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Changing land use and land cover impact on runoff characteristics of an upstream reach in Ala river watershed

Obiora-Okeke O.A..
Department of Civil Engineering. Federal University of Technology, Akure, Nigeria

ABSTRACT:*There has been significant urbanization in the upstream watershed of Alariver. Urbanization modifies land use and land cover to impervious cover thereby generating higher runoff in the watershed streams. This study is aimedat stimulating peak discharges and runoff volume at upstream watershed outlet for future (25 years) land use and land cover.Hydrologic Engineering Center- Hydrologic Modeling System was used in simulating 25 and 100-years return period storms. Markov model was used in predicting future land use based on the preceding land use and land cover between 2002 and 2017. In the 2042, the built up area is projected increase to 74.7% of the watershed from 46.5% in 2017.The curve and initial abstraction adopted for land use and land cover classifications in the watershed were 86 and 8.27. Peak discharge and runoff volume at the reach's outlet, estimated with 25-years return period stormfor land use and land cover in 2042were 169.0 m^3/s and 2,992,500 m^3. Peak discharge and runoff volume at the reach's outlet, estimated with 25-years return period storm for land use and land cover in 2042 were 254.3 m^3/s and 3,698,000 m^3.*

KEY WORDS*: peak discharges, runoff volume, land use and land cover, watershed and curve number*

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I. INTRODUCTION

Normal floods are expected and generally welcomed in many parts of the world as they provide rich soil, water and a means of transport, but flooding at an unexpected scale and with excessive frequency causes damage to life, livelihoods and environment (Alnap, 2008).There is a major challenge still remaining is the accurate prediction of catchment runoff responses to rainfall events (McColl and Aggett, 2006 and Yener, 2006). Hydrologic modelling system was designed to stimulate the rainfall runoff processes in a wide variety of watershed types. Yenaret al. (2008) applied HEC-HMS model to Yuvacık Basin, which is located in southeastern part of Marmara Region of Türkiye with the drainage area of 257.86 km^2 for hydrologic modelling studies. Event based hourly simulations were used and runoff scenarios using intensity-duration-frequency curves were carried out for three sub-basins: Kirazdere, Kazandere and Serindere to obtain seasonal average values. The infiltration loss and base flow parameters of each sub-basin were calibrated with hourly simulations. The runoff generated from frequency storm method was useful for future flood hazard and risk assessment studies. This research is aimed at determination of flood hydrographs of 25 and 100 years return period storm for future land use and land cover (LU and LC) at the outlet of the upstream watershed. This data obtained would assist researchers in design of hydraulic structures and flood mapping.

II. METHODOLOY

2.1 Description of the Study Area

The upstream watershed lies between longitude 5^o 7' E to 5^o 10' East and latitude 7^o 17' N to 7^o 20' North. The watershed covers an area of 12.63km^2 with the vegetative area occupying 4.39 km^2 and built-up area occupying 5.87 km^2. The watershed drains Ipinsha areas, the Federal University of Technology Akure north gate and south gates areas, and part of the road to Ijare town. The location mapin figure 1is the watershed in Akure and in Nigeria. Figure 2 is the contour map for the upstream watershed. Alariver ultimately discharges to Ogbese river.

The watershed area experiences regular rainfall between April and July with a short break in August which continues between September and November with the heaviest rainfall occurring in July. Annual rainfall depth varies from 1,500 mm to 3500mm. The average daily temperature ranges from 22˚ during the harmattan

period (December-Febuary) to 32˚C in March. The upstream watershed has an average annual relative humidity of 75 percent which is highest during the day during the rainy season when it rises to about 90 percent.
The area around the Akuremetropolics is underlain by the basement complex rocks of southwestern Nigeria. The petrologicalunit includeMigmatite-Gneiss-Quartzite complex, Charnockitic and Diorite rocks, older Granites and nnmetamorphosed dolerite dykes (Rahaman, 1998).

