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The Study of the Effects of Mau Catchment Degradation on the Flow of the Mara River, Kenya

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Abstract
There is growing concern however, regarding land degradation in the Mara River Basin in Kenya, particularly deforestation in the headwaters; that is affecting the natural resource base and the river flows. Scientific studies are required to advise on policy issues, and to plan appropriate mitigation measures in the basin. This study utilized remote sensing and geographical information system (GIS) tools, and hydrological and ground-truth studies to determine the magnitude of the land-use/cover changes in the Mara River Basin, and the effects of these changes on the river flows over the last 30 years. The results of the studies indicate that land-use/cover changes have occurred in the basin. In 1973, for example, rangelands (savannah, grasslands and shrublands) covered 10,989 km^2 (79%) of the total basin area. The rangelands have now been reduced to 7,245 km^2 (52%) by 2000. The forest areas have been reduced by 32% over the same period. These changes have been attributed to the encroachment of agriculture, which has more than doubled (203%) its land area over the same period. To investigate the effects of land cover change on river flow, stream flow was generated from derived land cover thematic maps of 1973 and 2000 using the same rainfall and evaporation data of 1983 to 1992 period. The other model input datasets for topography and soils were held constant during the two runs. The differences in the generated hydrographs could only be associated to the changes in land cover, which was the only variable. The percentage difference between the mean annual stream flows of the two hydrographs was negligible at 0.01%. This study therefore concludes that land cover changes in the basin have changed the day to day flow characteristics of the Mara river but the annual flow volumes remain unaffected. There is need for urgent action to stem the land degradation of the Mara River Basin, including planning and implementing appropriate mitigation measures.
Keywords: SWAT model, Mara River Basin, Hydrological Modelling, River Discharges

1 Introduction

Catchment degradation and the resultant impact on stream flow has been a major issue in Africa (Cleaver *et al*., 1994), including Kenya. The degradation of water catchments affects not only the stream flow regime but also the ecosystem and livelihoods of the people depending on the ecosystem (Krhoda, 2005 and Gereta *et al*., 2009). With increasing population in the Mara River Basin, demand for water in the basin has also increased significantly in the recent years (Dessu *et al*., 2014). More than 50% of households within the Mara River Basin rely on Mara River for domestic and livestock needs (Aboud, 2002 and Hoffman, 2007). Therefore, Mara river is crucial to the survival of the people as well as wildlife and livestock. Tourist facilities also use water from Mara River and thus impacts the overall water balance in the basin.

Despite the increasing demand for water in the Mara River Basin, previous studies indicate a decline in annual average flows of the Mara River (Dessu & Mellesse, 2012; Gereta *et al*., 2009; Krhoda, 2005). Krhoda (2005) and Gereta *et al*. (2009) attributed the decline of the flows to over grazing resulting from increased wildlife population and pastoral farming while Dessu and Mellesse (2012) attribute the decline to increased human activity in the basin and climate change which they claim has resulted to erratic rainfall pattern.

Change in land cover can lead to degradation of the basin (Defersha *et al.*, 2012). Other studies have noted that the main cause of land cover change in the Mara basin is encroachment by human populations requiring land for settlement, farming and cutting trees for timber and charcoal burning (Defersha *et al.*, 2012) . Degradation of the Mara River basin has led to increased overland flow, flash floods and soil erosion. The eroded soils is carried by overland flow and deposited in the rivers, lakes and dams/pans and this has led to reduction in storage/carrying capacity of the dams and water pans. This has subsequently led to increased magnitude of floods and droughts in the basin (Defersha *et al.*, 2012). Another major effect of degradation of the basin is reduced quantity and quality of the water in the river which consequently impacts the river ecosystem negatively (McCabe, 2011; Tharme *et al.,* 2007). Knowing the extent of the impacts of land use change is crucial not only to water resources managers but also to land use planners.

2. Study area description

The Mara River Basin is a trans-boundary basin shared between Kenya and Tanzania. The basin is located between longitudes 33.88372^{0} and 35.907682^{0} west, latitudes -0.331573^{0} and -1.975056^{0} South (**Figure 1**). The basin covers a surface area of about 13,750 km^2, of which about 65% is located in Kenya and 35% in Tanzania. The basin can be divided into four distinct land-use sections, mainly on the basis of location along the river. The upper basin comprises two of these sections: first, the forested Mau Escarpment where the Mara River originates from at an attitude of about 3000 meters above sea level (m.a.s.l). The second section is characterized by large-scale agricultural farms and ranches. Some of the large-scale agricultural farms are irrigated using water from the Mara River. The Mara River then runs through the third section, which is open savannah grassland protected by the Masai Mara Reserve on the Kenyan side and the Serengeti National Park on the Tanzanian side, two important and renowned protected areas in the region (**Figure 1).** The River flows in a south-westward direction over a stretch of 395 km before draining into Lake Victoria at Musoma in Tanzania at an attitude of about 1000 meters above sea level.

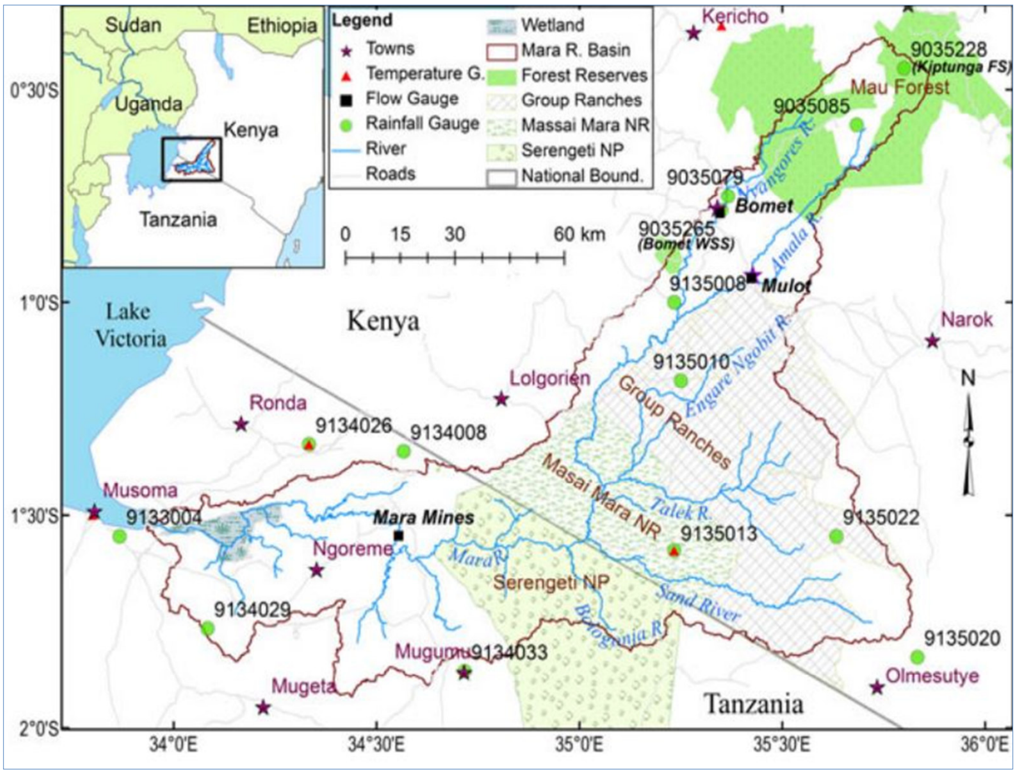

Figure 1: The location of Mara river basin in Kenya and Tanzania

The mean annual rainfall in the basin varies from between 1000mm to 1750mm on the Mau Hills, supplemented by mountain mist, to 300-800mm in the south. The northern and the western parts of the Mara Basin are the wettest, recording 1200mm to 1800mm per annum. The rainfall at Narok Town, which has one of the oldest rainfall stations is 1016mm per annum. The long rains start in mid-March to June with a peak in April while the short rains occur between the months of September and December. The temperature variations in the Mara River Basin are determined by altitudinal as well as rainfall variations, such that in elevated areas with high rainfall amount the temperatures drop to 10^{o}C, while the lowlands in the central and southwestern parts of the basin the temperatures rise to 20^{o}C. Temperatures are lowest in the wet months of March to May and the highest in the dry months of January and February. In general temperatures increase southwards and decrease northwards.

