Impact of Land Use /Cover dynamics on Streamflow: A Case of Nzoia River Catchment, Kenya

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Abstract

Degradation of watershed areas in Kenya's basins is on the increase and is currently a major concern for the government. The main causes of watershed degradation stem from the abuse and poor management of forests and soils, overgrazing, extension of settlements into watershed areas, and unsuitable felling of trees for fuel wood. Recent legislative reforms in the water and environmental sector have been introduced to stem these environmental negative trends. However, extensive quantitative hydrologic analysis is necessary for the assessment of the water balance of various basins to form a basis for policy actions. In this regard, modelling the hydrologic cycle at a local scale still remains the most important scientific method of research for the water balance assessment of basins.

The study area chosen in this study is the Nzoia basin in Kenya. This basin is a typical example of a flood disaster prone basin experiencing increased flood related disasters due to the increased watershed degradation in the recent past. The Nzoia basin is situated between latitudes 1^0 30'N and 0^0 05'S and between longitudes 34^0E and 35^0 45'E and is the largest basin in Kenya's Lake Victoria basin with an approximate area of 12,709km^2 and a length of 334km to its outfall into the lake. The Nzoia system has its sources in the forested highlands (Mt. Elgon, Cherangani Hills, Nandi Hills and Kakamega forest).

The objective of this study is to simulate streamflow changes as a result of the land use/cover status as at 1973, 1986 and 2000. Land use/cover data were based on Landsat images for these years. The runoff response as a result of the observed land use/cover change was tested by keeping constant all input datasets in a SWAT model and varying the land use. The results from the model showed that with the expansion of the area under agriculture, the stream flow increases during the rainy seasons and reduces during the dry seasons, whereas when the area under forest cover is increased the peak stream flow reduces, but when the forest cover is reduced to almost zero there is an increased peak and mean stream flow in the basin.

It is therefore worth noting that a decrease in surface runoff would be desirable, as this would also decrease the devastating effects of floods; the rapid expansion of urban centres in the lower parts of the catchment (Mumias, Bungoma, Rwambwa) can be said to be a major contributing factor to the annual devastating floods. The results also indicated an increasing trend in rainfall amounts in parts of the basin between the periods 1970 - 1998. A study of three rainfall stations (1BD02, 1DA02 and 1DD02A) has shown a significant increase in rainfall while one station, in the lower part of the catchment (EE01), has shown a significant decrease.

The area under forest cover decreased between 1970's and 1986 by 6.4% in the northwest and south of the catchment. But between the 1980's and the 2000's there was an increase in area under forest cover by 41.3%. Agricultural land use showed an increase in areal coverage between 1970's and 1986 by 6.7%, but in the year 2000's the agricultural activities declined by 4.6%. The area under bushland/shrubland/riverine agriculture increased between the 1970's, 1986 and the 2000's by about 123.4% and 11.10% respectively. This could be as a result of an expansion in riverine agriculture.

Key words: Streamflow, Baseflow, SWAT, GIS and ArcView

1. INTRODUCTION

1.1. Brief Description of Project Area

The River Nzoia basin is the largest river basin in Kenya's Victoria basin. It has its sources in the forested highlands. The River Nzoia discharges into Lake Victoria just a short distance north of the Yala swamp in Bunyala, Budalangi Division, and Busia District. The basin covers a catchment area of about 12,700 km^2 with heavy forest cover in the upper parts of the catchment and low trees and bushes in the lower reaches. The catchment area is bounded by latitudes 1° 30'N and 0° 30'S and longitude 34° E and 35° 45'E (Figure 1). The River Nzoia experiences perennial flooding in its lower reaches especially the Budalangi area of Busia district. The mean annual discharge of the River Nzoia is estimated at 1777Mm^3/year. From a physiographic and land use point of view the basin has four distinct zones: a mountain zone, plateau zone, transition zone and lowland zone. The mountain zone is forested but suffers severe land degradation; the plateau zone is the major farming zone. Small scale farming continues in the transition and flood prone lowland areas. The flood prone area is generally flat and swampy. There are two rainfall peaks in the catchment; the first peak comes in the months of April to June, while the other occurs in July to September. December through March are dry months in Nzoia. Comparatively to other parts in Kenya, the basin receives high rainfalls, whose average annual values vary between 1,000 to 1,500 mm.

The Nzoia basin has a high incidence of poverty with a rich natural resource endowment. While the Western Kenyan region is endowed with natural resources such as forests, rivers and lakes, which should be adequate for poverty reduction, poverty and vulnerability nonetheless afflict many in the region. The communities in the Nzoia basin are confronted with flooding, disease, and degradation of natural resources, especially land. The urban centres of Western Kenya have the highest incidence of poverty at 80 percent. The situation is aggravated by perennial flooding, mismanagement of natural resources, and the HIV/AIDS pandemic.

The economy of the region is still largely rural, and more than 90 percent of the population earns its living from agriculture and livestock. The farms are privately owned ranging from 1 – 3 ha. However, the large commercial farms with an average of 50 – 100 ha or more characterize such districts as Trans Nzoia and Uasin Gishu.

