Modeling the impact of land use and climate change scenarios of on the hydrology of the upper Mara River, Kenya

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Abstract

With the flow of the Mara River becoming increasingly erratic especially in the upper reaches, attention has been directed to land use change and climate variability as the major cause of this problem. The semi-distributed hydrological model Soil and Water Assessment Tool (SWAT) and Landsat imagery were utilized in the upper Mara River basin in order to 1) map existing field scale land use practices, 2) determine the impacts of land use change on water flux using plausible land use change scenarios; and 3) determine the impacts of rainfall and air temperature variations based on the Intergovernmental Panel on Climate Change projections on the water flux of the upper Mara River This study found that the different scenarios impacted the water budget components differently. Land use changes resulted in a slightly more erratic discharge while rainfall and air temperature changes had a more predictable impact on the discharge and water balance components. These findings demonstrate that the model results show the flow was more sensitive to the rainfall changes than land use changes. It was also shown that land use changes can reduce dry season flow which is the most important problem in the basin. The model shows also deforestation in the Mau Forest increased the peak flows which can also lead to high sediment loading in the Mara River.

Key terms: Mara River basin, SWAT, modeling land use change, climate change, discharge

1. Introduction

Water is an extremely important resource in Kenya and is the lifeline of its ecosystems. It is used for agriculture, industry, power generation, livestock production, and many other important activities. However, only 1.9 percent of Kenya is covered by water (SoK, 2003) and most of this is supplied by the country's rivers most of which are concentrated in the highlands. In terms of water supply, Kenya receives seasonally and annually variable marginal rainfall with an annual average rainfall of 630 mm which is relatively low for an equatorial country (FAO, 2005). It is also categorized as a water scarce country based on the average per capita water availability (WRI, 2007) and this is a major challenge to the country in several ways. The scarcity of this crucial resource therefore necessitates its quantification, and maintenance of adequate flows under the changing land use and climate variability.

Understanding hydrologic response of watersheds to the signals of physical (land use) and climatic (rainfall and air temperature) is important component of water resources planning management. These changes alter river flow (volume, timing, frequency) through alterations of the overland flow and infiltration, groundwater recharge, flow velocity, sediment detachment and transport. The climate change projected by Intergovernmental Panel on Climate Change (IPCC) includes predictions on deviations of temperature and precipitation from past and current conditions. Those changes could have significant impact on the hydrological characteristics and response of watersheds. The extent of the hydrologic impacts due to the climate variability resulting in rainfall regime change is region and watershed specific. In areas where river flows and stream discharges are the main sources of water for the different uses (domestic, irrigation, wildlife, livestock and environmental flows) the great concern is the change in potential surface runoff and quantity of water in streams. The reason for concern is the availability of sufficient water resources to sustain not only human activities but also the sustainability and integrity of ecological systems within a watershed. Reliable prediction of watershed scale availability of water under the inevitable changes of the climate change is crucial for water resources planning and management. The need for this prediction is even much stronger in watersheds like the Nyangores in the upper Mara River basin where human induced alteration (forest clearing, expansion of agriculture and irrigation) are happening at an alarming rate. The fact that Mara

River is one of the ecologically important rivers of the region because of its importance to the Mara Game Reserve and Serengeti National Park makes the need for predictive modeling of available water in the face of land use changes and climate variability an important and timely task.

In addition, land use changes are expected to intensify in the Mara Basin with the increase in population because of increased pressure on the available resources (Serneels et al., 2001; Mati et al. 2005). Natural lands such as forests, grassland and bushland are most likely to be converted to agriculture and settlements. Hence, the modeling of impacts of climate change scenarios combined with the alterations of the earth's surface due to land use changes can provide a useful tool for water resource management in the decision making process.

One way to model the effect of changed climatic conditions and land use regimes is to build a scenario framework that allows the comparison of watershed scale hydrological models as it responds to alternative conditions.

Hydrological model types allowing/facilitating scenario development

Hydrological models can be defined as mathematical formulations that determine the runoff signal that leaves a river basin from the rainfall signal received by the watershed (Beven, 2001). Hydrological models provide a means of quantitative prediction of catchment runoff that may be required for efficient management of water resources systems. The physically based models are based on the understanding of the physics of the hydrological processes controlling the catchment response and describe these processes using physically based equations. These hydrological models are used as a means of extrapolating from those available measurements in both space and time, in particular into the future to assess the likely impact of future hydrological changes otherwise known as forecasting.

The Soil and Water Assessment Tool (SWAT), a semi-distributed physically based model, (Arnold *et al*., 1998) has been used for simulation of different scenarios both land use impacts and climate change. The simulation of hypothetical impacts is an effective method of evaluating alternative land use and climate change in SWAT (Gassman et al., 2007).

Land use change scenarios are common in SWAT studies and these have been carried out in different watersheds around the world. The model is capable of identification of critical and priority areas for soil and water conservation or management in different watersheds. Land use scenarios enable the modeling of pollutant and sediment movement in relation to sets of developed scenarios. SWAT has been used to model the sediment and nutrient loss increase and reduction as a result of land use change in agricultural lands and it has also successfully been used to quantify the impacts of the implementation of best management practices (BMPs) through implementation of water quality management plans on the long term. The analysis of the effect of BMPs in reduction of pollutants such as industrial effluents has also been previously examined in various watersheds. The effects of tillage practices on sediment and water flow has been examined and the connection to nutrient losses. Land use scenarios have been run in watersheds some as small as 8.2km^2 to determine the effect of land use change on surface runoff and streamflow with accurate results (Nelson et al., 2005; Santhi et al., 2006; Nelson et al., 2005; Kaur et al., 2004; Tripathi et al., 2003; Vaché et al., 2002; Bracmort et al., 2006; Chaplot et al., 2004; Miller et al., 2002; Hernandez et al., 2000; Heuvelmans et al., 2005; Weber et al., 2001; Lorz et al., 2007; Fohrer et al., 2002; 2005).

Climate scenarios are used to provide quantitative assessments of climate impacts and can be defined as possible representation of future climate which have been developed to be used exclusively in conjunction with investigating the potential impacts of anthropogenic climate change (IPCC, 2001).

According to the IPCC (2007), General Circulation Models (GCMs) are currently the most advanced tools available for simulating the response of the global climate system to changing atmospheric composition. In general, the GCM is a numerical representation of the atmosphere and its phenomena over the entire Earth and it incorporates a variety of fluid-dynamical, chemical or even biological equations. The GCM is run using different climate change scenarios and produces outputs of annual and seasonal averages, which enable the determination of the likely changes in precipitation, temperature and runoff as a result of these scenarios taking place. Owing to the mismatch in scale due to the coarse spatial resolution of the GCM simulations of 250 and 350 km, the output of the GCM in assessing the hydrological impacts of climate change at watershed scale is regarded as inappropriate (Arnell, 1996; Russo & Zack, 1997; Robock et al., 1993). Temporal resolution also an issue because of the difference in time scales, the hydrological models operate within an hourly or daily time step while the GCM may operate with time scales of as little as 15 minutes. Downscaling is a means of relating large scale atmospheric predictor variables to local- or station- scale meteorological series (Semenov & Barrow, 1997).

Ficklin et al. (2009) used the WXGEN weather generator in SWAT (Sharpley and Williams, 1990) and the LARS-WG stochastic weather generator to quantify the climate change sensitivity of a highly agricultural watershed in San Joaquin, California based on IPCC A1F1 climate change scenarios of CO_2, temperature and rainfall changes. An implementation of a 2041-2060 climate change scenario by Gosain et al., (2006) on 12 major river basins in India resulted in a general decrease of surface runoff and an increase in flood and droughts. Mimikou et al. (2000) used the WBDUG model, a conceptual physically based hydrological model applied to simulate the effect of effect of climate scenarios on runoff coupled with a stream model R-Qual applied to simulate water quality downstream of a point source in the face of climate change.

Kim et al (2008) has shown that the increased rainfall and resultant water supply in the upper Blue Nile that is anticipated through the middle of the century. However, according to El Shamy et al (2009), over the longer term (2081-2098), the Blue Nile basin may become drier. Using the outputs from 17 GCM for the A1B scenario their predictions varied between a -15% and +14% change in precipitation, with the ensemble mean suggesting little change. Based on 15 GCMs, Setegn et al (2010) downscaled the temperature and precipitation to a watershed scale for the upper Blue Nile River basin for the 2046-2065 and 2080-2100 periods and assessed the impact on the hydrology of the Blue Nile River at selected gauge stations. The Soil and Water Assessment Tool (SWAT) model output based on the downscaled data shows that flow, soil moisture, evapotranspiration and groundwater levels can change significantly but also were highly variable across the different GCMs leading to high uncertainty and less conformity in the prediction.

Generally, climate change is predicted by GCMs hence in assessing the climate impacts of smaller areas such as the Mara River Basin, downscaling approaches should be adopted. SWAT has been used to simulate the impact of historical climate trends versus future climate projections for various river basins around the world. SWAT has been used together with inputs from downscaled climate model projections to predict the impact of climate change on aquifer recharge, water yields at river basin outlets, occurrence and impact of extreme climate hazards such as floods and droughts, (Gosain et al., 2006; Rosenburg et al., 1999; 2003; Thomson et al., 2003; Johns et al., 1997; Stone et al., 2001, Hotchkiss et al., 2000).

Hydrological modeling in regions with scarce data

Hydrological modeling has been carried out in areas with scarce data similar to the Mara River basin. Setegn et al. (2009) successfully used SWAT to model the hydrology of the Lake Tana basin in Ethiopia. The main objective of this study was to test the performance and feasibility of the SWAT model for prediction of streamflow in the Lake Tana basin. This was carried out despite scarce data and coarse resolution datasets such as a 90m resolution DEM, 1:50,000 scale land use map and missing values in the rainfall data.

Jayakrishnan et al. (2008) made use of the SWAT model to carry out a hydrologic modeling study of the Sondu River basin in Kenya to indicate the potential for application of the model in African watersheds with the scarce data where a 1-km resolution DEM data and one soil type was used for the entire basin. Streamflow data were missing for several days at the stream gauge, which were neglected in calculating the mean observed monthly streamflow values. Observed sediment data were absent to calibrate the sediment load simulation at the basin outlet.

