Water Quality Issues in Developing Countries – A Case Study of Ibadan Metropolis, Nigeria

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1. Introduction

To describe water as the engine of life will not constitute an overstatement. This is because water in its various forms, accounts for more than 70 per cent of the entire earth surface and all life forms regardless of their habitat depend on this abundant resource for their continuous existence. However, as huge as this vital resource is, only small percentage of its natural form could be readily used for drinking and sanitation purposes by man. These are normally stored up in repositories and embankments such as the aquifers, lakes, rivers and other surface freshwater bodies.

Due to the increasing influence of natural events and anthropogenic activities on these natural water sources, the pristine characteristics exhibited by these water sources often fade out with time. Today, the understanding of water quality has become conceptualised because of the numerous uses to which different types of water could be subjected to. More so, due to the complexity of several factors determining water quality and the countless choice of variables used to provide quantitative evaluation of this term, it is difficult to adopt a single definition of water quality (Chapman, 1996). In a simple term, however, water quality refers to the composition of any water body as affected by nature and human cultural activities, expressed in terms of both measurable quantities and narrative statements (Novotny, 2003). Depending on the area of application, the criteria for establishing water quality requirements differ in many aspects. Hence, water which is suitable for a particular purpose, for instance, agricultural irrigation might not be useful for other purposes due to differences in water quality requirements.

The causative factors responsible for the deteriorating water quality in most developing countries are quite similar. For instance, the city of Ibadan which is the largest indigenous city in Africa has several inter-related factors which directly or indirectly impact the quality of water bodies within the city. These are largely due to improper waste disposal, poor physical planning and increasing population pressures on the dilapidated infrastructures within the city. Omoleke (2004) also identified the culture of the indigenous people living in the core of the city as a vital factor contributing to these menace. Traditionally, the city has been a commercial centre for local marketers of maize, yam and other food stuffs where heaps of refuse are generated on a daily basis. Due to the clustered distribution of old houses within the interior of the city, the mechanised collection of these refuse becomes virtually impossible. Hence, people resort to dumping their solid wastes into drains and stream channels which often results into clogging and flooding. More so, most of the houses around these areas do not have toilet facilities, as such people defecate indiscriminately on undeveloped plots of land or along the streams and rivers within the city. These uncivilised behaviours have continued to aggravate many dimensions of water pollution problems within the city.

The consequences of these illicit practices are quite enormous. Besides the increasing number of waterborne diseases related cases in hospitals, the destruction of lives and properties caused by catastrophic flood incidences in the city are notable. In the last 60 years, the city had witnessed several flood disasters notably in 1951, 1955, 1960, 1963, 1969, 1978 and most recently in 2011. According to a newspaper report (Businessday, Nigeria) of 5th September 2011, more than 700 lives have been lost during flash flooding incidences between 1980 and 2011. The report further indicated that government's dereliction of duty and insensitivity to the plight of its citizenry, complete disregard to town planning rules by landlords and the awful traditional habits of small-scale business people and their patrons of dumping wastes in drainages as the cause of the sporadic flood disaster recently witnessed in the city. Interestingly, the cumulative effects of the water pollution problems arising from the flood disasters and industrial discharges are not restricted to the residents of the city. Many villagers living several miles away from the city who often depend on water from these polluted streams and rivers for their drinking and sanitation purposes are not exempted from these effects. Incidentally, the extracted water by these villagers, in most cases, is not subjected to any form of chemical treatment prior to their use. Although most of these streams and rivers do exhibit some natural regenerative potential as they flow further downstream, the extent to which these can be achieved generally depends on but not limited to these factors, namely the quality of industrial effluent discharged, the proximity of the village or other extraction points to the city and the hydrodynamics of the stream or river concerned.

As a result of the increasingly difficult nature of managing solid wastes in the city, little attention is paid to the potential impacts of discharges of untreated, partially treated or treated industrial effluents on the water quality of the receiving water bodies. Usually, the impact of industrial discharges is difficult to assess because there is no clear cut between the water pollution caused by industrial activities and that contributed by improper management of solid wastes. This study was therefore aimed to establish whether the pollution of the two major rivers (Ona and Alaro) within Oluyole Industrial Estate, Ibadan was due to industrial discharges or as a result of indiscriminate disposal of municipal wastes and transportation of pollutants into these rivers via urban run-off especially during high precipitation. To achieve this objective, this study was conducted at the peak of the rainy season so that the influence of urban run-off on the water quality could be readily evaluated. In this study, the water quality was assessed in terms of the physicochemical characteristics of the river water and the levels of trace and heavy metal of both the river water and bottom sediment collected from different sampling locations along the stretch of both rivers. Because of the pivotal role that solid waste management played on the subject matter, mention was made on the institutional and regulatory frameworks established to coordinate the proper management of the environment within the city; suggestions for better ways of protecting the environment were also mentioned.

2. Solid waste management in Ibadan: Current approach and practice and the role of institutional and regulatory frameworks

Since the advent of the disastrous flood of April 1978 in Ibadan, there has been an unprecedented public interest on the channelization of Ogunpa river and solid waste management within the city (Areola and Akintola, 1979). The massive accumulation of solid wastes in both Ogunpa and Kudeti rivers made these rivers overflow their banks resulting in severe flooding in parts of the city in the past years. When it became apparent to the city managers that the rivers within the city could no longer cope with the huge run-off generated during rainfall, the government began the channelization of the major river as early as 1970s. Several administrations have expended heavily on this project yet the problem of flooding still persists. The most recent was the flood incidence of August 25, 2011 where several lives and properties were lost. The extent of the damage caused is depicted in Figure 1. A critical look at this problem shows that the flood abatement measures are already in place but the major cause of the flooding which is the obstruction of drains and channels by dumped solid wastes is yet to be completely tackled.

Fig. 1. A picture showing the devastating effects of the flood incidence of 25th August 2011 in parts of Ibadan city

The task of keeping the environment of the city clean is vested in the hands of three government institutions, namely:

i. Ibadan Solid Waste Management Authority,
ii. Local Government Councils, and
iii. Ministry of Environment.