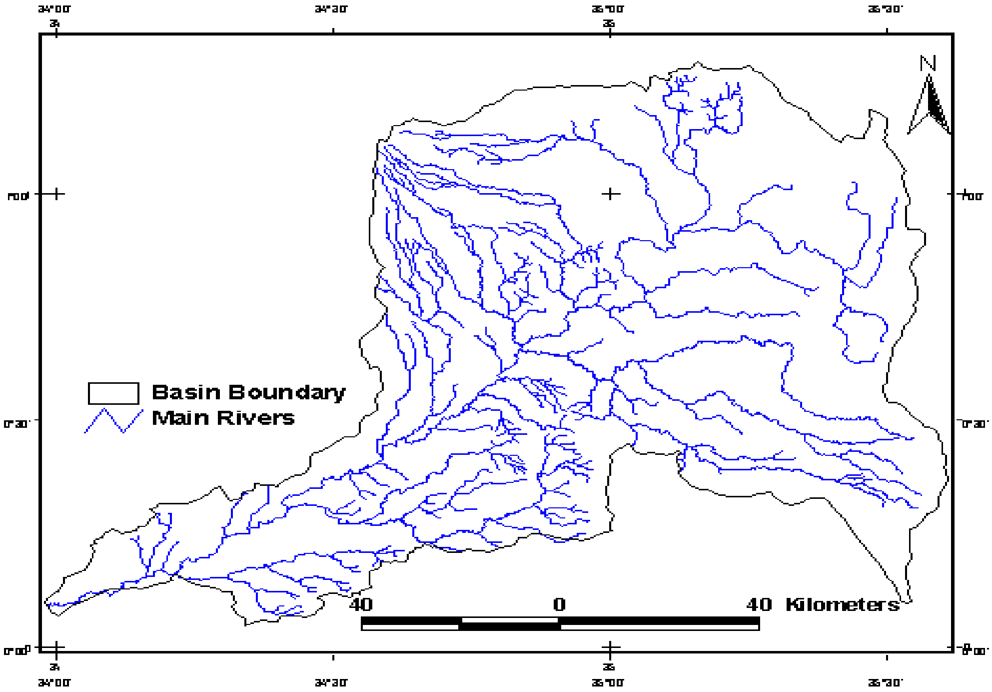

Figure 1: Nzoia Catchment

1.2. Use of Distributed Watershed Models

Hydrologic process and water resource issues are commonly investigated using distributed watershed models. These watershed models require physiographic information such as the configuration of the channel network, the location of drainage divides, channel length and slope, and sub-catchment geometric properties. Traditionally, these parameters are obtained from maps or field surveys. Over the last two decades this information has been increasingly derived directly from digital representations of the topography (Jenson and Domingue, 1988; Mark, 1984; Moore et al., 1991; Martz and Garbrecht, 1992). The digital representation of the topography is called a Digital Elevation Model (DEM). The technological advances provided by Geographic Information Systems (GIS) and the increasing availability and quality of DEMs have greatly expanded the application potential of DEMs in many hydrologic, hydraulic, water resources and environmental investigations (Moore et al., 1991).

SWAT is a process-based distributed-parameter simulation model operating on a daily time step, and is designed to predict the impact of management on water, sediment, and agricultural chemical yields. The model is physically based, computationally efficient, and capable of continuous simulation over long time periods. SWAT uses readily available inputs and has the capability of routing runoff through streams and reservoirs, and allows for the addition of flows and the inclusion of measured data from point sources. Major model components include weather, hydrology, soil temperature and properties, plant growth, nutrients, pesticides, bacteria and pathogens, and land management.

Apart from the ability to take into account land use and soil data, SWAT differs from other physical models in its ability to separate the watershed into sub-basins and Hydrologic Response Units (HRUs). The main basin is divided into smaller basins, by selecting points on the stream network that act as outlets. In this way, the model can provide output data, such as discharge, at specific points of the river network. The partitioning of the basin or sub-basins in HRUs has the means of dividing the watershed into no more than 100 different areas, which have the same properties regarding land use and soil. The equations are applied in each HRU separately and surface runoff and ground water flow are routed to neighboring HRUs to the outlet of the basin (Arnold et al., 1999). The hydrologic component of SWAT is based on the following water balance equation:

$$SW_t = SW + \sum (R - Q_i - ET_i - P_i - QR_i) \text{ ....} \quad (1\text{-}1)$$

where: SW_t is the final soil water content (mm);

SW is the water content available for plant uptake, defined as the initial soil water content minus the permanent wilting point water content (mm);

t is the time in days;

R is the rainfall (mm);

Q_i is the surface runoff (mm);

ET_i is the evapotranspiration (mm);

P_i is the percolation (mm); and

QR_i is the return flow.

The hydrologic processes simulated by the sub basins as included in the water balance equation are precipitation, surface runoff, evapotranspiration, percolation and return flow. The daily weather data required by SWAT are precipitation, temperature (maximum and minimum), solar radiation, relative humidity and wind speed. After inputting precipitation and temperature (maximum and minimum) data, the weather generator then generates solar radiation and relative humidity for the day. Finally, wind speed is generated independently.

Runoff is simulated separately for each of the HRU and combined to give the total stream flow for the sub-basin, which is then combined with the stream flow for the other sub-basins to give the stream flow for the whole basin. According to Neitsch et al, 2002, SWAT predicts the surface runoff using the modified SCS Curve number method or the Green and Ampt infiltration method. In this study the SCS Curve number, which is a function of the soil permeability, land use and antecedent moisture condition, was used. The basic equation used by the SCS curve number is

$$Q = \frac{(R-I)2}{R-I+S} \text{ ....} \quad (1\text{- }2)$$

where: Q is the accumulated surface runoff or excess rainfall (mm),

R is the rain depth for the day,

I is the initial abstraction, which includes the surface storage, interception and infiltration prior to the runoff (mm),

S is the retention parameter (mm).

Routing in a stream channel is divided into water, sediment, nutrients and organic chemical routing (Neitsch et al, 2002a). In routing the water, SWAT accounts for any losses. These losses include those due to evaporation, transmission or any diversion. The amount of water added as a result of the precipitation in the main channel and point sources discharges is also accounted for.

In the channel, the Manning equation is used to calculate rate and velocity of flow in the reach of each sub basin for a given time step. The Manning equation is given by equations 3 and 4 below for the rate and velocity respectively.

$$q = \frac{AR^{2/3}S^{1/2}}{n} \quad \text{(1-3)}$$

$$V = \frac{R^{2/3}S^{1/2}}{n} \quad \text{(1-4)}$$

where: q is the rate of flow in the main channel (m^3/s);
A is the cross sectional area of the channel (m^2);
R is the hydraulic radius for a given depth of flow (m);
S is the slope along the channel length (m/m);
n is the manning coefficient for the channel; and
V is the velocity of the flow (m/s).

The model assumes that the main channel has a trapezoidal shape with a 2:1 run to rise ratio. When the volume of water in the reach exceeds the maximum amount that can be contained by the main channel, the excess amount spreads across the flood plain. SWAT routes the stream flow downstream using either variable storage or the Muskingum method (Neitsch et al, 2002a).

The effects of the land use/change on the stream flows are manifested at different spatial and temporal scales. The possible changes in the land use/cover include deforestation (afforestation), intensification of agriculture, drainage of wetlands and urbanization.

Deforestation, which has converse effects to afforestation, affects significantly the characteristics of the stream flow (Calder, 1992). Though considered a myth or folklore (McCulloch and Robbinson, 1993, Calder, 1998) forests are thought to generate rain, regulate low flows, reduce floods, ameliorate soil erosion and sterilize water. The intensification of agriculture affects the runoff generated through the alteration of evaporation and the timing of runoff. These effects are compounded by the replacement of certain crops, which alters the leaf area index (Calder, 1992).

Wetlands do not or only marginally affect the basin's seasonal water balance (Calder, 1998). However, due to the presence of a free water surface and the lack of water stress, the wetland vegetation normally has a high evaporation rate compared to other land covers. This in turn affects the annual stream flow, which is likely to be less compared to other land uses (Calder, 1992).

