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Assessing the Impact of Landuse Change on Streamflow of Ajali River Watershed Using the SWAT Model

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Abstract
The increase in human population has led to high demand for food and shelter. These have severely affected our natural ecology with great impact on the hydrology of local watersheds. *SWAT model was used to predict the impacts of land use/cover changes of Ajali River watersheds, Aguobu-Umumba, Ezeagu, Enugu State, Nigeria. The objective was to calibrate the SWAT model and apply it to assess the effect of landuses from 1985 to 2015 on stream hydrograph. The required input data were obtained, processes using ArcGIS and used to perform model simulation. The model performed successfully for the study area with R^2 = 0.67. Landuse maps for 1985, 1995, 2005 and 2015 were used to perform model runs while keeping other inputs constant. The results showed that there was a general increase in stream discharge from 1985 to 2015 within the period investigated due to forest land conversion to agricultural land. Results show an increase in peak stream discharge by an average of 40m^3/s for the month of October within the time period investigated. This study showed the utility of the SWAT model for stream discharge prediction and a scientific tool for watershed management*

Keywords: Landuse, streamflow, SWAT, Landsat imageries

1.0 Introduction

The agricultural based economy and rapidly increasing population are the main cause of land use/cover changes in developing countries (Getahun and Haj, 2015).Conversion of a land cover has its accompanying effects and impacts, of which in most cases is negative and detrimental to the ecosystem (Amisigo *et al.*, 2015). Analyzing land cover change is important because surface changes affect a wide variety of ecological processes. Land-use and cover changes have a strong impact upon water resources both in terms of their quantity and quality. Land-use change alters runoff pattern, change streamflow patterns and can increase the likelihood of flood events. It also impact water supply by altering hydrological processes such as infiltration, groundwater recharge, base-flow and runoff.Changes in natural water storage as a consequence of urbanization also cause significant changes to the temporal characteristics of runoff from an urbanized area, such as shortening the runoff travel time, and can result in an increased incidence of flash flooding.

The impacts of land-use changes have received considerable attention from ecologists, particularly with respect to effects on aquatic ecosystems and biodiversity (Meyer and Turner, 2002). According to JunJie (2008), land-use change is arguably the most pervasive socio-economic force driving changes and degradation of ecosystems.

Hydrological impacts due to land use/cover changes and land use modifications can be predicted through remote sensing, geographical information system (GIS) and the SWAT model because there is a direct relationship between spatially distributed watershed properties and watershed processes (Meyer and Turner, 2002). Many hydrologic models have been documented in literature for modeling land-use effect on stream discharge. SWAT model has been widely used in various regions and climatic conditions on daily, monthly and annual time steps and for watersheds of various sizes and scales (Singh, 2009).

This study is aimed at assessing the impact of landuse change on the streamflow of Ajali River located in Ezeagu Local Government Area of Enugu State, Nigeria.

1.1 SWAT Model: Theory

The Soil and Water Assessment Tool (SWAT) model is a river basin or watershed scale model that predicts the impact of land management practices such as land-use and land cover changes, reservoir management, ground water withdrawals and water transfers, in complex watersheds over long periods of time (Neitsch et al., 2011). The Hydrologic Response Units (HRUs) are used to describe spatial heterogeneity in terms of land cover, soil type and slope class within a watershed. The model estimates relevant hydrologic components such as evapotranspiration, surface runoff and peak runoff, groundwater flows and sediment yields for each HRUs unit.

The hydrologic cycle simulated by SWAT is based on the water balance equation (Neitsch et al., 2011) below:

$SW_t = SW_o + \sum(R_{day} - Q_{surf} - E_a - W_{seep} - Q_{gw})$ (1)

Where SW_t is the final soil water content at time 't' (mm), SW_o is the initial soil water content (mm), t is time (days), R_{day} is the amount of precipitation on day i (mm), Q_{surf} is the amount of surface runoff on day i (mm), E_a is the amount of evapotranspiration on day i (mm), W_{seep} is the amount of water seepage entering the vadose zone from the soil profile on day i (mm), and Q_{gw} is the amount of return flow on day i (mm).

