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RESEARCH ARTICLE

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Effect of Land Use and Land Cover Changes on Land Degradation in Upper Turkwel Watershed

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Abstract

Land use and Land Cover changes continue in Turkwel watershed owing to climate changes and anthropogenic activities and has led to land degradation. Due to the increasing population in watersheds and growing unplanned human settlement with cultivation extending into ecologically fragile areas, others with relatively good agricultural potential, there is a need to manage the changes taking place. The study examined the land use and land cover changes that have taken place in the Upper Turkwel watershed in the period 1987 to 2017 and its effect on land degradation. The research used spatial land use supervised classification approaches to examine trend changes in land use to understand the changes taking place in the watershed and how it is affecting sustainable development of the watershed and in particular Turkwel dam reservoir. The research findings established six dominant land uses namely forest, farmland, shrubland, grassland, bare land, and water and that forest cover, farmland, and shrubland were on the decline in the watershed with a reduction of 73 km2, 116 km2, and 14 km2, respectively and this led to more land degradation dynamics across the watershed.

Keywords: Land Use Land Cover Changes (LULCC), Land degradation, GIS and Climate Change

INTRODUCTION

Sediments at the Turkwel dam similar to all other reservoirs in the tropics is increasing (Avery & Tebbs, 2018) and continuous monitoring is crucial. The Turkwel dam reservoir has a storage capacity of 1,641 million m^3 which is approximate twice the capacity needed in regulating the river flow effectively. Turkwel catchment covers about 5,900 km^2, 70% being within Kenya, and 30% in neighbouring Uganda. The dam was designed to generate 106 MW of electricity to the national grid and have adequate water to develop 1330 ha of furrow irrigation downstream. The dam reservoir levels have a minimum operating altitude level of 1,105 m.a.s.l and an optimum level for operation at 1,131 m.a.s.l. and a maximum water level of 1,150 m.a.s.l.

Increasing population across Turkwel watershed coupled with growing unplanned human settlement and cultivation in ecologically fragile areas of relatively good agricultural potential has accelerated soil erosion problems. Seventy per cent of this watershed is ASAL and very prone to land degradation through soil erosion. These are being aggravated by an in-migration into these ASALs as people from high-density agricultural areas around Kapenguria in the watershed move to these areas looking for a land resource for farming especially where land is communal. Pastoralism, agro-pastoralism, and dryland agriculture are the livelihood strategies adapted to climate conditions in these ASALs. Pastoralism is a livestock-based production system. The ASALs are both prone to droughts and floods despite the low annual rainfall received. Kenya experiences one major drought in every decade and minor ones every three to four years; flood events are frequent in ASALs whenever rainy seasons become too wet (Kagunyu, 2014). The soil erosion problem, in the ASAL area, was also affected negatively by other factors such as topography, soil type, and land cover, and climate change. Soil erosion in Kenya has been a problem since colonial times. Increased pressure on land use of the hilly slopes since the 1970s has resulted in soil losses in the highlands and medium altitudes (Tegegne, 2014; Tesfaye & Kasahun, 2015). Soil erosion in association with inappropriate land management practices is one of the main factors increasing land degradation. During the estimation of reservoir sedimentation rate, researchers mostly neglected the properties of the drainage catchment, the source of the sediment to the reservoir. Inappropriate land and water management practices in these watersheds and lack of planning and implementation approaches of soil conservation are responsible for environmental impacts and economic losses from decreased agricultural production and off-site effects on infrastructures and water quality by sedimentation process (Yihenew *et al.*, 2012; Pravat *et al.*, 2015). The study area, therefore, requires continuous monitoring as the population pressure on land increases and the dynamic effects of climate change continue to aggravate soil losses. It has been documented by many researchers around the world, that LULC change, climate condition, and anthropogenic activities in the upper catchment of reservoirs are responsible for increased reservoir sedimentation (Schiefer *et al.*, 2013). There was an urgent need to examine the Land Use Land Cover Changes in the watershed to understand the changes taking place in the watershed and how it was affecting the sustainable development of the watershed and Turkwel dam reservoir. To improve the technical, economic, and environmental sustainability of such projects, the sediment source, possible changes in the upper catchment, and climate conditions must be studied when considering the useful life of projects and this formed the main focus of the study.

The overall objective, therefore, was to use spatial approaches to study the land Use and Land Cover Changes (LULCC) in Upper Turkwel and assess the consequent land degradation arising from soil erosion; the study monitored Land Use Land Cover Changes over time in the watershed and its influence on the extent of soil erosion. The overall aim was to answer the question of how soil loss was changing with the human population and the land use patterns and how climate change was affecting these interactions.

