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WETLAND SUSTAINABILITY AND URBAN GROWTH IN SOUTHWESTERN NIGERIA: AN EXAMPLE FROM ILE-IFE

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Abstract

Wetlands, which are sinks for upstream sediments and other detritus, are subject to a natural ageing process. The culmination of the process, usually in geological time, is the elimination of wetlands. Anthropogenic activities, including uncontrolled urban growth and agricultural expansion, engender accelerated erosion and, thus, a sediment delivery rate far in excess of geological rates. This significantly accelerates the speed of wetland elimination. This study details changes in the morphology, and water and bed sediment chemistry of an artificial wetland (water supply reservoir), consequent to urban growth in Ile-Ife, southwestern Nigeria. Land use dynamics were determined from LANDSAT and ASTER imageries of the wetland's catchment. The contour survey method was used to construct a bathymetric map of the wetland, which was compared to an inception map of the reservoir to determine changes in morphology between specified time periods. The chemistry of wetland water samples was determined using atomic absorption spectrometer and auto analyzer, while the chemistry of bed sediment samples was determined using a nuclear accelerator. Accelerated elimination of water supply reservoirs and other wetlands through uncontrolled urban growth, agricultural expansion and poor environmental management is not uncommon in the developing world. This mandates a re-enforcement, or enacting and enforcement of land use control legislation, to prevent the region from facing, among others, imminent or continuing water supply shortages.

Introduction

Wetlands are usually formed where surplus water is available (during part of or the whole year) after local evaporation has been satisfied, and shallow soil is underlain by impermeable subsoil and/or subsurface or surface dykes impede lateral drainage. As such, wetlands are formed through natural and artificial processes, the latter involving the construction of weirs, barrages, dams and borrow-pits. Natural wetlands include valley-head depression wetlands, subsurface flow convergence wetlands, flood plains, and deltas. Natural and artificial wetlands abound in southwestern Nigeria. The artificial wetlands were created in connection with water supply, flood control, fish farming and hydro-electricity power generation projects through dam construction. Howbeit, once formed, wetlands being sinks for upstream sediments and other detritus, are subject to a natural ageing process occasioned by hydrophyte infestation, eutrophication and siltation. The culmination of the process, usually in geological time, is the elimination of wetlands (cf. Bruk, 1985; Webb, 1958).

Southwestern Nigeria is a region with a history of urbanization (Mabogunje, 1968). There has been a phenomenal growth in urban population over the past five decades. The main driver of this phenomenon is rural-urban migration caused by perceived employment opportunities in urban areas and the rural-urban wage differential. Current annual urban growth rate in Nigeria is 5.5%, approximately twice the national population growth rate of 2.9%. The proportion of the population living in urban areas rose from 15% in 1960 to 43.5 % in 2000, and is projected to rise to 60% by 2020 (Agbola and Agunbiade, 2009; Onibokun and Faniran, 1995; see table 1).

Table 1. Population characteristics of Nigeria, 1921-2020

Year	Total population (*000)	Total urban population (*000)	% of total population	Number of cities with population > 200000	Number of cities with population > 500000
1921	18,720	890	4.8	10	-
1931	20,056	1,343	6.7	24	-
1952/54	30,402	3,701	10.2	54	-
1963	55,670	10,702	19.2	185	2
1972	78,924	19,832	25.1	302	3
1984	96,684	31,902	33.0	356	14
2020	160,000	108,800	68.0	680	36

Source: Onibokun and Faniran (1995)

Taking Ibadan as an example, it was reported that the built up area of the city covered 36.2 km^2 in 1952 (figure 1). By 1973, 100 km^2 of land was completely built up, and by 2000, it was 400 km^2 (Afolayan and Thurston, 2010; Areola, 1994; Onibokun and Faniran, 1995). The city's population grew from 745,000 in 1952 to 2,551,000 in 2006 (NPC, 2009).

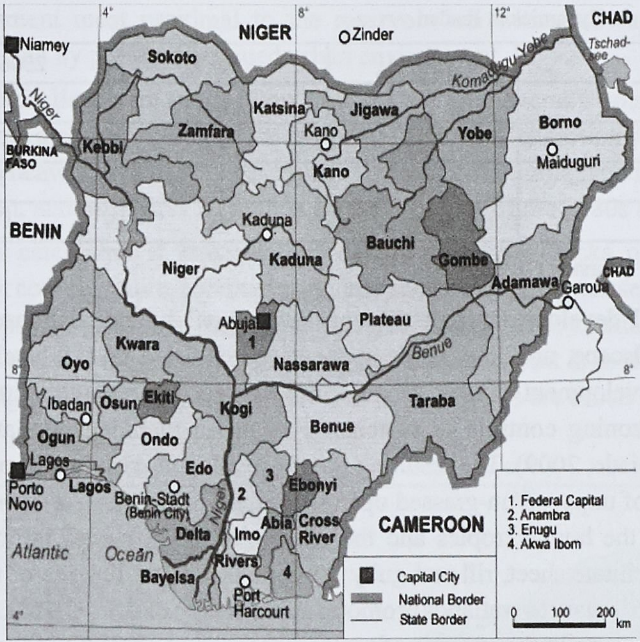

Figure 1. Map of Nigeria showing states and important cities.

An urban area by definition is characterized by a high population density and specific high order human agglomeration functions that are not available in other areas. Urbanization in Nigeria has however been described as different from that observed in developed nations (Agbola, 2005). High level services, including urban cleaning, sewage and waste disposal, efficient mass transit, water and electricity that attend urbanization in such nations are not available in most of Nigeria's urban centres. Hence, the idea that Nigeria's type of urbanization is 'false urbanization' (Hartshorn, 1992). The consequences of such false urbanization include underdevelopment, overpopulation, inadequate shelter, congestion, squalor, pollution, increasing incidence of poverty and attendant environmental problems (Jiboye, 2011). Also, though there is an 'urban sprawl' in Nigeria, which involves the spreading out of cities over vast areas of hitherto rural land (table 2), the driving force has little to do with dynamic economic and industrial activities.