The main tributaries of Mara River in the highlands are Amala and Nyangores. The tributaries originate from the Mau forest and flow south-west and join to form Mara River. An analysis of historical discharge data (1970 to 1996) for Mara River at Mara mines, Nyangores at Bomet and Amala at Mulot showed a mean of 33.9 m^3s^{-1}, 8.4 $m^3s^{-1}$and 9.9 $m^3s^{-1}$with standard deviation of 60 m^3s^{-1}, 7.1 m^3s^{-1} and 19.9 m^3s^{-1}, respectively (Dessu and Mellesse, 2012). The river experiences seasonal flow pattern characterized by high flows during rainy season and low flows during dry seasons. The peak river flows occurs during the months of May and September. The period of low flows is observed to be from January to March. The seasonal peak flows coincide with the long and short rains in the basin. The local geology, topography and rainfall determine the types and distribution soils of the Mara River Basin. In some areas, Quaternary lacustrine and fluviatile unconsolidated sediments of Pleistocene age overlie the Basement complex System rocks forming good aquifers (Krhoda, 1988).

The upper part of Mara basin consists of protected forest and woodland within the gazetted area of

Mau Forest Complex. Some of the areas which were originally forest have been cleared for cultivation. The middle part consists of grassland and bush land which is in the Maasai Mara National Reserve in Kenya or Serengeti National Park in Tanzania. Some of it is also under large-scale farming or ranching or small scale agriculture. The lower part in Tanzania consists also of agricultural land. Wetlands are found in the area close to Lake Victoria. The total population of the basin was estimated to be 805,000 (Geretaet *al*., 2002). Most of the basin has a population density of around 70 people per square kilometer with the urban centers of Bomet and Musoma having higher densities (cf. Mati*et al*., 2005).

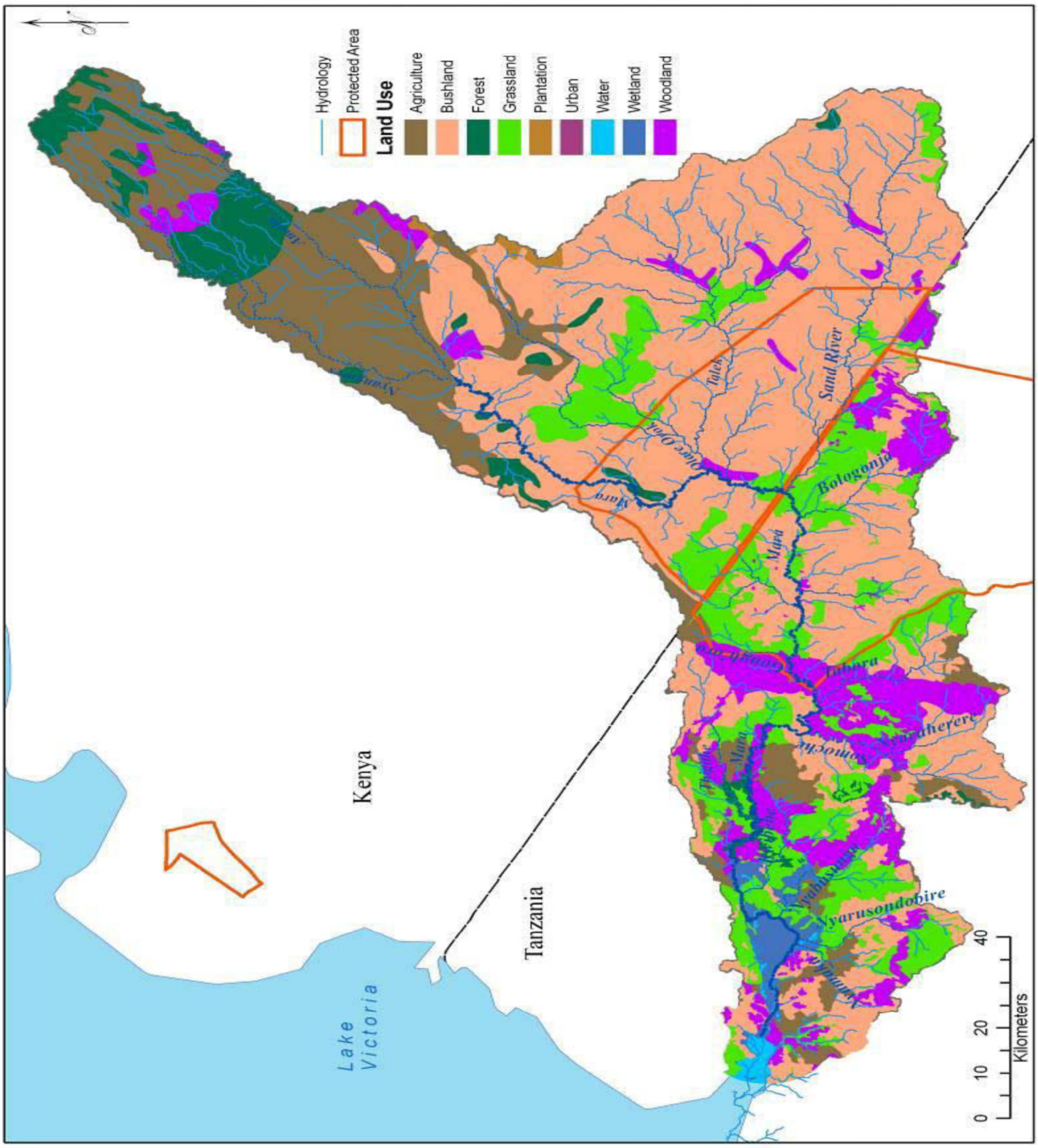

Figure 2: Landuse and vegetation cover in the Mara river basin (Source: Wandera 2011)

2.2 Data acquisition
For this study, various data that were obtained included river discharge data, rainfall data, land use/land cover data, soil data and socio-economic data.

2.2.1 River discharge data
The river discharge data on the Kenyan side of the Mara river basin were obtained from the Water Resources Management Authority (WRMA) regional office in Kisumu while for the stations in the Tanzanian side, data

were obtained from Lake Victoria Basin Water Office (LVBWO) in Mwanza, Tanzania. The time series analysis was used for developing mathematical models to generate synthetic hydrological records, to forecast hydrological events, to detect trends and shifts in hydrological records, and to fill in missing data and extend records (Salas, 1993).

Table 1: River gauging stations along Mara River and its tributaries including their start and end year of operation

River gauging station	Station code	Start Year	End Year
Nyangores	1LA03	1963	2008
Amala	1LB02	1955	2007
Mara-Lalgorian bridge	ILA04	1970	1977
Mara Mine	5H2	1969/2011	1994/2013
Mara Ferry	5H3	1969	1978

2.2.2. Rainfall data

Rainfall data was obtained from Kenya Meteorological Department and from Lake Victoria Basin Water Office (LVBWO through six rainfall gauging stations established within the basin from1978 to 2000. The rainfall data was used as an input to the SWAT model in this study.

