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Water Quality Assessment of Okpauku River for Drinking and Irrigation Uses in Yala, Cross River State, Nigeria

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ABSTRACT

Surface composite water samples from seventeen different locations along Okpauku river were analyzed for various water quality parameters following standard methods prescribed by American Public Health Association/American Water Works Association/Water Environment Federation (APHA/AWWA/WEF). The results revealed that the water quality parameters showed significant ($p \leq 0.05$) variations among the different locations on the river, except for the ammonia-nitrogen and iron. However, the physicochemical parameters of the river at different locations were below the WHO and FAO limits for drinking and irrigation water uses except for the temperature, turbidity and pH. Mean concentrations of major ions, nutrients and heavy metals in all the locations were generally low when compared to the acceptable standards for drinking water (WHO) except for ammonia-nitrogen and iron in location 2, but fall within the allowable limits for irrigation (FAO). The microbiological parameters examined were far above the recommended guidelines given by WHO and FAO, for drinking and irrigation water uses. Nevertheless, apart from the microbial organisms, turbidity and ammonia-nitrogen, the river water may be regarded as a suitable source of water for drinking, irrigation and other domestic uses in the area. Thus, a dam could be constructed across the river in order to subject the water to some treatment processes, especially elimination of enteric microbes and to reduce the turbidity to the required standard before being used.

Key words: Microbes, physicochemical analysis, irrigation water, water quality, Okpauku river, drinking water

INTRODUCTION

Water, the source of life and human civilization has become one of the major issues in recent years. It is probably the most valuable natural resources available to man, without which no life can survive. Adequate and safe water supply is therefore a pre-requisite for significant socioeconomic development of any community. Unfortunately, in many areas of the world, especially developing countries including Nigeria, it is difficult to obtain a steady source of pure water for drinking and agricultural uses. 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-Layla *et al*., 1977; GWSSA, 2000; Ahmad *et al*., 2004; Al-Harbi *et al*., 2009; Al-Naeem, 2011).

The supply of fresh water for domestic and agricultural uses is an important role of rivers, streams, wells and springs. Regardless of the source, water in its natural environment contains some impurities such as dissolved solids and gases. It also hosts a number of micro-organisms; pathogenic and non-pathogenic (George and Shroeder, 1987; Maybeck *et al.*, 1989). The level of its physical, chemical and biological impurities defines its quality which is evaluated relative to the requirement for its intended use (Chapman, 1997; Balachandar *et al.*, 2010). Rivers constitute one of the major sources of water supply in the world. The assessment and continuous monitoring of water quality sourced from rivers can be used to define existing conditions, detect trend and/or establish sources of pollution. The quality of water is often affected by natural (e.g., rocks, soils and surface through which it flows) and anthropogenic (e.g., industrial, agricultural and mining) activities (WHO, 1996; Nkolika and Onianwa, 2011). Several studies revealed that these activities coupled with atmospheric factors affect the suitability of water for any purpose (Faniraan *et al.*, 2001; Daghrah, 2009; El-Saeid *et al.*, 2011; Hakim *et al.*, 2009; Al-Tabbal and Al-Zboon, 2012).

The Okpauku river in Yala, Cross River State, Nigeria is no exception. The constant shortage of readily available pipe-borne water for human consumption and conventional water source for irrigation agriculture in the area has necessitated the use of water from the river for these purposes. As the river runs through many states and communities, it could be fed with contaminants brought by run-off from the upland into the river at the peak of floods (EIA Report, 2003). Moreover, natural variations can also have a negative impact on the suitability of the water for human use, in addition to the other human activities like agricultural practices, which is the major occupation of the people in the area (EIA Report, 2003).

It is against this background that the Federal Government of Nigeria, under the supervision of Cross River Basin Development Authority proposed the construction of a dam to assist the Yala community with a constant water supply of good quality for their domestic and agricultural uses. The dam will source its water from the Okpauku river. This study examines the water quality parameters of the Okpauku river in relation to WHO (2006) and Ayers and Wescot (1985) guidelines for drinking, irrigation and other domestic uses. It also aimed at assessing whether the river water is contaminated or polluted.

