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Assessment of Hydrological Impacts of Mau Forest, Kenya

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Abstract

Mau Forest Complex is the largest closed-canopy montane ecosystem in Eastern Africa that encompasses seven forest blocks namely Mau Narok, Maasai Mau, Eastern Mau, Western Mau, Southern Mau, South West Mau and Transmara regions and the main catchment area for 12 rivers. However, over the past years, it has undergone significant land use changes due to increased human population demanding land for settlement and subsistence agriculture. Previous studies carried out in Mau have always demonstrated the relationship between deforestation and rate of forest degradation, but the effects on water quality and the impact on tourism resulting from the flamingoes migration has not been addressed adequately.

Using Landsat images for four different epochs that is 1984, 1994, 2003 and 2015 comparative analysis of land-use land-cover (LULC) changes was carried out. The study demonstrated that the size of forest cover in Mau have been changing from 1984 to present. This is due to deforestation and agricultural activities taking place within the forested areas of Mau.

Keywords: Mau complex; Hydrological issues; Lesser flamingos; Lake nakuru

Introduction

The Mau Forest Complex is the largest closed-canopy montane ecosystem in Eastern Africa. It encompasses seven forest blocks within the Mau Narok, Maasai Mau, Eastern Mau, Western Mau, Southern Mau, South West Mau and Transmara regions. The area is thus the largest water tower in the region, being the main catchment area for 12 rivers draining into Lake Baringo, Lake Nakuru, Lake Turkana, Lake Natron and the Trans-boundary Lake Victoria [1].

However, in the past three decades or so, the Mau Forest Complex has undergone significant land use changes due to increased human population demanding land for settlement and subsistence agriculture. The encroachment has led to drastic and considerable land fragmentation, deforestation of the headwater catchments and destruction of wetlands previously existing within the fertile upstream parts. Today, the effects of the anthropogenic activities are slowly taking toll as is evident from the diminishing river discharges during periods of low flows, and deterioration of river water qualities through pollution from point and non-point sources [2].

The Mau Complex is drained mainly by 12 rivers including Rivers Njoro, Molo, Nderit, Makalia, Naishi, Kerio, Mara, Ewaso Nyiro, Sondu, Nyando, Yala and Nzoia. In the last three decades, physical evidence has revealed that the rivers in the complex have had significant decline in discharges, coupled by dwindling water quality. Other studies have also highlighted the changing hydrological response of the area are as a result of the land use/land cover changes [3].

The previous studies carried out in Mau have always demonstrated the relationship between deforestation and rate of forest degradation, but the effects on water quality and the impact on tourism resulting from the flamingoes migration has not been addressed adequately. For instance Landsat images from 1986 to 2000 have been used to address land degradation of Mau forest [1].

Apart from being the largest closed-canopy montane in Eastern Africa, the catchment basin has two important biodiversity zones namely the forests shrouding the catchment's upper reaches and Lake Nakuru national park. Interposed between these two zones are human habitations with less biodiversity value, but which are dependent either directly or indirectly on ecological services provided by high biodiversity zones [4]. Lake Nakuru is the home to various flamingoes. Currently the number of flamingoes in the lake has been declining with some migrating to other saline lakes due to urbanization and industrialization within the nearby Nakuru town.

Lake Nakuru national park

Lake Nakuru National park occupies 188km^2 [4]. It has very high concentration of wildlife consisting of 70 mammal species, 400 bird species and over 200 plant species. Lake Nakuru, which forms the centerpiece of this showcase of wildlife is internationally renowned for the large concentrations of lesser flamingos that use it for feeding, displaying and occasionally, for breeding. The water-bird assemblage, scenic beauty and central location of the town make this lake a tourist destination. The park has also contributed to the socio-economic development of Nakuru town and its environs through tourism development, hotel accommodation, food, curio sales and other entrepreneur activities.

Lesser flamingos have unpredictable spontaneous movements between the alkaline lakes, whose ecological triggers and forcing functions are not well known. This can be attributed to the following factors ranging from changes in food quality and quantity, breeding migrations, alkalinity changes, fresh water requirements and predation pressure. Lake Nakuru has witnessed dramatic changes in land use over the recent decades resulting in the destruction of critical

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watersheds. The most important threats relate to the sustained supply of water to the lake which is threatened by deforestation and degradation of the Mau catchment areas and by upstream water abstraction. The massive population of lesser flamingoes depend on a network of at least ten 'flamingo lakes', so any significant ecological change in any of the other lakes (in Kenya, Ethiopia and Tanzania) could have a devastating impact on the entire system.