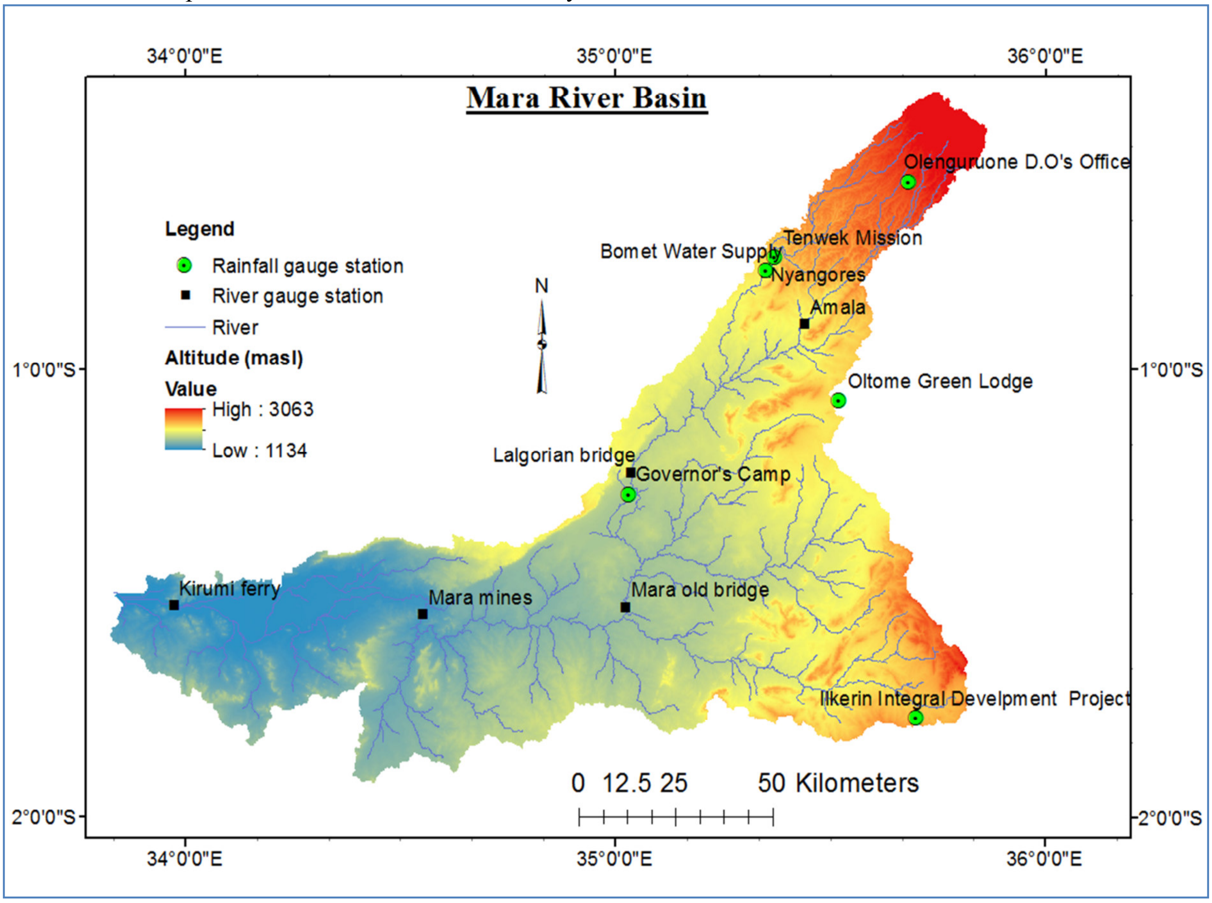

Figure 3: The location of rainfall and river gauging stations contributing to data used in this study. The map also shows the elevation above sea level in meters

2.2.3 Land Use/Cover data

The historical land cover data used in this research was retrieved from Landsat MSS and Landsat MSS/TM/ETM images. The data was pre-processed and classified using Integrated Land and Water Information System (ILWIS 3.8) and ArcGIS

2.2.4 Soil Data

Soil classification data for this research was based on Food Agricultural Organization of the United Nation Version 3.6 (FAO/UNESCO, 1995) data. Soil texture for various soil types was derived from the soil map obtained from the Soil Survey Department of Kenya. Soil data is a significant component of the SWAT model.

2.3 Hydrological Modeling

The stream flow modelling was undertaken using the Soil Water Analysis Tool (SWAT) model, which is open source software In this study, modelling was done basically to: analyse the relationship between changes in land cover and stream flow and; determine the future scenario of the flow of Mara River. Determination of key conceptual parameters in the SWAT model was done through sensitive analysis.

Model calibration and validation was carried out using the split sample method. Calibration was performed by comparing the simulated stream flows with the observed flows, whose value varies from less than zero for poor fit to one for perfect fit was used as an objective function. The parameter combination which gave the highest value of efficiency was taken as being representative of the catchment.

A number of simulations were run while iteratively adjusting the conceptual parameters to match the simulated flows with the observed flows. The process was carried out by changing one parameter while holding the others constant as simulation was being done

General model performance assessment was done by comparing the simulated results and the observed ones using both statistical methods and visual observation through graphical display. Statistical techniques that were used in this research were Nash and Sutcliffe Efficiency (NSE), and Root Mean Square Error (RMSE) observation Standard Deviation Ratio (RSR).

2.4 Statistical data analysis

The statistical data analysis methods that were applied in the study to test the significant difference among the different hydrological parameters include, the Analysis of Variance (ANOVA), correlation analysis and regression analysis.

3 Results and Discussions

3.1Analysis of River Discharge data

Results of the analysis of long-term (1978 to1993) river discharge data for Mara Mines, Nyangores and Amalariver gauging stations are illustrated in Figure 4 and 5. From these two figures it is shown that Amala River has a higher and early peak runoff than Nyangores. This could be attributed to the fact that Nyangores has more vegetation cover. It is also shown that Nyangores has higher base flow compared to Amala. The daily mean streamflow at Mara Mines gauging station calculated as depth over the entire basin shows that there are two peaks in the river discharge corresponding to the two wet seasons in the basin. The peak corresponding to highest rainfall season is 1.2 mm and occurs in the month of April.

