Land Use Changes in the Transboundary Mara Basin: A Threat to Pristine Wildlife Sanctuaries in East Africa

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Abstract

The Mara basin across Kenya and Tanzania is the lifeline to the Maasai Mara and Serengeti Game reserves respectively, both world-famous for their rich wildlife and natural beauty. The river plays an important ecological role during the annual wildlife migration between the two parks. Moreover, the basin also accommodates natural forests at its source on the Mau Escarpment, large-scale mechanized farming, smallholder subsistence farms, communal pastoral grazing lands and some wetlands. Draining into the Lake Victoria and ultimately forming the upper catchments of the Nile Basin, the Mara is considered to be one of the more serene sub-catchments of the Lake Victoria basin. This perception notwithstanding, there is growing evidence of unprecedented land use change in the upper catchments, resulting from deforestation affecting the headwaters, while current privatization of pastoral lands is attracting immigrants to the watershed with the population growth reaching 7% annually. This deterioration from the "pristine" Mara is affecting the hydrology of the river and its environments, with adverse impacts on wildlife and human environments starting to show. In this connection, a study is being undertaken to determine the impacts of land use change on the Mara basin and the consequent impacts on the flow regimes of the river. The study utilizes remotely sensed data and GIS tools, as well as ground truth studies to identify changes in land use/cover, hydrology and hydrochemistry. Preliminary analysis using Landsat TM satellite data has shown that in just 14 years between 1986 and 2000, agricultural land has increased by 55% through the combined encroachment of forests and savannah grasslands, which have in turn reduced by 23% and 24% respectively. In addition, destruction of closed forests has seen land under tea/open forest increase by 82%. These changes have caused sharp increases in flood peaks, attenuation of the river hydrographs and reduction in base flows, factors that could not be linked to changes in rainfall amounts and characteristics. Consequently, wildlife such as hippos can only swim knee-deep in the dry-season, due to the low flows of the Mara River. In addition, there has been increased sedimentation of downstream wetlands, causing them to expand by a factor of 131%, thereby forcing farmers and livestock to abandon formerly arable lands. Research on developing coping strategies is continuing, but these early results provide evidence for the need for urgent action to save the Mara ecosystems, and ultimately its wildlife and human livelihoods.

Keywords
Land use change, land cover, hydrology, wildlife, rangelands, croplands, forests, wetlands, remotely sensed data, GIS, East Africa, Mara Basin, Kenya, Tanzania.

INTRODUCTION

The transboundary Mara basin covers 13,750 Km^2, lying between Kenya and Tanzania. The 395 km long Mara has for a long time been considered one of the more pristine rivers draining into Lake Victoria, which consequently forms part of the upper catchments of the Nile basin. The Basin is located roughly between longitudes 33°47' E and 35°47'E and latitudes 0°38' S and 1°52' S, with the upper 65% area (8,941 km^2) in Kenya, while the remaining lower portion is in Tanzania (Figure 1). Originating from the Napuiyapui swamp in the Mau Escarpment in the highlands of Kenya, altitudes range from 2,932 m at its source to 1,134 m on Lake Victoria. The basin is bounded by the Soit Olooloo Escarpment on the west and the Loita and Sannia plains to the east. The main perennial tributaries are the Amala and the Nyangores, which drain from the western Mau escarpment. Other prominent tributaries include the Talek River, which starts from the Loita plains and joins the Mara in the Maasai Mara Game Reserve, the Engare Engito originating from the Ilmotyookoit Ap Soyet ridges and the Sand River, which is the last main tributary, joining the Mara at the Kenya-Tanzania border in the Serengeti plains. The Mara then flows through Mosirori Swamp, finally draining through the Mara bay into Lake Victoria at Musoma in Tanzania. Rainfall varies with altitude in the Basin. Mean annual rainfall ranges from 1,000-1,750 mm in the Mau Escarpment, 900-1,000 mm in the middle rangelands to 700–850 mm in the lower Loita hills and around Musoma. Rainfall seasons are bi-modal, falling between April and September, and again between November-December.