MATERIALS AND METHODS

Study area: The Okpauku river is geographically located approximately between latitudes 6°15'0" and 7°7'30"N and longitudes 8°18'0" and 8°49'30"E. The area is found in the derived Guinea Savannah vegetative zone, which experiences humid tropical climate with marked dry (November-March) and rainy (April-October) seasons. The mean relative humidity of the area varies from 50-75%, with the estimated annual rainfall range between 1750 and 2000 mm, the annual temperature varies from 27-28°C (Bulktrade Investment Company Limited, 1989). The geological formation of the area consists of the crustaceous sediment (Eze-Aku shale) made from the sedimentary formation of shells and the sandstones group (Bulktrade Investment Company Limited, 1989). Figure 1 shows the study area and sampling points.

Land use: The area has a number of surrounding villages with over 4000 ha of abundant land for irrigation agriculture (EIA Report, 2003). It is sandwiched between two major commercial agricultural towns: Ogoja and Okuku, all in Cross River State. It has a population of about 4,649 people (NPC, 1991) out of which about 70% are farmers (EIA Report, 2003). The major economic activities in the area are crop production and fishing. The major crops grown include: Cassava, maize, yam, melon, groundnut and vegetables.

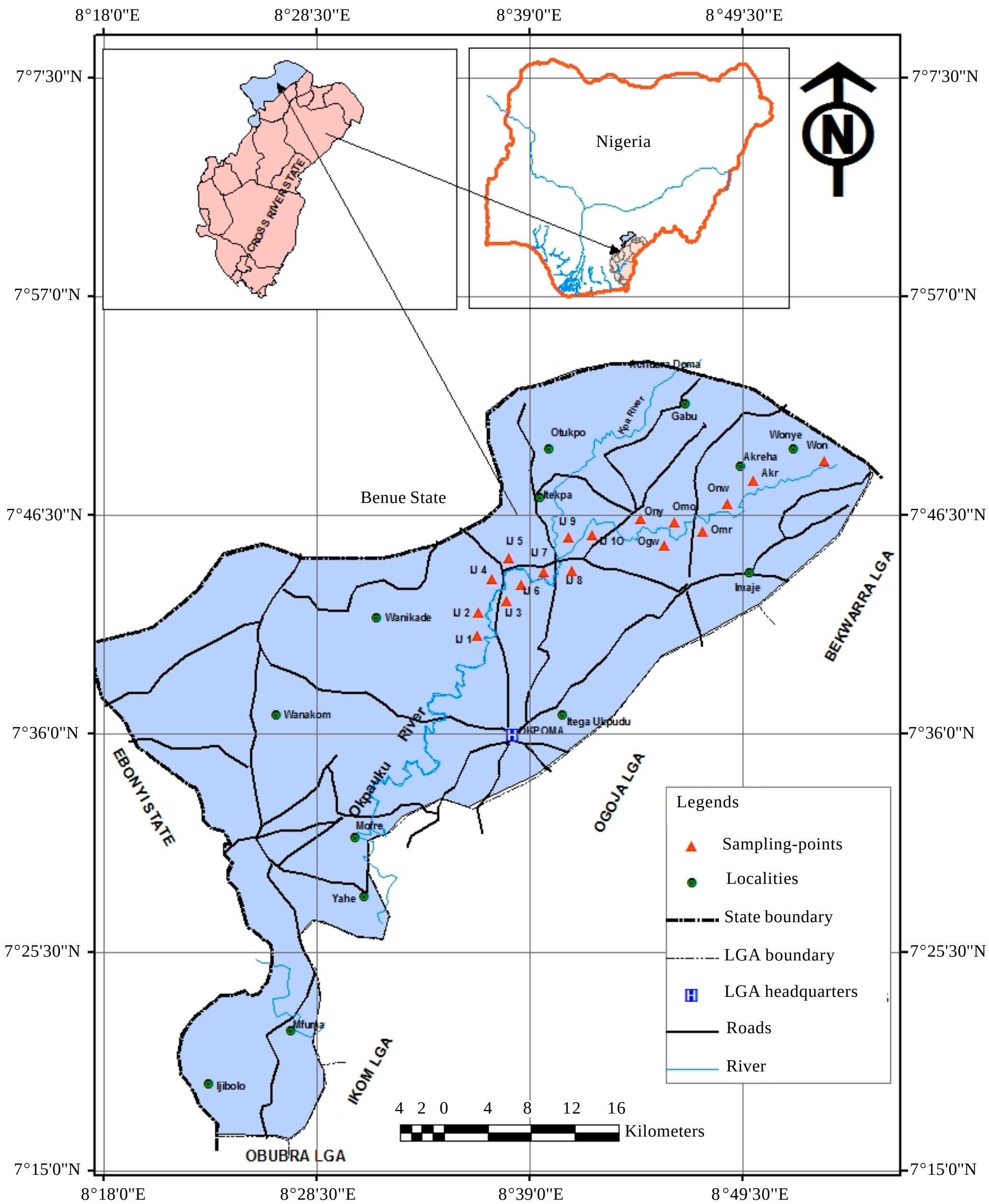

Fig. 1: Map of the study area showing sampling points

Sampling methods and analysis: Surface composite water samples were collected from seventeen different locations along the river (Fig. 1). The samples were collected in the month of November, 2010 and repeated in December, 2010 and January, 2011. The seventeen locations are sandwiched between eight villages through which the river flows. The villages include: Omra, Ogwaru, Omorokpo, Wonye, Onwu, Onyi, Akreha and Ijegu being the largest village.

