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IMPACT OF LAND USE AND LAND COVER CHANGES ON RUNOFF PREDICTION IN OGBESE RIVER WATERSHED

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ABSTRACT

Land use and land cover (LULC) changes in Ogbese watershed due to urbanization implies increased areas of low infiltration. This will result to higher flow rates downstream the watershed. Flood investigations studies have been limited to present LULC state without consideration of future LULC scenarios impact to the river runoff. This study estimates the changes in peak flow rates at the watershed's outlet for present and future LULC. Rainfall-runoff simulation was achieved with Hydrologic Engineering Centre-Hydrologic Modeling System (HEC-HMS) version 4.2 while future LULC was projected with Markov Chain model. Rainfall inputs to the hydrologic model were obtained from intensity-duration-frequency curves for Ondo state. Landsat 7, Enhanced Thematic mapper plus (ETM+) image and Landsat 8 operational land imager (OLI) with path 190 and row 2 were used to generate LULC images for the years 2002, 2015 and 2019. Six LULC classes were extracted as follows: built up area, bare surface, vegetation, wetland, rock outcrop and waterbody. Future LULC in year 2025 and 2029 were projected with Markov Chain model. The model prediction was verified with Nash Sutcliffe Efficiency index (NSE). NSE value of 0.79 was calculated indicating LULC changes in the watershed were Markovian. Results show that built up area cover in 2019 is projected to increase by 26.1% in 2024 and 39.9% in 2029 and wetland is projected to decrease by 1.2% in 2024 and 2.3% by 2029. Runoff peaks for these LULC projections indicate increase by 0.24% in 2024 and 1.19% in 2029 at the watershed's outlets for 100-year return period rainfall. This study concludes that there will be significant increase in impervious areas by 2024 and 2029 with consequent increase in river peak discharge for 25, 50 and 100 years return period rainfall.

Keywords: Land use and land cover, Markov Chain model, HEC-HMS model, Ogbese river, Watershed

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1. INTRODUCTION

Apart from climate-change, change in LULC is one of the major reasons of rising flood frequency in the world. The more land use is converted to impervious surface, the higher the volume and occurrence of flood. Land cover describes physical and biological cover over the surface of land, including water, vegetation, bare soil and/or artificial structures (Ellis and Pontius Jr., 2006, Fayaz *et al*., 2015). Land use however describes the way that the biophysical characteristics of the land are influenced and the purpose for which the land is used (Turner et al., 1995, Fayaz *et*

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al., 2015). Urbanization is associated with increase in paved areas, rooftops and conversion of forested lands and wetlands to built-up areas. It results in increases of areas with little or no infiltration areas thereby reducing drainage area's capacity to cut back on surface runoff volume and attenuate peak discharge. Changes in LULC have a direct impact on the drainage basin's underlying surface, altering rainfall-runoff processes but also on partitioning among hydrological channels such as interception, evapotranspiration, infiltration, and runoff (Ellis & Pontius Jr. 2006). Increase land use change is the consequences of rapid population growth of cities in developing countries with its negative consequences on the environment (Adegbola *et al*, 2020). There is need therefore to investigate the impact LULC changes - from forested lands and wetlands to built-up area cover - have on the flow regime in the watershed. LULC in the future 2024 and 2029 would be projected based on the trend of change in the past (between 2002 and 2015). Future LULC would be used to generate peak discharges and runoff volume at the outlet of the watershed. Ogbese watershed drains two state capitals (Akure and Ado-Ekiti) that have seen high urbanization rates. Eke *et al,* 2016 showed that built-up areas in Akure metropolis has increased by 294% between 1972 and 2006 from 977.2 hectares to 3852 hectares. They projected a built-up area of 5863 hectares in 2022. In Ado-Ekiti, urban areas have also expanded by 1710 hectares between 1996 and 2006 (Oriye, 2013). There is need to generate peak runoff from the watershed for present and future LULC. In September 2019, towns along the flood plains of Ogbese –Ayede-Ogbese and Idanre - lost properties worth several millions of naira and people rendered homeless to flooding (Esho, 2019). Hydrologic modeling using watershed models are useful techniques for simulating the impact of watershed processes on soil and water resources (USACE, 2000). The Hydrologic Modeling System (HMS), developed by the Hydrologic Engineering Center (HEC) of the United States Army Corps of Engineers (USACE), is a lumped, semi-distributed or distributed software package used to model rainfall-runoff processes in a watershed or region. The HEC-HMS hydrological model would be used in this research. Oleyiblo and Li (2010) investigated the HEC-HMS model's suitability for flood forecasting in China's Misai and Wan'an catchments, confirming its capabilities and usefulness. In this research Markov model was used to predict future LULC based on the trend in the past. Markov model is a robust approach in spatial and temporal dynamic modeling of LULC changes because geographic information systems (GIS) and remote sensing (RS) can be efficiently incorporated (Kamusoko, 2009, Sang, 2010). Cabral and Alexander, (2008) discovered LULC changes inside Natural park of Sintra-Cascais between 1989 and 2000 was Markovian unlike outside the park. Sathees *et al,* 2013 used Markov model and remote sensing to investigate temporal and spatial variability of LULC over a period of eight years (1998-2006). Result of their investigation showed that the spatio-temporal trend were Markovian in behavior. Jinkang *et al.,*(2012) used an integrated modeling system by coupling a distributed hydrologic and a dynamic land-use change model, to examine