Table 2. Urban land use dynamics in Ibadan

Land Use	1972 %	1984 %	2006 %
Urban	5	14	15
Sub-Urban	19	52	63
Water	13	8	5
Rural / Vegetation	63	26	17

Source: Afolayan and Thurston (2010).

Rather, the sprawl develops through the construction of individual houses across formerly rural landscape, until the whole space becomes filled up (cf. Nechyba and Walsh, 2004). Development of the urban space is unorganized with little or no consideration for zoning controls or sustenance of urban planning regulations (cf. Agbola and Agunbiade, 2009). The resulting poorly developed urban environment has a high percentage of unpaved/un-grassed open spaces, which in concert with the high energy rainfall of the humid tropics and the routing of storm runoff through open unlined sewers, facilitate sheet, rill and gully erosion. The direct linkage of township drains and streams tributary to wetlands promote rapid siltation of the wetlands. Massive quantities of urban waste in the absence of waste management capability are wantonly disposed-of at all locations including wetlands (Akintola and Gbadegesin, 1997). These have elicited significant environmental sustainability issues, including compromised ecological integrity of wetlands adjacent to or within urban areas and acceleration of their ageing process.

Many wetlands have been eliminated in southwestern Nigeria. These include the old Lagos lagoons (Webb, 1958), the Ilesha Water Supply Reservoir at Effon Alaye (7°43'N 4°56'E), and the River Ogunpa flood-control reservoir of Ibadan (7°24'N 3°54'E). This study looks at changes in the morphology, water and bed sediment chemistry, and sustainability of Opa reservoir in relation to urban growth in the Opa catchment, Ile Ife, southwestern Nigeria.

Opa catchment and reservoir

The Opa catchment lies between Latitude 7°27' N and 7°35' N and Longitude 4°31' E and 4°39' E in Osun State, southwestern Nigeria. It has an area of 110 km^2 that comprises the Obafemi Awolowo University Research Farm, the university staff quarters, the central campus, and a large part of the city of Ile Ife (figure 2). The catchment also contains rural communities and their associated land use patterns. These latter comprise villages and farmsteads, patches of secondary forests, mosaics of farm lands cultivated to a variety of tropical tree and food crops, and fallow land. The archetype vegetation is the Lowland rain forest (Keay, 1959), consisting of semi-deciduous species. This vegetation has however been so extensively disturbed that only small tracts remain in the more inaccessible sections of some inselbergs. The section of the catchment most proximal to the reservoir has witnessed rapid urban growth, characterized by poorly developed urban environment.

The roads in Ile Ife are mostly unpaved, sewers are generally open and unlined, and open spaces are ungrassed. The landscape of the university section of the catchment has also been heavily denuded within the last three decades through construction activities, cultivation, and bush fires facilitated by the droughts of the 1980s and 1990s.

The Opa catchment is underlain by deeply weathered rocks of the Precambrian Basement complex suite, comprising mainly schists, granite-gneisses and amphibolites. Though inselbergs formed on granite gneisses abound in the catchment, and constitute drainage divides, the general topography of the catchment is in the form of a gently undulating plain with local relief less than 30m. Valleys are broad and have short side

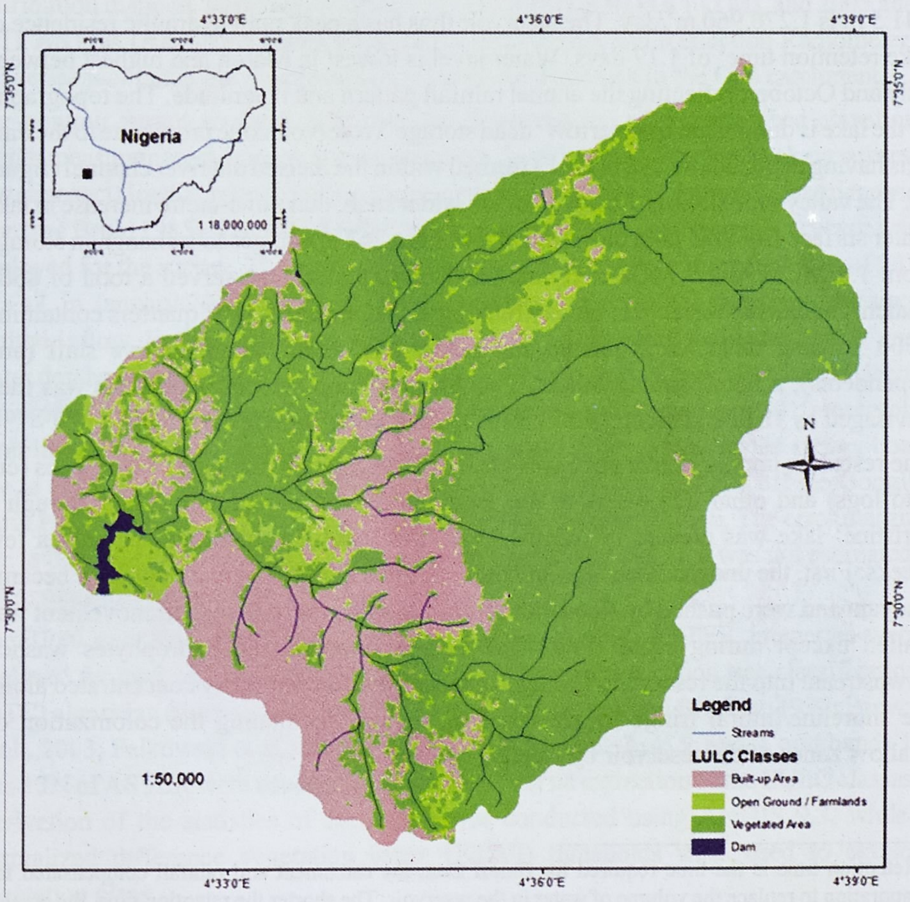

Figure 2. Opa catchment area showing 2011 land use/land cover.

slopes ($5^0 - 15^0$) and alluvial floors. Many of the valleys have swampy reaches (Jeje, 1976). The climate is a dry species of the Koppen's humid tropical (Af) type, characterized by a short dry season (November – March), during which the mean maximum temperature is 33 ^{0}C. The rainy season extends from April to October, and has a bimodal rainfall distribution marked by a break in rainfall in July-August, but during which humidity remains high. The mean annual rainfall is 1470 mm. Mean maximum temperature during the rainy season is 28 ^{0}C.

