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Climate, runoff and landuse trends in the Owo River Catchment in Nigeria

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Abstract. The Owo River is an important surface water source in Lagos particularly to the western section. It is the source of direct water intake for water supply by Lagos State Water Corporation to Amuwo-Odofin, Ojo and parts of Badagry Local Government Areas. This paper examines the complex interactions and feedbacks between many variables and processes within that catchment and analyses the future ability of this semi-urban watershed in sustaining water supply in the face of cumulative environmental change. Stationarity analysis on rainfall, change detection analysis and morphometry analysis were combined to analyse the non-stationarity of Owo River catchment. On rainfall trend analysis, since the correlation coefficient (0.38) with test statistic of 2.17 did not satisfy the test condition we concluded that there is trend and that rainfall in the watershed is not stationary. The dominant land use impacting on the bio-geochemical fluxes is built up area (including structures and paved surfaces) which grew from about 142.92 km^2 (12.20 %) in 1984 to 367.22 km^2 (31.36 %) in 2013 recording gain of 224.3 km^2 at average growth rate of 7.73 km^2 per annum. Total length of streams within the catchment reduced from 622.24 km in 1964 to 556 km in 2010, while stream density reduced from 0.53 in 1964 to 0.47 in 2010 an indication of shrinking hydrological network. The observed trends in both natural and anthropogenic processes indicated non-stationarity of the hydrological fluxes within the Catchment and if this continues, the urban ecosystem services of water supply will be compromised.

1 Introduction

The Owo River is an important surface water source in Lagos particularly to the western section. It is the source of direct water intake for water supply by Lagos State Water Corporation to Amuwo-Odofin, Ojo and parts of Badagry Local Government Areas. The watershed of the Owo River has undergone a number of changes in recent decades. These observed changes can be attributed to both natural and anthropogenic factors including climate change, landuse–landcover changes and urbanization amongst others. The changes have been observed to have impacts on some of the basin morphometric characteristics with concomitant consequences for water resources availability within the watershed. Basin physical properties have direct relationships with water resources availability and any change in stream properties can translate to reduction or increase in water yield and availability (Ojo et al., 2003). Also, high variability of rainfall characteristics is becoming more pronounced, a condition that is impacting seriously on raw water abstraction from Owo River for municipal water supply at Ishashi intake. Urbanization is also impacting on the hydrological response of the catchment, thereby contributing to the non-stationarity or otherwise of the catchment. This paper examines the complex interactions and feedbacks that have brought about changes in hydrological and morphological characteristics of the watershed and analyses the future ability of this semi-urban watershed in sustaining water supply in the face of cumulative environmental change.

2 Study area

Owo River Catchment is one of the watershed south of Ogun River Basin in South Western Nigeria. Its perculiarity can be attributed to its locaton, which is within the Lagos Mainland and it is the main source of water to Ishasi Waterworks. Geographically, it extends between latitudes 6°27′23″ and

6°54′22″, and longitudes 3°16′60″ and 3°4′6″. The major river, "Owo" drains about 12 Local Government Areas, 2 in Ogun State and 10 in Lagos State and has a total length of 71.15 km. It runs through as a tributary of River Ore in Ogun State and ends up in the Ologe Lagoon. River Owo has a safe yield of 28 million gallons per day MGD (127.1 million L per day [MLD]), which translates to a monthly average of about 840 MGD (3813 MLD). The catchment has about 156 settlements and covers about 1170.68 km^2 (Fig. 1). Agricultural activities remain the dominant human activities, although over the years the catchment has witnessed changes due to urbanization. The river supplies raw water to the Isashi Waterworks located at the Oto-Ijanikin Local Council Development Area of Lagos State. The Waterworks was constructed in 1974 jointly by the Federal Government of Nigeria and the Lagos State Government to supply water to the western part of the Lagos metropolis, thus it was designed to serve Amuwo-Odofin, Festac, Ojo, Satellite Town, Ijanikin and other settlements along the axis (Lagos State Water Corporation, LSWC, 2011).

The climate is humid tropical with a mean annual rainfall of about 2721 mm. Mean annual number of rain days is about 170, mean monthly rainfall is about 229 mm and mean annual temperature is about 27.8 °C. The geology of Owo River catchment which is generally described as Ilaro Formation comprises of marine and continental deposits and rocks of sedimentary origin. The vegetation of the catchment is composed of heavy forest, derived forest and intensive riparian forest along the drainage paths. (National Atlas of the Federal Republic of Nigeria, 1978). Figure 1 shows the location of Owo River catchment in Lagos and Ogun States.