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effects of urbanization on annual runoff and flood events of the Qinhuai River watershed in Jiangsu Province, China. HEC-HMS model was used to calculate runoff generation and the integrated Markov Chain and Cellular Automata model (CA-Markov model) was used to develop future land use maps. The simulation results of HEC-HMS model for the various urbanization scenarios indicated that annual runoff, daily peak flow, and flood volume, increased to different degrees due to urban expansion during the study period (1988–2009), and will continue to increase as urban areas increase in the future.

2. MATERIALS AND METHODS

2.1 Description of the study area

The watershed is located between the latitudes of 6°40°°N and 8°00°°N of the equator and longitudes 5°00°°E and 5°40°°E of the Greenwich meridian (see figure 1). The river originates in Ayede-Ekiti, Ekiti State, and flows to Edo State through Ondo State. River Ogbese is a tributary to River Ose and flows downstream for an approximate length of 265km from its source to join it. The elevation of the catchment ranges within the height of 740m to 37m above sea level (low). In central and northern zones of Ondo state, Nigeria, Ogbese River is one of main rivers (Oyelami *et al*., 2013, Akinbile & Olatunji, 2018). Farming and fishing is the major source of income for the people. Cash crops such as cocoa, orange, kolanut and plantain are cultivated in large quantities by large numbers of farmers. Regular rainfall is observed in the months of April to November with the heaviest rainfall occurring in September. A short break is experienced in August. Annual rainfall depth ranges from 1,500 mm to 3500mm. The harmattan period (December-February) has the lowest average daily temperature of 22˚ and the highest average daily temperature of 32˚ is observed in March. The average annual relative humidity for the watershed is 75 percent and rises to 90 percent in rainy season.

Figure 1: Map of the study area

2.2 Data Collection

Rainfall intensities for 25, 50 and 100-years return period were sourced from Intensity-Duration-Frequency Curves for Ondo state in the drainage designer manual (see figure 2). ArcGIS provided representations of topographic and spatial features of the study area. ETM+ and OLI images were used to extract LULC in Ogbese watershed. These were images collected in the years 2002, 2015 and 2017 respectively with path and row 188, 56 and 189, 56. The Administrative map of Nigeria was the source from which the study area, shape file was clipped out. Images had resolution of 30 meters. Satellite images were classified using supervised classification

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method.

