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Full Length Research Paper

Spatial and water quality classification of tributaries of Osun River network in Nigeria

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Osun River is important for domestic, recreational and other activities. It flows along a channel that may be polluted by inputs from industrial, agricultural and other anthropogenic activities. Surface water was sampled bimonthly from July 2006 to May 2008 at upstream and downstream points of the main river course and 31 tributaries. Water samples were analyzed for pH, alkalinity, hardness, ammonia, anions and turbidity. Statistical evaluation of data was carried out. The concentrations (mg/L) of alkalinity, hardness, ammonia, nitrate, phosphate and chloride were 93±130, 116±120, 4.2±6.6, 1.8±1.5, 0.15±0.23 and 54±110 and turbidity, 34±43 FTU. Spatial classification revealed tributary at Adeti (Ilesha) to be strongly polluted compared to other tributaries. All the tributaries met requirements for irrigation, recreation and livestock rearing, but they need pretreatment for other categories of industrial usage. Fifty-three locations were acceptable (Class 2), and four excellent (Class 1). Time series modelling, using Number Cruncher Statistical System fitted well for nitrate (R2= 0.79) and phosphate (R2= 0.84) data and gave their 2018 predicted values of 19.2 and 18.1 mg/L.

Keywords: Modeling, Osun River, tributaries, spatial variation, water quality.

INTRODUCTION

Pollution is the introduction of contaminants into an environment, of whatever predetermined or agreed upon proportions or frame of reference. Pollutants, the elements of pollution, can be foreign substances or energies, or naturally occurring. When water becomes contaminated above the normal permissible level, it can be termed as contaminants. Industrial growth is fast increasing globally, and so is the water demand for industrial productions or processes. River water quality is often a useful indicator of the state of community health in underdeveloped countries, where, because of inadequate supply of treated tap water, river water serves as a direct source of drinking water, in addition to its normal uses for irrigation, recreation and fishing. The impairment of river in urban settlements of such communities has been shown to be the primary source of health hazards in some cases (Oboh and Agbala, 2017).

Water the elixir of life, constitutes about 70% of the body weight in living beings (Singh *et al.* 2013; Singh and Kamal, 2014) but unfortunately only 1% out of whole earth's water is available in rivers, lakes, streams reservoirs and ground water is suitable for living being consumption, 2% locked in polar ice caps, and 97% is in the ocean. Water related issues were a major source of concern to developing countries and international agencies like WHO, FAO, UNICEF, UNDP among others.

These problems have challenged engineers in the water sector and other stakeholders to effectively develop and manage the water supply system (Al-Naeem, 2011). Asonye *et al*. (2007) examined heavy metals profiles of seventy two Nigerian rivers, streams and water ways in Southwestern Nigeria and found out that most of the metals studied were above the WHO and EEC guide limits implying that some of the rivers are toxic and might pose serious risks to the health of communities residing around and using these surface waters for domestic, commercial and socio-cultural purposes. Different types of industries exist and most of these, especially in Nigeria, do not treat their waste before being disposed. For example,

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Fakayode (2005) reported that the water qualities of Alaro River in Ibadan, Nigeria were adversely affected and impaired by the discharge of industrial effluent. The quality of the industrial effluent discharged into Alaro River was poor and did not meet the minimum requirement for discharged into surface water.

Also, the transfer of unfavourable releases from industries is detrimental to human and animal health and safety (Adekunle and Eniola, 2011). Investigation of the effect of brewery industries at different locations in Benin, Ibadan, and Lagos on surface water was reported by Folasegun and Kolawole (2008). Ipeaiyeda and Onianwa (2009) also reported significant levels of chloride, nitrate, ammonia, dissolved solid, turbidity and reduced pH downstream the river network of Olosun River in Ibadan, Nigeria, as a result of brewery effluents into this river.

The Osun River Channel

The Osun River lies on the latitude 08^{o}20′N and 6^{o}30′N and longitude 05^{o}10′N and 03^{o}25′E in the forest zone of Nigeria. It flows southwards through central Yoruba-land in South western Nigeria into the Lagos Lagoon and the Atlantic Gulf of Guinea. Osun River is perennial and its volume fluctuates with seasons. It flows through a narrow valley throughout its course across basement complex rocks and incised to the bedrock along many reaches. The river originates from Igede Ekiti (Ekiti State) and flows through many agricultural plains and cities of about 267 km. The drainage system of Osun River rises in Oke- Mesi ridge, about 5 km North of Effon Alaiye on the border between Oyo and Ondo States of Nigeria. It flows North through the Itawure gap to latitude 7^{o}53′ before winding its way Westwards through Osogbo and Ede and Southwards to enter Lagos Lagoon about 8 km east of Epe. It is underlain by metamorphic rocks of the basement complex, which outcrop over many parts. Rocks of the basement complex found here are schists, associated with quartzite ridges of the type found in Ilesha area. The metamorphic rocks are largely undifferentiated, but specific rock groups are identified. The first group consists of the migmatite complex, including bandid magmatic and auguengnesses and pegmatites which outcrop in Ilesha and Ife areas. Metasediments consisting of sciests and quartzites, calsilicates, metaconglomerates, amphibolites and metamorphic iron beds make up the second group. They are found in two Ikire areas (Tahal, 1976).

A variety of natural and human factors can affect the quality and use of the Osun River through the tributaries. Majorly, the kinds of land use activities in this study area are agriculture, transport, residential and commercial. A number of studies have shown that the density of population and housing can affect the concentrations of chloride and nitrate in streams that drain urban and suburban settings. Kumar *et al.* (2018) observed in their study that hydrological changes were not correlated with land use/land cover changes. They recommended that in order to manage water resources and develop the entire catchment of a river, a rational regulation policy for land use patterns is vitally important to assist stakeholders and policy makers.

The major occupation of the people living along the drainage area of the river is farming, but there are also some industries located near the river and its tributaries. More than 75% of those living along the river course are farmers (Osun State Website, 2009). Consequently, crops such as cocoa and palm produce that are produced in commercial quantities serve as raw materials for those industries that manufacture cocoa and chocolate-based products. River Osun flows through the forest zone in Nigeria, with the abundance of forest; it makes it a haven for any wood-based industry. The farmers living along the bank of the river and its tributaries produces commercial quantities of food crops such as yam, cassava, millet, rice as well as a variety of fruits. In this vein, these foods serve as raw materials for fruit and rice processing industries. Cocoa and kolanut are produced in large quantities. There are many poultry farms, fish ponds located along the banks of this river and its tributaries. Wastes from these farms are used as manure for crops, feed for fish or dumped into the bush and when it rains these get carried away into Osun River and its tributaries and impair the water quality. With regards to mineral resources, there have been discoveries of various mineral deposits at different locations along the course of the river and its tributaries. Domestic human wastes such as human excreta, urine and associated sludge (collectively known as black water) and waste generated through bathing and kitchen (collectively known as grey water) are not left out in this pollution saga. Sewage from large and small towns is discharged either into a water body or discharged on land for irrigation. Wastes entering these water bodies are both solid and liquid forms. They are mostly derived from various industries along the Osun River channel, agricultural and domestic activities. Point source pollution contributes to pollution of Osun River and it includes sewage treatment plants, untreated industrial discharges, or any type of a discharge from a location into a nearby stream. Non-point source, however, include run offs from road sorfields which are often diffuse sources of contaminants. The pollutants from point sources will always increase as flow increases during storm runoff. The type of severity of these pollution sources often are directly related to human activities especially by the uninformed inhabitants who discharge all forms of wastes into the river channel, which can be easily quantified by the concentration and the land use and the population of man and animals around the source-water areas.

The distribution of various industrial activities in the Osun River network is as shown in Figure 1.

Reports on the assessment of the physicochemical characteristics of Osun River in the literature are scarce. Very little research work has been carried out on the physicochemical characteristics of the river water, sediments and vegetation. Some researchers in the previous studies failed to carry out sufficiently detailed work on the physicochemical characteristics of River Osun with regards to the types of parameters studied, duration of the study and the number of sampling points used.

For example, Olajire and Imeokparia (2001) in their study did not investigate the level of gross organic pollutants. The investigation was only carried out in the rainy season and for only three consecutive months of only one year. Adeboye and Alatise (2009) carried out their investigation on the estimate of flooding at Apoje station alone for only two consecutive months using data previously collected. The study did not carry out comparison with other sub-stations to know where flooding will occur later.