MATERIALS AND METHODS

The Turkwel river basin covers an area of 5900 km^2 and stretches from Mt Elgon to the Turkwel Gorge. The watershed is drained, by the Kanyangareng and Konyao rivers from the North-West and Suam River from the South-West. Flow regimes of the Suam River at Kongelai and on the upper Suam are continuous throughout the year with two to three relatively dry months. There are two peak flow periods, May and August, corresponding to the wettest months. January to March is a relatively dry period and hence low flows. Turkwel begins from the lush green slopes of Mount Elgon and the Cherangany hills. The river flow is seasonally varied as it is subject to flash floods in the rainy season. The Turkwel Dam is an arch dam on the Turkwel River located at the coordinates 1° 53′ 53.47″ N 35° 20′ 1.34″ E about 76 km north of Kapenguria in West Pokot County, Kenya. The project is a multipurpose one supplying hydroelectric power, irrigation water, spurring tourism and fisheries activities. Turkwel Dam is in Kerio Valley Basin in the Rift Valley region in North-Western Kenya. The dam is Kenyas' tallest with a height of 153 m, crests length of 150 m, and a throwback of 35 km. The Power station is located underground and generates 106 MW to the National grid. The study area is shown in Figure 1.1.

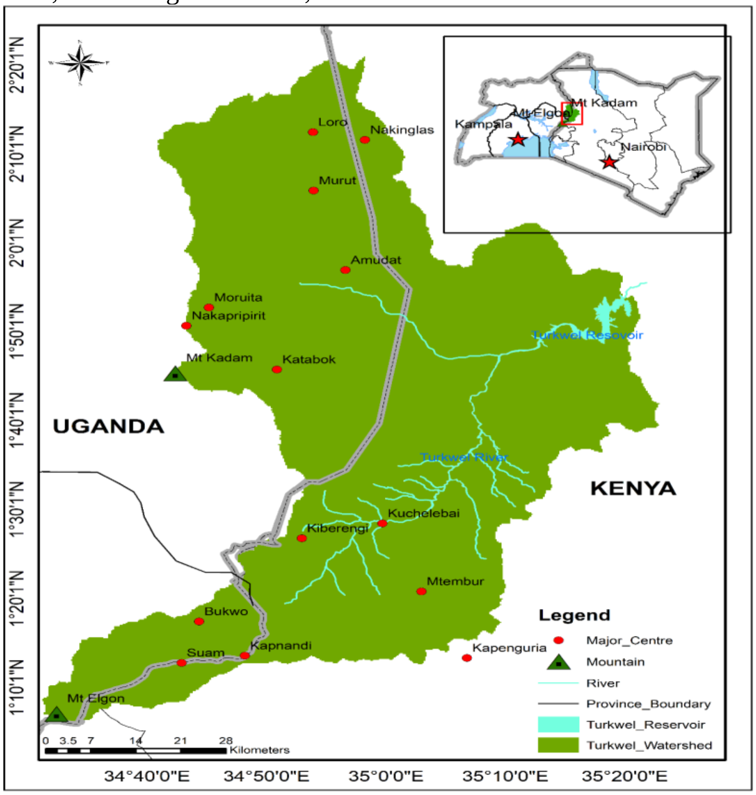

Figure 1.1: Turkwel watershed map.

Digital elevation model and stream network delineation

The digital elevation model (DEM) for 2014, was downloaded from earth explorer 2019 (open data file download service from United States Geological Survey's) Earth Explorer site (http://earthexplorer.usgs.gov/) in ASCII Grid format (2014). The 30 m by 30 m resolution DEM was used to identify and delineate the watershed under spatial analyst extension in ArcMap 10.2.2.1 software. The DEM was, used in creating depressions using the fill tool in ArcGIS. The drainage area was then established, from flow direction and to result in a raster data set and converted to polygons or shapefiles.

By use of the flow direction raster, the flow accumulation tool calculated the number of upstream cells flowing through each cell. Each cell was then assigned a value corresponding to the total number of upstream cells to create a network of streams.

Hydrological response units

Hydrological response units resulted from the main watershed being sub-divided into 19 sub-catchments. The catchment delineation and the Hydrologic Response Units (HRU) were generated primarily about the confluence at Turkwel Gorge dam since it is the basin outlet. By use of ArcGIS version 10.3 the area under each land use was determined and compared for several years to establish land use and land cover changes (LUCCC) that have taken place in the watershed for the last thirty years considering changes by analysing decadal time series satellite images of 1987, 1997, 2007 and 2017. The data were further analysed using STATGRAPHICS with the results given in the Tables highlighting the levels of significant changes in the watershed as of land Use and Land Cover Changes (LUCCC).