Prior to the enactment of edict No. 8 of 1997 which established the Ibadan Solid Waste Management Authority, the management of environment of Ibadan city was the primary responsibility of the local government councils that evolved from the defunct Ibadan Municipal Council. Upon the implementation of the edict, the functions of these local councils under the 1979 Nigerian constitution which were to collect, transfer and dispose solid wastes were delegated to the newly constituted authority (Omoleke, 2004). The authority has since its inception been fully responsible for the collection, transfer and disposal of solid wastes in the city. Other functions of the authority include the coordination of private practitioners engaged in solid waste collection and the enforcement of regulations related to the proper management of solid wastes within the city.

To further strengthen the decision-making processes and the implementation of relevant environmental policies, Oyo State House of Assembly passed a law to establish the Ministry of Environment and Water Resources which commenced functioning on 1st January, 2001. As highlighted by Omoleke (2004), the responsibilities of the ministry include:

a. formulation and enforcement of policies, statutory rules and regulations on waste collection and disposal, general environmental protection, control and regulation of the ecological system and all activities related thereto;
b. advise the government on the environmental policies and priorities and on scientific and technological activities affecting the environment;
c. coordinate the activities of the Local Governments and government agencies on environmental and ecological matters;
d. establish and take measure to ensure effective environmental structures in the state for flood control, solid and liquid wastes collection and disposal, water and air pollution eradication, noise control and general sanitation;
e. conduct public enlightenment campaign and disseminate vital information on environmental and ecological matters;
f. prepare master plans for drainage, solid and liquid wastes and general aesthetics for development of environmental technology and ensure the implementation of such plans;
g. promote cooperation in environmental science and technology with bodies whose main objective is the protection of the environment;
h. initiate appropriate policy action on the environmental implications of environmental related activities;
i. monitor sources of toxic pollutants into the air, land and water.

The ministry is empowered under Section 5 of this act to disseminate basic scientific data and other information pertaining to eradication of pollution and environmental protection matters through relevant publications; and to establish environmental criteria, guidelines, specifications or standards for the protection of the environment and public health. Besides these laws, there are many other associated legal regulations which specifically addressed diverse environmental problems at the federal, state and local government levels. Based on the aforementioned preview, it is clearly evident that the solid waste management problems commonly encountered in the city, as it is the case in most cities of other developing countries, has nothing to do with lack of appropriate institutional and regulatory frameworks but rather on the inability of relevant government's agencies to translate these policies into meaningful results.

Presently, waste collection methods in most parts of the city differ from place to place. This often depends on the ease of accessibility of mechanised technology adopted for this purpose. In the interior of the city where accessibility of motorised vehicle could be a problem, communal depots and block system (bring and dump) are the commonest means of solid waste collection. The house to house method is commonly practised in areas with better road networks. Since most of these services usually require some forms of financial commitment, the very poor who could not afford these costs mostly resort to sporadic and indiscriminate dumping of their wastes into available plots of land, sidewalks, roadways, streams, channels and drainages. Omoleke (2004) reported that more than 70% of the refuse generated in the city are mostly disposed in this way – a method commonly known as 'bulk loading'. This is partly responsible for the incessant flood disaster being witnessed in the city over the years. Unfortunately, most of the measures adopted by relevant government's agencies to combat these problems could not be sustained due to poor funding, lack of appropriate technology and manpower for effective management of solid wastes and the poor attitude of most of the residents of the city.

3. Methodology

3.1 Sampling sites

A total of ten sampling sites representing the upstream (mainly residential), industrial zones and downstream of both River Ona and River Alaro were carefully selected. The entire sampling locations where both river water and bottom sediment were collected are shown in Figure 2.

3.2 Sample collection

Two sets of water samples were collected at the region of good mixing into thoroughly cleaned polyethylene bottles from different sampling sites. The first set of water samples was required for the determination of the physicochemical parameters while the other set was acidified upon collection for the assessment of the following heavy metals, namely: Pb, Zn, Cd, Ni, Cu and Fe. Similarly, bottom sediment samples were collected from these sites using a hand trowel wrapped with several layers of polyethylene bags to prevent interaction with the metallic surface. These samples were collected into self-sealing polyethylene bags and were kept cool *en-route* to the laboratory. On arrival at the laboratory, all the samples were kept in the refrigerator until analysis. However, the debris in the bottom sediment samples was removed prior to their preservation.

