lands to meet their food requirements especially where such LULC changes have occurred. The poor farmers are trapped in a vicious cycle of poverty and land degradation. [5] Used different indicators such as, soil physical degradation, soil chemical degradation, loss of vegetation, and land use and used the RUSLE model to prepare soil erosion maps and NDVI for vegetation cover map.

In order to investigate which indicators were most effective in assessing the level of land degradation risks, [6] studied a total of 70 candidate, indicators were selected providing information for the biophysical environment, socio-economic conditions, and land management characteristics. The indicators were defined in 1,672 field sites located in 17 study areas in the Mediterranean region, Eastern Europe, Latin America, Africa, and Asia. [1] integrated NDVI with rainfall data to calculate what they referred to as the rain use efficiency (RUE), and revealed trends in land degradation by separating vegetation declines due to lack of rainfall from declines associated with longer term, and ascertained the long- term trends in the study area as basis for understanding the state and patterns of land degradation. Climate is among the most important determinants of LD [7] low precipitations usually limit the vegetation cover and represent a constraint for crop growth. Models can be used to integrate data on land processes and to validate direct measurements or assessments done using remote sensing.

II. STUDY AREA

Migori County is one among 47 counties in Kenya (fig.1). The town measures 2,586 sq. km with a last census population 917,170 in 2009 and a population density of 353 persons per sq. km. It lies between a latitude of -1.35 and -0.77000 and longitude of 34.06 and 34.73. The neighboring counties are Homabay County to the north, Kisii County and Narok County to the east and Tanzania to the south and 368km from Nairobi kenya

Migori county lies in the lake basin of Kenya The altitude varies between 1140 to 1600 m above sea level and 1700 meters with several undulating hills and plains Rainfall patterns in the region vary ranging from 700mm to 1800 mm annually It has one permanent river, Kuja and Migori and L.Victoria.

The total area under forest is about 695.5 ha the main economic activities are agriculture and mining which are contributing factors to land degradation

III. METHODOLOGY

This study employed a number of processes to model Land degradation in Migori County. Literature from previous studies and organisation that are concerned with land degradation singled out five variables that are used in modelling Land degradation, those are vegetation cover, rainfall erosivity soil erodibility slope and population factor. The Kenya Counties map from Survey of Kenya was scanned, georefferenced and digitized to obtain the Migori County Shapefile. For vegetation cover data, Land sat satellite imageries data was sourced from the USGS website, was used to process LULC classes. The imageries were for 1986 and 1995 Land sat 5 TM was, for 2008, Land sat 7ETM+ and for 2016, Land sat 8 ETM+ OLI. Rainfall data was sourced from e-Station based at Inter Governmental Climate Prediction and Application Centre (ICPAC) as 5km decadal Climate Hazard Group Infrared Precipitation and Station (CHIRPS). Soil erodibility data layer is a composed soil mineralogy and texture. The soil data was sourced from Kenya Soils and Terrain (KENSOTER) databases. Slope was computed from the corrected Shuttle Radar Topographic Mission (SRTM) DEM at a resolution of 30 m. from which slope length were computed. Population density layer was used as an indicator of Population pressure. Human population density layer of 1989, 1999, and 2009 was sourced from the Kenya Bureau of Statistics (population census) and to represent 2016, 2009 data was used due to lack 2019 population census data. The flow diagram (Fig.3) describes the workflow for this study.

