Assessment of Physico-Chemical Parameters and Water Quality of Surface Water of Iguedo River, Ovia South-West Local Government, Edo State

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Abstract
Study of physico-chemical parameters was conducted on water collected from three selected points along Iguedo River Ovia, south-west. The water samples were collected during the months of January to June. The water samples were analysed using standard procedures and the concentrations were between the following range; pH (5.53-5.75), Electrical Conductivity (94.92-135.50µS/cm), Chemical Oxygen Demand (28.57-41.15 mg/l), Dissolved Oxygen (5.75-6.41mg/l), Biochemical Oxygen Demand (2.39-2.66 mg/l), Nitrate (0.21-0.30mg/l), Phosphate (0.09-0.13mg/l), Sodium (0.30-0.58mg/l), Potassium (0.63-0.81mg/l), Calcium (0.12-0.20mg/l), Magnesium (0.23-0.32mg/l), Iron (0.28-0.36mg/l), Manganese (0.10mg/l), Zinc (0.07-0.10mg/l), Copper (0.02-0.02mg/l), Chromium (0.01-0.01mg/l), Cadmium & Lead (0.02-0.02mg/l), Nickel (0.06-0.06mg/l) and Vanadium (0.01-0.01mg/l). The concentrations of these physico-chemical parameters except cadmium did not show significant differences among the points ($P>0.05$). The concentrations of all the parameters were favourable according to the standard Federal Ministry of Environment (FMEnv) for surface water except cadmium which was higher than the stipulated values 0.10 mg/l.
Keywords: biological/chemical oxygen demand, Iguedo River, Environmental pollution, Water contamination

1. Introduction

The demand for fresh water always increases with ever increasing population in the world. Though water covers about 70% of the earth's surface, only 2.53% is fresh water while the remaining is salt water (UNESCO, 2003). The World Water Council records that of the about 3% of fresh water, only 0.3% is found in rivers and lakes, the rest being frozen (World Water Council, 2005). This suggests that man has a relatively low amount of fresh water resources with which he can carry out his activities. Unfortunately, man's influence has begun to degrade the limited fresh water resources available for his development. Pollution is the introduction of hazardous substances by man into the environment thereby causing harm to human health, living resources and ecological systems, damage to structures or amenity, or interference with legitimate use of the environment (Alloway and Ayres, 1993). The sources of water pollution vary and involve almost every significant human activity. In many parts of the world, both surface and ground water are fouled mostly by the dumping of domestic wastes, sewage, agricultural wastes and industrial effluents into water bodies (Agbozu *et al.,* 2007). Increase in industrialization as a result of modern and sophisticated technology has introduced many synthetic materials into our environment (Ezemonye *et al.,* 20004) of which some may be toxic or carcinogenic (Ezemonye *et al.,* 2004). Human activities affect both water quality and quantity. Human activities change land use and land cover, which changes the water balance and usually changes the relative importance of processes that control water quality (Gergel *et al.,* 1999). Furthermore, most human activities generate waste ranging from gases to concentrated radioactive materials. Although each issue can be subdivided into a myriad of individual processes or activities, the primary water-quality issues affected by human activities include organic materials, trace elements (heavy metals), acidic atmospheric deposition and runoff, salinization, nutrients runoff (primarily nitrogen and phosphorus), oil and grease, synthetic organic compounds, thermal pollution and radioactivity (Grey, 2004). Every human use of water, whether for drinking, irrigation, and industrial processes or for recreation has some quality requirements in order to make it acceptable. This quality criterion can be described in terms of physical, chemical and biological properties of such water (Kaizer and Osakwe, 2010). Water quality comprises the physical, chemical, and biological characteristics of a water body. The water body acquires these characteristics from a suite of complex interactions among the water, atmosphere, soils, and lithology (Olumukoro *et al.,* 2009). The provision of water for domestic and other uses in rural and urban centers is one of the most intractable problems in Nigeria today (Kaizer and Osakwe, 2010). Access to adequate water of good quality is essential to health, food production and sustainable development (Kaizer and Osakwe, 2010). Iguedo River is located at Okada Ovia

South West Local Government Area, Edo state, Nigeria. The river serves mainly as a source for domestic uses like bathing, drinking and washing of clothes. The river also serves as a source of livelihood for fishermen who fish in the river mostly during the rainy season when the water level is high.

