

Research Article

Assessment of the effect of land use /land cover changes on total runoff from Ofu River catchment in Nigeria

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Received 29 December 2017, Accepted 27 February 2018

Abstract : The total runoff from a catchment is dependent on both the soil characteristics and the land use/land cover (LULC) type. This study was conducted to examine the effect of changes in land cover on the total runoff from Ofu River Catchment in Nigeria. Classified Landsat imageries of 1987, 2001 and 2016 in combination with the soil map extracted from the Digital Soil Map of the World was used to estimate the runoff curve number for 1987, 2001 and 2016. The runoff depth for 35 years daily rainfall data was estimated using Natural Resource Conservation Services Curve Number (NRCS-CN) method. The runoff depths obtained for the respective years were subjected to a one-way analysis of variance at 95% level of significance. P-value < 0.05 was taken as statistically significant. Runoff curve numbers obtained for 1987, 2001 and 2016 were 61.83, 63.26 and 62.79 respectively. The effects of the changes in LULC for 1987-2001, 2001-2016 and 1987-2016 were statistically significant (P<0.001) at 95% confident interval. The average change in runoff depths were 79.81% -11.10% and 48.09% respectively for 1987-2001, 2001-2016 and 1987-2016. The study concluded that the changes in LULC of the catchment had significant effect on the runoff from the catchment.

Keywords: *curve number, LULC, Ofu River catchment, runoff, soil type*

To cite this article: Alfa, M.I., Ajibike, M.A., Adie, D.B. and Mudiare, O.J. 2018. Assessment of the effect of land use /land cover changes on total runoff from Ofu River catchment in Nigeria. *J. Degrade. Min. Land Manage.* 5(3): 1161-1169, DOI: 10.15243/jdmlm. 2018.053.1161.

Introduction

Runoff refers to that part of precipitation which is drained from land after all losses such as groundwater and evaporation and makes its way towards the river, stream or ocean (Patra, 2008; Suresh, 2008; Mustafa and Yusuf, 2012). Among other factors, land use/ land cover type has been identified as one of the major factors that could affect the amount of precipitation that ends up as runoff (Patra, 2008). Land use degradation can significantly affect infiltration and surface roughness which could lead to higher flood discharges (Saghafian et al., 2008). In as much as weather and climate are the major determinants of flood, land cover changes can also influence the occurrence and frequency of floods by changing

the responsiveness of river flows to rainfall (Solín et al., 2011). The assessment of land use/ land cover changes is therefore very important in catchment flood studies. Ofu River catchment in Nigeria has a very long history of being flooded which among other factors may not be unconnected with the consistent land use changes primarily due to urbanization in the area. A holistic understanding of the factors responsible for this menace will require an investigation into the role this land use changes play in the runoff to receiving water bodies. This knowledge will contribute to the management of the flood menace within the catchment. Notwithstanding the importance of this investigation, none has been carried out in the present study area to the best of

our knowledge. This is therefore the motivation behind the present study aimed at assessing the effect of land use/land cover changes on the runoff from the catchment.

Materials and Methods

Study Area

Ofu River catchment lies between latitudes 6° 46' N and 7° 39' N and longitudes 6° 42' E and 7° 21' E (Figure 1) covering parts of Dekina, Ofu, Igalamela/Odolu, Idah and Ibaji Local

Government Areas in Kogi State and Uzo-Uwani Local Government Area in Enugu State, Nigeria, within the humid tropical rain forest of Nigeria (Alfa, 2017). The study area falls within the Lower Benue River Basin Development Authority in North Central Nigeria. Figure 1 shows the Map of Nigeria showing the study area. The study area is characterized by a tropical sub-humid climate with a fairly wide seasonal/ diurnal range of Temperature. Rainfall within the catchment is concentrated in one season lasting from April/May to September/October.