Major indications of a stressed Lake Nakuru ecosystem dates back to 1990 when there was mass fish deaths followed by the 1993 flamingo mortalities and the 1994 lake drying, a response to cumulative effect of disastrous negative impact on the catchment that resulted into lake environmental degradation. Since 1995, the, Arthrospira fusiformis, (the preferred food for the lesser flamingoes) population in the lake has only made occasional and very transient appearances. Flamingo occupation of the lake over the same period has also shown a declining.

Dumping site

Nakuru Municipality, the region's largest town, has expanded its geographic reach more than four and half times since 1970. The expansion is due to high urban migration in the area resulting to high volume of waste collected by the municipality. The town is also located on a higher ground, which means all the waste from the town and dumping site easily finds their way to the lake.

Two miles to the North West of Nakuru municipality along Nakuru-Kabarak road is the Giotto dumpsite on a large site of about 50 hectares in a place known as Kiamunyi and it is an open dumping site. It was started in 1972 to help with the dumping of collected waste from the town. It is the main dumpsite for the domestic waste, agriculture waste, hospital waste and electronic waste. Each day the town generates an estimated 240 tons of domestic solid waste. About 60% of this is removed to approved dumping sites, the rest accumulates in the environment and is eventually deposited into the lake by storm water and wind. With the population increase, it has resulted to the growing burden of waste generated.

The previous studies carried on Lake Nakuru have not paid sufficient attention to the dumping site and industrial waste from Nakuru town. While exaggerating the effects of human activities on Mau forest which is the main source of Lake Nakuru, they have neglected the effects of the dumping site. Moreover, they have exaggerated the positive effects of human activities (ecological engineering) while neglecting the ecological risks of industrialization and urbanization. These two areas of exaggeration can potentially lead to misinterpretations of the outcomes of appropriate policies that support restoration projects.

Research Questions

The following questions are posed to help guide the study

What are some of the changes in forest cover within Mau complex for the past 20yrs?

What are some of the impacts on Lake Nakuru due to deforestation and various agricultural activities within the catchment area?

What impacts does the dumping site at Nakuru town has on Lake Nakuru?

What will be the impacts on lesser flamingoes and tourism sector if Lake Nakuru diminishes due to siltation?

Study Objectives

The main objective of this study is to determine forest cover within changes Mau complex for the past 20 years.

Specific objectives

To determine some of the impacts on Lake Nakuru given the current rate of deforestation and various agricultural activities at the source of various its rivers.

To determine the impacts of the dumping site at Nakuru town on lake Nakuru.

To determine the impacts on tourism sector and the lesser flamingoes if Lake Nakuru diminishes due to siltation and other environmental effects.

Scope of the Study

The study area has been limited to a section of Mau catchment area, this is because the whole catchment covers a large area. Therefore the study only focusses on south western and western parts of the catchment area as shown in Figure 1 below.

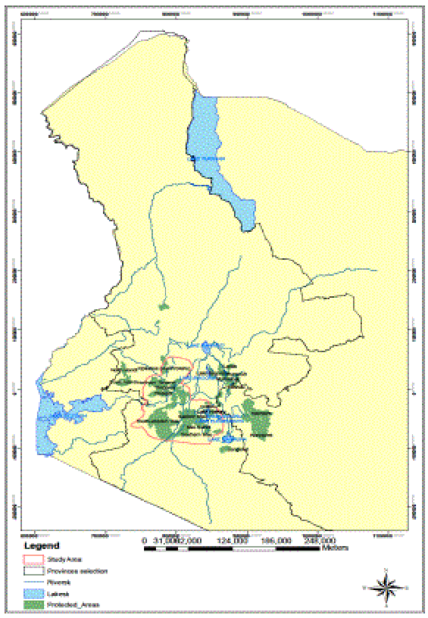

Figure 1: Map showing Mau catchment area.

Study Methodology

The study was divided into three parts, image analysis, GIS integration and theoretical analysis and concepts. Landsat images acquired from 1984 to 2015 were used for the analysis. The processing and analysis were done using Erdas Imagine, ENVI and ArcGIS. Figure 2 below shows the outline of the study.