The aim of this study is to determine the physico-chemical properties of water from three selected areas along Iguedo River.

The objectives are as follows:

- To assess physico-chemical parameters of Iguedo River.
- To compare the data generated with Environmental guidelines and Environmental Monitoring Agencies limits.
- To determine environmental condition of the stream and predict pollutions

2. Study Area

Iguedo River (Figure 1) a major river of economic and agricultural significant in Iguedo community is located within latitudes (N06°42-N06°43) and longitudes (E05°22, E05°22) of Ovia South-West Local Government Area, Edo State, Nigeria. The river is used for various human activities including washing, fishing, swimming and bathing. The river serves as source of drinking water to the occupants of the community.

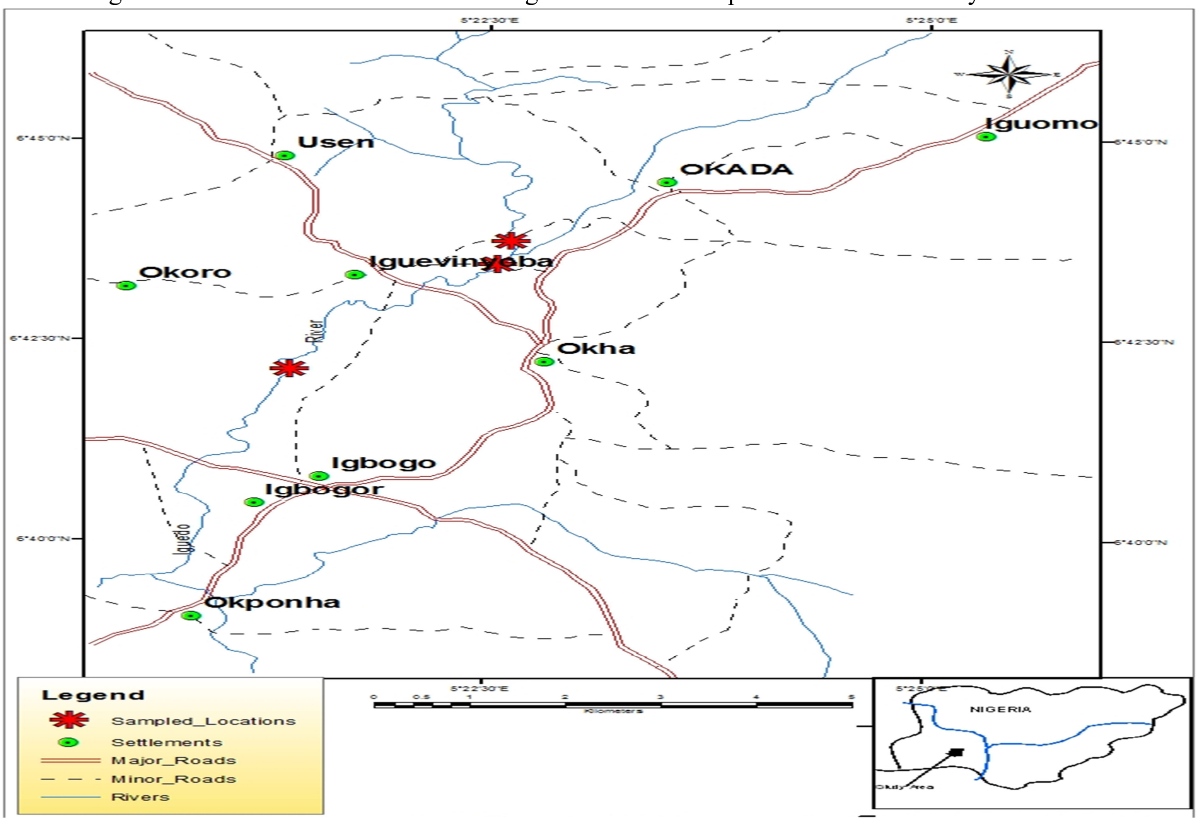

Fig 1: Map of sampling area (Source: online Google earth map).

3. Materials and Methods

3.1 Sampling Methodology

The water samples were collected from three designated sampling points along a given stretch of the river monthly from January-June, 2013 between the hours of 7:00am and 9:00am on each sampling day.

3.2 Point One

Point 1 is located upstream of Iguedo river. This is the area of the river where the major human activities are carried out. This area is mostly used for discharge of waste from the palm oil press located at the bank of the river and dumping of waste by residence of the community.