An earth-fill dam with a concrete ungated spillway and its associated reservoir were constructed for water supply purposes on the Opa River within the estate of Obafemi Awolowo University, Ile-Ife in 1978. The reservoir is about 2.5 km long and 0.80 km at its widest point, with an area of 0.66 km^2 (66 ha). The reservoir has a depth ranging between <1.0 m at the reservoir head to 7.5 m along the thalweg at the dam axis, with a 1.5 MCM storage capacity at full pool elevation of 241 m a.s.l. Reservoir outflow at 241.5 m is 1,276,960 m^3/day. The reservoir thus has a peak pool hydraulic residence or lake retention time[1] of 1.17 days. Water level is lowest in March and highest between July and October, reflecting the annual rainfall pattern and magnitude. The topography of the lake is dominated by a narrow 'dead storage' (reservoir zone proximate to the dam axis having depth below 236 m a.s.l.) formed within the incised old river channel (figure 3). The valley-side slope is, however, much wider such, that a one-metre increase in lake water surface from the pool elevation of 241 m to 242 m equates to a change in storage from 1.5 MCM to 2.7 MCM. At commissioning, the scheme served a total of 8500 students in halls of residence, faculty buildings, health centre, staff quarters containing >500 housing units for academic and junior and senior administrative staff (and dependents), a hotel, among others. Though maximum student population was then envisaged as 12,000 students, the current student population is > 30,000.

The reservoir impoundment zone was cleared of vegetation, but many felled trees (cut into logs) and other detritus were not removed prior to inundation. Thus, though a 'pristine' lake was created in August 1978, this condition persisted for only a few weeks. First, the unevacuated logs and other detritus in the impoundment zone became buoyant and were pushed by flood currents to the spill way, where their movement was stalled except during spate flow. The logs in turn trapped hydrophytes washed downstream into the reservoir. The hydrophytes were subsequently concentrated along the shoreline/littoral fringe by wave action, thereby facilitating the colonization of shallow zones of the reservoir by weeds.

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[1] Retention time is the time required for runoff from the catchment and rainfall compensated for evaporation to replace the volume of water in the reservoir. The shorter the retention time, the greater the penetration of inflow water into the reservoir, and thus transport of entrained material

Methods

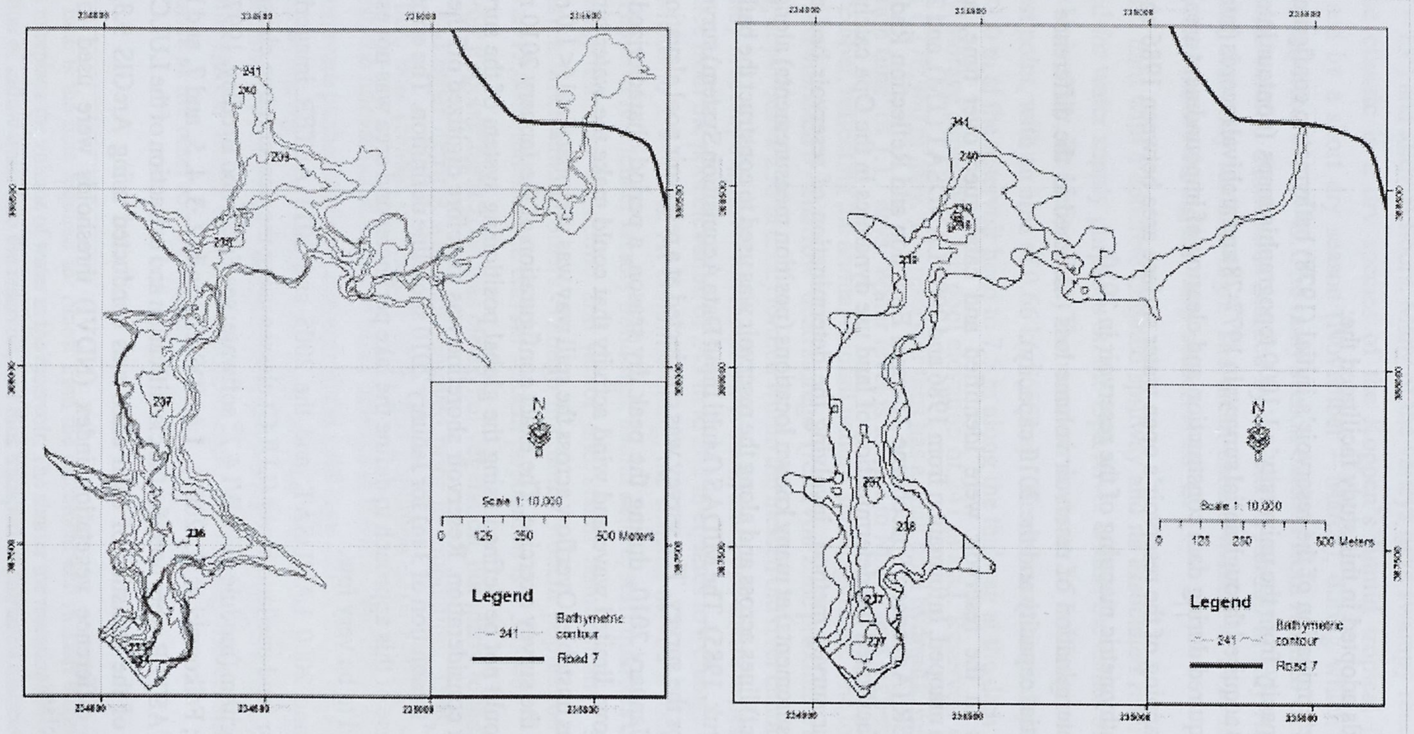
The methods adopted in this study facilitated the:

- Determination of the reservoir's initial (1978) bathymetric configuration and capacity from the university's 1:1000 topographic maps (contour interval: 0.5 m) acquired through aerial surveys in 1977-78 and archival records (survey data acquired during dam construction and clearing of impoundment area).
- Mapping of the reservoir's open water surface area between 1986 and 2011.
- Bathymetric mapping of the reservoir in 2010.
- Determination of reservoir volume loss (assumed as the difference between initial capacity and the 2010 capacity).