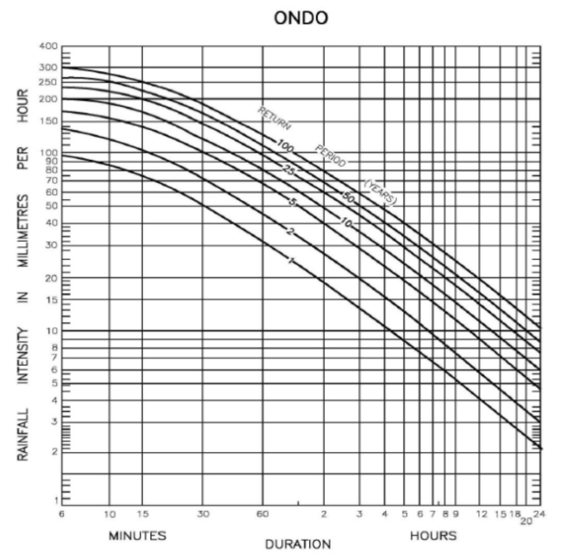

Figure 2: Intensity-Duration-Frequency Curves for Ondo [Source: Drainage Design Manual volume IV, 2013]

2.3 HEC-HMS Hydrologic model

HEC-HMS requires three input components: (i) a basin component, which describes the different elements of the hydrologic system (sub-basins, channels, junctions, sources, sinks, reservoirs and diversions) including their hydrologic parameters and topology, (ii) a meteorologic component, which describes space and time, of the rainfall event to be simulated, and consists of time series of rainfall at specific points or areas and their relation to the hydrologic elements, (iii) control specifications component, which defines the time window for the rainfall event and for the calculated flow hydrograph (Francisco and Maidment, 1999; USACE, 2000).

Rainfall excess and antecedent moisture was estimated based on the Soil Conservation Service (SCS) Curve Number (CN) which is a function of cumulative rainfall, soil types, antecedent moisture and LULC. The equation for the SCS CN is as in (1,2 and 3) (Knebl *et al.*, 2005):

$$Q = \frac{(P-I_a)(P-I_a)}{P-I_a+S} \quad (1)$$

$$I_a = 0.2\,S \quad (2)$$

P(t) is the accumulated rainfall, and I_a is the initial abstraction before ponding, the maximum amount of rainfall that can be retained on the surface before runoff occurs. *S* is the potential maximum retention, which measures the ability of a watershed to abstract and retain storm precipitation. The runoff will be zero unless the accumulated rainfall exceeds the initial abstraction. The potential maximum retention *S* is defined as:

$$S = \frac{2540}{CN} - 25.4 \quad (3)$$

Where CN is curve number. The cumulative runoff, *Q(t)* at time *t* is shown in the equation 4 below (USACE, 2000; Knebl *et al.*, 2005):

$$Q(t) = \frac{(P-0.2S)^2}{P+0.8S} \text{ For } p > I_A = 0.2S \quad (4)$$

The SCS Unit Hydrograph (UH) in the HEC-HMS model would be used in this research for transformation of excess rainfall to direct runoff across the watershed. The basic notion of UH is the linearity of the runoff process, so the runoff from greater or less than one unit is simply a multiple of the unit runoff hydrograph. The SCS UH method states that the peak and time of UH are expressed by the following (USACE, 2000):

$$U_p = C\frac{A}{Tp} \quad (5)$$

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where A is the watershed area, and C is the conversion constant (2.08 in *SI*). The time of peak which represents the duration of the unit of excess precipitation is calculated as:

$$T_p = \frac{\Delta t}{2} + t_{lag} \quad (6)$$

where Δt is the excess rainfall duration and t_(lag) is the basin lag or the time difference between the centre of mass of rainfall excess and the peak of the UH.

$$P = P_{ij} = \begin{vmatrix} P_{11} & P_{12} & \cdots & P_{1n} \\ P_{21} & P_{22} & \cdots & P_{2n} \\ P_{31} & P_{32} & \cdots & P_{3n} \\ P_{41} & P_{42} & \cdots & P_{4n} \end{vmatrix} \quad (7)$$

where P means probability from one state to another state (in this case state i to j). Equation (7) must meet the following two conditions:

$$\sum_{j=i}^{n} P_{ij} = 1 \quad (8)$$

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

Obtaining a primary matrix and transition probability matrix (P_{ij}) is a major step in Markov model. Hence, the Markov forecast model is expressed as stated in equation (9).

$$P_n = P_{(n-1)} \; P_{ij} = P_{(0)} P_{ij}^{n} \quad (9)$$

where $P_{(n)}$ represent the state probability while $P_{(0)}$ represents primary matrix.