The above segmentation enabled simulation of the operations in the sub-basins and estimation of the contribution of each. The analysis of the watershed was done by SWAT as a whole by subdividing it into sub-basins containing the same characteristics forming portions or Hydrological Response Units (HRU), where the dominant land use, soils, and slopes within the sub-basin represent the unit (Arnold *et al.*, 2011). All processes modelled by SWAT are simulated at the locative measure of these units while working on a GIS Platform (Ligonja & Shrestha, 2015). A better estimation of streamflow and sediment concentration is given by the multiple scenarios that accounted for 10% land use, 10% soil, and 20% slope threshold combination (Nilawar & Waikar, 2018). The Turkwel basin resulted in 19 HRUs as shown in Figure 1.2.

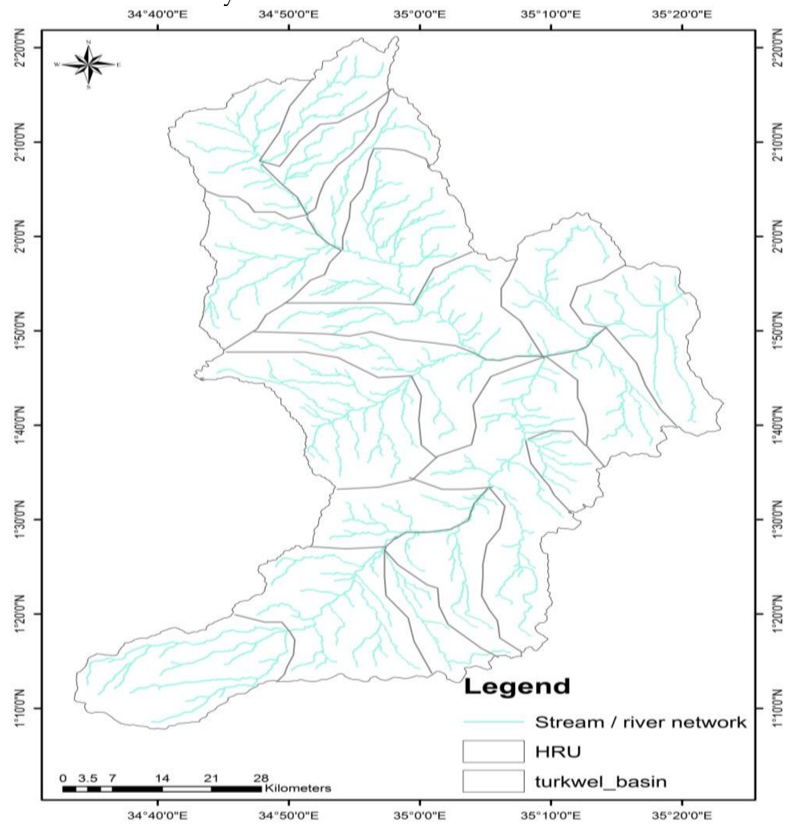

Figure 1.2: Hydrological response units.

This scenario results in the detailed land use, soils, and slope database, containing many HRUs, which in turn represent the heterogeneity of the study area. However, the features of HRUs are the key factors impacting the stream flow and sediment yield.

RESULTS AND DISCUSSION

Land Cover change Trends

The land cover change trends were determined, from 1987-2017, with six dominant lands uses that ranged from the forest through farmland, shrubland, grassland, bare lands to surface water. The land use, land cover change trends are indicated in Figure 1.3 and Table 1.1.