The weeds in the reservoir were identified and catalogued over time, and their distribution mapped. Information from 1986 and 2000 LANDSAT (TM), and 2005 and 2011 ASTER (Advanced Spaceborne Thermal Emission and Reflection Radiometer) imageries facilitated the determination of land use dynamics in the Opa catchment.

The contour survey method, involving the determination of reservoir bed elevation (depth measurements) at many known locations (position measurements) along several tow (transect) lines across and along the reservoir was used to construct the bathymetric map (see Bruk, 1985). The MIDAS (Multi Input Data Acquisition System) surveyor was deployed for the survey. The survey was conducted at a reservoir pool elevation of 241 m a.s.l. in January 2010, during the peak dry season, a period characterized by very limited inflow, limited wave and wind activity that could make the water turbid, and water depths unstable. Overflow across the spill way was very marginal (< 1.0 cm deep) throughout the survey exercise. The exact configuration of the January 2010 reservoir shoreline could not be defined using the global positioning system of the survey boat due to draft consideration. Reservoir shoreline was therefore digitized off the Google Earth Pro ™ (resolution of 3 m) for January 2010 shoreline definition. The error margin due to the use of this approach to define the lake perimeter and area was not estimated, but assumed to be very low.

The 1986 and 2000 LANDSAT, and the 2005 and 2011 ASTER imageries were analyzed for land use/land cover (LULC) classes using the decision tree classification (DTC) algorithm (module of ENVI 4.7® software; see Friedl and Brodley, 1997; Brown et al., 2003; Falkowski et al., 2005). LANDSAT bands 2, 3, 4, 5, and 7, and bands 1, 2 and 3N of ASTER were used for the classification and extraction of the LULC classes. Derivation of the statistics of each class was conducted using ArcGIS 9.3, while normalized difference vegetation index (NDVI) thresholds were used to extract vegetation class.



1978

2010

Figure 3. Opa reservoir bathymetry.

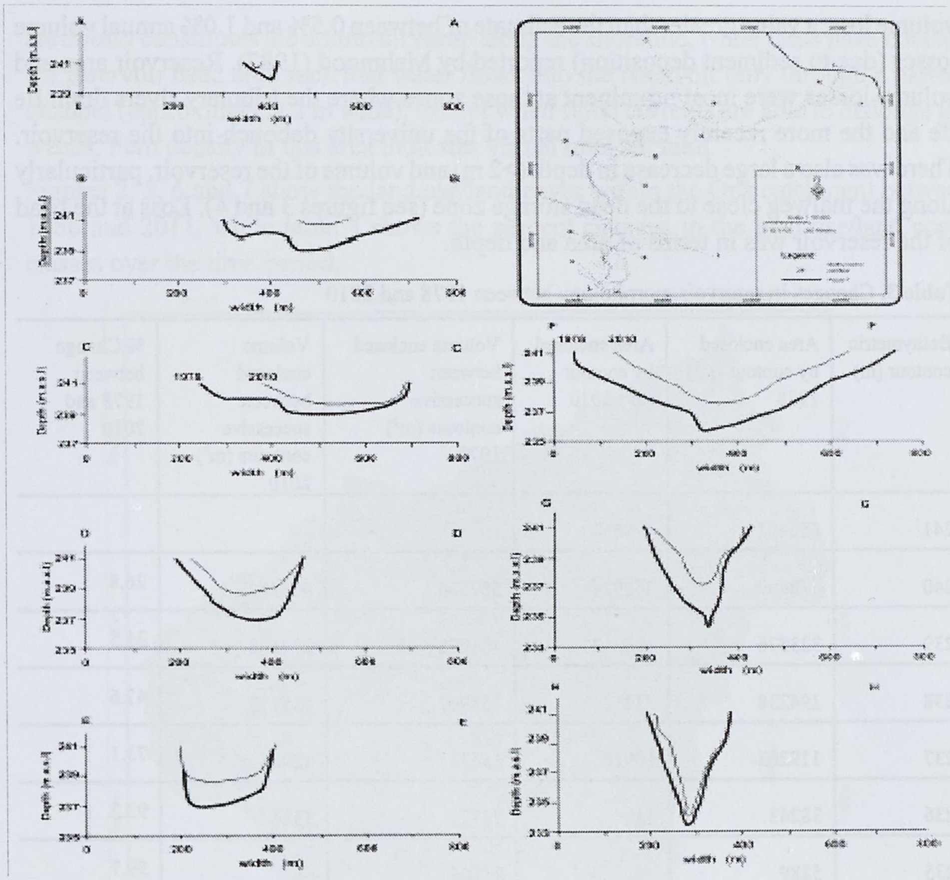


Figure 4. Bathymetric cross sections across Opa reservoir.

The reservoir's water and bed sediment were also sampled at several locations. All the samples were analyzed for a suite of determinants (including heavy metals) at the Centre for Energy Research and Development, Obafemi Awolowo University, Ile-Ife. Atomic absorption spectrophotometer and auto analyzer were used in water analyses, while the nuclear accelerator was used for bed sediment analyses.

Opa reservoir morphology, water quality and bed sediment chemistry, and Opa catchment's land use/land cover

Table 3 presents information on the morphology (area enclosed by specified bathymetric contour and volume between successive contours) of the Opa reservoir and the percentage change between 1978 and 2010. The data indicate that the reservoir surface area decreased by 27%, equating to a loss of 18 ha out of the original 66 ha, while 41.4% of storage volume was lost over 32 years. This corresponds to > 1.3% annual volume loss, a value greater than the estimate of between 0.5% and 1.0% annual volume losses (due to sediment deposition) reported by Mahmood (1987). Reservoir area and volume losses were most prominent at those zones where the tributary rivers drain Ile Ife and the more recently exposed parts of the university debouch into the reservoir. There was also a large decrease in depth (>2 m) and volume of the reservoir, particularly along the thalweg close to the dead storage zone (see figures 3 and 4). Loss at the head of the reservoir was in terms of area and depth.