At each location, four water samples were collected midstream at the depth of 10-30 cm, from four different points; 5 m apart at a bearing of 90° each. The four samples were collected using one-liter sterilized polyethylene bottles and emptied into a sterilized 5 L gallon, where it was gently shaken and thoroughly mixed together to obtain a 1 L composite sample. At the point of collection, the bottles were rinsed with the river water before being filled. For Dissolved Oxygen (DO), separate samples were collected in plain glass bottles and the azide modification of the Winkler method used. Samples for Biochemical Oxygen Demand (BOD) were collected in dark glass bottles and incubated at 20°C for 5 days. The BOD was determined as the difference between DO of sample for day one and day five for the same sample after incubation. Samples for the analysis of trace metals were immediately acidified to pH value of 2.0 using reagent grade nitric acid. After samples collection and during transportation to laboratory, all the samples were stored on ice-packed coolers.

Twenty-four water quality parameters were determined in each composite sample. pH, turbidity and electrical conductivity were determined using a portable pH meter (Model: Mettler Toledo MP 220, England), turbidity meter (Model: HANNA, LP-2000) and conductivity meter measured at 25°C (Model: HANNA, HI8733), respectively. Temperature was measured *in situ* using a mercury-in-glass thermometer. Standard techniques (APHA, AWWA and WEF, 1998) were used to analyse the other parameters: Total Dissolved Solids (TDS) were gravimetrically determined at 105°C, total hardness was determined by titrimetric methods, major cations (Na^+, Mg^{2+}, Ca^{2+}, K^+) as well as heavy metals (Fe, Mn) were determined by the flame Atomic Absorption Spectrophotometer (Model: Buck Scientific-200A/210), chloride was by argentometric method, nutrients (NO_2-N, NO_3-N, PO_4-P, NH_4-N) as well as sulphate were also measured by spectrophotometer, Sodium Adsorption Ratio (SAR) was obtained by calculation using the formula:

$$SAR = \frac{Na^+}{\sqrt{\frac{Ca^{2+} + Mg^{2+}}{2}}} \quad (1)$$

Coliform count was by lactose broth media incubation at 35±0.5°C (APHA, 1985), total heterotrophic bacteria and total heteratrophic fungi were obtained by surface spreading technique (Okafor, 1985). All reagents were analytically graded and instruments pre-calibrated prior to the analyses.