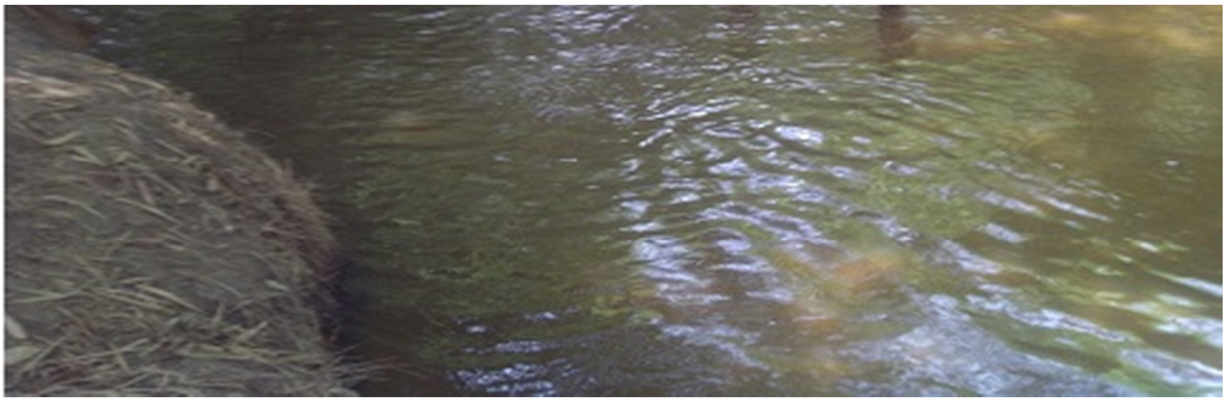

Plate 1; Sampling location point one, of Iguedo River (Source: Oscar *et al.,* 2013)

3.3 Point Two

Point two is located in the middle course of Iguedo River. Few activities like washing of clothes and domestic activities are carried out here.

Plate 2; sampling location, point two, of Iguedo River (Source: Oscar *et al.* 2013)

3.4 Point Three

Point three was located downstream. Very little activities were observed in this area of the study.

Plate 4; Sampling collection location point 3, along Iguedo River (Source: Oscar *et al.,* 2013)

3.5 Physico-Chemical Parameters

The water samples were tested for the following physico-chemical properties according to APHA 1988 standard: pH, electrical conductivity, nitrate, phosphate, sodium, potassium, calcium, magnesium, iron, zinc, manganese, copper, nickel, cadmium, vanadium, chromium, lead, chemical oxygen demand, dissolved oxygen and bio-chemical oxygen demand.

3.5.1 pH (Hydrogen Ion Concentration)

This was determined in-situ in the laboratory using a pH meter.

3.5.2 Electrical Conductivity

On each sampling day, water samples were collected in plastic containers and taken to the laboratory. A battery conductivity meter was calibrated before use for conductivity measurements. It was measured in μScm^{-1}.

3.5.3 Chemical Oxygen Demand (COD)
COD was determined using the dichromate titration method according to APHA 1988.
3.5.4 Dissolved Oxygen
This was determined in the laboratory using the Winkler's method (Winkler, 1963).
Dissolved Oxygen is calculated in mg/l using the formula:

$$DO_2 = \frac{8.0 \times C_b \times V_b}{(V_f - 20)}$$

Where C_b	=	Concentration of Sodium thiosulphate
V_b	=	Volume of Sodium thiosulphate
V_f	=	Volume of bottle used in collecting water sample of fixing oxygen

3.5.5 Biochemical Oxygen Demand
This is the quantity of oxygen required for the oxidation of biodegradable organic matters present in the water sample by aerobic biochemical action.

$$BOD\ (mg/l) = DO_0 - DO_5$$

3.5.6 Nitrate
Nitrate was determined by the Brucine method (Goplan and Wilfred 2008).
The concentration of nitrate in mg/l was determined using the formula:

$$NO_3\ (mg/l) = \frac{ml\ of\ KNO_3 \times 0.1 \times 1000}{ml\ of\ sample}$$

ml of sample =10ml.
3.5.7 Phosphate
The Vanadomolybdophoxsphoric method was used to determine phosphate (APHA, 1988).
3.5.8 Sodium
Sodium was determined using the conning flame photometer IV; lithium being the reference filter (APHA 1988).
3.5.9 Potassium
Potassium was determined using the conning flame photometer IV; Lithium being the reference filter (APHA 1988).
3.5.10 Calcium
This was determined by the use of titrimetric method as described byAPHA 1988.
3.5.11 Magnesium
This was determined by the use of 1-(2-pyridylazo)-2-napththol (PAN) method after APHA (1988) was adopted.