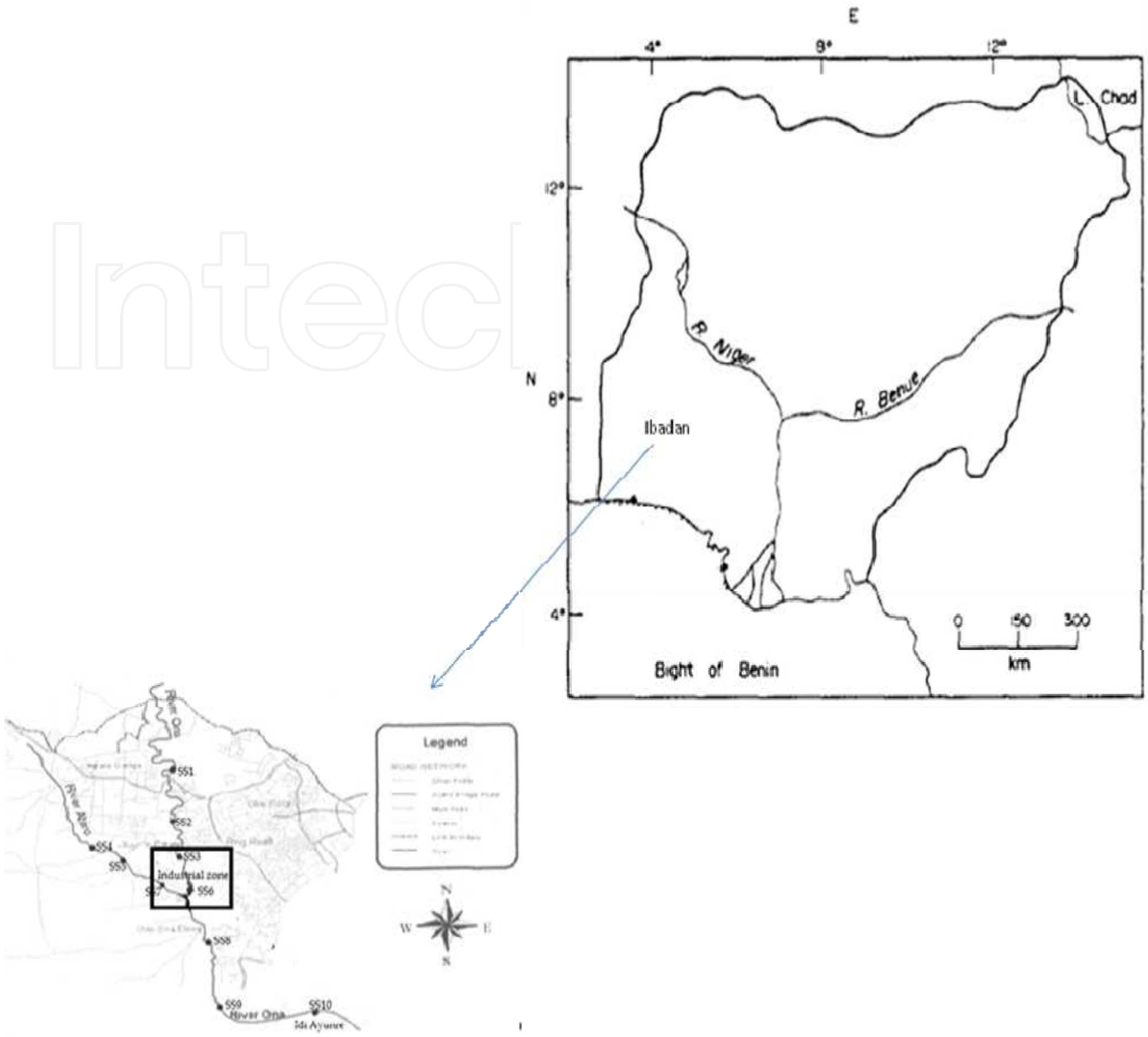

Fig. 2. The map of Nigeria showing its geographical coordinates as well as the sampling sites within the City of Ibadan

3.3 Sample analysis

The pH and temperature of water samples were determined on the field immediately after sample collection. The analysis of water samples for other physicochemical, inorganic and organic parameters was carried out according to the decreasing order of stability of parameters to be determined. In these cases, established analytical protocols were employed for the analysis of these parameters. All the parameters except nitrate were determined using the standard methods for the examination of water and wastewater (APHA, 1985). The analysis of nitrate was done by the spectrophotometric method described by Osibanjo and Ajayi (1980). In this case, nitrate was determined by nitration of 3,4-xynenol in acidic medium. This was followed by the extraction of the nitration product with a suitable alkali solution (NaOH) to form a coloured product whose absorbance was read at 432 nm using CECIL CE202 UV spectrophotometer.

For the heavy metal determination in water samples, an initial pre-concentration of water samples was carried out. In this case, 50 mℓ portion of water sample was measured into a thoroughly clean heat-resistant conical flask and evaporated to a final volume of 2 – 8 mℓ. In each case, the concentration factor was estimated to account for the actual metal concentration in each sample. The concentrated samples were thereafter transferred into 50 mℓ capacity digestion tubes following which 2M HNO_3 was added. The tightly covered tubes were then placed into a 1 ℓ capacity heat-resistant beaker containing water and boiled for 2 h. The digestion tubes were regularly checked at intervals to ensure that the content were intact. After digestion, the tubes were cooled and samples were filtered and made up to 25 mℓ mark. A blank sample was similarly prepared using 10 mℓ of the acid.

In the case of bottom sediment samples, the air-dried samples were ground and mechanically sieved using a 2 mm mesh size sieve. About 2 g of the sediment sample was weighed into a clean digestion bottle. The samples were digested as previously described for the water samples using the same strength and volume of the acid. The heavy metal contents of these digested samples were determined using a Bulk Scientific VGP 210 Model Atomic Absorption Spectrophotometer (AAS). This analysis was carried out at the Central Chemistry Laboratory of the University of Agriculture, Abeokuta, Nigeria. Equations 1 and 2 below were employed for the calculation of the heavy metal content of the river water and bottom sediment samples, respectively. The total organic carbon (TOC) content of the sediment samples was determined using the Walkey-Black method as described by Schumacher (2002).

$$\text{Metal conc. in water } (\mu g/\ell) = \frac{(a - b) * 25 * 1000}{c.f * d} \tag{1}$$

$$\text{Metal conc. in sediment } (\mu g/g) = \frac{(a - b) * 25}{e} \tag{2}$$

where:

- a, b = instrument reading (µg/mℓ) for sample and blank, respectively.
- d = volume of digested water (mℓ),
- c.f = concentration factor.

The TOC content was calculated using equation 3 and the organic matter reported was estimated using the conversion given below.

$$\text{TOC } (\%) = \frac{\left(meK_2Cr_2O_7 - meFe(NH_4)SO_4\right) * 0.003 * 100 * f}{\text{mass of air} - \text{dried sediment}} \tag{3}$$

where:

- f = correction factor = 1.33,
- me = Normality of solution * volume of solution used (mℓ),
- % Organic matter in sediment = % TOC * 1.72.

As part of the quality assurance measures taken, all the sampling bottles and glassware employed for sample collection and preparation of reagents were properly cleaned to avoid possible contamination problems. The analysis of procedural blanks during heavy metal determination in river water samples was carried out to eliminate trace levels of target analytes from the reagents used. Since the heavy metal analysis was carried out by an external analyst, several standard solutions of the heavy metals investigated were prepared and sent for analysis prior to the analysis of the real samples by groups of research scientists in the university to ascertain the accuracy of the results obtained. More so, blind samples were prepared and incorporated into the real samples to further establish the reliability of the results obtained from the instrumental analysis.

4. Results and discussion

4.1 Results

The results of the physicochemical, inorganic and organic parameters of river water samples collected from both River Ona and River Alaro are presented in Table 1. These results, except for the industrial zone of River Alaro, generally indicate the average values of each parameter investigated. It is necessary to point out that River Alaro discharges its contents into River Ona where these industries are mostly concentrated along the catchments of the river. Hence, samples were only collected at the upstream and industrial zones of this river. The quality of the surface water is also greatly influenced by the chemistry of the underlying sediment. Therefore, an assessment of the sediment (which serves as a sink for most water pollutants) as well as surface water for heavy metal concentrations was carried out. The results obtained are presented in Table 2.