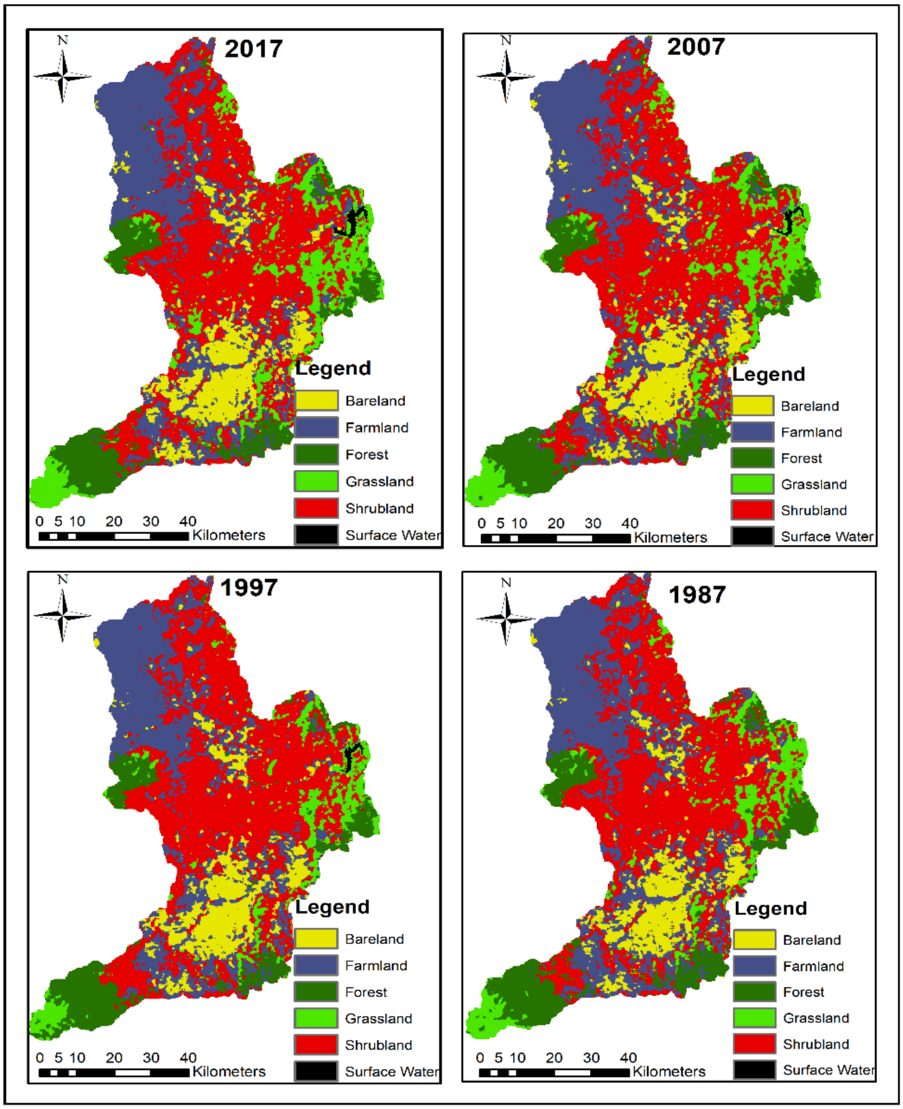

Figure 1.3: Land use and cover change in Turkwel Watershed from 1987 to 2017, derived from LANDSAT TM images path 170, row 59 and 58, and band combinations 4, 3 and 2.

The forest, farmland, and shrubland generally declined between 1987 and 2017 in the Upper Turkwel watershed, while bare land, surface water, and grassland generally increased as shown in Table 1.1 and further illustrated in Figure 1.4.

Table 1.1. Tabulated Land Use and Cover change from 1987 to 2017.

Land use land cover change	1987		1997		2007		2017	
	km²	%	km²	%	km²	%	km²	%
Forest	653.10	11.00%	583.12	9.82%	598.64	10.09%	580.12	9.77%
Grassland	648.87	10.93%	554.09	9.34%	785.31	13.23%	769.13	12.96%
Shrub land	2037.10	34.32%	2261.62	38.10%	2001.55	33.72%	2022.43	34.07%
Farmland	1847.34	31.12%	1731.73	29.18%	1732.21	29.18%	1730.77	29.16%
Bare land	748.20	12.61%	789.75	13.31%	801.53	13.50%	809.88	13.64%
Surface Water	0.86	0.01%	15.15	0.26%	16.22	0.27%	23.13	0.39%
Total	**5935.46**	**100.00%**	**5935.46**	**100.00%**	**5935.46**	**100.00%**	**5935.46**	**100.00%**