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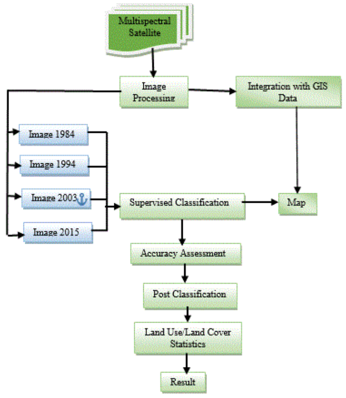

Figure 2: Study outline.

Study Area Location

The catchment is located in Rift valley province and is situated at 0° 34' 23".90 S and 35° 39' 26".61 E. Figure 3 below shows the map of the study area.

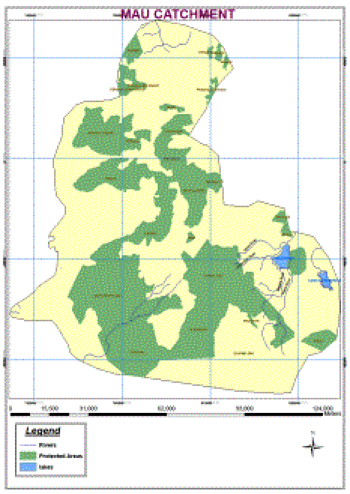

Figure 3: Mau catchment map.

Literature Review

Early studies in the Amazon basin investigated the degradation mapping potential of Landsat imagery by applying visual interpretation [5,6]. Extensive studies in Central Africa used Landsat imagery from three decades to derive area estimates of land cover change by combining a systematic regional sampling scheme, based on high-spatial-resolution imagery with object-based unsupervised classification techniques [7] to track the progression of logging roads. Higher resolution data has been used to track skid trails and tree felling [8]. Basic investigation work in the Congo Basin on the temporal and spatial resolution needed to detect selective logging from remote sensing data has been performed in the Central African Republic [9]. In Cameroon and the Republic of Congo, there has been some degradation monitoring work, based on SAR imagery, e.g., from CosmoSkyMed data using a 3D approach [9], with promising results.

Also, several studies focusing mainly on time analysis series for forest monitoring has been carried out in various areas around the world. For instance, drought forecasting in Somalia [10] or mapping selective logging activities in Brazil [11]. Same has also been applied in non-tropical areas, like forest disturbance detection in Northern Maine [12]. With regard to tropical forest monitoring, a supervised classification approach was followed in Indonesia [13]. individual epochs were classified and the changes in terms of tree cover were classified [14]. Considerable thematic developments and mapping work was done using a denser time series (bi-annual to annual) [15-17].

Data Analysis and Presentation

The analysis of the data was carried out in Erdas Imagine, ENVI and ArcGIS softwares. Several steps in image processing and analysis were carried out in order to obtain the final results.

Image processing

Remote-sensing-based detection of forest degradation is difficult, as these subtle degradation signals are not easy to detect in the first place and quickly lost over time due to fast re-vegetation. To overcome these shortcomings, a time series analysis has been developed to map and monitor forest degradation over a longer period of time, with frequent updates based on Landsat data [18].

Four Landsat TM satellite images of Mau were acquired for 1984, 1994, 2003 and 2015 with a spatial resolution of 30m. The images for the same months were not easy to obtain due to cloud coverage by some. Processing of these images was done using ERDAS Imagine and ENVI. ERDAS Imagine was used to layer stack the images and to subset. Classification, post classification and accuracy determination was carried out in ENVI.

Layer stacking: Landsat images are often distributed as Geotiff files (with separate Geotiff files for each band). A Geotiff is like a standard .tiff image file but has geographical information (coordinates) embedded. Each spectral band may be given as a separate Geotiff file and must be overlaid into one master file before analysis [19].

The Geotiff files were imported into ERDAS imagine and converted to .img files. Each band was then layer stack to form a new multiband image in ERDAS as shown in Figure 4.

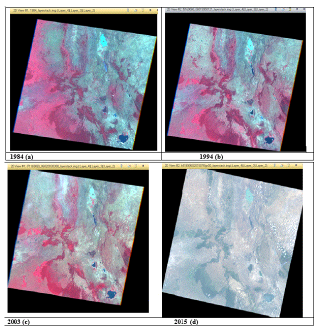

Figure 4: Layer Stacks for 1984, 1994, 2003 and 2015.

