From Space to Plot: Assessment of Land Degradation Patterns in Kenya and its Implication for Sustainable Land Management

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ABSTRACT

Land degradation occurs at varied temporal and spatial scales making its quantification a great challenge. Assessment of land degradation patterns and types can be done at different scales: plot, farm, landscape, and national/continental and global levels. The benefit of the hierarchical approach is that the findings from one scale can be used to verify the interpretation of information from other scales. Despite this recognition, most studies on land degradation have stopped at their respective scales of assessment with little if any scaling up or out of the results to explore implication at the next scales. This study assessed long term spatial and temporal patterns of land degradation in Kenya using multi-scale satellite data sets and detailed field observations and measurements. At national level, the study determined areas at risk of degradation using Normalize Difference Vegetation Index (NDVI) as a proxy. Systematic site characterization and soil sampling was then undertaken at identified benchmark sites following the Land Degradation Sampling Framework (LDSF). The assessment at national level revealed clear patterns of NDVI change and hence potential for degradation or improvement. The degrading areas span across different agroecological zones humid (Kakamega, Kisii) to arid (Kitui, Narok, Turkana, Garissa) lands suggesting that there are various drivers of degradation in these respective regions. Areas around Lake Turkana and the Eastern province showed greatest risk of degradation. Positive and significant changes in the NDVI slope were observed for some selected locations such as Wajir and Baringo that are located in the dryland areas implying that vegetation cover was increasing over the years. The assessment of land degradation at selected benchmark sites in Western Kenya was able to show in a much finer and clearer way patterns of land degradation often masked when national, continental and global assessments are performed. Over 55% of the farms sampled lacked any form of soil and water conservation (SWC) technologies. Sheet erosion was the most dominant form of soil loss having been observed in over 70% of the farms sampled. Agriculture (crop cultivation) was identified as the main activity with highest impact on the habitat. Major soil chemical properties were found to be below the critical thresholds needed to support meaningful crop production. Of particular concern was the high proportion (90%) of farms having slightly acidic to very strongly acidic soils (pH 4.9- 6.9) soils. The findings of this study provide a solid visual and quantitative basis of land degradation assessment for decision makers and land users in regard to designing and implementing programs for rehabilitation and restoration

INTRODUCTION

Ecosystems or landscapes are in a continuous state of spatio-temporal change caused by natural as well as man-made drivers. These changes have potential to create a mosaic pattern of patches of different sizes and shapes, with different impact on ecosystem functioning (Rapport, 1985). At interfaces of change, ecosystems are likely to experience stresses and this can reflect in some form of degradation. Unfortunately, the complexity of scale (temporal and spatial resolution) and multiple causes or drivers of the stresses makes quantification of these changes a great challenge (Vrieling, 2007).

Land degradation can be defined as the persistent reduction in the biological and economic productivity of terrestrial ecosystems, including soils, vegetation, other biota, and the ecological, biogeochemical and hydrological processes that operate therein (Reynolds, 2001). Literature cites various studies on land degradation, but the principal source of data on this problem include the global estimates of desertification by Dregne and Chou (1994), and of land degradation by the International Soil Reference and Information Centre (Oldeman *et al.*, 1992; Oldeman, 1994). A review of these studies shows that land degradation assessment approaches can take various forms: expert opinion, land user´s opinion, modeling, field observations, monitoring and measurements, productivity change estimates and remote sensing and GIS (Torion, 2002, Kapalanga 2008). Further, these approaches vary in terms of methodology, spatial and temporal scales and hence the application of the resultant outputs. Studies at global and continental scales provide general and broad assessments that are mainly valuable for global environmental monitoring and assessments. Studies at plot and farm levels can be used to target interventions for sustainable land management (SLM). Unfortunately, most studies on land degradation have stopped at their respective scales of assessment with little if any scaling up or out of the results to explore implication at the next lower or higher scales. Complicating the assessment is also the lack of standardized and comprehensive, methodologies or frameworks that can guarantee repeatability that is essential for monitoring long term environmental changes (Hill et al 1995, Vågen et al., 2010).