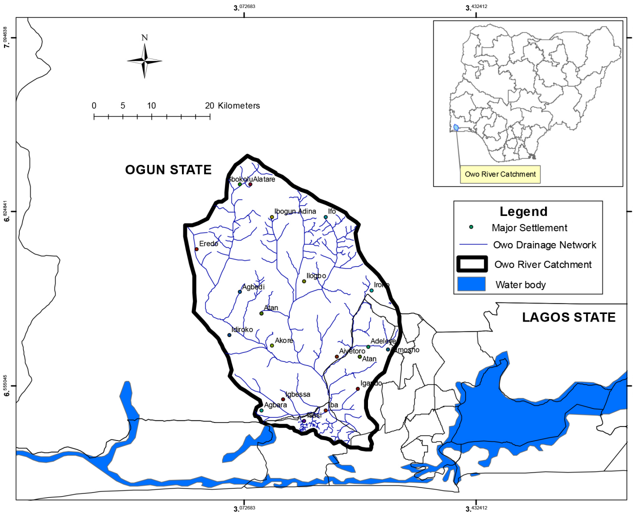

Figure 1. Owo River Catchment.

3 Methodology

Monthly rainfall data (Abeokuta and Lagos stations) for the period 1981–2011 was obtained from the Nigerian Meteorological Agency (NIMET), to establish the non-stationarity of rainfall through various statistical tests including; Spearman's Rank Order Correlation Test to verify the presence or absence of trend in the time series, the Mann–Whitney *U* test to detect if there is a shift in the mean of the rainfall time series (stability of mean) and cumulative deviations or departure test (CUSUM) to check for homogeneity and changes in the underlying mean of the time series (Dahmen and Hall, 1990; Machiwal and Jha, 2012). The freshwater abstraction and supply for years 2004–2011 at the waterworks were examined for temporal variability using *F* test or Fisher distribution and the coefficient of variation (CV). To determine the land use change, pragmatic hierarchical land use classification scheme following Nigeria topographic mapping was adopted. The dataset used for land use mapping is shown in Table 1. The change analysis was conducted on images of 1984, 2000 and 2013. Certain numbers of training datasets were randomly sampled from the spectral signature of each of the classes to define their respective landuse/landcover type.

The change detection analysis was performed using ENVI analytical tool to extract the image difference between the two periods of time. Other analysis carried out includes area calculation of the landuse/landcover change for the three static years (1984, 2000 and 2013). Comparative analysis of morphometric dynamics of the catchment was carried using drainage dataset derived from Nigeria Topographical Map series of 1964 and ASTER-DEM of 30 m spatial resolution of 2010. The topographic sheets that covered the basin were mosaicked, geometrically rectified and georeferenced to World Space Coordinate System. The mosaicked sheets were spatially aligned or adjusted to the Landsat image to maintain spatial accuracy. Thus, the drainage network pattern of 1964 was therefore extracted from the mosaicked topographical sheets. Likewise, using the ArcHydro extension tool of Arc GIS 10.2, the drainage pattern of 2010 from the ASTER-DEM was also extracted for comparative analysis of the morphometric variables. Spatio-temporal morphometric variables were examined between these two sources of drainage network patterns. These include bifurcation ratio, drainage density, stream frequency, drainage intensity and stream length.

4 Results and discussion

4.1 Rainfall non-stationarity

The analysis of annual rainfall data shows the existence of trend in the rainfall time series which is an indication of non-stationarity in a hydro-climatic time series. Although this existence of trend in the hydrologic time series which is an indication of low frequency oscillatory movement cannot be totally explained by local players including land use change

Table 1. Data sources and characteristics.

Data	Year	Instrument	Resolution	Source
LANDSAT TM	1984	Thematic Mapper7,4,2 bands	30 m	
LANDSAT ETM	2000	Enhanced TM-7,4,2 bands	30 m	USGS, glovis.org
LANDSAT 8	2013	OLI-5.3,2 bands	30 m	
Topographic Map	1964	279 NW, SW, NE, NW	1 : 50 000	Federal Survey Lagos
ASTER-DEM	2010	NO6E002, NO6E003	30 m	USGS, earthexplorer.org

at catchment level, they however, do contribute significantly to the micro climate and the dynamics that exist in rainfalls (Kottegoda, 1980). The positive correlation ($R_{sp} = 0.38$) is an indication of upward trend in annual rainfall. Also, the null hypothesis of equal mean is rejected because the test statistic (U_c) was calculated as 86 as against the critical value of (U) equal 70 at 5 % significance level. It was therefore, concluded that there has been a shift in the mean of the rainfall time series which implies the instability of mean and non stationarity of the time series.

