PAPER 12

Spatio-temporal Analysis of Land-use and Land-cover Changes in the Transboundary Mara River Basin

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ABSTRACT

Limited water availability during the dry season in the Mara River Basin has been a major problem to sustain ecosystems, domestic demands and other socio-economic requirements. Currently, there is no enough water allocated to meet these demands and its management is also inefficient. The problem is directly linked to land-use/land-cover and landscape pattern changes. Conversion of land poses risks of reduction in infiltration rates, ground water recharge or short-circuiting of vital hydrological process such as evapotranspiration. Objective of this study was to use open source GIS tools and remote sensing techniques to analyze Spatio- temporal land-use and land-cover changes in the Mara River Basin for the period 1961-2016. The study focused on three selected areas. Area 1 comprised of the upper Mara Nyangores and Amala tributaries. Area 2 included the Nyangores and Amala confluence at Emarti Bridge while area 3 includes the meandering section on the mainstream Mara River, and in Mara national reserve. These areas were purposely selected since they cover sites where environmental flow surveys were undertaken in 2015 and 2016. In this study, multi-temporal satellite images (1973, 1984, 2002, 2009, 2014 and 2016) and aerial photographs of 1961 were used. For the satellite image time series, a supervised image classification was applied. Reference data for the classification was derived from high resolution imagery provided by Google Earth. For the aerial photographs, manual digitization of land-use/land-cover classes was performed. Prior to digitization, aerial photographs were pre-processed. Image composite editor (ICE) was used for stitching while ImageJ was used to enhance contrast. Statistics derived from classification of the time series were analyzed. Results indicated that in study area 1, forests decreased from 7 473.7 ha (1961) to 2 270.8 ha (2016) while grasslands reduced from 5 208.8 .8 ha to 120.9 ha over the same period. In study area 2, forests reduced from 1 041.9 ha (1961) to 126.0 ha (2016) and grasslands from 640.7 ha (1961) to 481.6 ha (2016). In study area 3, the forest cover decreased from 1572 ha (1961) to 198.5 ha (2016), while grassland cover increased from 5 192.9 ha (1961) to 14 017.8 ha (2016). The study found that agriculture is the main driver of land-cover change in the basin. The study further demonstrated that remote sensing data from satellite sensors and aerial photographs in combination with open-source GIS tools are important for land-cover change detection in basins with poor in situ data.

1. INTRODUCTION

Land-use/land-cover (LULC) change is a major concern of the hydrological cycle and the environment (Qian et al. 2007). Land-cover refers to the biophysical material covering the earth surface such as forests, shrubs, grasslands while land-use refer to human activity or modifications such as agriculture (Odera, Kiio & Achola 2016; Wang, 2014). Scarcity of land, urbanization, rapid population growth and urban sprawl are some of the major drivers of global LULC changes (Barros 2004). Permanent LULC is a complex response to demographic, socio-economic, demographic and development pursuit forces triggered by human activities (Liu et al. 2017). Allocation of expansive land to elite and marginalization of the poor has also been cited as one the drivers of LULC change (De Waroux & Lambin 2012). LULC of any nature is often negative as it results to loss of diversity; increase in runoff, soil erosion, debris flows and accelerated climatological related events (Cheruto et al. 2016; Liu et al. 2017). Conversion of pristine lands to farmlands and urban centres increases evapotranspiration and reduces groundwater recharge respectively (Mati et al 2008). The consequence of reduced groundwater recharge is reduced streamflows during the dry seasons, and prolonged droughts (Pan et al 2011; Gbadebo 2013; Tran et al 2019; Adhikari 2020). Boretti & Rosa (2019) indicates freshwater will become more scarce due to human demand and LULC induced climate change. LULC change is thus an interesting entity whose effects affect hydrological processes such as infiltration, runoff genesis, streamflow regimes and evapotranspiration (Owuor et al 2016). One of the effects of LULC change is the reduction of low flow regime in streams especially during the dry periods (Gennaretti et.al 2011). Further, riparian vegetation loss subjects' rivers to nutrient loading from adjacent farms (Chua et al. 2016). Excessive nutrients expose downstream users to water related problems (NEMA 2011). The problem is even more crucial in developing countries where population and urban centres are increasing along the river reaches (Cullis 2019).