The aim of this study was to investigate the current status of the quality of River Osun in order to take into account the knowledge gaps in the literature on the subject. In achieving this, the scope of work was meant to achieve the following objectives:

1) To determine in detail the physicochemical characteristics of Osun River and its tributaries using surface water which other researchers are yet to investigate

2) To use the following tributaries of Osun River at their respective locations shown in bracket to carry out the investigation: Asejire (Ikire), Osun (Ede), Gbodofon (Osogbo), Ahoyaya (Ikirun), Isin (Iree) , Oyi (Oke-Ila), Osin (Ila-Orangun), Oloyo (Ibokun), Enja (Igbajo), Ashasha (Imesi Ile), Ounseku (Oyan), Kankere (Awo), Aro (Ejigbo), Arenounyun (OtanAiyegbaju), Oba (Iwo), Moginmogin (Apomu), Ope (AraromiOwu), Awsein (Ifon), Ojutu (Ilobu), Anne (Okuku), Aro*(Iragberi), Orufu (Bode Osi), Odoiya (Ilawo), Ishahsha (Odeomu), Adeti (Ilesha), Oni (IjebuIjesha), Etioni (Ifetedo), Oyika (Iperindo), Olumirin (Erinjesha), Yeyekare (EsaOdo) and Opa (Ife).

3) To study the physicochemical characteristics of River Osun and its tributaries bimonthly for twenty-four months from July, 2006 to May, 2008.

4) Comparison of the data obtained in wet (winter or rainy) and dry (summer) seasons for seasonal variations.

5) Pratti scale modeling of the data to study the degree of pollution for alllocations.

6) To investigate the industrial usage and other requirements of the tributaries.

7) Statistical analysis of the data obtained.

MATERIALS AND METHODS

Design of the Study

In meeting the objectives of the study, surface water was studied from July, 2006 to May, 2008 for a period of twenty-four months and samples collected bimonthly. A total number of 1,080 surface water samples (12 field trips at 90 sampling points each) were used for the study. Surface water was studied for pH, electrical conductivity, total solid, total suspended solid, turbidity, alkalinity, hardness and anions such as phosphate, sulphate, nitrate, chloride and ammonia. Modeling used for the quality characteristics of surface water include Pratti scale quality classification with data obtained fitted into Pratti scale model for surface water classification (Class I - V) and time series modeling for trend and seasonality analysis.

Figure 1 describes the types of industries located along the river banks. The wastes generated from these various activities impair the water quality of the study area. The sampling points are as shown in Figure 2. Thirty-one tributaries of River Osun were used. The length of Osun River is 267 km.

Sampling

Sampling for physicochemical parameters

Samples for physicochemical analysis involved taking at intervals along middle of the river (using a canoe) and at the river banks.

Some parameters require in situ analysis. These are pH, EC, temperature, total dissolved solid, for these, handheld portable meters were gently dipped into the river and value recorded. Collection and sample analysis for these are described separately under analysis of surface water. Physicochemical parameters in surface water samples collected were determined using standard methods (USEPA, 1979; APHA-AWWA-WPCF,1998;

Department of the Environment, 1972). pH was determined by directly dipping the battery operated pH meter (HANNAH HI96107) in a plastic container containing the surface water sample. Calibration was carried out using buffer solutions of pH 4.0 and pH 7.0.

Electrical conductivity was determined by dipping the portable EC meter (COM-100 model) into plastic container containing 200mL of the surface water. Calibration was carried out using 0.001MKCl. The temperature meter (COM-100 model) was dipped directly into the river and temperature was measured and recorded immediately. Total solid was determined gravimetrically, TDS was determined using a portable TDS meter (COM-100 model) calibrated with two solutions: 0.02M KCl and 0.20M KCl. Total suspended solid (TSS) was calculated as the difference between total solids and total dissolved solids. Turbidity determination was done spectrophotometrically. Alkalinity, Hardness, Calcium, Magnesium were determined by APHA-AWWA-WPCF (1998). Nitrate was determined using phenol disulfonic acid method (Gary, 1994), Chloride by mercurimetric titration, ammonia by direct nesslerization colorimetrically, sulphate determined spectrophotometrically, phosphate was determined using the ammonium molybdate spectrophotometric method.

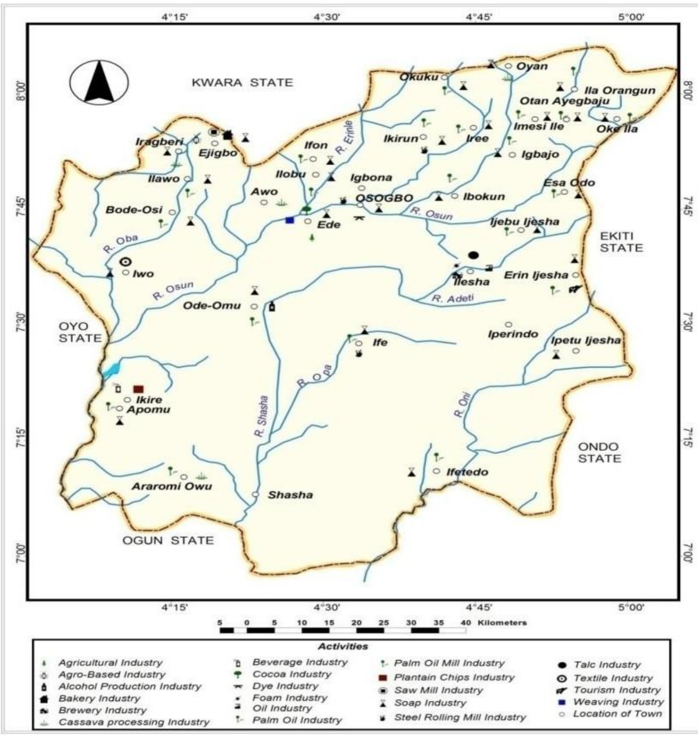

Fig. 1. Map of Osun River showing various industrial activities.

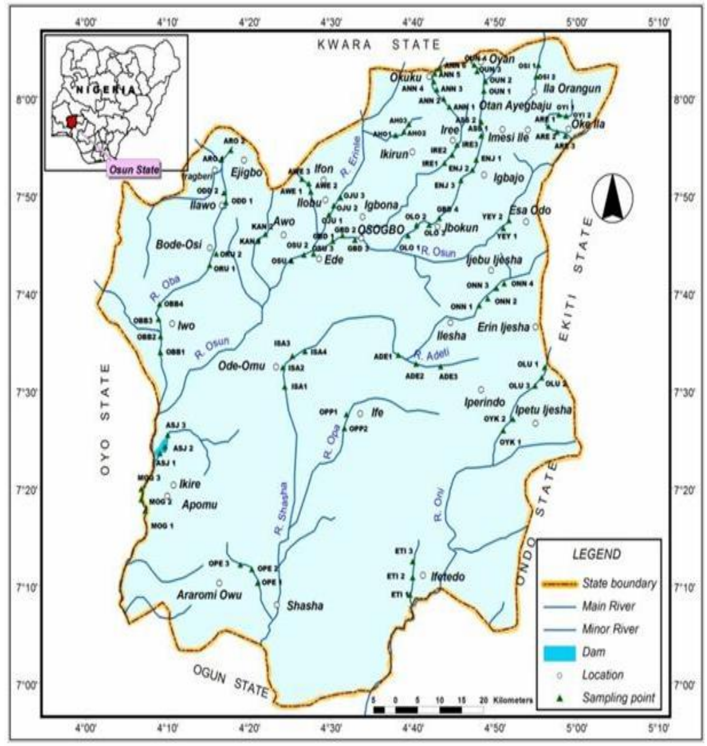

Fig. 2. Location of sampling points on Osun River and tributaries.

Pratti scale classification of surface water quality

Table 1 was used to model the surface water data obtained into different classes. The water samples collected for each of the 90 locations for the study were used for this classification. The classification was based on the average values of the concentrations of some parameters (pH, ammonia and suspended solids) according to Pratti *et al*. (1971). The interpretation of these various classes are:

Class 1 – excellent
Class 2–acceptable
Class 3 – slightly polluted
Class 4 – polluted
Based on Table 1, the surface water collected for each location was classified.

Time series modelling of surface water and sediment quality

The data obtained for surface water were subjected to time series analysis and forecasting (seasonality) using the Number Cruncher Statistical System (NCSS) (Lynwood *et al*., 1990). This was used to determine the pattern of distribution of specific parameters and to project the concentrations up to year 2018. Time series used involved trend and seasonality analysis, with the use of exponential smoothing to observe the trend and seasonality. Smoothing in time series involves some form of local averaging of data such that the non-systematic components of individual observations cancel each other out. This method filters out the noise and converts the data into a smooth curve that is relatively unbiased by outliers.

RESULTS AND DISCUSSION

Average characteristics (overall) of surface water

Average electrical conductivity was 216±380 µS/cm. The electrical conductivity was higher compared to the amount obtained at the control site as illustrated in Table 2. EC in the water body was most likely derived from limestone due to dissolution of carbonate minerals (Michaud, 1991). However, it was found to be within the SON (2007) limit for drinking water quality guidelines (1000 µS/cm) and guides for evaluating the quality of water for aquatic life (3000 µS/cm).

Table 1. Pratti scale classification of surface water.