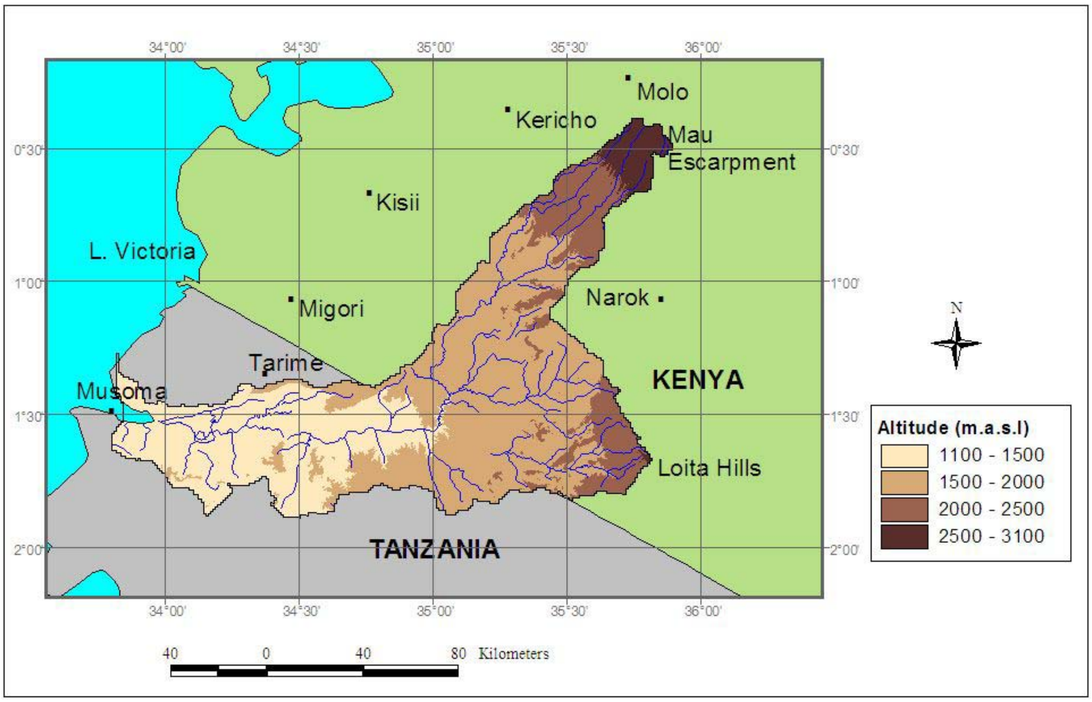

Figure 1 Location and Relief of the Mara River Basin in Kenya and Tanzania

The Mara-Serengeti ecosystem contains the most diverse combination of grazing mammals in the world, holding 400,000 wildlife and livestock. The River Mara is critical in the unique annual wildbeest migration and for balancing the ecosystem. However, this may not be for long, based on the findings of recent research in the Mara, which points to the fact that there is accelerated loss of vegetation cover in the upper catchments and associated land degradation, which consequently pose a threat to the river flows and the ecosystem (Mati et al, 2005; Machiwa, 2002; Dwasi, 2002; IUCN, 2000; Aboud et al, 2002). Despite the diversity in spatial extent and land use, the dominant social-economic activity to the majority of the population remains crop farming. About 62% of the households are smallholder farmers (Aboud et al., 2002), with livestock rearing being a second dominant activity, yet agriculture occupies about 28% of the available arable land. Tourism and wildlife are important economic activities. At the heart of the Mara basin lie the Maasai Mara Game Reserve on the Kenyan side and the Serengeti National park on the Tanzanian side. The Serengeti is a World Heritage site and a Biosphere Reserve and therefore of global conservation significance. The Mara-Serengeti ecosystem is a world-famous wildlife sanctuary of great economic international importance, supporting a thriving tourism industry. This area is surrounded by nomadic pastoralists, who sell traditional artifacts, while tourist related services provide important additional income for local communities (Thompson, 2002). In the dry season, the Mara River is vital to both tame and wild animals, including the migrating herds in the Maasai Mara and Serengeti national parks. The Mara basin also supports the livelihoods of pastoral people, farmers, fishers, some hunter-gatherers in the forested catchment areas, and other people who directly or indirectly rely on tourism. In addition, the use of forest resources remains an important source of livelihoods to the people in the highlands, while fishing is more important in the areas around the Lake Victoria.

For sustainable utilization of the resources of the Mara, there is a need to obtain reliable data for developing suitable policies and management principles integrated with socio-economic human activities affecting the ecosystems and livellihoods (e.g. agriculture, urbanisation, forests, wetlands, wildlife, national parks). Few historical hydrological and hydrochemical data exist. In this connection, this study was planned with the aim to answer questions such as determining the extent of land use/cover change in the basin, finding out what changes have taken place in the hydrology of the Mara, identifying the effects of these changes, including on the wetlands, and thereby proposing types of interventions that can result in the stabilization the hydrograph of the Mara, and ecosystem restoration.