In this study, the evaluation of the quality of the surface water of both rivers involves the monitoring of inorganic, organic and general water parameters at different sampling sites.

A comparative assessment of the results obtained in this study with those of other similar studies around the world was done. This, however, could only give a clue as to whether a significant pollution has occurred but will not necessarily imply that the pollution is caused by industrial discharges because several other factors have been found to significantly contribute to surface water pollution across the world. Some of these factors would include the geological formation of the study area, urban run-off, agricultural run-off, atmospheric deposition, acid mine discharges amongst others.

4.2 Discussion

4.2.1 Physicochemical characteristics of the rivers

The trend of most of the physicochemical parameters suggests that the rivers were properly mixed. This is not surprising, since the study was conducted at the peak of the rainy season when the rivers had excessive volume of water that flowed over the riverbanks at certain locations along their catchments. The pH of the river water, which ranged from 6.88 to 7.60 showed no inconsistency along the watercourses of both rivers suggesting that there were no significant inflows of substances that abruptly influence the pH of the water system. Generally, the temperature of water from both rivers reflects those typical of a tropical river ranging from 26 to 28^{o}C. However, the higher average of 27^{o}C recorded for River Ona which was higher than that recorded for River Alaro (26.3^{o}C) was indicative of possible thermal pollution from industrial processes.

The evaluation of solids at different sampling sites revealed possible contributions of industrial discharges at certain sampling locations. At sites 3, 8, 9 and 10, the dissolved solids content were found to be greater than the suspended solids levels of these sites, which was expected. In other cases, the suspended solids contents were greater than the dissolved solids which indicated turbulence in the water bodies during sampling and probably because the suspended solids were largely non-settleable. The elevated level of dissolved solids at site 3 may be attributed to the high volume of a combination of partially treated and untreated industrial effluents that are regularly discharged to this sampling site. The industries in this area are mostly food and household products manufacturing industries whose wastewaters may be rich in dissolved organics as reflected in the result obtained. Contributions from both urban run-off and industrial activities may be responsible for the levels obtained at other locations.

4.2.2 Inorganic characterization of the river water

Generally, the trend of the results of most inorganic anions studied agreed with those reported in a similar study (Sengupta *et al.*, 1988). The water samples from both rivers did not show a positive test to phenolphthalein alkalinity determination. By implication, the alkalinity results obtained in this study, therefore, could be attributed to the presence of carbonates (CO_3^{2-}) and bicarbonates (HCO_3^-) in these samples. It further indicates that hydroxide ion is not present in these samples and this claim is supported by the pH values (< 8.00) obtained for these samples. The methylorange alkalinity ranged from 96.9 to 142 mg $CaCO_3/\ell$ while the total acidity, on the other hand, ranged between 24.7 and 43.8 mg $CaCO_3/\ell$ in river water samples from both rivers.

For most of the anions, a somewhat unique pattern in their levels at different sampling sites of the rivers was observed. For instance, the levels of the major anions (Cl^-, NO_3^- and SO_4^{2-}) showed a distinct and regular pattern in its levels along the watercourse of both rivers, particularly before and after the convergence of these rivers. While these anions had a considerable decrease in their levels at the industrial zone of River Ona, all but one of these anions had an appreciable increase in their levels within the same sampling location in River Alaro. The average chloride level of 10.9 mg/ℓ obtained in River Ona was higher than that obtained in River Alaro (8.23 mg/ℓ). Incidentally, these levels were far below the WHO guideline for drinking water. Furthermore, the average chloride level in River Alaro found in this study was significantly lower than the average reported (475 mg/ℓ) in a similar study conducted on the same river during the dry season (Fakayode, 2005). The dilution effect of the rainwater could be responsible for the lower chloride levels obtained in this study. Common sources of chloride in the river water would possibly include the use of mineral acids (e.g. HCl), common salts and other chloride containing compounds often used as inputs in the food and other manufacturing industries.

The decreasing trend in the levels of these anions especially NO_3^- and SO_4^{2-} might be due to the possibility of chemical precipitation and the action of certain micro-organisms on these inorganic species. Nriagu (1978) highlighted several processes through which sulphur can be removed from sub-aqueous biogeochemical cycle to include: (a) the formation of insoluble iron (and other metal) sulphides, (b) the precipitation of sulphate (particularly gypsum and anhydrite) out of solution, which may be engendered by extended desiccation, (c) the removal of organic debris and other sulphur-containing suspended particulates; and (d) the exchange of sulphur across the air-water and sediment-water interfaces.

In view of the above, it follows that in aerobic surface waters; the loss of sulphur should be quite negligible and would primarily entail the sedimentation of suspended particulate and organic matter. The average levels of sulphate in both rivers were 4.94 and 5.64 mg/ℓ for River Ona and River Alaro, respectively. It was observed that the upstream of both rivers generally had higher levels of sulphate. This might be due to the increased utilization of cement for building and other construction works since these areas were mainly residential.

Similarly, the higher levels of nitrate at the upstream of River Ona and in the industrial zone of River Alaro could be attributed to increased usage of nitrogen-based fertilizers and from the decomposition of biodegradable household wastes commonly dumped along the banks of these rivers. Although the loss of nitrogen via the air-water and sediment-water interfaces cannot be ruled out, the reduction of nitrate to ammonia and nitrogen molecules by certain denitrifying bacteria can significantly contribute to the observed trend in the study. Brooks and Effler (1990) noted a rapid depletion of nitrate and nitrite in a typical lake waters an observation attributed to the actions of denitrifying bacteria and possible assimilation of these nitrogen species. The organic constituents of the industrial discharges might also aid the removal of nitrate from solution by facilitating the sedimentation process involved in its removal.

Although the average nitrate level in River Ona (7.91 mg/ℓ) was higher than that found in River Alaro (7.02 mg/ℓ), nitrate levels found at the upstream and industrial zone of River Alaro were generally higher than those found at the same locations in River Ona. This trend is expected because River Alaro is bound to several large-scale farms and industries where increased usage of nitrogen-based fertilizer, agricultural composts as well as poultry and other agricultural and industrial wastes could have significantly contributed to the elevated level of nitrate in the river. The high value of nitrate obtained at sampling site 10 was probably due to the influx of urban run-off into smaller streams that emptied their content into the river downstream.