In the upper Tana River catchment in Kenya, Jacobs et al. (2007) used SWAT to test the effectiveness of alternative land use interventions. This was done in the face of data constraints such as coarse soil data sets (1:1,000,000). Mulungu and Munishi (2007) used the SWAT model with an objective of parameterizing the Simiyu catchment, Tanzania, with a view of using the baseline results for application of SWAT in similar areas around the country and ungauged watersheds for land/ water management studies.

In the Mara River basin there have also been a number of hydrological studies with limited data. Gereta et al.(2002) made use of an ecohydrology model to predict the impacts of deforestation, water diversion for irrigation, and a proposed hydropower project on the Amala River, a tributary of the Mara River, would have on the Serengeti ecosystem, a major wildlife conservation area located downstream of the Mara River. Mutie (2006) used remote sensing tools and a hydrological model Geo-SFM model to determine the extent of land cover change, the effect of land use change on the flow regime of the Mara River. Terer (2005) investigated the hydrological characteristics and management approaches of the Nyangores River catchment in the Mara River Basin and its influence on land productivity and sediment delivery into Nyangores River. The success of the studies carried out in different watersheds similar to and including the Mara basin faced with problems of scarce data demonstrates the possibility of acquiring reasonably accurate results for hydrological studies in areas with scarce data.

Advantages of the Soil and Water Assessment Tool (SWAT) Model

The SWAT (Soil and Water Assessment Tool) model was the ideal choice for use in this study because of various reasons; it is a physically based model that requires specific information about weather, soil properties, topography, vegetation and land management practices which it uses as inputs to simulate the physical processes associated with water movement, nutrient transport, crop growth and sediment movement. This enables it to model ungauged watersheds and more importantly, quantify the impact of scenarios (alternative input data) such as changes in land use, land management practices and climate on water quality and quantity. Secondly, it uses readily available data, while more inputs can be used to simulate more specialized processes it is still able to operate on minimum data which is an advantage especially when working in areas with insufficient or unreliable data like the Mara River basin. SWAT also has a weather simulation model that generates daily data for rainfall, solar radiation, relative humidity, wind speed and temperature from the average monthly variables of the data that provides a useful tool to fill in gaps in daily data in the observed records. Third, the SWAT model is computationally efficient, able to run simulations of very large basins or management practices without consuming large amounts of time and expenses compared to lumped, conceptual or fully distributed, physically based models (Mulungu and Munishi, 2007). It is also a continuous time or a long-term model able to simulate long term impacts of land use, land management practices and build-up of pollutants (Neitsch et al, 2005). These qualities of the SWAT model will enable the quantification of long term impacts of land use changes, variations in rainfall and air temperature on the hydrology of the Mara River basin. SWAT is also able to simulate crop yield and biomass output for a variety of crop rotations, grassland/ pasture systems and trees with a growth submodel (Neitsch et al, 2005), which makes it very valuable in land use/ land cover change simulations.

Scenario building

Another advantage of the SWAT model is the ability to build different scenarios. Jayakrishnan (2008) made use of the SWAT model with a focus on assessing the environmental impact of changes in land use as a result of the adaptation of modern technology on the smallholder dairy industry in Sondu, Kenya. The land use within the Sondu River basin was estimated for the three scenarios of land use change specifically, different percentage increases of Napier grass at the expense of the native grass using a combination of population data and demographic survey.

SWAT can be used for simulation of climate change by means of its weather generator that can forecast climate data and also allows the input of climate data generated from different models if preferred (Neitsch et al., 2005). Ficklin et al. (2009) used the WXGEN generator included in SWAT to successfully generate climate variables including minimum and maximum temperature, precipitation and solar radiation close to the observed values as determined by coefficients for determination (R^2) for a climate change sensitivity assessment of a highly agricultural watershed. It was important to determine the appropriate climate change scenario for the study area in terms of accuracy, feasibility and suitability.

Land Use change Scenarios

The Mara basin is characterized by different land uses which result from the different activities carried out within the basin. The Mara River basin consists of mainly closed and open forests, tea plantations in the upper slopes of the Mau Escarpment, agricultural land, shrublands and grasslands used for livestock and game grazing or as game reserves, savannah grasslands which comprise shrub grasslands and wetlands (Mango, 2010). The ability to forecast land use/ land cover change and ultimately predict the consequences of hydrologic change will depend on our ability to understand the past, current, and future drivers of land-use/ land-cover change. In the Mara River basin, these factors as well as other emerging social and political factors may have significant effects on future land use/land cover. Patterns of land use/land cover change, and land management are shaped by the interaction of economic, environmental, social, political, and technological forces on local to global scales.

According to a study carried out by Mati et al. (2005) based on analysis of Landsat imagery, the different land cover in the Mara River Basin between the year 1986-2000 changed significantly in terms of spatial extent. The Mara River basin is mostly a rangeland and in 1986, 69% of the basin area consisting mostly of savannah grassland and shrubland. By 2000 however, the rangelands had been reduced significantly because of encroachment by agriculture, which on the other hand had increased by 55%. The closed forest area had also reduced by 23% as a result of forest clearance for timber and tea plantations, resulting in an increase in open land by 82%. The same study also reported that the wetlands showed a significant increase attributed to sediment build up in the mouth of the river resulting from erosion in the upstream and erratic river flows which have been caused by change in the vegetation cover in terms of deforestation, conversion of rangelands to agriculture and poor soil and water conservation practices within the basin.

According to a study conducted by Serneels et al., (2001), since the early 1970s, the land surrounding the Masai Mara National Reserve has been steadily converted into agricultural land with large scale wheat farming being a major part of it. From 1975 to 1995, wheat farming in the Loita Plains in the lower Mara River basin has increased by an area of 44,000 ha. The increase in mechanized agriculture and rangelands modification is said to be driven by factors such as land suitability and economic factors while smallholder agriculture is driven by factors such as changes in demography caused by in and out migration and population growth within the basin (Entwistle et al., 1998). The land use/land cover change in the upper part of the basin is brought about by smallholder agriculture while that of the lower basin is brought about mainly by mechanized agriculture in the form of wheat and maize farming.

In the case of this study, the land use change scenarios were based on the previous and current trends of land use within the last 50 years in the Upper Mara watershed. These trends are based on previous studies such as those mentioned above, land use maps, current land use and projections of future land use as predicted by the residents and experts such as natural resource managers and planners.

Climate Change Scenarios

The impacts of climate change in African countries have the potential to undermine and even, undo progress made in improving the socio-economic well-being of many of the African countries. The negative impacts associated with climate change are also compounded by many factors, including widespread poverty, human diseases, and high population density, which is estimated to double the demand for food, water, and livestock forage within the next 30 years (DFID, 2009).

According to Christensen et al. (2007), in Africa warming is very likely to be higher than the global annual mean warming throughout the continent and in all seasons, with drier subtropical regions warming more than the moister tropics. Annual rainfall is likely to decrease in much of Mediterranean Africa and the northern Sahara, with a greater likelihood of decreasing rainfall as the Mediterranean coast is approached. Rainfall in southern Africa is likely to decrease in much of the winter rainfall region and western margins. There is likely to be an increase in annual mean rainfall for the first part of the century in East Africa, where the Mara River basin is located.

Observed climatic changes in Africa include; warming of 0.7°C over the 20th century, 0.05°C warming per decade through the 20th century and increased precipitation for East Africa. Projected climate change includes; projected warming for Africa ranges from 0.2°C per decade (low scenario) to more than 0.5°C per decade (high scenario), 5-20% increase in precipitation from December-February (wet months) and 5-10% decreased in precipitation from June-August (dry months) (Hulme et al., 2001; IPCC, 2001).

For this study, regional projections of climate change were based on those documented in IPCC Fourth Assessment Report: Climate Change (2007) where regional averages of temperature and precipitation projections were developed from a set of 21 global models in the MMD (multi-model dataset) for the A1B scenario for Africa and other continents.

The specific objectives of this study are to determine the impact of land use change, rainfall and air temperature variation on the water flux of the upper Mara River in Kenya. For this purpose, we considered plausible scenarios of land use change based trends and information from the area and climate change prediction for the study area based on the IPCC report (IPCC, 2007). The results of this research add to the existing literature and knowledge base with a view of promoting better land use management practices in Kenya and it provides an evaluation of the application of semi-distributed physically-based hydrological models such as the SWAT model to densely populated, highly agricultural watersheds with highly variable precipitation patterns, where modeling is limited to data scarcity.

2. Methodology

Study Area

The transboundary Mara River basin is shared between Kenya and Tanzania and is located in East Africa between longitudes $33.88372^0$and 35.907682^0 West, latitudes -0.331573^0 and -1.975056^0 South (Figure 1). It covers about 13,750 km^2 (Mati et al., 2005). The Mara River flows from its source in the high altitude Mau Forest in Kenya across different landscapes and drains into Lake Victoria at Musoma Bay in Tanzania. Major tributaries of the Mara River are Nyangores, Amala, Talek, Sand The major land use drained by these rivers are urban settlements and villages, subsistence and large scale agriculture, forestry, livestock, fisheries, tourism, conservation areas, mining and other industries.

The Nyangores watershed is the focus of this study and is of importance because of its location in the upper catchment of the Mara Basin. The 395-km long Mara River encounters impacts of widespread human activities such as deforestation and subsequent cultivation of the land starting right at the headwaters in the Mau forest complex catchment in the highlands (Figure 1). Those activities have led to erratic flow in the Mara River in both the dry and wet seasons and this is a problem considering the high demand for water by the large populations of Mara River basin inhabitants downstream (Mutie et al., 2006; Mati et al., 2005). Downstream of the Mara River are human settlements, agricultural areas, protected areas such as the Masai Mara Wildlife Preserve and Serengeti National Park which support immense wildlife populations and wetlands that are dependent on the availability of this water in adequate quality and quantity (Gereta et al., 2002; Mati et al., 2005)).

Deforestation, irrigation practices and the construction of weirs on tributaries of the Mara especially the Amala River which is one of the two main tributaries may reduce the flow of the Mara river to a halt during severe droughts and this reduction in quantity and quality greatly impacts wildlife-water interactions and consequently, the ecology of ecosystems of the Mara river basin (Gereta & Wolanski, 1998; 2002). Serneels et al., (2001) in a study of land cover changes in the Mara ecosystem, noted that climatic, anthropogenic and other factors shape the vegetation, ecology and biodiversity of an ecosystem. According to Mutie et al., (2006), modification of natural land cover and soil conditions have brought about changes in the river flow regime such as high peak flows, reduced baseflows, enlarged river channel and silt deposition downstream. Reliable data is needed to develop policies and comprehensive management principles for sustainable resource utilization (Mati et al., 2005). Therefore, determining the impact of land use and climate change on the main tributaries of the Mara River; the Amala and Nyangores Rivers is considered an important step in ensuring adequate minimum and maximum river flows sufficient for all the stakeholder needs.