Parameter	Class 1	Class 2	Class 3	Class 4	Class 5
pH	6.5-8.0	6.0-8.4	5.0-9.0	3.9-10.1	3.9-10.1
NH_3	0.1	0.3	0.9	2.7	>2.7
SS	20	40	100	278	>268
Class I	=	Excellent			
Class II	=	Acceptable quality			
Class III	=	lightly polluted			
Class IV	=	Polluted			
Class V	=	Heavily polluted			

The average characteristics of the Osun River network was determined based on the mean of the data obtained at each point of each tributary for twenty-four months of the study period for each physicochemical characteristics. pH of the study area was 7.6±0.5. The pH was found to be comparable to what was obtained at the control site. This suggests that the overall pH of waters of Osun River tend to be alkaline and will be suitable for some species of fish and other aquatic organisms. High pH could alter the toxicity of other pollutants; it can also alter recreational uses of water. Temperature obtained was 25.3±2.6 ^{o}C. Temperature at the control site was found to be higher compared to what was obtained for the study. Temperature depends on the weather, sunlight and depth, and does not undergo changes during the year in the fluvaitile environment (Gupta, 2006; Akinyemi and Nwankwo, 2006) as compared to lacustrine environment. Generally, most of the locations in the study area were shaded with trees. Temperature was found to comply with all the guidelines for all the industries and guides for evaluating the quality of water for aquatic life and recreational water quality. Total solid (TS) was found to be higher in the study area compared to the control site. Osun River was found to be impaired with solids from various sources and it is as shown from the factor of accumulation obtained (2.32). TS were derived from the introduction of waste into Osun River. It was found to be within the limit of most of the industries but exceeds the threshold for light brewing industry (500 mg/L), pulp and paper industries (ground wood, 500mg/L) and tanning industries (100mg/L). Total dissolved solids obtained for the study was 111±200 mg/L. It was found to be higher compared to the level derived from control site with an accumulation factor of 1.79. The value indicates that the quality of the river water was impaired as a result of dissolved particles in the river. It was however noticed to be within the limits for all drinking water quality guidelines and within limits for some categories of industries except power generating industry for boiler feed water (<0.5mg/L) and food and beverage industry (Confectionary, 50 – 100mg/L). The total suspended solid for the study was 435±500 mg/L. This signifies that the river contained some suspended particles in the river that cannot dissolve and thus, impair the quality of the river and sometimes its aesthetic properties. Suspended solids are not desirable in water used for drinking and bathing. The value of total suspended solids obtained in this study has also been reported by a survey conducted by Ogunfowokan *et al*. (2005) where a high level of total suspended solids values (200.00±3.11 - 500.00±7.10 mg L^{-1}) were reported for a University sewage treatment oxidation pond at Ile-Ife. High levels obtained can affect the health of the aquatic ecosystem and can also have a deleterious effect on the health of rural dwellers that use the water for domestic purposes without treatment. The overall turbidity for Osun River was 34±43 FTU. The flow rate of a water body is a primary factor influencing turbidity. Fast running water can carry more particles and larger-sized sediment. The turbidity of Osun River was found to be higher than what was obtained at the control site as shown in Table 2, signifying contamination of the river. High TSS does not mean high turbidity and versa (Matthew and Michael, 2001). This anomaly may be explained by the fact that particles are effective at dispersing light and causing high turbidity readings, while not resulting in high TSS. On the other hand, large organic or inorganic particles can be less effective at dispersing light, yet their greater mass results in high TSS level. Alkalinity recorded in the river was 93±13mg/L.

Table 2. Average Characteristics of Surface Water for all Tributaries.

Parameters	Concentration	Control Area	Accumulation Factor (AF)
Electrical Conductivity(µS/cm)	216±380	101±45	2.14
pH	7.6±0.5	7.6±0.2	1.0
Temperature (^{o}C)	25.3±2.6	27.5±2.0	0.92
TS (mg/L)	546±570	235±75	2.32
TDS (mg/L)	111±200	62±24	1.79
TSS (mg/L)	435±500	187±69	2.33
Turbidity (FTU)	34±43	1.3±3.4	26.2
Alkalinity (mg/L)	93±13	66±25	1.41
Hardness (mg/L)	116±120	61±36	1.90
Nitrate (mg/L)	1.80±1.50	0.70±0.30	2.57
Sulphate (mg/L)	39±30	35±82	1.11
Phosphate (mg/L)	0.20±0.20	0.05±0.03	4.00
Chloride (mg/L)	55±110	33±8	1.67
Ammonia (mg/L)	4.20±6.60	1.50±0.50	2.80

This level is high compared to what was obtained at the control site as shown in Table 2. Measuring alkalinity is important in determining a stream's ability to neutralize acidic pollution.

Hardness value was 116±120 mg/L. This value was higher compared to what was obtained at the control site. It was found to exceed the limit for certain industrial applications such as textiles, general dyeing and boiler feed, pulp and paper, iron and steel, power generating stations (boiler feed water, <0.07mg/L), food and beverage industry (brewing, < 70 mg/L) and sugar manufacturing. Nitrate level was found to be 1.8±1.5 mg/L. This concentration was higher compared to the level at the control site, with an accumulation factor of 2.57. This signifies some level of contamination of the Osun River. Nitrate is a major ingredient of farm fertilizer and is necessary for crop production. When it rains, nitrate may be washed from farmland into nearby waterways. Nitrates stimulate the growth of plankton and water weeds that provide food for fish and increase fish population. Sulphate level was 39±30 mg/L. This value was higher compared to what was obtained for the control site with an accumulation factor of 1.11. This result suggests that the water quality of Osun river system is affected and impaired by the discharge of domestic, agricultural and industrial wastes and other sulphur containing substances. The level however complied with all the guidelines on drinking water quality standards, all guidelines for various industries except sugar manufacturing where the value exceeds the recommended limit of <20 mg/L. The overall concentration of phosphate was 0.20±0.20 mg/L. This level was about four fold of the level obtained in control sample. The accumulation factor (4.00) suggests contamination of Osun River compared to the control site. The level of phosphate in the study area was derived from anthropogenic activities. Izonfuo and Bariweni (2001) also recorded low phosphate concentrations (0.19±0.07 mg/L – 0.33±0.17 mg/L) in Epie Creek in Niger Delta, which were lower than the limit for drinking water. Olele and Ekelemu (2007) recorded a low concentration of phosphorous in Tigo Lake (0.03mg/L) and Victoria Lake (0.14mg/L). The concentration of chloride was 55±110 mg/L. This level was higher compared to the level at the control site, with accumulation factor of 1.67. Chloride in water might be derived from anthropogenic activities. Chloride was found to comply with all the drinking water guidelines but outside the range for dairy and sugar manufacturing industries. The level of ammonia in river Osun was 4.20±6.60 mg/L. In nature, ammonia is formed by the action of bacteria on proteins and urea at high pH values (pH >8.5) and is extremely toxic to fish and other aquatic life at high concentrations (>2.0mg/L N). The level of ammonia in this study was higher than the value obtained at the control site, with an accumulation factor of 2.80. This factor suggests a contamination of the surface water quality. The level was higher than level stipulated by S. O. N. (2007) for drinking water, and outside the range for power generating stations (boiler feed water) and guides for evaluating the quality of water for aquatic life. Paired t-test was used to check if there were significant differences between the means obtained for the revealed study area and control area. The result that the means were found not to be statistically significant except for pH, turbidity, hardness, temperature, nitrate and ammonia.

Average characteristics of surface water of the various tributaries

The average characteristics of surface water for the thirty-one tributaries of Osun River studied are as shown in Table 3. The value for each parameter shows the mean concentration obtained for each tributary at a specific sampling location. Electrical conductivity at Adeti was found to be higher than EC stipulated by S. O. N. (2007) for drinking water guidelines. This was due to the various discharges of all forms of waste into river Adeti. The physical appearance of the river looks so dirty. pH of all the tributaries was found to be higher than the level stipulated for certain industrial applications. The pH of these tributaries was alkaline. All tributaries had total solids higher than the limit stipulated for certain industrial applications for tanning. Thirteen of the tributaries had values higher than limits for certain industrial applications for light brewing and pulp and paper industry (ground wood). Adeti had values higher than what was stipulated for brewing but was found to be within the limit for general dyeing boiler feed and paper industry (for bleached paper). Only one of the tributaries had TDS that exceeds the limit for drinking water quality guidelines and for use in the paper and pulp industry (Unbleached). Six out of the tributaries had their TSS values greater than the value recommended for dairy production. All the thirty one tributaries exceeded the limit stipulated for boating/aesthetic for recreational water quality. All the tributaries had total suspended solids higher than the value prescribed for food canning, freezing, dried, frozen fruits and vegetables.