Several protocols for land degradation assessment have been developed to educate assessors on using observable indicators in order to interpret and assess ecosystem health. Examples of such protocols or frameworks include the Landscape Function Analysis (LFA) (Tongway, 2008), Visual Soil–Field Assessment Tool (VS-Fast) designed to support and enhance the LADA program of the FAO (McGarry, 2004) and the Land Degradation Sampling Framework (LDSF) (Vågen et al., 2010) designed to support the African Soil Information Service (AfSIS) Project. Recent advances in use of Geographical Information System (GIS) and spatial modeling has further improved deployment of the above approaches. Where applied some of these methods have proven to be simple yet robust, ensuring immediate data availability, farmer acceptance and rapid update of the descriptive and measurement tools, leading to rapid assessment of the current condition with a potential for longer-term monitoring (McGarry, 2004).

Based on the problem and opportunities discussed above, a study was conducted in Kenya to assess long term spatial and temporal patterns of land degradation and its implication for sustainable land management.

METHODS

Study area

The study was conducted in Kenya as a whole and in selected districts in western Kenya. The benchmark sites in Western Kenya covered areas of Kakamega, Butere-Mumias and Siaya Districts that lie at 34° 2' 48" - 34° 58' 45"E and 0° 4' 26"S - 0° 36' 15"N and covers an area of about 3,800km^2 (Figure 1). Selection of these sites was based on their potential high risk to degradation due to the high population pressure and intensity of land use. The diversity in the geomorphology, land use and other demographic factors present in these districts offered a unique opportunity to assess the impact of land use change on land degradation and specifically soil erosion and redistribution, deforestation, declining soil fertility, overgrazing among others. The study also meant to complement ongoing research in the region. For example, the region falls within the randomly selected ‘Sentinel sites’ under the African Soil Information Services (AfSIS) project for detailed soil sampling and mapping for the development of the digital soil map of Africa. The region represents a key ‘breadbasket’ area of Kenya and is a focal area for investment by the Alliance for a Green Revolution in Africa (AGRA) and other development partners. The Kenya Agricultural Research Institute (KARI) is implementing projects on scaling out Integrated Soil Fertility Management (ISFM) technologies in Northern Kakamega and Siaya districts. The study therefore aimed at filling an important knowledge gap on land degradation that is essential for the implementation of the above initiatives.

Study design

The hierarchical design of the study enabled assessments at national and local scales. At national level, the study determined areas at risk of degradation using Normalize Difference Vegetation Index (NDVI) as a proxy. Inter-annual changes in NDVI as well as correlations between NDVI and mean annual precipitation (MAP) following the methodology as described by Vlek et al. (2008). This component employed the use of 500 m, Moderate Resolution Imaging Spectroradiometer Normalized Difference Vegetation Index (MODIS/NDVI) data for the period (2000-2009). The data was downloaded from the GLOVIS-USGS website (http://glovis.usgs.gov/). Mean annual precipitation was calculated from gridded climate CRU TS 3.1 (0.5° × 0.5°) data downloaded from the CGIAR-CSI website (http://www.cgiar-csi.org/). The NDVI and the MAP sets of data were then subjected to statistical analyses to assess variability and trends in vegetation productivity. The relationship between inter-annual green biomass (NDVI) and rainfall (MAP) dynamics was computed using Pearson’s correlation coefficient while linear regression was performed to determine the magnitude of change of the NDVI over time (inter-annual change in NDVI) following the procedures as described by Vlek et al. (2008). These procedures enabled identification of areas at risk of degradation, stable or improving.