The result of the Mann–Whitney U test shows that the mean of the subseries of rainfall are unequal, indicating instability in the mean. The mean of the yearly rainfall time series for the first subseries ($\overline{X}K_1 = 1257$ mm) differ from the mean of the second subseries ($\overline{X}K_2 = 11\,421.8$ mm). The cumulative departures from the mean, $\Sigma(XK_1 - \overline{X}K_1)$ and $\Sigma(XK_2 - \overline{X}K_2)$ shown in Table 2 and illustrated in Figs. 2 and 3 showed non-stationarity in the annual rainfall of the watershed. The positive slopes on the charts of the subseries indicate a period of above average values corresponding to wet years, while negative slopes indicates a below average period or dry years.

Table 2. Cumulative Departures from the mean of the two time series.

Rainfall time series I (Subset I)			Rainfall time series II (Subset II)		
Year	Xk$_1$	$\Sigma(XK_1 - \overline{X}K_1)$	Year	Xk$_2$	$\Sigma(\overline{X}K_2 - \overline{X}K_2)$
–	–	0.00	–	–	0.00
1981	1463.35	205.65	1996	1523.5	101.7
1982	902.55	−149.5	1997	1687.4	367.3
1983	895	−512.2	1998	1079.15	24.65
1984	1245.8	−524.1	1999	1476.4	79.25
1985	1160.35	−621.45	2000	1230.5	−112.05
1986	918.8	−960.35	2001	1121.15	−412.7
1987	1476.45	−741.6	2002	1496.05	−338.45
1988	1774.6	−224.7	2003	1459.65	−300.6
1989	1384.75	−97.65	2004	1434.2	−288.2
1990	1208.55	−146.8	2005	1204.55	−505.45
1991	1439.65	35.15	2006	1408.65	−518.6
1992	1130.2	−92.35	2007	1632.4	−308
1993	1444.6	94.55	2008	1593.85	−135.95
1994	1016.65	−146.5	2009	1428.6	−129.15
1995	1403.65	−0.55	2010	1550.7	−0.25
	$\overline{X}k_1 = 1257.7$		$\overline{X}k_1$	1421.8	

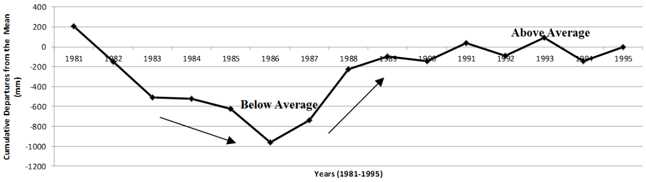

Figure 2. Cumulative departures from the mean for Subset 1 (1981–1995).

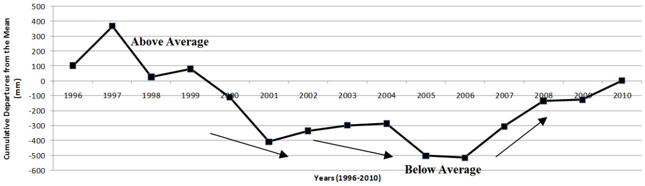

Figure 3. Cumulative departures from the mean for Subset 2 (1996–2010).

4.2 Impact of non-stationarity on water supply

Owo River is an unregulated river. Raw water is being abstracted through direct intake on the river, and therefore the free flow, variation and variability (fluctuations) of water level and other natural processes of the river in its natural course is not obstructed in any way. Between 2004 and 2011, the volume of raw water abstracted varied between a minimum of 433.4 million L in 2010 to maximum of 2207.7 million L in 2008 while the volume supplied ranged between a minimum of 392.5 million L in 2010 and a maximum of 2051.5 million L in 2008. Average volume of water abstracted between 2004 and 2011 was 1437.3 million L while an average of 1344.1 million L was supplied within the same period. Results of the F test shows that no significant difference exists in the annual water abstraction ($F_t < F_{0.05} = 1.65 < 9.3$) and annual water supply ($F_t < F_{0.05} = 1.67 < 9.3$) at the stated level of significance. The computed value of F_t is less than its critical value hence we accept the null hypothesis and conclude that no significant difference exists in the annual water abstraction as well as water sup-