Pratti Scale Classification of the River Waters

The water samples, collected for each of the 90 locations, for the thirty-one tributaries in the study were used for this classification. The classification was based on the average values of the concentrations of the parameters according to Pratti *et al*. (1971). The interpretation of these various classes are:

Class 1 – excellent
Class 2 – acceptable
Class 3 – slightly polluted
Class 4 – polluted
Class 5 – heavily polluted

Based on Table 1, the locations used were classified. Table 4 shows the quality classes that each of the locations belongs to. The study reveals, four of the locations showed excellent surface water quality and these account for 5%. Fifty-three of the locations showed acceptable surface water quality and accounts for 59%. Thirty-one of the locations were slightly polluted, accounting for 34%; while two of them were polluted and accounted for 2%. Ishasha (ISA-1), Isin (IRE-2, IRE-3) and OYI-1 had excellent surface water quality. This suggests why some residents along these tributaries fetch and drink water from these sources. Fifty-three locations have acceptable surface water qualities, included those on the tributaries.
Osun, Gbodofon, Ahoyaya, Isin, Osin, Oloyo, Enja, Ashasha, Ounseku, Odoiya, part of Ishasha, Oni, Etioni, Olumirin, Aro, Oba, Ope, Anne and Aro*. Olumirin is a tourist centre and pollution activities around this vicinity are minimal. But the downstream point however was exposed to visitors and anthropogenic activities, which accounted for the slightly polluted nature of this water body, downstream. Thirty-one locations had slightly polluted surface water quality as a result of industrial, agricultural and municipal activities. These included those on Asejire, Osin, Oloyo, Ounseku, Kankere, Arenounyun, Oba, Moginmogin, Awesin, Ojutu, Anne, Orufu, Adeti, Oyika, Yeyekare and Opa. Two percent of these locations account for the polluted nature of surface water of Osun River and are located on Moginmogin (MOG-2) and Asejire (ASJ-2) as a result of the activities along this watercourse.

Spatial variations of physicochemical characteristics in surface water of Osun River

Figures 3.1 - 3.14 illustrate the spatial variations of each physicochemical characteristic observed for all the tributaries used in this study. It can be noticed that for each of the parameters for all the tributaries, the concentration of the parameters varies depending on the tributary. This is as a result of different environmental factors of industrial, urbanization and agricultural activities.

Seasonal variations of the physicochemical characteristics in surface water

Table 5 shows the variations in the physicochemical properties of Osun River in the wet (winter or rainy) and dry (summer) seasons.
No significant seasonal variation was recorded for temperature as shown in Table 5. Temperature depends on the climate, sunlight and depth and does not undergo changes during the year in the fluvaitile environment (Gupta, 2006) as compared to lacustrine environment. Parameters with high concentrations during dry seasons include electrical conductivity, total solids, total dissolved

Table 3. Average characteristics of the tributaries of Osun River.

Parameter	Oyi (OYI)	Osin (OSI)	Ounseku (OUN)	Arenounyun (ARE)	Ashasha (ASS)	Isin (IRE)	Anne (ANN)	Ahoyaya (AHO)	Enja (ENJ)
EC	71±32	179±84	99±46	229±150	242±160	136±120	128±49	320±390	91±51
pH	7.4±0.6	7.2±0.5	7.2±0.5	7.7±0.5	7.7±0.3	7.4±0.4	7.5±0.6	7.5±0.3	7.1±0.5
Temperature	23±2	24.6±2.3	22.9±2.1	26.0±2.1	25±2	26.5±1.7	26.0±2.2	26.7±2.7	24.3±2.0
TS	342±210	507±280	457±370	511±350	453±190	520±380	485±330	685±690	352±270
TDS	37±19	92±44	31±25	123±89	118±90	71±62	66±29	169±200	47±30
TSS	305±210	415±290	405±370	388±340	335±180	448±360	419±330	516±650	305±280
Turbidity	27±27	38±53	53±41	37±39	31±41	36±36	15±15	57±66	72±79
Alkalinity	41±9	80±24	58±23	89±17	85±34	68±63	64±15	109±98	49±20
Hardness	95±95	135±130	101±99	133±140	139±140	110±120	123±110	139±160	87±100
Nitrate	1.0±1.0	1.8±1.2	2.2±1.7	2.0±1.2	3.0±3.6	1.6±1.0	1.9±1.7	2.2±1.2	2.5±2.2
Sulphate	30±22	31±25	50±23	36±22	34±28	38±23	22±19	42±32	64±46
Phosphate	0.10±0.10	0.10±0.10	0.10±0.10	0.10±0.10	0.20±0.20	0.10±0.10	0.10±0.10	0.30±0.40	0.10±0.10
Chloride	17.7±9.7	32±13	17±12	45±23	41±28	28±21	23±17	501±39	25±15
Ammonia	3.2±2.6	2.9±1.4	4.5±3.3	3.9±3.0	3.2±2.7	4.4±4.2	3.6±2.9	5.3±4.4	4.6±2.6

solids, total suspended solids, alkalinity, hardness, phosphate, chloride, ammonia, nitrate. Oguunfowokan *et al.* (2005) reported a high total solid of (900±8 - 500±9 mg/L) and high suspended solids values of (500±7 - 200±3mg/L) in their study and this was as a result of waste water, which entered the river, which contains human excreta, urine and other semi solid wastes. Strahler and Strahler (1973) stated that all rainfall wherever it occurs carries with it a variety of ions, some introduced into the atmosphere from the sea surface, some from land surfaces undisturbed by man and some from

Table 3. Cont.

Parameter	Oloyo (OLO)	Gbodofon (GBD)	Awesin (AWE)	Ojutu (OJU)	Osun (OSU)	Yeyekare (YEY)	Oni (ONN)	Olumirin (OLU)	Orufu (ORU)
EC	80±53	173±100	243±170	113±45	139±81	139±77	113±69	39±39	55±11
pH	7.5±0.6	7.6±0.4	7.7±0.4	7.6±0.4	7.8±0.5	7.4±0.6	7.7±0.6	7.5±0.6	7.9±0.5
Temperature	23±2	26.2±2.1	26.7±1.5	26.9±1.8	25.1±1.9	24.0±1.7	23.0±1.9	23.4±2.0	26±1.4
TS	459±380	659±410	700±500	491±40	559±460	310±230	397±270	311±280	284±290
TDS	40±26	89±54	128±94	58±27	70±41	69±39	57±35	19±15	27.2±5.90
TSS	419±370	570±400	570±480	432±400	489±460	241±240	339±270	292±280	257±290
Turbidity	30±23	43±51	74±92	28±40	25±29	19±20	35±42	16±14	72±69
Alkalinity	52±24	70±26	101±138	58±15	65±29	71±20	59±19	28±11	53±27
Hardness	86±110	112±100	119±120	96±79	86±53	90±53	82±47	59±38	37±23
Nitrate	1.3±0.8	1.7±1.6	2.8±2.6	2.4±1.3	1.3±0.7	1.4±0.8	1.5±0.7	1.6±0.6	1.3±0.9
Sulphate	39±29	43±29	53±49	25±11	33±18	35±20	31±16	26±12	59±52
Phosphate	0.10±0.10	0.20±0.10	0.30±0.30	0.10±0.10	0.10±0.10	0.10±0.10	0.10±0.10	0.10±0.10	0.10±0.10
Chloride	27±14	38±24	53±28	25±11	31±14	27±12	30±15	26±12	18.0±9.5
Ammonia	3.4±2.0	3.1±1.8	4.8±4.8	2.4±1.3	2.9±2.5	2.7±1.2	2.8±1.5	2.6±0.8	5.5±3.3

man-made sources. The ions and other substances carried into the streams or rivers via rainfall may result into pollution. These ions during dry season now get concentrated because there is no rain to wash them away.

The increase in nitrate and phosphate level in the dry seasons could lead to eutrophication in the nearest future if not controlled. Those parameters that showed higher concentrations during wet seasons include pH, turbidity and

Table 3. Cont.

Parameter	Kankere (KAN)	Adeti (ADE)	Aro (EJI)	Aro* (ARO)	Odoiya (ODD)	Oba (OBB)	Oyika (OYK)	Etioni (ETI)	Ishasha (ISA)
EC	198±82	1760±1200	143±88	147±89	83±31	192±140	53±24	98±54	212±130
pH	7.4±0.5	7.8±0.4	7.6±0.4	7.6±0.5	7.5±0.6	7.7±0.5	7.4±0.5	7.5±0.4	7.8±0.5
Temperature	25.1±1.3	24.7±2.2	24.4±2.4	24.3±2.3	26.1±1.4	26.4±1.9	24.9±1.9	26.3±1.9	25.5±1.7
TS	538±320	2000±1800	412±300	385±330	443±360	493±370	285±190	409±280	612±440
TDS	102±45	893±610	71±45	73±45	41±16	95±71	26±13	49±27	107±69
TSS	436±330	1110±1800	341±290	312±330	401±360	398±340	258±190	360±280	506±480
Turbidity	27±22	37±37	15±13	35±53	32±23	34±30	19±21	22±17	28±22
Alkalinity	72±26	657±280	72±18	102±63	53±27	82±40	36.1±2.3	54±19	98±41
Hardness	107±61	401±210	94±75	96±110	37±23	106±89	61±42	70±40	129±120
Nitrate	1.5±0.8	2.8±2.7	1.3±0.8	1.5±1.0	1.3±0.90	1.90±1.80	1.40±0.80	1.80±1.70	1.40±0.80
Sulphate	46±21	91±50	33±25	41±22	59±52	37±24	24±13	31±26	38±21
Phosphate	0.30±0.30	0.80±0.60	0.01±0.01	0.20±0.20	0.10±0.10	0.10±0.10	0.10±0.10	0.10±0.10	0.10±0.10
Chloride	54±19	603±220	26±15	43±23	17±15	48±31	23±12	43±92	46±25
Ammonia	2.9±1.5	27±25	3.1±2.6	3.6±2.1	2.8±1.5	3.2±1.4	2.6±0.8	2.8±1.0	3.5±2.8

sulphate. These parameters were derived mainly from anthropogenic sources. Urbanization, industrial and agricultural activities along the river channel contaminate the river. Paired sample t-test was used to see if there were any differences between the means obtained for wet and dry seasons. The results showed that there was no significant difference in some of the means obtained except turbidity and sulphate, which were statistically significant.