Subsetting: Subsetting involves clipping of the datasets for instance the layer stack images using by either defining the boundary from the image or by use of a polygon. It removes data outside the area of interest reducing the file size and improving the processing time for many operations [20-22].

Mau forest covers a large area; therefore a subset of the area was used based on a shape file generated in ArcMap. The shape file was used to create a subset of the study area. All the four images were clipped using the same shape file as shown in Figure 5 below.

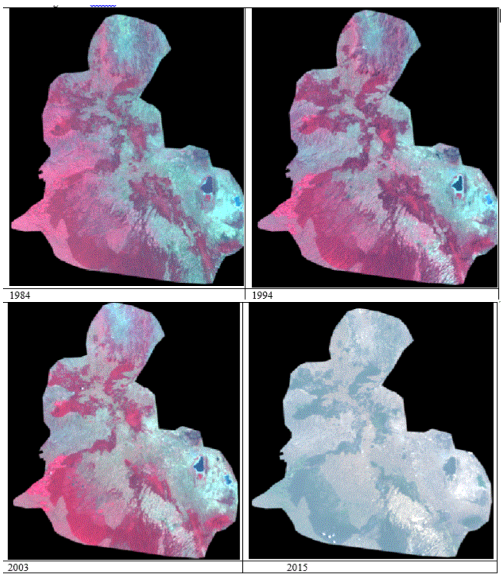

Figure 5: Subsets for 1984, 1994, 2003 and 2015 images.

Classification: Classification involves dividing the study area into distinct classes as determined from spectral reflectance of the classes. This is done in the software. There are two types of classification, unsupervised and supervised classification that can be performed with any Remote Sensing software, this study was based on supervised classification.

Supervised classification involves selecting representative samples for each land cover class (training sites) in the digital image. The training sites are used by the software to identify land cover classes in the entire image. The classification of land cover is based on the spectral signature defined in the training set. The digital image classification software determines each class on what it resembles most in the training set. Most common type of supervise classification is maximum likelihood and minimum distance. This study utilized maximum likelihood classification technique to come up with seven classes as shown in Table 1a below. The process was carried out using ENVI 4.7. The signature file was generated for all the regions of interest taking into account homogeneous representation of all areas. The signatures were then used to obtain the various classes for the image.

Post classification: In order to obtain the class statistics for all the classes generated, post classification was carried out in ENVI.

The values obtained were used to compute changes for the classes.

Integration of satellite images with GIS data

Integration was done in ArcGIS. The processed images were opened in ArcMap and various shape files such as rivers and districts overlaid on the image. Lakes and forest were digitized from the processed image to show the changes that have taken place.

Data Analysis and Discussion of Results

Image analysis

Supervised classification: A supervised (full Gaussian) maximum likelihood classification was implemented for the four images and the final classification products provided an overview of the major land use/land cover features of Mau forest reserve for the years 1984, 1994, 2003 and 2015. Classification was carried out in ENVI by defining seven homogeneous training classes (Region of Interest) for the four images. The training classes were then used to obtain the classes from classification [23].

Seven categories of land use/land cover were identified; these are: Dense forest, cultivated land, forest, plantation, vegetation, bare land and water body. Figures 6 and 7 below illustrate the land use/land cover map of Mau forest reserve for the year 1984, 1994, 2003 and 2015 and comparison between each two successive epoch. In each image, atleast one feature class shared a color with the background; however this was accounted for in post classification by subtracting the background the area of the background from the total area covered by the color.

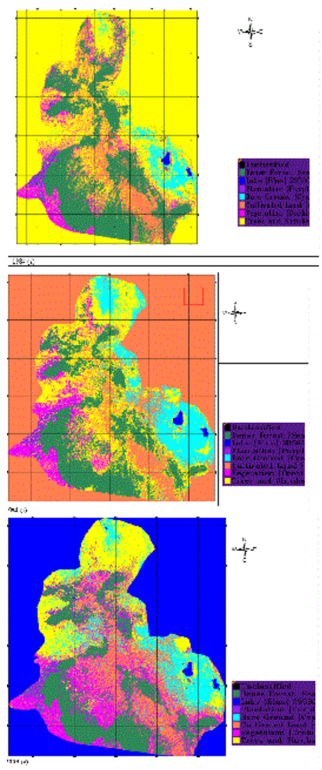

Figure 6: Classified Images for 1984, 1994, 2003 and 2015.