Major Ecosystem Threats in the Mara Basin

Even though the Mara is among the more pristine of the rivers draining into Lake Victoria, yet there are major threats to the formerly serene ecosystem. Over the last 50 years, the Mara basin has undergone large changes in land cover. Forests and savannah grasslands have been cleared and turned into land for agriculture, charcoal burning, overgrazing and expansion of agricultural activities (Machiwa, 2002; Dwasi, 2002; IUCN, 2000), while grazing resources have dwindled. For instance, the area under cultivation in the Amala sub-catchment increased from less than 20% in 1960 (Olenguruone Settlement Scheme) to more than 51% in 1991. This is partly due to the rapid population growth, as a result of high rates of immigration, as between 1999-2002, the number of households increased by 13% in the upper catchments. The middle catchments of the Mara basin around Mulot, Longisa, Norengore and Kaboson in Kenya used to be sparsely populated rangelands, but in recent years, the district has attracted immigrant farmers. As a consequence, the water cycle has become short-circuited leading to faster runoff which erodes the landscape and causes eutrophication of the receiving wetlands and waters, including Lake Victoria. But data on sediment yield is scarce, estimated at between 113 and 432 tonnes/day (Scheren et al, 2002; LVEMP/COWI, 2002; Machiwa, 2001). These changes have had impacts on riparian wetlands affecting their stabilizing filtering effects (Makota, 2002; Mwanuzi et al. 2002). As more land is opened for crop production, pastoralists are finding it increasingly difficult to support their families and are highly vulnerable to drought. For instance, in 2000, pastoralists lost 35% of their cattle due to drought, while over the last 20 years there has been a decline in wildlife of over 50% (Reid et al. 2003; Ottichilo et al., 2001). The livestock water demand in the Mara catchment has been estimated as 159 m^3yr^{-1} in 1990, 190 m^3yr^{-1} in 2000, and is predicted to rise to 228 m^3yr^{-1} in 2010 (JICA, 1992) and the rising pollution levels, from agricultural activities upstream is threatening wildlife habitats. For instance, local people reported that hippos used to swim certain sections of the river, but now the water can be only knee-high during the dry season, and they are starting to migrate. Field surveys revealed that at Keekorok where the Mara leaves Kenya into Tanzanian, the river crosses the border heavy laden with sediment. In addition, the locally driven degradation has increased the vulnerability of thousands of families who have no alternative incomes (Thompson, 2002).

Smallholder farming, growing subsistence crops like maize, sorghum and cassava, forms the predominant economic activity in the lower reaches of the Mara basin, including around the Mosirori wetland lying at the lowest end towards Lake Victoria. Here, the upper hills have been deforested mostly through charcoal burning resulting in massive land degradation. Major environmental changes have been observed in recent years including scouring of the riverbed and silt build-up near the Lake causing back-water flow from the lake up to 40 km inland. Moreover, the wetland has increased in area affecting the ecology and economic activities. Field studies revealed that local people at Bisarwi can recall walking across the wetland to the other side of the river Mara about 20 years ago, and also grazing livestock on the lowlands. By 2004, the entire valley was so waterlogged that livestock grazing and cultivation were impossible. The increased erosion from Kenya has brought rich alluvial soils, which are cultivated without the need for fertilizers on the edges of the wetland. In general, land degradation upstream has caused increases in the spatial extent of the wetland, as well as excessive flooding of the river during the rainy season. In addition, the water resources of the Mara are inefficiently utilized, resulting in lost development opportunities, low economic growth, rural poverty and upstream-downstream conflicts in the Basin (Sweco, 2003), calling for new approaches in addressing these constraints. There is a need to discuss hydrological impacts due to land use change since the introduction section focused only on the basic features of the basin and activities taking place in the basin. Jumping from that aspect to hydrology directly might mislead the reader.

DATA AND METHODS

Mapping of land cover change utilized available high spatial resolution snapshots of Landsat TM/ETM, for the years 1986 and the 2000 respectively covering a span of 15 years (We also analysed 1974 MSS data). Image preprocessing of satellite images was carried based on techniques like those of Coppin et al., (1996); Lillesand and Kiefer, (1987).Ttherefore, the data used in this study was geo- referenced and corrected for sensor irregularities. In addition, topography was mapped from the recently released Shuttle Radar Topography Mission (SRTM) data. GPS-supported field surveys for collecting ground data on vegetation, land cover, and participatory socio-economic studies to verify scientific data and capture logical and local knowledge were also done. This information is considered as the ground truth in developing the land cover maps for the time frame considered.