Rainfall drives the major hydrologic processes in a hydrologic unit. Precipitation inputs for hydrologic calculations can either be measured data or simulated with the weather generator available in the SWAT model. The soil-water processes include infiltration, percolation, evaporation, plant uptake, and lateral flow. Surface runoff is estimated using the SCS curve number or the Green-Ampt infiltration equation. Percolation is modeled with a layered storage routing technique combined with a crack flow model. Potential evaporation can be calculated using Hargreaves, Priestly-Taylor or Penman-Monteith method. Surface runoff is estimated in SWAT using two methods: the SCS curve number (SCS, 1972) or the Green & Ampt infiltration method (1911). According to Neitsch *et al.*(2011), the SCS curve number equation is given as:

$$Q_{surf} = \frac{(R_{day} - 0.2S)^2}{(R_{day} + 0.8S)} \quad (2)$$

Where Q_{surf} = Accumulated runoff or rainfall excess (mm), R_{day} = Rainfall depth for the day (mm), S = retention parameter (mm) is given as

$$S = 25.4 \frac{1000}{CN} - 10 \quad (3)$$

Where, CN= curve number for the day.

The Green & Ampt Mein-Larson excess rainfall equation (Green and Ampt, 1911) was incorporated into SWAT to provide an alternative option for determining surface runoff. This method requires sub-daily precipitation data supplied by the user. The Green & Ampt Mein-Larson infiltration rate is given as:

$$f_{inf,t} = K_e \left(1 + \frac{\Psi_{wf} \cdot \Delta\theta_v}{F_{inf,t}}\right) \quad (4)$$

Where f_{inf} = Infiltration rate at time t (mm/hr), K_e = Hydraulic conductivity (mm/hr), Ψ_{wf} = Wetting front matric potential (mm), $\Delta\theta_v$ = Change in volumetric moisture content across the wetting front (mm/mm), F_{inf} = Cumulative infiltration at time t (mm)

2.0 Material and methods

2.1 Study Area

The Ajali River Aguobu Umumba watershed has an area of about 1176744000 ha and is located in Ezeagu, of Enugu State, Nigeria as shown in Fig. 1. It is geographically situated between Latitude $06^{o}21^{'}\ 49^{''}$ N and Longitude $07^{o}\ 17^{'}\ 06^{''}$E and is predominantly underlain by Ajali and Nsukka Formations at upland and Mamu Formations in the lowlands. This watershed houses the Ajali water works which supplies water to Enugu metropolis, has not been serviced since 1985 (Nweke, 2015). The poorly sorted Ajali Sandstones are easily washed away by concentrated runoff from prolonged and torrential rainfall. The soil of the study area is sandy with small percentage of silt/clay (Nweke, 2015). The average annual rainfall within this study area is about 1600 mm which falls during the rainy season (April – October) each year.

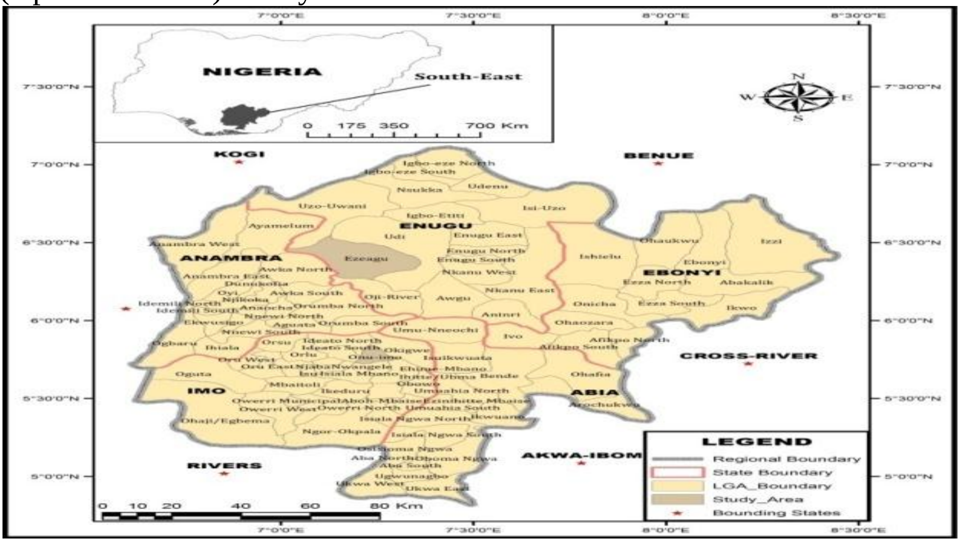

Fig. 1: Location of the Study Area

2.2 Input Data Processing

The ArcSWAT/ArcGIS extension is a graphical user interface for the SWAT model and was used to prepare and process digital input datasets for streamflow simulation. Inputs required by SWAT model includes Digital elevation model (DEM), soil map, land-use data and climate data.