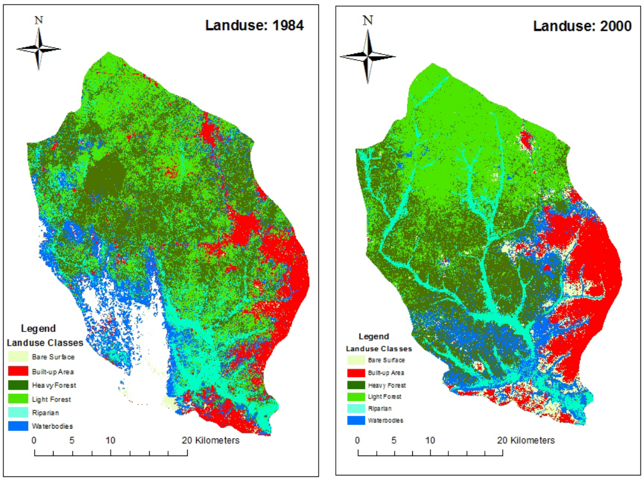

Figure 4. Landuse dynamics of Owo River Basin between 1984 and 2000.

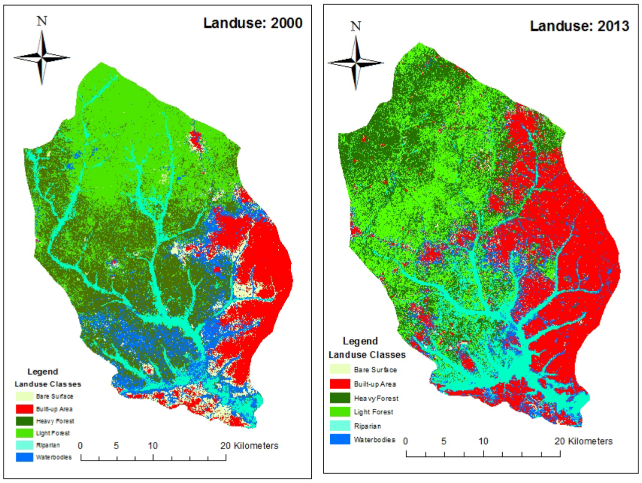

Figure 5. Landuse dynamics of Owo River Basin between 2000 and 2013.

Table 3. Landuse dynamics of Owo River Basin in 1984, 2000 and 2013.

	Landuse in 1984		Landuse in 2000		Landuse in 2013	
	Area (km^2)	%	Area (km^2)	%	Area (km^2)	%
Built-up area	142.92	12.20	242.33	20.69	367.22	31.36
Heavy forest	331.79	28.34	298.38	25.48	259.61	22.17
Waterbodies	162.38	13.87	143.47	12.25	98.63	8.42
Light forest	292.43	24.97	285.27	24.36	261.33	22.32
Riparian	155.12	13.25	133.79	11.42	122.47	10.46
Bare surface	12.03	1.02	67.44	5.76	61.42	5.24
Cloud cover	74.01	6.32	–	–	–	–
Total	1170.68	100	1170.68	100	1170.68	100

ply at 5 % level of significance. It can be concluded that the non-stationarity of Owo River Catchment has not critically affected water supply from the catchment. However, 42.49 % (CV) for abstraction and 42.60 % (CV) for water supply indicate the existence of high level of variation in the annual water abstraction and annual water supply at the waterworks.

4.3 Landuse change analysis

Table 3 shows the land use changes in km^2 and percentage of land uses. In each of the periods, built-up area remains the dominant landuse with a progressive landuse change that increased from 12.20 % in 1984 to 20.69 and 31.36 % in 2000 and 2013 respectively. The patterns of the changes over these periods of time are shown in Figs. 4 and 5. The changes reveal increasing human activities in the area.

Tables 3 and 4 describe the change matrix; the diagonal figures highlighted in bold represent the percentage of landuse/landcover classes that have remained in the same locations (area of stability) (Odunuga et al., 2011) while other matrices indicate the change to the principal landuse (Table 5).

4.4 Morphometry dynamics

Tables 6 and 7 reveal the morphodynamics of the Owo River catchment between 1964 and 2010. These variations are shown in the spatial properties or dimensions of the river basin. The result shows that the Owo River catchment is a 4th-order river catchment which has the capacity to drain a relatively large area, with a considerable kinetic energy to transport, erode and deposit sediments.