Table 3. Changes in reservoir morphology between 1978 and 2010

Bathymetric contour (m)	Area enclosed by contour (m^2) 1978	Area enclosed by contour (m^2) 2010	Volume enclosed between successive contours (m^3) 1978	Volume enclosed between successive contours (m^3) 2010	% Change between 1978 and 2010
241	656861	479650			
240	478499	350924	567680	415287	26.8
239	323576	198212	401038	274568	31.5
238	194238	73253	258907	135733	47.6
237	119203	10918	156721	42086	73.1
236	38243	130	78723	5524	93.3
235	5289		21766	65	99.7
234	1561		3425		100
Total volume			1489040	873263	41.4

Hydrophytic weed species and their locational distribution and areal coverage on the surface of the reservoir changed over the years. *Pistia stratiotes* (water lettuce) was the first water weed to be observed covering parts of the reservoir surface. The following have since successively been dominant in terms of areal coverage and occupation of various niches/locations previously filled by the preceding species: sedge (*Scirpus brachyceras*, *Rhynchospora corymbosa*, *Cyperus*), grass (*Typha australis*, *Coix lacryma*), ferns (*Cyclosorus dentatus*) and shrubs (*Alchornea cordifolia*)

Currently, *Cyclosorus dentatus*, *Typha australis*, *Scirpus brachyceras* and *Eichhornnea crassipes* (water hyacinth) are the dominant species around the dam axis. *Alchornea* *cordifolia* constitutes the dominant shrub along the shoreline, while ferns have covered the reservoir head area such that water flows into the reservoir only through a narrow channel (approximately 2 m wide), except when flood currents are able to dislodge the weeds. Fern density in this area indicates virtual total siltation.

Figures 2, 5, 6 and 7 show the land use/land cover within the Opa catchment between 1986 and 2011, while table 4 shows the percent changes in the land use/land cover classes over the time period.

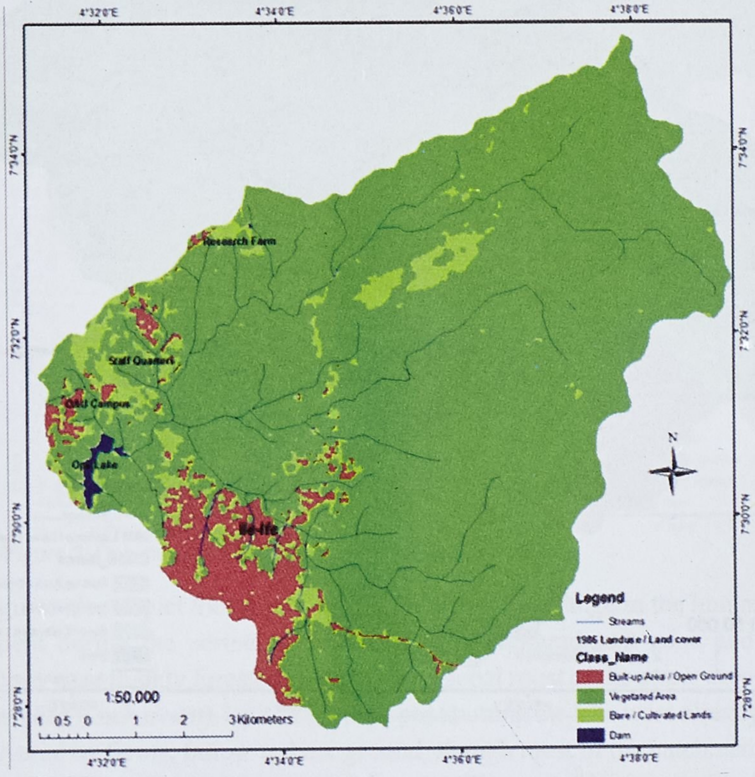


Figure 5. Opa catchment's land use/land cover in 1986.