The earth's climate is also changing gradually. In East Africa for example, catchments are displaying a small increase in annual precipitation received and this makes them wetter. These changes definitely affect the quantity of stream flow.

2. METHODOLOGY

This study was carried out in four steps. First, a database was established and land use/cover maps for the years 1973, 1986 and 2000 were produced to analyse the land use/cover dynamics. Second, a SWAT simulation run was carried out using a set of input variables, and a sensitivity analysis was performed to identify parameters that influence the predicted streamflow the most. Third, the efficiency of the model was assessed by comparing simulated and observed annual and monthly streamflow. Fourth, in order to test the assumption that land use/cover change has affected the watershed streamflow; further simulations were performed using both maps for the same period with different land use/cover scenarios.

The basic data set that are required to develop an input database for the model are: topography, soil, land use and climatic data. A Digital Elevation Model (DEM) of the study area at a 30 metre resolution was obtained from the World Agroforestry Centre (ICRAF). The DEM was used to delineate the topographic characterisation of the watershed and to determine the hydrological parameters of the watershed such as the slope, flow accumulation, flow direction, and stream network. AVSWAT-X, an ArcView interface, was used to delineate the watershed. To capture the heterogeneity in physical properties, the watershed was subdivided into 29 (twenty-nine) sub-watersheds, and each one of the sub-watersheds was partitioned into Hydrologic Response Units (HRUs) that consist of homogeneous land use, management, and soil characteristics.

Simultaneously, spatial databases were developed using satellite images in their raw form. The images available were MSS Datasets for 1970's, TM datasets for 1980's and ETM datasets for 2000's. The Nzoia river basin is mapped fully by four images, that is: p169r59, p169r60, p170r59, p170r60, where p=path r=raw. For the MSS Datasets two images i.e p180r59 and p181r60 were used. The satellite images were obtained from the ICRAF library.

Three land use/cover maps from 1973, 1986 and 2000 were produced using the ENVI 4.3 software. Visual interpretation and supervised classification based on the maximum likelihood methods for the satellite images were employed. A representation of the regions of interest known as the training sites were digitized giving them different IDs and unique colours.

2.1. SWAT Input Data and Their Sources

The following sources were used to provide the input data for SWAT:

Digital Elevation Model (DEM): A Digital Elevation Model (DEM) gives the elevation, slope and defines the location of the streams network in a basin. A DEM with a spatial resolution of 30 m by 30 m was used in this study and it was obtained from the International Centre for Research in Agroforestry (ICRAF).

Land Use/Cover Map: The land use/cover map gives the spatial extent and classification of the various land use/ cover classes of the study area. The land use/cover data combined with the soil cover data generates the hydrologic characteristics of the basin or the study area, which in turn determines the excess precipitation, recharge to the ground water system and the storage in the soil layers. The land use/cover data was obtained from ICRAF for three years, that is, for 1970, 1986 and 2000.

Soil Map and data: The soil data as required by SWAT to predict the stream flow should include the relevant hydraulic conductivity properties: the soil bulk density, the saturated hydraulic conductivity and the soil available water capacity (SOL_AWC). The soil data was obtained from the Internet (ISRIC website), the parameters of the soil such as the Soil Bulk Density (g/cc), Saturated Hydraulic Conductivity, Ks (mm/hr) and Soil Available Water Capacity were missing and were estimated using a hydrology programme called the Soil Water Characteristics which was downloaded from the Internet.

Stream Flow data: Stream flow data was available for four Stations 1BD02, 1DA02, 1DD01A and 1EE01. The stations had data ranging in time from 1947 to 1999, though they had missing gaps. Table (2) gives the summary of the streamflow data and the percentage of missing data for the quality of data used in the study.

Table 2: Summary of available streamflow data for Nzoia basin (Source: MWI)

Gauging Station	River	Period Recorded	Percentage Missing
1BD02	Large Nzoia	1966 - 1990	21
1DA02	Nzoia	1947 - 1996	38
1DD01A	Nzoia	1962 - 1999	29
1EE01	Nzoia	1963 - 1999	27

Weather data: Rainfall data were available for eight rainfall recording stations in the basin. The collected data ranges in time between 1960 and 1998, though there were quite a number of missing data. The other weather data used were: temperature data (maximum and minimum) for the Kitale and

Kakamega Meteorological stations. Tables (3) and (4) give the summary of the weather data used for this study.

Table 3: Summary of available rainfall data for Nzoia catchment (Source: KMD)

Rainfall Station ID	Name	Period Recorded	Percentage Missing
8834098	Kitale Met. Station	1976 - 1990	5
8935025	Eldoret Loreto Convent Station	1976 - 1990	4
8934016	Lugari Ltd. Station	1976 - 1990	6
8934096	Kakamega Experimetal Station	1976 - 1990	7
8934098	Kimilili Forest Station	1976 - 1990	25
8934013	Mumias St. Mary Teresa's School	1976 - 1990	22
8934127	Ukwala Dispensary	1976 - 1990	45
8935061	Kipkabus Tilal Station	1976 - 1990	40

Table 4: Summary of available weather data for Nzoia catchment (Source: KMD)

Meteorological Station	Weather Parameter	Period Recorded	Percentage Missing
Kitale	Maximum Temperature	1981 - 2007	27
	Minimum Temperature	1981 - 2007	49
Kakamega	Maximum Temperature	1981 - 2007	26
	Minimum Temperature	1981 - 2007	38

3. RESULTS AND DISCUSSION

From the study and data obtained from the satellite imagery for Nzoia (Table 5, and Figure 2and 3*)*, the catchment has undergone numerous land use/cover changes in recent decades. Forest cover decreased markedly between 1970's and 1986 by 48.3%, especially for the regions in the northwest and the south of the catchment. But the situation changed: between 1980's and 2000's there was an increase in areas under forest cover of 41.3% (Table 5). The decrease could be attributed to the cutting of trees in the forests for various uses such as firewood, timber and clearing for agricultural purposes, and the increase in forest cover in the second period could be due to government intervention through tree planting campaigns and an increase in area under tea plantation with forest cover used for wind breaks. In contrast, the area under agricultural use is seen to have decreased between 1970's, 1980's and 2000's by 22.4% and 4.6% respectively. These decreases could be linked to changes in weather patterns, and the effects of urbanization and population growth. The change matrix results (Table 5) reveal that there is a gradual increase in the area under bush land/ shrub land/riverine agriculture; for the years 1970's to 1986 and 1986 to 2000's the percentage increase registered 123.4% and 11.1% respectively. This change could be linked to invasion of river banks by small scale farmers due to continued failure of enough rainfall to sustain the rainfed agricultural practices especially in the middle and the lower parts of the catchment. The built up area also changed significantly due to rapid development of urban centres such as the expansion of the towns Kakamega, Eldoret and Kitale. The growth of these urban centres can be attributed to high rate of rural urban migration, hence the decline in agriculture.