Natural forests in upper, middle Mara and along Amala and Nyangores tributaries have rapidly been converted to agricultural lands (Kilonzo 2014; Ayuyo et al 2020). The previously mixed forests and shrubs covered lands have become large scale ranches and irrigated farmlands (Mati et al. 2008). Pressure arises from rapid population growth, unplanned infrastructure development, poor land-use management practices and unregulated agricultural expansion. Scholars such as (Mati 2005; Hoffman 2007; Mati 2008; Mwania 2014; Kilonzo 2014 and Ayuyo et al 2020) have studied LULC change in Upper Mara between 1973-2007 upto 2016. There is a gap between 1961 and 2016 which this study fills as well as detailing viability of using aerial photos, open source dataset, GIS and remote sensing techniques for land-use/land-cover studies in basins with little in Situ data such as the Mara basin. Further, the study explores LULC changes in areas covering the environmental flow assessment (efa) sites. The main objective was to detect, map and assess the extent and rate of land-use and land-cover changes at the three (efa) selected study areas and within a 100 m buffer riparian zone for the three areas.

The study further analyzes the spatial metrics on fragmentation of different land covers in Upper Mara. Upper Mara is considered for spatial metrics because it covers the main town (Bomet) and other urban centres which have over years expanded into the formerly protected forests. The Upper Mara also forms a vital recharge area for Nyangores and Amala distributaries which joins to form the Mara River at Emarti Bridge. The research has also looked at the criteria of combining different sensors for sustainable monitoring of LULC change in Mara River Basin (MRB). Finally, the study has assessed efficiency of using open source datasets, open source GIS tools, remote sensing (RS) techniques, QGIS SCP plugin, and Lecos, which is a spatial metrics plugin in QGIS). Application of Image J and Image composite editor tools to detect land-use/land-cover studies on old aerial photography in MRB has also been assessed.

TABLE 1: Remotely sensed data

Satellite	Sensor	Observed date	Scene ID	Resolution
Landsat	1-5 MSS	31-Jul-73	LM11820611973212AAA05	60 m
Landsat	4-5 TM	29-May-84	LT51690611984151XXX03	30 m
Landsat	4-5 TM	20-Jun-09	LT51690612009171MLK00	30 m
Landsat	7 ETM	24-May-02	LE71690612002144SGS00	30 m
Landsat	8 OLI	02-Jun-14	LC81690612014153LGN00	30 m
Landsat	8 OLI	22-May-16	LC81690612016143LGN00	30 m

2. STUDY AREA

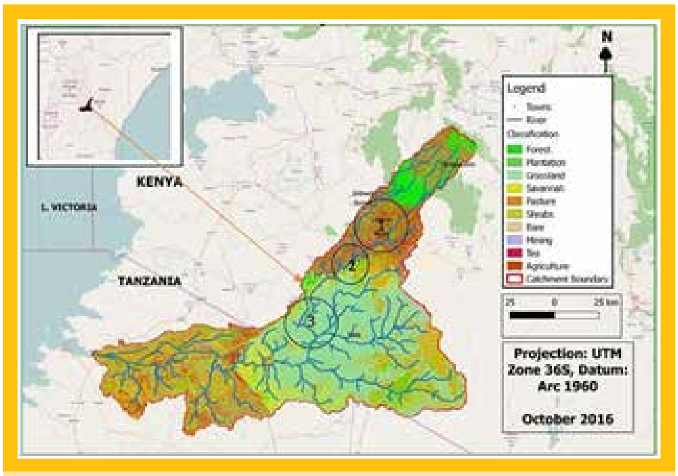

FIGURE 1: Location of the study area and study areas

The three study areas lie in Mara river Basin (MRB) which has a total area of about 13 750 sq.km. MRB is located between 33º 47′ E and 35º 47′ E and 0º 38′ S and 1º 52′ S. Topography varies from 2 932 m at the headwaters in the Upper Mara to about 1 134 m near Lake Victoria. Amala and Nyangores perennial tributaries originate from Napuiyapui Swamp located in Mau escarpment. The two join at Emarti bridge to form the Mara river. Mara river is also fed by Talek and the ephemeral sand rivers near the border between Kenya and Tanzania. Talek originate from Loita plains. The Mara then flows through the Mara national reserve, through Mosirori swamp (Mara wetland), opening onto Mara bay before entering Lake Victoria, near Musoma on Tanzanian side.