The hydrometeorological data for the basin were acquired from Kenya and Tanzania. Due to gaps in the available records, only stream flow records from Mara Mines gaging station in Tanzania and the Nyangores River (1LA03) at Bomet in Kenya were used. The data span the period 1970 -1991 and 1963-2000 periods for the two stations respectively and were considered appropriate for this study (Figure 2). Daily rainfall data varied in time and space. The data is not evenly distributed throughout the basin. More rainfall stations are concentrated in the Kenyan side while fewer stations are available for the Tanzanian side. Most of the data are available for the recording period of 1960's to late 1990's.

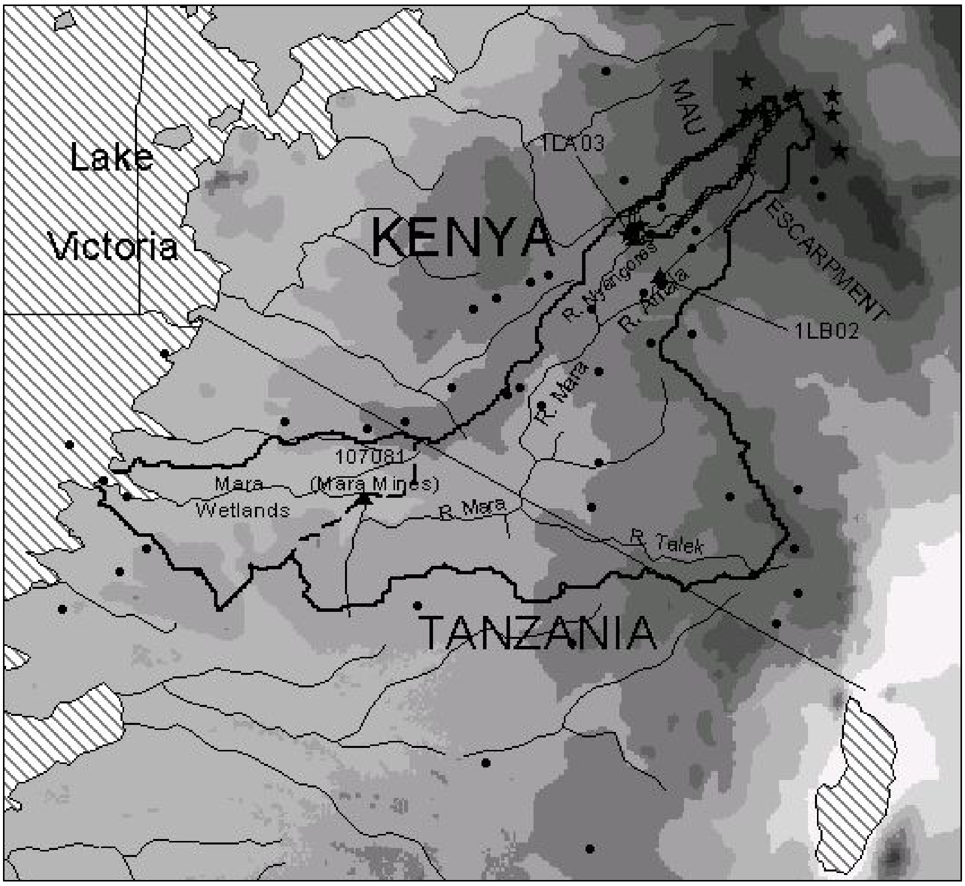

Figure 2: Location of the rainfall and river gauging stations in the Mara Basin

Data reconstruction is carried out to fill missing gaps. Rainfall time series is filled using seasonal mean values for the specific missing dates. For monthly discharges and excess and deficit flow volumes, cross correlations were used between monthly values at the same gauging station. The replacement of missing excess and deficit flow frequencies uses both the behaviour of the time series and correlation analysis. Cross correlations were used whenever the filling by this procedure was not possible particularly for the cases of fluctuating series or when the flows before and after the gap are on the opposite sides of the threshold (Valimba et al, forthcoming). The variable quality, length and period of rainfall records necessitated their selection. Rainfall records were further required to span the period encompassing that of flow record. Therefore only 10 records with 30 or more years of data and which started before or in 1961 and continuing through the early-1990s to 2002 were retained and the criterion of less than 10% of missing monthly values finally retained only 9 stations for the inter-annual variability analysis. However, monthly discharges were determined only for months with at least 90% of the daily observations available while monthly indices of excess and deficit flows as well as rainfall amounts were determined only for complete months. The frequency and severity of floods and drought in the Mara River basin were studied using excess and deficit flows as well as maximum and minimum flows. The excess (deficit) flow frequency was defined as the number of days above (below) the threshold defining the flood (drought) flow while excess (deficit) flow volume was the cumulative flow volume above (below) the respective thresholds (Valimba *et al*., forthcoming).

