Effects of Land Use Changes on Water Quality in a disturbed Tropical Stream in Njoro, Kenya

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Abstract

This study investigated the effects of land use /land cover changes on water quality in the Njoro stream over a period of 27 years. Land sat MSS and Land sat ETM+ (path 185, row 31) were used in this study. The Land sat ETM+ image (June 1987, May, 2000 and July, 2014) was downloaded from USGS Earth Resources Observation Systems data website. Remote sensing image processing was done using ERDAS Imagine 9.1. Three Land Use/Land Cover (LULC) classes were established as forest, shrub land and settlement. Severe land cover changes were found to have occurred from 1987-2000, where settlement increased by -52%, shrub land reduced by +19%, and forestry reduced by +72%. In 2000 – 2014, settlement increased by -121%, shrub land reduced by +45%, and forestry reduced by +64% (where positive denotes decrease and negative denotes increase). Forestry and shrub land were found to be consistently reducing while settlement was increasing. It was found that 21% of the watershed community used bore hole or tap water, 59% used river water, 19% wells and 1% dams. It was also found that 10 years ago the clarity of water in the stream was higher than the present. It was observed that the water has been increasingly becoming muddy over this period. Water quality assessment showed that Egerton Bridge had the highest Biological Oxygen Demand incubated for 5 days (BOD_5) of 24mg/l followed by Canning factory, Kenyatta bridge and Njoro bridge each with 20mg/l with the least being Mary Joy followed closely by Confluence and Nessuit with 13 and 14mg/l respectively. Nitrate and phosphate were significantly different among the seven sampling sites. Despite the sediment loads from erosion and the impacts of land cover change, the stream water remained suitable for human consumption.

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Introduction

Social scientists and land managers define land use in terms of social and economic purposes and contexts for and within which lands are managed (or left unmanaged), such as subsistence versus commercial agriculture, rented vs. owned, or private vs. public land. Land cover, which is the concern of this study, can be observed directly in the field or by remote sensing. Observations of land use and its changes however, require the integration of natural and social scientific methods (expert knowledge, interviews with land managers) to determine which human activities are occurring in different parts of the landscape, even when land cover appears to be the same. For example, areas covered by woody vegetation may represent an undisturbed natural shrub land, a forest preserve recovering from a fire, re-growth following tree harvest (forestry), or a tea plantation. As a result, scientific investigation of the causes and consequences of Land Use/Land Cover change (LULCC) requires an interdisciplinary approach integrating both natural and social scientific methods, which has emerged as the new discipline of land-change science.

The LULCC is continuously changing the Njoro stream ecosystem, thereby threatening sustainability and livelihood systems of the people. Biodiversity is facing widespread competition with humanity as human population increases, resulting in increasing conflict between economic development and the need for biodiversity conservation. LULCC plays a major role in the study of global change. LULCC and human/natural modifications have largely resulted in deforestation, biodiversity loss, global warming and increase of natural disaster-flooding (Fan *et al*, 2007, Dwivedi, *et al*, 2005). These environmental problems are often related to LULC changes. Therefore, available data on LULC changes can provide critical input to decision-making on environmental management and planning the future (Fan, *et al*, 2010, Prenzel, 2004). The growing population and increasing socio-economic necessities create a pressure on land use/land cover and water resources. This pressure results in unplanned and uncontrolled changes in LULC (Seto, *et al*, 2002). The LULCC alterations or change in the state of the ecosystem are generally driven by pressures resulting from mismanagement of agricultural, urban and forest lands including water resources which lead to severe environmental impacts such as landslides and water pollution that require a response to abate disaster.

The middle Njoro stream Watershed has experienced significant land cover transformations with attendant concerns related to environmental and economic sustainability. This area has been undergoing a new phase of rapid land use change in the upper and middle portions of the middle watershed and continued significant growth in both rural and urban population. This change in land use has exposed the land and water to various pressures resulting from poor management, low cost technologies for soil fertility management, water protection, continued use of inappropriate technologies and intensive cultivation. There was therefore a need to understand how land use changes had affected the environmental sustainability and water resources of the study area. This study was therefore aimed at establishing the extent of land cover/land use change and its impact on water quality over the last 27 years from1987 to 2014.