Table 3. Cont.

Parameter	Opa (OPP)	Ope (OPE)	Moginmogin (MOG)	Asejire (ASJ)
EC	176±97	287±200	604±400	167±85
pH	7.6±0.5	7.6±0.5	7.7±0.4	7.7±0.4
Temperature	25.6±1.7	26.4±2.1	28.6±2.7	28.8±3.2
TS	460±350	722±570	760±590	560±580
TDS	87±49	154±120	330±270	70±41
TSS	373±360	571±500	435±430	489±460
Turbidity	35±38	42±69	26±26	25±29
Alkalinity	88±29	139±100	195±92	64±18
Hardness	99±50	170±190	222±190	89±58
Nitrate	1.6±0.9	1.7±1.0	2.7±1.6	1.5±0.6
Sulphate	39±27	42±24	43±20	47±44
Phosphate	0.10±0.10	0.30±0.50	0.30±0.20	0.10±0.10
Chloride	32±14	50±39	144±80	34±20
Ammonia	2.8±1.7	4.4±4.4	4.1±3.1	2.7±1.1

Pearson correlation matrix for parameters in surface water

Table 6, shows the correlation matrix obtained for the physicochemical characteristics in surface water at $p<0.05$. Strong and positive correlations were noticed between some parameters.

The probable sources of the pollutants varied widely and may include leachates from wastes waters, generated municipally, domestically and industrially and wastes from intensive agricultural practices. Turbidity does not include settled solids that rolls along the river bed, though it is used to estimate total dissolved solids, but it is not always exact. Table 6 shows a poor correlation between turbidity and total dissolved solids in this study. This discrepancy might be due to some coloured dissolved organic matter that turbidity cannot determine since it measures light scattered off particles. Generally, one might not expect a strong correlation between electrical conductivity and turbidity, the correlation is poor and could be specific with this water source as at the time of sampling. Gupta *et al*. (2014) also reported high correlation between conductivity, alkalinity and TDS in their study.

Table 4. Pratti scale classification for each location of surface water samples.

Tributary	Location Classification	Pratti Scale	Interpretation
Asejire	ASJ 1	3	slightly polluted
	ASJ 2	4	polluted
	ASJ 3	3	slightly polluted
Osun	OSU 1	2	acceptable
	OSU 2	2	acceptable
	OSU 3	2	acceptable
Gbodofon	GBD 1	2	acceptable
	GBD 2	2	acceptable
	GBD 3	2	acceptable
	GBD 4	2	acceptable
Ahoyaya	AHO 1	2	acceptable
	AHO 2	2	acceptable
	AHO 3	2	acceptable
Isin	IRE 1	2	acceptable
	IRE 2	1	excellent

Table 4. Cont.

IRE 3	1	excellent	
Oyi	OYI 1	2	acceptable
	OYI 2	1	excellent
Osin	OSI 1	2	acceptable
	OSI 2	3	slightly polluted
Oloyo	OLO 1	2	acceptable
	OLO 2	2	acceptable
	OLO 3	3	slightly polluted
Enja	ENJ 1	2	acceptable
	ENJ 2	2	acceptable
	ENJ 3	2	acceptable
Ashasha	ASH 1	2	acceptable
	ASH 2	2	acceptable
Ounseku	OUN 1	2	acceptable
	OUN 2	2	acceptable
	OUN 3	3	slightly polluted
	OUN 4	2	acceptable

Table 4. Cont.

Kankere	KAN 1	3	slightly polluted
	KAN 2	3	slightly polluted
Aro*	ARO 1	2	acceptable
	ARO 2	2	acceptable
Arenounyun	ARE 1	2	acceptable
	ARE 2	3	slightly polluted
	ARE 3	3	slightly polluted
Oba	OBB 1	2	acceptable
	OBB 2	2	acceptable
	OBB 3	2	acceptable
	OBB 4	3	acceptable
Moginmogin	MOG 1	3	slightly polluted
	MOG 2	4	polluted
	MOG 3	2	acceptable
Ope	OPE 1	2	acceptable
	OPE 2	2	acceptable
	OPE 3	3	slightly polluted
Awesin	AWE 1	3	slightly polluted
	AWE 2	3	slightly polluted
	AWE 3	2	acceptable
Ojutu	OJU 1	3	slightly polluted
	OJU 2	2	acceptable
	OJU 3	3	slightly polluted

Table 4. Cont.

Anne	ANN 1	2	acceptable
	ANN 2	3	slightly polluted
	ANN 3	2	acceptable
	ANN 4	2	acceptable
	ANN 5	3	slightly polluted
	ANN 6	3	slightly polluted
Aro	EJI 1	2	acceptable
	EJI 2	2	acceptable
Orufu	ORU 1	2	acceptable
	ORU 2	3	slightly polluted
Odoiya	ODD 1	2	acceptable
	ODD 2	2	acceptable
Ishasha	ISA 1	1	excellent
	ISA 2	2	acceptable
Ishasha	ISA 3	2	acceptable
	ISA 4	2	acceptable
Adeti	ADE 1	3	slightly polluted
	ADE 2	3	slightly polluted
	ADE 3	3	slightly polluted
Etioni	ETI 1	2	acceptable
	ETI 2	2	acceptable
	ETI 3	2	acceptable
Oyika	OYK 1	3	slightly polluted
	OYK 2	2	acceptable
Olumirin	OLU 1	2	acceptable
	OLU 2	2	acceptable
	OLU 3	3	slightly polluted
Yeyekare	YEY 1	3	slightly polluted
	YEY 2	3	slightly polluted
Opa	OPP 1	3	slightly polluted
	OPP 2	3	slightly polluted

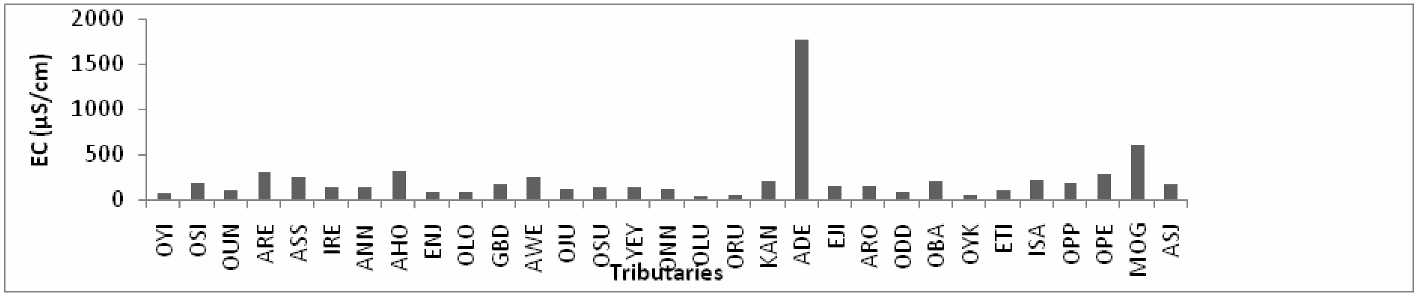

Figure 3.1. Spatial variation of electrical conductivity in surface water.