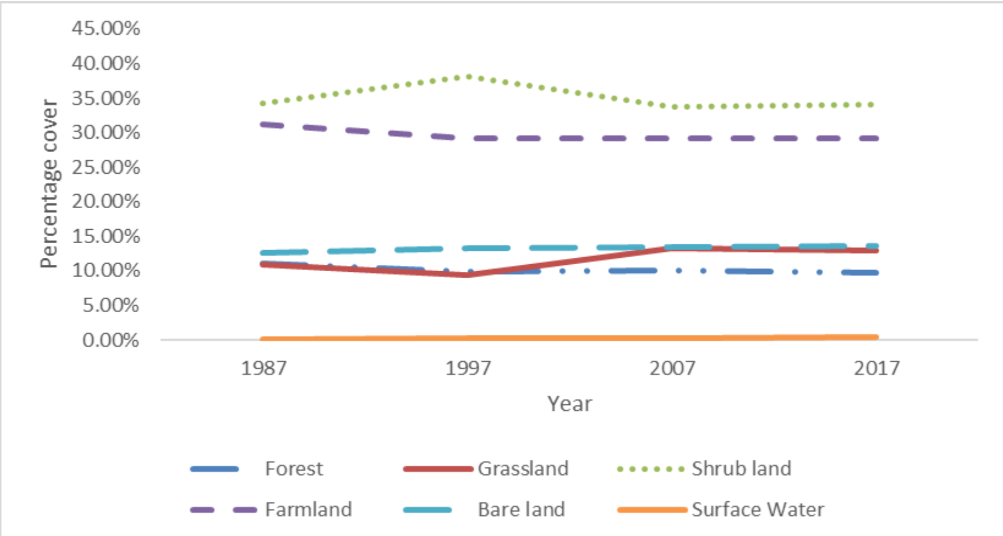

Figure 1.4: Land use and land cover changes in Upper Turkwel (1987-2017).

Rate of Land Use Change in Upper Turkwel (1987-2017)

The forest and grassland decline was highest between 1987 and 1997 mainly due to low precipitation experienced in the area and at the time which resulted in the highest rate of bare land increase as droughts, were experienced in the area during this time. The surface water increased from 1990, following Turkwel dam completion and impounding from 10th January 1990 to date with minor fluctuations from season to season but generally increasing in level due to sedimentation. Various soil conservation practices applied by farmers on their farm plots are critical components of natural resource management in order to achieve, acceptable and sustainable agricultural ecosystem integrity (Tegegne, 2014; Tesfaye & Kasahun, 2015). The period between 1997 and 2007 had more conservation efforts by KVDA and VI Agroforestry and led to the highest rate of grassland increase mainly due to the establishment of several enclosures spread over 24 sites in the basin as in Table 1.2.

Table 1.2: Rate and magnitude of land use land cover change

	1987-1997		1997-2007		2007-2017		1987-2017	
Area change	**km^2**	**%**	**km^2**	**%**	**km^2**	**%**	**km^2**	**%**
Forest	-69.98	-1.18%	15.53	0.26%	-18.53	-0.31%	-72.98	-1.23%
Grassland	-94.78	-1.60%	231.21	3.90%	-16.17	-0.27%	120.26	2.03%
Shrub land	224.52	3.78%	-260.07	-4.38%	20.88	0.35%	-14.67	-0.25%
Farmland	-115.61	-1.95%	0.48	0.01%	-1.45	-0.02%	-116.57	-1.96%
Bare land	41.55	0.70%	11.78	0.20%	8.35	0.14%	61.68	1.04%
Surface water	14.30	0.24%	1.07	0.02%	6.91	0.12%	22.28	0.38%

DISCUSSION OF RESULTS

The general trends in Land Use Cover Changes per land-use varied during the study period as detailed below.

Forest land

The forest cover plays a very significant role as a habitat for the millions of animals taking refuge there, and for general ecological balance around entire watershed regions. Therefore, there is quite a demanding and necessary task in improving the amount of forest cover in watersheds. According to the study, the forest cover experienced a gradual insignificant decrease by 73 km^2 from 1987 to 2017($F_{0.05}$ (1, 2) =3.01, p=0.2251). The forest cover increased insignificantly by 15.53 km^2, between 1997 and 2007. These were mainly due to reliable rains experienced and intensified efforts by environmental bodies during this period, that included MENR, KWS, UNEP, VI - Agroforestry, KVDA, KENGEN, and Educational Institutions. The residents during this period helped in improving the ecological balance through planting more trees on farms to increase forest cover being the habitat for a large number of animals and plants. The efforts by KVDA and VI agroforestry through the supply of tree seedlings at affordable prices resulted in many trees planted during this period. The effort led to several enclosures and woodlots established on farms, and primary as well as secondary schools. These followed the intensive campaigns that led to several commercial forest establishments on farms with many existing to date (Wairore *et al*., 2016).