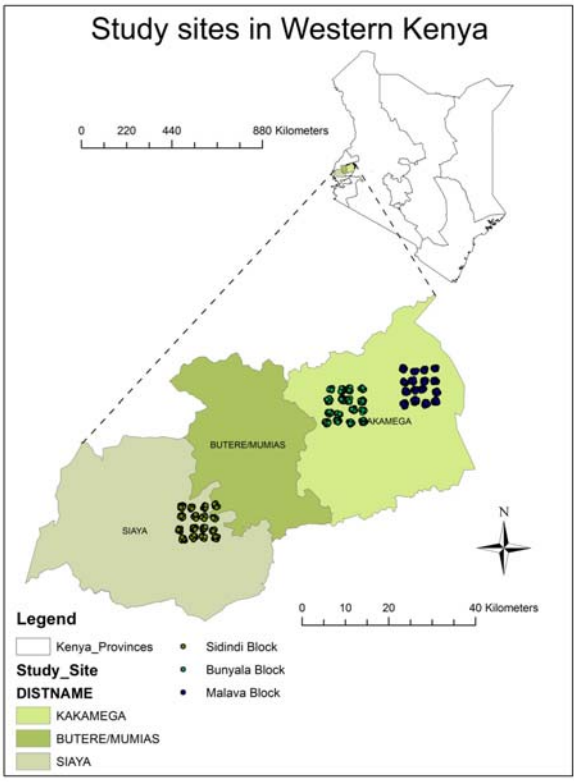

Figure 1. Location of the study site

The study then focused on detailed assessments of environmental changes in selected districts of Western Kenya namely Kakamega, Butere-Mumias and Siaya Districts (Figure 1). Land use/cover change assessment was done by classifying Landsat images for the period 1973, 1988 and 2003. These imageries are freely available for download from the USGS website (http://glovis.usgs.gov/). The data sets comprised of Landsat Multi Spectral Scanner (MSS) for 1973, Thematic Mapper (TM) for 1988 and Enhanced Thematic Mapper (ETM+) for 2003. For consistency in vegetation and land use change comparison, selection of the images was done to ensure that the period of assessment was the same (dry season between January and March). The images were cloud free and fitted very well to the study site since they were already georeferenced. Image processing and land use/cover change assessment was performed using the software Environment for Visualizing Images (ENVI, 4.8 Student Edition). The procedure involved use of both supervised and unsupervised classification (Lillesand and Kiefer, 2000).

Systematic site characterization and soil sampling was undertaken following the adaptation of the Land Degradation Sampling Framework (LDSF) (Vågen et al., 2010). LDSF is a spatially stratified, randomized sampling design framework built around a hierarchical field survey and sampling protocol using "Blocks" and "Clusters". Three (3) sampling "Blocks" measuring 100 km^2 (10 × 10 km) were demarcated in the lower (Sidindi, Siaya), middle (Bunyala, Kakamega) and upper (Malava, Kakamega) catchment of the study area (Figure 1). Location of the blocks was done such that the blocks overlaid areas observed to have had changes in NDVI and to capture the diversity in agro-ecologies, geomorphology and dominant land uses across the study area. Each block was further subdivided into 16 tiles (2.5 × 2.5 km in size) in which a "Cluster" of 10 plots were randomly allocated for detailed sampling and characterization.

All plots were given an identification number (ID), georeferenced using a GPS and altitude recorded. Soil samples were collected from the plots at 0-20 and 20-30cm using a 5 cm diameter and 40 cm long *Eijkelkamp* (model 04.17) undisturbed Split-Tube-soil sampler and processed for standard soil analysis using both wet chemistry and infra-red (IR) spectroscopy techniques (Shepherd *et al.*, 2003; Okalebo et al., 2002). The parameters assessed included total organic carbon (C) and nitrogen (N), phosphorus (P), potassium (K), magnesium (Mg), Calcium (Ca), pH and cation exchange capacity (CEC).

Other data recorded at plot and subplot levels included slope, presence or absence of soil and water conservation structures, herbaceous and tree cover rating, presence of soil erosion as well as impact of various human activities such as grazing, cultivation, fuelwood collection and fire on the environment. These and several other indicators of land degradation were identified, assessed visually and coded on either categorical or ordinal rating scales. These were systematically recorded in a standard field data sheet.

Data analysis

LULC change analysis as well as land degradation pattern mapping were done in remote sensing and GIS environments using ENVI 4.8, ArcGIS 9.2 and ERDAS 8.6. Spatial analysis was performed in ArcGIS to extrapolate biophysical and socioeconomic data to the entire catchment. Pearson Correlation and linear regression models were used to determine trends in NDVI and precipitation and their interrelations for each pixel. Regression analysis and Analysis of Variance (ANOVA) of the soil properties and the LULC was performed in SPSS and STATA.

RESULTS

The assessment at national level revealed clear patterns of inter-annual NDVI change and hence potential for degradation or improvement. Significant changes in NDVI over time were observed across the different agroecological zones: humid (Kakamega, Kisii) to arid (Kitui, Narok, Turkana, Garissa) lands suggesting that there are various drivers of environmental change in these respective regions (Figure 2). Areas around Lake Turkana, Isiolo, Narok, Kitui Makueni and Kwale showed greatest risk of degradation (brown). Positive and significant changes in the NDVI slope were observed for some selected locations such as Wajir and Baringo that are located in the dryland areas (blue) implying that above ground biomass was increasing over the years.