2.5 Validation/Testing the Model

The accuracy of the Markov chain model was verified using the observed LULC values for 2019. The predicted LULC for 2019 was compared with the observed 2019 LULC data using Nash Sutcliffe efficiency index (E_f) (Ref). The Nash Sutcliffe efficiency index NSE using equation 10.

$$\text{NSE} = 1 - \left\{ \frac{\sum_{i=1}^{n} \left(Y_i^{obs} - Y_i^{sim}\right)^2}{\sum_{i=1}^{n} \left(Y_i^{obs} - Y_i^{mean}\right)^2} \right\} \quad (10)$$

where Y_i^{obs} is the i_{th} observation for the component being assessed

Y_i^{sim} is the i_{th} simulated value for the component being assessed

Y^{mean} is the mean of the observed data for the component being assessed,

n is the total number of observations.

Nash and Sutcliffe index values ranges between 1 and ∞. Interpreting, 1 is a perfect fit while a value below 0 shows that the average of the observed time series has a better predictor than the developed model (Krause *et al.,* 2005).

3. RESULTS AND DISCUSSION

3.1 Predictions for different LULC Classifications

3.1.2 Primary Matrix for Ogbese River Watershed

The primary matrix was based on area cover of different LULC types from the Landsat images. LULC maps for years 2002, 2015 and 2019 are shown in figures 3-5. The areas of the LULC for years 2002, 2015 and 2019 are also shown in Table 1. The primary matrix becomes P(o)= [52.81, 4.06, 1111.24, 691.77, 142.3, 0.21].

3.1.3 Matrix of Transition Probability for Ogbese Watershed

Transition probability is the rate of transition from one state to another within a given period. It is determined as the annual average rate of transition of a certain LULC classification to another. Table 2 shows

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Table 1: LULC area cover for years 2002, 2015 to 2019

	Area (km^2)		
LULC	**2002**	**2015**	**2019**
Built Up	15.58	52.81	78.14
Bare Surface	0.71	4.06	4.09
Vegetation	738.48	1111.24	1124.01
Wetland	974.40	691.77	597.6
Rock Outcrop	273.14	142.35	142.17
Water Body	0.15	0.21	0.17

