

# **EFFECTS OF INCREASED LAND USE CHANGES ON RUNOFF AND SEDIMENT YIELD IN THE UPPER RIVER NZOIA CATCHMENT**

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## **ABSTRACT**

*River Nzoia originates from three water towers namely Nandi hills, Cherengany Hills and Mount Elgon. With increased anthropogenic activities in Nzoia river catchments, land cover has continuously been altered. This scenario has resulted into increased quantity of physical parameters in runoff among them, sediment load and turbidity, during rainy season. This study modelled effects of increased land use changes on runoff and sediment loads. Digital Elevation Model, spatial soil data, sediment loads and meteorological data for the year 2000 to 2012 were the main input into the Soil Water Assessment Tool (SWAT 2012) model for calibration and validation. Data from 1990 to 2014 was as well collected for comparison purposes. Arc GIS 10.1 was used for spatial data analysis. Supervised Land classes were processed from satellite images for the year 2000 and 2010 using ENVI 4.7 software. The upper river catchment had an area of 10, 859km<sup>2</sup> compared to 12,904km<sup>2</sup> for entire watershed, has 27 catchments, and 36 Hydrologic Response Units. The sediment load during period of study went as high as 3767.9 tons/months in the projected year 2030 compared to 1400.79tons /month in the year 1990. The study also revealed that 51% of rainfall received converted to surface runoff in the year 2014 compared to 44% as at the year 2000 implying reduction in base flow and*

*ground water recharge. A 3.1% forest cover, 2.2% wetland, 15.3% tea, 5.5% sugarcane were destroyed for human settlement. Ground Water Delay, a lag between when water exits the soil profile to shallow aquifer was 31 days. In conclusion man's activities have put pressure on land altering its use. This has changed hydrology of the catchment putting sediment loads on increase. Threat for further increase in sediment load is real, base flow is diminishing as well as ground water recharge. Policies should be guided by this work to enhance good land use.*

**Key words:** Catchments, Modelling, Sediments, Landuse Changes.

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## 1. INTRODUCTION

The cost of treating water for high volume abstractors is now higher than in the past years. This is not only due to higher costs of coagulants but as a result of degradation in the catchments resulting to poor quality of raw water abstracted. This is observed within the river Nzoia catchment especially where sediment loads and turbidity have increased to uneconomic limits in rain seasons. This study aims to close the gap between the expectations for a healthy watershed and realities that come with poor quality water in the river, and further points out areas that will guide policies to better management especially the Water Resources Users Associations (WRUAs).

### 1.1. Objectives

The goal of this research was to study the effects of land use change on runoff and sediment yield in the upper river Nzoia catchment using SWAT. The study determined in particular the relationship between the catchment use over time and sediment yield in the river as well as future scenarios.

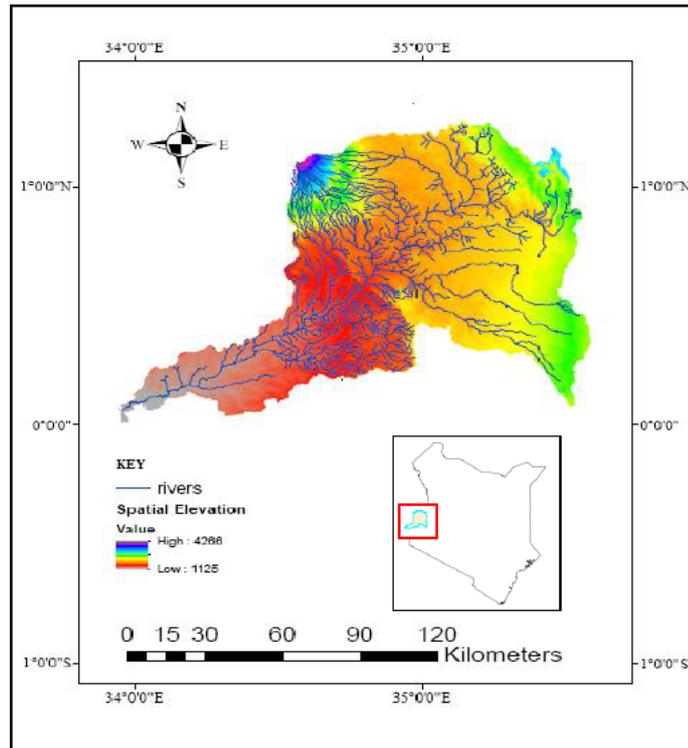
### 1.2. Specific Objectives

To evaluate the runoff and sediment loads within river Nzoia as a result of increased land use changes.

### 1.3. Study area

The study area covered the upper part of river Nzoia. This majorly focused on the watersheds of the water towers that are drained by the trunk of river Nzoia.

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**Figure 1** Deleneated study area

From figure 1, Nzoia River Basin lies between latitudes  $1^{\circ} 30' N$  and  $0^{\circ} 05' S$  and longitudes  $34^{\circ}$  and  $35^{\circ} 45' E$ . The Nzoia River originates from Cherengany Hills at a mean elevation of 2300 m Above Sea Level (ASL) and drains into Lake Victoria at an altitude of 1000 m ASL. It runs approximately South-West and measures about 334 km with a catchment area of about  $12,903 \text{ km}^2$ , with a mean annual discharge of  $1,777 \times 10^6 \text{ m}^3/\text{year}$  (WARMA, 2006). The study covers the upper part with an average area of  $10,859 \text{ km}^2$  which is 84% of the river Nzoia catchment. It predominantly lies in  $34^{\circ}$  and  $36^{\circ} E$  and 0 to  $1^{\circ} N$ . The study shall focus on the highlighted part shown below the map of Kenya.