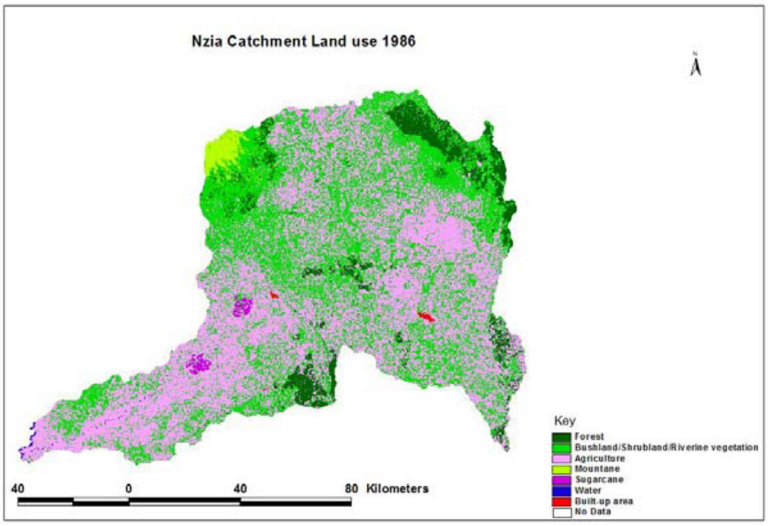

Figure 2: Land use/cover map 1986

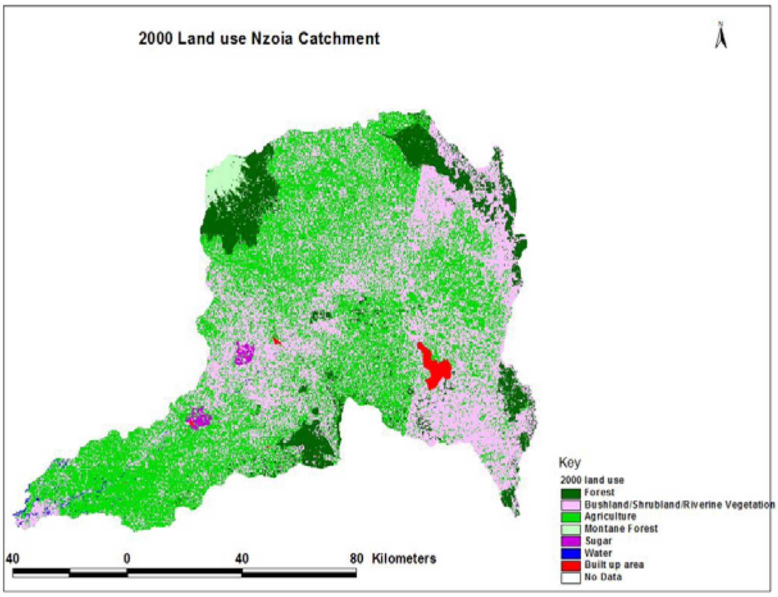

Figure 3: Land use/cover map 2000

Table 5: Land use/cover change in Nzoia between the years 1986 and 2000

	1986		2000		Change	
Land use/ Cover type	Area (km^2)	%	Area (km^2)	%	Area (km^2)	%
Forest	1110.2	8.7	1568.69	12.4	458.49	41.3
Mixed Forest	936.82	7.4	1402.3	11.0	465.48	49.7
Mountain Forest	173.38	1.3	166.39	1.3	-6.99	-4.0
Agriculture	11560.79	91	11030.97	86.8	-529.82	-4.6
Mixed Agriculture	4963.18	39.1	5514.92	43.4	551.74	11.1
Agriculture dense	6542.35	51.5	5460.88	43	-1081.47	-16.5
Sugar cane	55.26	0.4	55.17	0.4	-0.09	-0.2
Built Up areas	14.23	0.1	84.77	0.7	70.54	495.7
Water	16.24	0.13	37.63	0.3	21.39	

The results of the impact on the streamflow due to land use/cover change scenarios, against the baseline, deduced by this research work are given in Table (6). The baseline scenario was selected on the basis of the results obtained from the analysis using the landsat images. The other scenarios are based on a hypothetical variation of land use/cover using certain percentages so as to see the impacts of land use changes on the streamflow.

Table 6: Land use/cover scenarios used to study the impact of land use/cover change on streamflow

Scenario	**Forest (%)**	**Agriculture (%)**	**Urban (%)**	**Others (%)**
Base	8.7	90.9	0.1	0.3
2	0	75	20	3
3	100	0	0	0
4	50	13	35	2

Scenario 2: Expansion of agricultural land: During this study; the area under forest cover was taken to be zero and the area under agricultural land to be 75% (Table 6);. The result from the model simulation showed an increase in streamflow during the rainy months up to 4% and a reduction during the dry months of 8% (Figure 4). This can be explained in terms of the crop soil moisture demand. Crops need less soil moisture than forests, therefore the rainfall satisfies the soil moisture deficit in agricultural lands more quickly than in forests thereby generating more runoff when the area under agricultural land is extensive. Hence, this leads to an increased streamflow. Consequently, the expansion of riverine agriculture and the agricultural land more than the forest cover results in an increase in the surface runoff following rainfall events. This expansion also results in the reduction of water infiltrating the ground and supplying the shallow aquifers. Therefore, the baseflow during the dry months (baseflow is a function of total infiltration) decreases, whereas the discharge during the wet months increases.