The upper, middle and lower MRB receive about 1 000 to 1 750 mm, 900-1 000 mm and between 900 and 1 000 mm rainfall per annum respectively. Lower Mara near Loita hills and Musoma area receives between 700-850 mm per annum. The rains are highly variable with major rains being experienced between March and start of June. The second season starts from November to December (Mwania 2014; GLOWS- FIU 2012). MRB boasts the world famous wildebeests migration that occurs between Serengeti National Park and the Maasai Mara National Reserve on annual basis (Mati et al. 2008). In this context, water availability in MRB plays a vital a key role of sustaining livelihoods, ecological role of sustaining wildlife and enhancing biodiversity.

Study area 1 extents an area of 351.4 km^2 that covers Nyangores and Amala tributaries, Bomet town, smallholder rain-fed agricultural farms and large-scale tea farms. Population in Bomet was estimated as 875 689 persons according to 2019 census report (KNBS, 2019). Main land covers include forests, shrubs and tea farms, with small randomly distributed grassland patches. River reaches in this area are dominated by Hippos as the main wildlife whose grazing is now limited by the changing riparian vegetation. Other diversified animal and bird species are confined in the remaining protected forest patch. LULC changes in these areas are rapid and more concerning due to population growth and rise in food demand (Omonge et al 2020).

Study area 2 extents 37.8 km^2 and covers Nyangores and Amala river confluence area. Main land covers in this area include shrubs, partly forested riparian zone and randomly distributed grasslands. It is characterized with extensive commercial pivot irrigation in South-East direction of the confluence. Subsistence farming with few homes is also evident in the study area. Wildlife in this area consists of hippos, and a variety of bird species.

Study area 3 has an area of 147 km^2 and covers the mainstream Mara river meanders and a section where Talek River joins the Mara river. It further covers part of the Mara national reserve which is a habitat to wildebeests, hippos, lions, leopards, elephants, and a variety of bird species.

3.MATERIALS AND METHODS

3.1. Data collection

Landsat satellite family project provide freely available spatio-temporal products for environmental studies and natural resources monitoring. The 1973, 1984, 2002, 2009, 2014 and 2016 Landsat imagery were collected from the USGS earth explorer website (USGS 2017). Time series from end of a rainy season were selected in order to reduce chances of encountering images with much cloud cover. Aerial photos taken by the Royal Airforce were also used to study land-cover change for the year 1961. Summary of remotely sensed data used is presented in Table 1.

3.1. Image manipulation

Various techniques were applied to develop a dynamic reference dataset. The reference dataset was used to generate the training samples, and to assess classification accuracy. High resolution imagery provided by Google Earth and an MRB land-use map of August 2015 (scale 1:30 000) were used as ancillary data during classification. Validation was accomplished using data from Biopama, which is a group dedicated in global LULC change analysis (Biopama 2017). Further validation was done using the 1961 aerial photos composite.

3.2. Classification, spatial metrics and analysis

Storing, analysis and presentation of land-cover maps was done using open source QGIS tool. Atmospheric correction of remotely sensed