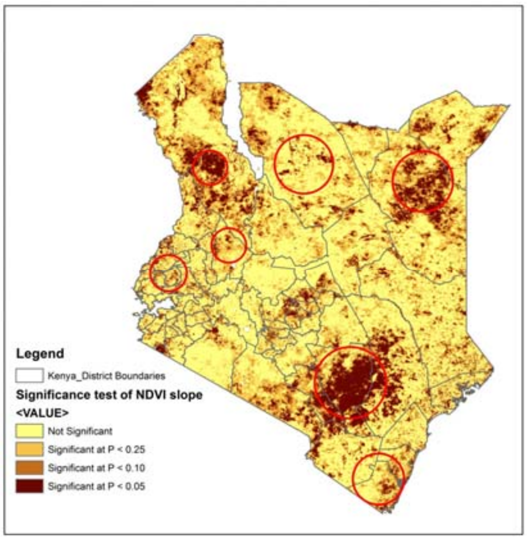

Figure 2. Pixel-based significance of linear slope A over the period 2000-2009

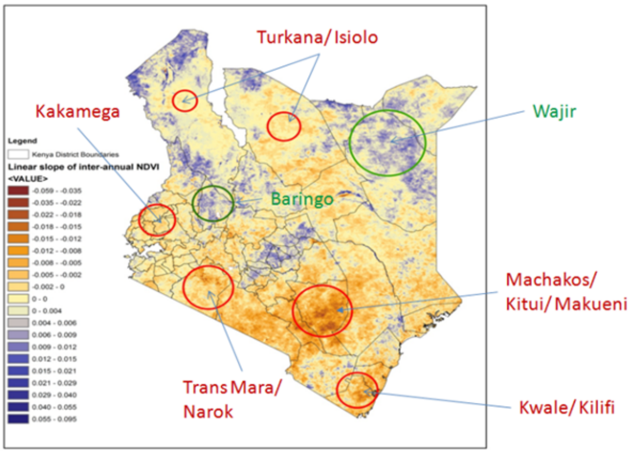

Figure 3. Linear slope of annual NDVI for the period 2000-2009

The assessment at selected districts in Western Kenya showed significant changes in land use had occurred since 1973 (Table 1). The area under agricultural activities increased from 27.9% in 1973 to 70.4% in 2003. Conversely, natural forest cover decreased from 3.9% in 1973 to 3.4% in 2003 and areas under wooded grassland decreased from 51.3% in 1973 to 11.8% in 2003. This increase in agricultural areas can partly be due to conversion of forest and wooded grasslands to farmlands

Table 1. Land use/cover evolution (%) between 1973 and 2003

Class	1973	1988	2003
	Percentage (%)		
Natural Forest	3.9	3.8	3.4
Plantation Forest	0.2	0.1	0.3
Secondary Forest	0.3	1.2	0.5
Bushland	1.7	3.1	5.7
Wooded Grassland	51.3	30.2	11.8
Agricultural Land	27.9	50.5	70.4
Bareland	12.3	8.9	7.4
Water Bodies	2.3	1.1	0.5
Unclassified	2.6	2.1	2.0
Total	100.0	100.0	100.0

Zooming in on benchmark sites revealed even finer patterns of degradation. Over 55% of the farms sampled lacked any form of soil and water conservation (SWC) technologies (Figure 4). Sheet erosion was the most dominant form of soil loss having been observed in over 70% of the farms sampled. Agriculture (crop cultivation) was identified as the main activity with highest impact on the habitat.

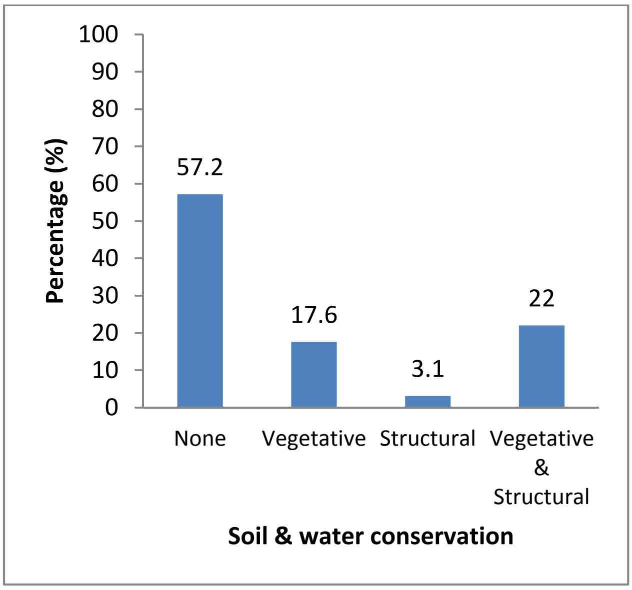

Figure 4. Soil and water conservation practices on the farms

Major soil chemical properties were found to be below the critical thresholds needed to support meaningful crop production. Of particular concern was the high proportion of farms (over 90%) having slightly acidic (pH 6.1-6.5) to very strongly acidic (pH 4.5-5.5) condition. Figure 5 shows pH pattern in Malava Block where areas to the north east had the most acidic soils.