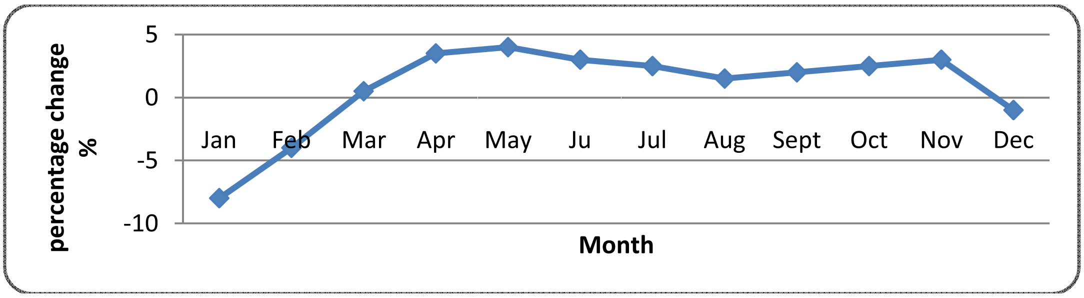

Figure 4: Mean monthly total discharge changes under Scenario 2 (Expansion in Agricultural land)

Scenario 3: 100% forests cover in the Nzoia basin: In this scenario, the entire Nzoia basin was assumed to be fully (100%) covered by forest (Table 6). The result indicated a reduced runoff resulting in a reduced peak streamflow, but the mean streamflow was moderate. When the forest cover was taken to be 50% of the total basin area, the mean streamflow was the lowest. Taking the area to be without any forest cover, both the mean streamflow and the peak streamflow recorded high values. This result supports the principle that forests have the effect of reducing the runoff, thus the smaller the area under forest cover the more the runoff. A 100% forest cover gave a lower percentage change in streamflow during the rainy season but, in contrast, gave a high percentage streamflow during the dry months of the year (Figure 5). Taking the basin to be without any forest cover, there was a percentage increase in streamflow during the rainy season with a decrease in percentage of streamflow during the dry season.

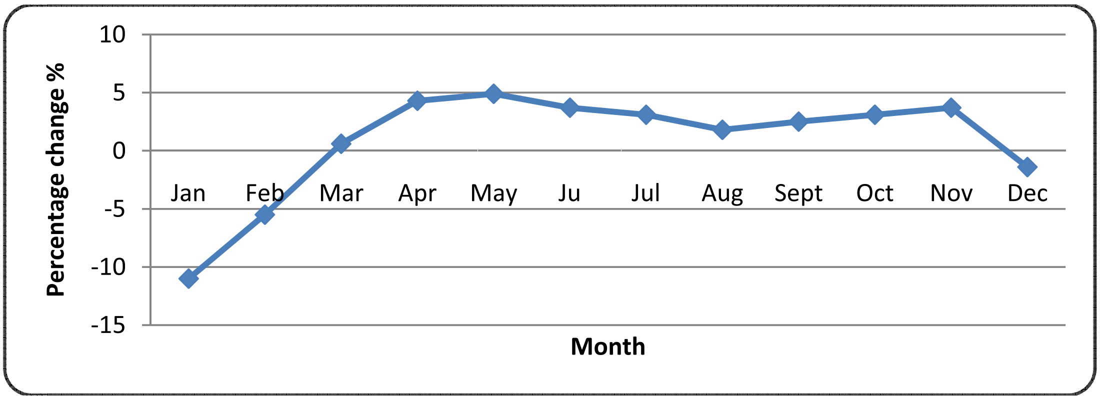

Figure 5: Mean monthly total discharge changes under Scenario 3 (100% forest cover)

Scenario 4: Expansion of Urban land: For this scenario, the area under urbanization was taken to have grown by about 35% of the total basin as shown in Table (6). In this case, the percentages of streamflow change during dry months are significantly lower; this result can be mainly attributed to the type of applied land use/cover changes. The baseflow, which is mainly a result of water infiltration, more so in the forest areas, undergoes little modification, since only a small portion of the forest area changes in this scenario. In addition, the significant increase in the streamflow during the rainy months of the year is most probably the result of the immediate runoff response of the expanded urban land to the first rainfall events (Figure 6) due to the increased impervious surfaces (pavement) within the urban area, and therefore depending little on the antecedent soil moisture. It is worth noting that a decrease in the surface runoff would be desirable, as this would also decrease the devastating effects of floods. Hence the rapid expansion of urban centres in the lower parts of the catchment (Mumias, Bungoma, Rwambwa) can be said to be a major contributing factor to the annual devastating floods.

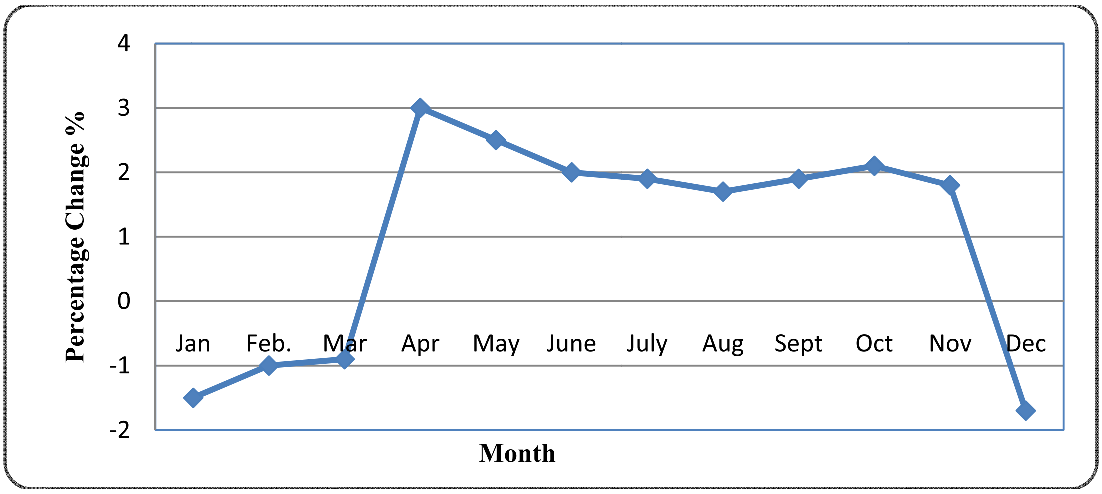

Figure 6: Mean monthly total discharge changes under Scenario C (Expansion in Urban land)

3.1. SWAT Model Setup

This procedure involved integrating the DEM, land use/cover map, soil map and data, and weather data to create sub-basins and hydrologic response units (HRUs). This was followed by the creation of the watersheds. The soil and land use data were input to the SWAT database. When defining a Hydrologic Response Unit (HRU), SWAT uses two options, that is, the dominant land use/ land cover in a sub-basin and the corresponding soil type, or the generation of multiple HRUs within the sub-basin (Di Luzio et al, 2002). In this study the dominant land use/cover and the soil type for a basin were used to define the HRU. This means that the number of HRUs was the same as the number of sub-basins.

3.1.1. Parameter sensitivity analysis

After the model set up (Simulation) using the rainfall data to compare the results of the model output vs. the actual measurements, a sensitivity analysis was carried out. This is an important process in guiding the subsequent calibration process. The sensitivity analysis identified the effects of changing the calibration parameters on streamflow following the procedure given by Neitsch et al, 2002b).