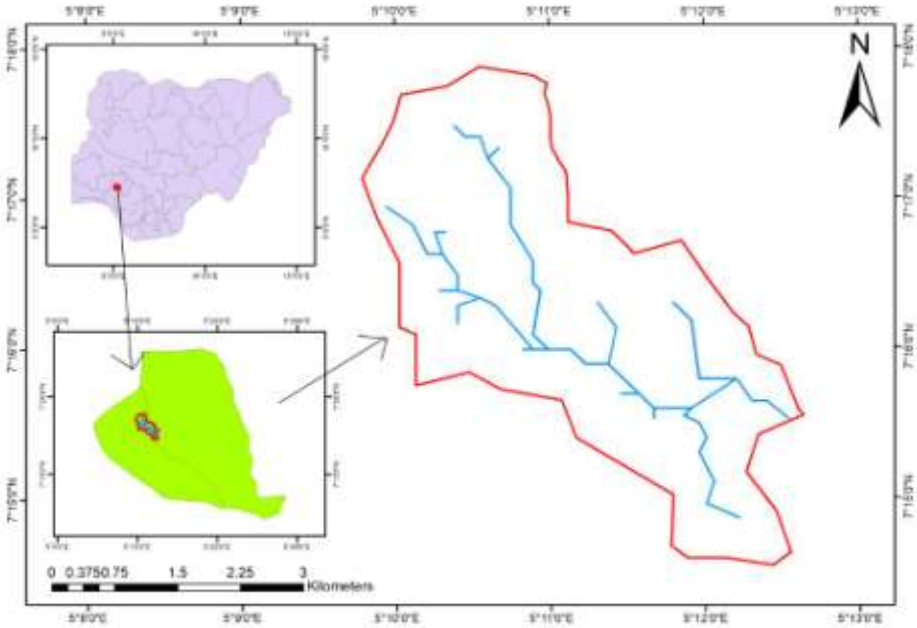

Figure 1: Location map for the Ala upstream watershed

Fig 2:Contour map for Ala upstream watershed

2.2 HEC-HMS model
2.2.1 Model

The Hydrologic Modeling System, developed by the Hydrologic Engineering Center of the United States Army Corps of Engineers, is a lumped or semi-distributed software package for modeling rainfall-runoff processes in watershed. It is public domain software developed by the US Army Corps of Engineers. It also has a wide range of methods to set up and control variables for simulating a rainfall-runoff (USACE, 2000).

2.2.2 Model Application

In this model, interception, evaporation and infiltration processes in a watershed are determined from loss components while runoff processes are computed as pure surface routing using transform component. The selected methods used for parameterization were the SCS curve number (CN) method for loss component and Unit Hydrograph method for transformation routines. The SCS curve number corresponds to interception and depression storages with an initial abstraction.

2.2.3 GIS Model

The GIS model is used to create the basin model for HEC-HMS and is based solely on topography. It drives watershed network from the topographic information to calculate their relevant characteristics. With this topographical map, other maps like soil type, land slope, land use/pattern, drainage network, curve number and watershed boundary map were extracted

2.3 Remote-Sensed Images

2.3.1 Satellite Images

Landsat 7 Enhanced Thematic Mapper plus (ETM+) image and Landsat 8 Operational Land Imager (OLI) were used in studying LU and LC changes in Ala upstream watershed .These were images collected in the years 2002 and 2017 respectively with path and row 188, 56 and 189, 56. The images were downloaded from the United States Geological Survey (USGS) website. The Administrative map of Nigeria was the source from which the study area shape file was clipped out, this was done using ArcGIS. The 2002 and 2017 images have resolution of 30 metres. All the images were enhanced, georeferenced and classified for the assessment of spatio-temporal pattern of land use and cover changes in the study area. In this study, the satellite images were classified using supervised classification method.

2.3.2 Image Classification

In this study, three LU and LC classes were considered, namely built up, agricultural land, dense vegetation and rock outcrop. The classes in the images were decided based on the LU and LC classification system. A supervised approach for classification of the image was adopted with the maximum likelihood rule used as a parametric rule (Lillesand& Kiefer 2003; Coskunet al. 2008).The classified LU and LC maps for years 2002 and 2018 were produced from landsat images.