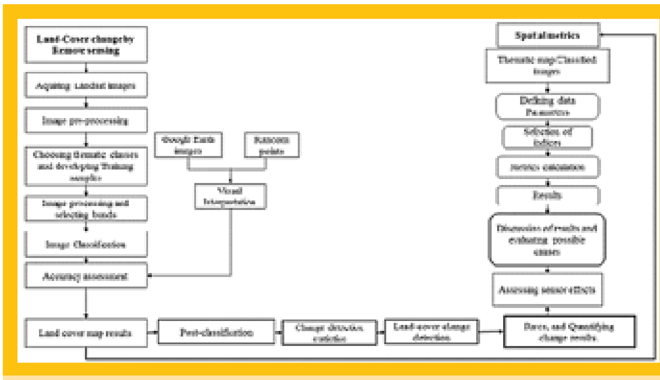

FIGURE 2: Remotely sensed data methodology

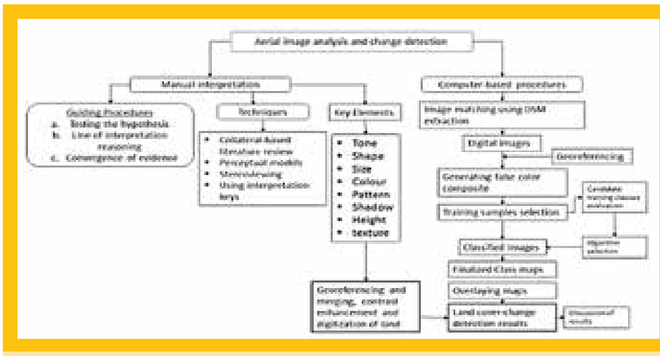

FIGURE 3: Aerial photo methodology

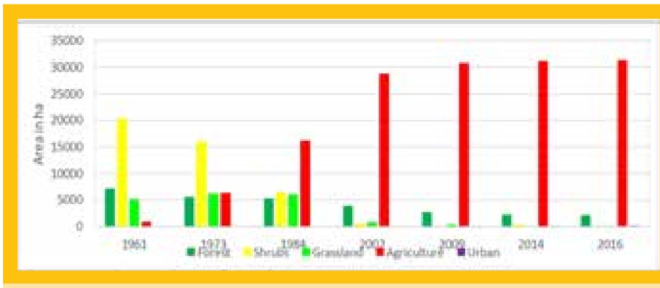

FIGURE 4: Land cover maps for study area 1

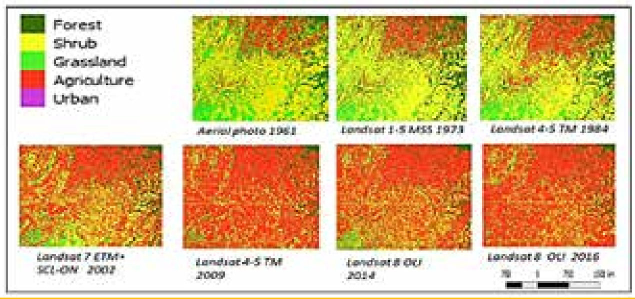

FIGURE 5: Land-cover change for study area 1

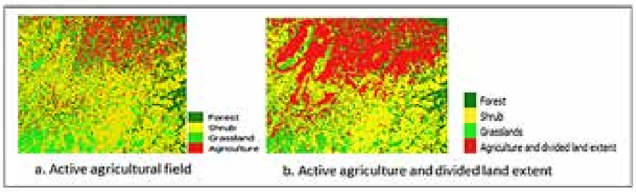

FIGURE 6: Divided land extent and active field comparison

data, band setting, classification and accuracy assessment of classified maps was done using the QGIS-SCP plugin (Congendo 2016). QGIS enabled Lecos plugin McGarigal (2015) was used to study spatial metrics and fragmentation in Upper MRB (Study area 1).

Methods used for LULC change detection on Landsat Imagery and Royal Airforce photos are presented in Figure 2 & 3.

Analysis of aerial photos first involved identification of flight path. Photos were then sorted according to study area and stitched together into a composite tiff file using the open source Microsoft Image Composite Editor (ICE) tool. ImageJ, an open source tool, was then used to improve contrast of the land-covers on the stitched photo composite by adding a green channel. Land covers were then digitized into polygons and converted to raster (Tiff) formats for visualization. Lastly, PCRaster python Library was used to change tiff files into maps and resampling classified maps from 30 m to 60 m spatial resolution for visualization.

4. RESULTS AND DISCUSSION

4.1. Classification accuracy

Accuracy assessment was done by comparing classified against the reference dataset. For each year and study area, a separate dataset was used to generate random points on each class during which, high resolution Google earth image was used as a reference. In addition, QGIS also allows use of open layers as a reference. Error matrices were generated to calculate the overall, producer and user accuracies. Overall accuracies for the study areas 1, 2 and 3 were all above 80% and Kappa statistic above 75%. Producer and user accuracies for each class in the three study areas were above 60 % although some classes were of small areas, and random points falling on them were less. This hence led to either 50%-100% user or producer accuracy. Accuracy assessment results indicated that the higher the number of random test samples, the higher the effectiveness of the accuracy assessment. The accuracy results also depended on the percentage of land-cover classes in the study area and each random point generated had equal chance of falling in a certain class.