Statistical analysis: The results obtained were subjected to statistical analysis using the analysis of variance (ANOVA). Detection of differences among the location means for significance was done by Duncan's New Multiple Range Test (DNMRT) procedures at 5% level of probability (Obi, 2002).

RESULTS AND DISCUSSION

The study revealed that there were significant variations in the water quality parameters evaluated among the different locations of Okpauku river. In general, the physicochemical properties of the river which include: pH, temperature, turbidity, ammonia-nitrogen, nutrient elements, major ions, heavy metals, etc., where within the limits recommended by WHO (2006) and Ayers and Wescot (1985) for drinking and irrigation purposes, respectively. However, the presence of certain enteric microorganisms makes the river unwholesome for drinking purpose, but suitable for irrigating agricultural crops that are not to be consumed raw. The inhabitants of the area should be enlightened of the potential risk and benefits of using Okpauku river as a source of water for drinking and irrigation. Most of the water quality parameters measured showed significant ($p \le 0.05$) variations among the different locations of the study area.

Physicochemical parameters: The mean physicochemical parameters measured are presented in Table 1. Mean temperature values of the river water varied significantly ($p \le 0.05$) among the different locations. Locations 8 and 15 had the highest temperature of 26.4°C, while location 1 recorded the least (25.8°C). The values obtained for the temperature in all the locations are within the natural background level of 22-29°C for water in the tropics (Stumm and Morgan, 1981) and slightly above the limit of 25°C allowed for WHO drinking water standard (Table 1).

The mean values of turbidity differed significantly ($p \le 0.05$) among the locations of the river. Location 2 differed significantly from the other locations with the highest value of 76.0 NTU. The water appeared to be turbid in all the locations as the measured values were equal to or above 5 NTU as recommended by WHO standard (Table 1) except for the location 10. This indicates the presence of insoluble pollutants discharged into the river at different points. However, comparing with the FAO irrigation water quality guideline value of 35 NTU (Table 1), about 8 locations (1, 5, 6, 9, 10, 12, 15, 16) fall within the recommended guidelines. The findings suggest that the water is unsafe for drinking, but might be used for irrigation depending on the irrigation system to be employed.

Total Dissolved Solid (TDS) values differed significantly ($p \le 0.05$) among the different locations, with location 2 recording the highest significant value of 85.1 mg L^{-1}. Location 13 had the least