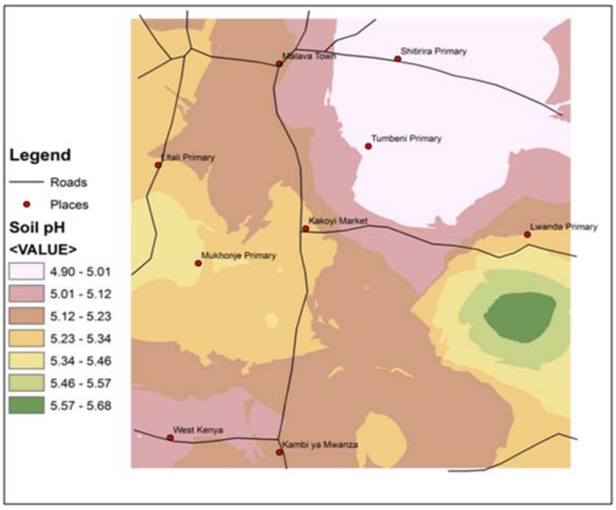

Figure 5. Soil pH pattern in Malava Block

High variation in soil total organic carbon (TOC) was observed across the study site (Figure 6). The values ranged from 1 to 5.9% depending on the land use. Native areas such as forests had the highest TOC as compared to most cropped areas. A critical look at the TOC variation revealed that 17% and 47% of the farms sampled in Malava and Sidindi blocks respectively had low (<1.5%) TOC levels, corresponding to less than 2.5% soil organic matter (SOM). There was a strong positive correlation between CEC and TOC (Figure 7) and this is due to the observation that CEC is highly determined by the level of soil organic matter.

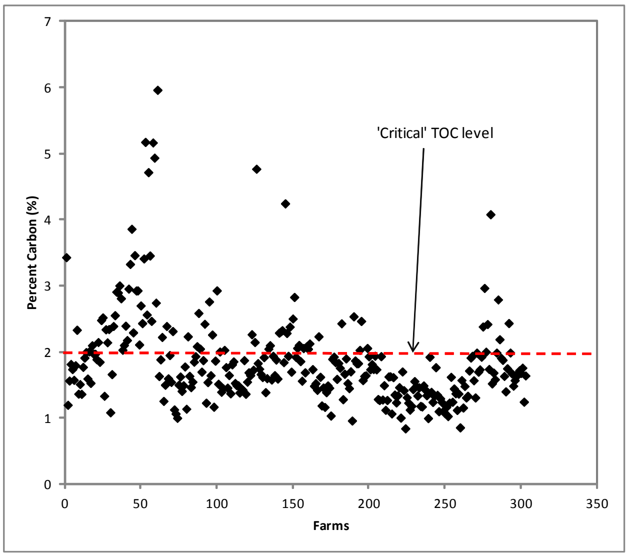

Figure 6. Soil organic Carbon (TOC) variation across the farms sampled in Malava and Sidindi Blocks

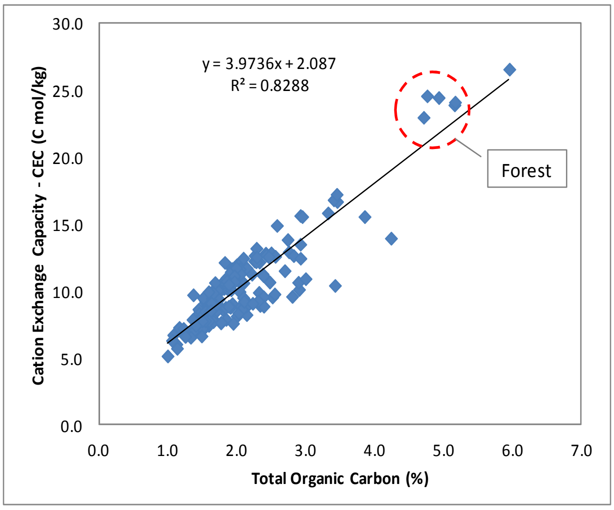

Figure 7: Correlation between Cation Exchange Capacity (CEC) and Total organic Carbon (TOC) for Malava Block