The initial parameter values (model defaults) were varied one after the other by changing them within their suggested range of application as given in Table (7). The results of the percentage changes in streamflow were then plotted against each parameter input to test the sensitivity of the parameters for the Nzoia basin. The parameters are described briefly below.

Table 7: Calibration parameters used in Sensitivity analysis, their default value and range of application

Parameter	**Default Value**	**Range of Variation**
Available water capacity of the soil layer (SOL _ AWC)	Var*	± 0.05 mm water mm of soil
Soil evaporation compensation factor (ESCO)	0.95	- 1
Threshold depth of water in the shallow aquifer required for return flow to occur (GWQMN)	0	0 - 5000 mm
Threshold depth for water in the shallow aquifer for "revap" or percolation to the deep aquifer to occur (REVAPMN)	0	0 - 500 mm
Initial soil curve number for moisture condition II (CN2)	Var*	± 8
Ground water "revap " coefficient (GWREVAP)	0.02	0.02 - 0.2 mm

Threshold depth of water in the shallow aquifer required for the return flow to occur (GWQMN): The ground water flow to the main channel is allowed only when the depth of water in the shallow aquifer is equal to or greater than the threshold depth of water in the shallow aquifer required for the return flow to occur (GWQMN). In this study the GWQMN was varied in the range of between 0% and 50%. The value of GWQMN was put at 0 mm initially; increasing the value of GWQMN gave a decreasing trend in the simulated baseflow and consequently in the streamflow. The effects of GWQMN on the surfaceflow are not significant. GWQMN was found to affect the streamflow as shown in Figure (7).

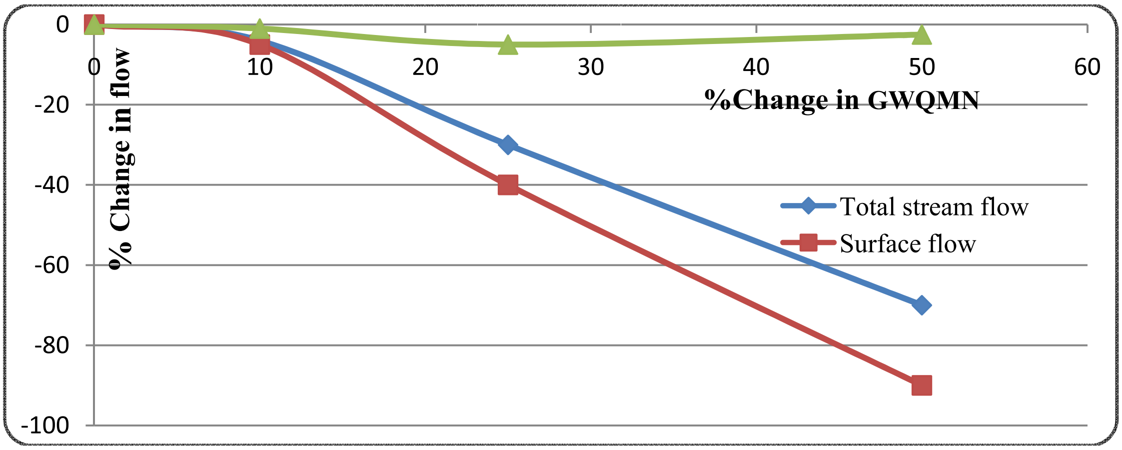

Figure 7: Effects of changing GWQMN on simulated stream flow

Soil Evaporation Compensation factor (ESCO): ESCO is a coefficient used to modify the depth distribution used to meet the soil evaporative demands, (Neitsch et al, 2002b). The default value of ESCO as used during this work was 0.95; this parameter was varied between 0.1 – 0.95. The result obtained from performing the variation of the ESCO value showed that a decrease in the ESCO value results in a decrease in the streamflow as well. This can be explained by more water being available for evapotranspiration. ESCO affects both baseflow and surfaceflow at the same rate, as illustrated in Figure (8).

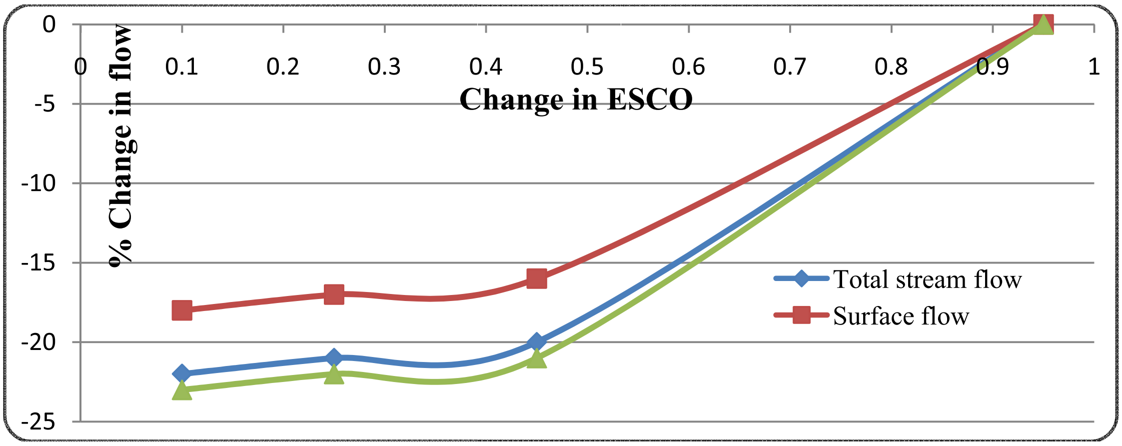

Figure 8: Effects of varying ESCO on simulated stream flow

Initial Curve number (CN2): CN2 is a function of the soil permeability, land use/cover and the antecedent soil moisture; it therefore affects the rate of surface runoff generation. From the graph in Figure (9) an increase in CN2 increases the streamflow, but the effect is more pronounced on surface runoff. The slight increase in total streamflow could be a result of the ratio of surface runoff to baseflow. The amount of streamflow contributed by the baseflow was more than 50% of the total streamflow as shown by the baseflow separation (Table 8).