Study Area

Njoro town is located in Nakuru County on the eastern edge of the Mau Forest Complex, the largest single forest blocks in Kenya. The area lies between the forest and Lake Nakuru National Park, a world famous flamingo habitat. The greater Nakuru District is situated between 35° 28′ – 35° 36′ E longitude and 0° 13′ – 1°10′ S latitude. The area of the study covers about 8,170 Ha and lies between latitudes 0° 15′ S and 0° 25′ S and longitudes of 35° 50′ E and 36° 00′ E. The whole watershed has a population of about three hundred thousand (300,000) people with more than three thousand (3000) individual farm holding units (Baldyga, *et al.,* 2003). However, according to Kenya National Bureau of Statistics, Njoro Sub County registered a population of 23,551 people having grown by 3% from a population of 22, 845 people in 1999 (KNBS, 2009). Based on the same growth rate, the watershed population may have also grown to 309,000 people with around 3100 households. Due to the heavy settlement in the middle watershed, it is estimated to be home to about 2000 farm holding units in an area of more than 8,000 hectares with slopes ranging from < 2 to > 18 % and soils being predominantly volcanic clay loam except near the lake where silt clay is found (Mainuri and Owino, 2013

Methods

A baseline survey at household-level encompassing socio-economic changes and impacts of land use activities in the middle Njoro stream Watershed was established. Additionally, information on factors influencing land use decisions, productivity factors and change in economic activities were sought through use of a questionnaire. The middle Njoro stream Watershed household survey was to target an area of approximately 8000 hectares. Three Landsat scenes were selected

(1987, 2000 and 2014) for this study. These dates captured the major excision and settlement changes that have taken place in the watershed. Effort was made to acquire imagery that corresponds with major land use/land cover changes within this period and then relating them to changes in water quality.

The study utilized 200 questionnaires which were administered to homesteads that were initially identified at random on both sides of the stream. The questionnaires were subjected to scrutiny for completeness and consistency and the way they addressed the various issues intended to be captured. The questionnaires were sorted out and entered into the SPSS (version 20) work sheet. With the descriptive and categorical nature of most of the questions, simple descriptive analysis was done using SPSS and inferential statistics performed based on the results.

Land Use field data

Data on the driving factors that influence land use decisions in the Middle Njoro stream drainage basin was gathered through semi-structured interviews with the farmers (land owners) and six (6) key informants selected at random based on their areas of operation including an agriculturist, environmentalist, social economist and NGOs in the region. Local group officials such as self-help groups, Friends of River Njoro and Water Resource Users Association (WRUA), were also interviewed concerning stream water quality, land use history and the perceived processes driving land use in the area.

Image Classification

Land sat MSS and Land sat ETM+ (path 185, row 31) were used in this study. The Land sat ETM+ images (June 1987, May, 2000 and July, 2014) were downloaded from USGS Earth Resources Observation Systems data. The dates of both images were chosen to be as closely as possible in the same vegetation season. All visible and infrared bands were included in the analysis. Remote sensing image processing was performed using ERDAS Imagine 9.1.Five LULC classes were established as commercial farms, forest, settlement, subsistence farms and shrub land. Three dated Land sat images (1987, 2000 and 2014) were compared using supervised classification technique. In the supervised classification technique, three images with different dates were independently classified. A Supervised classification method was carried out using training areas. Maximum Likelihood Algorithm was employed to detect the land cover types in ERDAS Imagine 9.1.

Water Quality Assessment

The water assessment entailed the assessment of all human activities and impacts on the water resources. The current status of physical environment, the land-use activities, the demands and the various impacts, impacting on water resources were determined through a questionnaire during the study and water samples taken for laboratory analysis. In addition, to the investigation of the prevailing conditions, future developments and impacts on the water resources within the watershed were also captured.