4. Results
The physico-chemical characteristics of water at the different sampling points from Iguedo River indicating the mean and maximum values for each parameter analysed for the different points are as shown in Table I.

4.1 Chemical Oxygen Demanded (COD)
Figure 2, shows the Chemical oxygen demand (COD) monthly variations in chemical oxygen demand concentrations amongst the points. The trend observed across the points was closer and similar. The highest (41.15mg/l) mean Chemical oxygen demand (COD) concentration was recorded at point 1, while the lowest (28.57mg/l) at point 3. The chemical oxygen demand concentration ranged from 25.11-61.38mg/l, 20.46-53.32mg/l and 13.33-44.64mg/l respectively. The Chemical oxygen demand (COD) concentrations recorded above each points, when subjected to one way analysis of variance (ANOVA) indicated no significant difference (P>0.5).

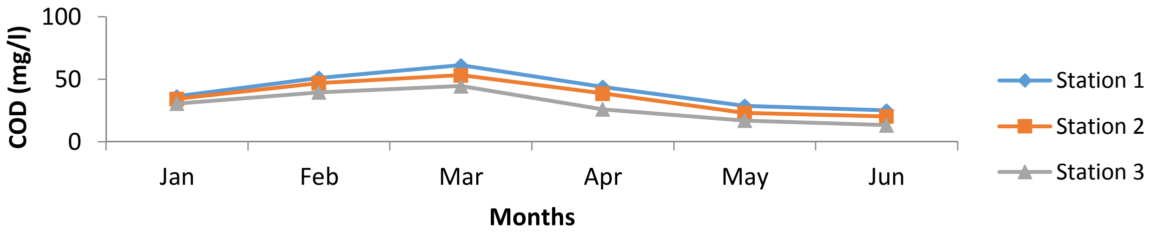

Fig 1: Monthly Variation in Chemical Oxygen Demand of Water Samples from three different points along Iguedo River

4.2 Dissolved Oxygen (DO)

The spatial variations recorded among the points in relations to Dissolved oxygen (DO) are shown in Figure 3. The variations recorded are directly similar. The highest (6.41mg/l) and the lowest (5.75mg/l) concentrations of dissolved oxygen (DO) were recorded at point 2 and 3. The values of dissolved oxygen (DO) concentrations at points 1, 2 and 3 ranged from 4.67-6.53mg/l, 5.26-7.38mg/l and 5.09-6.04mg/l respectively. The dissolved oxygen (DO) concentration when subjected to one way analysis of variance (ANOVA) showed no significant difference (P>0.5).

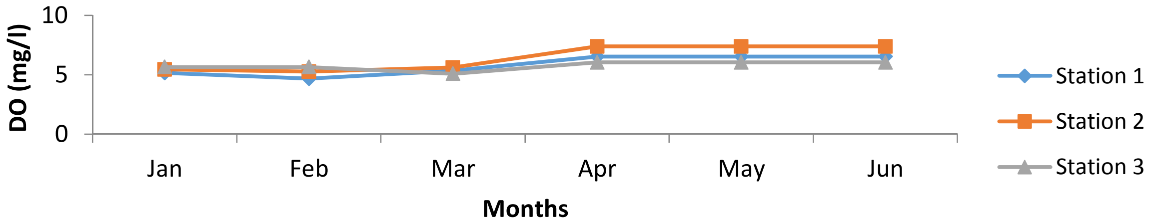

Fig 2: Monthly Variation in (DO) of Water Samples from three different points along Iguedo River

4.3 Biochemical Oxygen Demand (BOD)

The temporal variation recorded in Biochemical oxygen demand (BOD) among the points 1, 2 and 3 are shown in Figure 4. Trends observed across the points are directly similar. The variations recorded were directly similar. The highest mean biochemical oxygen demand (2.66mg/l) was recorded at point 2 and the lowest (2.39) at point 3. The biochemical oxygen demand concentration (BOD) values ranged from 1.92-2.68mg/l, 2.16-3.03mg/l and 2.09-2.48 mg/l at points 1, 2 and 3 respectively. The biochemical oxygen demand (BOD) concentration when subjected to one way analysis of variances (ANOVA) showed no significant differences (P>0.5).