Table 1: Physicochemical parameters of water samples collected from Okpaku river

	Parameters							
Locations	Temp. (°C)	TDS (mg L^{-1})	Turbidity (NTU)	EC (NS cm^{-1})	pH	DO (mg L^{-1})	BOD (mg L^{-1})	Total hardness (mg L^{-1})
1	25.8^{d}	27.6^{e}	20.0^{h}	55.6^{ef}	6.99^{c}	4.20^{bc}	1.2^{cd}	12.80^{d}
2	26.0^{cd}	85.1^{a}	76.0^{a}	170.8^{a}	6.72^{fg}	3.80^{d}	1.6^{a}	19.20^{a}
3	26.2^{abc}	28.7^{d}	49.3^{b}	57.9^{def}	6.79^{e}	4.00^{cd}	1.1^{de}	16.00^{c}
4	26.3^{ab}	24.45^{h}	48.0^{bc}	49.4^{defg}	6.54^{i}	2.80^{f}	1.0^{ef}	19.20^{a}
5	26.2^{abc}	57.2^{b}	17.0^{i}	114.5^{b}	7.30^{a}	3.80_{d}	0.9^{f}	9.62^{e}
6	26.1^{bc}	22.6^{k}	21.0^{h}	62.2^{de}	6.69^{g}	4.20^{bc}	1.1^{de}	19.00^{ab}
7	26.0^{cd}	23.5^{i}	37.0^{de}	47.3^{defg}	6.86^{d}	4.33^{b}	1.2^{cd}	19.20^{a}
8	26.4^{a}	23.1^{j}	46.0^{c}	63.3^{d}	6.87^{d}	4.10^{c}	0.9^{f}	15.30^{c}
9	26.3^{ab}	24.8^{g}	5.0^{j}	49.9^{defg}	7.27^{a}	4.40^{b}	0.9^{f}	19.20^{a}
10	26.2^{abc}	16.8^{n}	1.0^{k}	36.3^{ghi}	6.58^{h}	4.70^{a}	0.2^{g}	6.41^{f}
11	26.2^{abc}	44.3^{c}	39.0^{d}	89.1^{c}	6.49^{j}	3.20^{e}	1.4^{b}	19.10^{ab}
12	26.2^{abc}	14.3^{o}	25.0^{g}	29.1^{hi}	7.17^{b}	3.80^{d}	1.2^{cd}	6.41^{f}
13	26.2^{abc}	11.3^{p}	38.67^{de}	25.2^{i}	6.97^{c}	4.10^{c}	1.1^{de}	12.80^{d}
14	26.2^{abc}	27.1^{f}	36.0^{e}	54.6^{defg}	6.35^{k}	3.20^{e}	1.2^{cd}	6.41^{f}
15	26.4^{a}	20.7^{m}	30.0^{f}	41.8^{fghi}	6.86^{d}	4.10^{c}	1.2^{cd}	6.41^{f}
16	26.2^{abc}	21.9^{l}	20.0^{h}	44.2^{efgh}	6.75^{f}	4.10^{c}	1.3^{bc}	12.57^{d}
17	26.2^{abc}	44.3^{c}	39.0^{d}	89.1^{c}	6.47^{j}	3.20^{e}	1.4^{b}	9.61^{e}
[1]WHO	25.0	1000.0	5.0	4000.0	6.5-8.5	5.00	3.0	200.00
[2]FAO	-	2000.0	35.0	3000.0	6.5-8.5	-	4.5	-

Means followed by the same letter are not significantly different at 5% level of probability as determined by the DNMRT, [1]World Health Organization (WHO, 2006). Drinking water quality standards, [2]Food and Agriculture (Ayers and Wescot, 1985), Irrigation water quality standards value of 11.3 mg L^{-1}. It was observed that none of the locations had TDS value that exceeded the WHO standard of 1000 mg L^{-1} for drinking water and the FAO recommended guidelines of 2000 mg L^{-1} for irrigation water (Table 1). Similarly, values for the electrical conductivity were observed to be generally low in all the locations when compared with the WHO and FAO standards of 4000 and 3000 μs cm^{-1}, respectively (Table 1). However, there was a significant variation in the EC values among the locations of the river. Since the TDS and EC are indices for salinity hazard in water (Schwab *et al*., 1993), the EC values confirmed the low level of TDS in the river water. The results also imply that the river water is palatable for domestic and agricultural uses.

The pH value of locations 5 and 9 was significantly ($p \leq 0.05$) higher than the rest of the locations. Location 13 had the lowest pH of 6.35. Most of the values recorded conform to the range (6.5-8.5) found in freshwater as given by WHO and FAO standard (Table 1). Only about 17% of the locations were slightly less than the lower limit of 6.5, indicating that the water in these locations was slightly acidic in nature. Dissolved Oxygen (DO) value differed significantly among the locations, with location 10 recording the highest value of 4.7 mg L^{-1}. The Biochemical Oxygen Demand (BOD) values range from 0.2-1.6 mg L^{-1}. Location 2 had the highest value of 1.6 mg L^{-1}, followed by locations 17 and 16. When compared with the WHO and FAO guideline values of 3.0 and 4.5 mg L^{-1}, for drinking and irrigation water, respectively, the BOD values obtained were low (Table 1). It was also reported that natural water with BOD values of 4 mg L^{-1} is considered to be slightly polluted with organic matter, but safe for drinking (APHA, AWWA and WEF, 1998).