The total phosphorus levels showed a progressive increase along the sampling sites in both rivers. These generally ranged from 0.71 to 5.71 mg/ℓ and were similar to those previously reported for some Nigerian rivers (Ajayi and Osibanjo, 1981). The discharge of effluents of high phosphate content into these rivers could have resulted into the increased levels observed. Phosphorus-rich detergents are important sources of phosphorus into surface water bodies especially in urban areas. More so, the use of super-phosphate fertilizers and leaching from municipal dumpsite could also contribute to these elevated levels of phosphorus in these rivers. The extremely high level of phosphorus at the sampling site 10 was a reflection of the cumulative effects of industrial discharges and urban run-off conveyed into River Ona via other notable rivers (e.g. R. Ogunpa and R. Kudeti) and streams which converged at a point few metres away from sampling site 9.

Besides certain parameters which gave an indication of good mixing in both rivers, the levels of total hardness found in this study further suggested that the river water were properly mixed during sample collection. These levels were generally uniform at the sampling sites of these rivers. The average level of the total hardness in River Alaro (103 mg $CaCO_3$/ℓ) was slightly higher than that obtained for River Ona (102 mg $CaCO_3$/ℓ). These levels were generally lower than the WHO standard of 500 mg $CaCO_3$/ℓ for drinking. Apart from the economic losses associated with the extremely high levels of hardness in form of poor lather formation with use of soap during washing, there is no known health effects related to this parameter at levels commonly found in natural waters.

Parameters	**River Ona**			**River Alaro**	
	Upstream (1,2)	**Industrial zone (3,6)**	**Downstream (8,9,10)**	**Upstream (4,5)**	**Industrial zone (7)**
pH	7.56	7.57	7.17±0.32	7.55	7.40
Temperature ^{0}C	28.0	27.5	26.0±0.00	26.0	27.0
Total solids (mg/L)	370	420	490±168	290	260
Suspended solids (mg/L)	250	230	140±20.0	250	240
Dissolved solids (mg/L)	120	190	350±150	40.0	20.0
Acidity (mg $CaCO_3$)	29.5	31.4	39.5±4.71	35.6	29.5
Alkalinity (mg $CaCO_3$)	112	108	134±11.4	112	96.9
Total hardness (mg $CaCO_3$)	92.0	102	110±12.2	108	94.0
Sulphate (mg/L)	5.51	3.31	6.25±1.53	6.62	3.68
Total phosphorus (mg/L)	1.07	2.855	4.64±1.48	2.15	2.86
Chloride (mg/L)	11.8	9.63	12.0±1.59	7.59	9.52
Nitrate (mg/L)	3.75	3.32	18.2±15.4	6.26	8.55
Dissolved oxygen mg DO/L	5.08	5.77	5.08±0.21	6.87	5.47
COD mg O_2/L	91.8	71.4	133±20.4	40.8	81.6
Oil and grease mg/L	197	398	379±21.3	407	431

number(s) in parenthesis – sampling sites

Table 1. Mean (±standard deviation) concentrations of physicochemical, inorganic and organic parameters in water samples

Parameters	**River Ona**			**River Alaro**	
	Upstream (1,2)	**Industrial zone (3,6)**	**Downstream (8,9,10)**	**Upstream (4,5)**	**Industrial zone (7)**
River water (µg/ℓ)					
Pb	156	53.5	100±73.7	68.5	88.5
Zn	159	195	151±2.75	228	183
Cu	22.0	31.3	25.7±5.25	21.8	28.5
Cd	5.00	7.50	0.50±0.87	2.50	5.50
Ni	145	ND	65.0±104	65.0	80.0
Fe	802	956	1560±425	1160	1320
Bottom sediment (µg/g)					
Pb	19.4	27.9	31.1±16.9	24.9	24.6
Zn	26.9	156	74.0±37.5	46.7	20.7
Cu	5.88	3.78	6.27±2.38	5.66	7.59
Cd	3.67	11.2	1.60±0.87	5.31	1.58
Ni	8.13	9.13	9.67±6.87	14.4	12.9
Fe	2260	4280	3420±444	4790	2780
OM (%)	0.26	0.74	0.98±0.71	1.48	0.48
pH	7.10	7.28	7.68±0.37	7.81	7.08

OM – organic matter; number(s) in parenthesis – sampling sites

Table 2. Mean (±standard deviation) concentrations of selected heavy metals in river water and bottom sediment samples

4.2.3 Organic pollution indicators

A holistic evaluation of surface water quality will be deficient if the organic constituents are not properly examined. In this study, some gross organic pollution parameters were carefully selected and determined to establish the organic pollution status of the investigated rivers. For instance, a cross-section examination of the dissolved oxygen (DO) content of the river water samples collected at different sampling sites showed that the rivers were not highly polluted with organic matter. It is, however, pertinent to note that the slight drop in DO levels at sampling site 2 could be indicative of influx of organic matter or oxygen demanding substances into the river. Interestingly, this drop in DO levels did not result in appreciable increase in the COD value obtained for the sampling site. The variation in the dissolved oxygen concentrations along the sampling sites in River Ona is presented in Figure 3.