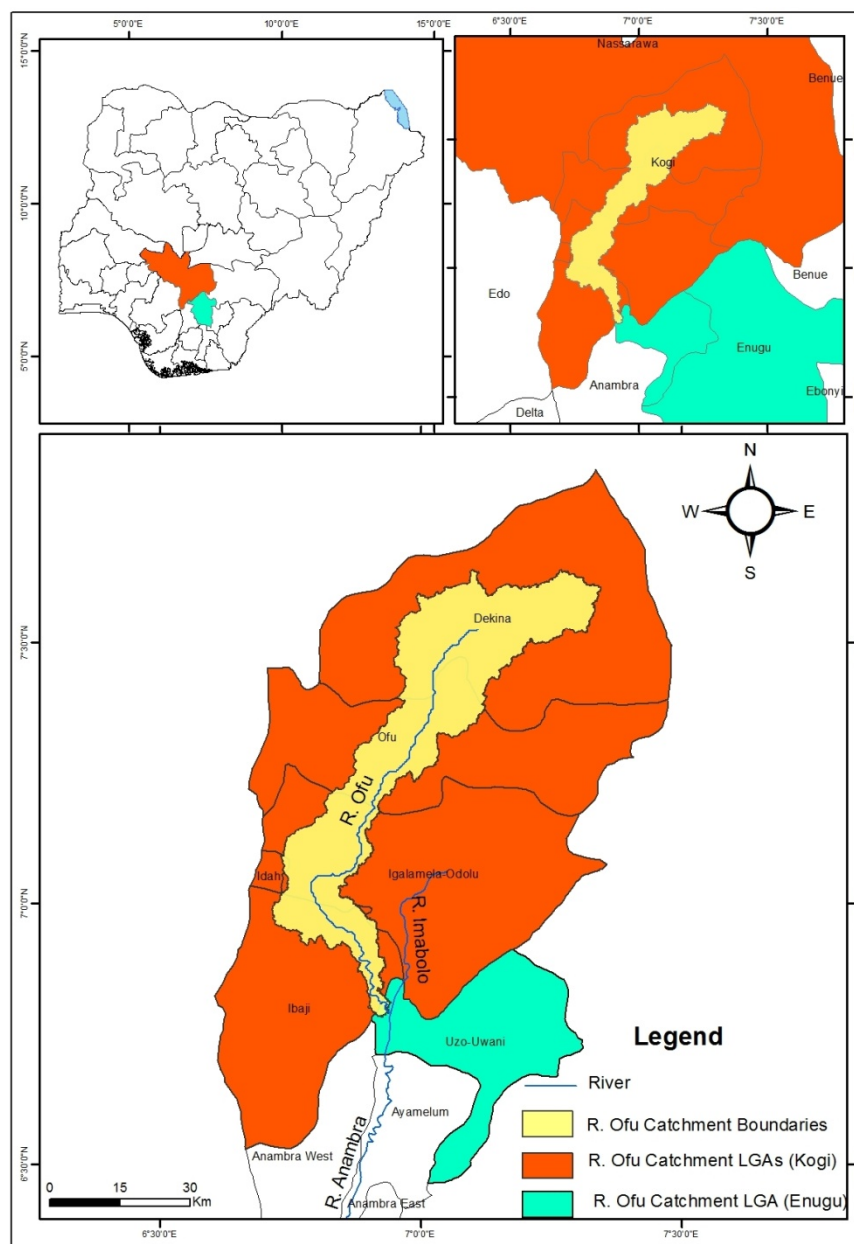


Figure 1. Map of study area

Source: Adapted from the Administrative Map of Nigeria, LOC (n.d); www.nationsonline.org

The overall climatic characteristics of the area are generally determined by the Inter Tropical Convergence Zone (ITCZ) and air mass movements. Climatologically, the study area falls within the tropical continental north region (AR-AR, 2004). Ofu River catchment is underlined by cretaceous sediments. Basement complex rocks, mainly granites and granitic gneisses are found at the upstream of the River the outcrops of which appears to be scarce or absent (AR-AR, 2004).

Data Collection and preparation

The datasets used in the study are the soil map and satellite imageries for 1987, 2001 and 2016. The soil map was extracted from the Digital Soil Map of the World (DSMW) obtained from (<http://www.fao.org/geonetwork/srv/en/metadata.s how?id=14116>). The soil types, area covered and hydrological soil group (HSG) for the extracted soil map (Figure 2) are presented in Table 1.