### 1.4. Topography

Nzoia River flows from the western side of the Elgeyo Escarpment (Sergoi, Sosiani and Kipkelion tributaries) and the Cherangani Hills (Chepkotet and Kaisungur tributaries) from an elevation of approximately 2,286 meters above sea level. The tributaries, which flow from the high slopes of Mount Elgon attain maximum elevation in the river's basin and is estimated at about 4,300m above mean sea level. The tributaries in Mt. Elgon include Kuywa, Sioso, Ewaso Rongai and Koitobos.

### 1.5. Rainfall

Highest rainfall occurs in the north-western parts of the basin, which gradually reduces in the south-eastern parts. The north-western part of the basin drained by the streams Malaba, Malikisi and Alupe receives an annual rainfall of 1682mm with little spatial variation. In Sio sub-basin to the southeast the rainfall varies from 1802mm in its upper catchment to 1589mm in its outfall reaches. The Nzoia basin with its vast catchment witnesses a large variation in rainfall from a minimum of 1076mm in the catchment of the left bank tributary Kipkarren to a maximum of 2235mm in the south-western edge of the catchment.

## 1.6. Hydrology

The stretch of the longest Nzoia River channel is about 355 km, with a mean discharge of 118 m<sup>3</sup>/s. However, the flow regime of the Nzoia is varied and is occasionally as low as 20m<sup>3</sup>/s, with extreme floods that may surpass 1,100m<sup>3</sup>/s. The discharge varies from a low flow of 2.8m<sup>3</sup>/s to a 100-year flood flow of 930m<sup>3</sup>/s. In its upper reaches from Km 135 to 257 in the highlands, the river flows in a slightly meandering V shaped valley. The width of the channel is about 40m and bed gradient 1 in 240.

## 2. LITERATURE REVIEW

Sediment is ranked as the number one pollutant of surface waters in most parts of the world. The same applies to the case of Kenya. Excessive sediment in surface water causes problems to aquatic life, drinking water treatment plants, industry, Agriculture, and other users of the resource (Vellidis et al., 2003).

Water quality encompasses the physical, chemical and biological characteristics of water. Both natural water quality and human induced changes in quality are important consideration in river basin management. Sediment load is a geologic term referring to the solid matter carried by a stream or rivers (Strahler and Strahler, 2006). Erosion and bed shear stress continually remove mineral material from the river bed and banks of the stream channel, adding this material to the regular flow of water in a given reach.

Furthermore, at a global scale, Suspended Solid (SS) concentrations in many rivers have dramatically changed in recent years (Walling, 2006). Existing evidence suggests that natural sediment loadings have been substantially exceeded in many catchments in the UK, particularly since World War II (Evans, 2006).

Sediment load delivered to watercourses originate from a number of upstream primary and secondary sources, including cultivated fields and bank erosion (Collins *et al.*, 1997). The land use part relates to the human activity or economic function associated with a specific piece of land, while the term land cover relates to the type of feature present on the surface of the earth (Lillesand and Kiefer, 2000).

According to Githui (2009), there has been an increase of population over the last three decades with an estimated population density of about 221 persons/km<sup>2</sup> in 2002 within the River Nzoia basin. She also reports that the forest cover has decreased markedly from 12.3 to 7%, especially for the regions in the northwest and south of the catchment. This could be attributed to the cutting of trees in the forests for various uses such as firewood, timber and clearing for agricultural purposes. In contrast, the agricultural area is seen to have increased over the years from 39.6% in 1973 to 46.6% in 1986/1988 and to 64.3% in 2000/2001. Her study did not bring out evolution of land use in terms of settlement and built up area.

Runoff can be described as the part of the water cycle that flows over land as surface water instead of being absorbed into groundwater or evaporating after a storm event. According to the U.S. Geological Survey (USGS), runoff is that part of the precipitation, snow melt, or irrigation water that appears in uncontrolled surface streams, rivers, drains or sewers.

From past research, the main anthropogenic activities increasing sediment supply to watercourses include, Changes in agricultural practices, for example, increased areas of arable cultivation, leading to greater areas of bare exposed soil susceptible to erosion by rainfall (Greig, *et al.*, 2005), and mechanized farm practices which compact the soil and increase runoff and soil erosion (McMellin *et al.*, 2002; Bilotta, *et al.*, 2007)

### 3. MATERIALS AND METHODS

#### 3.1. Data and data sources

The table 1 below shows the data that was used in the modeling study. Different data sets were obtained from different sources and processed prior to use. Processing entailed filling gaps or use of surrogate techniques to arrive at missing parameters.