4.2 Study area 1 land-cover change detection

Figure 4 and 5 shows land-cover changes in the formerly forested study area 1 between 1961 and 2016.

Forests decreased from 7 474 ha in 1961 to 2 220 ha in 2016 with a rapid change being detected as from 1984. About 3 404 ha of grasslands were converted to agriculture between 1973 and 2002 and since then, intensification of agriculture and increased reduced land parcels sizes were evidenced. Urban centres are not detected before 2009 since most of them had grass thatched roofs whose spectral signatures resemble shrubs. Increase in iron sheets covered buildings was noticeable from 2009 with a positive trend from 47.7 ha in 2009 to 181.7 ha in 2016 (Figure 5). While shrubs decreased from 20 414 ha in 1961 to 6 494 ha in 1984, and to 188 ha in 2016 and the conversion has been to farmlands and urban centres.

Aerial photos of 1961 availed rich information on status of MRB before independence. In 1961, data mining from aerial photos showed a land cover mix of mostly shrubs grasslands and forests. Farm fields especially those near roads, and rivers as shown in Figure 6 (a) ranged from small and large sizes with rectangular and trapezoidal shapes and had crops on them.

4.3. Study area 2 land-cover change detection

Figure 7 and 8 shows land-cover change in study area 2 between 1961 and 2016. The size of the area is 3 780 ha and is significant since

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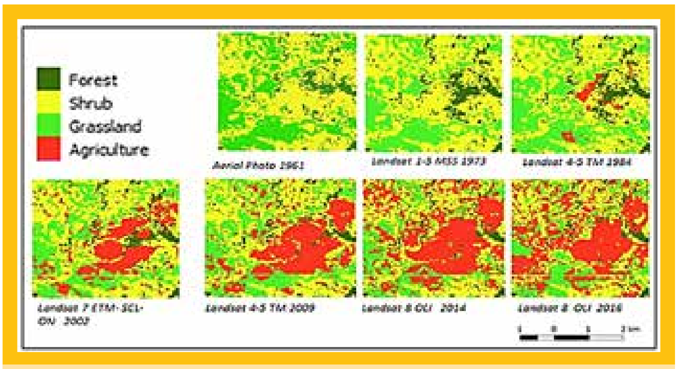