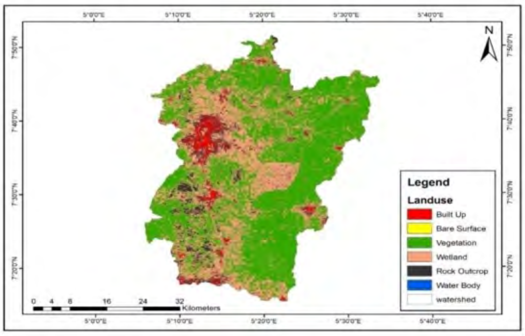

Figure 4: LULC classifications of Ogbese watershed for year 201

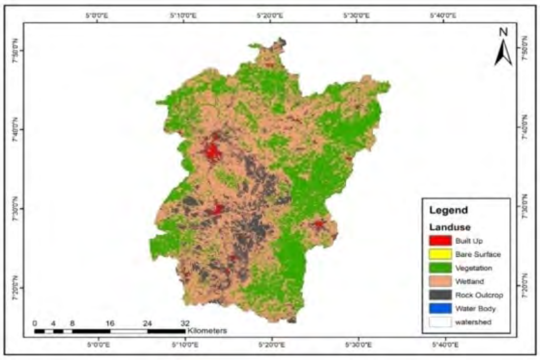

Figure 3:LULC classifications of Ogbese watershed for year 2002

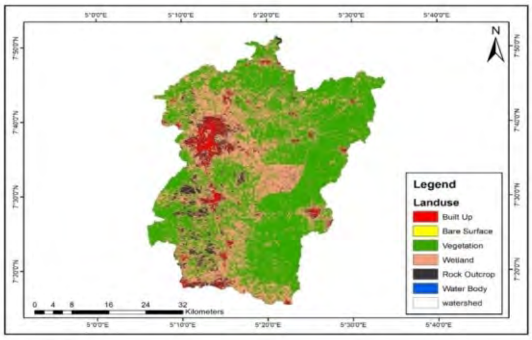

Figure 5: LULC classifications of Ogbese watershed for year 2019

transition matrix for six LULC classifications with areas in square kilometers. Using equation 8, that is $\sum_{j=i}^{n} P_{ij} = 1$, the transition probability of a LULC classification in 2019 converted into LULC classification in 2029 and 2039 was determined. Tables 3 and 4 show the primary transition probability matrix of six land use types during years 2015 - 2024 and 2015 - 2029. As shown in tables 3 and 4 wetlands have 1.7% and 2.8% probability of conversion to built-up areas in 2024 and 2029 respectively while rock outcrops have 5.6% and 7.9% chance of being converted to built-up area in 2024 and 2029 respectively.

3.1.4 LULC prediction

The prediction of future LULC types in 2024 and 2029 was analyzed using Markov chain analysis. Figures 6-8 are projected digitized LULC maps of Ogbese watershed for future scenarios. Presented in Table 5 is the result of the past and projected LULC. The result was converted into percentage as presented in Table 6.

Table 5 and 6 indicate there are changes LULC classifications considered in this study. It is obvious in the above tables that the built-up areas would increase from 4.35% to 5.46% of the watershed area between 2019 and 2024 thereby increasing the impervious areas in the watershed. Wetland area cover would decrease from 47.70% to 46.62% between 2019 and 2029 pointing to the decrease watershed's runoff detention capacity. These two LULC classification changes would

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Table 2: Transition Matrix 2015-2019

2015 \ 2019	Built Up	Bare surface	Vegetation	Wetland	Rock Outcrop	Water Body
Built Up	0.9717	0.0198	0	0	0.0085	0
Bare surface	0.3092	0.4089	0	0.2819	0	0
Vegetation.	0	0	0.9302	0.0698	0	0
Wetland	0.0054	0	0.1025	0.8277	0.0645	0
Rock Outcrop	0.0339	0.0056	0	0.5237	0.4367	0.0001
Water Body	0	0	0.0004	0	0.0045	0.9951

Table 3: Transition Matrix 2015-2024

2015 \ 2024	Built Up	Bare surface	Vegetation	Wetland	Rock Outcrop	Water Body
Built Up	0.9434	0.0334	0	0.007	0.0162	0
Bare surface	0.3714	0.3239	0	0.2997	0.005	0
Vegetation.	0	0	0.8711	0.1289	0	0
Wetland	0.0171	0.0002	0.1601	0.7585	0.0641	0
Rock Outcrop	0.0558	0.0064	0	0.5818	0.3557	0. 0000
Water Body	0	0	0.0006	0	0.0266	0.9728

Table 4: Transition Matrix 2015-2029

2015 \ 2029	Built Up	Bare surface	Vegetation	Wetland	Rock Outcrop	Water Body
Built Up	0.9163	0.0369	0	0.0273	0.0195	0
Bare surface	0.4249	0.2495	0	0.3109	0.0146	0
Vegetation.	0	0	0.8173	0.1791	0.0036	0
Wetland	0.0281	0.0009	0.2116	0.6962	0.0632	0
Rock Outcrop	0.0793	0.0072	0	0.6288	0.2845	0.0002
Water Body	0	0	0	0.0021	0.047	0.9509

Table 5: Past and Predicted LULC

	Areas (km^2)					
LULC	**2002**	**2015**	**2019****	**2019***	**2024**	**2029**
Built Up	15.58	52.81	78.14	87.02	98.54	109.34
Bare Surface	0.71	4.06	4.09	3.07	2.80	2.56
Vegetation	738.48	1111.24	1124.01	827.87	827.87	827.87
Wetland	974.40	691.77	597.60	955.31	944.07	933.51
Rock Outcrop	273.14	142.35	142.17	129.07	129.07	129.07
Water Body	0.15	0.21	0.17	0.24	0.24	0.24

Values obtained from satellite **Value predicted by the model. The two values were used to verify the model before predicting for 2024 and 2029 using equation 10.