**Table 1** Data format and sources

S/NO	Data Type	Data Format	Source
1	Climate Data	Daily data in excel sheet	Water Resource Management Authority-Kakamega Office
2	Stream Flow Data	Monthly data in excel sheet	Water Resource Management Authority-Kakamega office
3	Soil Data	Shape file	Kenya Soil and Terrain database. KENSOTER), <a href="http://www.isric.org/projects/soter-kenya-kensoter">http://www.isric.org/projects/soter-kenya-kensoter</a> , 1mx1m
4	Digital Elevation Model	Raster file	Advanced Spaceborne Thermal Emission and Reflection, Radiometer (ASTER) Global Digital Elevation Model (GDEM) a 30m by 30m, <a href="https://wist.echo.nasa.gov">https://wist.echo.nasa.gov</a>
5	Sediment load data	Monthly data in excel sheet	Water Resource Management Authority-Kakamega Office
6	Land use data		This was Downloaded from <a href="http://glovis.usgs.gov">http://glovis.usgs.gov</a> as Tiff file

#### 3.2. Climate data

Climate data is a measure of the average pattern of variation in temperature, humidity, atmospheric pressure, wind, precipitation, atmospheric particle count and other meteorological variables in a given region over long periods of time. Climate data was obtained from Kenya Meteorological Department which was captured on monthly basis as well as weather stations within the catchments available at Water Resource Management Authority (WARMA) for a range of year 2000-2012. Climate data was an input in the model for calibration and validation purposes.

#### 3.3. Stream flow data

This refers to the volume of water passing a given point of the river in m<sup>3</sup>/day. It usually varies dependent on the rainfall intensity to particular catchment soil parameters, slopes, among others. This was obtained from WARMA offices in Kakamega). The span of years of interest is 2000 to 2012. Discharge data collected from the ground was in terms of months. The data was collected in m<sup>3</sup>/sec and used for analysis as recorded without any alteration. The existing river gauging stations in the catchment used in data collection included Moi's bridge, Nzoia at Maili Tatu, Koitobos, Kamukuywa, and Nzoia at Webuye, Mumias and Rwambua. Stream flow data collected on the ground was compared with the model output and from the variances, sensitive parameters adjusted accordingly.

#### 3.4. Land classification and change detection.

The land use changes map is derived from satellite images over the years and processed as per the steps below. Land classes followed Moderate Resolution Imaging Spectrometer (MODIS) approach. This follow Leaf Area Index (LAI) to do classification of land cover.

Satellite images were downloaded from <http://glovis.usgs.gov> in tiff format for different set of years. Using ENVI 4.7 software the upper part of river nzoia basin was further reclassified using supervised classification, the same is done in detail in table 3.

### 3.5. Soil map

Soil map gives the spatial variation of soil properties of a given basin. Soil data that will be required for SWAT to predict stream flow are those that describe hydraulic properties of the soil. The basin under study has six types of soils, namely clay light, heavy clay, loam, sandy clay, sandy clay loam, and sandy loam. The Loam soil composed mostly of sand and silt, and a smaller amount of clay (about 40%-40%-20% concentration, respectively). Mountainous regions like Mt. Elgon and Cherengany Hills have heavy clay with hydraulic conductivity of 0.1m<sup>3</sup>/year. The same soils are covered with forest and crops out of human encroachment.

The middle part of the catchment is predominantly covered by clay (light) which has a hydraulic conductivity of 0.0001m<sup>3</sup>/year. The same has enormous use as agricultural land mostly annual crops and settlements. The peak of Mt. Elgon has loam soils and covered by both forest and rock. Generally a large area of the catchment has sandy clay soils with Agriculture and settlement as the main land use.

### 3.6. Data processing

Data processing entailed the steps undertaken to make data usable for the model. SWAT does require that data sets such as meteorological data must be filled prior to use. In the study, documented and scientific approaches were used to fill the missing data where possible. Rainfall data had more gaps and documented scientific method was used to fill the gaps.

### 3.7. Estimating missing rainfall Data

Missing data in both rainfall and runoff was obtained using techniques of interpolation and surrogate as explained. Tobler 1<sup>st</sup> law of geography states that everything is related to everything else, but near things are more related than distant things'' (Tobler, 1970). The same can be correlated by their distance. Filling of missing data was not only embedded on the Inverse-distance weighting method (IDWM) equation 1 but also using the Tobler's law.

This method employs the Tobler's First Law of Geography by estimating unknown measurements as weighted averages over the known measurements at nearby points, giving the greatest weight to the nearest points (Longley *et al.*, 2011). Inverse-distance weighting method was used to determine missing rainfall data. The inverse-distance (reciprocal-distance) weighting method (Simanton & Osborn 1980) is most commonly used for estimation of missing data. The weighting distance method for estimation of missing value of an observation,  $\theta_m$ , using the observed values at other stations is given by

$$\theta_m = \frac{\sum_{i=1}^n \theta_i d_{m,i}^{-k}}{\sum_{i=1}^n d_{m,i}^{-k}}$$

Equation..... 1

Where  $\theta_m$  is the observation at the base station m; n is the number of stations;  $\theta_i$  is the observation at station I,  $d_{m,i}$  is the distance from the location of station i to station m; and k is referred to as the friction distance (Vieux, 2001) that ranges from 1.0 to 6.0. The most commonly used value for k is 2. The distances were found using measure distance tool on ArcGIS 10.1 and inserted into excel sheet. The excel sheet was then programmed with the



The land phase and hydrological cycle is based on equation below,

$$SW_t = SW_o + \sum_{t=1}^t (R - Q_s - E_a - W_{seep} - Q) \dots \dots \dots \text{Equation} \dots 4$$

$SW_t$  = Final water content in (mm)

$SW_o$  = Initial water content on day I (mm)

$R$  = Amount of precipitation on day I (mm)

$Q_s$  = Runoff on day I (mm)

$E_a$  = Amount of evapo-transpiration on day i (mm)

$W_{seep}$  = amount of water entering the vadose zone from soil profile on day i.