SWAT Model

The Soil and Water Assessment Tool (SWAT) is a hydrological model that can be applied at the river basin, or watershed scale. It was developed for the purpose of simulation of impact of land management practices on water, sediment and agrochemical yields in large watersheds with varying soils, land use and agricultural conditions over extended time periods (Neitsch et al., 2005). Arnold et al., (1998) defines SWAT as a semi-distributed, time continuous simulator operating on a daily time step. It is developed for assessment of the impact of management and climate on water supplies, sediment, and agricultural chemical yields in sub-basins and larger basins. The program is provided with an interface in ArcView GIS (Di Luzio et al., 2002) for the definition of watershed hydrologic features and storage, as well as the organization and manipulation of the related spatial and tabular data. The SWAT (Soil and Water Assessment Tool) model was the ideal choice for use in this study because of various reasons; it is a physically based model that requires specific information about weather, soil properties, topography, vegetation and land management practices which it uses as inputs to simulate the physical processes associated with water movement, nutrient transport, crop growth and sediment movement. This enables it to model ungauged watersheds and more importantly, quantify the impact of alternative input data such as changes in land use, land management

practices and climate on water quality and quantity. Secondly, it uses readily available data, while more inputs can be used to simulate more specialized processes it is still able to operate on minimum data which is an advantage especially when working in areas with insufficient or unreliable data. Third, the SWAT model is computationally efficient, able to run simulations of very large basins or management practices without consuming large amounts of time and expenses. Lastly, it is a continuous time or a long-term yield model able to simulate long term impacts of land use, land management practices and build up of pollutants (Neitsch et al, 2005). These qualities of the SWAT model will enable the quantification of long term impacts of land use changes, variations in rainfall and air temperature on the hydrology of the Mara River basin.
The SWAT model application can be divided into five steps: (1) data preparation, (2) sub-basin discretization, (3) HRU definition, (4) parameter sensitivity analysis, (5) calibration and validation (6) uncertainty analysis. The flowchart showing the modeling steps are shown in Figure 2.

(1) Data preparation

Hydrological modeling using SWAT requires the use of detailed spatially explicit datasets on land morphology or topography, land use or land cover, soil classification and parameters for hydrological characteristics, and climate and hydrological data on a daily time-step (Schuol et al., 2007). While general global, continental or regional datasets exist they often lack sufficient spatial and temporal resolution or sufficient continuity in the time series records. The generation of specific local datasets from raw data sources could increase resolutions that are more appropriate for localized models or data gaps can filled and data. For the purpose of this study we identified two areas where the generation of data layers could significantly improve the modeling effort (e.g., land use /land cover and rainfall estimates). For other essential datasets no good alternatives to the very coarse and general datasets could be found (e.g., soils). A complete list of variables and utilized data sources are presented in Table 1. The preparation of those data are described in the following sections and summarized in Figure 2.

<u>*Land use / land cover data*</u>

Land use and management is an important factor affecting different processes in the watershed such as surface runoff, erosion and evapotranspiration. The model calibration was performed for a land use/land cover (LULC) status as mapped from 30 meter resolution Landsat Thematic Mapper data for 2008. Following the basic principles of the USGS land use/land cover classification system (LULCCS) for use with remote sensor data level classification (Anderson et al., 1976), we formulated a schema that would accurately and adequately represent the land cover/land use within the Mara River basin and at the same time allow for reclassification to match classes that are comparable to the SWAT land cover and land use database (Table 2). The first and coarse level classes we identified in the study area are (1) bushland including shrubs, (2) forest composed of primary and secondary forest including forestry plantations, (3) water and (4) cropland which was divided into general crops mainly represented by annual plants and tea plantations. This distinction for cropland was established based on the fact that annual crops undergo a yearly cycle that leaves plots barren for part of the year. The cropland class includes plots at all stages of the cycle including bare soil. On the contrary tea is a perennial crop, and therefore exhibits very different hydrological properties.

The image classification was performed using a supervised machine learning procedure that uses a binary recursive partitioning algorithm in a conditional inference framework (Hothorn, et al 2006) ctree procedure in the party package or the statistical software R). Estimates for class specific and overall accuracy were performed on the training set with 843 samples. The resultant error matrix gave a $\hat{K}$ statistic value of 83% while the overall classification accuracy for the classification was 90% (Table 3). The class with the highest accuracy is cropland (93.8%) followed by forest (89.4%), cropland tea (87.5%), water (85.7%) and bushland (73.3%). The highest omission and commission errors were associated with bushland.

Soil data

The response of a river basin to a rainfall event depends on nature and conditions of underlying soils (Shrestha et al., 2008).The SWAT model requires soil property data such as the texture, chemical composition, physical properties, available moisture content, hydraulic conductivity, bulk density and organic carbon content for the different layers of each soil type (Setegn, 2009). Soil data was obtained from the Soil Terrain Database of East Africa (SOTER) and is shown in Figure 3. The scale of the spatially explicit soil data layers is a very coarse 1:2,000,000. A soil property table (Table 4) specific for the Mara River basin soils was appended to the SWAT database, since the soil types found in the study area are not included in the US soils database provided with SWAT.

Climate data

Climate data used in the SWAT model consists of daily rainfall, temperature, wind speed, humidity and evapotranspiration data. The weather variables used were the daily precipitation values obtained from the Bomet Water Supply Office Station located at Bomet Town and Kiptunga Forest Station located in Elburgon District, minimum and maximum air temperature values for the period of 1996-2003 obtained from the Kericho Hail Research and Narok Meteorological weather stations (Figure 1). These data were obtained from the Ministry of Water Resources of Kenya and the Lake Victoria South Water Resource Management Authority in Kenya.

The rain gauge records of daily rainfall were observed to have numerous gaps in them for many time periods. The spatial location of these 2 stations was a major cause of concern in this study and raised the question of whether the data they recorded would be sufficient to accurately represent the rainfall received across the entire watershed. With these concerns noted, an additional source of rainfall data the Meteosat rainfall estimate data was employed and used in the model simulations. It is discussed in more detail in the paragraph that follows.

Augmentation of the rainfall data record for the hydrological modeling was achieved by utilizing rainfall estimates derived from remotely sensed data as provided by the Famine Early Warning System (FEWS) daily Rainfall Estimation (RFE). RFE data are derived from Meteosat infrared data and stationary rain gauges generating daily rainfall estimates at a horizontal resolution of 10km (Xie and Arkin, 1996). The rainfall time series for the SWAT model was obtained by calculating daily area weighted averages across all 30 delineated sub-catchments that form the Amala and Nyangores watersheds. The continuous and complete time series was then applied to the virtual rain gauges represented by the centroids of the delineated sub-catchments (Figure 1). The rainfall estimates were processed for the time period from January 1st, 2002 to

December 31, 2008. A comparison of the virtual rain gauge precipitation estimates with records from actual rain gauge revealed that the artificial rain gauges exhibit similarities in trend. The two different sources differ in magnitude and this can be attributed to spatial location and the nature of point estimation of rainfall that makes it difficult to capture variations in amounts of rainfall in an area especially without a dense network of ground stations. Figure 4 shows comparison of the two rainfall data sources.

River discharge

Daily river discharge data was obtained for the Nyangores River from the Bomet gauging station located LA03 at the outlet of the basin (Figure 1). The discharge values for the Nyangores River were used for calibration and validation of the model. The available discharge data ran from the year 1996 to the year 2008.

(2) Sub-basin discretization

Topography of the basin influences the rate of movement and direction of flow over the land surface and is therefore necessary to derive physical properties of the basin (Shrestha et al., 2008). The digital elevation model (DEM) of 90m by 90m resolution for the study area obtained from the Shuttle Radar Topography Mission (SRTM) of NASA was used. The DEM is a necessary input in the SWAT model as seen in Table 1 and it gives the elevation of a particular point at a particular spatial resolution and was used in the delineation of the watershed and analysis of the land surface characteristics and drainage patterns.

(3) Definition of hydrological response units

Hydrologic response units (HRUs) are portions of a subbasin possessing unique land use, management or soil attributes and are incorporated into the SWAT model to account for the complexity of the landscape within the subbasin (Neitsch et al., 2005). Watershed and sub-watershed delineation was carried out using the DEM and included various steps including: DEM setup, stream definition, outlet and inlet definition, watershed outlets selection and definition and calculation of sub basin parameters. The resulting sub-watersheds were then divided into HRUs based on their combinations of land use, soil and slope combinations.*(4) Model calibration and validation*

A sensitivity analysis was performed on the model to select the most sensitive parameters, out of the total of 27 flow parameters that are included in SWAT, for calibration. The model incorporates Automated Latin Hypercube One-factor-At-a-Time (LH-OAT) global sensitivity analysis procedure (Van Griensven et al., 2006), which was used for the sensitivity analysis of the parameters following the initial parameterization.

The Auto -calibration and uncertainty analysis were done using two different algorithms, i.e., Parameter Solution (ParaSol) (Van Griensven and Meixner, 2007) that is incorporated in SWAT and Sequential Uncertainty Fitting (SUFI-2) (Abbaspour et al., 2004; 2007).

ParaSol is a multi-objective uncertainty method that is efficient in optimizing a model and providing parameter uncertainty estimates (Van Griensven and Meixner, 2007). It calculates objective functions (OF) based on the simulated and observed time series, aggregates the OFs into a Global Optimization Criterion (GOC). The optimization is done by adapting the Shuffled Complex Evolution Approach for effective and efficient global minimization method (SCA-UA). The SCA-UA algorithm is a global search algorithm for the minimization of a single function that is implemented to deal with up to 16 parameters (Duan et al. 1992).

SUFI-2 (Sequential Uncertainty Fitting) is the calibration algorithm developed by Abbaspour et al. (2004; 2007) for calibration of SWAT model. In SUFI-2, parameter uncertainty accounts for all sources of uncertainties such as uncertainty in driving variables (e.g., rainfall), parameters, conceptual model, and measured data (e.g. observed flow, sediment).