Results and Discussions

Assessment of water quality showed that the mean Biological Oxygen Demand incubated for 5 days (BOD_5) values varied between 12 and 24 mg/l) and were significantly different among the seven study sites (one-way ANOVA, F9.11, $P < 0.05$). Egerton Bridge had the highest BOD_5 of 24mg/l followed by Canning factory, Kenyatta bridge and Njoro bridge each with 20mg/l with the least being Mary Joy followed closely by Confluence and Nessuit with 13 and 14mg/l respectively. Nitrate and phosphate were significantly different among the seven sampling sites. The phosphate was 94% dependent on the site and highly significant $p<0.005$, while nitrates were only 9% controlled by site with $p>0.005$ (Table 1). This therefore meant that phosphate accumulation in the water was highly controlled by the site while accumulation of nitrates depended on other factors other than the site. Nitrates remained constant in all the sites meaning that nitrates build up is not a serious problem in surface water. Runoff from the surrounding fields can also be a source of nitrates and phosphates in water because soil contains organic matter, which contains nitrogen compounds. Just like the ammonia in water, the nitrogen compounds in the soil are converted by bacteria into nitrates. Although nitrates occur naturally in soil and water, an excess level of nitrates can be considered to be a contaminant of surface water. Most of these nitrates come from human activities within the watershed and even neighboring regions. The source of excess nitrates can usually be traced to agricultural activities, human wastes being deposited into the stream. Nitrogen fertilizers being applied to the fields, also add nitrates to the stream through runoff. Rainwater can therefore wash nitrates in the fertilizer into the stream. This can also occur with animal waste and manure.

Table 1. One way ANOVA (pH, DO, BOD, temperature, Nitrates and Phosphates versus site

Level	pH		DO		BOD_5		Temp		NO_3		PO_4	
	m	sd	m	sd	m	sd	m	sd	m	sd	m	sd
Canning factory	6.8	0.3	9.7	5.8	20	9.7	21	1.7	0.4	0.04	0.39	0.03
Confluence	6.3	0.6	8.2	1.7	13	5.7	19	1.0	0.4	0.07	0.10	0.01
Egerton bridge	6.7	0.7	12.1	8.9	24	11.6	20	0.7	0.4	0.08	0.18	0.03
Kenyatta	6.5	0.3	10.2	7.6	20	9.0	22	0.9	0.4	0.02	0.39	0.05
Mary Joy	6.5	0.2	8.2	2.2	12	3.9	20	1.0	0.4	0.05	0.13	0.03
Nessuit	6.6	0.3	8.0	2.7	14	5.8	17	1.6	0.4	0.08	0.13	0.04
Njoro bridge	6.8	0.5	10.1	6.8	20	9.2	21	0.7	0.4	0.01	0.36	0.03
R^2values %	15		7		26		72		9		94	
P values	0.713		0.944		0.322		0.000		0.539		0.000	

Key: BOD - Biological Oxygen Demand, DO – Dissolved Oxygen, ANOVA – Analysis of variance

Nitrates however, were 43% dependent on the season with $p<0.005$. This may be due to the effects of runoff and dry spells. Phosphates were not dependent on the season possibly suggesting that phosphate inputs were not dependent on rainfall or no rainfall as evidenced by the low dependence of only 3% (Table 2). Agricultural practices that are season based can contribute to elevated phosphorous levels in surface waters through the addition of phosphorous in the form of manure or commercial fertilizer in the fields. Phosphorous however, tends to bind tightly to soils and therefore does not leach into water systems as easily as some other nutrients. This therefore, may be the reason why it is not dependent on the seasons.

Table 2. One way ANOVA (Ph, DO, BOD, Temperature, Nitrates and Phosphates versus season)

Level	pH		DO		BOD_5		Temp		NO_3		PO_4	
	m	sd	m	sd	m	sd	m	sd	m	sd	m	sd
Dry	6.8	0.5	12.1	6.6	11.9	6.8	19.0	1.8	0.4	0.02	0.2	0.1
Wet	6.4	0.3	7.0	0.5	23.1	6.0	21.0	1.6	0.4	0.03	0.3	0.1
R^2 values%	18		24		45		25		43		3	
P value	0.025		0.008		0.000		0.007		0.000		0.3777	