Comparison of the morphometric properties of the catchmen between the two periods shows that there are variations in the numbers of streams, stream length and bifurcation ratio. Within the study period first and second order streams have greatly reduced. Thus, some of the first-order streams are lost to anthropogenic activities. This situation has serious implications on the water yield within the catchment. Table 7 shows changes in other morphometric indices within the catchment while Fig. 6 shows the morpho-dynamic characteristics of the Owo River Basin between 1964 and 2010.

5 Conclusion

The study has shown that the Owo river catchment is a highly dynamic catchment as can be deduced from the non-stationarity of rainfall and the anthropogenic induced land use and hydro-morphometric changes that has occurred in the last four decades. The observed changes therefore call for sustainable catchment management practices that ensure ecofriendly development that do not compromise environmental integrity of the catchment and sustainable urban water supply.

Table 4. Change detection matrix between 1984 and 2000 (%).

	Built-up	Heavy forest	Waterbodies	Light forest	Riparian	Bare surface
Built-up area	**11.058**	2.455	9.631	9.317	0.853	41.355
Heavy forest	0.716	**36.662**	40.852	20.623	28.981	13.945
Waterbodies	1.233	7.293	**14.764**	9.24	20.825	14.767
Light forest	1.67	38.859	19.95	**50.636**	11.81	4.922
Riparian	83.107	11.525	8.039	4.354	**34.6**	2.104
Bare surface	2.216	3.206	6.764	5.829	2.864	**22.906**
Class total	100	100	100	100	100	100
Class changes	88.942	63.338	85.236	49.364	65.333	77.094
Image difference	−81.83	2.213	−11.639	18.01	511.852	459.987

Table 5. Change detection matrix between 2000 and 2013 (%).

	Built-up	Heavy forest	Waterbodies	Light forest	Riparian	Bare surface
Built-up	**93.241**	12.628	32.863	13.178	0.152	73.555
Heavy forest	0.436	**30.595**	12.877	42.872	3.133	2.466
Waterbodies	4.715	10.981	**16.706**	3.928	0.675	16.447
Light forest	0.158	30.742	5.226	**35.855**	3.022	0.941
Riparian	0.189	12.31	29.848	1.339	**7.873**	1.728
Bare surface	1.261	2.744	2.481	2.828	85.145	**4.863**
Class total	100	100	100	100	100	100
Class changes	6.759	69.405	83.294	64.145	92.127	95.137
Image difference	115.554	−12.13	−31.253	−24.34	−81.038	973.443

Table 6. Morphometry dynamics of Owo River Basin.

Stream order	River: 1964			River: 2010		
	Number	Length	Bifurcation	Number	Length	Bifurcation
1	218	322.71	2.20	160	297.97	1.95
2	99	158.56	1.34	82	149.45	2.83
3	74	92.33	2.18	29	51.36	1.45
4	34	48.64	–	20	57.20	–
Total	425	622.24	–	291	555.98	–

Table 7. Changes in other morphometric indices of Owo River Basin.

Morphometric variables	River: 1964	River: 2010
Drainage density ($\mathrm{mi\,mi^{-2}}$)	0.53	0.47
Stream frequency ($\mathrm{mi\,mi^{-2}}$)	0.0003	0.0002
Drainage intensity ($\mathrm{mi\,mi^{-2}}$)	0.00056	0.00042

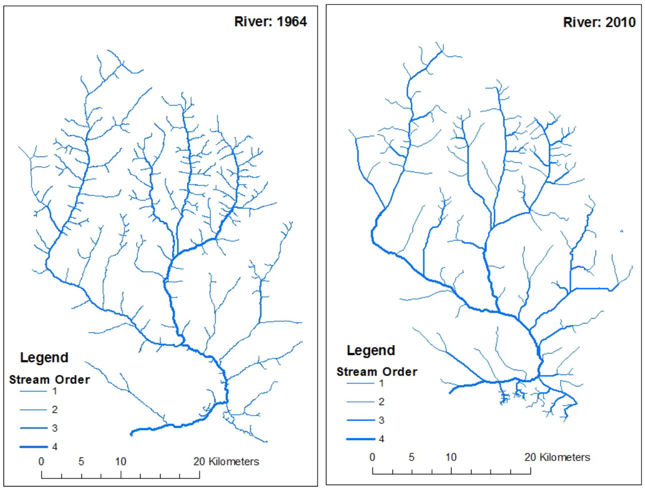

Figure 6. Morphodynamic characteristics of Owo River Basin between 1964 and 2010.

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