Table 1: Characteristics of soil within Ofu River catchment

SMU	FAO Soil Symbol	Area (km ²)	Name	Textured Class	HSG
1021	Af13-1a	975.61	Ferric Acrisols	Sandy loam	A
1567	Nd5-1a	259.77	Dystric Nitosols	Loam	B
1193	G2-2/3a	366.61	Gleysols	Clay Loam	D
677	Jd3-2a	2.59	Calcaric Fluvisols	Sandy Clay Loam	C

Source: extracted from DSMW (www.fao.org)

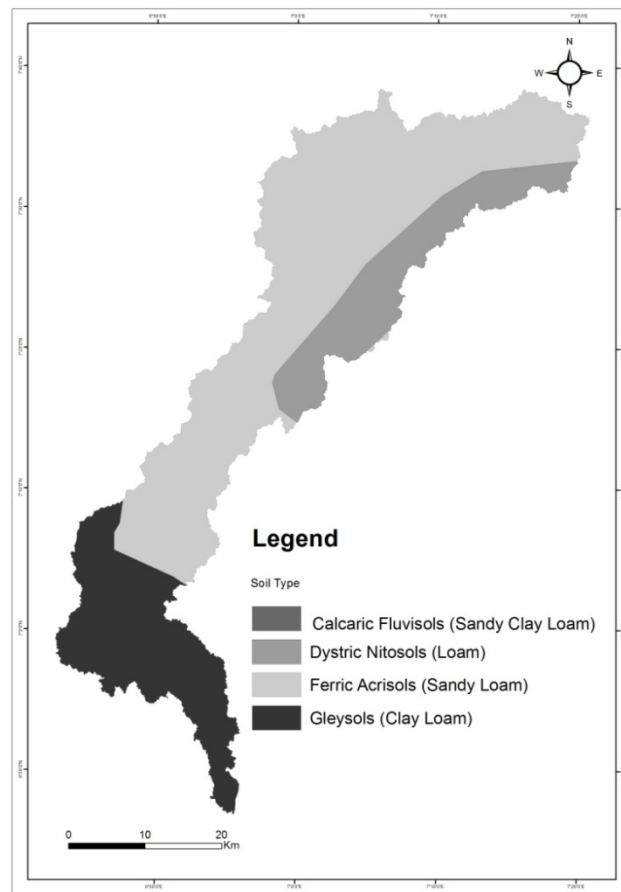


Figure 2. Soil Map of study area extracted from DSMW

The land cover was extracted from Landsat 5 imagery of January 11, 1987, Landsat 7 Imagery of January 9, 2001 and Landsat 8 Imagery of March 15, 2016 respectively obtained from <https://glovis.usgs.gov>. The imageries were

atmospherically corrected since the spectral reflectance was the vital component for their classification. The rainfall data used for this study were obtained from the radar data available on http://www.waterbase.org/download_data.html.

They consist of data from 41 stations surrounding the study area. The data covered a 35-year period from January, 1979 to December, 2013. They were respectively plotted in ArcGIS 10.2.2, interpolated using the ordinary kriging method and the surface raster for the study area extracted. The average precipitation in mm for the respective daily rasters were estimated and used for the assessment.

Image classification

The Band composites (Mausel et al., 1990) were created for the respective imageries using the *image analysis* extension in ArcGIS 10.2.2 after which the *extraction spatial analyst* tool was used to subset the image to the study area. The Normalized Difference Vegetative Index (NDVI) (Pettorelli et al., 2005; Anyamba and Tucker (2005) and the Normalized Difference Built-up Index (NDBI) (Li et al., 2009; Varshney, 2013) were respectively calculated for each year to show the extent of vegetative covers and built-up areas. The NDVI and NDBI were both derived using the *Raster Calculator* in *Spatial Analyst Map Algebra* toolbox in ArcGIS 10.2.2 using (1) and (2)

respectively. The details of the bands used for the generation of the indices are shown Table 2.

$$NDVI = \frac{NIR - R}{NIR + R} \quad (1)$$

$$NDBI = \frac{SWIR - NIR}{SWIR + NIR} \quad (2)$$

The NDVI and NDBI obtained for 1987, 2001 and 2016 are shown in Figures 3 and 4. The generation of these indices helped in the creation of training signatures for the Maximum likelihood supervised classification of the imageries. This served as an accuracy check for the classified Land use/Land covers. In addition, an Iso Cluster unsupervised classification was performed in order to have an idea of the maximum number of distinct classes and a general overview of the area which was followed by the maximum likelihood supervised classification for the final land cover classes for 1987, 2001 and 2016 (Rozenstein and Karnieli, 2011; Su et al., 2011). Ground truthing was embarked upon after the classification of the imageries so as to reaffirm the land use /land cover classes for the 2016 imagery.