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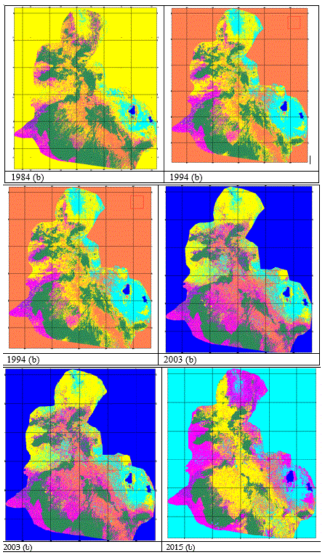

Figure 7: Comparison of Each Two Successive Image.

Post classification: In order to obtain the area extent of the resulting land use/land cover type for each study year and for subsequent comparison, post classification was carried out in ENVI to obtain class statistics in area in meters square. A constant figure of 8387.796 km^2 was subtracted from all the classes that had the same color as the background color in order to obtain the exact area of the feature class. The percentage change for every year was also computed and results shown in Tables 1a and 1b below.

	1984(km²)	1994(km²)	2003(km²)	2015(km²)
Water	72.03	67.32	57.5	44.12
Dense Forest	4138.408	2971.94	2695.328	2100.384
Plantation	191.6964	324.8019	619.8174	498.2762
Bare Ground	636.2676	1736.625	1493.375	1136.573
Cultivated Land	1347.354	1449.505	1984.38	1093.728
Vegetation	1108.332	1012.982	1758.144	3046.075
Trees and Shrubs	3674.442	3565.999	2500.987	3165.849
Total	11168.53	11129.172	11109.531	10586.729

Table 1a: Land Use/Land cover Distribution for Year 1984, 1994, 2003 and 2015 in km^2.

	1984 (%)	1994(%)	2003 (%)	2015 (%)
Water	0.64	0.6	0.52	0.42
Dense Forest	37.05	26.7	24.26	19.84
Plantation	1.716	2.92	5.58	4.71
Bare Ground	5.7	15.6	13.44	10.74
Cultivated Land	12.06	13.02	17.86	10.33
Vegetation	9.92	9.1	15.82	28.77
Trees and Shrubs	32.9	32.04	22.51	29.9

Table 1b: Land Use/Land cover Percentage Distribution for Year 1984, 1994, 2003 and 2015.

Confusion matrix: Confusion Matrix shows the accuracy of a classification result by comparing a classification result with ground truth information. Confusion matrix was calculated in ENVI using ground truth Region of Interest (ROIs). This was in order to produce the overall accuracy, producer and user accuracies as shown below for each year (Figure 8).

Class	Prod. Acc. (Percent)	User Acc. (Percent)	Prod. Acc. (Pixels)	User Acc. (Pixels)
Unclassified	0.00	0.00	0/0	0/0
Dense Forest	100.00	100.00	4598231/4598231	4598231/4598231
Lake [Blue] 2	100.00	100.00	49018/49018	49018/49018
Plantation [P	100.00	100.00	212996/212996	212996/212996
Bare Ground [	100.00	100.00	706964/706964	706964/706964
Cultivated La	100.00	100.00	1497060/1497060	1497060/1497060
Vegetation [O	100.00	100.00	1231480/1231480	1231480/1231480
Trees and Shr	100.00	100.00	13402487/13402487	13402487/13402487

Class	Prod. Acc. (Percent)	User Acc. (Percent)	Prod. Acc. (Pixels)	User Acc. (Pixels)
Unclassified	0.00	0.00	0/0	0/0
Water [Blue]	100.00	100.00	63888/63888	63888/63888
Dense Forest	100.00	100.00	3302156/3302156	3302156/3302156
Plantation [P	100.00	100.00	360891/360891	360891/360891
Bare Ground [	100.00	100.00	1929583/1929583	1929583/1929583
Cultivated La	100.00	100.00	10930335/10930335	10930335/10930335
Vegetation [O	100.00	100.00	1125535/1125535	1125535/1125535
Trees and Shr	100.00	100.00	3962221/3962221	3962221/3962221