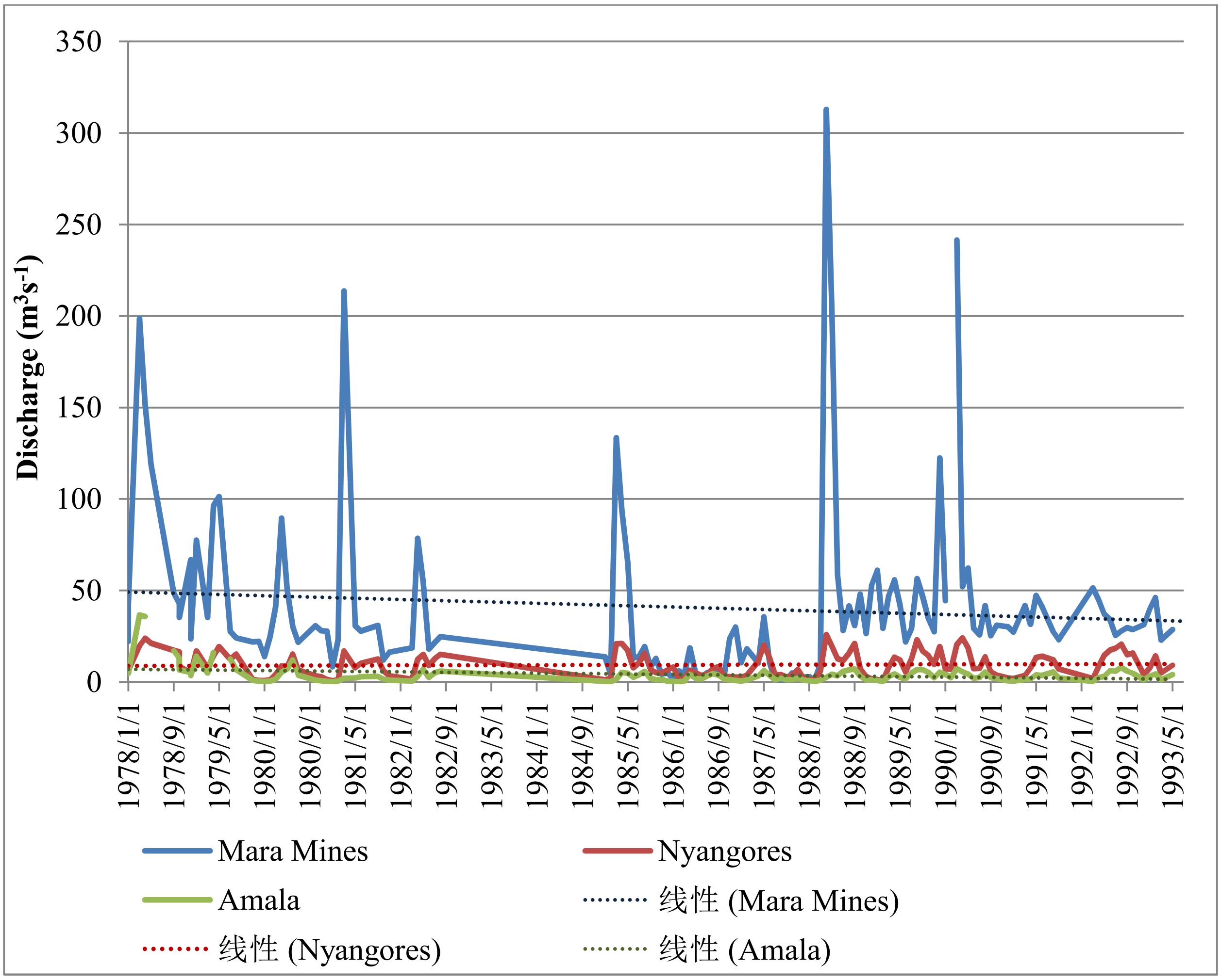

Figure 4: Time series plot for monthly average discharge for Mara Mines, Nyangores and Amala RGSs. The plot also includes the linear trends of the data from 1978 to 1993

The peak flow in the September to December season is 0.58 mm and occurs in the month of December. The monthly mean streamflow at Nyangores River (1LA03 gauge) is 8.7m^3s^{-1} though it does not always prevail in all years due to temporal variability of rainfall. The trends at the adjacent Amala tributary gauging station (1LB03) are relatively similar to those at Nyangores tributary. The long term trend for the time series discharge data from Mara Mines, Nyangores and Amala RGSs shows a decline in monthly average flows (Figure 4). Two high flow seasons whose magnitudes are related to the rainfall amounts are clearly evident at this station. One season occurs from May to August followed by recession in month of September then another season around November to December. At Mara mines gauging station flow seasons are clearly defined. Two seasons with the first one occurring from March to July and the second one from October to December are clearly identifiable. The March-July flow is the highest. The mean flow at the station is 36.8 m^3s^{-1} contributed from Amala, Nyangores and other seasonal tributaries upstream of this station during the rainy season.

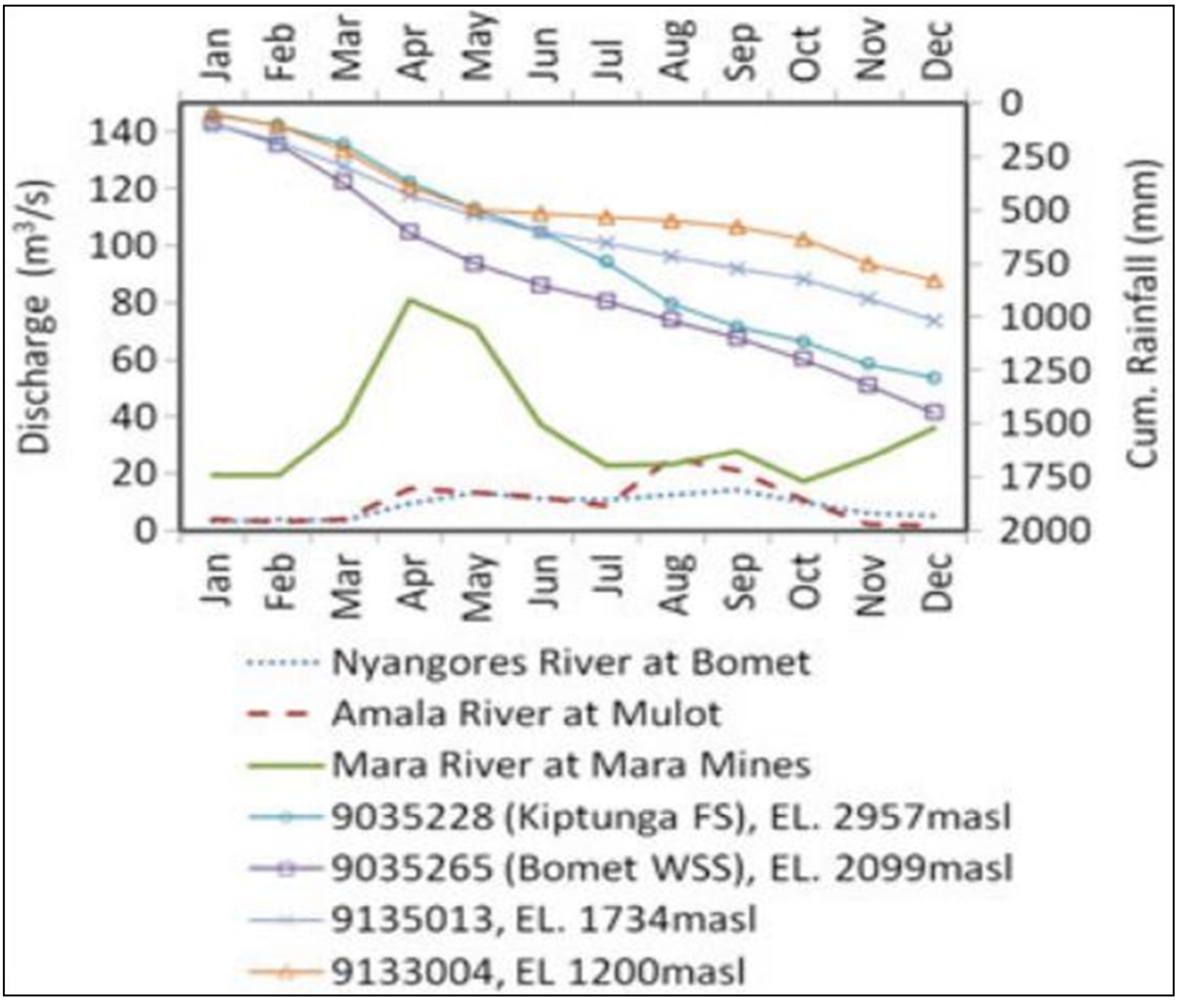

Figure 5: Long-term (1978 to 1993) average monthly cumulative rainfall and discharge at selected Monitoring stations of the Mara River Basin.