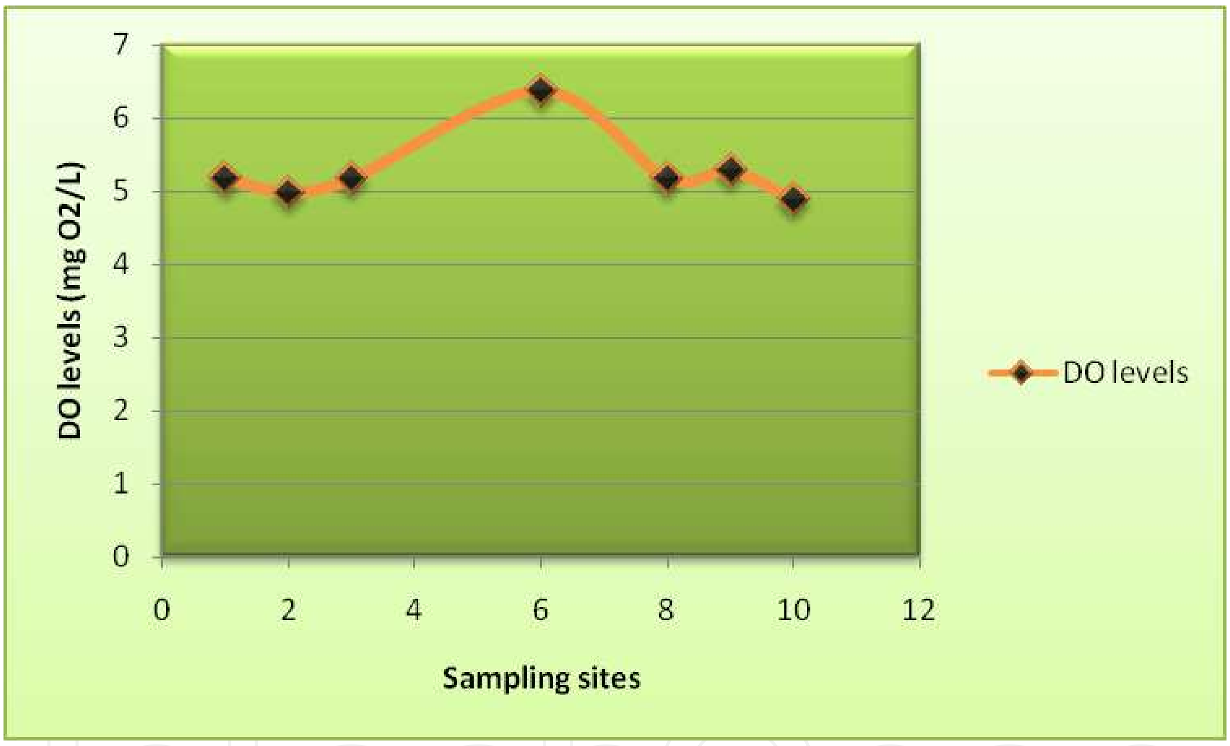

Fig. 3. Variation in dissolved oxygen levels along the sampling sites of River Ona

A seemingly interesting observation was found around the industrial zone of River Ona with relatively high DO level at the sampling site 6 which was contrary to our expectation. The observed level could be due to the additional measures taken by a major agricultural farm along the catchments of the river to further reduce the impacts of its discharges into the river. It was noted that some forms of physical treatments (e.g. aeration) of the river water some distance upstream of the sampling site 6 was undertaken by the farm management. As shown in Figure 3, the slight drop in DO level at sampling site 10 might be due to the influx of high oxygen demanding substances in urban run-off conveyed into the river by other rivers and streams.

The COD values obtained in this study ranged from 20.4 to 143 mg/ℓ with average levels of 99.1 and 54.4 mg/ℓ for River Ona and River Alaro, respectively. The lower COD values obtained in the industrial zone of River Alaro imply that most industries might probably have efficient wastewater treatment plants which in reality is not true. Apart from the dilution effects of the rainwater, the possibility of decreased production rates during the period of sample collection could also be responsible for observed results. Furthermore, the relatively higher COD levels after the convergence of the rivers further corroborate the influence of both urban and agricultural run-offs into River Ona via other streams and rivers as previously mentioned. Based on the classification of surface waters by Prati *et al*. (1971), River Ona with an average COD value of 99.1 mg/ℓ may be categorised as being heavily polluted while River Alaro with an average of 54.4 mg/ℓ may be categorised as being slightly polluted.

The assessment of oil and grease levels in both rivers revealed a high level of oil pollution at most sampling sites. The average levels of this parameter were found to be 338 and 415 mg/ℓ for River Ona and River Alaro, respectively. The relatively higher levels of oil and grease in River Alaro especially at the upstream region could be due to urban run-off which conveyed spent oils from various auto-repair workshops and particularly from the oil depot sited further upstream of the river. The Pearson correlation analysis performed on the three organic pollution indicators revealed that only DO had a significantly strong negative relationship (r = -0.829) with the COD at 0.01 level (2-tailed). Furthermore, a weak positive relationship (r = 0.220) exist between the DO and oil and grease while a moderately strong negative correlation (r = -0.580) was observed between the COD and oil and grease. Going by these statistical analyses, it can be inferred that oil and grease did not contribute appreciably to the total amount of chemical oxidisable organic pollutants in the river water samples. However, the presence of oil and grease in water bodies could significantly impair the normal growth and development as well as the survival of diverse aquatic fauna and flora.

4.2.4 Heavy metals

The evaluation of the quality of the river water with respect to heavy metal concentrations of both rivers before and after their convergence is an essential index of establishing the pollution status of the investigated rivers. A summary of these metals in both rivers before their convergence is presented in Table 3.

Metals	**River Ona**	**River Alaro**
Pb	105 (23.6)	75.2 (24.8)
Zn	177 (52.6)	213 (38.0)
Cu	26.6 (4.83)	24.0 (6.30)
Cd	6.25 (7.45)	3.50 (4.07)
Ni	72.5 (8.63)	70.0 (13.9)
Fe	879 (3270)	1210 (4120)
pH	7.57 (7.19)	7.50 (7.56)
OM (%)	(0.50)	(1.15)

values in parentheses represent the heavy metal concentrations in sediment samples; OM – organic matter.

Table 3. Average concentrations of heavy metals, pH and organic matter in river water (μg/ℓ) and sediment (μg/g) before the convergence of the rivers

From this assessment, it is evident that all the heavy metals except Zn and Fe had higher levels in river water samples of River Ona than in River Alaro. Similarly, relatively higher levels of these metals were found in bottom sediment of River Ona except Pb, Ni and Fe which had higher levels in River Alaro.

The concentrations of Lead (Pb) ranged from 38.5 to 184 µg/ℓ and 6.38 to 50.5 µg/g for river water and bottom sediment, respectively. The levels of Pb found in bottom sediment were higher than those obtained for river water samples; hence the bottom sediment could be an important influential factor contributing to the observed levels in river water samples of both rivers. Although the statistical correlation between Pb levels in sediment and water samples showed a weak positive relationship (r = 0.175), There is, perhaps, the possibility of sediment contributing to the Pb levels in the river water samples.