RESULTS AND DISCUSSION

Land use/cover change

The respective land use/cover (LULC) as derived from Landsat TM/ETM data for 1986 and 2000 are shown in Figures 3 and 4 respectively. The spatial coverage of each land use and land cover class may be visualized on both maps. In general, the major land use/covers in the Mara Basin include closed forest, open forest and tea in the upper mountain slopes, agricultural land, shrublands and grasslands used for grazing or as game reserves, savannah grasslands, which comprise shrub-grasslands, and wetlands. Figure 5 shows the land use/cover change in the Mara basin between 1986 and 2000 based on the analyses for the Landsat imagery, and the spatial extent of these changes have been shown in Table 1. From these maps, it emerges that, the Mara Basin is predominantly a rangeland, whereby in 1986, about 69% (9,594 km^2) of the land was under natural pasture, as savannah, grasslands or shrublands, mostly used for grazing livestock and/or wildlife reserves. However, by 2000, these rangelands had been reduced by 24% to only 7,245 km^2 due to encroachment by agriculture, whose area has increased by 55%. Similarly, except for the water body, all the other land use/covers have undergone change in the 15 years under review (Table 1). The natural vegetation has been declining as closed forests reduced by 23%. due to forest clearing for tea and/or as timber harvests, which have increased opened land by 82%. Meanwhile, downstream wetlands especially the Mosirori in Tanzania have increased in area by a factor of 131%. This increase has been associated with the build up of sediments downstream, as a result of erosion in the catchment due to high water velocities and high peak flows, which in turn has been caused by reduction in the vegetation cover due to deforestation, opening of natural rangelands to agriculture, and poor soil conservation efforts.

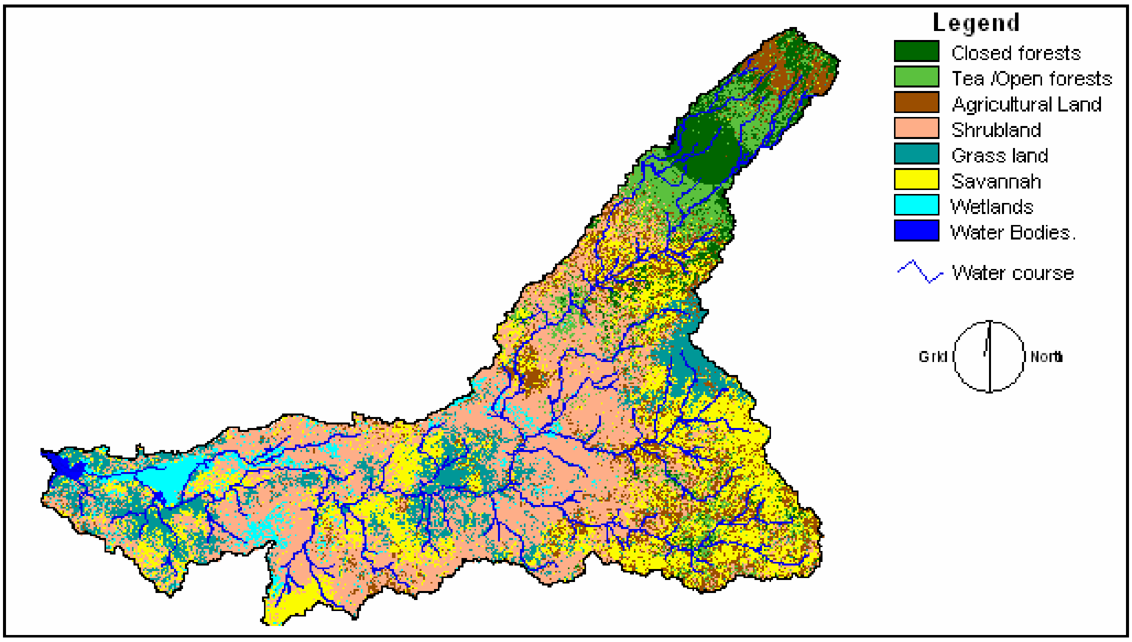

Figure 3. Land use/cover in the Mara basin in 1986 (from Landsat TM)