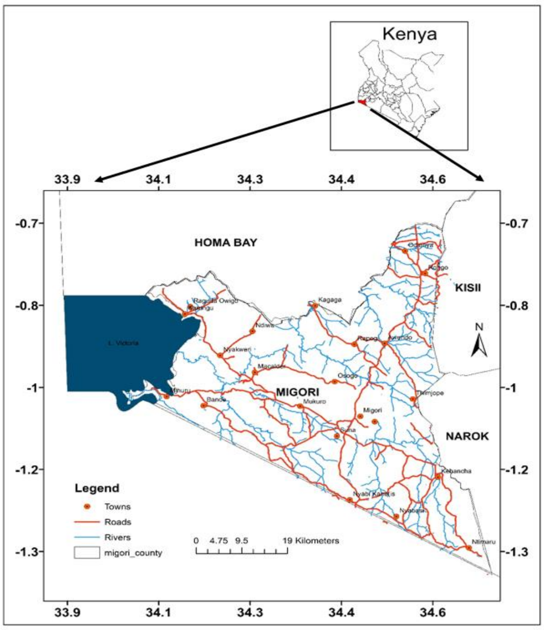

Figure 1: study area of Migori County

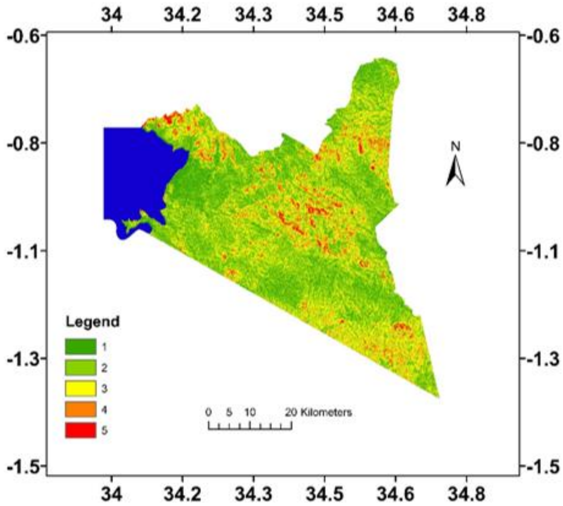

Figure 2: slope length

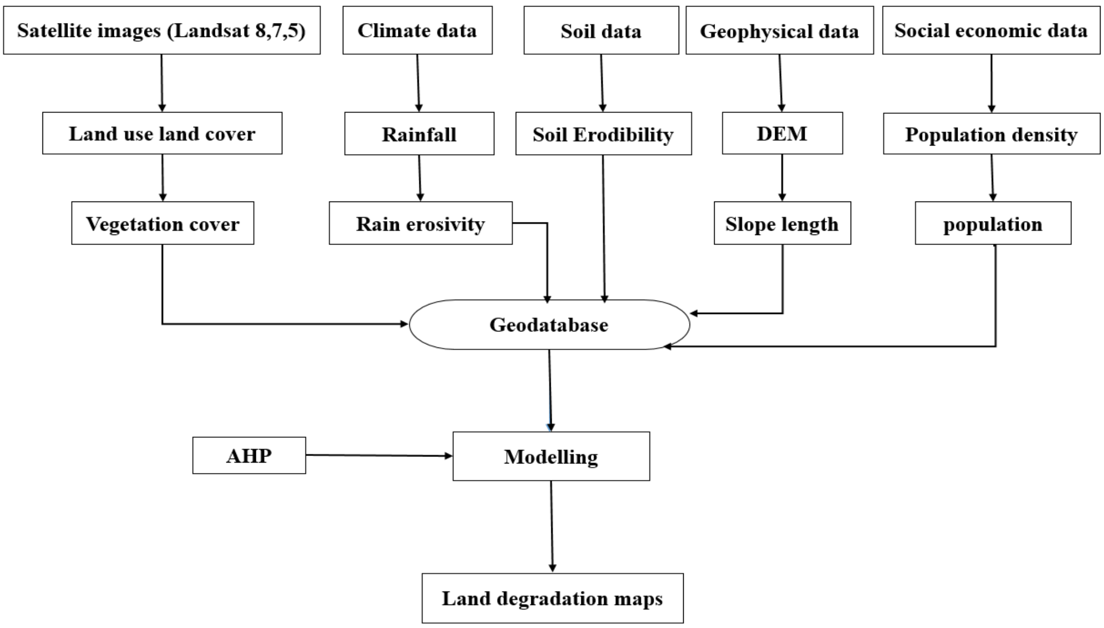

Figure 3: flow diagram

A. Processing land degradation indicators

According to [8] three basic concepts in multicriteria analysis are standardization, criteria weighting and combination. Standardization is a process of converting criteria to a common unit. In this study, the raster maps were scaled to a value range from 1 to 5 indicating very low and very high vulnerability respectively. Criteria weighting was performed to an indicator to show its significance in relation to other indicators. Pairwise comparison method was used to compare two criteria at one time based on the scale given in [9] Consistency of pairwise comparison was checked using a scripted extension of ArcGIS, known as Analytic Hierarchy Process (AHP. Evaluation was performed (maps are combined) to get the final composite index Weighted overlay technique were used to combine the criteria maps. Each standardized criterion was multiplied by its weight in the overlay process [10]. The resultant ranking from the experts are in table 1

B. The land degradation modelling inputs

1. Population Density -P
2. Rainfall Erosivity-R
3. Soil Erodibility- K
4. Slope Aspect- S
5. Vegetation Index- VI

TABLE 1: RANKING FROM EXPERT OPINION

Land degradation input	Team A	Team	Average Ranks
Vegetation index	3	5	4
Slope aspect	5	5	5
Soil erodibility	2.5	3.5	3
Rainfall erosivity	2	2	2
Population density	1	1	1
Total Ranking			15

C. Processing vegetation cover (VI)

Landsat for the year 1986 and 1995 land sat 5TM, 2008 land sat 7 ETM+ and Landsat 8 ETM+OLI for 201 dry season between January and February. The images were uploaded and radiometric preprocessing was to remove these exogenous effects and standardize the images. This process was done in ArcGIS 10.3 and Erdas 2013 The calibrated image scenes were then clipped against the administrative boundaries of the study area for subsequent processing and analysis. Different color composites were generated by compositing individual bands in a Red, Green, Blue (RGB) combination. True color composites were made by combining bands 3- 2- 1 in a Red, Green, Blue (RGB) combination for the Landsat TM and ETM+. The standard false color composite (FCC) were derived by combining bands 4- 3- 2. Other band combinations used included 4- 5- 3 to visualize different vegetation types and 5- 4- 1, and bands 2-3-4-5-6-7&11 for Land sat 8ETM+OLI to help visualize agricultural vegetation. Supervised classification methods was used to cluster pixels in a data set into classes corresponding to user defined areas of interest (AOIs) by use of Maximum Likelihood method. Classification accuracy assessment or confusion matrix was performed to give an overview of the preciseness of the classification The resultant matrix displays producer and user accuracies for each class as well as the overall accuracy of the classification change detection was conducted. The good overall accuracy assessment justified the use of the classification to assess LULC changes in the study area. Reclassification was performed according to the susceptibility of each land use land cover class to land degradation

D. Processing rainfall erosivity (R)

Rainfall and runoff play an important role in the process of soil erosion, expressed as the R factor. The greater the intensity and duration (depth) of the rain storm, the higher the erosion potential [11]. The RUSLE rainfall- runoff erosivity factor (R) for a given period was obtained by summing each rainstorm the product of total storm energy (E) and the maximum 40mm intensity [12]. For the computation of R factor two components were computed from the CHIRPS rainfall data, which is Rainfall depth and Rainfall intensity using expression 1 below. The results showing that the higher the R factor the higher the degradation (fig7)

Equation 1: rainfall erosivity factor where RD is rain depth and RI is rain intensity

$$RD*0.4+RI*0.6=R$$

E. Processing soil erodibility (K)

Factor represents both susceptibility of soil to erosion, the amount and rate of runoff. Soil texture, organic matter, gravel content and soil drainage capacity (water holding capacity) determines the erodibility of a particular soil [13]. The K factor reflected the ease with which the soil is detached by splash during rainfall and/or by surface flow, and therefore shows the change in the soil per unit of applied external force of energy [14].the resultant k factor was obtained by combining the four factors using by use of equal weight overlay (fig8)

F. Processing slope factor(S)

The L and S factors represent the effects of slope length. An increase in hill slope length and steepness results in an increase in the LS factor [14The longer the slope length, the greater is the amount of cumulative runoff, and the steeper the slope of the land, the higher the velocities of the runoff hence degradtion. This study utilised the 30m digital elevation model provided by Shuttle Radar Topography Mission (SRTM) as the input elevation for computation of slope factor (LS). For estimation and processing of the LS factor, this study adopted the expression (2) below, since it is integrated within ArcGIS and enables easier manipulation of the DEM [15] Equation 2 slope length

Equation 2

$$LS = POW\left([flowaccumulation] * \frac{resolution}{22.1, 0.4}\right) * Pow\left(\sin\frac{([slopeofDEM])}{0.09, 1.4}\right) * 1.4$$

Where POW (which means power) is a function in the ArcGIS spatial Analyst. The derived LS was then reclassified in the five soil erosion susceptibility

G. Processing population density (P)

Population density one of socio-economic indicators that aggravate the pressure on the land resource. Population numbers were obtained with the name of the sub counties as a text file, then was imported to ArcMap and joined with the shapefiles representing sub counties. Population density for each sub county Then the values were reclassified to a scale of 1 to 5(fig7) which was later used in modelling the land degradation map. In areas of high population density, the pressure on land resource is high, especially areas where livelihood is predominantly dependent on traditional agriculture. Thus, vulnerability to land degradation will also be high.