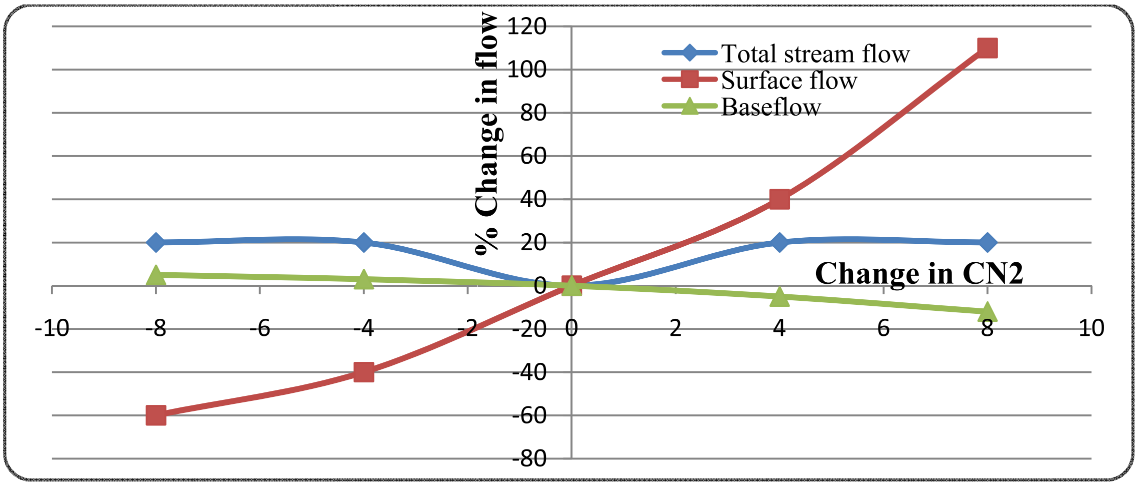

Figure 9: The effect of changing CN2 on simulated stream flow

Soil available water capacity (SOL_AWC): This is defined as the ability of the soil to hold water and depends on the soil characteristics; hence it varies within the soil profile and also in the basin. During the study SOL_AWC was varied within the range of ±0.05 mm of water/mm of soil. The results showed that SOL_AWC affects the streamflow as shown in Figure (10).

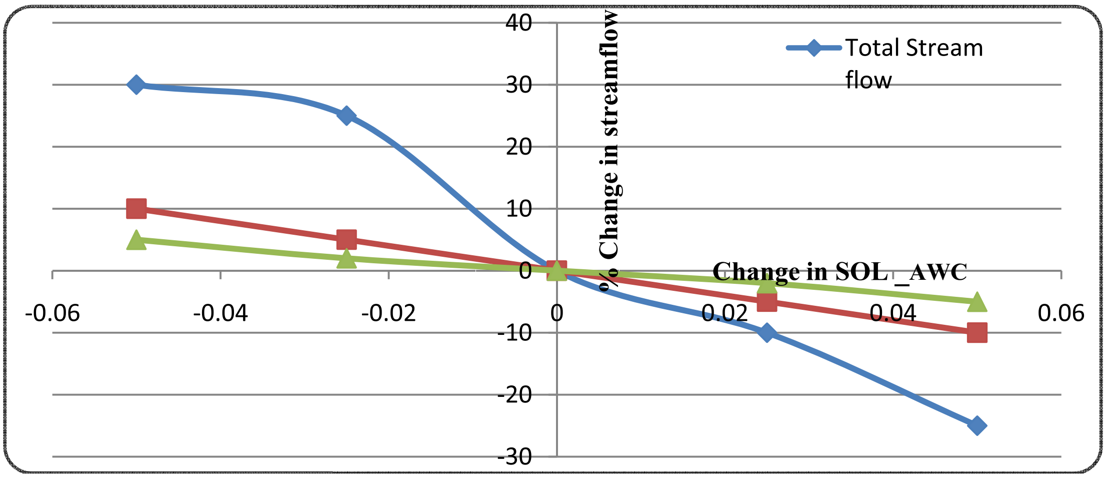

Figure 10: Effects of varying SOL _ AWC on simulated stream flow

SOL _AWC affects both the surfaceflow and baseflow. An increase in SOL _ AWC results in a decrease in the streamflow because of an increase in the ability of the soil to hold more water.

Groundwater "Revap" Coefficient (GW _ REVAP): The groundwater "Revap" coefficient (GW_REVAP) has an effect on the amount of water that recharges the capillary fringe after evaporation during the dry periods. The capillary fringe is recharged by the shallow aquifer during dry periods. By putting the initial value of the GW_REVAP at 0 mm, and then varying it in the range of 0% to 50%, the results showed that when the groundwater "Revap" coefficient increases there is a slight decrease in the amount of simulated baseflow and in the total streamflow (Figure 11). The effects of GW_REVAP on the baseflow were not significant as it was observed to be less than 2%. The change in GW_REVAP is critical as it affects the movement of water from the shallow aquifer to the root zone.

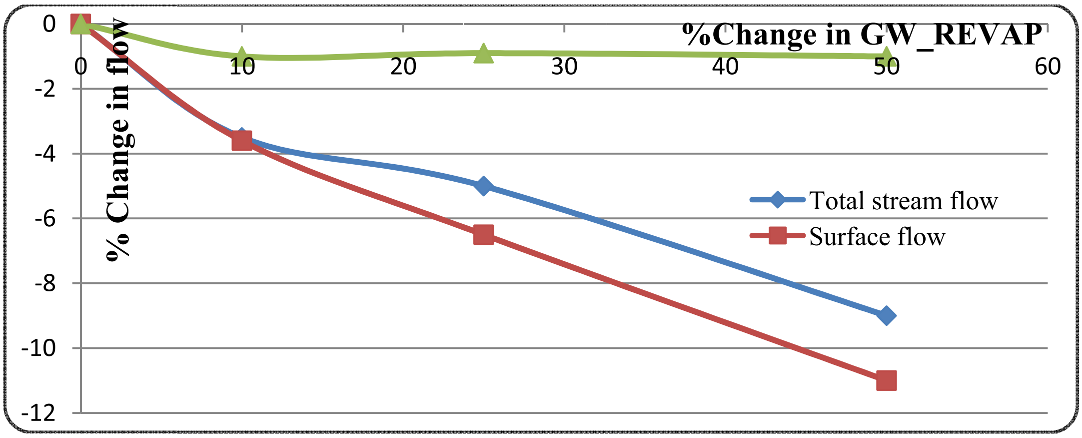

Figure 11: Effects of changing GW_REVAP on simulated stream flow

3.2. Model Calibration and Validation

Calibration involves testing the model with known input and output data in order to adjust some parameters, while validation involves comparison of the model results with an independent dataset during calibration without any further adjustment of the calibration parameters.

3.2.1. Calibration

Calibration procedures were performed while following the advice provided in publications by the principal SWAT model developer, Dr. Jeff Anorld, and his colleagues at the USDA ARS-Blackland (Texas) Research Centre (Arnold et al, 2000; Santhi et al, 2002; Neitsch et al, 2002b).