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Table 6: Percentage Representation of Past and Predicted LU and LC

LULC	**Areas (%)**				
	2002	**2015**	**2019**	**2024**	**2029**
Built Up	0.78	2.64	4.35	4.92	5.46
Bare Surface	0.04	0.20	0.15	0.14	0.13
Vegetation	36.88	55.49	41.34	41.34	41.34
Wetland	48.66	34.55	47.70	47.14	46.62
Rock Outcrop	13.64	7.11	6.45	6.45	6.44
Water body	0	0.01	0.01	0.01	0.01

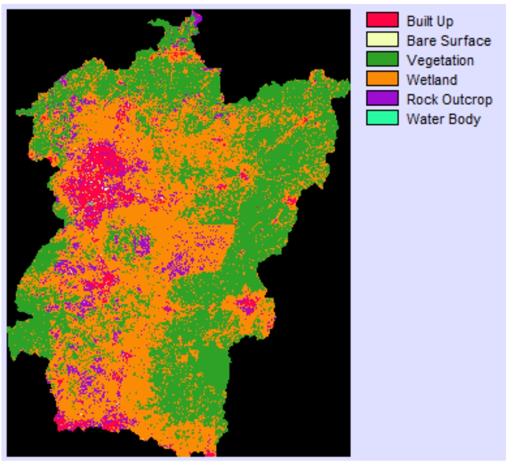

Figure 6: LULC Map of Ogbese watershed (Predicted 2019)

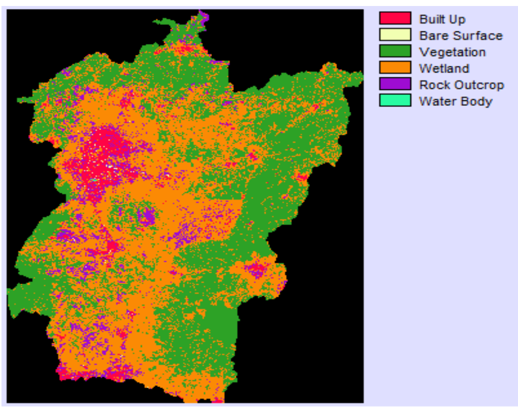

Figure 7: LULC Map of Ogbese watershed (Predicted 2024)

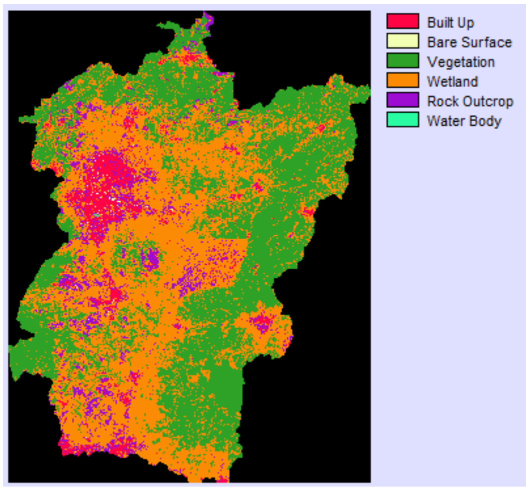

Figure 8: LULC Map of Ogbese watershed (Predicted 2029)

combine to increase runoff peak discharge values.