3.2 Rainfall Time Series Analysis

Daily mean rainfall for the entire basin calculated from an isohyetal map developed from the six stations used in this study for the period of 1978 to 2000 showed two distinct rainfall seasons in the basin (Figure 4).The first and longer rain occurs between mid-March and June, whereas the second and shorter rain is between September and December. The heaviest rains occur during the long rain season with a mean highest peak of 8.8 mm in the month of April. The peak for the short rain season is 5mm and is in November. The other months are relatively dry with the recorded rainfall lying between 2 and 3 mm. The annual rainfall decreases with altitude ranging from 1000 to 1750 mm in the upper reaches, from900 to 1000 mm in the middle and from 300 to 850 mm at the lower reaches of the river. Daily mean evaporation in the basin also has two high seasons (Figure 4). The highest value of 6.9 mm occurs in the month of March, whereas the other peak of 6.6 mm occurs in the month of September. The two evaporation peaks occur during the dry seasons just before the onset of the rains. The trend of the rainfall for the last 30 years shows a very slight decline in rainfall in the recent years. This could be attributed to climate change but more research needs to be done to ascertain the reasons with certainty.

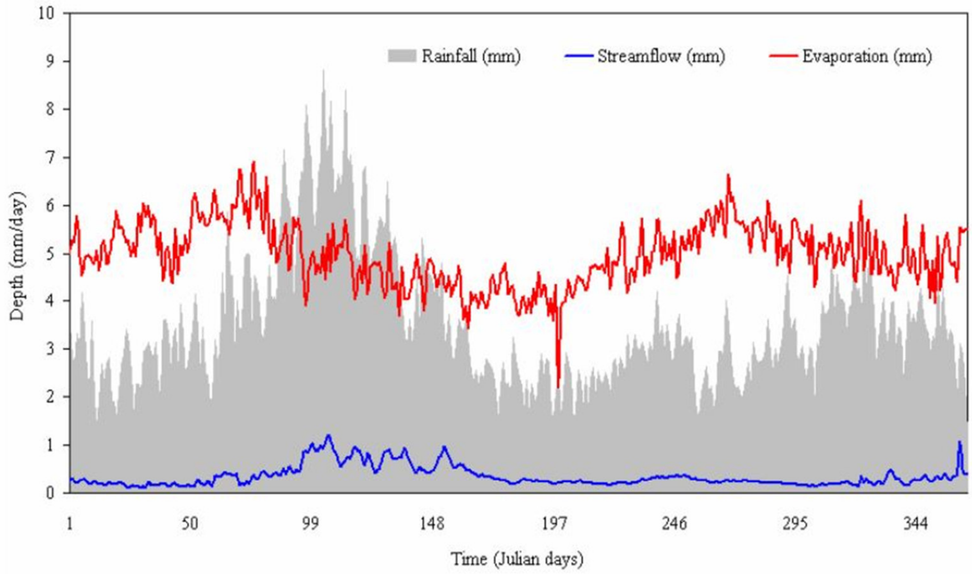

Figure 6: Average seasonal mean depths of rainfall, evaporation over the entire Mara River Basin and discharge at Mara Mines from 1978 to 2000 (Source of data: Rainfall and evaporation, KMD and streamflow, WRMA).

3.3 Land Use/Land Cover Analysis

Land cover/use thematic maps were produced based on the analyses of Landsat MSS, TM and ETM images of Mara River basin for the years 1973, 1986 and 2000(Figure7). The area of the basin covered by each land cover/use type for 1973, 1986 and 2000 were also calculated. The results are shown in Table 3 and graphically illustrated in Figure 8.

The results showed that the spatial areas of the natural forests, rangelands (shrub land, grassland, and savannah) and water bodies have declined while the areas under tea and open forests, agricultural land and wetlands have increased. Between 1973 and 2000 there has been a decrease in closed forests of 31%. Tea plantations and open forests have increased by 214%.

The rangelands (shrub land, grassland and savannah) which were the grazing areas for livestock and wildlife have decreased by 35%. Agricultural areas have increased by 203%. The areas that have been forested, deforested, changed to agriculture and changed to wetlands.

The agricultural fields have been opened in most parts of the basin except at the central region of the basin where the protected Serengeti and Maasai Mara wildlife sanctuaries are found. Overlying the river channel on the change maps show that the opening of agricultural fields is more intense along the river channel.

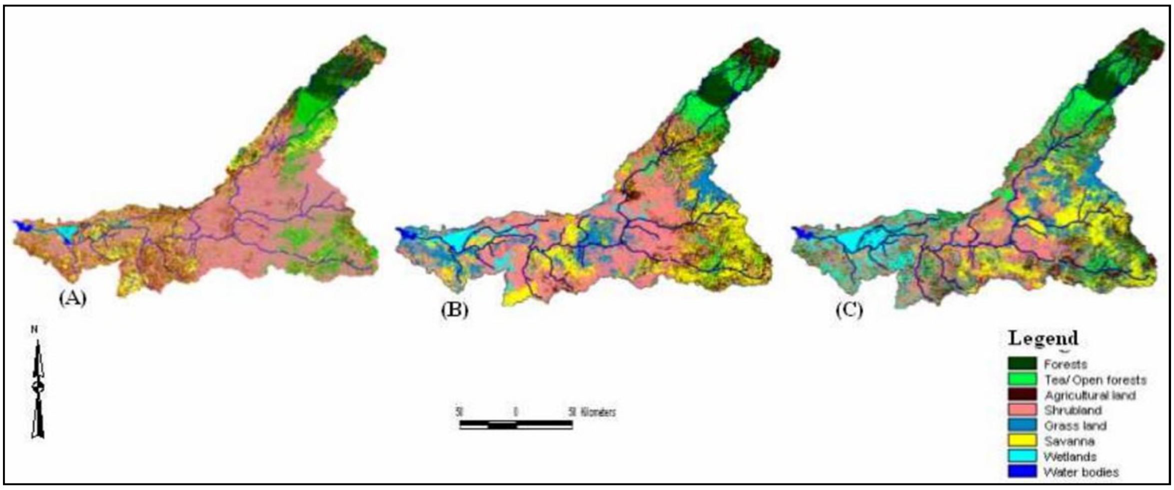

Figure 7: Land use/land cover maps of (A) 1973, (B) 1986 and (C) 2000 for the trans-boundary Mara River Basin

Table 3: Land use/land cover areas change statisticsas analysed from LandSat MSS, TM and ETM images of Mara River basin for the years 1973, 1986 and 2000 respectively.