Table 2: Band characteristics for NDVI and NDBI calculation for Ofu River catchment

Year	Satellite	Sensor	Red	NIR	SWIR
1987	Landsat 5	TM	Band 3	Band 4	Band 5
2001	Landsat 7	ETM+	Band 3	Band 4	Band 7
2016	Landsat 8	ETM+	Band 4	Band 5	Band 7

Source: <https://glovis.usgs.gov>

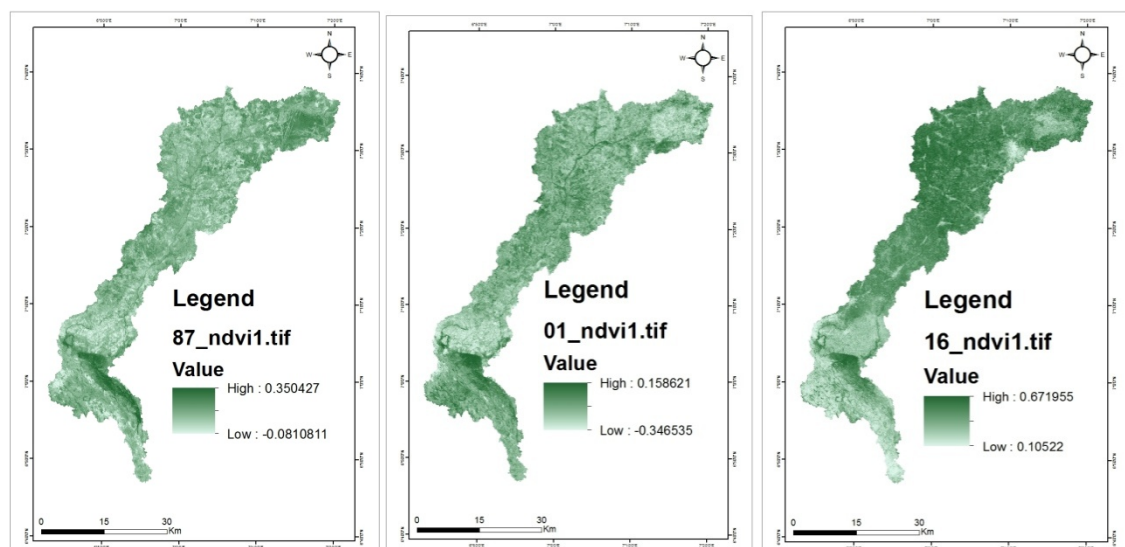


Figure 3. Normalized difference vegetation index of Ofu River catchment for 1987, 2001 and 2016 respectively