DISCUSSION

The land degradation at national level showed clear patterns of vegetation changes that could be an indicator of degradation. This assessment did not however pin point which types of degradation or drivers are responsible for the patterns observed. The NDVI trend results at national level to a great extent corroborate findings of previous assessment by (Bai and Dent, 2006) which concluded that areas around Lake Turkana and the Eastern province were at the greatest risk of degradation. These two regions are among those identified in this assessment to have significant negative correlation between NDVI and rainfall and also exemplified in the negative inter-annual NDVI slopes. Positive and significant changes in the NDVI slope were observed for some selected locations such as Wajir and Baringo that are located in the dryland areas implying that vegetation cover was increasing over the years. A similar trend of greening of drylands has been documented in studies by Olsson et al. 2005, Vlek et al 2008 and Vlek et al. 2010).

The results on LULC indicate a significant increase in area under agricultural production and a general decrease in areas under natural vegetation formations. Githui et al (2009) in a study of the Nzoia Basin of Western Kenya observed a similar trend where area under agricultural land increased from 39.6% in 1973 to 46.6% in 1986/1988 and to 64.3% in 2000/2001. Conversely, there was a decrease in area under forest. Various studies in and around Kakamega have documented a general decrease in areas under forests cover (ICRAF, 1996; Kamugisha, 1997; Kokwaro, 1988; Lung & Schaab, 2004; Mitchell, 2004; Schaab et al 2009). The study by Mitchell (2004) showed that the forest formations covering Kakamega, North Nandi and South Nandi Forests totaled 74,718 ha in 1913 but had decreased by 34.4% to 25,727 by 2001. Specially, the area of Kakamega forest decreased from 18,388 ha in 1965/67 to 13,335 ha in 2001. The study attributed the changes in forest cover to forest excision to pave way for agricultural land expansion, charcoal burning, pitsawing, grazing and collection of fuelwood. Whereas some of the forest excisions have been legal, the forests continue to suffer from illegal harvesting by timber traders and illegal felling by local communities

Soil acidity was noted to be a major problem across the study sites. Studies indicate that acid soils cover over half a million ha of maize growing areas in Kenya (Kanyanjua et al. 2002). In western Kenya alone, about 57,670 ha of the soils are acidic. Soil acidity can reduce yields through reduced phosphorus (P) availability and increased aluminium (Al) and manganese (Mn) toxicity (O'Hallorans et al., 1997; Hue and Licudine, 1999). Crops tolerance to soil acidity varies. For example, maize the staple crop for the farmers in the region, lies in the medium tolerance range and would do well in soils of pH 5.5-6.0 pH but as indicated most soils have pH below this tolerance level. This justifies the investment by the Alliance for a Green Revolution in Africa (AGRA) to support an initiative by the Kenya Agricultural Research Institute (KARI) that seeks to promote the use of agricultural lime by smallholder farmers in parts of western Kenya.

The results indicated that majority of the farms had very low soil organic carbon contents. Researchers generally agree that despite variation in behaviour of different types of soils, 2% soil organic carbon (SOC) (ca. 3.4% SOM) is a critical threshold below which potentially serious decline in soil quality will occur (Greenland et al. 1975; Kemper and Koch, 1966; Pretty, 1998; Loveland and Webb, 2003). Considering the above threshold, about 55% and 88% of farms in Malava and Sidindi respectively are considered having SOM below the critical level, hence are at a threat of degradation if not well managed. Soils with low SOM have poor water holding capacity and nutrient availability. Such soils also exhibit poor responses to fertilizer application. This can explain why most farmers interviewed observed that the production of the main crop maize was low even with continued use of inorganic fertilizer.

CONCLUSION

Different patterns and indicators of land degradation are evident at different scales of assessment implying that for effective targeting of any interventions scale of assessment is a key consideration in land degradations studies. The results show that the study area has undergone varied land use land cover (LULC) change over the period of assessment with some of the changes resulting in degradation of the land. The findings of this study provide a solid visual and quantitative basis of land degradation assessment for decision makers and land users in regard to designing and implementing programs for rehabilitation and restoration.

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