FIGURE 7: Land cover maps for study area 2

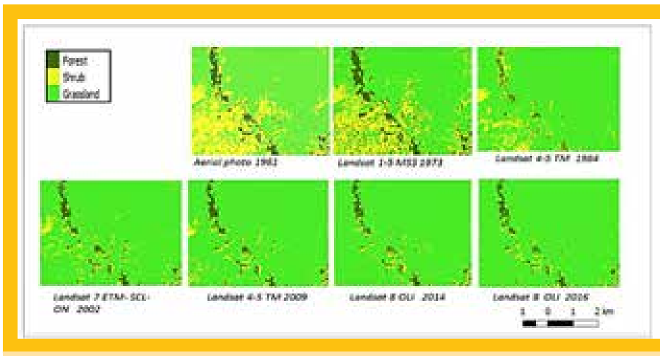

FIGURE 9: Land-cover change maps for study area 3

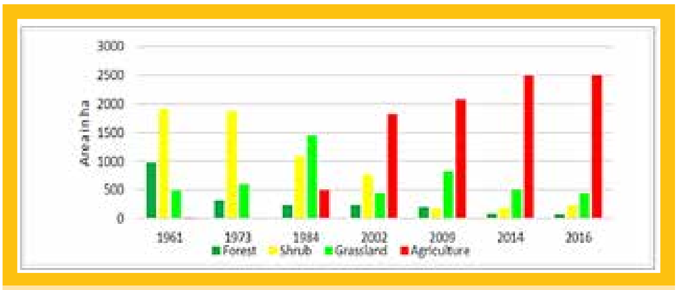

FIGURE 8: Land-cover change for study area 2

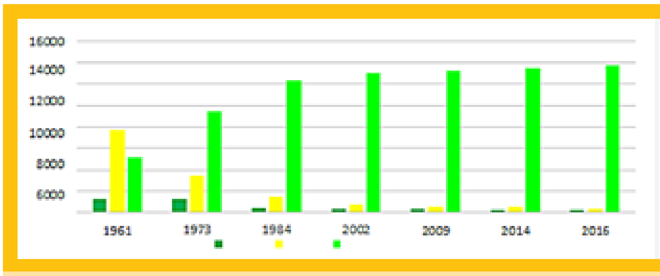

FIGURE 10: Temporal land-cover change for study area 3

it consists of Amala and Nyangores confluence that gives birth to the Mara River. The aerial composite photo of 1961 showed little human activity. In this year, only rectangular strips running through grasslands and shrubs where the current pivot irrigation is located were observed.

Rectangular plots in the North-West direction of the confluence were also observed. These plots appeared as burnt fields associated with shifting cultivation practice.

Using a Landsat 1-5 MSS for 1973 analysis detected no change and that the land-cover was naturally intact compared to 1961 analysis that involved use of Royal Airforce photos. Technically, this indicates influence of sensor choice for land-use/land-cover change detection. Landsat 1-5 MSS satellite which was operational in 1973 has a coarse spatial resolution of 60 m and could not capture the small land-cover details captured by a low moving Royal Airforce aircraft in 1961. In 1984 rectangular and trapezoidal farms concentrated near the confluence were detected. This might have started even before 1984 and the changes are linked to an era when water decline might have started in Mara river. This is because flows significantly respond to any change in land-cover as cited by (Maasai Mara Science and Development initiative 2015). A combination of water from Nyangores and Amala tributaries played a key role to start rectangular and trapezoidal irrigation that existed by then and that changed and expanded to pivot irrigation in 2016. Forests generally reduced by 739 ha between 1961 and 1984 and the forest reduction by 121 ha between 1973 and 2009 matches with an increase in commercial farming in form of rectangular irrigation blocks and pivot irrigation (commercial farming) which increased from 3 in 2002 to 5 in 2009 through 2016. Shrubs however, changed to grasslands (783 ha) between 1973 and 1984 while the grasslands increased by 12.8% for the year period 1961-1973 and then reduced to agriculture between 1984 and 2016.

4.4 Study area 3 Land-cover change detection

Study area 3 falls within the Mara National Reserve. Results for this area are presented inform of maps to visualize and compare changes. Figure 9 and 10 shows a land-cover change time-series for hotspot 3 from 1961 to 2016.

It covers an area of 14 700 ha and lies in Maasai Mara National Reserve. The reserve is a protected area under the directives of the Kenyan wildlife act of 1977 revised in 1989 and 1997 as mentioned by Anon (2014). The directives protect the wildlife against hunting and other illegal activities from the general public and the Maasai community living in the Reserve under the Trust land law (G.O.K 2010). Analysis of 1961 aerial photo composite revealed presence of regularly shaped cuts in parts of the forests. The shapes indicated intervention of human activity. These formerly forested areas gradually reduced to shrub patches over time while other forest patches directly changed to grassland evidently starting from 1973.

4.4.1. Riparian vegetation in study area 3

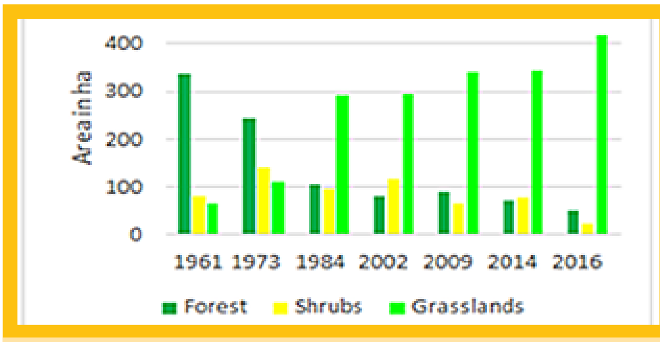

FIGURE 11: Riparian changes

Figure 11 presented below shows land-cover change in a 100 m riparian buffer for study area 3.