In similar studies conducted between 1977 and 1979, the Pb levels found at different sampling sites of River Ona ranged between 0.20 to 21.0 µg/ℓ (Mombeshora *et al.*, 1983), and the levels found in the sediment were from 0.2 to 17 µg/Kg (average of 2.50 - 5.00 µg/Kg) (Mombeshora *et al.*, 1981). Based on these present findings, the accumulation of lead in River Ona has escalated over the past years which are also true for other rivers within the city. Of utmost concern is the higher level of this metal found in the river water samples. Three out of the ten sampling sites had levels exceeding the WHO maximum permissible limit of 0.1 mg/ℓ, hence making the water unsuitable for drinking. This calls for immediate concern as the infants and young children are the most vulnerable to the health effects of lead, especially in rural areas of most developing countries where drinking water are fetched from these rivers without subjecting it to any form of treatment.

The levels of Zinc ranged from 105 to 251 µg/ℓ and 14.3 and 135 µg/g for river water and bottom sediment, respectively. The levels of Zn in river water samples of these rivers were several orders of magnitude lower than those found in four different rivers (1.10 – 3.03 mg/ℓ) within Ibadan city between July – August, 1990 (Fatoki, 1993). However, the levels obtained for sediment samples were comparable to those reported for a typical tropical rivers where Zn levels ranged from 24.9 – 148 mg/Kg (Adekola and Eletta, 2007). Zinc being an essential element for living organisms and due to its relatively low toxicity to humans, a maximum permissible limit of 5 mg/ℓ has been set as guideline value by WHO for drinking and other domestic purposes. Although the levels found in this study were generally lower than the permissible limit, it could however exert its toxic effects on sensitive biota in the aquatic ecosystems.

The levels of Copper in river water samples ranged from 18.5 to 31.5 µg/ℓ while these ranged from 2.28 to 8.24 µg/g for the bottom sediment samples. Appreciable increases in Cu levels were observed along the sampling sites of both rivers particularly in the industrial areas thus suggesting the possible influence of industrial discharges and agricultural run-off on the contamination of the rivers. The levels of Cu found in this study were generally lower than the WHO limit of 0.05 mg/ℓ for drinking water and much lower than those found in Challawa River, Kano (Nigeria) which ranged from 0.32 to 0.57 mg/ℓ (Akan *et al.*, 2007).

Cadmium levels ranged from nd to 7.50 µg/ℓ and 0.65 to 19.3 µg/g for river water and bottom sediment samples, respectively. Although the levels of Cd found in this study were comparatively lower than the WHO maximum permissible limit of 0.05 mg/ℓ, the fact that it is very persistent and toxic especially to aquatic organisms at relatively low concentrations calls for concerns. In fact, it was reported that 95% of its lethal effects in freshwater occur at concentrations > 2 µg/ℓ while in marine waters the corresponding concentration is > 95 µg/ℓ (Taylor, 1981, as reported in Taylor, 1983). Furthermore, the fact that it was not detected in river water samples of four different rivers within the city of Ibadan about two decades ago calls for concerns (Fatoki, 1993). This, however, suggest that industrial discharges as well as improper solid wastes management could be responsible for the observed trend.

A statistical correlation between Cadmium and other heavy metals in water samples revealed that Cd showed a significantly strong positive relationship with Zinc (r = 0.677) and Copper (r = 0.713) at the 0.05 level (2-tailed). This implies that notable sources of both Zn and Cu into the environment may be responsible for the release of Cd into these rivers and *vice versa.* In addition to the natural sources of this metal, other probable sources into the surface water bodies would include leaching from Ni-Cd based batteries, run-off from agricultural soils where phosphate fertilizers were previously used and other metal wastes. With the indiscriminate dumping of solid wastes and the crude techniques of managing solid wastes without proper sorting of electronic wastes from other municipal wastes before disposal, the freshwater systems will continue to be negatively impacted with the toxic effects of Cd and other pollutants contained in these wastes.

Nickel, at low concentrations, can cause allergic reactions and certain Ni compounds may be carcinogenic (Denkhaus and Salnikow, 2002). Nickel occurs naturally in the environment, however, because of its unique physical and chemical properties; metallic nickel and its compounds have found increased usage in modern applications. Several activities related to its handling during production, recycling and disposal can result into serious environmental pollution. In this study, the levels of Ni ranged from not detected (ND) to 185 µg/ℓ and 1.75 to 21.0 µg/g for river water and sediment samples, respectively. These levels were higher than the typical concentration of 0.0005 mg/ℓ in surface water given by the South African Department of Water Affairs and Forestry (DWAF, 1996). All the sampling sites except where the levels were not detected had higher concentrations than this concentration thus suggesting the possibility of water contamination from diverse sources. Possible sources of nickel in surface waters would include combustion of fossil fuels, old battery and other e-wastes, components of automobiles, old coins and many other items containing stainless steel and other nickel alloys. Among the known health-related effects of nickel are skin allergies, lung fibrosis, variable degree of kidney and cardiovascular system poisoning and stimulation of neoplastic transformation (Awofolu *et al*., 2005).

The levels of Iron (Fe) ranged from 538 to 1920 µg/ℓ and 1900 to 6570 µg/g for the river water and bottom sediment samples, respectively. The maximum permissible limit for Fe in drinking water is 1.00 mg/ℓ, a guideline value set by the WHO. Three out of the ten sampling sites had river water levels higher than the set limit suggesting that the direct use of the river water for drinking can be detrimental. Iron is one of the most abundant elements in the earth; hence the elevated levels found especially in the sediment samples were expected. This assertion does not rule out the possibility of anthropogenic sources of this metal into the freshwater systems as there were several steel industries within the industrial areas of both rivers which could significantly contribute to the observed levels.

The organic matter content of sediment samples ranged from 0.26 to 2.58%. Organic matter is the organic fraction of decomposed plant and animal residues that plays critical roles in water retention, aggregation and soil structure. Organic matter has great influence on the mobility, flux as well as the availability of heavy metals, especially in the aquatic environment. Although all the metals investigated showed positive correlation with the organic matter, only Zn (r= 0.638), Ni (r= 0.771) and Fe (r= 0.811) showed a statistically significant positive correlation with the organic matter. These metals had significant positive correlation at 0.01 level except Zn which showed a significant correlation at 0.05 level.