$Q_{gw}$  = Amount of return flow on day I (mm)

$t$  = Time in days

For water routing, SWAT used Manning’s equation to define the rate and velocity of flow. Water was routed through the channel network using the variable storage routing method. Manning’s equation for uniform flow in a channel was used to calculate the rate and velocity of flow in a reach segment for a given time step:

$$q_{ch} = \frac{A_{ch} \cdot R_{ch}^{2/3} \cdot slp_{ch}^{1/2}}{n} \dots \dots \dots \text{Equation 5}$$

$$v_c = \frac{R_{ch}^{2/3} \cdot slp_{ch}^{1/2}}{n} \dots \dots \dots \text{Equation 6}$$

Where  $q_{ch}$  = the rate of flow in the channel ( $m^3/s$ ),  $A$  = the cross section area of flow in the channel ( $m^2$ ),  $R_{ch}$  = the hydraulic radius for a given depth of flow (m),  $slp$  = the slope along the channel length (m/m),  $n$  = Manning’s coefficient for the channel and  $v$  = the flow velocity (m/s).

### 3.10. Entering meteorological data into SWAT

The input file storing the amount of daily precipitation data was in ASCII text file with one column. The period of precipitation measurement started on January 1<sup>st</sup> and ended on December 31<sup>st</sup>. In other words, the first precipitation value in the input file had the value of January 1<sup>st</sup> and the last value one of December 31<sup>st</sup>. Even though there was no limit to the number of years employed, calculations were based on the entire period of 2000-2005 for calibration and 2006-2012 for validation.

### 3.11. Land use land cover changes

River Nzoia basin has four distinct zones: a mountain zone which covers mount Elgon part, Cherengany hill and Nandi hills, plateau zone, transition zone and lowland zone. The mountain zone is forested but has suffered enormous land denudation and degradation; the plateau zone is the major farming zone with annual crops e.g. maize millet, beans, sunflower and perennial crops sugar cane and Napier grass being predominant.

### 3.12. Predicting Future Land Use

This research uses the CA-Markov analysis statistical technique combined with Markov chain and Cellular Automata (CA) theory frameworks. This was done via a module in software called IDRISI. Although the Markov chain model is easy to calculate using grid based GIS data and current land use change patterns, it does not accurately reflect actual land use changes because of the difficulty in processing of spatial data. The method uses fixed transition probabilities and is applied equally to all locations despite of temporal changes. To solve this problem, CA-Markov changes the states of adjacent grids consistently by applying common change patterns of temporal and spatial data to adjacent grids. Status of changed adjacent grids that are repeatedly practiced can simulate complex attributes and forms, and change the rules of adjacent grids so local characteristics are applied equally to local grids (Lee and Kim, 2007).

In processing for the future land use covers for the basin under study, the first land use cover image for the year 2000 was uploaded in IDRISI software in the CA markov module. The second image of 2010 was uploaded, followed by output conditional probability image of 85%. The number of periods between the images represented the difference in the years between the images, and in this case was set to 10years and proportional error put at 15%. The software has the ability of predicting the land use for the basin as at 2020 and 2030.

## 4. RESULTS AND DISCUSSION

From SWAT 2012, the images for sub basins, rivers and river gauge stations for the upper part of river Nzoia basin were developed as shown below.

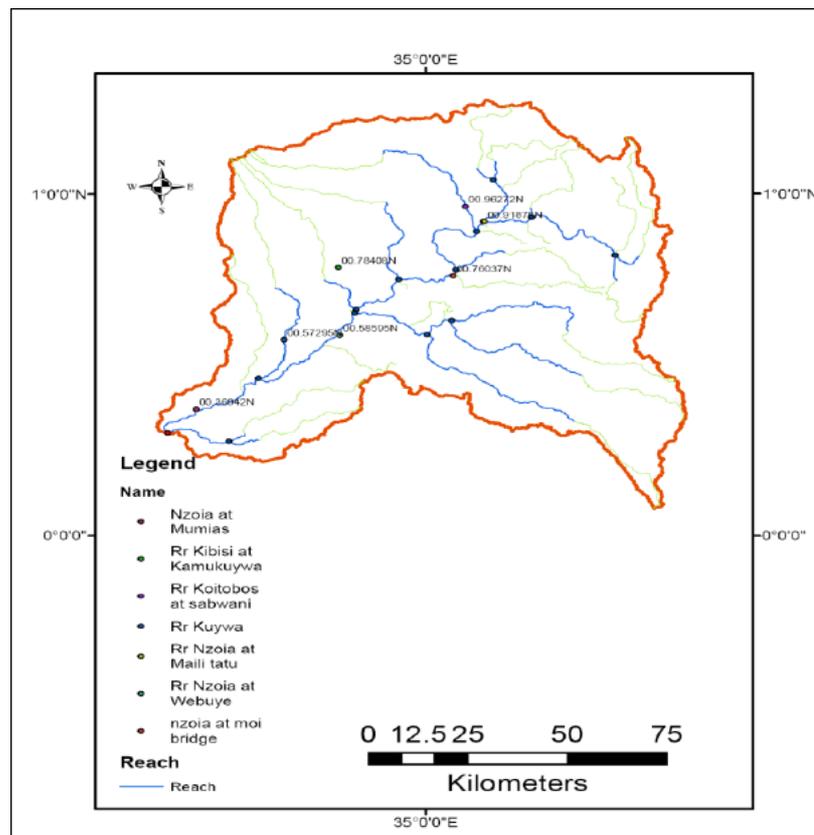
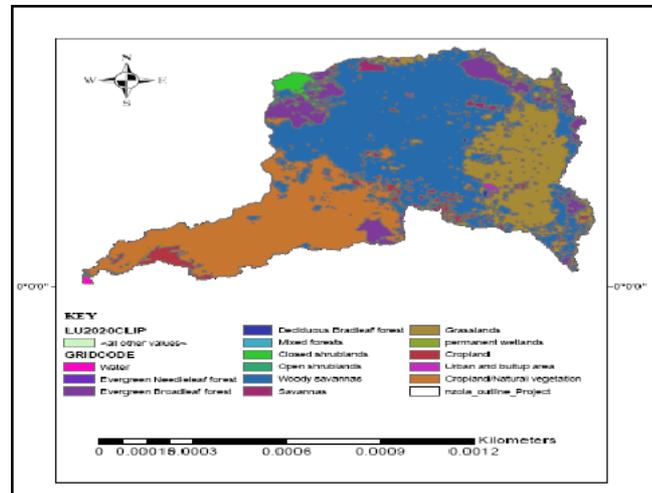
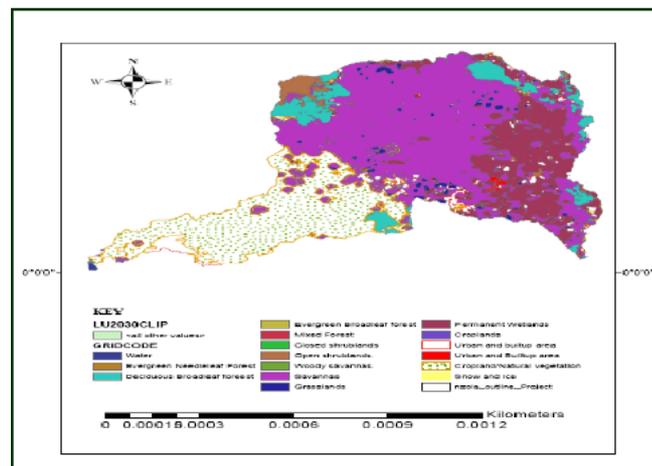