Digital Elevation Model (DEM): The DEM for the study area was derived from the ASTER DEM from the United State Geological Survey (USGS) database, diva-GIS archive and ground control points; these were combined using the raster calculator to make a single composite detailed DEM for the study area. The DEM has a spatial resolution of 30m and was utilized for delineating the watershed and also to derive the drainage patterns and stream networks for the study watershed. The DEM was used to divide the watershed into multiple sub-basins that are further subdivided into hydrological response units (HRUs) which consist of homogenous land-use, digital elevation map and soil characteristics (Gassman *et. al.*, 2007).

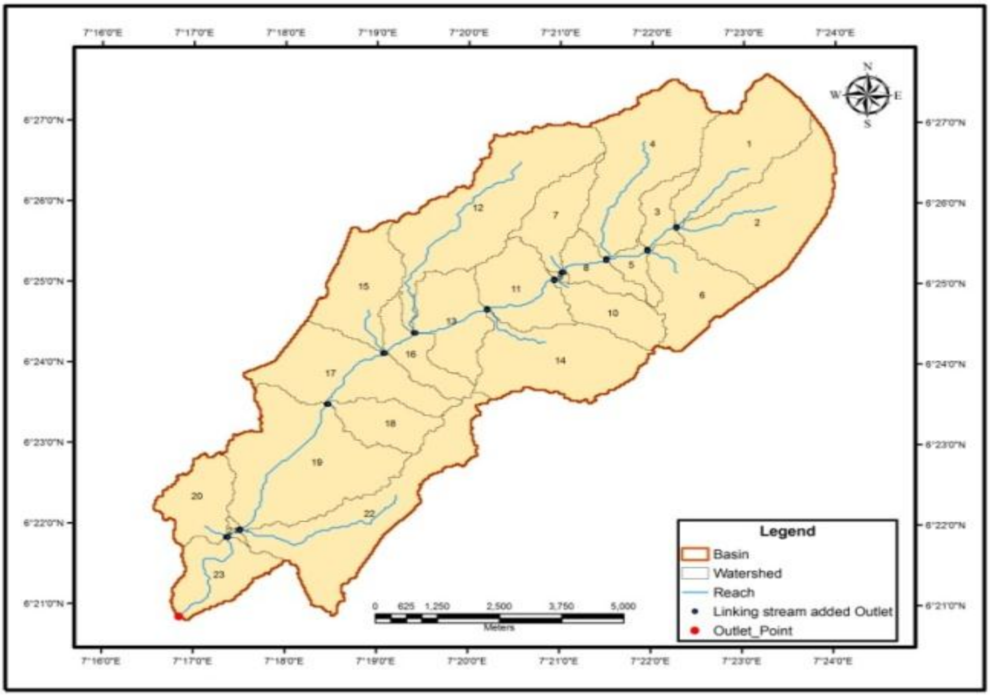

Fig. 2: Delineated Map of the Study Area

Land use Map: Landuse data of the study locations were produced from the USGS Data Archive (earthexplorer.usgs.gov). The land sat images were processed and vectorized using the Geographic coordinate systems of World Geodetic System 1984, to create their vector shapefiles, which were also masked using the shapefile of the study watersheds and analyzed using the ArcGIS tool. The following procedures were undertaken in the image processing of the land use data:

Layer stacking: Bands 4, 3, 2 of the 1985, 1995, 2005 and 2015 landsat TM images were in turn, layer – stacked together using ARC GIS 9.3 to form a single layer each, for the analyses. These bands were chosen because of their capacity to reflect vegetation component, and landuse variables.

Radiometric and Geometric Correction: It was discovered that most open source imageries were often distorted by excessive cover. As such, IDRISI Selva was used to correct the haze distortion where necessary.

Image sharpening: This was meant to enhance the appearance of the images using IDRISI Selva so as to increase their spatial resolution and visualization of the multiband images.