For the rain gauge data model, out of that the 8 years of complete time series datasets 4 years were used for calibration and the remaining 4 years were used for validation. For the RFE model, 4 years were used for calibration and 3 for validation. The length of the simulations was determined by the availability and length of time series data for discharge, air temperature and rainfall which are key pieces in the model simulation. The model was run on a default simulation of 8 years from 1996 to 2003 for the Rain gauge data and from 2002 to 2005 a period of two years for the RFE data.

Scenario Analysis

Land use

To explore the sensitivity of SWAT outputs to land use and the effect of land use/land cover changes on the discharge of the Nyangores River, land use scenarios were explored. Attention was paid to ensure these were realistic scenarios in accordance to the ongoing trends of land use change within the study area. The percent coverage and details of the conversions are presented in the Tables 8 and 9. The land use scenarios included;

1. Partial deforestation, conversion to agriculture (PDA)

   This scenario involved manipulation of the forest cover reducing it partially by converting the deciduous forest type to small scale or close grown agricultural land.

2. Complete deforestation, conversion to grassland (CDG)

   This scenario involved replacing all the existing forest cover with grassland to simulate a complete absence of forest cover in the watershed.

3. Complete deforestation, conversion to agriculture (CDA)

   Replacement of forest land by agriculture is a common trend within the study area and is seen to be one of the major causes of erratic river flows and increased sediment load in the Nyangores River. This scenario was carried out by replacing all forest cover with agriculture particularly small scale agriculture.

Climate Change Scenarios

For the climate change scenarios in this study, regional projections of climate change were based on those documented in IPCC Fourth Assessment Report: Climate Change (2007). The regional averages of temperature and precipitation projections were developed from a set of 21 global models in the MMD (multi-model data set) for the A1B scenario for Africa and other continents as shown in Table 5. GCM's are numerical coupled models that represent various earth systems including the atmosphere, oceans, land surface and sea-ice and offer considerable potential for the study of climate change and variability. Scenarios are images of the future, or alternative futures. They are neither predictions nor forecasts.

The Special Report on Emissions Scenarios (SRES) are grouped into four scenario families (A1, A2, B1 and B2) that explore alternative development pathways, covering a wide range of demographic, economic and technological driving forces and resulting GHG emissions. B1 describes a convergent world, with the same global population as A1, but with more rapid changes in economic structures toward a service and information economy with reductions in materials intensity, and the introduction of clean and resource efficient technologies.

The A1 storyline assumes a world of very rapid economic growth, a global population that peaks in mid-century and rapid introduction of new and more efficient technologies. The SRES A1B Emissions Scenarios (a scenario in A1 family) describes ‘‘a future world of very rapid economic growth, global population that peaks in mid-century and declines thereafter, and rapid introduction of new and more efficient technologies”. A2 describes a very heterogeneous world with high population growth, slow economic development and slow technological change.

B1 describes a convergent world, with the same global population as A1, but with more rapid changes in economic structures toward a service and information economy with reductions in materials intensity, and the introduction of clean and resource efficient technologies. B2 describes a world with intermediate population and economic growth, emphasizing local solutions to economic, social, and environmental sustainability. B2 describes a world with intermediate population and economic growth, emphasizing local solutions to economic, social, and environmental sustainability.

The projections for mean temperature for the MMD-A1B scenario show an increase in the monthly seasons. For precipitation, the model ensemble shows an increase in rainfall in East Africa, extending into the Horn of Africa, is also robust across with 18 of 21 models projecting an increase in the core of this region, east of the Great Lakes. This East African increase is also evident in Hulme et al. (2001) and Ruosteenoja et al. (2003).

This prompted the precipitation and temperature scenarios below purposely set to capture the effect of both increase and decrease of precipitation and increase in surface temperature.

The climate scenarios explored are included in Table 10and were;

1. A change in the mean temperature and
2. A change in rainfall for selected months

These were carried out by adjusting the monthly precipitation and temperature files in the model and running the simulations with the best parameters acquired from the calibration process.

3. Results and discussion

The results presented in this paper are those of the Nyangores watershed. The Nyangores watershed had a longer time series data set which made it possible to capture both short and long term variations in rainfall and discharge. The hydrological modeling results provide data on the discharge amounts and water balance components of the Nyangores watershed and the influence of land use and climate change.

3.2 Hydrological Modeling

Twenty seven hydrological parameters were tested for identifying sensitive parameters for the simulation of the stream flow. A sensitivity analysis was carried out and the most ten 10 most sensitive parameters (Table 6) were chosen for calibration of the model. These parameters were; Baseflow alpha factor (ALPHA_BF), threshold water depth in the shallow aquifer for flow (GWQMN), Soil evaporation compensation factor (ESCO), Channel effective hydraulic conductivity (CH_K2), Initial curve number (II) value (CN2), Available water capacity (SOL_AWC), Maximum canopy storage (CANMX), Soil depth (SOL_Z), Maximum potential leaf area index at the end of the time period (BLAI), the water in the shallow aquifer returning to the shallow aquifer returning to the root zone in response to a moisture deficit during the time step (mmH_2O). This also includes water uptake directly from the shallow aquifer by deep tree and shrub roots (GW_REVAP) and (REVAPMN) (Neitsch et al., 2005).

The hydrological modeling exercise resulted in discharge simulation values for the Nyangores watersheds for different rainfall inputs; Rain gauge measurements and remote sensing based rainfall estimates (RFE). The measured rainfall and RFE artificial gauge measurements were plotted for comparison as shown in Figure 4. The resulting hydrographs from model simulations with these different data are shown in Figure 5. The discharge hydrographs for monthly data were compared for calibration and scenario analysis (Figure 6).

Model calibration and validation

Calibration is the process of estimating model parameters by comparison of model predictions or output for a given set of assumed conditions with observed or measured data for the same conditions (Moriasi et al., 2007). Comparison was carried out for the datasets obtained and the resulting statistics for the daily and monthly simulations are shown in the Table 7. Statistical measures such as the Nash-Sutcliffe Efficiency (NSE) and the Coefficient of Correlation (R^2) were used to describe and compare the different datasets (observed and simulated).

In the case of the Nyangores rain gauge data model, as shown in Table 7, there was a clear underperformance of the model in the case of discharge simulation as shown by the different model evaluation statistics in Moriasi et al., (2007). Calibration of the rain gauge data produced a very low NSE value for Nyangores which was considered poor. One of the main sources of model uncertainties is errors in the input variables such as rainfall and temperature. The poor model performance using weather data from limited rain gauges was attributed to poor quality of the gauged climate variables as well as very course spatial distribution of weather stations in the watersheds.

For the RFE data, the comparison between the observed and simulated streamflow indicated a good agreement between the observed and simulated discharge which were verified values of coefficient of determination (R^2) and Nash Sutcliffe efficiency (NSE) for the Nyangores River (Table 7). The RFE data resulted in NSE values of 0.43 and R^2 value of 0.56 for the Nyangores for the calibration period.

After the calibration exercise completed the final calibrated parameter values were incorporated into the SWAT model for validation and further applications. Validation is comparison of model results with an independent dataset. Moreover the validation was carried out to determine whether these models were suitable for evaluating the impact of land use and climate change. For the RFE models, NSE values of 0.43 and 0.23 were obtained for the calibration and validation respectively of the Nyangores model and taking into consideration the errors that may have been introduced by missing data values, the SWAT model was considered suitable for predicting the impacts of climate and land use change. According to Abbaspour et al., (2007), watershed scale model calibration is challenging and is impeded by uncertainties like watershed processes unknown to the modeler, processes not captured by the model and simplification of the processes by the model.

Land use change scenarios

The land use change scenarios were based on observed trends and expert predictions. The resulting land use coverages in area (square kilometers and percentages) are shown in Tables 9 and 10. The hydrographs (Figures 6 and 7) show the effect the different land use scenarios on the river discharge. From observation of the graphs, it is evident that all the land use scenarios significantly reduced the baseflow and average flow of the whole period of simulation. The PDA and CDA scenarios resulted in high peak flows and lower baseflows while the CDG scenario was characterized by high peak flows but has a baseflow that appears almost equivalent to that of the present day scenario (RFE calibrated model). Details on how these different land use scenarios affected the different water balance components can be seen in Tables 11 and 12 and Figure 8.

In Table 11 the percent changes in the annual average water balance components from the base model (Nyangores calibrated RFE model) are shown. Surface runoff is increased in all the land use change scenarios and moreso in the complete deforestation to grassland and agriculture scenarios. The complete deforestation to agriculture scenario is the only scenario with increased lateral flow contributing to streamflow where the other scenarios had a reduced lateral flow. The complete deforestation to grassland shows an interesting response because among all the scenarios it shows the lowest decrease in ground water recharge and percolation. It also had the lowest rates of water yield and evapotranspiration. This shows that as much as complete deforestation to grassland would be a loss in terms of biomass and vegetation, it is probably the scenario with the least impact in terms of changes in water balance components and the general flow regime of the Nyangores River. From the ratio of water balance components to precipitation in Table 12, the components with the highest ratios are potential evapotranspiration, evapotranspiration, ground water recharge (deep and shallow aquifer), percolation and water yield. It can be said that in a rainfall event these water balance components will be impacted the most.

Climate change scenarios

Ogutu et al., (2007) examined the influence of the El Nino-southern Oscillation on rainfall and temperature and Normalized Difference Vegetation Index fluctuations in the Mara-Serengeti ecosystem and it is anticipated that climate change will accelerate habitat dessication and deterioration of vegetation quality. Generally, the reduction of precipitation brought about a reduction in available water in the watersheds reducing baseflows to very low levels. The increase in temperature also reduces the water availability to some degree by increasing evapotranspiration in the watershed thus reducing amount of water and discharge. According to Ficklin et al., (2009), temperature is one of the most important factors governing plant growth and depending on the optimum temperature of the plants, the plant growth cycle will be shifted also affecting the water balance components. Increases in precipitation by 10 percent and 20 percent increased the discharge and baseflow in the rivers but on the other hand may have negative effects across land such as erosion and in the reach such as increased sediment load and flooding.