Farm Land

The farmland insignificantly decreased from 1847. 34 km^2 in 1987 to 1730.77 in 2017 ($F_{0.05}$ (1, 2) =3.08, p=0.2211). With notable insignificant decrease by 115.61 km^2 between 1987 and 1997 arising mainly from farmers in the low altitude areas preferring livestock keeping instead of crop farming and an overall insignificance reduction from 1987 to 2017 by 116 km^2. There is however an inconsistent trend in agricultural activities which could result from climate change effects being experienced in the region especially the unpredictable weather and more frequent droughts due to climate change leading to many farmers not consistently carrying out crop farming especially in the ASAL areas. Similar findings were, noted from studies in Mandera County in North-Eastern Kenya (Tawane & Wahkhungu, 2018)

Grassland

Area covered by grassland has been insignificantly increasing from 1987 to 2017 by 120.26 km^2 ($F_{0.05}$ (1, 2) =1.95, p=0.2975). There was a notable increase in area covered by grassland between 1997 and 2007. These are due to reliable rains during this period and many the abandoning the nomadic lifestyles. The farmers, during these periods following intensive extension service by KVDA and VI Agroforestry, established their enclosures. These enclosures were spread over 24 sites in the ASAL areas of the study area and laying appropriate conservation measures reinforced by a supply of pasture seeds for reseeding that included Boma Rhodes, *Cenchrus ciliaris* and *Eragrostis Superba*. The enclosures accorded the natural vegetation opportunity to rejuvenate naturally improving ground cover as the vegetation is allowed to establish for some time without livestock interferences giving a sustainable livelihood option as was observed in studies in Chepareria in the same County with environmental benefits and other studies elsewhere (Wairore, 2015; Cerda & Doerr, 2005).

Shrubland/Rangeland

The area covered by shrubland has generally been constant during the study period; where there has been change, it has been insignificant, with a negligible decline of 14.67 km^2 (($F_{0.05}$ (1, 2)) =0.23, p=0.6769). The area is occupied by pastoralists and given the fact that more than 70% is rangeland/shrubland and many farmers got discouraged to continue crop farming owing to frequent droughts.

Bare land

There was a consistent and statistically insignificant increase of bare land in the Upper Turkwel watershed between 1987 and 2017 with a total of 61.68 km^2 **(**$F_{0.05}$ (1, 2) =12.49, p=0.0716). These are due to climate change and the increasing population leading to more pressure on land resources with growing livestock and frequent droughts experienced in the area which is one of the consequences of global warming (Cramer *et al*., 2018). This increase leads to more land degradation arising from soil erosion acceleration on bare lands. Soil erosion is both a cause and effect of land degradation in especially the ASAL areas with climate change and land-use dynamics as important drivers (FAO & ITPS, 2015; Serpa *et al*., 2015).

Surface Water

The area under water increased by a large margin following the completion of the Turkwel dam and impounding in 1990. The surface area increased to 14.3 km^2 in 1997. The surface water area consistently continued to increase insignificantly to 23. 13 km^2 in 2017 ($F_{0.05}$ (1, 2) = 14.49, p=0.0626). These are due to the conservation effort by conservation agencies that include KVDA, KWS, MENR, Line Ministries of Agriculture, Non-Governmental Organisations such as VI -Agroforestry conservation of forest in the gazetted areas such as Mt. Elgon Forest (a Ramsar site and classified as a well-conserved biosphere) and within farms in the study area. Turkwel dam has never filled to full capacity. The blue colour appearance of the water is an indication of lower turbidity and therefore a positive effect brought about by the concerted conservation efforts of the past. More conservation efforts will lead to a prolonged lifespan of the project and sustainable development at the upper catchment.

CONCLUSION

The forest land and farmland declined by 73 km^2 and 116 km^2, respectively with bare land area increasing by 61.68 km^2 during the study period this could be a pointer of growing desertification and land degradation confirming the reality of global warming as bare land was a precursor to increasing soil erosion by both wind and water with worst-case scenarios observed in the expansive ASAL areas of the catchment. The increasing grassland cover by 120 km^2 has led to increasing livestock production as the mainstay of the inhabitants on the fragile ASAL ecosystems leading to overgrazing and more crop farmland converted to grassland with a noted decline by 116 km^2 during the study period.

RECOMMENDATION

It is therefore necessary that more studies to establish the reasons for many farmers switching to livestock ventures and explore more sustainable ways of sustainable development through carefully introduced conservation approaches and grazing systems that reduce the negative impacts on the environment. Development partners and County Governments should intensify efforts to improve the ecological balance and increase vegetation cover in the low altitude areas and increase forest cover in the high altitude areas.

Acknowledgments

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