Class	Prod. Acc. (Percent)	User Acc. (Percent)	Prod. Acc. (Pixels)	User Acc. (Pixels)
Unclassified	0.00	0.00	0/0	0/0
Water [Blue]	100.00	100.00	9394575/9394575	9394575/9394575
Dense Forest	100.00	100.00	2994809/2994809	2994809/2994809
Plantation [P	100.00	100.00	688686/688686	688686/688686
Bare Ground [	100.00	100.00	1659305/1659305	1659305/1659305
Cultivated La	100.00	100.00	2204867/2204867	2204867/2204867
Vegetation [O	100.00	100.00	1953493/1953493	1953493/1953493
Trees and Shr	100.00	100.00	2778874/2778874	2778874/2778874

Class	Prod. Acc. (Percent)	User Acc. (Percent)	Prod. Acc. (Pixels)	User Acc. (Pixels)
Unclassified	0.00	0.00	0/0	0/0
Lake [Blue] 1	100.00	100.00	320159/320159	320159/320159
Dense Forest	100.00	100.00	9335040/9335040	9335040/9335040
Plantation [P	100.00	100.00	2214561/2214561	2214561/2214561
Bare Ground [	100.00	100.00	42330529/42330529	42330529/42330529
Cultivated La	100.00	100.00	4861014/4861014	4861014/4861014
Vegetation [O	100.00	100.00	13538113/13538113	13538113/13538113
Trees and Shr	100.00	100.00	14070440/14070440	14070440/14070440

Figure 8: Over producer and user accuracies from 1984-2015.

Discussion of the Results

The 1984, 1994, 2003 and 2000 land use/land cover practice in this depleting Mau Forest Reserve were determined in order to ascertain the causes of deforestation and various impacts on Lake Nakuru. Seven major classes were identified and classified as land use/cover of all the four images as follows: Lakes, bare ground, cultivated land, dense forest, plantation, vegetation and trees and shrubs. However, amongst these seven major classes, cultivated land and plantation were found to be the practices leading to forest depletion. Vegetation and trees and shrubs are the results of the depleted dense forest while bare ground describes either areas that had been cleared or could not sustain growth of any kind of vegetation.

The sizes of dense forest and lakes have been declining significantly from 1984 to 2015 as shown in the Figure 9 below. This is from the fact that there has been a lot of illegal cutting down of trees and clearing of land for cultivation within. As a result, the impact of depleting forest

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has negatively impacted on various lakes that draw their water from Mau forest and the surrounding as a whole.

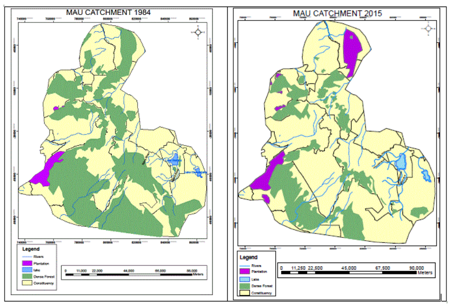

Figure 9: Mau Catchment Map in 1984 and 2015.

Impacts of deforestation and agricultural activities on Lake Nakuru

When forest cover bonding the soil in a lake basin is destroyed, the result is usually an increase in land erosion and sediment transport, which in turn leads to reduced lake water quality which limits the penetration of light into the water column. The soil being of volcanic origin and due to its high porosity, permeability and its loose structure is highly susceptible to erosion, land sinking and fractures during or after heavy rain. Deforestation would therefore decreases natural seepage into underground aquifers, leading to accelerated surface runoff.

Soils have only a limited capacity to absorb nutrients used to increase crop production. The nutrients which are not taken up by the soil/plant system leach into the surface and are carried into the lake by runoff resulting in water quality problems related to Eutrophication. In addition the amount of organic nitrogen from animal waste also increases due to high livestock densities. It has been estimated that the average sediment yield in Lake Nakuru watershed is of the order 100 to 300 tons/km^2/year. Nutrient enrichment is a large-scale problem in Lake Nakuru. It results in reduced productivity of the lake's natural primary producer Arthospira fusiformis and frequent occurrence of toxic blue-green algae blooms. This phenomenon easily leads to desertion of the lake by lesser flamingos.