For this study, we have used regional climate projections that are documented in IPCC Fourth Assessment Report: Climate Change 2007. They developed regional averages of temperature and precipitation projections from a set of 21 global models in the MMD (multi-model data set) for the A1B scenario for Africa and other continents. According to the report, the mean temperature and precipitation responses are first averaged for each model over all available realizations of the 1980 to 1999 period from the 20th Century Climate in Coupled Models (20C3M) simulations and the 2080 to 2099 period of A1B. Table 13 shows the minimum, maximum, median (50%), and 25 and 75% quartile values among the 21 models, for temperature (°C) and precipitation (%) changes for east Africa. Based on the reported changes in temperature and precipitation the hydrological model was run for minimum, median and maximum changes condition. Some models predicted a minimum increment in annual temperature by 1.8 (°C) and annual rainfall reduction by 3 percent for the year 2080-2099 as compared to the base period 1980-1999. Similarly some models predict maximum annual increments of temperature by 4.3% and rainfall increment by 25 percent.

The hydrological model was run for the minimum, median and maximum changes in temperature and precipitation that are shown in Figure 9. The model simulation result shown in Table 13 shows that a minimum changes in temperature and precipitation for each seasons of the year, resulted in 25.34% reduction in stream flow. For a median weather variables changes the model estimated about 2.8% increments in stream flow. Likewise a maximum temperature and rainfall increment scenario resulted in 35.7 % of increase in streamflow. Table 13 also shows changes in stream flow for the year 2080-2099 with respect minimum, median and maximum changes to temperature and precipitation in East Africa.

Changes in the annual averages of the water balance components for the climate change scenarios are shown in Figure 10, Table 13 and Table 14 where a range of the changes and their effect on the water balance components are shown. In Table 13 the changes in stream flow from the base period (8.86 m^3/s) are detailed. The median flow will increase by about 2.79% in the face of the climate change scenarios detailed and the flow will reduce by about 25.34% for the minimum and will increase by about 35.7% for the maximum flows. This means there will be high wet season flows and low dry season flows. This shows extremes in the flows that may not be erratic but may have a major effect on the water users without proper planning and management of water resources in the Nyangores Basin. The water balance components as shown in Table 14 vary proportionally to the amount of precipitation received and it can therefore be concluded that the outcome of climate change scenarios in these simulations are governed mainly by the amount of precipitation to a larger degree and minorly impacted by temperature. The effect of land cover growth and reduction as a result of these climatic changes was not considered in this study.

4. Conclusions

The model evaluation results (Table 7) suggest that the calibration process may have not adequately captured the variations in the different hydrological years (periods) especially in the Rain gauge model which may be due to the fact that the time series data was not long enough to achieve this. In the case of the Rain gauge models compared to the RFE models, the statistics and hydrographs show the rainfall values from the Rain gauge data were not well representative of the actual rainfall that was received in the basins under study. Lack of a dense rain gauge station network within the study area that was unable to capture the different rainfall amounts and account for the spatial variability of the rainfall received is the most likely cause of this result.

Rainfall is the main driving force of the hydrological cycle and when the rainfall for large watersheds such as the Nyangores watersheds cannot be accurately accounted for this presents a problem in the simulation process and when calibrating the model. However, it can inferred that the set-up and calibration of a semi-distributed hydrological model such as SWAT in a large watershed with variable land cover, soils and topography yielded satisfactory results given reliable data and proper attention to manual or automatic calibration.

The model simulations showed that the upper Mara River flow is sensitive to and will be significantly affected in the face of the climate and land use change posing difficulties in adaptation to the altered flow regimes of the Nyangores and consequently, the Mara Rivers. The different water balance components were affected regardless of the type and amount of change that was undergone thus affecting the magnitude and timing of the flow. It is therefore prudent to work towards establishing and maintaining adequate minimum flows that would mitigate the effects of reduced baseflows and put in place measures to maintain adequate sustained river flows to the benefit of the stakeholders of the Mara River basin such as proper land and water management practices.

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Table 1 List of variables used in the SWAT model and their sources

VARIABLES	DATA SOURCE
Land use/land cover map	Landsat 5 Thematic Mapper (USGS/ GLOVIS)
Soil map	Soil Terrain Database of East Africa (SOTER) Database
Digital Elevation Model	Shuttle Radar Topography Mission (SRTM)
Measured streamflow	Lake Victoria South Water Resource Management Authority
Measured rainfall	Lake Victoria South Water Resource Management Authority
Measured temperature	Lake Victoria South Water Resource Management Authority

Table 2 Land use/land cover type reclassification into SWAT LU/LC classes

Land Cover Type	SWAT LU/LC Type
Forest	Forest Evergreen Forest Deciduous
Water	Water
Bushland	Forest Mixed
Grassland	Range Grasses
Agriculture	Agricultural Land Generic Agricultural Land Close Grown

Table 3 Land cover classification accuracies as provided by binary recursive portioning algorithm in conditional inference framework. comError = proportional error of commission, omError = proportional error of omission.

Reference Data	**Cropland**	**Crop. Tea**	**Bushland**	**Forest**	**Water**	**rowTotal**	**comError**	**comError(%)**
Cropland	439	3	13	4	0	459	0.04	**4.4**
Cropland Tea	2	35	0	0	0	37	0.05	**5.4**
Bushland	26	0	74	19	0	119	0.38	**37.8**
Forest	1	2	14	203	1	221	0.08	**8.1**
Water	0	0	0	1	6	7	0.14	**14.3**
columnTotal	468	40	101	227	7	**843**		
omError	0.06	0.13	0.27	0.11	0.14			
omError(%)	**6.2**	**12.5**	**26.7**	**10.6**	**14.3**			
Accuracy (%)	**93.8**	**87.5**	**73.3**	**89.4**	**85.7**			
Overall Accuracy (%)	**89.8**							

K̂	**83.2**

Table 4 Texture of the soils in the Upper Mara

SOIL TYPE CODE	CLAY %	SILT %	SAND%
KE200	31	29	40
KE196	42	42	16
KE386	41	29	30
KE 45	9	67	24
KE187	38	35	27
KE183	30	26	44
KE190	10	28	62
KE192	20	48	32

Table 5 Regional averages of temperature and precipitation projections from a set of 21 global models in the MMD for the A1B scenario for East Africa

EAF 12S, 22E	**Temperature Response (°C)**							**Precipitation Response (%)**						**Extreme Seasons (%)**		
	Season	Min	25	50	75	Max	T Yrs	Min	25	50	75	Max	T yrs	Warm	Wet	Dry
To	DJF	`	2.6	3.1	3.4	4.2	10	-3	6	13	16	33	55	100	25	1
	MAM	1.7	2.7	3.2	3.5	4.5	10	-9	2	6	9	20	>100	100	15	4
	JJA	1.6	2.7	3.4	3.6	4.7	10	-18	-2	4	7	16		100		
18N, 52E	SON	1.9	2.6	3.1	3.6	4.3	10	-10	3	7	13	38	95		100	21
	Annual	1.8	2.5	3.2	3.4	4.3	10	-3	2	7	11	25	60	100	30	1

Table 6 sensitivity ranking of parameters towards water flow

SENSITIVITY RANK	**NYANGORES RAIN GAUGE**	**NYANGORES RFE**
1	ESCO	ESCO
2	CN2	GWQMN
3	ALPHA_BF	CN2
4	GWQMN	SOL_Z
5	SOL_Z	ALPHA_BF
6	REVAPMN	SOL_AWC
7	SOL_AWC	REVAPMN
8	CH_K2	CANMX
9	BLAI	GW_REVAP
10	CANMX	BLAI

Table 7 Model evaluation statistics for monthly discharge

STATISTIC	Rivers			
	Nyangores			
	RFE		Rain gauge	
	Cal	Val	Cal	Val
NSE	0.43	0.23	-0.533	-0.057
R^2	0.56	0.43	0.085	0.321
r	0.803	0.57	0.291	0.566

Table 8 Annual average water balance components for the calibrated Nyangores watershed models

COMPONENTS	NYANGORES RG 1996-2003	NYANGORES RFE 2002-2008
PRECIP (mm)	1329.9	1097.2
SURQ (mm)	15.03	11.51
LATQ (mm)	60.67	43.09
GW_Q (mm)	354.59	481.23
REVAP (mm)	21.89	3.48
DA_RCHG (mm)	22.47	25.33
GW_ RCHG (mm)	449.43	506.63
WYLD (mm)	429.28	535
PERC (mm)	450.02	509.52
ET (mm)	789	530
PET (mm)	1150.3	1179
TLOSS (mm)	1.01	0.82
SEDYLD (T/HA)	0.686	0.704

Table 9 Areal coverage of land use/ land cover in the Nyangores watershed in square kilometers

Land Use Scenario / Basin	Land use/ Land cover (2008)	Partial Deforestation, Conversion to Agriculture (	Complete Deforestation Conversion to Grassland	Complete Deforestation Conversion to Agriculture
Forest Evergreen	182.4	182.4	0	0
Forest Deciduous	25.95	0	0	0
Forest Mixed	40.11	0	0	0
Agricultural Land Generic	121	161.09	121	121
Agricultural Land Close Grown	323.03	349	323.03	571.49
Range Grasses	0	0	248.46	0
TOTAL (Sq. Km)	692.49	692.49	692.49	692.49

Table 10 Percent areal coverage of Land use/ land cover type in the Nyangores watershed

Land Use/ Land Cover Type	Land use/ Land cover (2008)	Partial Deforestation, Conversion to Agriculture (PDA)	Complete Deforestation, Conversion to Grassland (CDG)	Complete Deforestation, Conversion to Agriculture (CDA)	Upper Mara (Nyangores + Amala)
Forest Evergreen	26.34	26.34	0.00	0.00	24.81
Forest Deciduous	3.75	0.00	0.00	0.00	9.06
Forest Mixed	5.79	0.00	0.00	0.00	3.71
Agricultural Land Generic	17.47	23.26	17.47	17.47	9.13
Agricultural Land Close Grown	46.65	50.40	46.65	82.53	53.29
Range Grasses	0	0	35.88	0	0.00
TOTAL (%)	100	100	100	100	100

Table 11 Percent changes in annual average water balance components for the Nyangores watershed land use change scenarios.

	Partial Deforestation, Conversion to Agriculture (PDA)	Complete Deforestation, Conversion to Grassland(CDG)	Complete Deforestation, Conversion to Agriculture (CDA)
PRECIP (mm)	0.00	0.00	0.00
SURQ (mm)	3.15	12.40	13.70
LATQ (mm)	-2.55	-2.70	0.80
GW_Q (mm)	-6.28	-3.54	-10.51
REVAP (mm)	-2.51	-2.73	-4.02
DA_RCHG (mm)	-6.03	-3.60	-10.07
GW_ RCHG (mm)	-5.99	-3.59	-10.02
WYLD (mm)	-3.88	0.25	-4.28
PERC (mm)	-5.95	-3.93	-10.41
ET (mm)	2.57	0.24	3.05
PET (mm)	0.00	0.00	0.00
TLOSS (mm)	10.83	14.86	38.00
SEDYLD (T/HA)	15.72	14.38	55.02

Table 12 Ratio of water balance components to precipitation for the Nyangores watershed land use change scenarios.