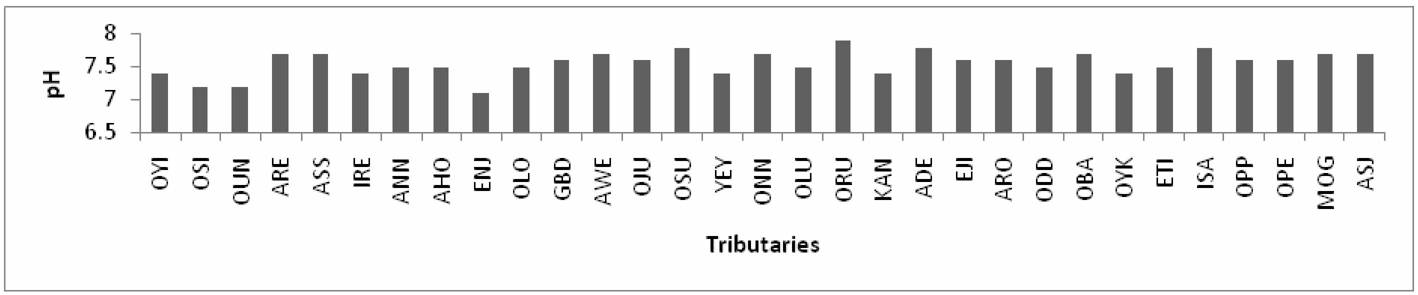

Figure 3.2. Spatial variation of pH in surface water.

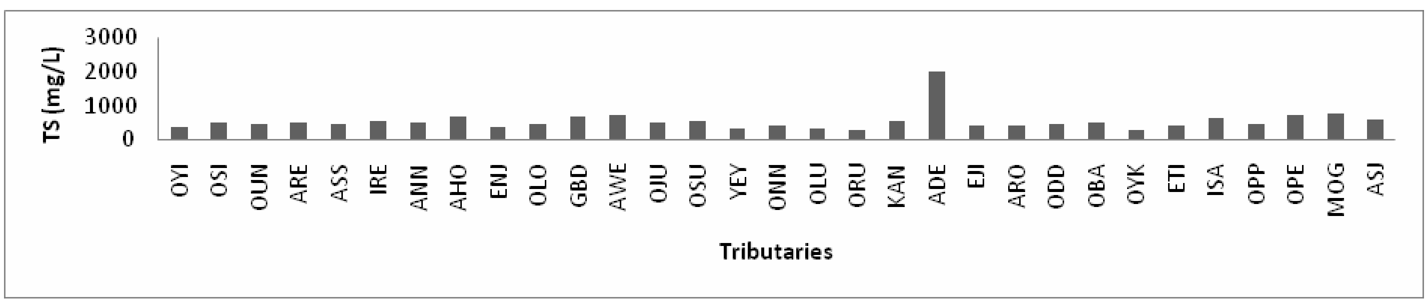

Figure 3.3. Spatial variation of total solids (TS) in surface water.

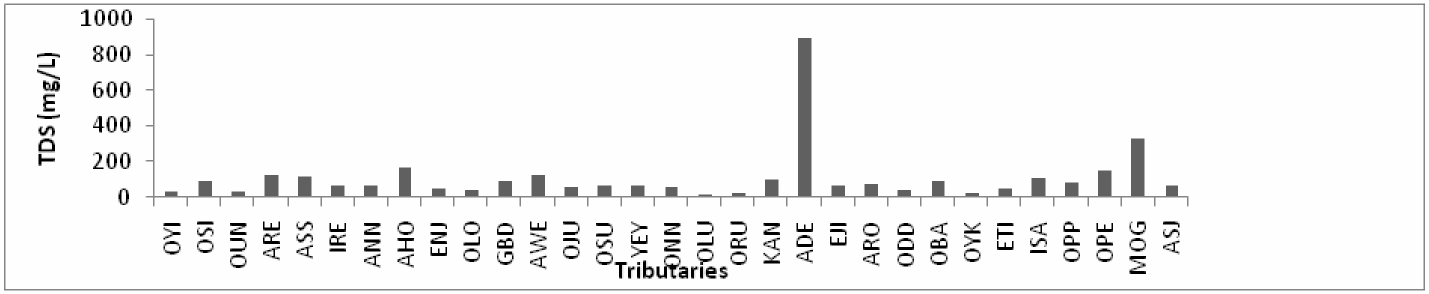

Figure 3.4. Spatial variation of total dissolved solids (TDS) in surface.

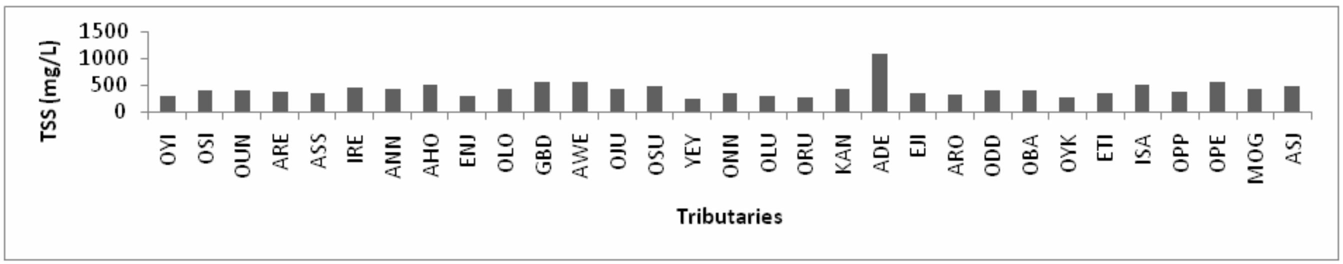

Figure 3.5. Spatial Variation of total suspended solids (TSS) in surface water.

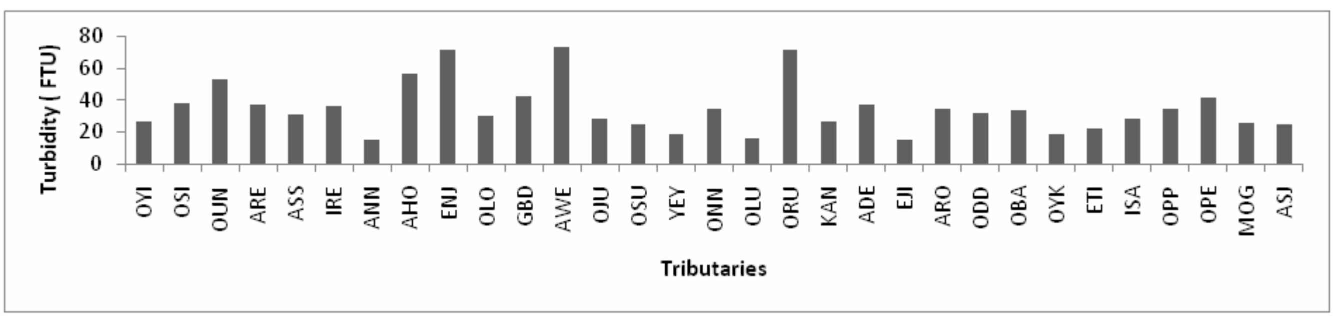

Figure 3.6. Spatial variations of turbidity in surface water.

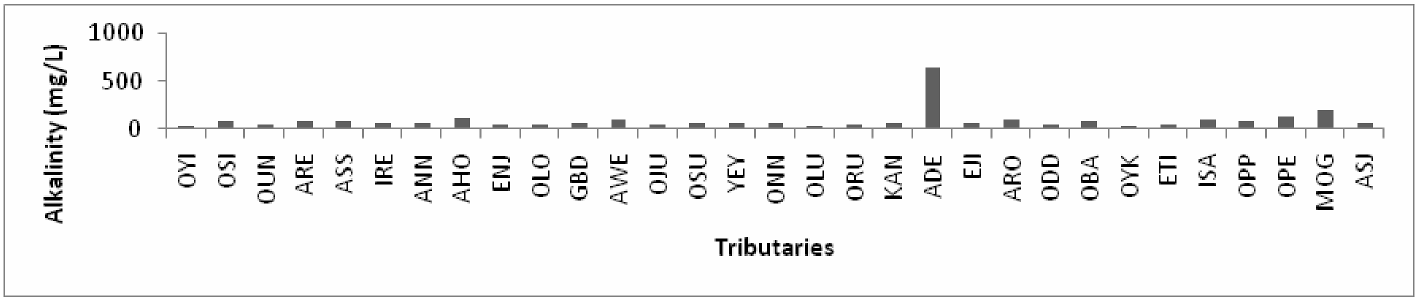

Figure 3.7. Spatial variation of alkalinity in surface water.

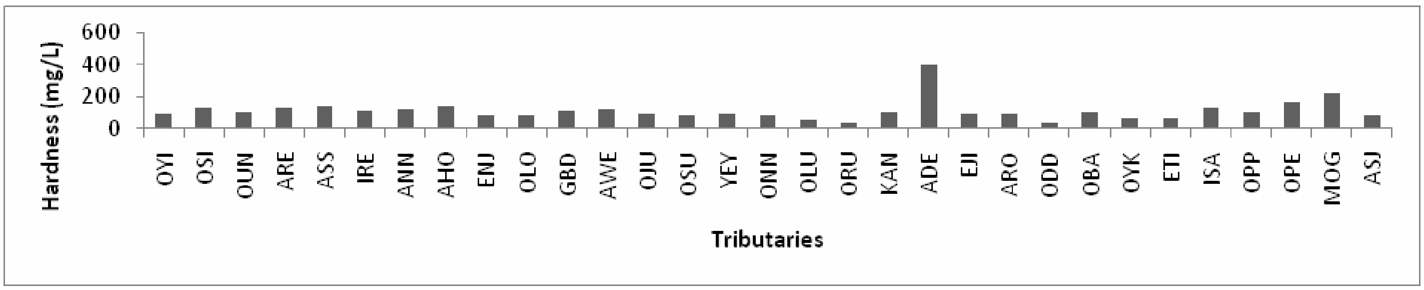

Figure 3.8. Spatial variation of hardness in surface water.