Key: BOD - Biological Oxygen Demand, DO – Dissolved Oxygen, ANOVA – Analysis of variance

The regression equation for BOD_5 which was; $BOD_5 = - 21.4 + 1.94$ temp $- 0.53$ ph $- 0.889$ DO$+ 24.0$ nitrates $+ 8.4$ phosphates, indicated that an increase in Dissolved Oxygen (DO) and pH brought a reduction in BOD, while a reduction in the two parameters caused an increase in BOD. An increase in temperature nitrates and phosphates resulted in an increase in BOD_5. BOD_5 = - 21.4 + 1.94 temp - 0.53 ph - 0.889 DO + 24.0 nitrates + 8.4 phosphate (Table 3). BOD in water was telling how much oxygen was being consumed by bacteria in the decomposition of organic material in the water and also the oxygen that was required for the oxidation of various chemicals in the water. On the other hand Dissolved Oxygen (DO) gave an indication of how much oxygen was available for use by the bacteria. The temperature of the water helped in the determination of how much of the oxygen was to be dissolved. During the wet seasons when the temperatures were low dissolving was easier. Due to land cover/land use change resulting from deforestation and removal of riparian vegetation by human activities, oxygen concentration in the water may be lower due to increased water temperature resulting from lack of canopy shade. Increased suspended solids resulting from erosion of the bare soil will also be a factor in reducing oxygen concentration in the water. All the eight stations in the stream had high values of dissolved oxygen which is an indicator of a healthy stream. These high levels will also support a greater diversity of aquatic organisms.

Table 3. Regression Analysis: BOD_5 versus Temperature, ph, DO, Nitrates, Phosphates

	coef	SEcoef	T	P
Predictor constant	-21.36	25.98	-0.82	0.420
Temp	1.943	0.883	2.20	0.038
pH	-0.528	2.925	-0.18	0.858
DO	-0.889	0.230	-3.87	0.001
Nitrates	23.96	31.69	0.76	0.458
Phosphates	8.37	12.72	0.66	0.518

Key: BOD - Biological Oxygen Demand, DO – Dissolved Oxygen

S = 4.90665 R-Sq = 72.7% R-Sq (adj) = 66.5%

The results also show that the dependence of BOD_5 and nitrates on the season was highly significant p<0.005, while DO and temperature were significant (p=0.008 and p=0.007) respectively (Table 3). The seasons explained 45% and 43% of the variability in nitrate and BOD_5 concentrations in the seven sites. In contrast, a non significant variation was recorded for phosphates and pH in all the seven sites. Nitrate concentrations remained the same among the seven sites. A narrow range of average values was observed on the phosphate concentrations in the seven sites during the study period. The highest mean value of phosphate concentrations were recorded in Canning factory, Kenyatta Bridge and Njoro bridge with 0.39, 0.39 and 0.36mg/l respectively, whilst the lowest was recorded at the Confluence, 0.1mg/l.

The main source of drinking water for the residents of Kenyatta, Njoro and Nessuit was from the stream by 59% of the respondents. This therefore meant that the quality of the stream was a major concern because more than half of the residents depended on it. Quite a number depended on boreholes (21%), with wells taking 19%. A very small proportion (1%) of the total relied on dams as a main source of water for drinking.

Color of Water in Streams

It can be noted that 10 years ago the clarity of water in the nearby streams was higher than the present. On the other hand, water has been increasingly becoming muddy for the last 10 years. The reasons for these changes could possibly be due to runoff from surrounding farms as a result of clearing the buffer zones by the farmers in search of cultivation areas. It was also observed that the paths that animals and human beings use to the river generated a lot of runoff which also contributed great amounts of sediments to the river.

Flow of Water in Streams

At present the stream flow in most of the streams (43.5%) is more seasonal as it varies depending on the amount of rainfall (Table 4). The same stream's volume has relatively gone down (38.5%) as compared to 6.5% which is increase in the flow volume. Nevertheless, 11.5% of the streams have maintained unchanging stream flow. An interview carried out with some key informants concerning land use activities that have been observed over the period of study indicated that the main environmental impacts were the general increase in agricultural activities on riparian zones that have heavily changed the flow and quality of stream water. This has emanated from pressures exerted by the increase in the number of people settling along the river Njoro. There is also a lot of water abstraction along the entire stretch of the stream either through domestic use, animal watering and irrigation. There are also incidents along the stream of people diverting the water and also obstructing the flow by blocking the water way.