	Land use/ Land cover (2008)	Partial Deforestation, Conversion to Agriculture (PDA)	Complete Deforestation, Conversion to Grassland(CDG)	Complete Deforestation, Conversion to Agriculture (CDA)
PREC (mm)	1.000	1.000	1.000	1.000
SURQ (mm)	0.072	0.077	0.087	0.094
LATQ (mm)	0.040	0.040	0.040	0.034
GW_Q (mm)	0.285	0.273	0.282	0.258
REVAP (mm)	0.013	0.013	0.013	0.013
DP AQ RCHRG (mm)	0.016	0.015	0.016	0.014
TOTAL AQ RCHRG (mm)	0.316	0.303	0.313	0.287
WYLD (mm)	0.393	0.385	0.405	0.381
PERC (mm)	0.315	0.301	0.311	0.284
ET (mm)	0.567	0.576	0.556	0.581
PET (mm)	1.075	1.075	1.075	1.075
TLOSS (mm)	0.004	0.004	0.005	0.005
SED (T/HA)	0.005	0.006	0.005	0.006

Table 13 Changes in stream flow for the years 2080-2099 with respect to minimum, median and maximum changes to temperature and precipitation in East Africa

Flow for base period (m^3/s)	Median Flow (2080-2099) (m^3/s)	Min flow (2080-2099) (m^3/s)	Max flow (2080-2099) (m^3/s)
8.86	9.11	6.62	12.02
Change in m^3/s	0.25	-2.25	3.16
Changes in %	2.79	-25.34	35.70

Table 14 Changes in the annual averages of the water balance components for Nyangores watershed climate change scenarios

	Base Period	Minimum Change	Average Change	Maximum Change
PRECIP (mm)	1040.10	943.90	1117.60	1318.90
SURQ (mm)	71.14	52.28	83.10	128.63
LATQ (mm)	42.70	35.09	44.14	54.71
GW_Q (mm)	299.85	223.64	298.79	376.61
REVAP (mm)	12.77	10.88	13.54	15.48
DA_RCHG (mm)	16.78	12.58	16.76	21.09
GW_ RCHG (mm)	335.51	251.54	335.16	421.84
WYLD (mm)	410.10	308.14	422.13	555.05
PERC (mm)	338.27	253.66	337.74	425.40
ET (mm)	586.40	596.30	648.00	706.7 0
PET (mm)	1169.70	1243.60	1304.20	1357.40
TLOSS (mm)	3.59	2.88	3.90	4.89