Geographic coordinate systems of World Geodetic System 1984: This was necessary in order to assign accurate spatial reference to the Raster image (Landsat imageries) and for vector shape files that was created in the study area.

Image extraction through the process of Masking and extraction: Shape file for the area of interest was purchased and created in ArcGIS 9.3 and used to clip out the area of interest. The various land use classifications in 1985, 1995, 2005 and 2015 have been presented in Table 1including their percentages of accuracy during the classification.

Table 1: Land use Classification in Hectares (ha) for Ajali River Watershed

	Built Up	Vegetation	Wet Land	Bare Land	Total Area	Accuracy%
1985	301678400	677488600	169847100	27729900	1176744000	79
1995	318791700	418366800	280691100	158894400	1176744000	80
2005	381716200	393253200	224343800	174430800	1173744000	78
2015	413376200	363253200	224343000	172771600	1173744000	69

Soil Data: 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 *et al.*, 2009). Some of these properties were determined in the laboratory while others were extracted from the Harmonized World Soil Database. The soil maps were obtained from Dominant Soil Map of Nigeria (FAO, 2015) at a scale of 1:1,300,000. Using the Harmonized World Soil Database (HWSD v1.2) viewer software, at a spatial resolution of 10 kilometers, (FAO, 2015) the required Soil characteristics at two layers of 30 cm and 100 cm were derived. According to HWSD classification, the soil types found in Ajali watershed include a combination of Fluvisols (FL), Acrisol (AC) and Plinthosols (AC).

Climate Data: One of the major limitations to hydrological studies in developing countries is the non-availability of representative spatial rainfall especially in developing countries. Obtaining representative meteorological data for watershed-scale hydrological modeling can be difficult and time consuming (Fuka, *et al.*, 2012). However, with development and improvement in remote sensing, weather variable can be obtained from global climate model databases.

In this study, daily weather variables (minimum and maximum temperature, precipitation, relative humidity, wind speed and solar radiation) were obtained from the Nigeria Metrological Service Agency (NIMET) and also downloaded from the Climate Forecast System Reanalysis (CFSR) global meteorological dataset (http://globalweather.tamu.edu/) for the period of January 1979 to December 2015 for the study area. CFSR data have been applied and validated in different watersheds globally (Fuka *et al.*, 2012).

3.0 Results and Discussions

3.1 Sensitivity Analysis

The ability of a watershed model to sufficiently predict stream flow for a specific application is evaluated through sensitivity analysis, calibration, validation and uncertainty analysis (Kassa, 2009). Sensitivity analysis determines the model input parameters that are key drivers of the model output. The sensitivity of SWAT – stimulated streamflow to SWAT input parameters was assessed using the automatic sensitivity analysis tool provided in the SWAT model. The model uses the Latin Hypercube One – Factor – AT- a- Time (LH – OAT) method proposed by Morris (1991) to perform the sensitivity analysis. Parameters sensitive to streamflow were subjected to sensitivity analysis as shown in Table 1. The default parameters are based on the range suggested in SWAT user manual (Neitsch et al., 2011).

Table 2: SWAT Parameters Sensitive to Streamflow

Parameter	Description	Range	Standard Value
ALPHA_BF	Baseflow alpha factor (days)	0 - 1	0.048
CN2	SCS runoff curve number	25 – 98	53
GW_DELAY	Groundwater delay (days)	0.02 – 0.2	0.1
RCHRG_DP	Deep aquifer percolation fraction	0 – 1	1
SURLAG	Average slope length	0 - 5000	0
CH_K2	Effective hydraulic conductivity in main channel alluvium	0.01 - 0.3	0.01
CH_N2	Manning's "n" value for the main channel	0 - 1	1
EPCO	Plant uptake compensation factor	0 - 500	0
ESCO	Soil evaporation compensation factor	0 - 1	1
GW_REVAP	Groundwater "revap" coefficient	0 - 1	0.02
GWQMN	Threshold depth of water in the shallow aquifer required for return flow to occur (mm)	0 - 5000	0
SLSUBBSN	Surface runoff lag time	1 - 12	4

3.2 Model Calibration

Model calibration was performed using 1985 monthly discharge data for the study watershed. A comparison of observed and simulated streamflow hydrographs for Ajali River Watershed at monthly time steps showed good correlation for most parts of the simulation periods as shown in Figures 3. The evaluation of hydrologic model behavior and performance is commonly made and reported through comparisons of simulated and observed variables (Krause *et al.*, 2005). In this study, SWAT model was evaluated using only Coefficient of determination (R^2)

which was obtained as 0.6776. Generally, model simulation can be judged as satisfactory if $R^2 > 0.50$ for streamflow (Moriasi *et al.*, 2007).