An attempt was made to compare the results of the heavy metal analysis with similar studies around the world to establish the degree of industrial pollution of surface water of the investigated rivers. The evaluation showed that the average levels of all the metals in river water samples were higher than the 'world average' reported for freshwaters. These were also relatively higher than those reported in other similar studies except for the South African study where higher levels of some of these metals were reported. Of greater concern is the fact that most of these metals had average values which exceeded the WHO guideline limit for drinking water. It is therefore necessary to stress that the exposure of vulnerable groups (i.e. infants and young children) in local communities who depend on this water bodies as source of drinking water would be most affected. The higher average level of Pb is of utmost concern as it is known to exert its toxic effects on the developing brains resulting into a condition termed encephalopathy.

The average levels of these metals in bottom sediment samples were generally lower than those reported in other studies except for the South African study where lower levels were observed. This trend might be due to the significant contribution of bottom sediment to the overall heavy metal content of the river water samples. The high turbulence witnessed in most parts of these rivers could greatly affect the deposition of suspended solids thus influencing the metal distribution in these rivers. Although most of these metals occur naturally in the environment, their detection at levels higher than their natural background levels is indicative of additional sources of these metals into the investigated rivers.

5. Conclusion

The evaluation of the surface water quality at different sampling sites over the stretch of both rivers has been conducted. The pattern exhibited by most of the physicochemical as well as inorganic and organic parameters monitored revealed that the negative impacts of industrial discharges were quite significant in both rivers. However, the detection of relatively high levels of some of these parameters at the upstream of both rivers especially River Alaro suggests that sources other than industrial discharges are also contributing to the water quality deterioration of these rivers.

The heavy metal contamination of these rivers was more pronounced in River Ona than in River Alaro. This is because the average levels of at least four out of the six metals were higher in the industrial zone than in the upstream region for water and sediment samples of River Ona whereas only two of the six metals had higher average levels in the industrial zone than in the upstream region of River Alaro for the sediment samples. Interestingly, the levels of most parameters monitored downstream were significantly elevated than the levels found in the upstream before the convergence of these rivers. The influx of discharges via other notable rivers and streams into River Ona further downstream was responsible for the observed trend.

Sample type/Location	**Metals**						**Reference**
River water (µg/ℓ)	Pb	Zn	Cu	Cd	Ni	Fe	
R. Gomti, India	4.00–55.0	30.0–91.0	0.00–35	BDL	73.0–105	NR	Gaur et al. (2005)
Diep River, South Africa	0– 0	100–4400	– 800	NR	0.00–400	100–513000	Jackson et al. (2009)
Niger Delta Rivers, Nigeria	8.08	15.2	11.3	1.61	6.00	383	Kakulu and Osibanjo (1992)
Ona and Alaro Rivers, Nigeria	94.5	180	25.6	3.70	69.5	1180	**This study**
World Average for freshwater	1.00	30.0	10.0	NR	2.20	40	Ikem and Adisa (2011)
WHO limit	10	NGV	2000	3	70	NGV	WHO, 2006
Bottom sediment (µg/g)							
Ottawa River, Canada	26.0	84.0	28.0	NR	22.0	9200	Oliver (1973)
R. Calabar, Nigeria	31.0	184	64.0	0.30	67.0	30,800	Ntekim et al. (1993)
R. Derwent, England	96–3120	82–2760	NR	0.6–13.8	NR	NR	Burrows and Whitton (1983)
R. Gomti, India	5.80–100	14.9–182	3.89–91.2	0.41–17.3	5.32–57.6	NR	Gaur et al. (2005)
Pearl River, China	168–264	268 -426	49.3–69.0	7.2–7.8	42.1–65.1	NR	Cheung et al. (2003)
Tyume River, South Africa	0.04–0.07	0.08–0.49	0.08–0.50	ND–0.005	0.40–0.98	NR	Awofolu et al. (2005)
Ona and Alaro Rivers, Nigeria	26.2	54.7	5.70	4.68	10.5	3570	**This study**

BDL – below detection limit; ND – not detected; NGV – no guideline value given; NR – not reported.

Table 4. Comparison of heavy metal concentrations in water and sediment samples with the other studies around the world

The non-point intrusion of seepage from indiscriminately dumped solid wastes in the drainages and along the banks of major rivers within the city was responsible for the elevated levels of most parameters found at the upstream of the rivers investigated in this study. The perennial flood disaster witnessed in the city in recent times would persist unless measures are taken to address the problems of solid wastes management. The inadequate attention given to environmental issues in the past is being reflected in the form of serious ecological problems. To overcome these challenges, government must be proactive in its attempts to address environmental issues as anything short of this would amount to huge losses in the form of properties and human lives.

Furthermore, there is need to strengthen the government agencies responsible for waste management in the city. Waste management is capital intensive, has the potential to deliver good returns on investment and can provide countless number of jobs if properly managed. The heavy duty machineries required for handling these wastes must be maintained at all times so as to prolong their lifespan. Since one of the factors contributing to the poor environmental conditions in the city is illiteracy, government must embark on vigorous environmental education to enlighten the people about the consequences of untidy environment. This could even be integrated into the school curricula of primary and secondary school students to provide a forum whereby good ethics can be inculcated into these young children.

The roles of the legislative instrument to forestall these problems must not be overlooked. Government must critically review relevant environmental laws and amend them appropriately so as to be able to address immediate environmental challenges. The relevant authorities must ensure that personnel responsible for the enforcement of these laws demonstrate a sound understanding of the laws enacted. Appropriate sanctions in the form of fines must therefore be levied on the violators of these laws regardless of their societal status. The implementation of these recommendations would assist in proffering a lasting solution to solid waste management problems and this would directly or indirectly enhance the quality of water bodies within the city.

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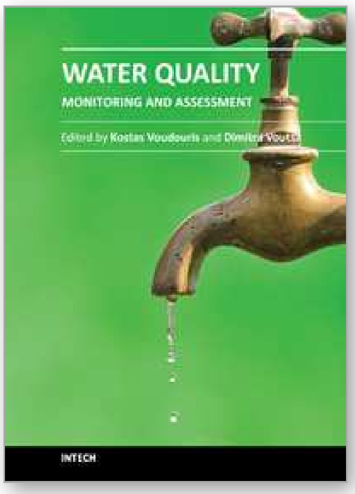

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