2.3.3 Supervised Classification

With supervised classification, we identify examples of the information classes (i.e., LU and LC type) of interest in the image. These are called "training sites". The image processing tool in Arc GISsystem is then used to develop a statistical characterization of the reflectance for each information class. This stage is often called "signature analysis" and may involve developing a characterization as simple as the mean or the range of reflectance on each bands, or as complex as detailed analyses of the mean, variances and covariance over all bands. Once a statistical characterization has been achieved for each information class, the image is then classified by examining the reflectance for each pixel and making a decision about which of the signatures it resembles most.

2.4 Markov's Model

Markov model is a useful tool for prediction of future LU and LC change when dynamics landscapes changes are difficult to project. The Markov process predicts future state of a system based on the preceding state. This is achieved by developing a transition probability matrix of LU and LC change from time one to time two, showing the nature of change while still serving as the basis for projecting to a later time period (Logsdon, 1996). Markov method of predicting future state of a landscape requires the state transition of a system to another. This transition of one state to another is described by the transition probability expressed below as

$$P = P_{ij} = \begin{vmatrix} P_{11} & P_{12} & \cdots & P_{1n} \\ P_{21} & P_{22} & \cdots & P_{2n} \\ P_{31} & P_{32} & \cdots & P_{3n} \\ P_{41} & P_{42} & \cdots & P_{4n} \end{vmatrix} \quad (1)$$

whereP stands for probability from state i to state j. Equation (1) must satisfy the next two conditions:

$$\sum_{j=i}^{n} P_{ij} = 1 \quad (2)$$

$$0 \leq P_{ij} \leq 1$$

The key step of the Markov model lies in getting a primary matrix and matrix of transition probability (P_{ij}). Then the Markov forecast model is as follows:

$$P_n = P_{(n-1)}P_{ij} = P_{(0)}P_{ij}^n \quad (3)$$

where P_n stands for state probability of any time and $P_{(0)}$ stands for primary matrix.