Land cover/use type	**1973 (km^2)**	**1986 (km^2)**	**2000 (km^2)**	**Change (1973-2000) (km^2)**	**Change (%)**
Forests	1008	893	689	-319	-32
Tea/Open Forests	621	1073	1948	+1327	+214
Agricultural land	826	1617	2504	+1678	+203
Shrubland	5361	5105	3546	-1815	-34
Grassland	2465	1621	1345	-1120	-45
Savannah	3163	2867	2354	-809	-26
Wetlands	286	604	1394	+1108	+387
Water Bodies	104	54	55	-49	-47

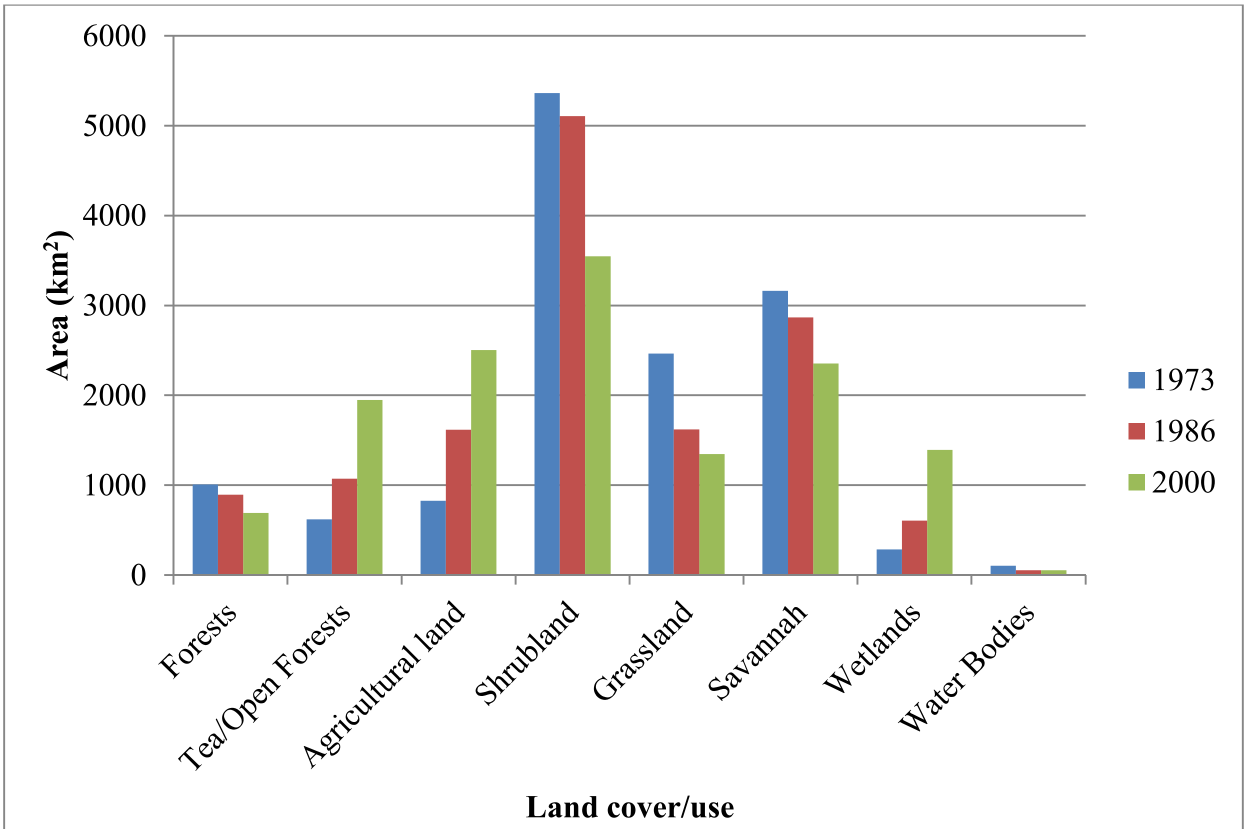

Figure 8: Land cover/use in area (km^2) derived from LandSat MSS, TM and ETM images of Mara River basin for the years 1973, 1986 and 2000 respectively

3.4 Simulation of Stream flow Change in the Mara River

During sensitivity analysis, the observed flow at Mara mines is found to be more sensitive to curve number (Cn2), but the model structure favours Sol_AWC. This difference indicates the added value of calibration and validation as well as the caution to be exercised in simulating rainfall–runoff process of the other sub-catchments of the basin. On the basis of the mean Sensitivity Index, Sol_AWC was highly sensitive (≥1.0) followed by Cn2. The Sensitivity Index may suggest that the uncertainty due to coarse resolution soil data might considerably affect the overall performance of SWAT model.

The observed SD at Mulot (Amala river gauging station) is 56% higher than the calibrated flow, which could be due to the spikes in the observed monthly hydrograph not captured in the simulated flow. A small hydroelectric dam serving Tenwek Hospital, 7 km upstream of Bomet gauging station and commissioned in August 1986, could have a smaller contribution to the lower R^2 and NSE during validation at the Nyangores River. The satisfactory model performance at Mara Mines could possibly be attributed to the larger area or better quality of the observed discharge

Quantitative analysis of long term runoff simulations shows that Nyangores and Amala sub-catchments which make about 12% of the total area of Mara River Basin contribute about 54% and 32% of the total simulated runoff in the Mara River respectively. This is in agreement with previous studies which indicate that Nyangores has higher base flows than Amala(Dessu et al., 2014;Dessu & Mellesse, 2012; Mango et al., 2011; Mati et al., 2008 and; Mwania, 2014). A comparison of groundwater runoff components by Mwania (2014) indicates that Nyangores sub-catchment generates higher volumes of the same than Amala sub-catchment. It can thus be deduced that in Nyangores sub-catchment there is higher infiltration than in the Amala sub-catchment. These results support the arguments by previous studies which attribute the high infiltration in Nyangores to the relatively higher forest cover compared with Amala sub-catchment (Dessu et al., 2014; Dessu & Mellesse, 2012; Gereta et al., 2009; Mango et al., 2011; Mati et al., 2008). The reasoning is that the forest cover promotes infiltration hence more water is available to sustain base flow. Amala with less forest cover and steep slopes quickly drains most of the rainfall as quick runoff with little left infiltration.