H) Field validation

Field validation was carried out to establish evidence of degradation. Due to budget limitations and time constraints, field validation was restricted to a small section of Migori County which registered massive land degradation, (Macalder and Mohuru).A note book and pen for writing down the characteristics of hotspots based on observations and a Garmin GPS for picking the coordinates of degraded spots which were compared with the land degradation map prepared and satellite image for 2016.

IV. RESULTS AND ANALYSIS

A. Migori County Land Use Land Cover States of 1986, 1995, 2008 & 2016

As depicted by the LULC maps of 1986, 1995, 2008 and 2016, this study observed that woodland and cropland are the dominant Land use land cover classes in the study area covering 62.7% of the total area in 1986, 56.7% in 1995, 42.3% in 2008 and 70.8% in 2016.and of this percentage the greatest share goes to crop land which keeps gaining over the years while the other classes lose to cropland indicating that land degradation takes place. Cropland gained by 14.125% in 1986-1995, 4.109% in 1995-2008 and 15.225% in 2008-2016

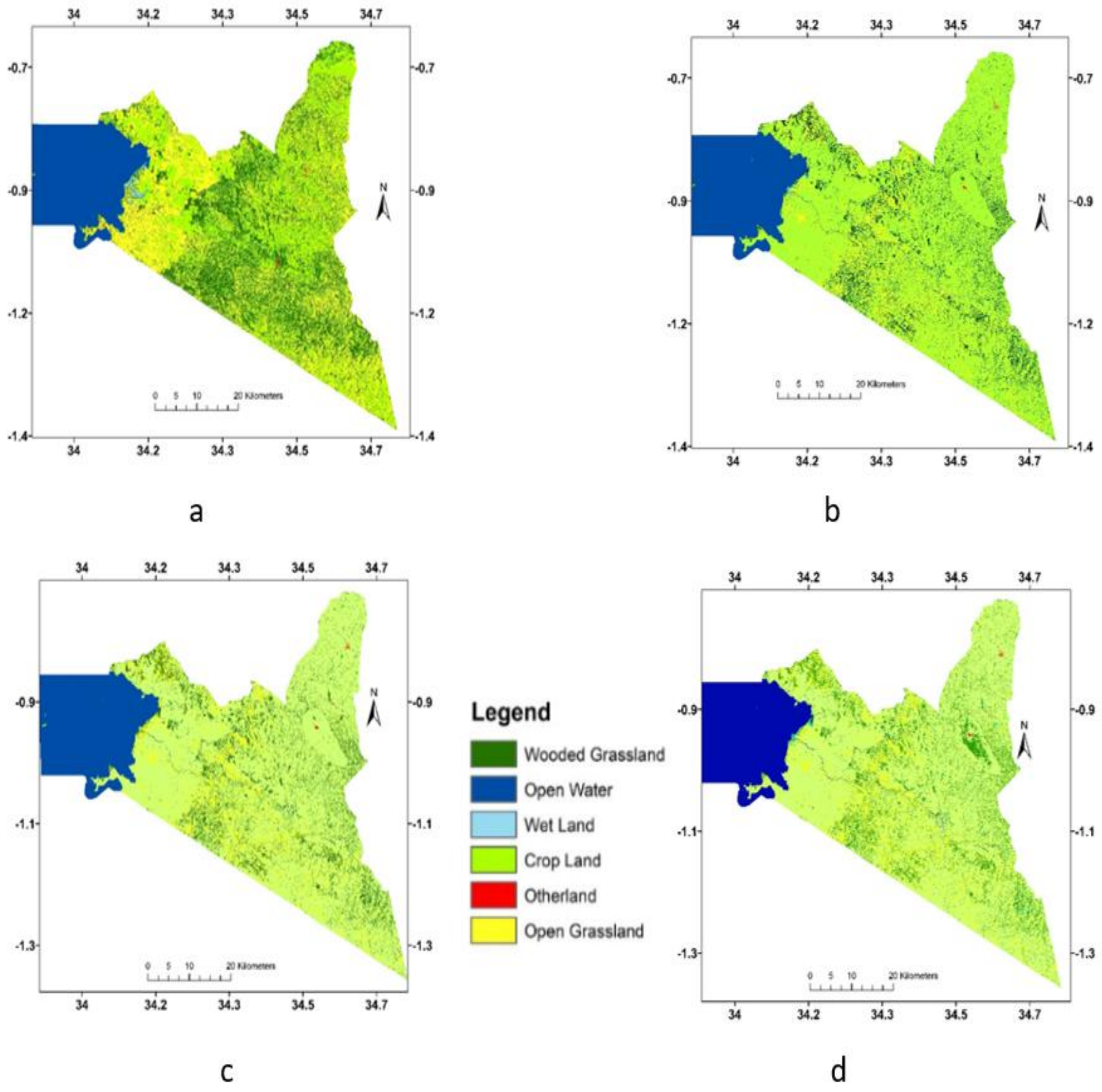

Figure 4: land use land cover classification of Migori County 1986,1995,2008,2016