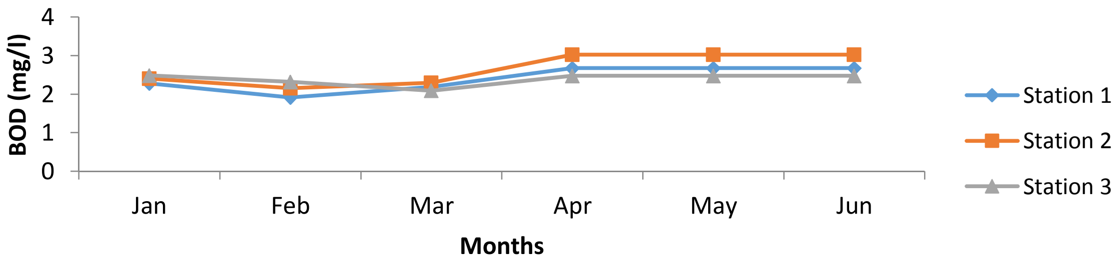

Fig 3: Monthly Variation in Biochemical Oxygen Demand of Water Samples from three different points along Iguedo River

4.4 Nitrate

The temporal variation recorded among the points in relation to Nitrate is shown in figure 5. The trends observed are likely similar. The highest (0.30mg/l) and the lowest (0.21mg/l) concentration of nitrate were recorded at point 1 and point 3. The values of nitrate at point 1, 2 and 3 ranged from 0.18-0.44 mg/l, 0.15-0.38 mg/l and 0.09-0.32 mg/l respectively. The nitrate concentrations when subjected to one way analysis of variance (ANOVA) indicated no significant difference (P>0.5).

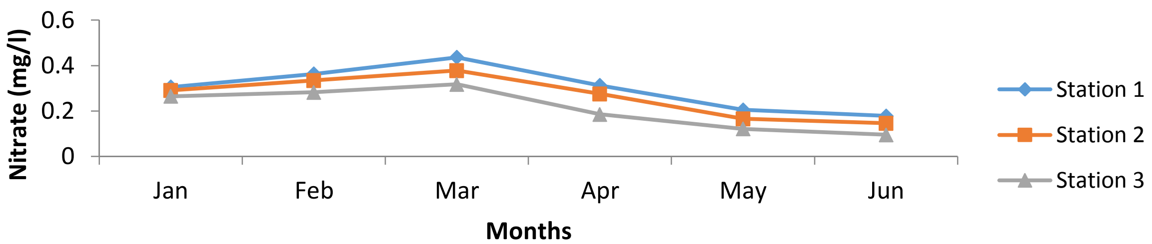

Fig 4: Monthly Variation of Nitrate concentrations of Water Samples from three different points along Iguedo River

4.5 Lead

Figure 6 shows the spatial and temporal variation of lead concentrations in water samples. The variations recorded are slightly similar. The mean concentration value of lead was recorded as 0.02mg/l at points 1, 2 and 3 respectively. The values of lead concentration at point 1 ranged 0.00-0.04mg/l, while point 2 and 3 had the same range (0.01-0.05mg/l) separately. The concentration of lead at various points when subjected to one way analysis of variance (ANOVA) showed no significant difference (P>0.5).

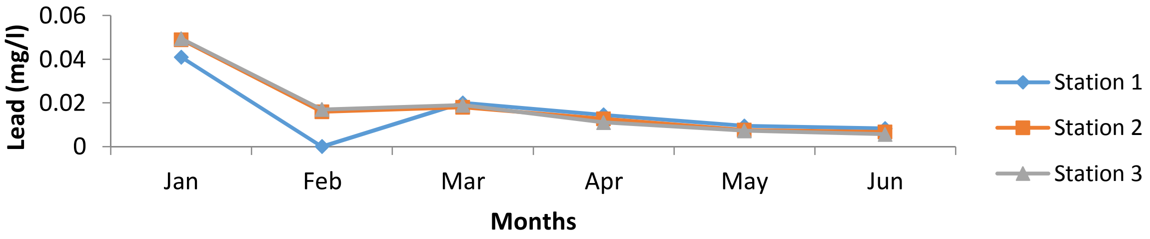

Fig 5: Monthly Variation in Lead concentrations of Water Samples from three different points along Iguedo River

Table I: Summary of the physico-chemical characteristics of water at the three sampling points along Iguedo River.