The destruction of forests in the Lake Nakuru catchment basin not only has consequences for the biodiversity they support but also cumulative impacts on the catchment hydrology. The hydrology of the lake is dependent on catchment supply through rivers, demanding for catchment integrity to sustain the lake levels. The shallow depth of 4.5m, the high evaporation rates and seasonal rivers make the lake a hydrologically impacted ecosystem, since it does not have any buffering capacity to withstand hydrological impacts driven by catchment processes [4].

Impacts of environmental effects and siltation to the tourism sector

Water pollution is a significant threat. The presence of pollutants in the lake has resulted in an imbalance in the ecosystem that has caused a food shortage for the flamingos. The diminishing flamingo food could also be the result of the introduction of tilapia that led to competition for the planktonic blue-green alga, (Spirulina platensis) fed on by the flamingos. This could be a possible cause for migration of flamingos to other lakes including Lake Simbi Nyaima in Western Kenya among others.

In the place of Arthrospira fusiformisthe algal composition of the lake has been largely dominated by undesirable species of blue-green algae such as Microcystis sp. and Anabaena sp. Both these species are known to flourish in nutrient rich waters with high organic content and both are capable of elaborating potent hepatic and neuro toxins to which birds and fish are susceptible.

Encroachment on wetlands and flamingo breeding areas has resulted to flamingo and fish mortality due to diseases, parasites, predation and toxic pollution. The ecological effect of this has been the loss of biodiversity through migration of the birds to other water bodies within the rift valley where complimentary food is available. All these cumulatively result in the reduced revenues associated with ecotourism [4].

Impacts of the dumping site to Lake Nakuru

Like most cities, Nakuru is a huge consumer of resources, and a prodigious producer of waste. Of the municipal waste generated in the urban centers, 21% emanates from industrial areas and 61% from residential area. Generally, about 40% of the total waste generated in urban centers is collected and disposed of at the designated disposal sites. About 60% of this is removed to approved dumping sites, the rest accumulates in the environment and is eventually deposited into the lake by storm water and wind. With the population increase, it has resulted to the growing burden of waste generated. As a result of these developments, water balance and water quality of Lake Nakuru and its feeder streams have been adversely affected. Studies done on the site reveal high concentration of heavy metals in soil sample. This indicates how dangerous the site might be to human health and the surrounding environment.

Conclusion

The study have demonstrated that the size of forest cover in Mau have been changing from 1984 to present. This is due to deforestation and agricultural activities taking place within the forested area.

When forest cover bonding the soil in a lake basin is destroyed, the result is usually an increase in land erosion and sediment transport, which in turn leads to reduced lake water quality which limits the penetration of light into the water column. Deforestation would therefore decreases natural seepage into underground aquifers, leading to accelerated surface runoff causing siltation in the lake. Therefore the size and depth of Lake Nakuru is expected to reduce if the current situation proceeds.

Nakuru dumping site is located on higher ground meaning water from the dumping site do find its way easily to the lake hence affecting water quality of Lake Nakuru and its feeder streams.

The presence of pollutants in the lake has resulted in an imbalance in the ecosystem that has caused a food shortage for the flamingos. The diminishing flamingo food could also be the result of the introduction of tilapia that led to competition for the planktonic blue-green alga, (Spirulina platensis) fed on by the flamingos. This could be a possible cause for migration of flamingos to other lakes including Lake Simbi Nyaima in Western Kenya among others. This will greatly affect tourism in the area since flamingoes are the main tourism attraction in the area.

Recommendations

Deforestation is not an unstoppable or irreversible process. Increased and concerted efforts in forest plantation 'rebirth' and rejuvenation will bring to use the type of forest reserve we envisaged. In order to reduce the effects of deforestation in Mau forest, the study has the followings as its recommendations:

Government by way of policy should be strict in preserving forest reserves from illegal occupation.

The dumping site in Nakuru town should be relocated to a lower ground where water from the site cannot find its way to Lake Nakuru.

Promotion of alternative energy source for fire wood in order to reduce the pressure on the forest.

Development and promotion of trade in non-timber forest product to reduce the pressure on timber resources and to enhance rural livelihood.

It is strongly recommended that any form of forest plantation degradation should be stopped forthwith, having realized the purpose for which the reserve was meant for.

The available vegetation area and the farmland must be converted into forest plantation of exotic fast growing species.

Lastly, the technology of remote sensing and GIS should be employed in major studies, concerning national issue such as deforestation, desertification etc.

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