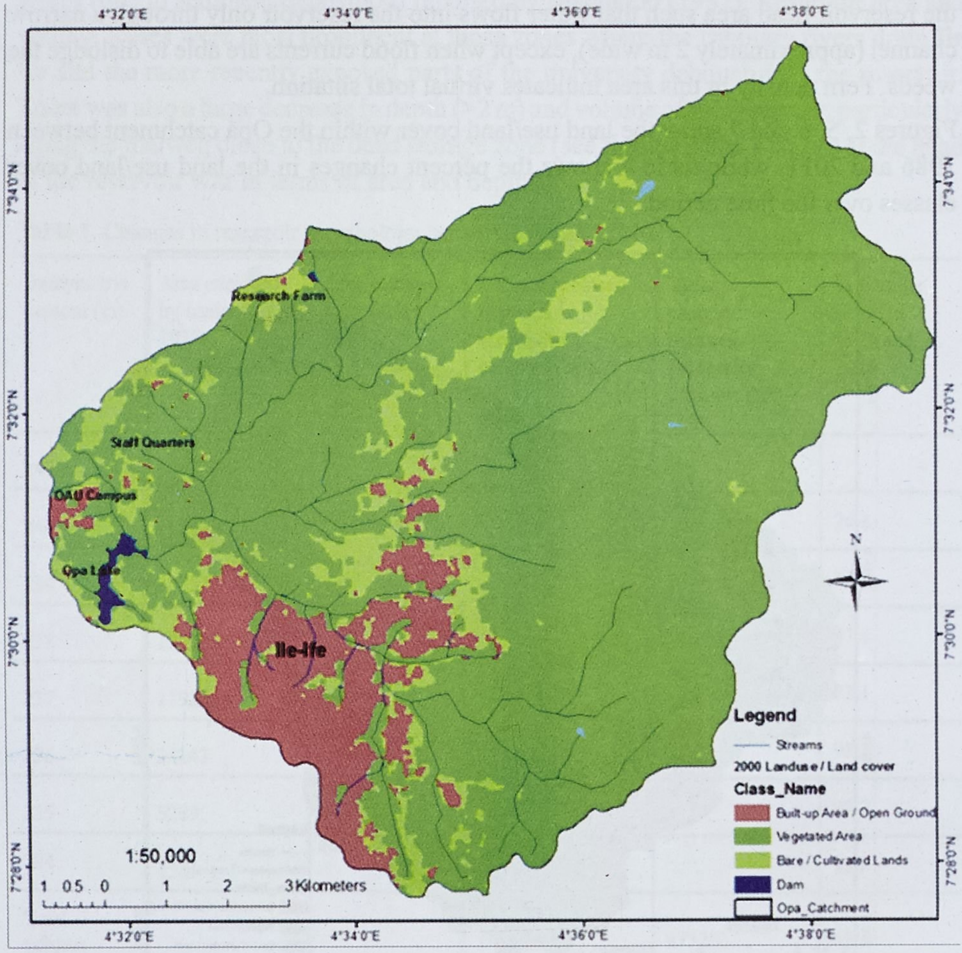


Figure 6. Opa catchment's land use/land cover in 2000.

Table 4. Changes in land use/land cover within the Opa catchment

Year	1986	2000	2005	2011
LULC TYPE	% Cover	% Cover	% Cover	% Cover
Vegetated	85.6	79.7	69.1	67.0
Built-up Area / Open Ground	7.2	10.1	12.2	13.7
Bare/ Cultivated Lands	6.9	9.8	18.4	18.9
Human Use Index	14.1	19.9	30.6	32.6

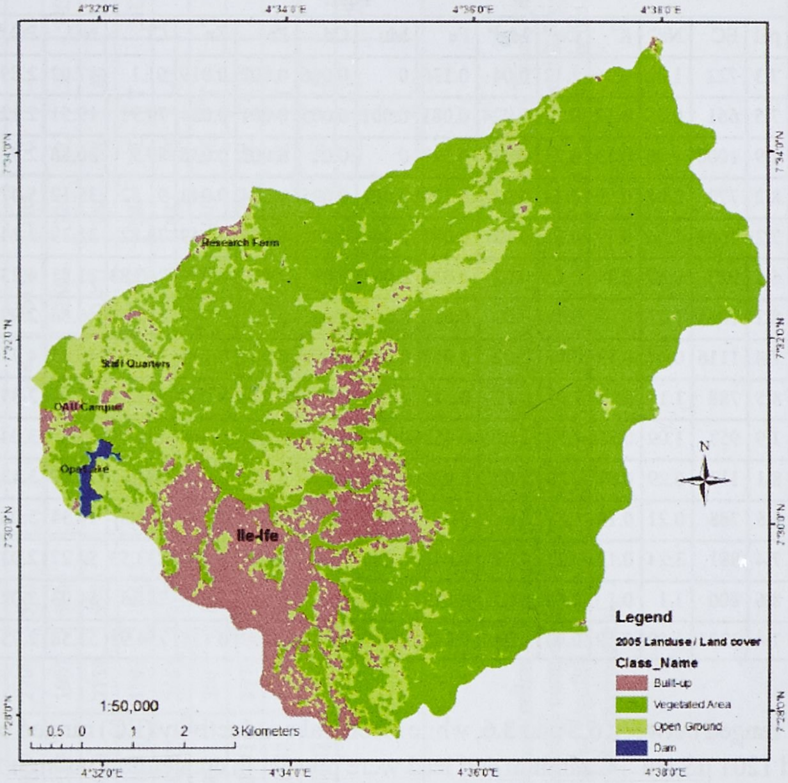


Figure 7. Opa catchment's land use/land cover in 2005.

The figures also depict the direction and magnitude of change in the human use of the catchment during the period. Before 1978, the impoundment zone and the slopes abutting it were thickly forested and a main regional roost of the straw-colored African fruit bat (*Eidolon helvum*). By 1986, the slopes abutting the lake were already deforested and covered by farms, fallow or bare ground, though most of the catchment, including the river valleys and adjoining wetlands was still covered by vegetation (forests and agro-forests). The Human Use index of the catchment (a sum of the proportions of cultivated, bare and urban land use; see EPA, 2001), which was 14% in 1986, had increased to 31% by 2005. The index was 33% in 2011. The city had also grown towards the lake and the university, with the growth terminating along the university's boundary. The area between the reservoir and the city limits were however covered by farms, which tend to leave the area bare at the beginning of the rainy season.

The concentrations of the determinants in the surface water of the reservoir at the fifteen sampling stations are presented in table 5.

Table 5. Opa reservoir's surface water chemistry

Sample location	mg/L														
	pH	EC	Na^+	K^+	Ca^{2+}	Mg^{2+}	Fe	Mn	Cd	Pb	Zn	Cl^-	NO_3^-	PO_4^{3-}	SO_4^{2-}
1	7.3	722	1.02	0.16	1.12	0.04	0.136	0	0.006	0.002	0.019	61.1	47.02	2.89	57.3
2	7.5	661	0.55	0.17	0.13	0.024	0.081	0.001	0.005	0.001	0.024	79.91	19.51	2.12	91
3	7.9	1000	1.06	0.13	0.23	0.03	0.127	0	0.01	0.002	0.036	89.9	30.88	2.9	45.8
4	8.2	772	2.08	0.09	0.43	0.02	0.129	0.001	0.005	0.004	0.043	91.52	35.12	5.47	88.5
5	7.2	1009	1.06	0.1	0.33	0.02	0.088	0.004	0.008	0.008	0.049	78.82	31.39	3.34	65.2
6	6.5	922	0.47	0.21	0.15	0.02	0.025	0.004	0.011	0.01	0.039	260.83	21.81	4.23	113.4
7	8.2	1005	1.21	0.09	0.12	0.02	0.018	0.006	0.006	0.003	0.045	61.9	46.56	2.99	179.7
8	7.4	1116	0.64	0.13	0.07	0.02	0.017	0.005	0.008	0.004	0.125	76.65	40.45	4.7	245.1
9	8.5	788	1.1	0.18	1.02	0.02	0.125	0.003	0.003	0.01	0.099	241.12	41.82	2.35	251.05
10	7.9	953	1.09	0.18	0.53	0.02	0.052	0.01	0.005	0.002	0.048	176.71	33.2	3.04	100.1
11	8.1	1123	0.29	0.07	0.23	0.02	0.028	0.01	0.006	0.003	0.023	98.55	20.78	3.33	165.2
12	6.5	788	0.21	0.19	1.81	0.04	0.034	0.008	0.015	0.013	0.17	282.81	54.54	5.06	307
13	7.4	881	3.24	0.11	0.21	0.03	0.043	0.003	0.005	0.006	0.14	233.53	52.27	2.03	171.15
14	8.6	800	1.1	0.1	0.42	0.03	0.033	0.007	0.003	0.01	0.114	281.5	54.03	3.02	186.15
15	7.4	1201	1.09	0.19	0.43	0.03	0.042	0.009	0.007	0.009	0.115	254.91	51.58	2.73	288.5