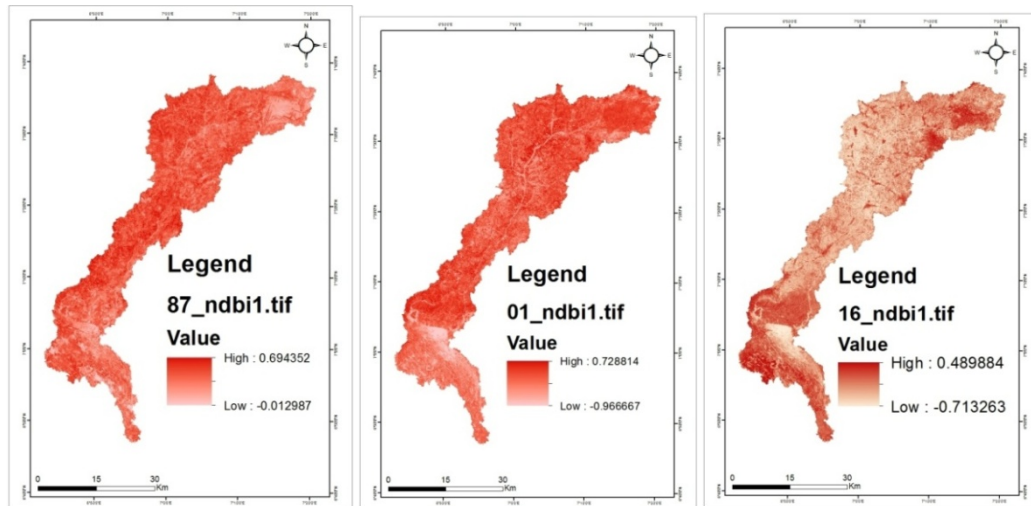


Figure 4. Normalized difference built-up index of Ofu River catchment for 1987, 2001 and 2016 respectively

Estimation of curve number

The Curve Numbers for all the Hydrologic Soil Groups (HSG) A, B, C and D corresponding to the various land cover classes were obtained from the tables in TR-55 (1986). The Composite Curve number for the respective hydrologic soil group, CN_h was calculated using (3).

$$CN_h = \frac{\sum_{i=1}^n A_i CN_i}{\sum_{i=1}^n A_i} \quad (3)$$

Where A_i = Area of land cover class i , CN_i = Curve number for land cover i and h = HSG.

The values of CN obtained for the respective HSG were used to compute the composite CN for the catchment based on the soil classes and their corresponding HSG and CN. The composite CN for the Catchment was computed using (4).

$$CN = \frac{\sum_{j=1}^n A_j CN_j}{\sum_{j=1}^n A_j} \quad (4)$$

Where A_j = Area of soil class j , CN_j = Curve number for HSG/Soil class j

Estimation of runoff depths

The Natural Resource Conservation Services (NRCS) Curve number method was used to estimate the daily runoff from the Catchment. The method described in the TR-55 (1986) was adopted for the estimation of runoff depth using the rainfall values. The first step was the estimation of the storage, S using (5). The storage is a function of the catchment runoff curve number. The initial abstraction, I_a which is a function of the storage, S was calculated using (6)

assuming AMC II condition while the runoff depth was calculated using (7).

$$S = \frac{25400}{CN} - 254 \quad (5)$$

$$I_a = 0.2S \quad (6)$$

$$Q = \frac{(P - I_a)^2}{\{(P - I_a) + S\}} \quad (P \geq I_a \text{ else } Q = 0) \quad (7)$$

Where P is the precipitation.

The process was used to estimate runoff depths for 1987, 2001 and 2016.

Statistical analysis

Student's t-test statistics was used to compare the runoff depths of 1987 with 2001, 2001 with 2016 and 1987 with 2016 at 95% level of significance. A P -value < 0.05 was accepted as statistically significant. More so, the average percentage changes in the runoff depths between 1987-2001, 2001-2016 and 1987-2016 were also estimated and used to buttress the results of the statistical analysis.

Results and Discussion

Land use/Land cover changes within Ofu River catchment

The classified LULC for 1987, 2001 and 2016 for Ofu River catchment are presented in Figure 5. Three distinct LULC classes (Built Up, Vegetation and Bare Surfaces) were identified and classified accordingly. The respective areas covered by different classes on the other hand are presented in Figure 6.