3.2 Increases in CN Parameter Values and runoff simulation

The CN parameter values for Ogbese watershed increased from 89.45 to 89.81 as shown in Table 7 below. CN values range from 30 to 100 with lower values indicating low runoff potential while larger values imply increased runoff potential (Ponce and Hawkins, 1996). Applying the new value of

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CN in 2024, the runoff hydrograph for the predicted LULC is shown in figure 8, 9 and 10. Also applying the new value of CN in 2029, the runoff hydrograph for the predicted LULC is shown in figure 11,12 and 13. Table 8 lists the runoff peaks and volumes in the present and projected years. CN parameter values increased from 89.45 in 2019 to 89.73 and 89.81 in 2024 and 2029. Peak discharge values projected at the outlet of the watershed for 25, 50 and 100-years return period rainfall are 354.4m^3/s, 837.6m^3/s and 1012.5m^3/s in 2024, and 362.1m^3/s, 848.6m^3/s and 1021.7m^3/s in 2029. Runoff volumes for projected LULC 2024 and 2029 for 25, 50 and 100-years return period are 140,446.4 m^3, 572, 278.7 m^{3}and 748,151.2 m^3, and 142,448.1 m^3, 574,280.1 m^3 and 749,159.7 m^3 respectively. The above results indicate there would be increase in peak discharge and runoff volumes as LULC changes with increase of built up areas and decrease of wetlands.

4. CONCLUSION

It was established in this study that LULC changes in Ogbese watershed is Markovian as model verification has good NSE values of 0.79. LULC changes showed increase in built-up area cover and decrease wetland. Built-up area cover was projected to increase from 87.02 km^{2}in 2019 to 98.52 km^{2}and 109.34 km^2 in 2024 and 2029 respectively. Wetland area cover was projected to decrease from 955.31 km^2 in 2019 to 944.07 km^{2}and 933.51 km^2 in 2024 and 2029 respectively. CN parameter values increased from 89.45 in 2019 to 89.73 and 89.81 in 2024 and 2029. Runoff peaks for these LULC projections indicate increase by

Table 7:SCS CN Value for Predicted Land Use/ Land Cover Scenarios

YEAR 2019		YEAR 2024		YEAR 2029	
CN Value	Built-up%	CN Value	Built-up%	CN Value	Built-up%
89.45	4.26	89.73	4.82	89.81	5.35

Table 8**:** Different Peak Discharges for Different Occurrence Intervals

YEARS	PEAK DISCHARGE (m^3/s)			VOLUME (1000m^3)		
	25 – years period	50 - years period	100 - years period	25 -years period	50 -years period	100 -years period
2019	352.5	835.2	1009.7	139,447.1	570,749.8	746,817.4
2024	354.1	837.1	1012.1	140,446.4	572,278.7	748,151.2
2029	362.1	848.6	1021.7	142,448.1	574,280.1	749,153.7

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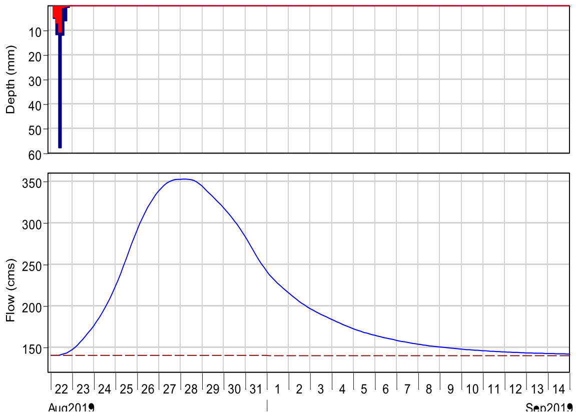

Figure 9: Simulated hydrograph of 25-years return period rainfall for the year 2024

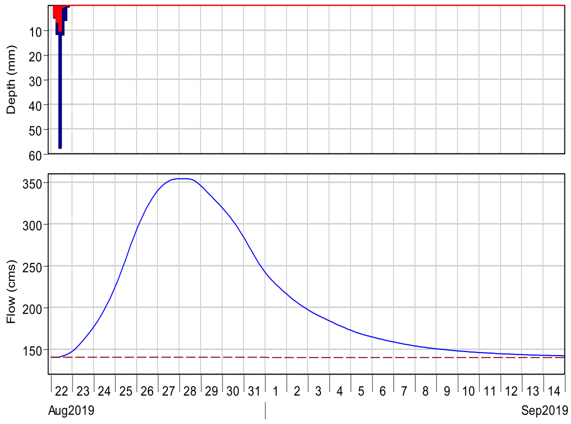

Figure 10: Simulated hydrograph of 25-years return period rainfall for the year 2029