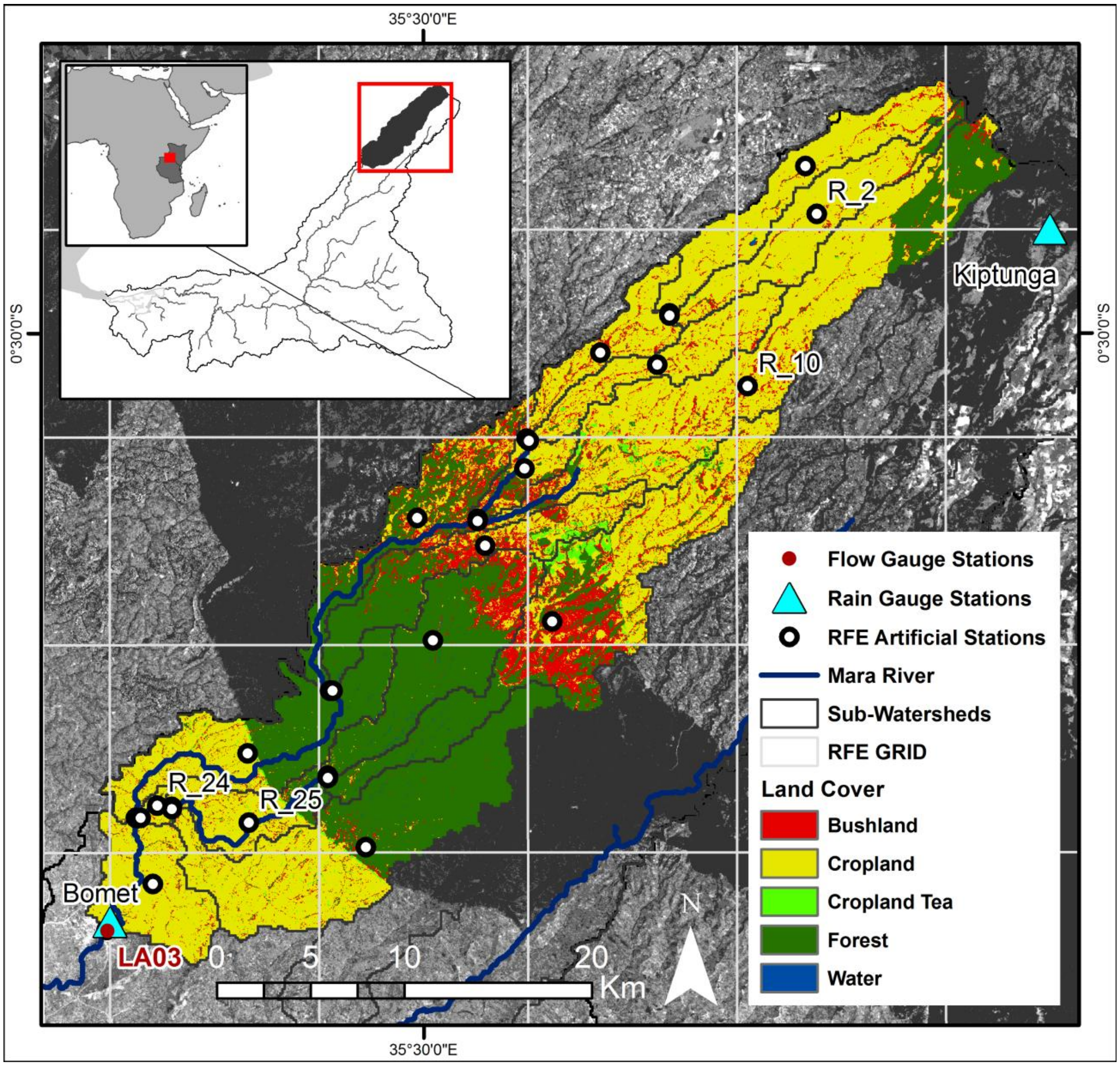

Figure 1 Study Area

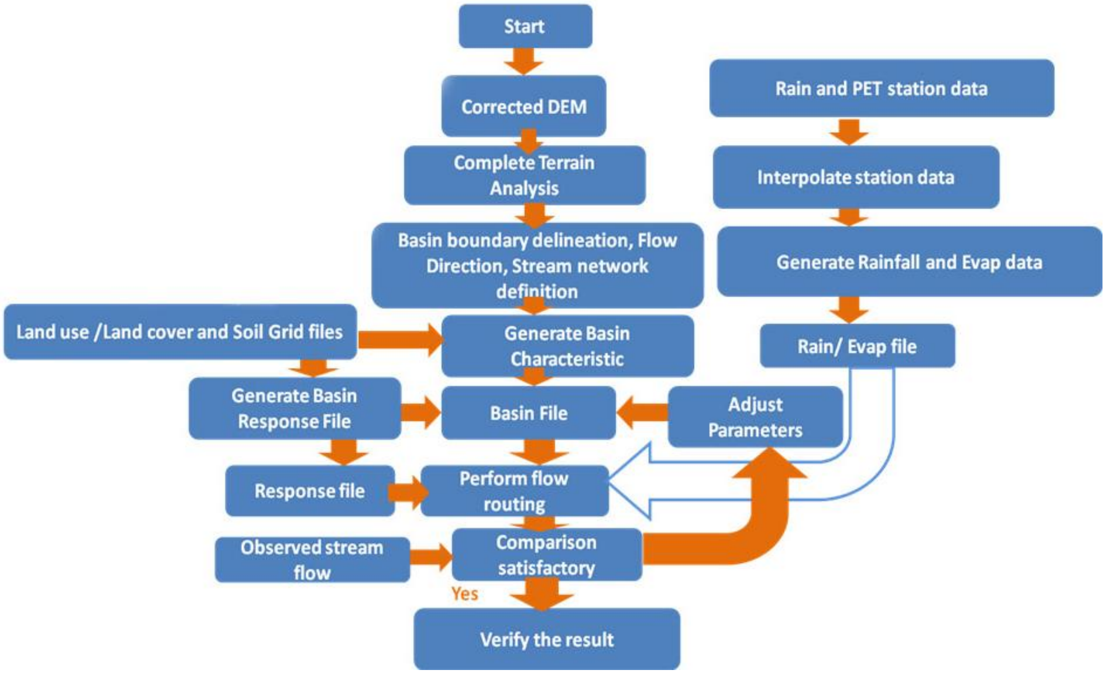

Figure 2 Modeling process, inputs and outputs

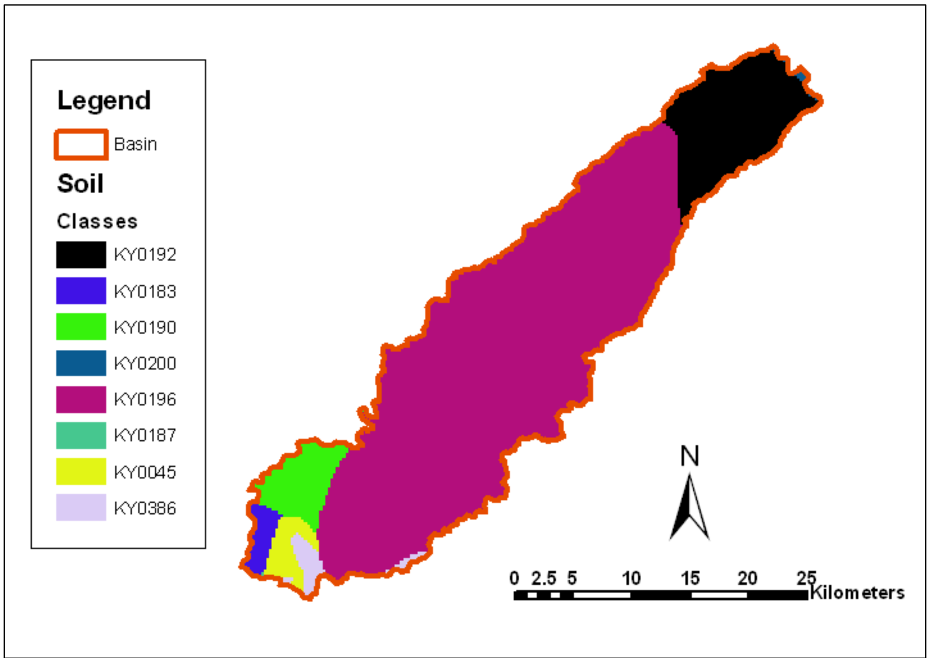

Figure 3 Nyangores soil types

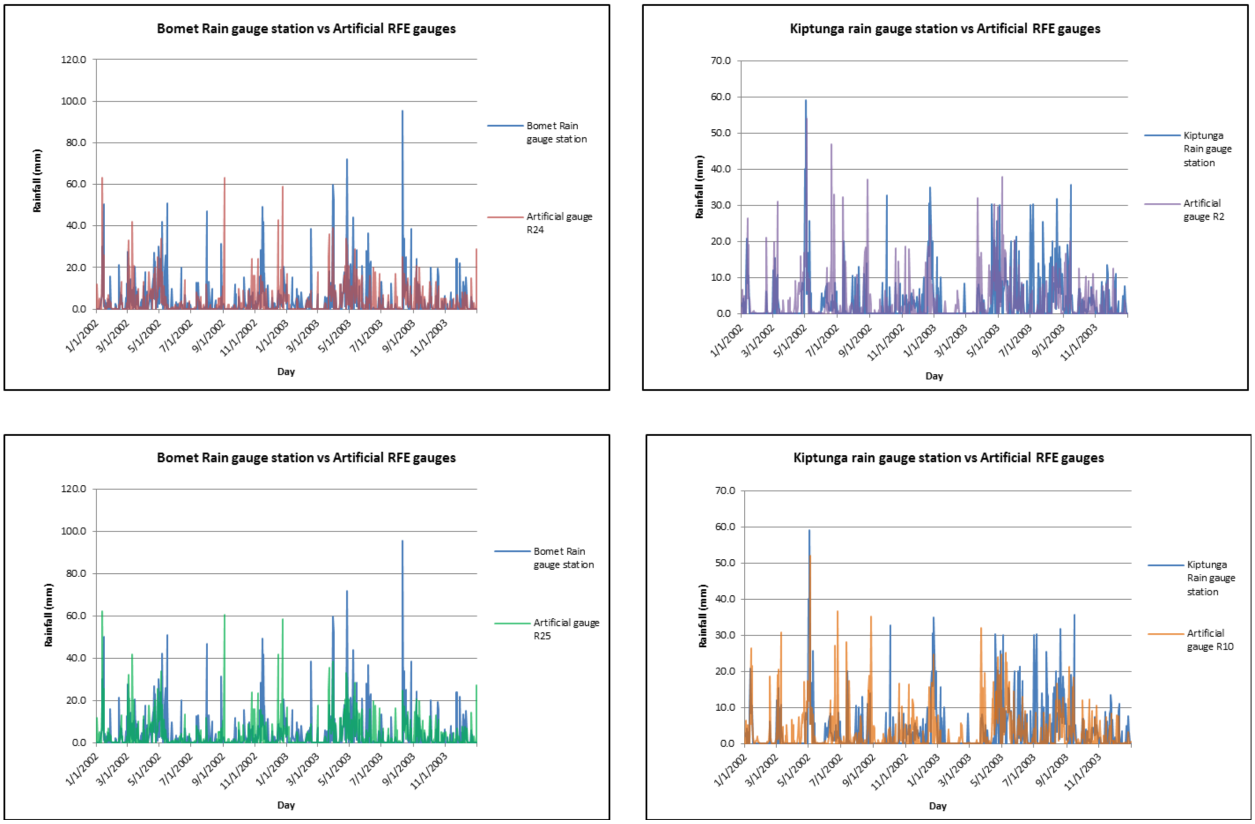

Figure 4 Comparison between the rain gauge and artificial RFE gauge data

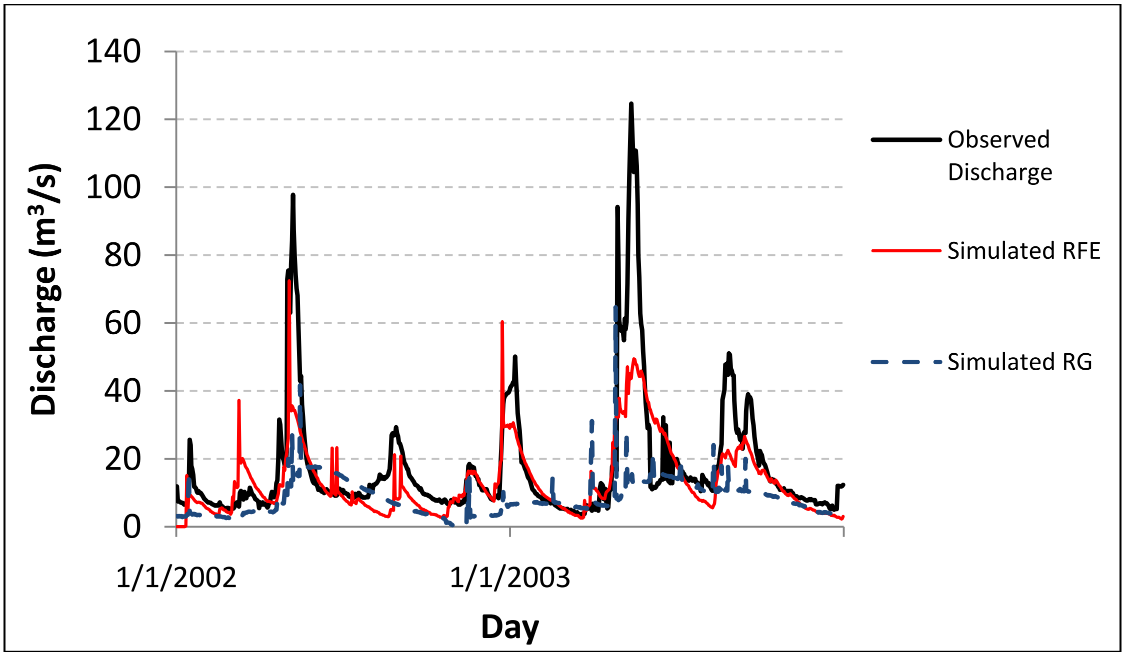

Figure 5 Simulated discharge for different rainfall sources for Nyangores River

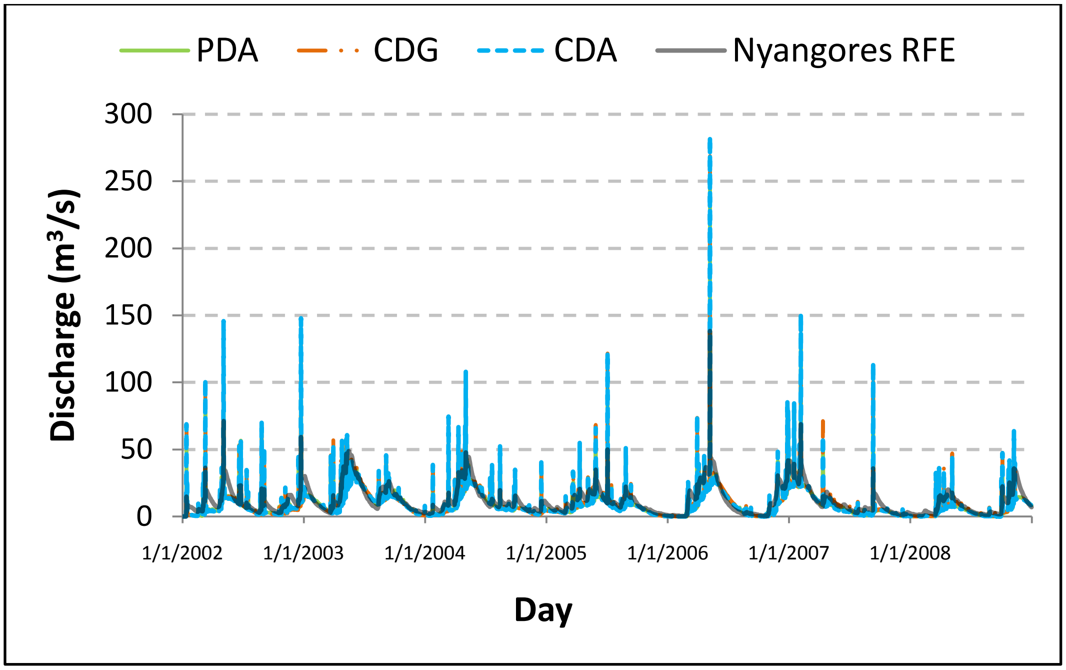

Figure 6 Nyangores River simulated daily discharge for land use scenarios

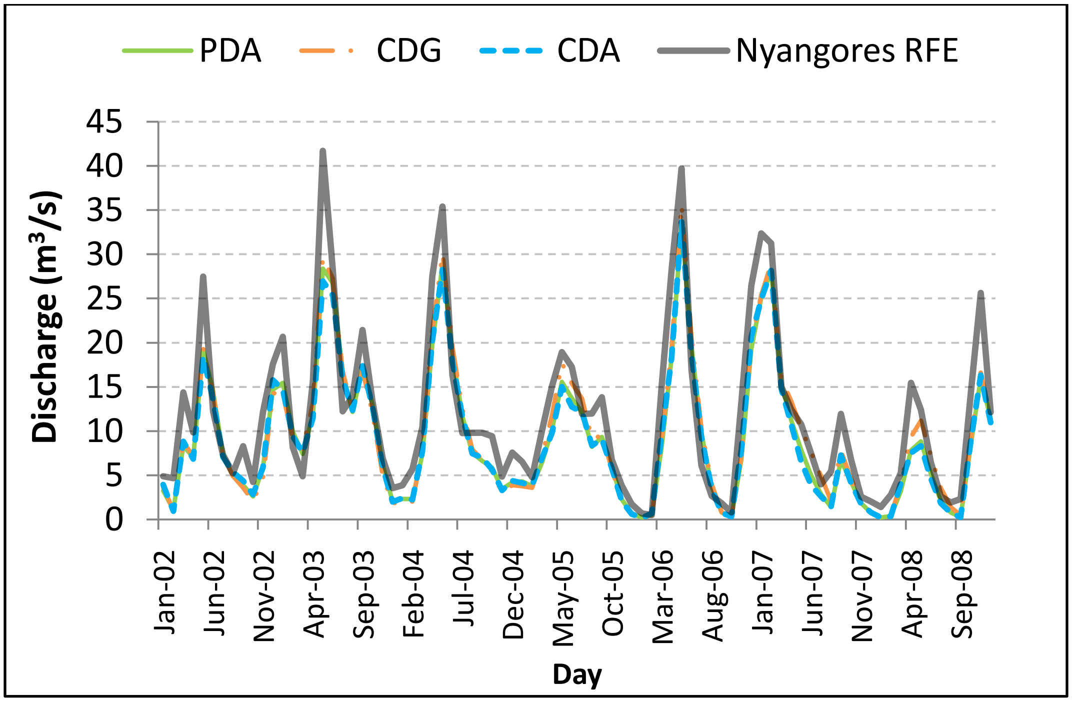