	Point 1	**Point 2**	**Point 3**		**FMEnv. Permissible Limit**
Parameters	$\bar{X}\pm$ SD	$\bar{X}\pm$ SD	$\bar{X}\pm$ SD	p-Value	
pH	5.53±0.18 (5.32-5.71)	5.75±0.14 (5.55-5.95)	5.67±0.19 (5.41-5.87)	p>0.05	6.5-8.5
EC (µS/cm)	135.50±43.81 (81.00-198.00)	119.58±41.83 (66.00-172.00)	94.92±40.83 (43.00-144.00)	p>0.05	N/A
COD (mg/l)	41.15±13.78 (25.11-61.38)	36.21±12.94 (20.46-53.32)	28.57±12.31 (13.33-44.64)	p>0.05	40
DO (mg/l)	5.79±0.84 (4.67-6.53)	6.41±1.07 (5.26-7.38)	5.75±0.38 (5.09-6.04)	p>0.05	5.0
BOD (mg/l)	2.40±0.32 (1.92-2.68)	2.66±0.41 (2.16-3.03)	2.39±0.16 (2.09-2.48)	p>0.05	NA
NO_3^-(mg/l)	0.30±0.10 (0.18-0.44)	0.26±0.09 (0.15-0.38)	0.21±0.09 (0.09-0.32)	p>0.05	10
PO_4^{3-}(mg/l)	0.13±0.04 (0.07-0.18)	0.12±0.04 (0.06-0.16)	0.09±0.05 (0.04-0.15)	p>0.05	<5
Na^+(mg/l)	0.58±0.19 (0.32-0.79)	0.37±0.24 (0.13-0.71)	0.30±0.24 (0.09-0.66)	p>0.05	200
K^+(mg/l)	0.81±0.99 (0.24-2.82)	0.69±1.04 (0.13-2.80)	0.63±1.05 (0.09-2.77)	p>0.05	NA
Ca^{2+}(mg/l)	0.20±0.10 (0.10-0.37)	0.13±0.12 (0.04-0.36)	0.12±0.12 (0.03-0.35)	p>0.05	NA
Mg^{2+}(mg/l)	0.32±0.11 (0.18-0.44)	0.29±0.11 (0.15-0.42)	0.23±0.12 (0.09-0.39)	p>0.05	NA
Fe^{3+}(mg/l)	0.36±0.39 (0.121.15)	0.32±0.41 (0.08-1.14)	0.28±0.41 (0.05-1.12)	p>0.05	1
Zn^{2+}(mg/l)	0.10±0.04 (0.05-0.15)	0.09±0.04 (0.04-0.15)	0.07±0.04 (0.03-0.14)	p>0.05	1.0
Mn^{2+}(mg/l)	0.10±0.21 (0.01-0.53)	0.10±0.21 (0.01-0.53)	0.10±0.21 (0.00-0.53)	p>0.05	0.05
Cu^{2+}(mg/l)	0.02±0.01 (0.01-0.05)	0.02±0.01 (0.01-0.05)	0.02±0.02 (0.01-0.05)	p>0.05	0.1
Ni^{2+}(mg/l)	0.06±0.09 (0.02-0.24)	0.06±0.09 (0.01-0.24)	0.06±0.09 (0.01-0.24)	p>0.05	0.05
Cd^{2+}(mg/l)	0.00 ± 0.00^a (0.00-0.00)	0.00 ± 0.00^b (0.00-0.00)	0.00 ± 0.00^b (0.00-0.00)	p<0.01	0.01
V^{2+}(mg/l)	0.01±0.00 (0.01-0.02)	0.01±0.00 (0.01-0.01)	0.01±0.00 (0.00-0.01)	p>0.05	0.01
Cr^{6+}(mg/l)	0.01±0.00 (0.01-0.02)	0.01±0.00 (0.00-0.02)	0.01±0.00 (0.00-0.02)	p>0.05	0.05
Pb^{2+}(mg/l)	0.02±0.01 (0.00-0.04)	0.02±0.02 (0.01-0.05)	0.02±0.02 (0.01-0.05)	p>0.05	0.05

p>0.05 – No significant difference; p<0.01 – Highly significant difference; Similar superscript in a row – No significant difference