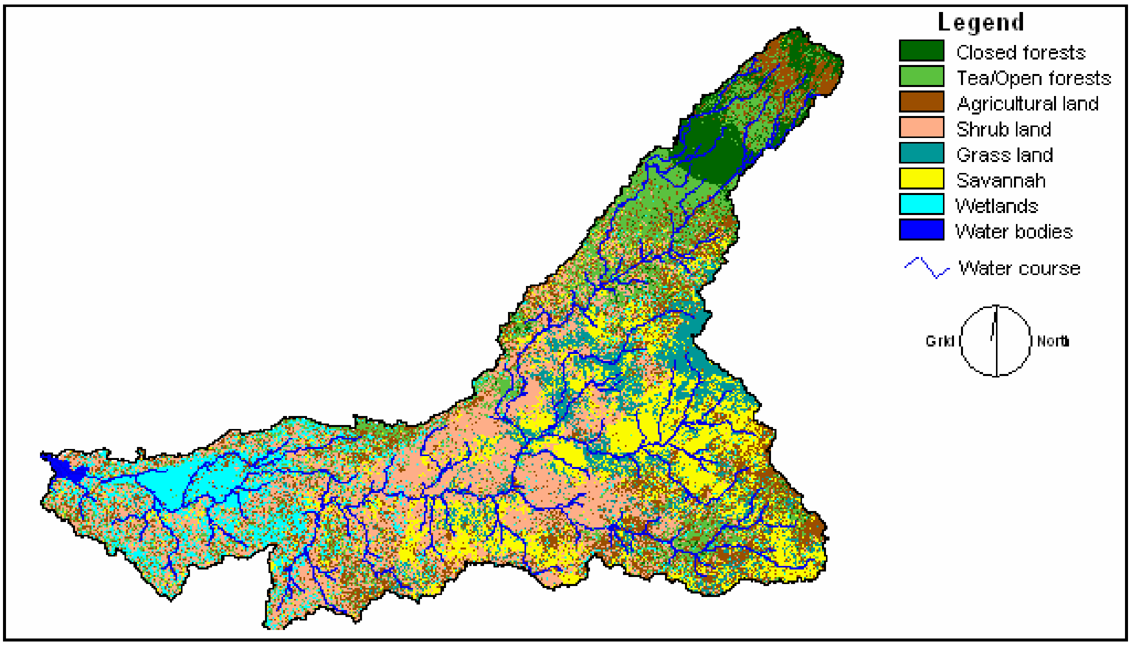

Figure 4. Land use/cover in the Mara basin in 2000 (from Landsat ETM)