Figure 3 Watershed as delineated and sediment data collection points

Results of this study came from both the model and graphical interpretation of maps, tables and images. From a snap shot, one can tell the land cover in given water tower, soil and size of the sub basins. The watersheds were assigned numbers and sediment load from each analyzed. The figures for sediment loads were compared with the model output for the current state and future.



**Figure 4a.** Predicted land use for thr year 2020



**Figure 4b.** Predicted land use for thr year 2030

**Table 2** MODIS Land Classes

Total	Area in km <sup>2</sup> at 2030	Area in km <sup>2</sup> at 2020	Projected % change 2020-2030	Area in km <sup>2</sup> at 2009	projected %change 2009-2020	Area in km <sup>2</sup> at 2001	%change 2001-2009
Land cover	2030	at 2020	2030	at 2009	2020	2001	2001-2009
Water	35.21	34.36	2.47	35.78	-3.99	37.03	-3.38
Evergreen Needle leaf Forest	11.4	13.87	-17.81	22.70	-38.91	24.75	-8.28
Deciduous Broadleaf Forest	443	457.6	-3.19	293.20	56.07	185.35	58.18
Evergreen Broadleaf forest	10.4	10.85	-4.15	11.28	-3.79	11.45	-1.48
Mixed Forest	10.46	11.1	-5.77	11.28	-1.57	13.99	-19.39
Closed Shrub lands	1228.6	514.66	138.72	268.39	91.76	87.43	206.97
Open Shrub lands	618.64	519.66	19.05	400.13	29.87	332.11	20.48
Woody Savannas	2645.1	2468.28	7.16	2655.79	-7.06	2769.80	-4.12
Savannas	1246	1214.14	2.62	1299.10	-6.54	930.26	39.65
Grassland	727.81	2274.15	-68.00	2474.15	-8.08	2477.64	-0.14
Permanent Wetlands	23.18	25.47	-8.99	27.06	-5.89	27.98	-3.26
Croplands	2051.56	2037.05	0.71	2109.03	-3.41	2739.30	-23.01
Urban and Built-up Area	198.5	98.07	102.41	91.50	6.08	85.40	7.14
Cropland & Natural							
Vegetation	3648.68	3218.08	13.38	3203.43	0.46	3180.72	0.71
Snow/Ice	5.2	6.93	-24.96	1.75	296.51	1.75	-0.08

Predicted Land cover for the year 2020 and 2030 were placed on same table as above for quick conceptualisation and judgement. A comparison of Predicted areas for different land use as at 2020 and 2030 shows that closed shrub land and urban built up area will experience positive change in the entire watershed. Evergreen needle leaf forest, deciduous broad leaf forest, evergreen broadleaf forest and mixed leaf forest are on the decline as indicated in the table above.

The output for the land use for the year 2020 and 2030 were given as in the figure above using CA Markov. Cropland and natural vegetation, woody savannas and grassland will have predominant area as per table 2.