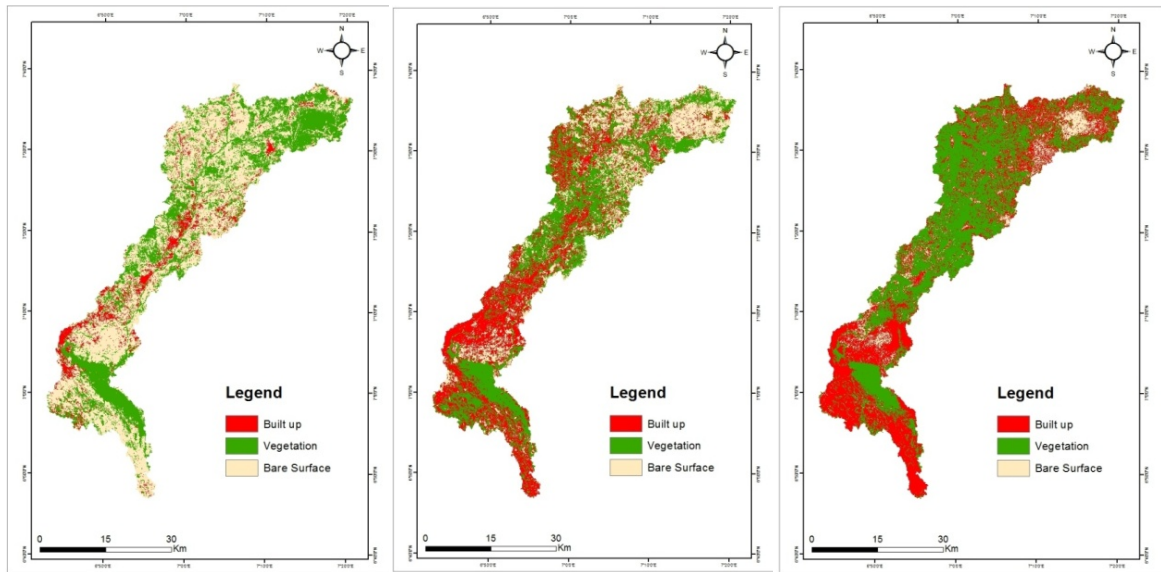


Figure 5. Ofu River catchment land use/land cover classifications for 1987, 2001 and 2016

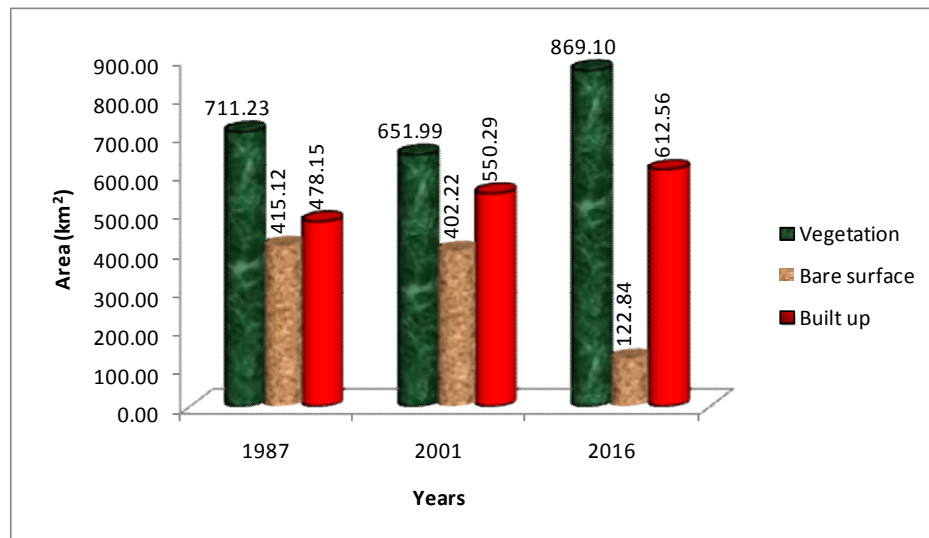


Figure 6. Area of each land cover class (km²)

The results show that vegetation covered a land area of 711.23 km² (44.33 %), 651.99 km² (40.64 %) and 869.10 km² (54.17 %) in 1987, 2001 and 2016, respectively. Meanwhile, the bare surface area was 415.12 km² (25.87 %), 402.22 km² (25.07 %) and 122.84 km² (7.66 %) in 1987, 2001 and 2016, respectively. Finally, the built up areas were 478.15 km² (29.80 %), 550.29 km² (34.30 %) and 612.56 km² (38.18 %) in 1987, 2001 and 2016, respectively. Furthermore, the LULC changes for Ofu River catchment are presented in Figure 7. The results show that the land area covered by vegetation reduced by 8.3 % between 1987 and 2001 but suddenly increased by 33.3 % between 2001 and 2016. This probably could be a function of the date of acquisitions of the