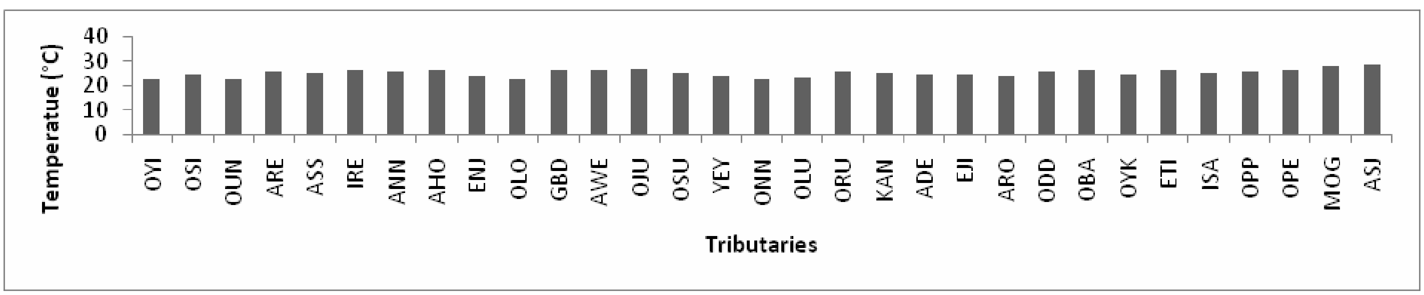

Figure 3.9. Spatial variation of temperature of surface water.

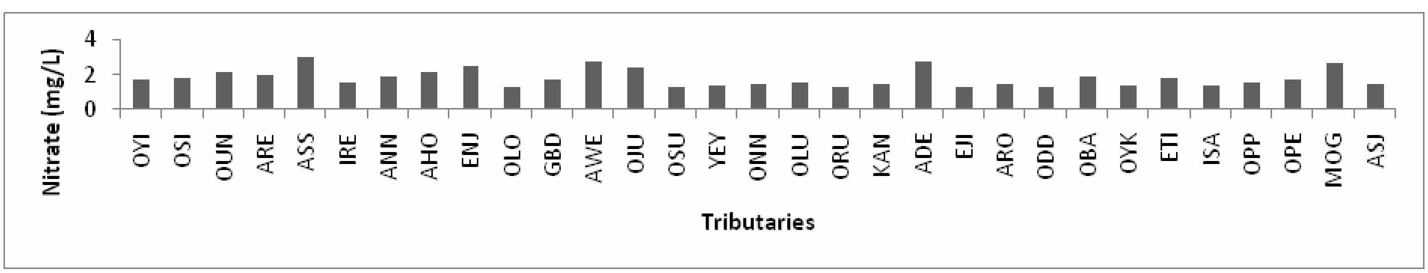

Figure 3.10. Spatial variation of nitrate in surface water.

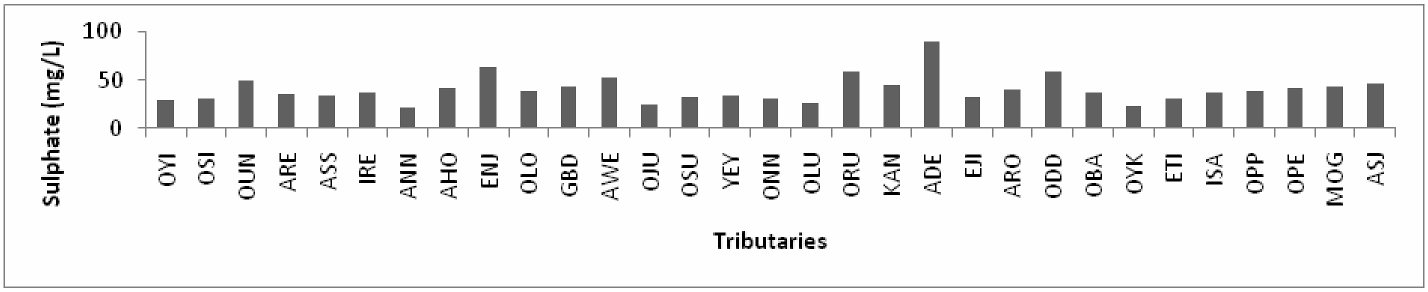

Figure 3.11. Spatial variation of sulphate in surface water.

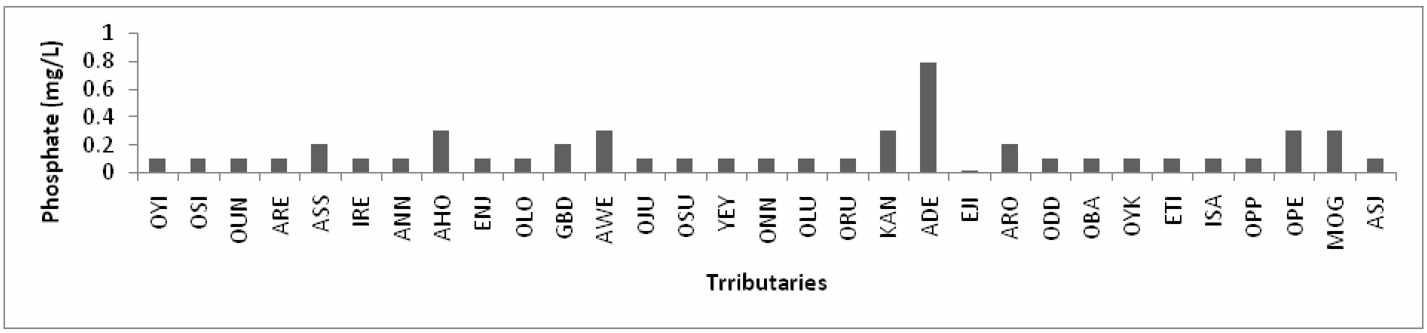

Figure 3.12. Spatial variation of phosphate in sulphate water.

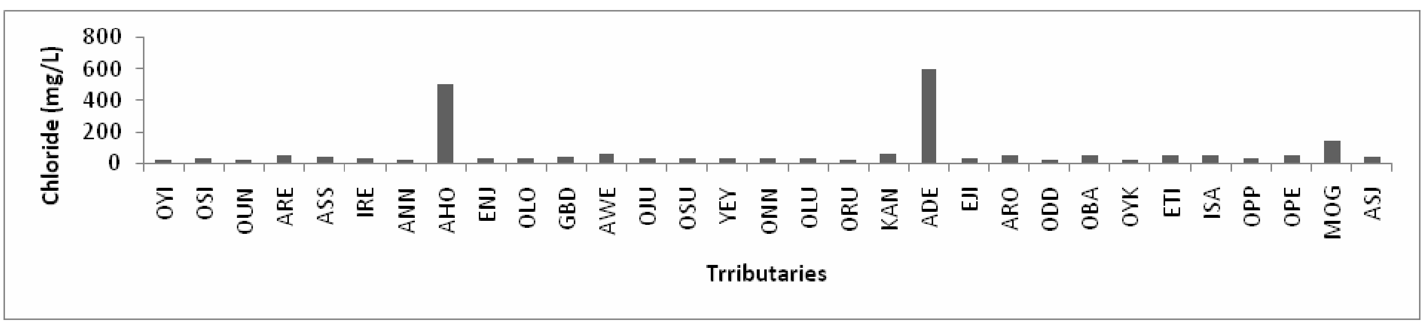

Figure 3.13. Spatial variation of chloride in surface water.

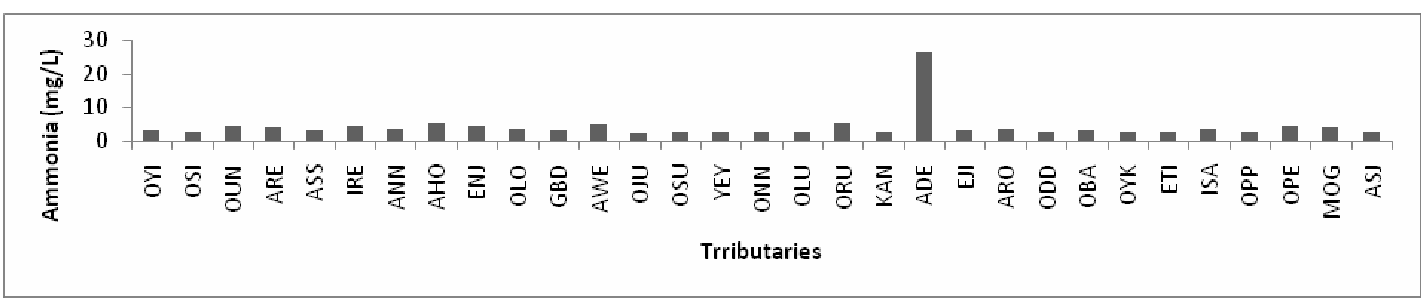

Figure 3.14. Spatial variation of ammonia in surface water.