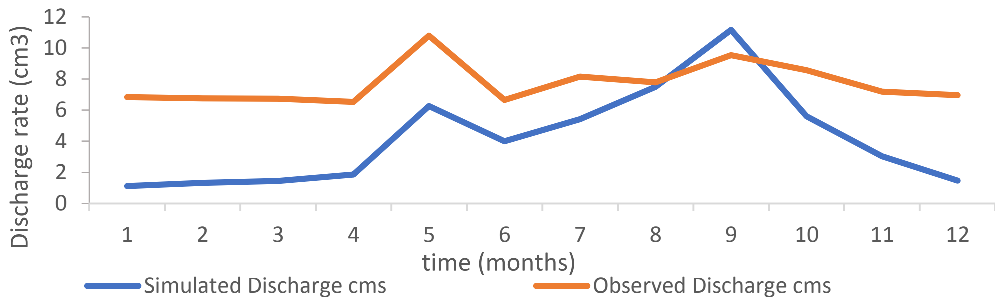

Fig. 3: Model Calibration for the Study Area

Land-use Assessment

Landuse maps for 1995, 2005 and 2015 for the study area were obtained and processed as discussed above. These were inputted saparately into the model and used to perform discharge simulations for a one year period. Hydrographs for the simulation periods are plotted as shown in Fig. 4.

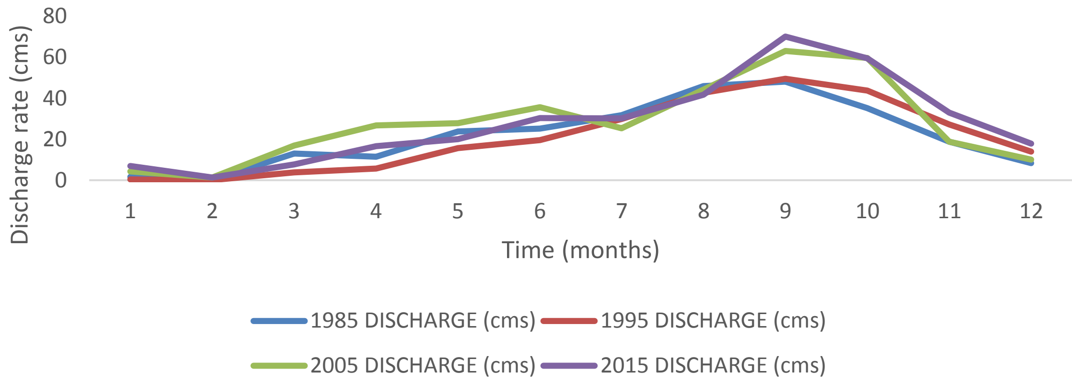

Fig. 4: Hydrographs Using Landuse Maps for Different Years

From Fig. 4, it was observed that the different hydropgraphs followed the same trend with peaks around october. Discharges for the different landuses were observed to increase generally from about average monthly dicharge of 20 m^3/s to about 80 m^3/s as a result of a greater percentage of the study area been converted to agricultural land. High discharge peaks were observed around october and this concides with the period of high seasonal rainfall for the region. This no doubt explains the increased flooding events within this study area which can be attributed to climate change ccupled with incresased conversion of forest land to agricultral and grazing lands.

4.0. Conclusion

The SWAT model was successfully calibrated for the Ajali River Watershed using observed discharge data. Statistics evidence showed that the model performed well having shown a coefficient of determination greater than 0.5 ($R^2 \geq 0.5$). Landuse maps for different years were used for discharge simulation showed an increase in discharge for the study area from 1985 to 2015. It was also observed that there was also a greater percentage of the watershed land area was transformed from forest area into agricultural land. This change in landuse within the study area was not surprising as the growing human population requires more land to be put under cultivation and for other agricultural purposes.

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