**Table 3** A table of predicted sediment load as per the year 2020 and 2030

Month	Year					
	1990	2000	2010	2014	2020	2030
JANUARY	53.7	56.45	48.09	57.27	93.67	101.73
FEBRUARY	107.5	49.23	64.39	124.86	140.00	168.33
MARCH	97.48	70.39	37.56	47.39	104.97	111.43
APRIL	282.33	49.84	135.12	72.05	450.67	502.33
MAY	191.58	212.38	247.53	140.89	529.67	538.33
JUNE	163.58	96.29	209.92	143	355.33	388.67
JULY	115.54	161.88	161.04	165	365.00	374.67
AUGUST	117.02	176.07	218.21	228	405.00	480.33
SEPTEMBER	101.99	173.97	318.64	365	339.00	391.67
OCTOBER	62.43	181.23	297.56	302	405.67	244.30
NOVEMBER	72.64	158.01	147.71	168	223.33	279.43
DECEMBER	35	106.19	54.81	154	179.77	186.67
TOTAL	1400.79	1491.93	1940.58	1967.46	3592.07	3767.90
MONTH AVERAGE	116.733	124.3275	161.715	163.955	299.3389	313.9917

From the table above, it is predicted from the model that by the year 2020 and 2030, the sediment loads per month will be 299.3 tonnes/months.

**Expected future scenarios**

It is expected that as the human activities intensify, search for more land for farming, wood for construction, land for brick making, settlements and livestock rearing, there shall be drastic changes in land use. As depicted in the predicted land classes as the year 2020 and 2030, the modelled responded as in a way that will leave rivers with more badly raw water quality in the rivers. Sediment loads for the year 2020 and 2030 showed an upward trend. By the year 2020 and 2030, it is expected that the average sediment loads will be 311.28tonnes/months,

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316.76tonnes/months for the year 2020 and 2030respectively up from an average of 124.32, 161.72, and 163.96tonnes/months for the year 2000, 2010 and 2014 respectively. This trend is worrying and affects the raw water even in terms of turbidity.

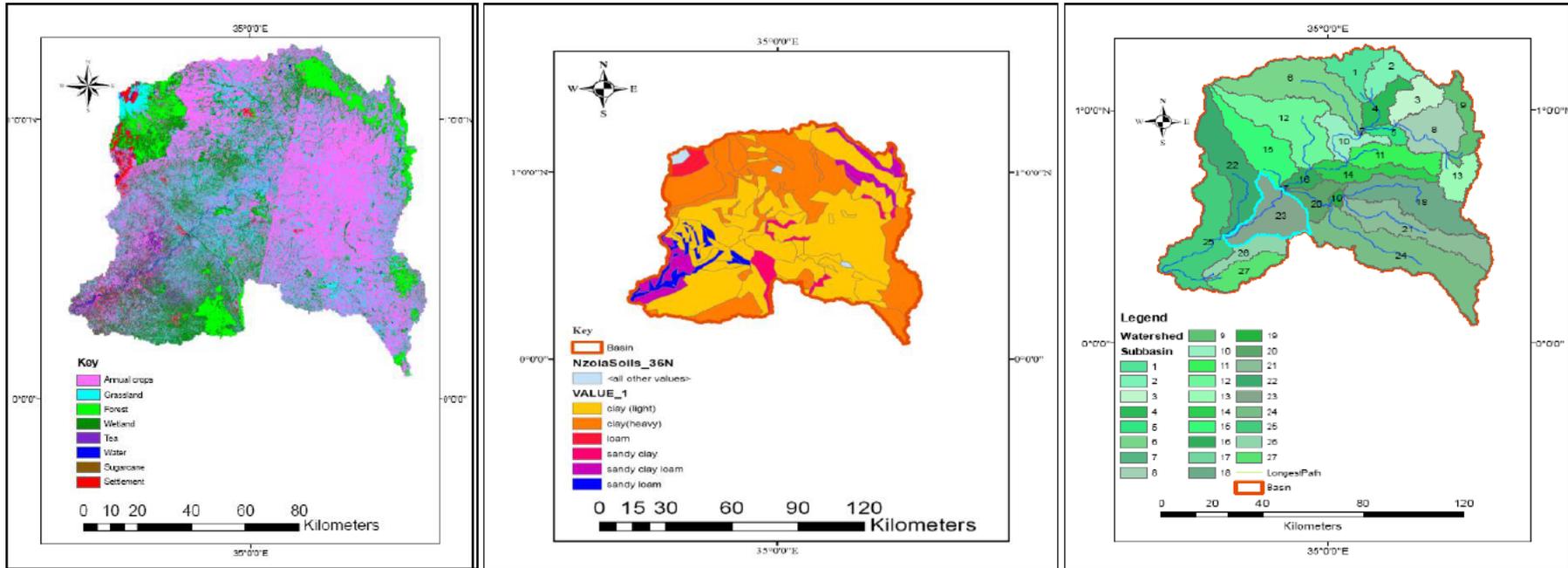


Figure 5 Land use, basinsoils and deleneated subbasins

The table below gives the land use change with the initial state on the horizontal and final state on the vertical axis. The changes have been discussed