III. RESULTS AND DISCUSSION

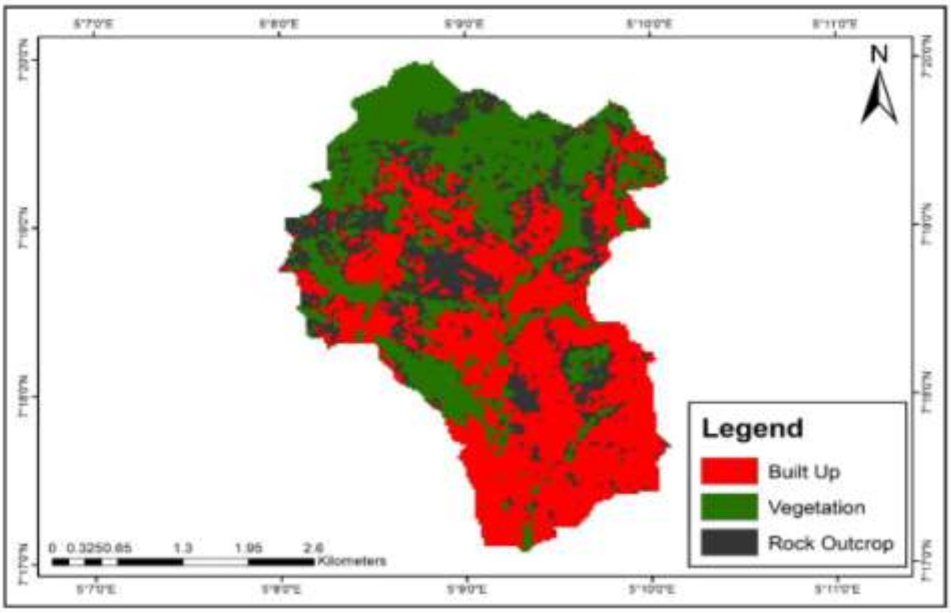

Figure 3: LU and LC map showing land use in 2017

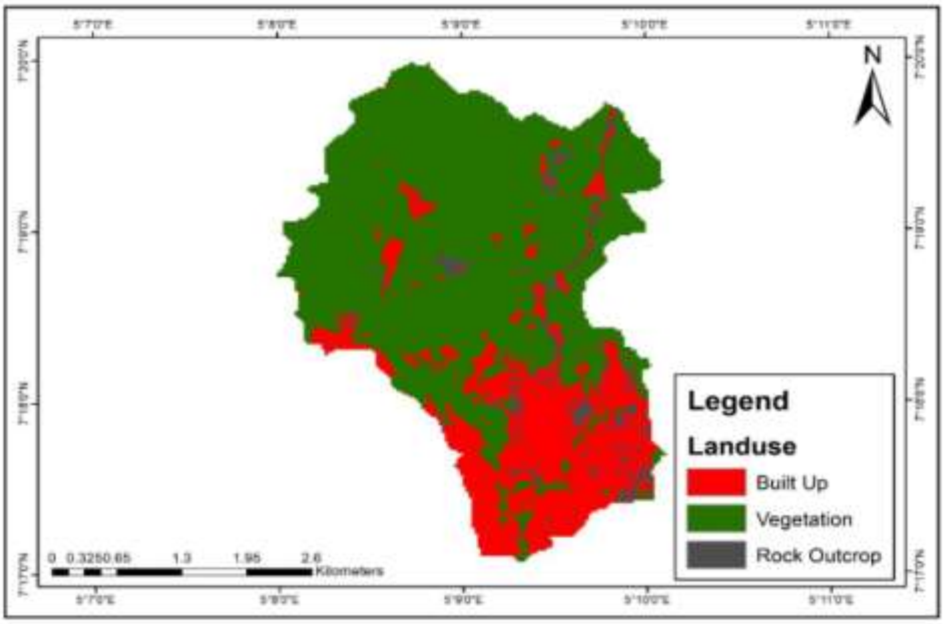

Figure 4: LU and LC map showing land use in 2002

3.1 Primary Matrix for FUTA South Gate Stream Watershed

The primary matrix is based on the calculated areas of the land use types extracted from the Landsat images. The area statistics calculated for 2002 and 2017 are listed in table 1 and shown figures 3 and 4. The primary matrix becomes $P_{(0)} = [5.87, 4.39, 2.37]$ for further analysis.

Table 1: Areal Extent Statistics 2002-2017

LU and LC Classes	Area (km^2) 2002	2017
Built-up	3.27	5.87
Vegetation	8.39	4.39
Rock outcrop	0.47	2.37

3.2 Matrix of Transition Probability for FUTA South Gate Stream Catchment

The rate of transition from one state to another is called transition probability and is calculated through annual average rate of transition of a certain land use and land cover type. Table 2 shows matrix of primary transition probability between 2017 and 2042for three land use types (areas in square kilometers). Using equation X, that is $\sum_{j=i}^{n} P_{ij} = 1$, the transition probability of a certain land use type in 2002 converted into land use type in 2017 was calculated. Table 2 show the matrix of primary transition probability between 2017 and 2042. Table 3 show areal extent statistics of past and predicted LU and LC.

Table 2: Matrix of Primary Transition Probability between 2017 and 2042

2002	2017 Built-up	Vegetation	Rock Outcrop
Built-up	0.8086	0.1029	0.0885
Vegetation	0.3697	0.4487	0.1817
Rock Outcrop	0.4990	0.2313	0.2698