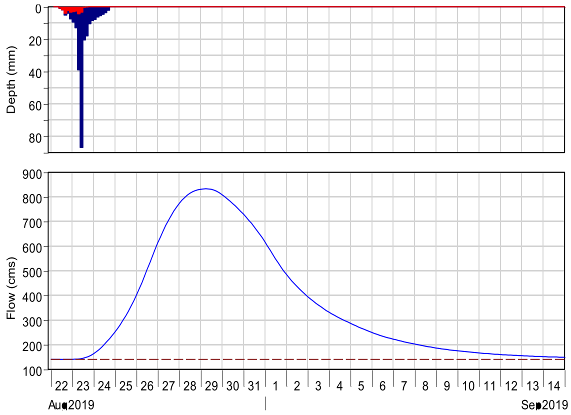

Figure 11: Simulated hydrograph of 50-years return period rainfall for the year 2024

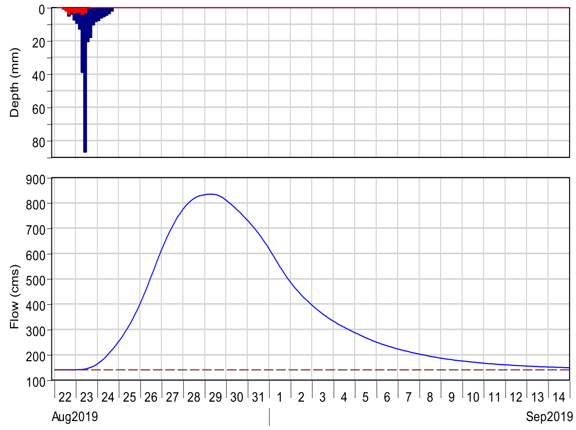

Figure 12: Simulated hydrograph of 50-years return period rainfall for the year 2029

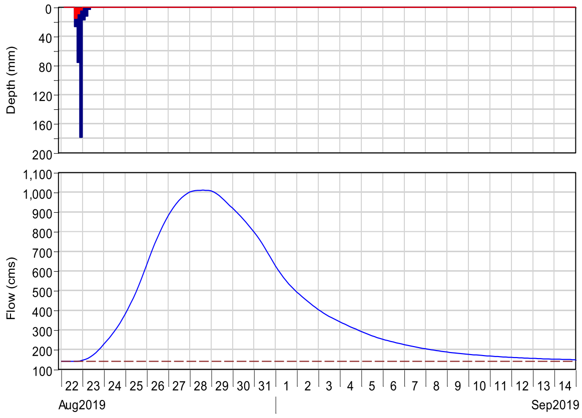

Figure 13: Simulated hydrograph of 100-years return period rainfall for the year 2024

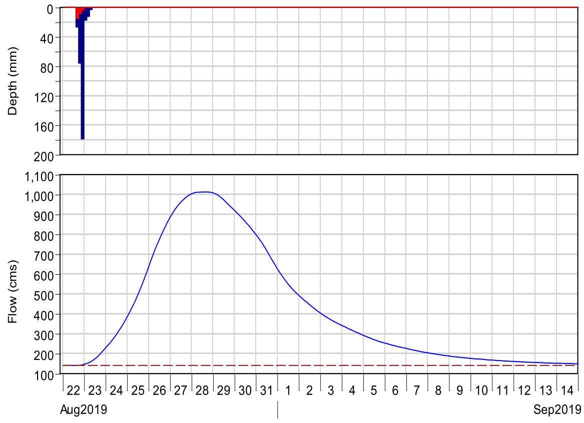

Figure 14: Simulated hydrograph of 100-years return period rainfall for the year 2024

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0.24% in 2024 and 1.19% in 2029 at the watershed's outlets for 100-year return period rainfall.

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