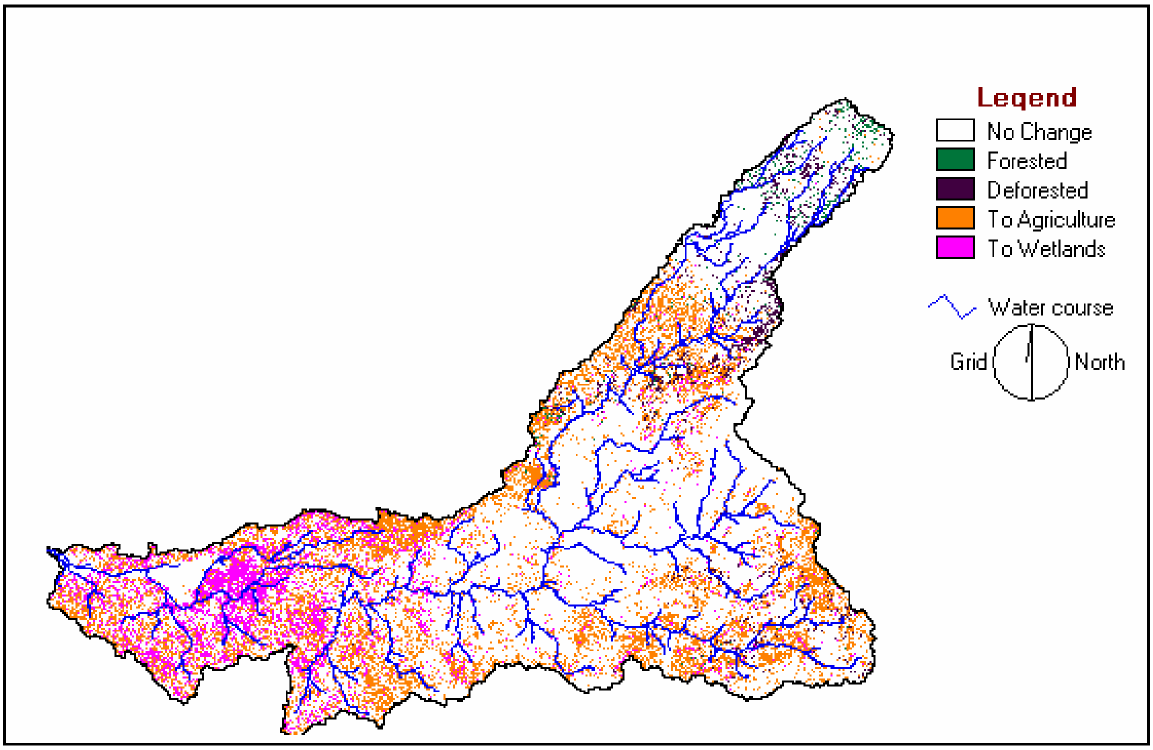

Figure 5. Land use/cover change in the Mara basin between 1986 and 2000

Table 1: Extent of Land use\cover changes in the Mara Basin between 1986 and 2000

Land use\cover types	**1986(km^2)**	**2000(km^2)**	**LULC Km^2**	**LULC (%)**
Closed forest	892.7	688.6	-204	-23
Tea/Open forest	1072.9	1948	875	82
Agricultural land	1617.4	2503.5	886	55
Shrub and grassland	9593.8	7244.5	-2349	-24
Wetland	603.6	1394.4	791	131
Water body	54.2	55.6	1	3

Changes to the hydrological regime

Statistical methods of change-point analysis indicated significant changes of the flow regimes in the Mara River basin which have mainly occurred in the 1973-1977 period. These changes correspond mainly to increasing flows in December, April and May (Table 2). However, the mean flow increases in these months at the most downstream gauge (Mara Mines) are mainly caused by increases in the high (excess) flows while low flows are not significantly affected. Furthermore, there are indications of decreasing flows during the low flow (February and March) period as indicated by increasing frequencies and volumes of deficit flows (Table 2). The changes were more evident in the upstream catchment of the Nyangores than at Mara Mines gauge. The results further indicated a reduction of the frequency of flows exceeding the flood flow index in June at the Nyangores gauge. The implication of increasing flood flows in April and May and decreasing in June could be that the flood flows have become voluminous and slowly attenuates than they used to be. Consequently, the flood characteristics are hypothesized to have undergone changes to peaked behaviour. Thus, less time is available for infiltration of flood water to recharge the ground water and this could be responsible for the decreased flows during the low flow period (e.g. February-March) indicated by increasing volumes and frequencies of deficit flows (Table 2).

The indices characterising the high and flood flows (flow maxima, excess flow frequencies – EFF and volumes – EFV) indicated a significant increase of high flows in December and April and slightly in May around 1977. The increases characterise both the averages (Table 2) and variances. At the threshold of average plus half standard deviation flow of the series of flow maxima in each month, the monthly maxima in April and December at Mara Mines, for example, have exceeded these thresholds by 6-94% and 46-100% respectively. The record maxima occurred in 1988/89. No exceedence was observed in December in the pre-1977 while all the four exceedences were observed after 1977 while five exceedences in April characterised the post-1977 compared to a single exceedence in the pre-1977. At the Nyangores, the increase characterised only April and May. Moreover, EFV and EFF have increased since 1977 and characterised mainly these indices in December, April and May (Nyangores) and December (Mara Mines). In the post-1977, flows in April and May in the catchment of the Nyangores frequently and abundantly exceed the flood flow threshold in these two months suggesting that floods are becoming more frequent and severe in the basin. The changes in the high flows suggest some modification of the characteristics of high flows. The disappearance of EFF in June since the late-1960s in the catchment of Nyangores (Table 2) while the increase characterise EFF and EFV in May indicate that high flows are become less persistent in this catchment in recent decades. This further suggests a shortening of the duration of floods resulting rather into flashy-like floods.

Isolated intense rainfalls (exceeding 40mm) and persistent heavy (30-39.9mm) rainfalls for several consecutive days were hypothesized to be instrumental to river flooding (Valimba et al, forthcoming) The short-duration heavy rainfall intensities normally result in voluminous direct runoff volumes due to little time available for infiltration. As a consequence, there will be insufficient recharge of groundwater leading to a decrease of dry season flow resulting sometimes into prolonged and severe droughts. Such flow regime changes are hypothesized to be driven either by rainfall changes or artificial influences that altered the surface of the catchment and consequently its runoff production mechanisms. Therefore, analyses of indices of rainfall are expected to highlight the potential influences of changes of rainfall on the identified flow regime changes. The changes of land cover due to changing socio-economic activities in the catchment could independently lead to such flow regime changes or intensify the changes induced by changing rainfall characteristics.