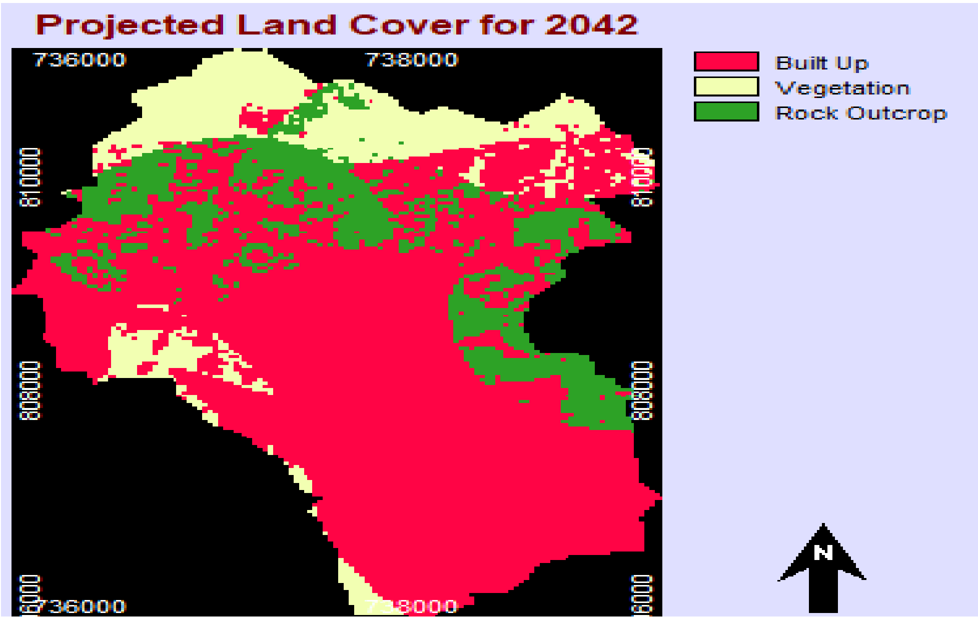

Figure 5: Projected LU and LC in 2042

Table: 3: Areal Extent Statistics of Past, Current and Projected LU and LC

LU and LC Classification	2000	2017	2042
Built-up	**3.26**	**5.87**	**9.43**
Vegetation	**6.52**	**4.39**	**1.32**
Rock Outcrop	**2.85**	**2.37**	**1.87**

Table 4: SCS CN Value for Projected LU and LC Scenarios

YEAR 2017		YEAR 2042	
CN Value	**Built-up%**	**CN Value**	**Built-up%**
75	46.5	86	74.66

Figure 5 is the projected LU and LC in 2042. The projected LU and LC show increase in LU and LC classification of built-up area increasing from 74.66% to 46.5% between 2017 and 2042. This implies increase in curve number parameter value from 75 in 2017 to 86 as shown in table 4. This CN value was used in simulating peak discharges and runoff volume in 2043 as shown in figures 8 and 9.

3.3 Simulation of peak discharge and runoff volume for current LU and LC.

In flood mapping, extreme rainfall conditions are used to generate direct runoffs. Commonly used for engineering design is 25 years return period rainfall of 24 hours duration. In delineating floodplains 100 years return period rainfall of 24 hours duration is used. The runoff hydrograph for 25-year and 100-year return period storm in figures 6 and 7 was used simulated with land use and cover. Peak discharges for both 25-year and 100-year return period are 160.9 m/s^3 and 254.3 m/s^3 respectively.