respective satellite imageries. The Imageries for 1987 and 2001 were acquired in January while that of 2016 was acquired in March. The imageries used for the respective years were the ones with minimal cloud cover to allow for easy classification. The monthly rainfall characteristics of the catchment shown in Figure 8 reveal that January is actually the lowest rainfall month with an average monthly rainfall of 4.70 mm while March has slightly higher average monthly rainfall of 41.49 mm which is usually the beginning of the rainy season. This implies that a part of the vegetations in 1987 and 2001 would have been so dry and unhealthy that the maximum likelihood may interpret them as bare surfaces while that of 2016 obtained at the onset of the

rainy season would appear healthy and rightly interpreted as vegetation. This probably explains the vegetation trend mentioned earlier. Meanwhile the change in vegetation between 1987 and 2016 was found to be 22.2 %. The change in bare surface area showed a downward trend. There was a 3.1 % reduction from 1987 to 2001 and 69.5 %

reduction from 2001 to 2016. The change in bare surface area from 1987 to 2016 was 70.4 %. This confirms the explanation given earlier for the vegetation trend. The built up areas on the other hand increased continuously between 1987 and 2016 in agreement with urbanization trend.

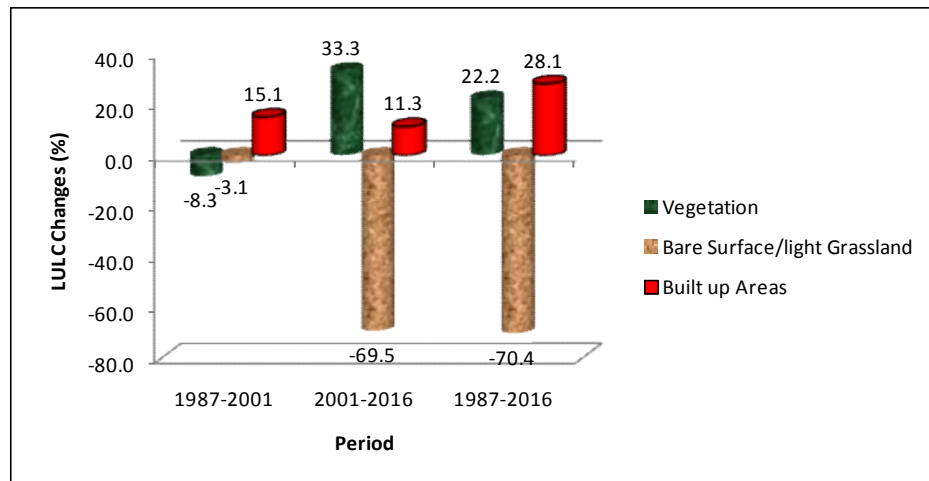


Figure 7. Ofu River catchment LULC changes from 1987 to 2016

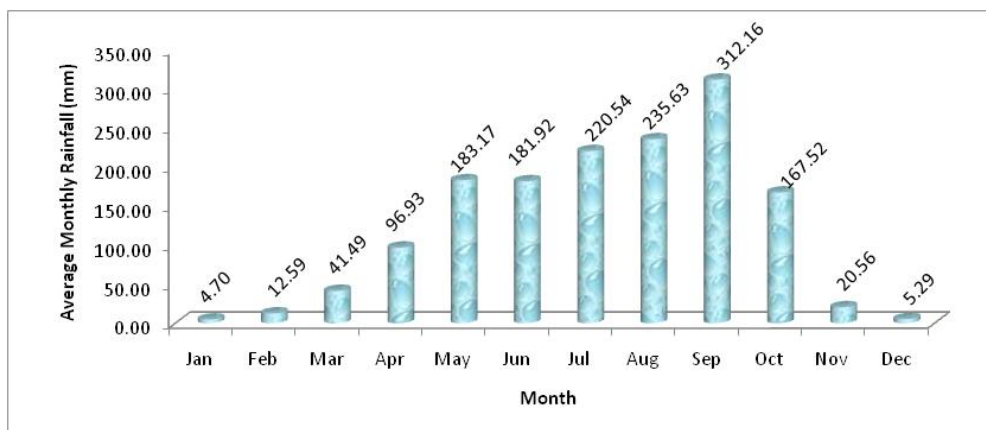


Figure 8. Average monthly rainfall characteristics of Ofu River catchment

Extracted from www.waterbase.org

Runoff depths

The respective runoff curve numbers, catchment storage and initial abstraction for 1987, 2001 and 2016 are presented in Table 3. The runoff depths were estimated using the curve number, storage, and initial abstraction presented in Table 3. The 95% confidence interval plot of the runoff depth (mm) and the mean for 1987, 2001 and 2016 are shown in Figure 9. The results show that there was an increase in the average runoff depth between 1987 and 2001 but a slight drop was observed between 2001 and 2016 which confirms