Table 2: Summary of changes in indices characterizing flow regimes of the Mara. EFV = excess (flood) flow volume, EFF = excess flow frequency, DFV = deficit (drought) flow volume, DFF = deficit flow frequency (empty cells indicate discontinuities in data)

1LA03 (Nyangores)	Dec			Feb			Mar			Apr			May			Jun		
Monthly flow index	**Date**	**Before**	**After**	**Date**	**Before**	**After**	**Date**	**Before**	**After**	**Date**	**Before**	**After**	**Date**	**Before**	**After**	**Date**	**Before**	**After**
Mean (m3/s)							**1970**	4.8	2.2	**1976**	5.6	10.1	**1976**	9.2	15.3			
EFV (m3/s/d)	**1981**	0.2	8.9							**1977**	10.3	28.8	**1977**	4.5	16.5			
EFF (days)	**1980**	0.1	2.3							**1976**	2.7	5.6	**1976**	1.3	6.6	**1969**	2.6	0.4
DFV (m3/s/d)	**1980**	25.8	16.6	**1979**	34.7	49.5	**1979**	37.6	58.7	**1976**	25.3	11.6	**1976**	10.2	0.0	**1974**	5.5	0.0
DFF (days)	**1975**	18.7	11.6				**1969**	11.5	24.3	**1975**	14.9	8.3	**1975**	7.3	0.0	**1973**	3.0	0.0
Mara Mines	Dec			Feb			Mar			Apr			May			Jun		
	Date	**Before**	**After**	**Date**	**Before**	**After**	**Date**	**Before**	**After**	**Date**	**Before**	**After**	**Date**	**Before**	**After**	**Date**	**Before**	**After**
Monthly flow index																		
Mean (m3/s)	**1977**	6.2	30.7							**1976**	48.3	89.1	**1976**	32.9	73.5			
EFV (m3/s/d)	**1977**	0.0	130.5							**1973**	178.5	772	**1976**	43.6	345.			
EFF (days)	**1977**	0.0	2.3							**1973**	3.3	5.9	**1976**	1.0	5.4			
DFV (m3/s/d)																		
DFF (days)																		

CONCLUSIONS

The Mara basin is a complex agro-ecosystem in terms of natural and demographic characteristics, and due to its trans-boundary nature, solutions to the problems facing the basin require a joint effort between the two countries, Kenya and Tanzania as was done in this study. The study has produced baseline and derived thematic data on land use/cover as well as rainfall and river flows to enable assessment of their effects on the hydrology of the basin. The results have shown that although the major land use/cover type in the Mara still remains rangelands, comprising savannah grasslands or shrublands, mostly used for grazing livestock and/or wildlife reserves. However, agricultural encroachment is taking its toll, reducing these lands from 9,594 km^2 in 1986 to 7,245 km^2 in 2000, a net decline of 24%. Similarly, forest cover has been reducing by 23% while the open forest and/or tea areas have increased by 82% and agricultural lands holding field crops have increased by 55%. One major observation has been the increase in wetlands and the lower reaches of the Mara, at, especially the Mosirori wetland in Tanzania, which has increased in area by a factor of 131%. The increase in wetlands has been associated with backwater flow from Lake Victoria due to sediment build up downstream, resulting from soil erosion in the upper catchments. This in turn has been caused by reduced vegetation cover due to deforestation, overgrazing of the dwindling rangelands, farming on hilly slopes and poor soil conservation efforts.

The flow regimes in the Mara River and its tributaries have also experienced significant changes since the mid-1970s, resulting in increasing high flows particularly during the long rains months of April and May, and corresponding low flows in January to March. The local people have reported that hippos used to swim certain sections of the river, but these days, the water can be only knee-high during the dry season, forcing the animals to migrate. In general, land degradation upstream has adversely affected the water resources of the Mara, which are also inefficiently utilized. This translates to lost development opportunities, low economic growth, rural poverty and upstream-downstream conflicts in the Basin. The water cycle has become short-circuited leading to higher runoff flows, which can reach over 89 m^3s^{-1}. As more land is opened for crop production, pastoralists are finding it increasingly difficult to support their families and are highly vulnerable to drought. In addition, the locally driven degradation has increased the vulnerability of thousands of the wildlife and posing a risk to the sustainability of their natural habitats. This calls for new approaches in addressing land use policies and how they affect land allocation, planning, utilization and management in the Mara at local, national and sub-regional levels.

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