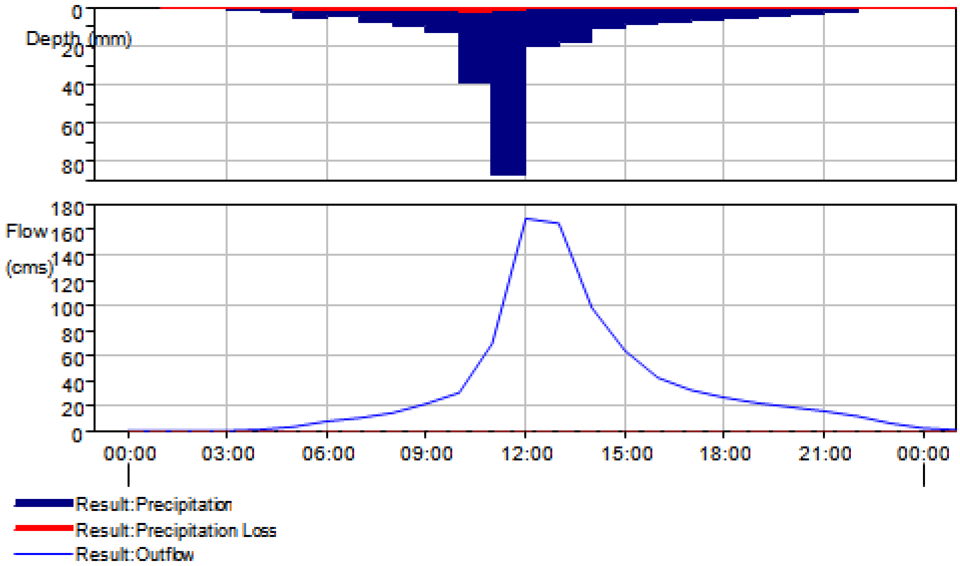

Figure 6: Hyetograph and Simulated Runoff for 25-Year Return Period Rainfall for 2042 LU and LC

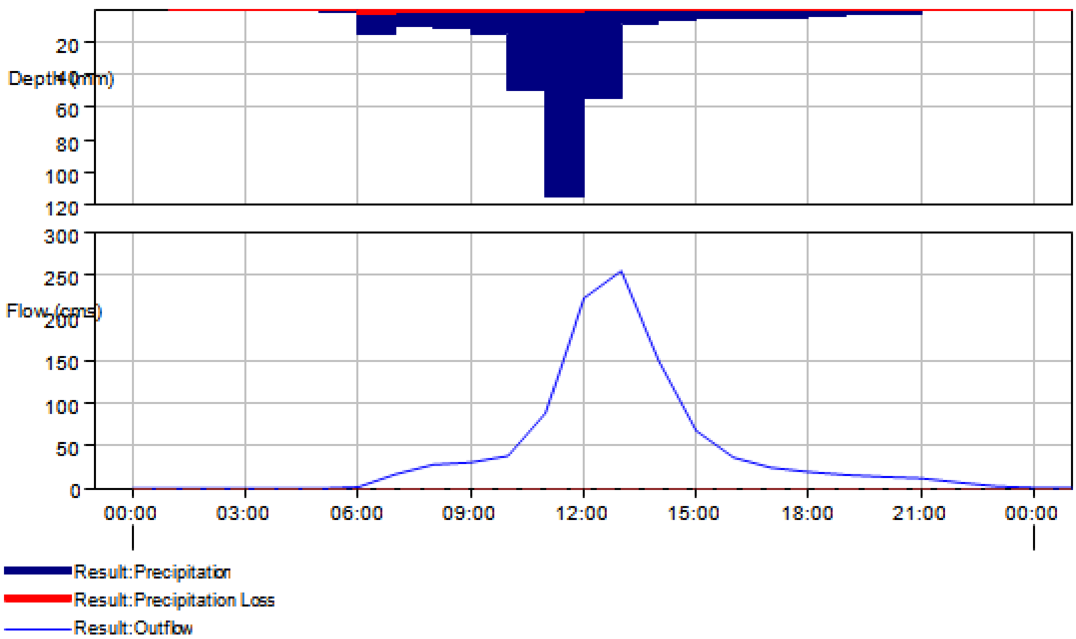

Figure 7: Hyetograph and Simulated Runoff for 100-Year Return Period Rainfall for 2042 LU and LC

1V. CONCLUSION

HEC-HMS model is user-friendly model used in estimating runoff in an unguaged watershed. The hydrologic model was used in simulating the peak discharge and runoff volume for Ala river upstream watershed at its outlet located in Alaba estate. Future values of runoff are needed for sustainable planning and design. This was achieved by calculating future LU and LC in the 2042 with Markov model to determine curve number which is the key variable parameter describing the model. LU and LC value in 2042 were calculated as 9.32 km^2 for built-up,1.32 km^2 for vegetation and 1.87 km^2 for rock outcrop. Peak discharges and runoff volume simulated for the 2042 LU and LC are 160.9 m^3/s and 254.3 m^3/s respectively.

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