Total hardness values of locations 2, 4, 7 and 9, significantly had the highest value of 19.20 mg L^{-1} and did not differ significantly from locations 6 and 11. Locations 10, 12, 14 and 15 had the lowest value of 6.41 mg L^{-1}. It was observed that the values obtained for total hardness were very low when compared with WHO standards of 200 mg L^{-1} (Table 1), implying that the water is safe and could leather well with soap.

Major ions: The mean values of the respective major ions determined are presented in Table 2. The concentration of potassium was highest in location 12 (0.6 mg L^{-1}) and differed significantly ($p \leq 0.05$) from the rest of the locations. Sodium concentration was lowest in location 11 (3.29 mg L^{-1}) and significantly differed from the other locations. Location 2 recorded the highest concentration (34.23 mg L^{-1}) of sodium. Magnesium and calcium concentrations were also significantly higher in location 2 (1.00 and 3.55 mg L^{-1}). These major cations determined were observed to be low when compared with the WHO permissible limits of 12, 200, 150 and 75 mg L^{-1} for potassium, sodium, magnesium and calcium, respectively (Table 2). Although, these cations may not pose serious health problems, but excess contents above their threshold values may impart unacceptable taste to the water. However, Akpoveta *et al*. (2011) cautioned against high content of Ca and Mn ion concentration in borehole water in Edo and Delta States of Nigeria. The average value of the respective cation also falls below the FAO permissible limit (Table 2) for irrigation water quality implying that the river water might be safe for irrigation, thus, no or little restriction should be imposed on its use.

Chloride concentration in locations 2 and 7 were significantly higher than the other locations. Location 15, recorded the least concentration of 5 mg L^{-1} followed by location 11 (5.92 mg L^{-1}). Sulphate was significantly higher in location 2, with a value of 8.59 mg L^{-1}. Location 11, recorded the least concentration of 0.84 mg L^{-1}. The concentration of chloride and sulphate ions in all the locations was less than the recommended standards given by WHO and FAO (Table 2) for drinking and irrigation water, respectively. Thus, this low concentration of the cations and anions measured

Table 2: Mean concentrations of major ions nutrients and heavy metals of water samples collected from Okpaku river