TABLE 2: 1986, 1995, 2008 & 2016 LAND USE LAND COVER COVERAGE CATEGORIES BY AREA EXTEND

	1986		1995		2008		2016	
CLASS	**AREA(ha)**	**%AREA**	**AREA(ha)**	**%AREA**	**AREA(ha)**	**%AREA**	**AREA(ha)**	**%AREA**
1.OW	55918.800	17.921	56491.740	18.105	54609.750	17.502	55556.640	17.805
2.WG	122133.870	39.142	59417.370	19.042	53167.950	17.039	42887.610	13.745
3.CL	73796.760	23.651	117871.740	37.776	153482.220	49.189	178198.740	57.110
4.WL	47434.500	15.202	41983.290	13.455	24552.990	7.869	20467.980	6.560
5.OL	3529.080	1.131	22959.720	7.358	14825.880	4.751	3995.370	1.280
6.OG	9214.920	2.953	13304.070	4.264	11389.050	3.650	10921.590	3.500
TOTAL	312027.930	100.000	312027.930	100.000	312027.930	100.000	312027.930	100.000

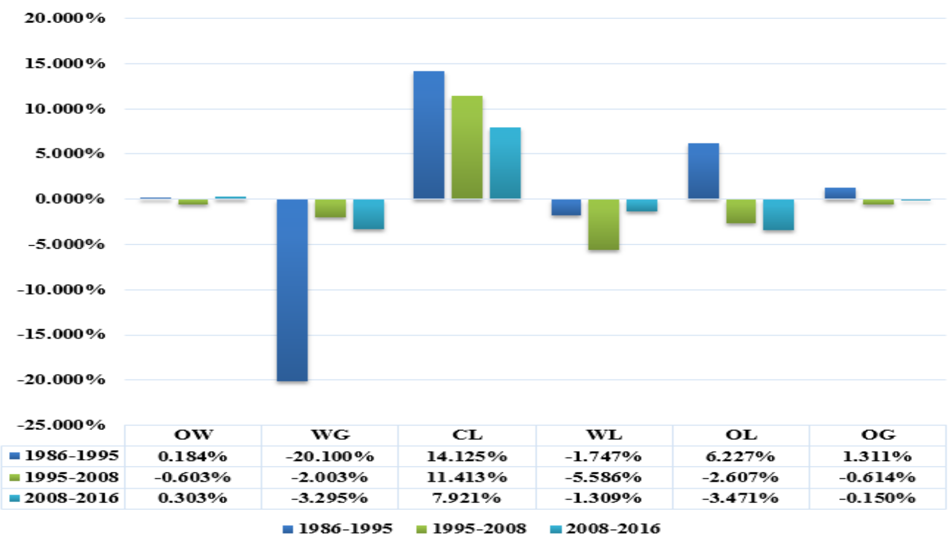

Figure 5: magnitude and nature of detected change, 1986-1995, 1995-2008, and 2008-2016

The impact of elevation was not significant, while it may suggest that, in the areas with higher elevation, there would be less impacts of anthropogenic factors on the land degradation. The slope had clear significant impacts on land degradation, suggesting that steep slopes would lead to land degradation more easily, as steep slope regions were more vulnerable to severe water-induced soil erosion

Zones with scanty population experienced low land degradation. The population density for more than half of the study area is between 100 and 200 people per square Kilometre. Twenty nine percent of the area has a low population density. Thirteen percent of the County has a high population density that varies between 200 and 500 people per square Kilometre. High population density exerts high pressure on land resource and this increases susceptibility for degradation hence the classification. Increases in the population density would lead to land degradation but not significantly. Previous studies show that the impact of population density on land degradation is ambiguous, while this study results suggested that there would be more serious land degradation in areas with higher population density [16]. Soil erodibility factor which represents both susceptibility of soil to erosion and the amount and rate of run- off is shown. The results of soil erodibility in the county reflect the ease with which the soil is detached.

B. Assigning weights

To determine the weights to be used in the model Weights were associated with the output from the pairwise ranking criteria (table 1 and table 2) so that the relative ranking from the pair wise comparison is satisfied, two basic constraints on how to assign the weights (RCMRD, 2015) were put into consideration, i.e. the total of all the weights must be 100%**,** and weights must obey the relative ranking given by the pair wise comparison (table4). The outcome indicates that experts considered slope to be more significant to land degradation, followed by vegetation index, soil erosivity then population density.

C. Land degradation vulnerability model

GIS based multicriteria analysis was used in modeling land degradation vulnerability in this study. Different factors contributed differently to land degradation, depending on economic activities, calculating weights for each factor in Migori County was through pairwise comparison method, using the principles of AHP (analytical hierarchy process). The classification was into three level, preparation of indicator maps and analysis of degradation based on each indicator. The

Reclassify tool in ArcGIS was used to reclass the indicators on a scale varying between 1 and 5, where 1 corresponds to very low and 5 to very high vulnerability. Then pairwise comparison to calculate weights and prepare an index map for each category was performed. Lastly the Analytic Hierarchy Process was performed to produce a single land degradation map. This was performed on all the study periods to produce 4 land degradation maps. The overall land degradation vulnerability result indicates that 48% of the Migori County is highly susceptible (fig 10&11)