**Table 4.**change detection matrix

<b>Area (Km<sup>2</sup>)</b>	<b>Forest</b>	<b>Grassland</b>	<b>Annual Crops</b>	<b>Wetland</b>	<b>Water Body</b>	<b>Tea</b>	<b>Sugarcane</b>	<b>Row Total</b>
Unclassified	0.46	0.51	2.52	0.58	0.06	0.64	0.10	4.87
	9.4%	10.5%	51.8%	11.8%	1.1%	0.0%	2.1%	
Annual Crops	207.04	392.14	4,329.81	125.07	35.79	335.88	63.52	5,489.24
	3.8%	7.1%	78.9%	2.3%	0.7%	6.1%	1.2%	
Grassland	132.43	208.78	1,381.22	56.36	13.86	152.18	10.92	1,955.75
	6.8%	10.7%	70.6%	2.9%	0.7%	7.8%	0.6%	
Forest	658.01	12.67	21.80	96.58	1.86	0.58	0.63	792.12
	83.1%	1.6%	2.8%	12.2%	0.2%	0.1%	0.1%	
Wetland	334.93	260.07	1,090.16	339.37	76.98	193.00	16.39	2,310.90
	14.5%	11.3%	47.2%	14.7%	3.3%	8.3%	0.7%	
Water body	4.42	4.28	18.16	1.77	11.73	11.55	1.97	53.87
	8.2%	7.9%	33.7%	3.3%	21.8%	21.4%	3.7%	
Tea	11.33	10.00	93.80	8.59	8.78	170.83	27.27	330.60
	3.4%	3.0%	28.4%	2.6%	2.7%	51.6%	8.2%	
Sugarcane	4.52	4.23	44.01	6.05	2.91	15.9	892.30	170.00
	2.7%	2.5%	25.9%	3.6%	1.7%	9.4%	54.3%	
Settlement	3.41	17.66	63.38	2.41	1.37	17.08	6.13	111.44
	3.1%	15.8%	56.9%	2.2%	1.2%	15.3%	5.5%	
Clouds	16.86	,424.60	35.02	8.04	2.41	7.20	1.68	95.46
Shadows	8.02	6.98	14.47	4.14	1.50	0.32	0.21	35.65
Class Total	1,381.43	941.56	7,094.34	648.96	157.25	981.57	144.79	
Class Changes	723.42	732.78	2,764.53	309.58	145.53	810.74	128.81	-
Image	(578.89)	1,021.46	(1,593.80)	1,675.3	(103.32)	(650.78)	25.74	-
Difference								

## **Change detection for different land uses**

### ***Forest***

83.1% of the forest area remained unchanged which represent 658.01km<sup>2</sup>. 1.6% ( 12.67km<sup>2</sup> ) of forest cover due to anthropogenic activities changed to grassland, 2.8% representing 21.8km<sup>2</sup> was destroyed and replaced with crops, 12.2% representing 96.58km<sup>2</sup> was destroyed along the water bodies and wetlands, 1.86km<sup>2</sup> to water body. In the period of study (2000-2010) a total of 16.9% of the forest cover in the upper river Nzoia water were destroyed to other use as per table 4 above. Implying that these percentages especially in the water towers were changed to other usages. This exposed the soils to erosion causing an increase in the sediment load. The same increased chances of runoff as there was reduced percolation.

### ***Grassland***

10.7% (208.78km<sup>2</sup>) of total area under grassland remained the same. 6.8% (132.43km<sup>2</sup>) changed to forest, 70.6% (1381.22km<sup>2</sup>) was changed to annual cropland, 2.9% (56.36km<sup>2</sup>) changed to wetland and 0.7% (13.86km<sup>2</sup>) to the water body. A total of 7.8% (152.18km<sup>2</sup>) changed to tea and 0.6% (10.92km<sup>2</sup>) changed from grassland to sugarcane.

### ***Annual cropland***

A total of 78.9% (4329.89km<sup>2</sup>) in the 10years of study (2000-2010) remained intact. A total of 3.8% (207.04km<sup>2</sup>) under crops changed to wetland, 0.7% (35.79km<sup>2</sup>) to water body, 6.1% ( 335.79km<sup>2</sup>) was converted to fields for tea production and 1.2% (63.52km<sup>2</sup>) changed sugarcane. During ground truthing, the photos were taken from the catchment to illustrate how man has altered the land use from the original land cover to mostly settlements and cropland. The photo was taken from around Cherengani hills (Kapolet forest). Despite high slopes in the parcels of land surrounding kapolet forest, encroachment on forest land is observed. Farming and livestock activities are on the increase thus posing the soils to more danger of erosion.

### ***Wetland***

A total of 339.37km<sup>2</sup> of wetland remained intact in the period of study.1090.16km<sup>2</sup>, 260.07km<sup>2</sup>, 334.93km<sup>2</sup>, 76.98km<sup>2</sup> 193km<sup>2</sup> and 16.39km<sup>2</sup> changed from wetland to annual crops grassland, forest water body tea and sugarcane respectively.

### ***Water body***

Only 11.73km<sup>2</sup> of the area under water body remained .the other land changed to unchanged.4.42km<sup>2</sup> 4.28km<sup>2</sup> 18.16km<sup>2</sup> 1.77km<sup>2</sup> ,11.55km<sup>2</sup>, and 1.77km<sup>2</sup> to forest, grassland, annual crops, wetland, tea and sugarcane respectively.

### ***Tea and sugarcane***

These two close grown crops have common characteristics of dense canopies. A total of 51.6% (170.83km<sup>2</sup>) of tea remained unchanged whereas 54.3% (892.3km<sup>2</sup>) of sugarcane remained unchanged. During ground truthing it was established that more sugarcane fields have been developed in Transzoia and Bungoma North while the lower part of the watershed such as Mumias have had sugar cane field destroyed and either left to open fields annual crops or grassland.

In summary grassland area was adversely destroyed with a whopping 70.6% changing to annual cropland. A total of 3.41km<sup>2</sup>(3.1%) of forest was destroyed for human settlement and 2.2% to wetland. Human activities such as pressure to increase land under agriculture and harvesting of forests have led to encroachments to the riparian land (water body) by 1.2% in the last 10 years, 15.3%of land under tea was destroyed for human settlement and finally 5.5%of sugarcane destroyed for human settlement. Grassland was most hit by human activities with only 10.7% remaining unchanged followed by water body at 14.7%.