Table 4. Perceived changes in flow of water in the stream

Nature of flow	Frequency of respondents	Per cent
Increasing	13	6.5
Decreasing	77	38.5
Unchanging	23	11.5
More seasonal	87	43.5
Total	200	100.0

Land Use Activities and Factors influencing decisions

In Table 5, out of the two hundred (200) respondents interviewed, 88 per cent of them were farmers, 3 per cent were business persons, 3 per cent masons, 3 per cent crafts men and 3 per cent teachers. Respondents' level of education refers to the actual number of years spent in school. It is observed from Table 5 that 50 per cent of the respondents have obtained up to primary education, while 20 per cent have not obtained any formal education. A lower proportion (33%) had obtained secondary and post secondary level of education. Seventy per cent (70%) of the respondents had primary level education and below. The finding indicates that most of the respondents in the middle river Njoro watershed had low formal education and this affected the way in which they responded to new information on resource conservation and how they also received innovative ideas. A big portion of the watershed inhabitants (73 %) agreed that settlement has been increasing while 27 per cent of them feel that settlement has not been significant. This is because some of the people have settled recently and after their settlement no notable additions of new people have come in compared to the older settlers who have experienced tremendous changes in the number of people settling in the area. Ninety three per cent of the watershed inhabitants have observed massive land use changes which have also translated into tons of soil going to the river during the wet seasons indicated by the water color. A small group of people (7%) have the feeling that there has not been any noticeable change in land use. This possibly could be that they have recently settled in the area and since they settled there has been no change. Climate change impacts through heavy rains and drought have been felt by 31 per cent of the people with a bigger population of 69 per cent not having experienced any effects of climate change. The main reason is that older settlers have experienced the older days of heavy rains and current frequent droughts as compared to the new settlers who have not seen a change in the current frequent droughts and low rains. The pressures exerted by the society through waste disposal, over cultivation and deforestation may have led to unintentional or intentional changes in the state of the stream ecosystem. However, only 4 per cent of the respondents had observed any pollution or degradation of the stream ecosystem with a huge population of 96 per cent not feeling or not being aware of the impacts possibly because they may have been used to the water color and its general condition.

Table 5. Responses on the current environmental condition of the Watershed

Age of respondent (years)		Highest level of education		Climate change		Pollution/ degradation		Settlement		LULCC of natural vegetation		Occupation	
	%		%		%		%		%		%		%
<30	3	Pry	50	Y	31	Y	4	Y	73	incr	93	Fr	88
30-40	30	Sec	17	N	69	N	96	N	27	N/incr	7	Bp	3
40-50	30	Trt	13									Ms	3
>50	37	None	20									Cm	3
												Tr	3

Key: Y-yes, N-No, Pry- primary, Sec- secondary, Trt- Tertiary, B/p- business person incr- increased, N/incr – not increased, Cm- craftsman, Ms- Mason, Tr- teacher, Fr- farmer

Almost all the land portions, as per the data gathered from the respondents do not have title deeds although allocation was done by the government about 20 years ago. It was established during the study survey that most farms were seriously affected by soil erosion which was evidently seen in the red color of the stream during rains as most farmers were not observing any conservation measures due to land tenure/ land ownership issues and the fact that most of the population had very low or no formal education to be able to respond appropriately by adopting new technologies of soil and water conservation. Hence, soil erosion was found to be notably rampant in Nessuit areas which have higher slopes with 70 per cent of the respondents reporting severe erosion in the steeper slopes, 20 per cent reported severe erosion on gentle slopes and 10 per cent on flat grounds, while 20 per cent of the people reported moderate erosion on steep areas, 69 per cent reported moderate erosion on gentle slopes and 11 per cent on flat grounds. Eighty per cent of the respondents reported no erosion on gentle slopes and 20 per cent reported no erosion on flat areas. Nobody gave any evidence of no erosion on steep slopes (Table 6).