5.0 Discussion

The pH of Iguedo River did not compare favourably with the water quality standards set by the Federal Ministry of Environment for surface waters. The acidity of this water concurs with previous reports on Nigerian waters (Asonye *et al.,* 2007; Kaizer and Osakwe, 2010; Idise and Maduka, 2011). The similarity between the mean pH values of the points could be an indication of natural activities like organic matter decay and the dissolution of atmospheric CO_2. The mean pH values recorded in the present study are lower than the values reported by Asonye *et al.,* 2007 at different fresh water bodies in the same Local Government but, exceeded those reported by Edokyayi and Victor (2005) at Benin River.

Electrical conductivity (EC) is the ability of the water to conduct electricity which is as a result of ions dissolved in the water. The highest mean value in EC was recorded at point 1. This is because the highest concentration of ions (NO_3^-, PO_4^{3-}, Na^+, K^+, Ca^{2+} and Mg^{2+}) was recorded at this point. This could be as a result of the increased anthropogenic activities like discharge of wastes, prevalent at this point.

Biochemical Oxygen Demand (BOD) and Chemical Oxygen Demand (COD) are two common measures of water quality used to gauge the degree of organic matter pollution of an aquatic system (Okaka *et.,al* 2011). BOD is a measure of the amount of oxygen removed from aquatic environments by aerobic micro-organisms during the breakdown of organic substances while COD is a measure of the oxygen equivalent of the organic matter in a water sample that is susceptible to oxidation by a strong chemical oxidant (Radojevic and Bashkin, 1999). High BOD and COD depict low Dissolved Oxygen (DO) in the water.

The mean COD concentration of point 1 was higher than the Federal Ministry of Environment permitted limit while the rest points compared favourably with the regulatory limit. On the other hand, the mean DO concentrations compared favourably with the Federal Ministry of Environment limits at all the points. The high COD recorded in point 1 could be because of the palm oil press located at this point because palm oil press effluents are rich in organic substances. In contrast to the values recorded in this study, Obiand Ibe (2011) reported much higher values (up to 360 mg/l for BOD) in a river contaminated with abattoir waste in Port Harcourt.

The both nutrients (PO_4^{3-} and NO_3^-) analysed in this study compared favourably with the Federal Ministry of Environment standards. This is probably because of the lack of heavy agricultural activities in this community. The values observed in this study were much lower than the values reported by Rim-Rukeh*et al.,* 2006 in Orogodo, an agricultural community. Nutrients are important in water quality monitoring because they are the major cause of eutrophication.

The major cations measured in this study appeared in this order of dominance; $K^+>Na^+>Mg^{2+}>Ca^{2+}$. This sequence disagrees with that reported by Kaizer and Osakwe (2010) in 5 different rivers in Delta State. The low concentration of these ions is consistent with the Nigerian freshwater chemistry (Kaizer and Osakwe, 2010; Anyanwu, 2012). These values were also within Federal Ministry Environment regulatory limit.

There was uniformity in the concentrations of the heavy metals across the points except for Cadmium (Cd) which was only detected in point 1. This is probably as a result of the discharge of waste and washing of motorcycles at this point. Cadmium has been long associated with municipal waste and automobile tyres (Lagerweff and Specht, 1970; Oguzie and Okhagbuzo, 2010). However, all the investigated heavy metals compared favourably with the FMEnv limits except Mn and Ni.

The Fe>Mn>Zn>Ni>Cu>Pb>Cd>Cr>V>Cd order of dominance in the heavy metals investigated in this study means that Fe was the most dominant heavy metal in Iguedo River during the period of study. This agrees with the report of Asonye *et al.,* 2007 who also reported iron as the most dominant metal in the different rivers. They studied in this same zone but, seem relatively different with that of Kaizer and Osakwe (2010) who reported Zn as the most dominant in Ase River. However, the concentrations of Mn, Ni and a BOD of above 2 mg/l is an indication of a substantial human activities in this river especially at point 2 which may be the result of washing of motorcycles in water which was discovered in plate 3 of this research.

6.0 Conclusion

The water quality of Iguedo River is fairly good. Of all the parameters investigated in this study, pH, Mn and Ni failed to meet the Federal Ministry of Environment guidelines for surface waters. This also means that this water is not good for drinking and certain precautionary measures should be taken. This research should be a source of guidelines and extension report for intending researchers.