Statistics indicate that grasslands increased from 66 ha in 1961 to 419 ha in 2016, while forests declined by 138.2 ha between 1973 and

1984. Forests to shrubs conversion was evidenced between 1984 and 2002 with a direct conversion of forests to grasslands between 2009 and 2016 (a sign of illegal logging). The findings call for protection of the Mara reserve in order to protect wildlife ecosystems and minimize human-wildlife conflicts.

5. SPATIAL METRICS RESULTS AND DISCUSSION FOR STUDY AREA 1

Spatial metrics are used to detect level of fragmentation in a landscape. Upper MRB is located in Mau forest, a key recharge area where most tributaries originate. The area also consists of springs which sustain flow regime of various streams. In 1961, forests and shrubs were dominant. However this is no longer the case as many have been converted to urban centres and permanent team farms. The population in this sensitive part of MRB is rocketing is with settlements also expanding at faster rates. It was therefore considered important to analyze fragmentation patterns to inform sustainable restoration programs, reforestation efforts, water allocation programs, spatial planning best practices for watershed management. This section therefore describes fragmentation patterns of LULC classes in study area 1 (Upper MRB). Classified LULC maps for study area 1presented in Figure 4 formed the input into Lecos, which is a landscape metrics analysis plugin in QGIS (McGarigal & Marks 1994).

5.1 Shannon evenness Index

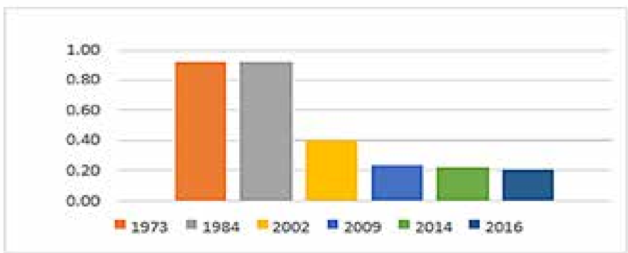

FIGURE 12: Shannon evenness index

The index is used to describe the status of even distribution of different land-cover class patches. Land- cover patches of all classes (forests, shrubs, grasslands, agriculture and urban) are used in calculations. A value of 1 indicates an even distribution of different land-cover class patches in terms of size and 0 indicates poor distribution.

As shown in Figure 12, the indicator measures how different LULC classes co-existed. These classes have been separating from each other beginning in 1973 as detected from the Landsat 1-5 MSS and their closeness even reduced faster between 1984 and 2002. The reduction matched with the increased conversion of forests, shrubs and grasslands into farmlands and urban centres.

5.2 Number of patches

As shown in Figure 13, number of forest patches increased from 1 032 in 1973 to 11 156 in 2002. 2002 recorded the highest fragmentation in Upper Mara as agricultural activities and urbanization increased. Intensification of agriculture on subdivided land parcels was even faster between 2002 and 2009, a scenario which was detected as a decrease in patches. Forest patches slightly increased from 4 753 ha in 2009 to 9 302 ha in 2014, and decreased again by 2 315 ha between 2014 and 2016. The increase between 2009 and 2014 is associated with reforestation efforts that were initiated to save Mau forest.

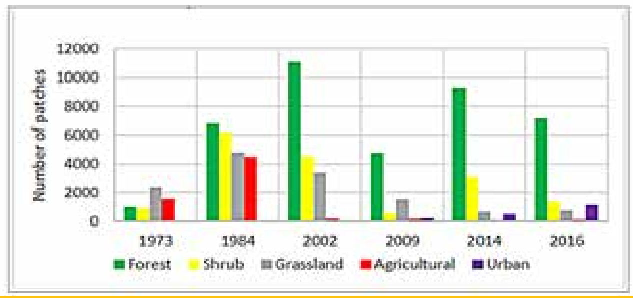

FIGURE 13: Number of patches

A decline between 2002 and 2009 indicated more conversion of the existing forest patches to farmlands and urban set-ups rather than targeting new forest covers.