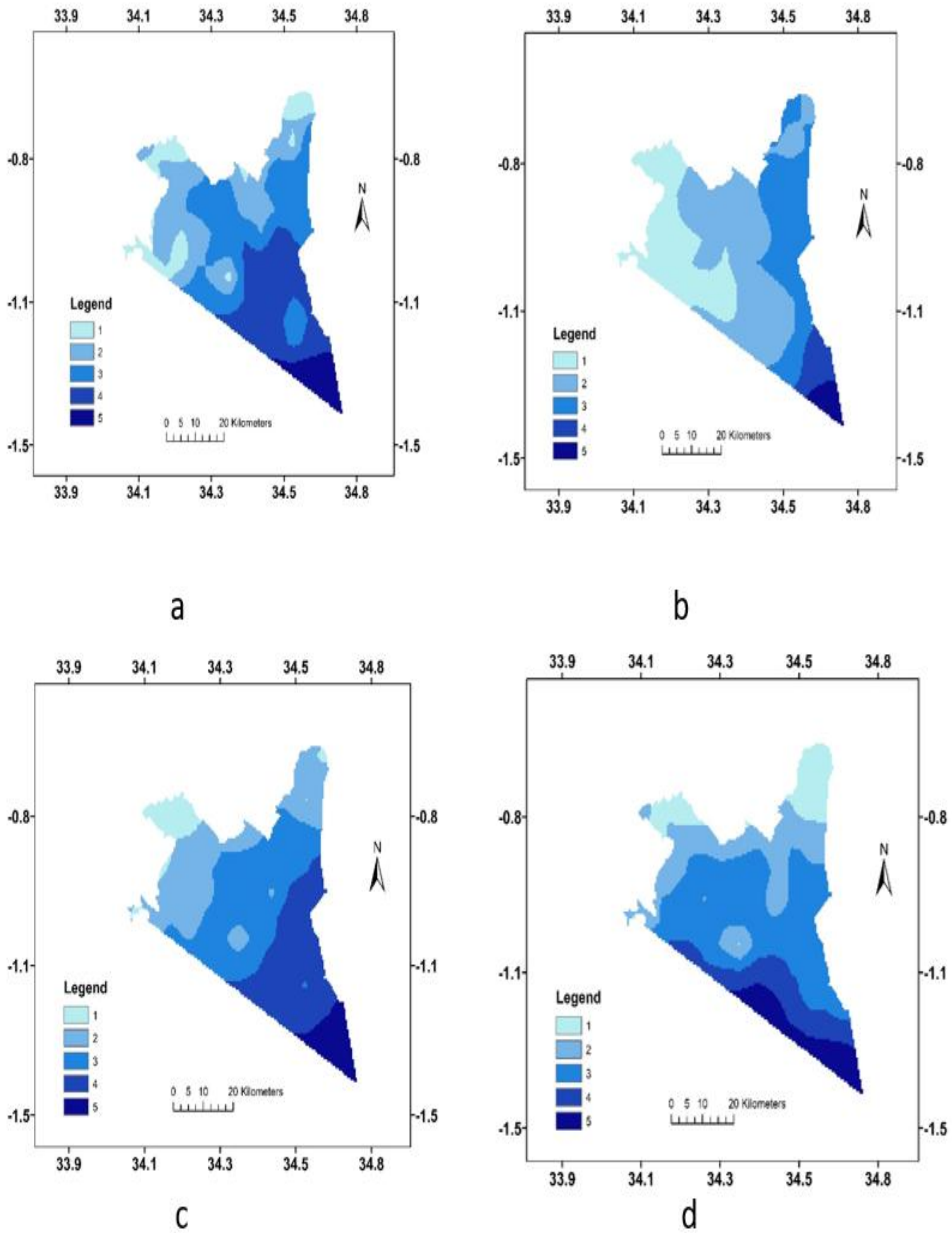

Figure 6: rainfall erosivity for the years (a) for 1986, (b) for 1996, (c) for 2008 and (d) for 2016

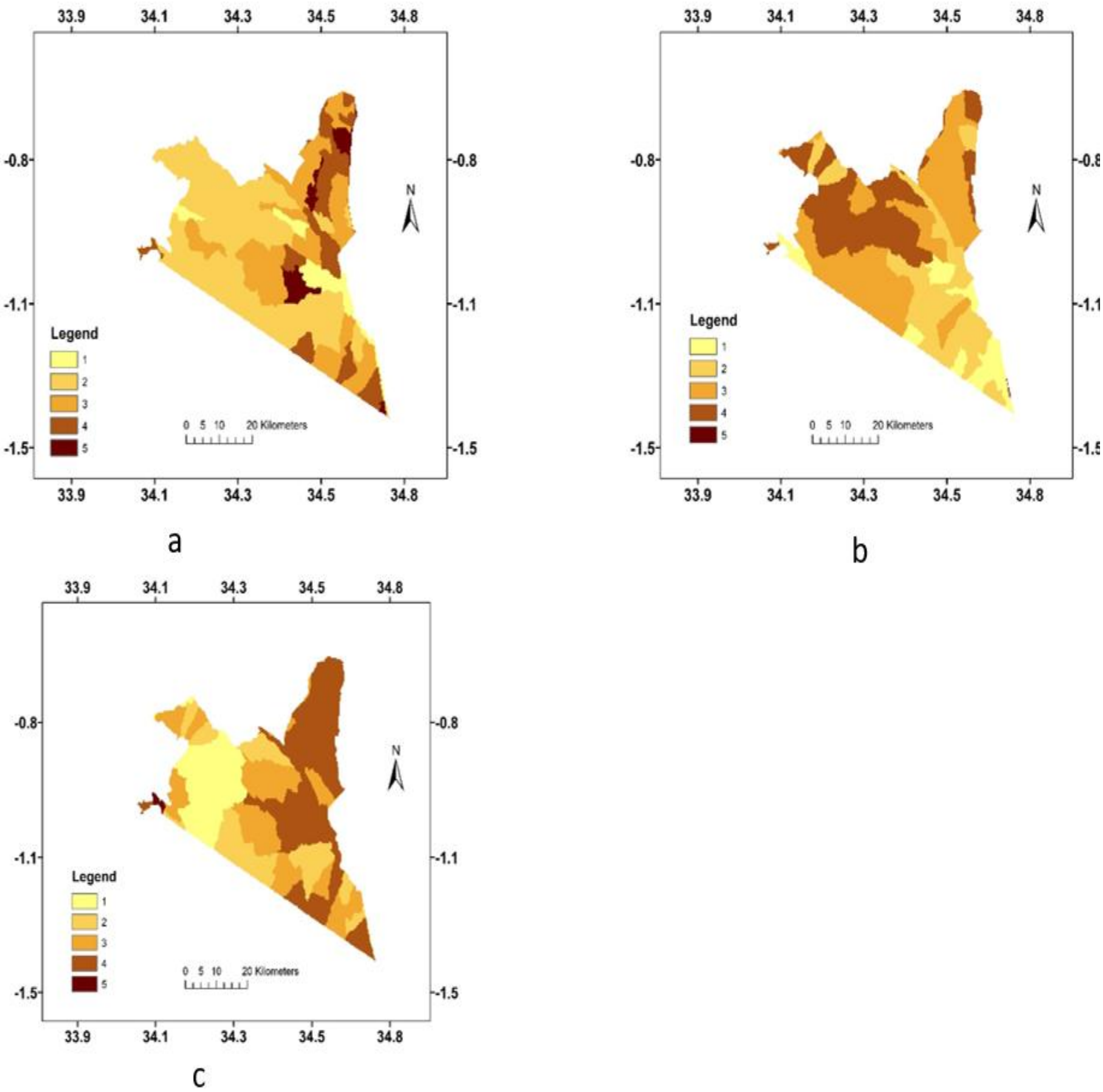

Figure 7: population density for the year (a) 1989, (b) 1999, and (c) 2009

Table 3: final variable weights from expert opinion

For modelling (rcmrd (2015).