The pH ranged between 6.5 and 8.6, while electrical conductivity (EC) ranged between 661 and 1201 µS cm^{-1}. Cadmium and lead were present in concentrations significantly higher than the maximum allowable concentration (0.003 mg/L) under the WHO and other international drinking water quality standards. The water samples were well enriched with SO_4^{2-}, NO_3^- and PO_4^{3-}. The cationic dominance pattern (based on µeq/L analysis) was $Na^+ > Ca^{2+} > K^+ > Mg^{2+}$, except at the dam axis and at those points with high concentrations of heavy metals (where the pattern was $Ca^{2+} > Na^+ > K^+ > Mg^{2+}$). The anionic dominance pattern was consistently $Cl^- > SO_4^{2-} > NO_3^- > PO_4^{3-}$. Data on bed sediment chemistry are presented in table 6. Cadmium was not detected in any of the bed sediment samples, while lead was only in trace quantities at two locations though there were heavy loadings of K, Mn, Fe and Zr at some locations.

Table 6. Opa reservoir's bed sediment chemistry (ppm)

Location	Al	Si	P	S	K	Ca	Ti	V	Cr	Mn	Fe	Pb	Cd	Zn	Cu	Zr
2	60720	105405	T	2468	3989	2708	5607	T	T	1548	86144	ND	ND	122	T	T
4	73096	136996	T	4680	4589	1907	5105	T	T	1984	92503	120	ND	150	ND	T
5	83862	143411	T	2458	5619	2132	5530	T	163	1483	91997	160	ND	180	ND	T
6	14953	47952	ND	ND	11943	1993	13441	T	T	1112	50776	ND	ND	T	ND	771
8	46146	109761	T	T	11752	2664	7607	T	T	3813	66570	ND	ND	144	T	T
9	46966	142234	ND	ND	18811	3017	12098	T	203	2916	54314	ND	ND	T	T	1060
10	272109	614099	ND	T	20781	3979	13758	T	T	5906	78792	ND	ND	124	T	258
13	165061	718337	ND	ND	51352	2790	5508	T	ND	360	17459	ND	ND	T	T	T
14	193327	477301	T	T	20322	4064	13257	T	T	3611	68659	ND	ND	214	T	1382
Basement complex background*										229	15555	68	0.2	71	12	

T: Trace

ND: Not detectable

*The reference background employed is that of average concentration of basement rocks of southwestern Nigeria, as compiled by Tijani, Okunlola and Ikpe (2007). This reference background constitutes the average composition of weathered regolith over the different rock types and its application as reference background is based on the fact that such weathered regolith are source materials of the erosional wash-out and runoff sediments transported from the catchment area into the drainage system and the lake environment.

Discussion

The creation of artificial wetlands brings about a change of vegetation status from hydrophytic plants to hydrophytic weeds. Superimposed on this change is the effect of land use dynamics, which promote erosion and enhanced delivery of sediments into the wetland. Adejuwon (1978) observed that natural wetlands within the Opa catchment were infested with various hydrophytes including *Polygonum salicifolium, Acroceras zizanioides, Pennisetum purpureum, Coix lacryma, Echinochloa colonum, Pistia stratiotes, Pteridium aquilinum, Scirpus brachyceras* and *Ipomoea aquatica*, and that the Opa reservoir would be readily colonized by weeds. Since these plants were already fully established in the catchment, it was expected that they could be washed downstream to colonize the new reservoir. He noted that these plants had contributed to a reduction in the surface area of ponds and marshes in the catchment through the building up of decaying organic matter and trapped sediments. Ogunkoya. Oyinloye and Oke (1997) observed this trend and, reported that by 1986, an area approximately 0.17 km^2 or 25% of the original surface area of the reservoir had become heavily infested by weeds. The zones of heaviest weed infestation corresponded to the mouths of tributary rivers draining Ile Ife, some parts of the university and the spillway area. Vegetation has an important effect on water flow and sediment transport. It increases flow resistance, reduces velocity and sediment transport capacity, and thus induces deposition. The roughness coefficient increases as the number of plants per unit bed area increases (Bridge, 2003).

The increased cross-sectional area and wetted perimeter of a reservoir compared to that of its tributary promotes a decrease in flow velocity and turbulence, which eventually get dissipated over the increasingly larger areas in the reservoir. The plants enhance the stilling effect, and their roots anchoring them to the reservoir bed act as filters stalling the movement of sediment. The consequence is that the tributary stream flow becomes ineffective as a transporting medium, and sediment is deposited on the bed of the reservoir. In such a case, delta formation and maximum siltation and volume loss should be at the reservoir head zone and at other locations where tributaries debouch into the reservoir. But this was not the case in the Opa reservoir. Although the reservoir head area had lost significant area/volume due to siltation and weed infestation, a major occurrence is the siltation near the dam axis (see figures 3 and 4). This indicates a reservoir with through flow characteristics and short hydraulic retention time. The unregulated large scale land use conversion in the catchment over the past three decades involving deforestation, cultivation, and uncontrolled/poorly planned urban development has promoted massive erosion. The transportation of eroded material into the reservoir has facilitated the narrowing and siltation of the reservoir.