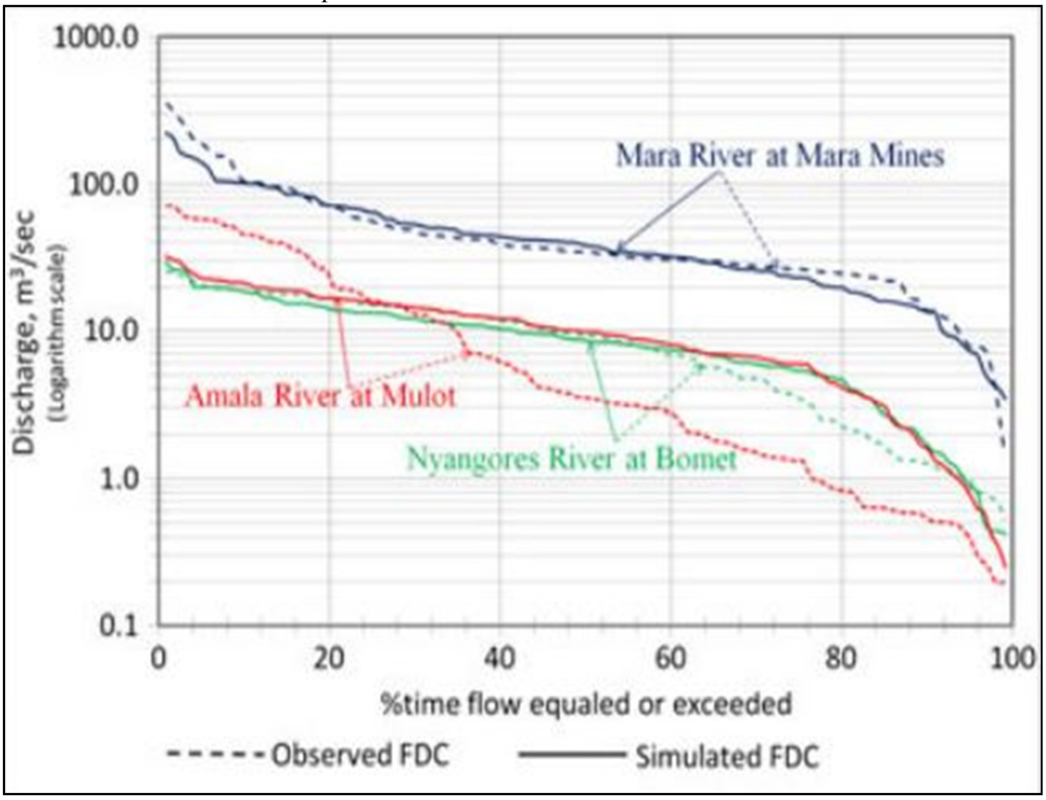

Figure 9: The flow duration curves of the Mara river main tributaries

3.5. Analysis of Different Land Cover Change Scenarios on River Mara Stream flow

SWAT model was run for each condition under: current situation, business as usual scenario, basin conservation scenario, basin degradation scenario, completely forested land, completely agricultural land and completely bare land. The resulting river flow hydrographs were plotted (Figure 10 and 11) then analysed for differences. Table 4 and 5 shows the different stream flow parameters obtained from the hydrograph under each scenario.

Table 4: parameters differentiating hydrographs from each of the scenario developed.

Scenario	Flow peak (m^3/s)	Time of peak	Mean flow (m^3/s)
Current	271.8	7th May	32.1
Business as usual	275.3	8th May	28.7
Forest conservation	283.5	7th May	33.6
Forest degradation	248.1	9th may	25.2
Completely bare land	400.2	3rd May	41.2
Completely agricultural land	376.2	7th May	36.6
Completely forested land	225.3	9th May	23.8

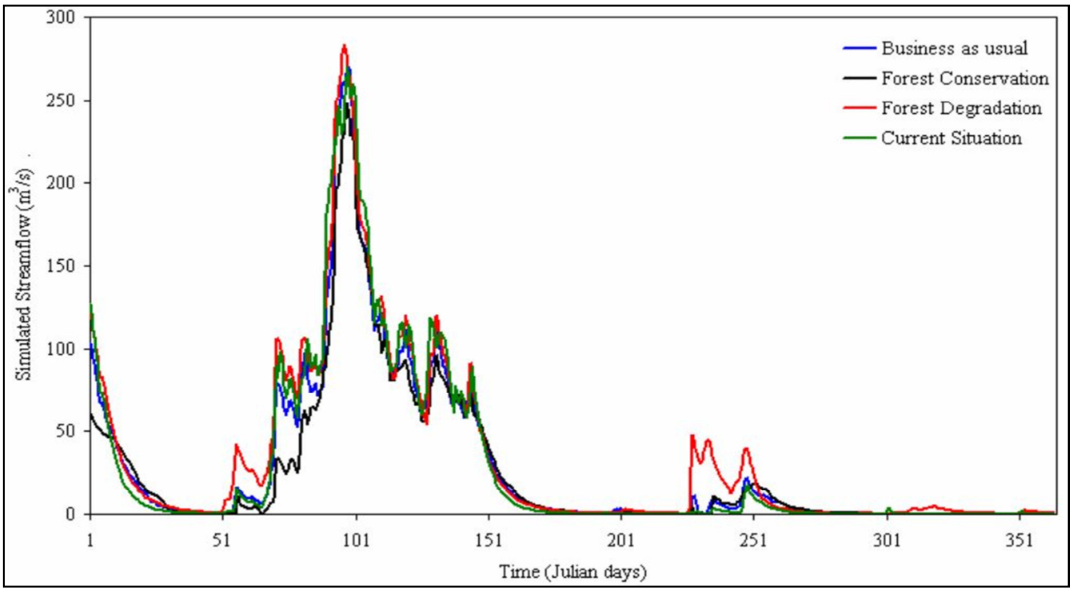

Figure 10: Simulated hydrographs of Current scenario Business as usual, Forest conservation and Forest degradation scenarios for Mara River Basin at Mara mines.

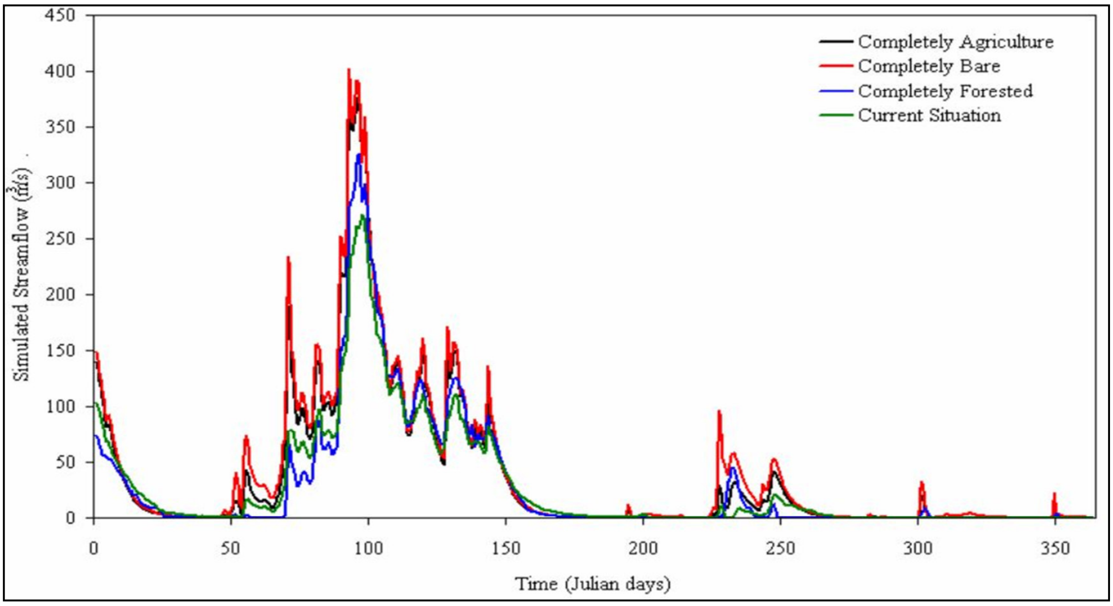

Figure 11: Simulated hydrographs of current situation, completely agriculture, completely bare and completely forested scenarios for Mara River Basin at Mara mines.

Table 5: The differences of the various parameters of the hydrographs generated from scenarios of year 2025 compared to the current situation of year 2000.

Scenario	Flow peak change (%)	Shifting of peak occurrence (days)	Mean flow Change (%)
Business as usual	+1.3	+1	+0.6
Forest conservation	+4.3	0	+0.9
Forest degradation	-8.7	+2	-2.5
Completely bare land	+47.2	-3	+3.3
Completely agricultural land	38.4	0	+1.7
Completely forested land	-17.1	+2	-3.1

4. DISCUSSIONS

4.1. Effects of Land Cover Changes and Use to Mara River Flow

To investigate the effects of land cover change in Mara River Basin, runoff was generated from derived land cover thematic maps of 1973 and 2000 using the same rainfall and evaporation data of 1983 to 1992 period. Since the other model input datasets for topography and soils were held constant during the two runs, the differences in the generated hydrographs could only be associated to changes in land cover, which was the only variable. The percentage difference between the mean annual runoff of the two hydrographs was negligible at 0.01%. Since the annual flow volumes remain unaffected, the change in the day to day flow characteristics of the Mara River can be attributed to land cover changes in the basin.