Land degradation input	calculation	weight
Vegetation index	4/15	26
Slope	5/15	34
Soil erosivity	3.5/15	20
Rainfall erosivity	2/15	13
Population density	1/15	7
Total ranking		100

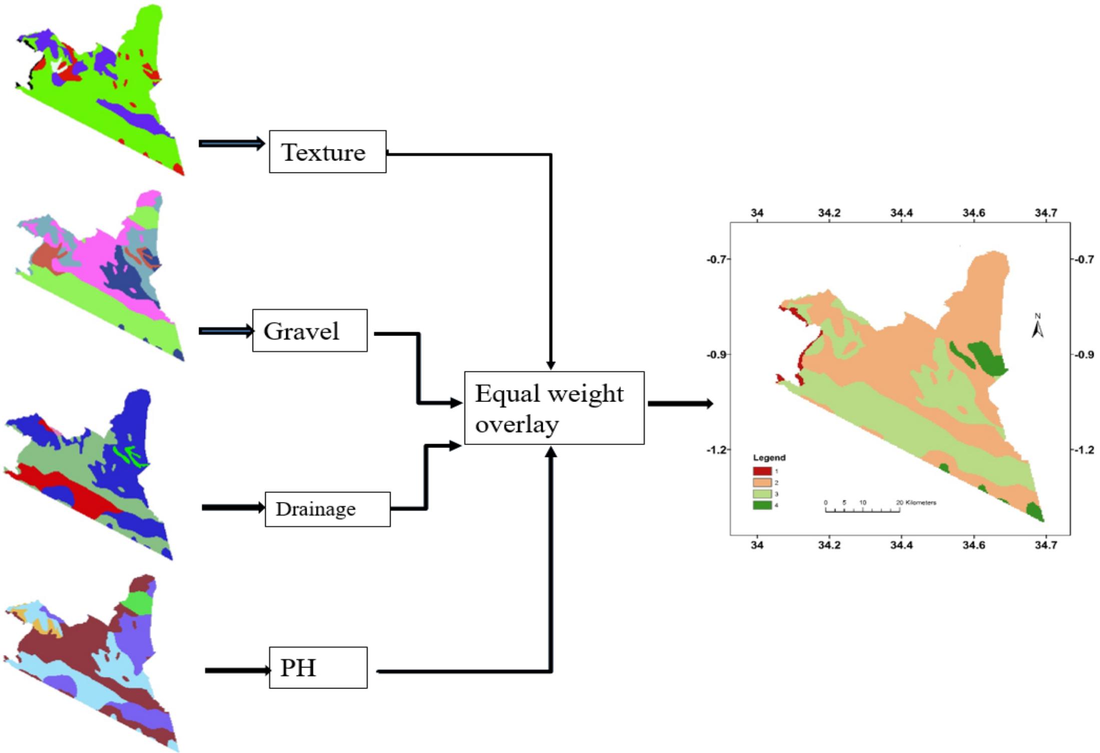

Figure 8: showing soil erodibility factor as weighted overlay of texture, gravel content, drainage capacity, soil PH