**Best model parameters**

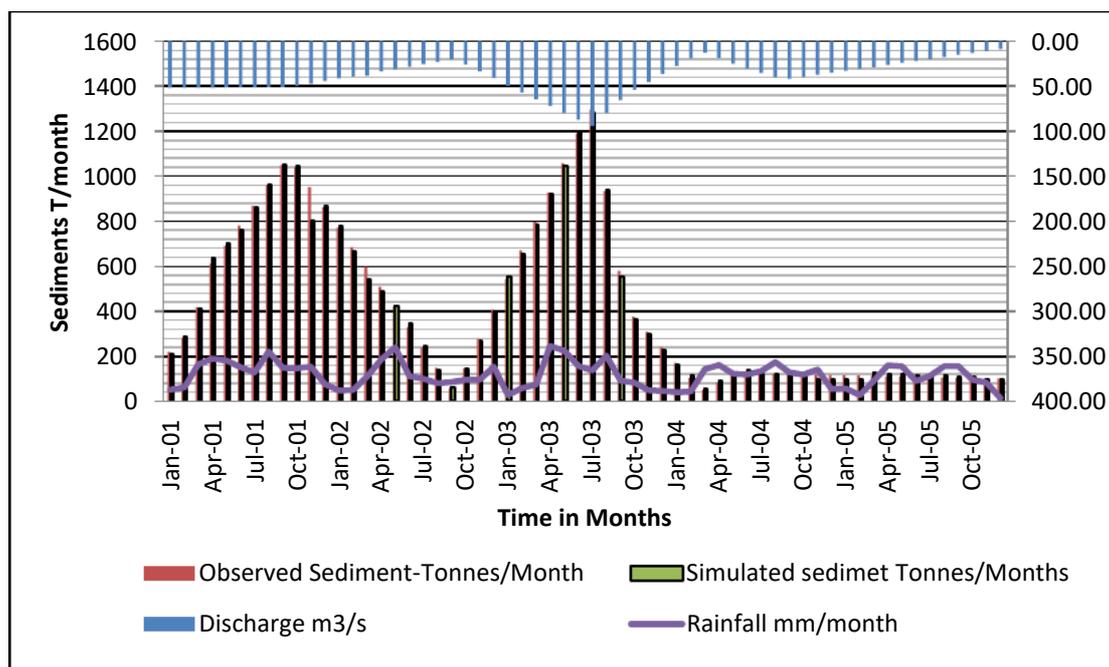
The model was calibrated with data for the year 2000 to 2005 daily meteorological data. One year was allowed as warm up period (Warm-up” is the very essential part of the simulation process that ensured the establishment of the basic flow conditions for the simulations to follow by converging the hydrologic processes to an equilibrium condition). The sensitive parameters were manipulated to ensure the modelled output is close to the observed value on the ground for runoff and sediment. The parameters are as in the table 3 below.

**Table 5** Best parameters effects and range

S/ No	Parameter	Effect on simulation-increase/decrease	Minimum to maximum range	Modeled value
1	CN2	Increase In this figure increases surface runoff and vice versa	35-98	65
2	GWQMN	Increase in this figure Decrease base flow	0-5000	1000
3	ESCO	Decreases evaporation from the catchment	0-1	0.95
4	RCHRG-DP	Increases deep aquifer recharge	0-1	0.05
5	GW-REVAP	Decreases base flow by increasing water transfer aquifer to root zone	0.02-0.2	0.02
6	GW DELAY	Increase in this parameter increased the time it takes for water to exit soil profile and enter shallow aquifer	0-500	31
7	ALPHA BF	The higher it is the more rapid the response to ground water flow	0-1	0.048

## Calibration for runoff and sediments

The model gave near accurate results for sediment loads



**Figure 6** Calibrations for Discharge and Sediments

## 5. RESEARCH BENEFICIARIES

The immediate beneficiaries of this study are Water Resources Users Associations (WRUAs) who are mandated to take care of the catchment by the Water Resource Management Authority. The Kenya Forest Service will also be a beneficiary of the report. They will use the report's findings and recommendation as a decision support tool to improve the land cover especially in the mountainous region of the catchments which are the water towers of river Nzoia and other rivers that trickle from the same source.

## 6. CONCLUSION AND RECOMMENDATIONS

The model calibrated well to predict the sediment and runoff with up to 10% error. When subjected to long term prediction of over 10 years, the model over predicted sediments and runoff. It is therefore recommended that the study can further be scaled down for individual tributaries and smaller areas for more accurate results. It model should as well be validated using other watershed models so as to compare outputs from different models.

For studies related to this with missing sediment data, surrogate approaches that make use of turbidity from water treatment plants should be adopted.

Catchments with land use such forests, broad-leafed forests and low percentage of slope with long travel time of the runoff generates low sediment loads. Catchment 2, 27 and 26 had best abilities to resist generation sediment loads to its reaches. Zone number 2 even though has high slope of 15.25%, only 0.192tonnes/month of sediment load was generated. This tells that catchment with broad-leafed forest cover is excellent in reduction of sediment load. Broad-leafed cover forests reduce the rain impact to the soils, allow for maximum infiltration of rain water and enhance base

flow to the reaches. This ensures that all the water reaching the reaches are free of sediment loads and hence better quality water to the users.

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