The effects of forests on stream flow behaviour and water yield are clearly seen in the three scenarios developed that is: completely forested land; completely agricultural land and; completely bare land. The differences in the hydrographs can be explained in context of obstructions and evapotranspiration under each scenario. Land cover change affected the runoff curve number and evaporation aspects of the model. Increase in forest cover as opposed to agricultural and bare land, reduced the runoff curve number and increased evapotranspiration whereas increase in agricultural/bare area increased runoff curve number and decreased evaporation. The reduction of forests reduced the interception and obstruction hence reducing the infiltration of runoff to interflow. This resulted in the increase and early occurrence of flood peaks. The increase in mean flow was due to decrease in evapotranspiration. Evapotranspiration decreases with decrease in tree cover.

Similar results were obtained by Luijten et al. (2000) in their study of the impacts of land cover change in the water balance of the Cabuyal watershed in California. In their study, they compared scenarios of completely cropped, forested and bare. Comparing each case against the actual land use, under forests scenario, the surface runoff and base flow both reduced by 41.5 % and 22.6% respectively. He associated this decreases to the forests ability to intercept rain and to extract water from deeper soil. Because of the increase in evapotranspiration, less water was left for surface runoff and base flow. Completely cropped land increased the basin surface runoff by 5%. Bare soil produced more frequent and higher surface runoff. The average river flow increased by 49% and the minimum flow decreased by 77%. Douglas (1987) in their study on the changes in stream flow peaks following timber harvest of a coastal British Columbia watershed showed that clearing 19% of the forest in a basin could increase the peak flows by 13.5%.

5 CONCLUSIONS

This study has demonstrated that the set-up and calibration of a semi-distributed hydrological model such as SWAT in a poorly-gauged rural African basin with variable land cover, soils and topography can yield useful results given satellite-based land cover/use thematic maps and proper attention to calibration of the SWAT model. In this study, the modeling exercise produced fair results and it is therefore considered an exploratory analysis and evaluation of trends describing the response of the Mara River basin to future land use/cover scenarios. Much of the original forest in the Mara Basin has already been converted to agricultural lands, and water managers are arguing for protection of remaining forests. The Study concluded that any additional forest conversion, whether to agriculture or pasture lands, is likely to reduce dry-season flows and intensify peak flows. These changes would exacerbate already serious problems related to water scarcity in dry periods and hill slope erosion during wet periods. Long-term planning in the basin is also complicated by uncertainties related to projected climate change. These results emphasize the importance of building adaptation to climate change into current and future planning efforts.

REFERENCES

Albergel, C., de Rosnay, P., Gruhier, C., Muñoz-Sabater, J., Hasenauer, S., Isaksen, Wagner, W. (2012): Evaluation of remotely sensed and modelled soil moisture products using global ground-based insitu observations. Remote Sensing of Environment, 118(0), 215-226.

Anderson, M. J. (2001): A new method for non-parametric multivariate analysis of variance. Austral Ecology, 26: 32–46.

Aronson J., Floret, C., Le Floc'h, E., Ovalle, C., and Pontanier R. (1993): Restoration and rehabilitation of degraded ecosystems in arid and semi-arid lands. A view from the south. Restoration Ecology 1: 8-17.

Artan, G., Asante, K. and Kiesler, J. (2001): Use and Description of Famine Early Warning System Flood Model. USGS, Eros Data Centre, Sioux Falls, SD, 57198.

ASCE (1993): Criteria for Evaluation of Watershed Models. Journal of Irrigation and Drainage Engineering, ASCE 119, (3), pp. (429 - 442).

Berndhardt, M., Belnap, J., and Miller, M. (2005): Spatial modeling of biological soil crusts to support rangeland assessment and monitoring. Rangeland Ecology and Management 59: 519-529.

Black, A. R., J. S. Rowan, et al. (2005): DHRAM: a method for classifying river flow regime alterations for the EC Water Framework Directive. Aquatic Conservation: Marine and Freshwater Ecosystems 15(5):

427-446.
Cleaver, K.M., Schreiber, G.A., (1994): Reversing the Spiral, The Population, Agriculture and Environment Nexus in Sub-Saharan Africa. World Bank, Washington, DC.
Dessu, S. B., Melesse, A. M., Bhat, M. G., & McClain, M. E. (2014): Assessment of water resources availability and demand in the Mara River Basin. CATENA, 115(0), 104-114.
Dessu, S. B., & Mellesse, A. M. (2012): Modelling the rainfall–runoff process of the Mara River basin using the Soil and Water Assessment Tool. Hydrological Processes.
Douglas, L. (1987): Changes in stream flow peaks following timber harvest of a coastal British Columbia watershed. Forest hydrology and watershed management Proceedings of Vancouver symposium. IAHS public, 167, 509-517
FAO (2004): Shuttle Radar Topographic Mission (SRTM) Technical Guide. University of Advanced Computer Studies, University of Maryland, Department of Geography, Maryland.
FAO (1997): The Digital Soil and terrain Database of East Africa (SEA). Notes on the Arc/Info files. Version 1.0 completed 3rd April 1997.
Gereta, E., Mwangomo, E., &Wolanski, E. (2009): Eco-hydrology as a tool for the survival of the threatened Serengeti ecosystem. Ecohydrology & Hydrobiology, 9(1), 115-124.
Gereta, E., Wolanski, E., Borner, M., Serneels, S. (2002): Use of an ecohydrology model to predict the impact on the Serengeti ecosystem of deforestation, irrigation and the proposed Amala Weir Water Diversion Project in Kenya. Ecohydrol. Hydrobiol. 2, 135–142.
Juston, J., Jansson, P.E., & Gustafsson, D. (2013): Rating curve uncertainty and change detection in discharge time series: case study with 44-year historic data from the Nyangores River, Kenya. Hydrological Processes, n/a-n/a. doi: 10.1002/hyp.9786
Krhoda, G. O. (2005): The Hydrology of Mara River. WWF–Eastern Africa Regional Programme Office (EARPO) Mara River Catchment Basin Initiative.
Luijten, J. C., Jones, J. W. and Knapp, E.B. (2000): Dynamic modeling of strategic water availability in the Cabuyal River, Columbia: the impact of Land Cover change on the Hydrological Balance. Advances in Environmental Monitoring and Modeling, Volume 1, No. 1 (2000) pp. 36-60.
Mango, L. M., Melesse, A. M., McClain, M. E., Gann, D., & Setegn, S. G. (2011): Land use and climate change impacts on the hydrology of the upper Mara River Basin, Kenya: Results of a modeling study to support better resource management. Hydrology and Earth System Sciences, 15(7), 2245-2258.
Mwania, J. M. (2014): Runoff Modeling of the Mara River Using Satellite Observed Soil Moisture and Rainfall: Master of Science Thesis, University of Twente, ITC, doi: http://www.itc.nl/library/papers_2014/msc/wrem/mwania.pdf
Nile Basin Initiative (2004): Mara River Basin Transboundary Integrated Water Resources Management and Development Project – Project Document
Salas, J. D. (1993): Analysis and modeling of hydrologic time series. Handbook of Hydrology (ed. by D. R. Maidment), 19.1–19.72. McGraw-Hill, Inc., USA.
Tashakkori, A., &Teddlie, C. (2003b): The past and future of mixed methods research: From data triangulation to mixed model designs.
UNEP (2009): Kenya Atlas of Our Changing Environment. Division of Early Warning and Assessment (DEWA), United Nations Environment Programme, Nairobi, Kenya.
Walubengo, D. 2007. “Participatory Forest Management and the New Forest Legislation: Is It a Promise or a Reality?” Paper presented at First National Participatory Forest Management Conference, Nairobi, June