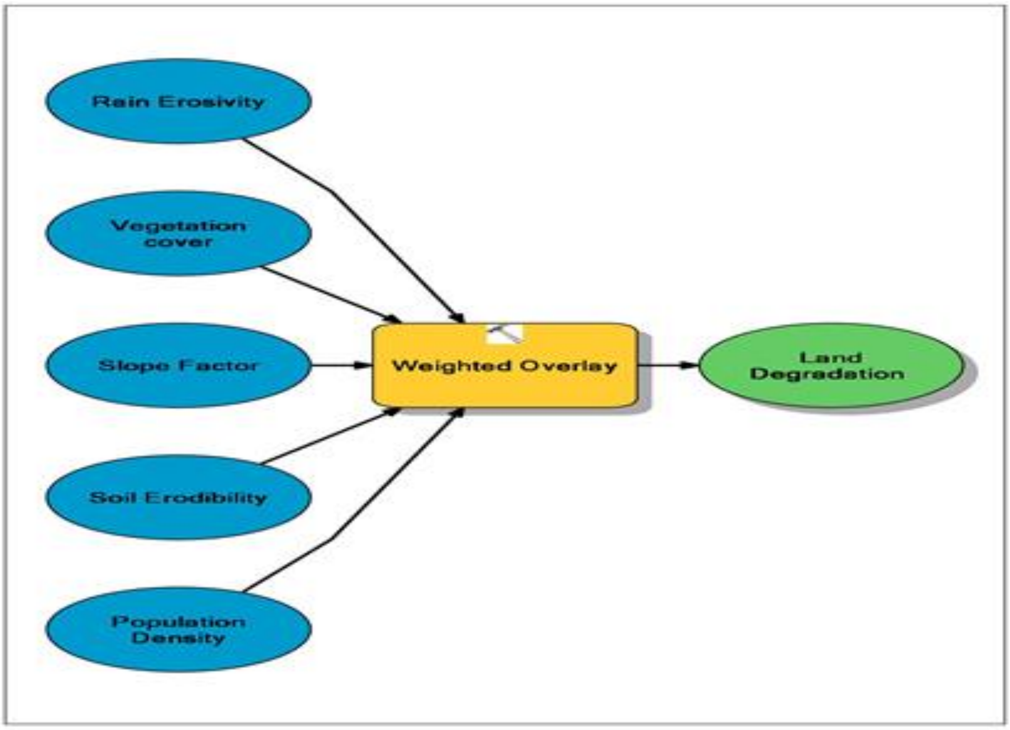

Figure 9: showing weighted overlay model for modelling land degradation

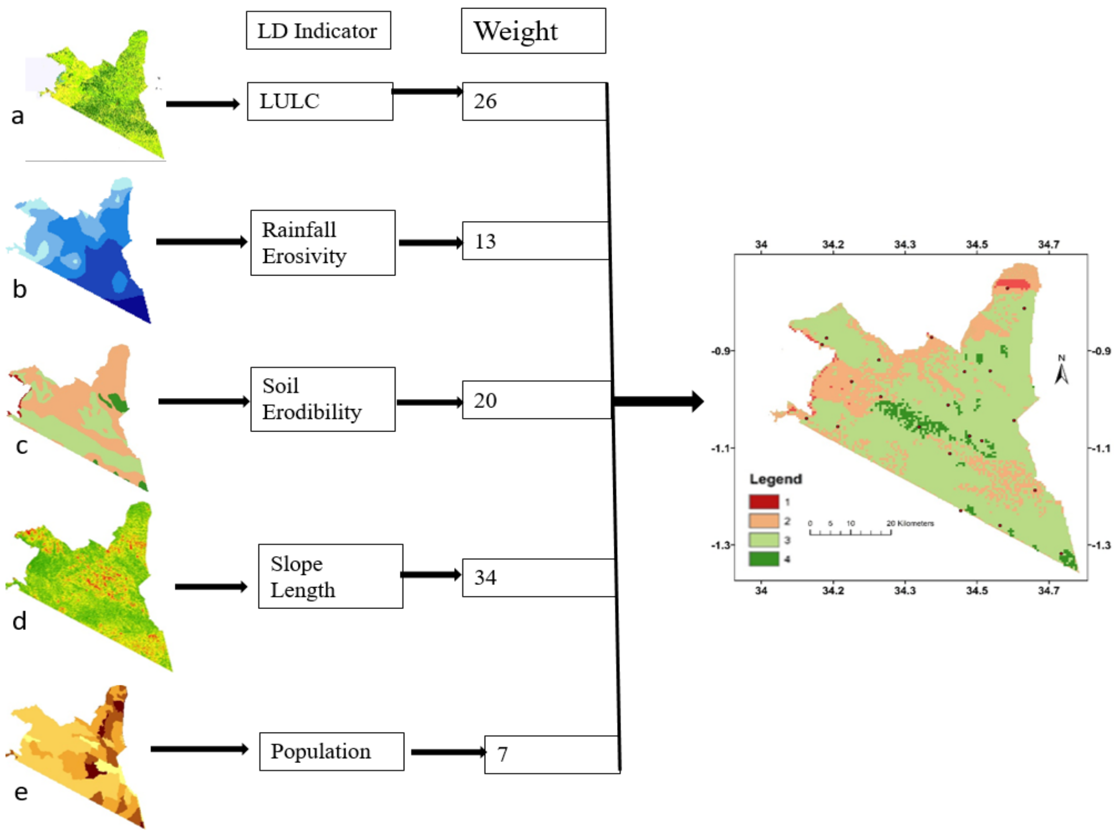

Figure 10: land degradation map 1986 from the model above

This model was used for all the study years to give the resultant land degradation maps below (12)

V. CONCLUSIONS

Several tasks have been carried out in this study to assess land degradation vulnerability trends in Migori County. The major tasks were identification of the variables, land use and land cover classification and change detection, modeling soil erodibility, modelling rain erosivity calculating population density and use of multicriteria analysis to assign weights to the variables. The findings of land use and land cover classification show that agriculture is the dominant land use type in Migori County. The main change observed between the 1986 and 2016 was an expansion of crop land at the expense of 11.15% of other land use and land cover classes. The slope analysis show that half of the Migori County falls under steep and very steep gradient classes. A big proportion of crop land is on moderately steep and steep slope gradients. Cultivation on steep slopes will aggravate land degradation processes.

As many counties are increasing in population, demand for land to provide food, shelter and fibre is also increasing. Forested areas are replaced by crop lands and other lands due to human activities which increase exposure of top soils. The impact of top soil exposure is the loss of organic matter content due to topsoil rainfall runoff hence reducing soil fertility and crop yield [17].

The spatial multicriteria analysis results, reveals that vulnerability to land degradation varies from low degradation levels to high degradation levels in Migori County. Zones with very low degradation changed from 4% in1986 to 5% in 1996 to 6% in 2008 and finally to 7% in 2016. Zones with low degradation from32% in 1986 to 35% in 1996 to 33% in 2008 to 31% in 2016. Zones with moderate degradation from 48% in 1986, 36% in 1996 in 32% in 2008 in 31% in 2016. Zones with high degradation fro16% in 1986 to 24%in 1996, 29% in 2008, and 31% in 2016. This indicates that land degradation in Migori is increasing in an upward trend which raises an alarm, and requires urgent measures to curb it

Generally, the integration of GIS, RS, and multicriteria analysis provides a great utility to investigate land degradation vulnerability. The overall result of land degradation obtained from this study suggests the need for land conservation and management