the LULC trend discussed earlier. The results of the statistical analysis on the other hand are presented in Table 4. The P-value of 0.000 obtained for all the comparisons show that the difference in the runoff depths for the respective years were significant. The significant differences observed in the runoff depths for the respective years, demonstrates that the LULC changes actually has a significant effect on the runoff depth. The average change in runoff depths presented in Table 4 demonstrates that while an average 79.81 % increase in runoff depth was observed between 1987 and 2001, a decrease of

11.10% was observed between 2001 and 2016. On the other hand, an overall increase of 48.09% was recorded between 1987 and 2016. The findings of this study agrees with previous studies on the effects of cover changes as well as other factors

on total runoff from a river catchments (Hernandez et al., 2000; Zimmermann et al., 2006; Franczyk and Chang, 2009; Nunes et al., 2011; Peng and Wang, 2012).

Table 3. Curve number, storage, and initial abstraction for 1987, 2001 and 2016 for Ofu River catchment

Year	Curve Number, CN	Storage, S	Initial Abstraction, I_a
1987	61.83	156.78	31.36
2001	63.26	147.52	29.50
2016	62.79	150.53	30.11

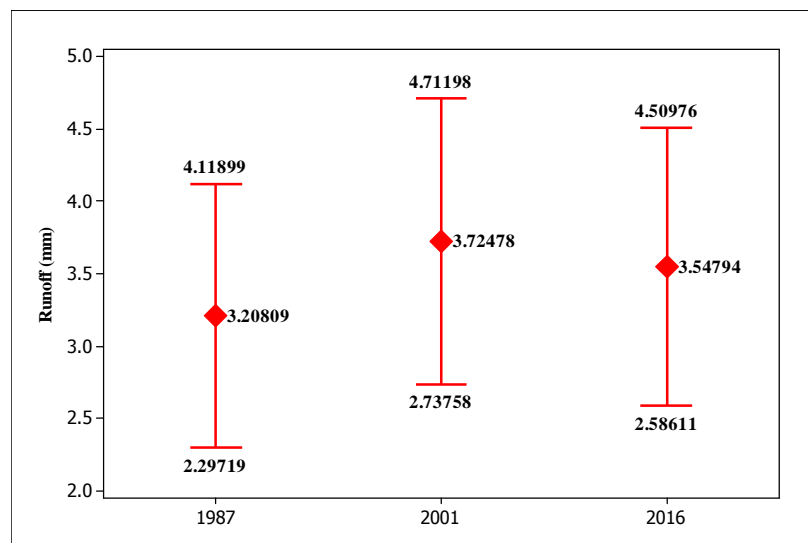


Figure 9. 95% Confidence interval plot of runoff (mm) for 1987, 2001 and 2016.

Table 4. Results of the t-test for the comparison of runoff depths for respective years.

Period	Av. Change (%)	P-value	95% Confidence Interval	Remark
1987-2001	79.81	0.000	-0.597737, -0.435642	Significant Difference
2001-2016	-11.10	0.000	0.149948, 0.203740	Significant Difference
1987-2016	48.09	0.000	-0.393998, -0.285694	Significant Difference

Conclusion

This study has demonstrated that the land use /land cover changes in Ofu River catchment between 1987, 2001 and 2016 has overall effect of 48.09% increase in the total runoff from the catchment. This implies that attention be given to adequate land use pattern in the development of strategies for ameliorating the devastating effect of flood in the study area.

Acknowledgements

Authors hereby acknowledge the contributions of every staff of the Department of Civil Engineering, University of Jos, Nigeria and the Department of Water Resources

and Environmental Engineering, Ahmadu Bello University, Zaria, Nigeria for their immense contribution to the success of this study.

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