Table 6. Level of Soil Erosion in the farms

Slope of the land	Level of erosion as reported by farmers (%)		
	Severe	Moderate	No erosion
Steep	70	20	0
Gentle	20	69	80
Flat	10	11	20

As a result of no proper land ownership, most people are shy to invest in long term development activities and majority are sluggish or unable to take soil and water conservation measures. Assessment of driving forces behind land use change and their impacts on water quality was done to capture past patterns and also to be able to forecast future patterns. Driving forces on land use included most of the factors that influenced human activity that exert pressure on the stream ecosystem, including population increase, poverty, land tenure and markets. In addition, other underlying factors that drive actions like food preference and demand for specific products, financial incentives and environmental state indicators such as soil quality, water quality, and terrain and moisture availability played a great role.

Increasing land use changes were observed in the middle river Njoro watershed ecosystem over the last twenty seven (27) years. These changes resulted from a number of factors, but mainly related to habitat loss due to agricultural encroachment and settlement which have also affected the quality and quantity of water in the stream. Information about changing patterns of land use/cover through time and the factors influencing such changes have been captured in the change detection maps of 1987, 2000 and 2014 and the results summarized in Table 7.

Table 7. Areal extent of land cover change

Class Type in hectares	1987 Hectares T1	2000 Hectares T2	2014 Hectares T3	ΔHa 1987-2000 T1-T2	ΔHa 2000-2014 T2-T3
Forest	1460.898	405.351	145.712	+72%.	+64%
Settlement	437.403	664.109	1470.364	-52%,	-121%
Shrub land	849.281	687.820	373.150	+19%,	+45%

In the year 1987 the area occupied by forest was 1461 ha which was quite huge compared with other years. This was the time when the East Mau had its forest intact with rich biodiversity and a lot of forest resources and cool moderate temperatures. The area was receiving more and reliable rainfall than it is today. The number of people settled in this area during this time was also low occupying only 437 ha.

In the year 2000, only 13 years later, the forest reduced by almost four times from 1461 ha to 405 ha which was a drop of 72 per cent. This was a clear indicator of massive forest destruction which also turned the once permanent Njoro stream to a semi permanent stream, a situation that has persisted to date. Huge areas of forest were turned to agriculture or the trees were cut for timber. The timber harvesting was actually a big business in this region indicated by the numerous saw mills that were established in the area during this period (personal communication). The settled area went up from 437 ha in 1987 to 664 ha. This was an increase of 52 per cent. The settled area meant more people who also strained the water resources in the area through pollution and abstraction.

The settled area in the year 2014 went up by 121 per cent from 664 ha to 1470 ha. This was a huge increase in the number of people in the area of study. The people come with demands on forest and water resources. These demands have exerted pressure on the forest reducing it by a further 64 per cent from 405 ha to 146 ha. It was evident from the respondents that 44 per cent of the people agreed that the stream flows only in the rainy seasons. About 40 per cent of the residents feel that the quantity and quality of the water in the stream has drastically gone down.

Conclusion

The removal of natural vegetation (LULCC) in the middle River Njoro watershed has decreased the forest area by 1314 hectares and shrub land by 475 hectares. Settlement increased by 1032 hectares. These changes in land cover/land use have left soil exposed to erosive forces with 70 per cent of the respondents reporting severe erosion in the steeper slopes, 20 per cent reporting severe erosion on gentle slopes and 10 per cent on flat grounds. These land use changes and the impacts of erosion have affected the stream quantity and quality of water with 44 per cent of the inhabitants acknowledging a reduction in the flow of the stream with water only flowing in the rainy season and even at this time the water is too muddy/ brown in color making it quite uncomfortable for human use. A further 39 per cent of the people agree that the volume of water in the stream has decreased drastically over the years. Despite the sediment loads from erosion and the impacts of land cover change, the stream water remained suitable for human consumption as supported by average BOD of above 20mg/l across the stream.

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