In this study, the model calibration was done against both surface flow and the baseflow. The input data (streamflow and weather) used for the calibration were for the period of 1976 and 1981 (based on daily values). The gauging stations 1BD02 and 1EE01 which are located within the main Nzoia River were used for calibration.

The goodness of fit between observed and simulated stream flow was assessed for the station (1EE01); the R2 was found to be 0.94. The model under-estimated the low flows at this station while the high flows were over- estimated, as illustrated in Figure (12).

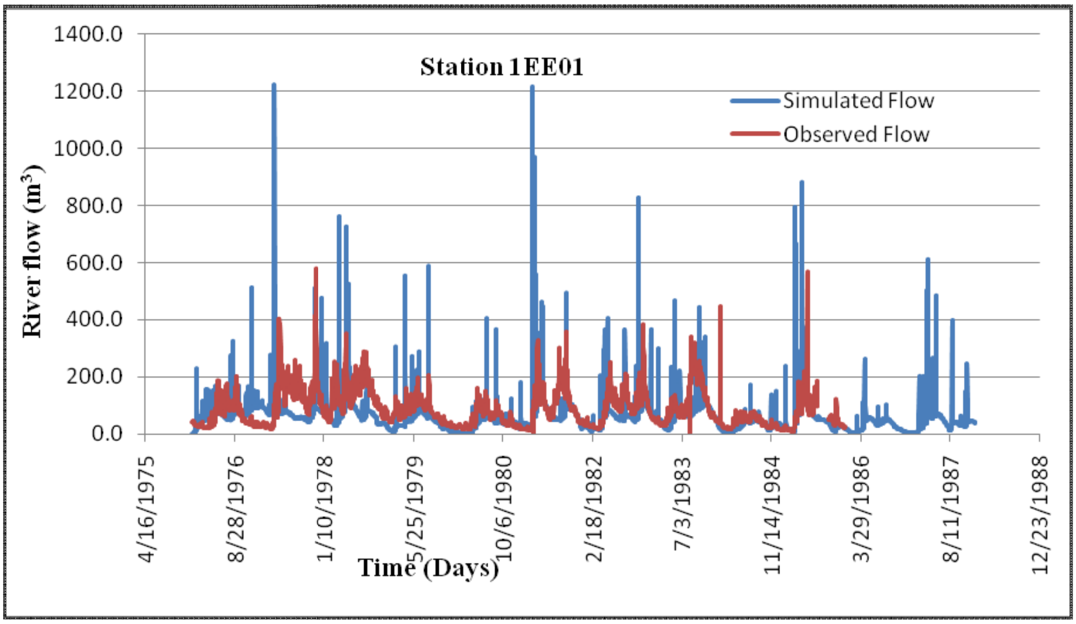

Figure 12: Model results of observed flow and estimated flows in Nzoia River (1EE01)

Baseflow separation: The streamflow data was split into baseflow and surface flow. Table (8) gives a summary of the baseflow separation results. The daily streamflow data used to perform the separation was for the four gauging stations 1BD02, 1DA02, 1DD01A and 1EE01 for the period 1976 - 1990. The alpha factor gives the baseflow recession constant factor; it is an important parameter in baseflow estimation. Baseflow days are the number of days for the baseflow recession to decline in the log cycle.

Table 8: Summary of Base flow separation results

Gauge Station	Baseflow Fraction Pass 1	Baseflow Fraction Pass 2	Baseflow Fraction Pass 3	NPR	Alpha Factor	Baseflow Days
1BD02	0.70	0.55	0.47	21.00	0.0258	89
1DA02	0.80	0.68	0.61	48.00	0.0300	77
1DD01A	0.77	0.64	0.56	9.00	0.0221	104
1EE01	0.85	0.77	0.71	28.00	0.0234	98

Based on the average pass 1 and 2 from the table, the fraction of streamflow contributed by the base flow at gauging station 1EE01 was between 0.79 and 0.98 of the streamflow. The value is dependent on the location of the gauging station and the number of tributaries joining at the gauging station.

3.2.2. Validation

To ascertain that the calibrated model could be used reliably in the Nzoia basin, a model validity test was carried out. This was achieved using different datasets from the ones used during the calibration of the model (1985-1987).

The calibration and validation of the SWAT model for the Nzoia basin showed that the model could be used to simulate the streamflow in the basin as it gave good results. The fair performance of the model in terms of the values obtained for R^2 can be improved later on by applying good quality datasets and using representative historic data.

4. CONCLUSIONS

The method presented for quantifying the effects of land-use/cover change on the streamflow for the Nzoia catchment combined two advanced models: the hydrological model SWAT and the land use/cover change procedure ENVI. Four different land use change scenarios were applied to the study basin and the discharge outputs were compared to those for the base run. All the four scenarios gave an increase in discharge during wet months, and a decrease during dry periods.

SWAT has been used in this study to analyze the impact of environmental chang, in the Nzoia catchment within the Lake Victoria Basin. The results include water balance statistics, land cover maps, land cover change scenarios. The study has also investigated land cover changes that have taken place within the catchment and their impact on the hydrology of this catchment.

The SWAT model was calibrated against streamflow data and parameters were adjusted based on a sensitivity analysis, as well as those that were deemed needing adjustment because their initial values were not adequately estimated. Keeping the model parameters within reasonable ranges minimized the uncertainty in the simulations. In general, there was good agreement between the measured and simulated daily streamflow for the calibration period (NSE=0.94). The simulation of baseflow was slightly underestimated but overall, the agreement between the observed and simulated streamflow was acceptable. The statistical and graphical evaluations of the model performance showed that it could be reliably used for assessing impacts of land use /cover change on streamflow.

This study has shown that SWAT, which was developed in the USA, could be used to model hydrology in Kenyan watersheds with some few changes and modifications, such as to the crop and soil databases. These results show that for this study region and for the considered period, land cover changes have contributed to greater runoff changes affecting the streamflow amounts and baseflow, hence resulting in more frequent devastating floods.

5. ACKNOWLEDGMENTS

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7. ABBREVIATIONS

MWI	Ministry of Water and Irrigation
ICRAF	International Centre for Research in Agroforestry
GIS	Geographical Information System
SWAT	Soil and Water Assessment Tool
DEM	Digital Elevation Model
KMD	Kenya Meteorological Department
R^2	Coefficient of Determination
NSE	Nash Sutcliffe Efficiency
SCS	Soil Conservation Service
HRU	Hydrologic Response Unit
ASCE	American Society of Civil Engineers