Akinbuwa (1988) observed that the Opa reservoir was still in a pristine condition as at 1987. The pH ranged between 6.5 and 7.6, while EC ranged from 150 to 309 (uS cm^{-1}), with the values reflecting dilution of the reservoir water by inflows. There was no trace of heavy metals. But by 2010, the waters had become eutrophic. And when compared with fresh water quality standards and the WHO's drinking water quality standards, the concentrations of cadmium (Cd) and lead (Pb) had become significantly higher than the maximum allowable concentration (0.003 mg/L). There was no analysis of the effect of plastics flushed into the reservoir on its water quality (figures 8 and 9).

Figure 8. Refuse at reservoir head.

But Fatoki and Ogunfowokan (1993) analyzed the reservoir's water for the presence of phthalate esters and found a concentration of 462mg/L of dimethyl phthalate ester (DMP). The DMP values are from water samples collected between 1990 and 1991. This was when Ile Ife had relatively little impact on the reservoir. Even then, the values were much higher than those reported for polluted rivers in western industrialized countries and 10^5 higher than the 3 µg/L US EPA standard criteria for the protection of aquatic life.

The situation in the Opa catchment is rather ubiquitous in Nigeria, and most probably in the developing world. Akoto, Bruce and Darko (2008) examined the As, Cr, Cd, Ni, Pb, Mn, Co, Cu, Fe and Zn concentrations in the waters of the Owabi reservoir in Kumasi, Ghana. This reservoir provides drinking water to the Kumasi metropolis and its environs. Human activities found within the area include metal fabrication, auto garages, residential, farming, road construction, as well as municipal waste disposal. The results showed that the water of the Owabi reservoir was very polluted. Tijani, Okunlola and Ikpe (2007) found high concentrations of Pb, Zn, Cd in water and bed sediments of the Eleiyele reservoir in Ibadan.But Fatoki and Ogunfowokan (1993) analyzed the reservoir's water for the presence of phthalate esters and found a concentration of 462mg/L of dimethyl phthalate ester (DMP). The DMP values are from water samples collected between 1990 and 1991. This was when Ile Ife had relatively little impact on the reservoir. Even then, the values were much higher than those reported for polluted rivers in western industrialized countries and 10^5 higher than the 3 µg/L US EPA standard criteria for the protection of aquatic life.

Figure 9. Refuse at location ~150 m downstream from reservoir head.

During the colonial era, when many water supply dams and reservoirs were constructed, the urban space was small and limited. Further, the catchments of the reservoirs were protected by forests. Since the end of that era, population increase and re-distribution have pushed city limits in the direction of the reservoirs and, in many cases, encircled the reservoirs. Zoning controls that were enacted during the colonial era appeared to have been ignored. Thus, for instance, the catchment of the old Ibadan city water supply reservoir (Eleiyele; $7^0$26’ N $3^0$52’ E), built in 1942, was virtually covered with planted forests, protected and managed by the State Forestry Department. But protection controls have either been abandoned or are unenforced. Consequently, most of the catchment is now covered by the usual poor urban environment, comprising un-grassed open spaces, unpaved roads, unlined open sewers and absolutely ineffective waste management. Un-enlightened urbanites even dispose trash into the tributaries of the reservoir (Tijani, Okunlola and Ikpe, 2007; Olubode, Awodoyin and Ogunyemi, 2011). The flood control reservoir of the city (7^{0}24’20”N 3^{0}53’53”E) has experienced the same fate and is now almost totally silted up.

As reported by Holland et al. (1995), conversion to urban land use was the predominant cause of wetland loss from human activities, with agricultural conversion as the next cause. Glymph (1973) reported annual storage loss of up to 25% in some small reservoirs in the United States, with the result that the aquatic ecosystem could be exterminated within four years. Although there was an estimated 1.3% average annual loss of the Opa reservoir capacity, this included an era when there was relatively low human use of the catchment. The annual rate of capacity loss should be much greater now given the current development in the catchment. It has become apparent that so long as urban growth occurs and engulfs wetland catchments, urban landscapes remain poorly developed and managed, urban and state authorities do not have the capacity to or do not concern themselves with environmental and waste management, and the populace cursorily dispose waste of all types in drains and river channels, wetlands such as the Opa reservoir are inexorably on their way to an accelerated demise.

Given the need to forestall a continuing case of ‘build and abandon’, specific land use zoning controls have to be built into urban growth within catchments of regulated rivers. These controls describe the restrictions on land uses in specific locations, and deter or segregate emergent land uses that may not be compatible with existing uses. The goals are environmental sustainability and protection of the integrity and sustainability of existing land use, e.g., water supply reservoir. An example of a successful application of this type of policy is that of New York City's water supply reservoirs (EPA, 2001; Germain, Munsell and Brazill, 2007), which has enabled the city to have a low cost filtration-free water supply system. It should be noted that the city’s water supply is based on a system of well-protected catchments and reservoirs built in them. The city has 90% of the catchments covered with forests and restricts development in them. A consequence is that the city has the largest unfiltered surface storage and supply system in the USA, which supplies drinking water to 9 million people in the greater New York City area, plus another one million tourists and commuters (EPA, 2001; Germain, Munsell and Brazill, 2007)

Conclusion

Wetlands, which are sinks for upstream sediments and other detritus, are naturally ephemeral features on the earth surface, though the rate of elimination could be geological. The life span of wetlands is now being so shortened, particularly in the developing world, through uncontrolled urban growth and agricultural expansion, and accelerated erosion. A terminal consequence in the case of artificial wetlands such as water supply reservoirs, is the loss of the reservoir through eutrophication and siltation. But even before then, water treatment costs could become so prohibitive as to outstrip the benefits derivable from the continued use of the waters of the reservoir. It therefore behoves authorities to ensure that once artificial wetlands are created, attempts are made at conserving their ecological integrity for long-term productivity. Current urban growth trends in Nigeria appear antithetical to such conservation. Appropriate catchment management that can facilitate sustainability of wetland integrity will incorporate strict zoning controls. If such controls are not urgently established, as urban centres grow to engulf catchments of water supply reservoirs, and urban and state authorities do not have the capacity for, or concern themselves with environmental and waste management, artificial wetlands such as the Opa reservoir are inexorably on their way to an early demise.

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