Table 5. Average dry (summer) and wet (rainy or winter) season characteristics of the Osun River Water.

Parameter	Dry Season	Wet Season
EC (µS/cm)	238±444	195±316
pH	7.5±0.5	7.7±0.5
Temperature	25.2±3.3	25.5±1.8
TS	591±471	504±650
TDS	126±238	97.5±160
TSS	466±397	408±55
Turbidity	24±28	43±45
Alkalinity	98±126	88±123
Hardness	132±146	102±94.9
Nitrate	1.84±1.51	1.80±1.56
Sulphate	32.1±28.7	45.9±30.1
Phosphate	0.16±0.26	0.15±0.20
Chloride	56.3±127	53.4±97.7
Ammonia	4.32±8.55	4.11±4.05

*Units in mg/L, except EC- µS/cm, turbidity – FTU, temperature – oC and pH (no unit).

Time Series Analysis of Parameters of Osun River Surface Water

Table 8 explains time series analysis of some selected tributaries and forecast for 2018. The table explains predicted concentrations of some tributaries in 2018 for some parameters at the months in which they show highest levels. The reasons for the observed level of some of these parameters may be attributed to natural and human activities along the river network channel for the predicted year. Table 9 illustrates the overall time series analysis obtained for surface water in Osun River for all the tributaries. This explained 79% variation of nitrate with predicted concentration of 19.0 mg/L for March, 2018 and 84% variations of phosphate with a predicted concentration of 18.1 mg/L for March 2018. Parameters such as EC, pH, TDS, turbidity, alkalinity, hardness and sulphate do not show significant variations. Nitrate and phosphate were predicted to be prevalent by March 2018. The predicted concentration of nitrate exceeded the limit stipulated by drinking water quality guidelines for SON and others except WHO guidelines and will impair the water quality of Osun River. it will not make the river water to be useful for the food and beverage industry.

SUMMARY, CONCLUSION AND RECOMMENDATION

Summary

Everyday water systems all over the world receive polluting runoffs of industrial processes, fertilizers, pesticides, sewage, and mining drainage. River Osun flows through Osun State along with several tributaries and some manmade canals. Along this channel, rapid industrialization is taking place day by day and so most peaceful area is changing in industries and urbanization. Most drains of these industries carry effluents from factories and also from adjacent residential colonies with their sewage which is finally poured into River Osun and its tributaries. The study was carried out to evaluate the impact of industrial, agricultural and urbanization activities on River Osun as it flows by studying the physicochemical properties in surface water for twenty-

Table 6. Pearson correlation matrix for the physicochemical characteristics of surface water ($p<0.05$).

Parameters	EC	TS	TDS	TSS	Turbidity	Alkalinity	Hardness	Temp.	NO_3^-	SO_4^{2-}	PO_4^{3-}	Cl^-	NH_3
EC	1.000												
TS	0.497	1.000											
TDS	0.996	0.493	1.000										
TSS	0.165	0.937	0.160	1.000									
Turbidity	0.048	0.062	0.039	0.055	1.000								
Alkalinity	0.860	0.488	0.843	0.217	0.055	1.000							
Hardness	0.524	0.447	0.496	0.309	0.130	0.550	1.000						
Temp.	0.140	0.085	0.133	0.043	-0.008	0.081	0.155	1.000					
NO_3^-	0.142	-0.007	0.145	0.066	0.179	0.089	0.016	0.031	1.000				
SO_4^{2-}	0.219	0.199	0.205	0.144	0.551	0.245	0.238	-0.017	0.138	1.000			
PO_4^{3-}	0.540	0.345	0.526	0.181	0.379	0.543	0.449	0.081	0.220	0.394	1.000		
Cl^-	0.868	0.476	0.852	0.199	0.036	0.899	0.496	0.022	0.141	0.301	0.564	1.000	
NH_3	0.531	0.294	0.516	0.127	0.212	0.555	0.459	0.075	0.118	0.343	0.597	0.658	1.000

four months to know the level of pollution of River Osun and thirty one different tributaries so as to capture the main point of the river and its tributaries. Water quality characteristics were determined in the thirty one tributaries and control area.

The overall mean concentrations obtained for surface water characteristics were below the water quality guidelines excerpt turbidity.

Table 7. Tributaries with water quality meeting specific industrial and other requirements.

Industry Type	Tributaries
Pulp and Paper	None, suspended solids> 10 mg/L
Iron and Steel	None, alkalinity > 0.5 mg/L
Petroleum Industry	None, suspended solids > 10 mg/L
Power Generating Stations	None, ammonia > 0.07 mg/L
Food and Brewing	None, turbidity > 10 mg/L
Dairy Production	None, turbidity > 10 mg/L
Irrigation	All tributaries
Aquatic Life Support	None, ammonia > 0.5 mg/L
Recreation	Anne, Aro, Oyika, Olumirin, Yeyekare boating and aesthetic activities
Livestock Rearing	All tributaries

However, some of the tributaries showed concentrations above the water quality guidelines and other categories of water usage. This was due to discharge of waste entering the river and its tributaries from homes and industries. The result revealed that this discharge could pose significant health and environmental risk to those who rely on River Osun as their source of domestic water purpose without treatment and may also affect the health status of the aquatic milieu in this river. The tributaries grossly affected include, Adeti (Ilesha), Moginmogin (Apomu), Kankere (Awo), Ope (Araromi Owu), and Awesin (Ifon). A look at these rivers physically, shows that the rivers are not healthy. Pratti scale classification revealed the characteristics of each location studied. Seasonally, River Osun shows more significant pollution during the dry (summer) seasons for most of the parameters studied due to low flow rate of most of the rivers which helps to increase the concentration of contaminants.

Table 8. Time series analysis results of selected parameters at selected tributaries.

Tributary	Parameter	R^2	Model equation	Forecast for 2018
Asejire	EC	0.56	63.3 +18.3b	799µS/cm, September.
Etioni	TDS	0.39	18.1 + 4.74b	684 mg/L, March.
Gbodofon	EC	0.31	68.6 + 16.1b	1324 µS/cm, March.
	TDS	0.34	31.0 + 8.97b	840 mg/L, March.
Ishasha	NO_3^-	0.60	0.28 + 0.18b	5.79 mg/L, November
Oba	pH	0.49	8.27-9.20x10$^-$2b	4.9, November.
Ojutu	EC	0.61	50.7 + 9.80b	2923 µS/cm, July.
	TDS	0.49	23.7 + 5.32b	1620 mg/L, January.
Oloyo	NO_3^-	0.23	0.49 + 0.11b	19.9 mg/L, March.
Olumirin	NO_3^-	0.71	0.67 + 0.14b	11.1 mg/L, July.
	NH_3	0.59	3.24 - 0.10b	3.26mg/L, September.
Osun	NO_3^-	0.69	0.39 +0.15b	14.1mg/L, September.
Oyi	EC	0.70	26.1 + 7.63b	549 µS/cm, July.
	TDS	0.67	11.2 + 4.27b	173 mg/L, July.

Table 9. Time series analysis of overall concentrations of surface water parameters in Osun River.

Parameter	R^2	Forecast for 2018
EC	0.27	2367µS/cm, January.
TDS	0.33	1404 mg/L, January.
Turbidity	0.06	46.9 FTU, September.
Alkalinity	0.03	129 mg/L, March.
Hardness	0.08	163 mg/L, March.
Nitrate	0.79	19mg/L, July.
Sulphate	0.03	54.7 mg/L, July.
Phosphate	0.84	18.1 mg/L, March.

CONCLUSION

The study showed a need for a continuous pollution monitoring programme, of surface water in River Osun and its tributaries in Southwestern Nigeria. The study has revealed that there was impact on the physicochemical characteristics of River Osun as a result of inadequately treated discharges from homes, farms and industries that finally pour into the Osun River and its tributaries.

RECOMMENDATION

Effluents and wastes from industries and homes should be treated to safe level before discharging to River Osun and its tributaries. People should desist from the use of contaminated water for irrigation of any kind. Simple water treatment such as filtration and boiling are recommended before water is used for washing, cooking or drinking to prevent the outbreak of epidemics in this fast growing developing and highly populated country. Nigerian Environmental Protection Agency and other environmental regulatory bodies should be more effective in environmental monitoring assessment, and enforcement of environmental laws and regulations. The level of impact on River Osun, by man, in other states where river Osun flows through, should also be investigated, to know and compare how activities in these states pollute the river.

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