Figure 7 Nyangores River simulated monthly discharge for land use scenarios

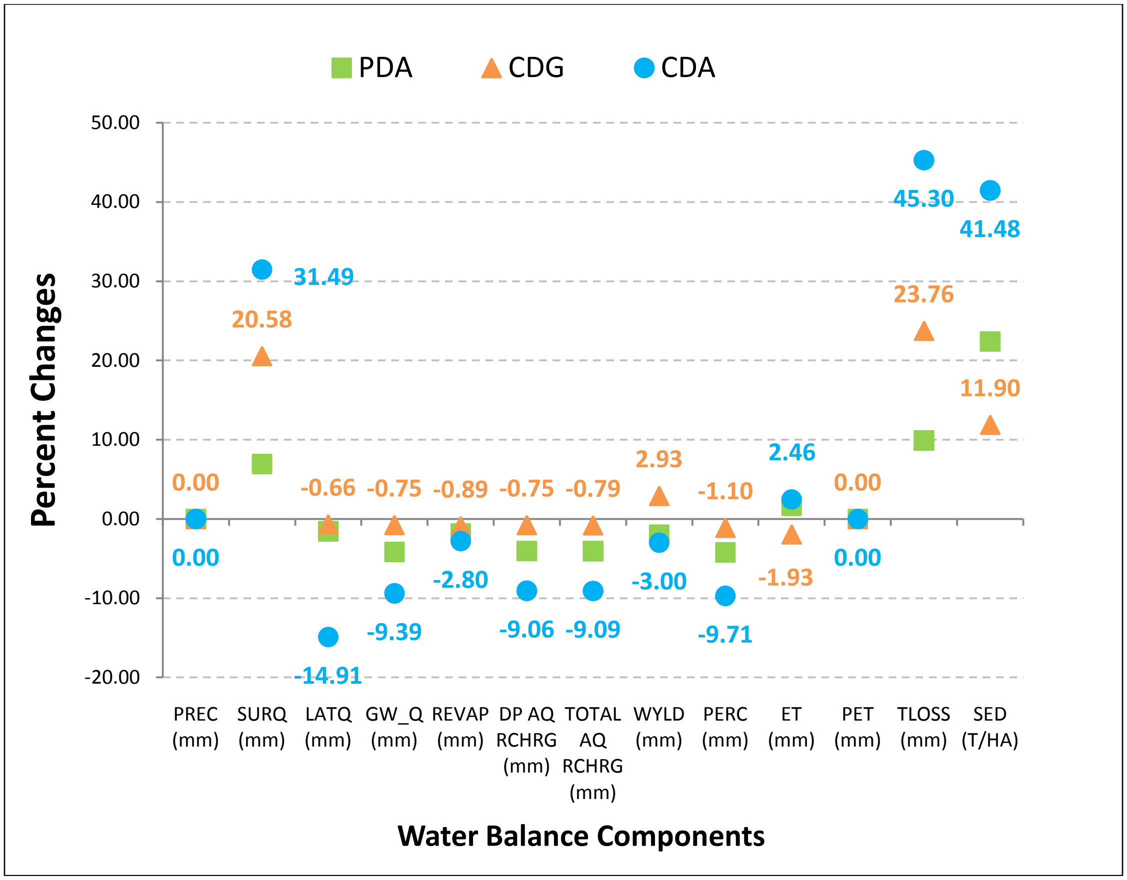

Figure 8 Percent changes in water balance components for simulated land use change scenarios in the Nyangores watershed

PDA=Partial Deforestation, conversion to Agriculture, CDG=Complete Deforestation, conversion to Grassland, CDA=Complete Deforestation, conversion to Agriculture

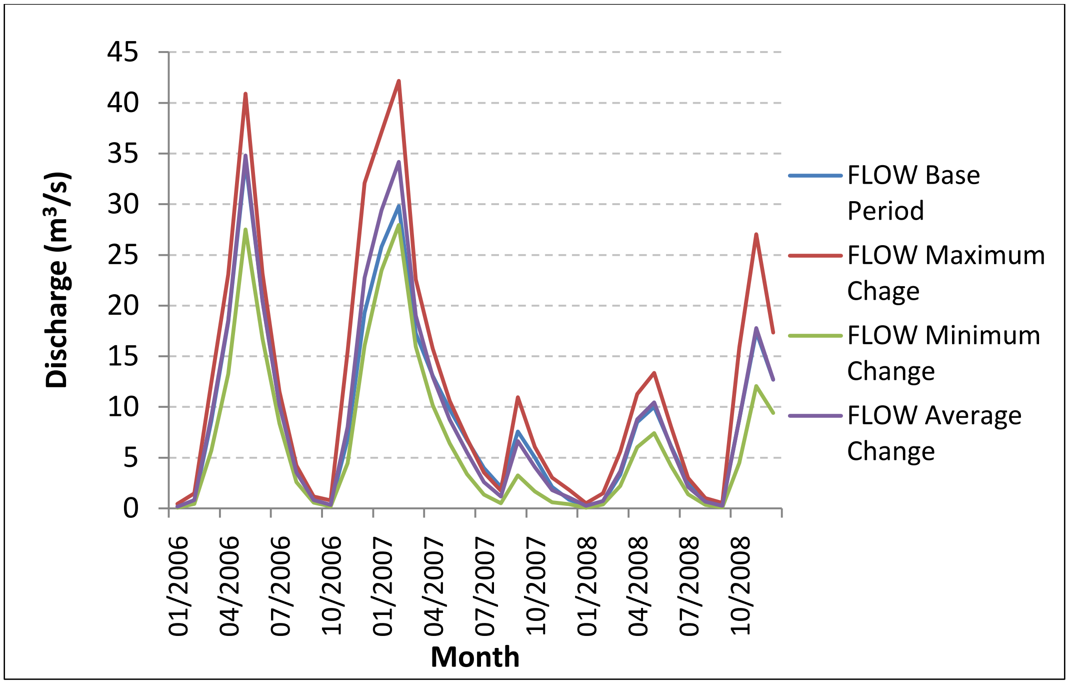

Figure 9 Nyangores monthly discharge for base period and climate change scenarios

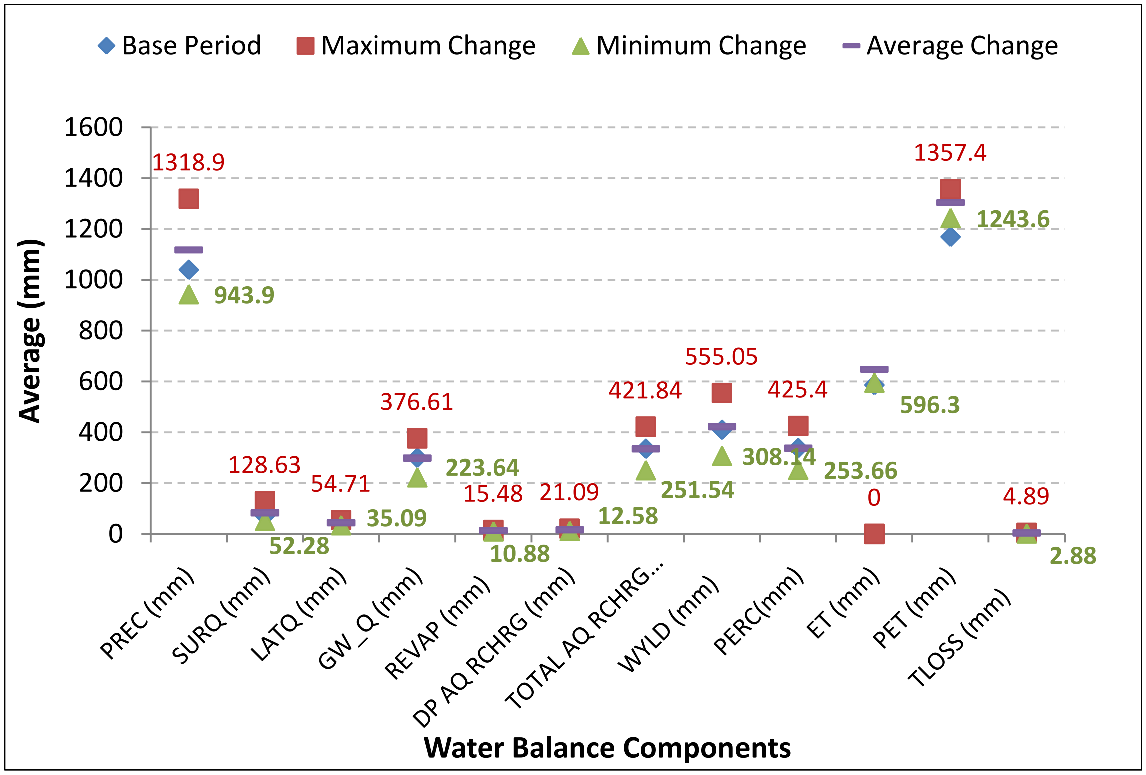

Figure 10 Nyangores water balance components for the base period and climate change scenarios