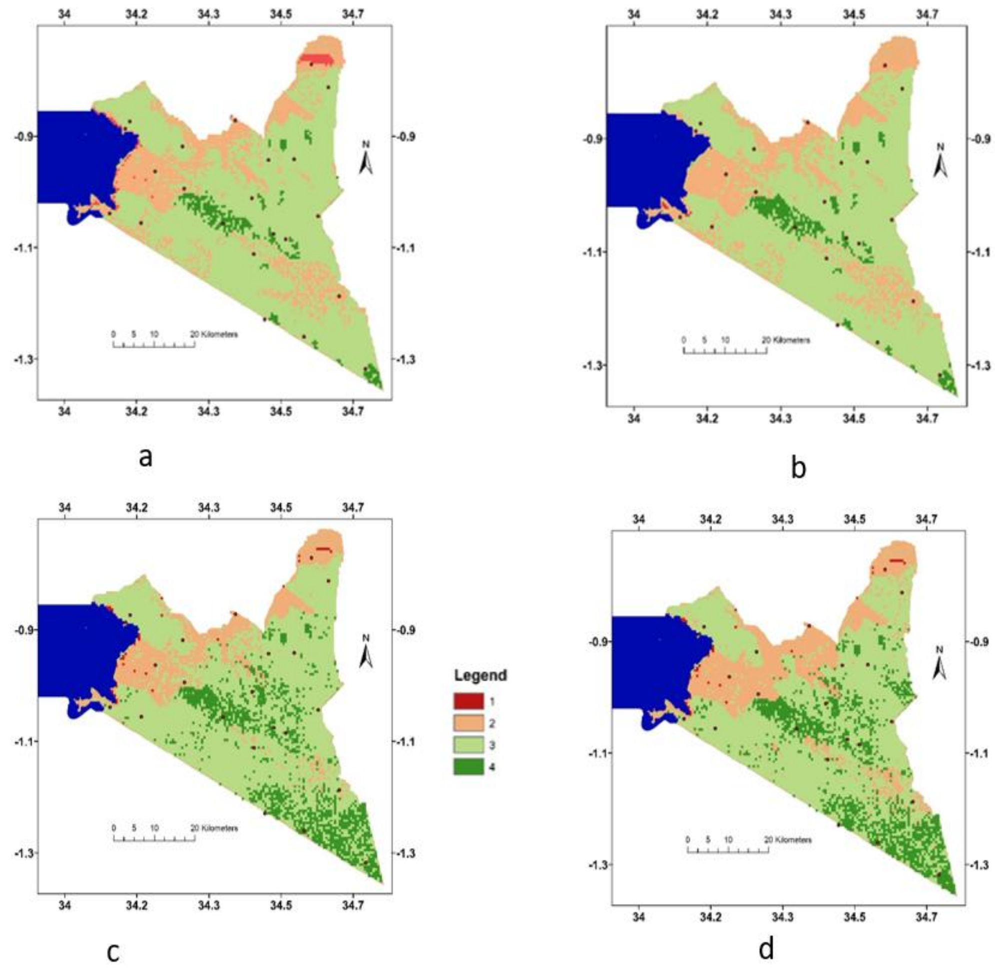

Figure 11: land degradation maps (a) 1986, (b) 1995, (c) 2008, (d) 2016.

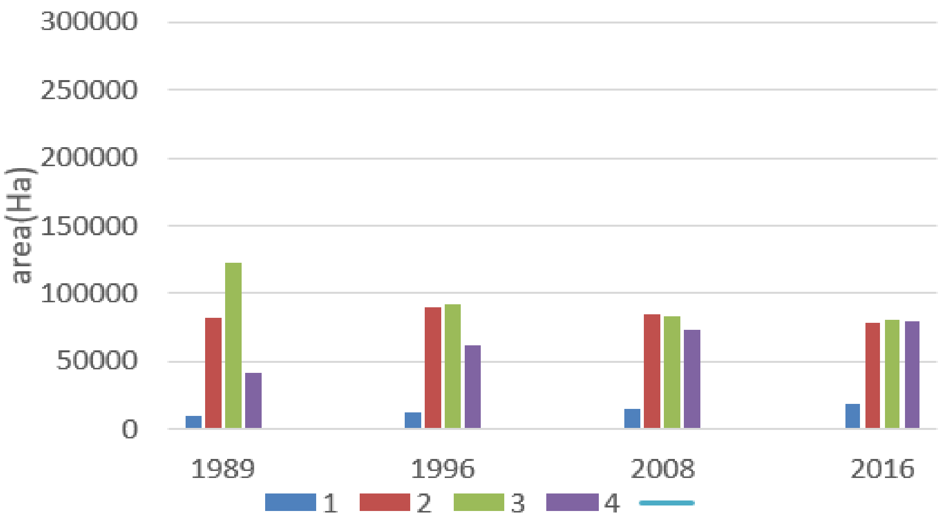

Figure 12: land degradation by area extend

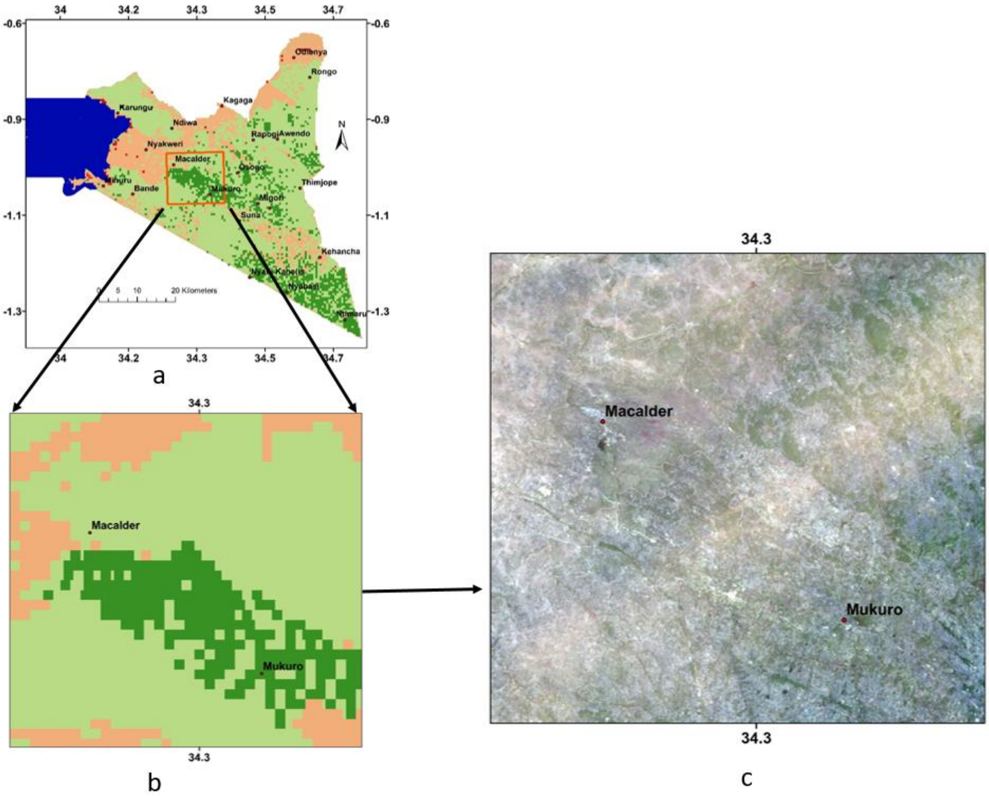

Figure 13: validation of land degradation using satellite image (2016)

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