5.3 Largest patch area

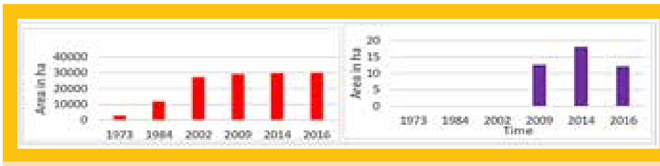

FIGURE 14: Largest patch area (a) Agriculture and (b) Urban

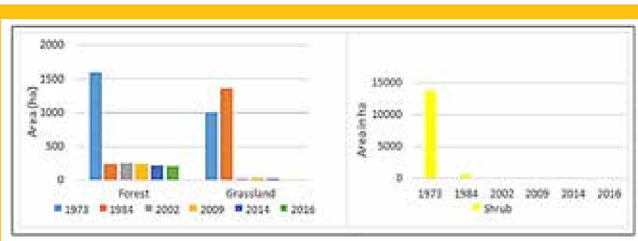

FIGURE 15: Largest patch area (a) Forest and grassland (b) Shrubs

An increase in largest patch for agriculture coincides with an increase in agricultural activities as large parcels of land continued to be subdivided into smaller parcels beyond the detection capabilities of the Landsat satellites. Urbanization also spread very fast in 2014 with more interconnections.

Fragmentation results into different sizes of land-cover classes and changes over time. Hence 15 shows the variation of largest patch size of forest over time. The trend of forest-cover change showed a general decline. Forests were converted to agriculture, shrubs and possibly, timber for development. Increase in population and families has further divided forests into small areas and the resilience of the existing degraded forests is low such that permanent conversion is persistently affecting the hydrology of MRB (Mati et al., 2008). Shrubs largest area decreased between 1973 and 2016 as shown in Figure 15.

5.4 Edge density

Edge segments in a landscape consist of lengths which correspond to different patch type. Edge density is computed by dividing the sum of edge segments of the (landscape) area. Edge density results are presented below in Figure 16.

The edge density of forest-cover increased by 0.007 m-1 between 1973 and 1984. This is the same period when forest patches increased hence leading to increase in edge density. A decrease was experienced between 1984 and 2002 when formerly fragmented patches were

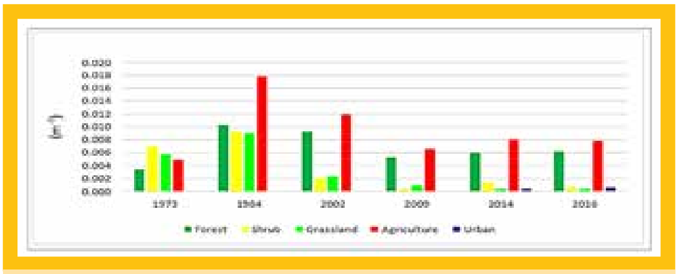

FIGURE 16: Largest patch area (a) Forest and grassland (b) Shrubs

further converted to agricultural lands. This was followed by a faster decrease of 0.004 m-1 between 2002 and 2009 as intensification of agriculture took place. Another increase for 2009-2014-2016 period is linked to increase in demand for forest products which also coincided with an increase in population and urbanization (Bomet County, 2013). Edge of shrubs decreased between 1984 and 2016 due to a reduction in its coverage (Figure 4 & 5) while urban edges increased between 2002 and 2016 as urban centres increased. However, agriculture decreased between 2009 and 2016 as the land parcels continued to be subdivided and detected by satellites as one large parcel.

6. CONCLUSION

Combining old photos and remotely sensed products forms the best approach of studying LULC changes especially in developing countries. Even though tools to analyze old aerial photos are not readily available, they do provide vital information about the state of the MRB during the 1960s and before satellite missions for environmental modelling became popular. The study has also found that fragmentation existed in the upper part of Mara basin as early as 1960s. This was in form of divided parcels of land. However, most conversation from pristine vegetation to agriculture lands and grasslands is seen from 1970 and becoming more intensive in the first and second decade of the 21st century. Findings further suggest the need for governments and policy makers to establish archives that combine remotely sensed data and old imagery in order to have a better understanding of what sustainable restoration efforts are required to manage fragmented catchments.

7. RECOMMENDATIONS

The author of this research would like to recommend further research that will apply use of the 10 m spatial resolution sentinel 2A and 2B products because of their fine resolution when compared to Landsat products which have been used in this study. Lastly, the author would like to recommend a study to look at how land-use and land-cover has changed the water balance scenario in MRB using the freely available water accounting datasets.

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