References

APHA (1992). Standards methods for the examination of waste water 18th edition. *American Public Health Association Washington D.C.* 874pp.

APHA (1988). Standards methods for the examination of waste water 14th edition. *American Public Health Association Washington D.C.*300pp.

Agbozu, I.E., Ekweozor and. Opuene, K. (2007). Survey of heavy metals in the catfish (Syndontisclarias). *International Journals of Environmental Science and Technology,* **4**, 93-97.

Alloway, B. J. and Ayres, D. C. (1993). Chemical Principles of Environmental Pollution, Glasgow: Blackie Academic and Professional.

Asonye, C. C., Okolie, N. P., Okenwa, E. E. and Iwuanyanwu, U. G. (2007). Some Physico-Chemical Characteristics and Heavy Metal Profiles of Nigerian Rivers, Streams and Waterways. *African Journal of Biotechnology* **6**(5), 617-624.

Edokyayi, C. A and Victor, R. (2005). Some Aspects of the Ecology of *Macrobrachium macrobrachion* Herlots, 1851 (Crustacea: Decapoda:Natantia) in the Brackish Water Zone of the Benin River at Koko, Southern Nigeria.

Ezemonye, L.I.N., Olomukoro, J.O and Igbinosun, E. (2004). Comparative studies of macro-invertebrate community structure in the river-catchment areas (Warri and Forcades River) in Delta state, Nigeria. *African Scientist.* **5(4)**: 181-191.

Gergel, S. E., Turner, M. G. and Kratz, T. K. (1999). Dissolved organic carbon as an indicator of the scale of watershed influence on lakes and rivers. *Ecological Application* **9**, 1377-1380.

Grey, L. (2004). Changes in water quality and macro-invertebrate communities resulting from urban storm flows in the Provo River, Utah, USA. *Hydrobiologia* **518**, 33-36.

Kaizer, A. N. and Osakwe, S. A. (2010). Physio-chemical Characteristics and Heavy Metal Levels in Water Samples from Five River Systems in Delta State, Nigeria. *J. Appl. Sci. Environ. Manage.* **14**(1), 83 – 87.

Lagerweff, J. V. and Specht, A. W. (1970). Contamination of roadside soil and vegetation with Cd, Ni, Pb and Zn. *Environ. Sci. Technology* **5**, 483-586.

Obi, G. I. and Ibe, S. N. (2011). Coliforms And Enterococci As Ndicators Of Faecal Pollution of Woji River Receiving Abattoir Effluents in Port Harcourt, Rivers State Nigeria. *Scientia Africana* **10**(2), 55 – 69.

Oguzie, F. A. and Okhagbuzo, G. A. (2009). Concentrations of heavy metals in effluent discharges downstream of Ikpoba river in Benin City, Nigeria.*African Journal of Biotechnology* **9**(3), 319-325.

Olomukoro, J.O. (2004). Salinity and the Macro-benthic Community structure in *Eichhornia crassipes* of warri river, Nigeria. *Journal of Biological Sciences* **7**(20), 309-314.

Olomukoro. J. O. and Azubuike, C. N. (2009). Heavy metals and macro-invertebrate communities in bottom sediment of Ekpan Creek, Warri, Nigeria. *Journal of Biological Sciences* **2**(1), 1-8.

Olomukoro, J. O. and Ezemonye, L. I. N. (2006). Assessment of the macro-invertebrate fauna of rivers in Southern Nigeria. African Zoology **42**(1), 1-11.

Radojevic, M. and Bashkin, V.N. (1999). *Practical Environmental Analysis.* The Royal Soceity of Chemistry Cambridge, UK. 466pp.

Rim-Rukeh, A., Ikhifa, O. G. and Okokoyo, A. P. (2006). Effects of Agricultural Activities on the Water Quality of Orogodo River, Agbor Nigeria. *Journal of Applied Sciences Research* **2**(5), 256-259.

UNESCO, (2003). Water for People, Water for Life: UN World Water Development Report (WWDR), Paris, United Nations Educational, Scientific and Cultural Organization.

WHO, (2001). Water for Health: Taking Charge, Geneva, World Health Organization.

WHO, (1993). Guidelines for Drinking-Water Quality, Volume 1, Recommendations. 2nd edition, World Health Organization, Geneva