	Parameters (mg L^{-1})												
Locations	K	Na	Mg	Ca	Cl	NO_2-N	NO_3-N	PO_4-P	NH_4-N	SO_4	SAR	Fe	Mn
1	0.16^{k}	11.20^{de}	0.32^{f}	1.15^{de}	20.00^{e}	0.001^{b}	5.42^{a}	0.013^{a}	0.53^{a}	2.797^{f}	13.00^{b}	0.136^{a}	0.054^{a}
2	0.46^{b}	34.23^{a}	1.00^{a}	3.55^{a}	61.40^{a}	0.001^{b}	0.31i^{j}	0.013^{a}	0.92^{a}	8.591^{a}	15.00^{a}	0.527^{a}	0.000^{c}
3	0.16^{f}	11.60^{d}	0.34^{e}	1.20^{d}	20.80^{d}	0.002^{a}	0.33i^{j}	0.009^{cd}	0.73^{a}	2.910^{e}	13.00^{b}	0.207^{a}	0.020^{b}
4	0.14^{h}	9.88^{fg}	0.28^{gh}	1.03^{fg}	17.70^{f}	0.001^{b}	0.77^{e}	0.010^{bc}	0.69^{a}	2.724^{f}	12.00^{c}	0.163^{a}	0.020^{b}
5	0.13^{i}	9.11^{h}	0.60^{c}	1.10^{ef}	16.40^{g}	0.000^{c}	0.67^{f}	0.009^{cd}	0.39^{a}	2.291^{g}	1.00^{j}	0.097^{a}	0.000^{c}
6	0.33^{c}	16.40^{b}	0.67^{b}	2.38^{b}	41.20^{b}	0.000^{c}	1.10^{b}	0.004^{f}	0.47^{a}	5.505^{b}	3.00^{h}	0.102^{a}	0.000^{c}
7	0.13^{i}	9.45^{fgh}	0.27^{hi}	0.99^{gh}	61.90^{a}	0.001^{b}	0.33^{ij}	0.011^{b}	0.72^{a}	2.376^{g}	2.00^{i}	0.157^{a}	0.000^{c}
8	0.13^{i}	9.32^{gh}	0.27^{hi}	0.97^{gh}	16.70^{g}	0.001^{b}	0.39^{h}	0.010^{bc}	0.74^{a}	2.345^{g}	12.00^{c}	0.147^{a}	0.020^{b}
9	0.14^{h}	9.97^{f}	0.29^{g}	1.04^{fg}	17.90^{f}	0.001^{b}	0.30^{j}	0.003^{f}	0.97^{a}	3.863^{d}	12.00^{c}	0.182^{a}	0.017^{bc}
10	0.10^{k}	7.26^{j}	0.21^{k}	0.76^{j}	13.00^{i}	0.001^{b}	0.09^{l}	0.010^{bc}	0.71^{a}	2.809^{f}	10.00^{e}	0.184^{a}	0.043^{a}
11	0.04^{m}	3.29^{l}	0.09^{m}	0.34^{l}	5.92^{l}	0.001^{b}	0.20^{k}	0.000^{g}	0.50^{a}	0.840^{l}	7.00^{g}	0.176^{a}	0.017^{bc}
12	0.60^{a}	4.58^{k}	0.13^{l}	0.47^{k}	8.25^{k}	0.001^{b}	0.21^{k}	0.001^{g}	0.63^{a}	1.153^{k}	8.00^{f}	0.167^{a}	0.001^{bc}
13	0.09^{l}	6.80^{j}	0.20^{k}	0.71^{j}	12.20^{j}	0.001^{b}	0.53^{g}	0.000^{g}	0.51^{a}	1.710^{j}	10.00^{e}	0.491^{a}	0.010^{bc}
14	0.19^{e}	8.82^{hi}	0.26^{i}	0.92^{hi}	15.60^{h}	0.001^{b}	0.86^{d}	0.006^{e}	0.50^{a}	1.826^{i}	11.00^{d}	0.116^{a}	0.010^{bc}
15	0.12^{j}	8.37^{i}	0.24^{j}	0.87^{i}	5.00^{m}	0.000^{c}	0.36^{h}	0.008^{d}	0.59^{a}	2.105^{h}	11.00^{d}	0.122^{a}	0.000^{c}
16	0.26^{d}	13.80^{c}	0.53^{d}	1.85^{c}	32.00^{c}	0.001^{b}	0.67^{f}	0.010^{bc}	0.77^{a}	4.481^{c}	12.00^{c}	0.112^{a}	0.010^{bc}
17	0.15^{g}	10.90^{e}	0.32^{f}	1.13d^{e}	19.60^{e}	0.001^{b}	0.96^{c}	0.006^{e}	0.71^{a}	2.747^{f}	13.00^{b}	0.161^{a}	0.010^{bc}
[1]WHO	12.00	200.00	150.00	75.00	250.00	0.10	10.00	5.00	0.50	400.000	-	0.30	0.10
[2]FAO	2.00	920.00	120.00	800.00	1065.00	-	10.00	2.00	5.00	960.000	15.00	5.00	0.20

Means followed by the same letter are not significantly different at 5% level of probability as determined by the DNMRT, [1]World Health Organization (WHO, 2006). Drinking water quality standards, [2]Food and Agriculture (Ayers and Wescot, 1985), Irrigation water quality standards

in all the locations indicate that the river water might be free from unpleasant taste and corrosion potential of metals in the distribution system. Sodium adsorption ratio (SAR) of location 2, had the highest value of 15 (Table 2) and differed significantly from the other locations. SAR is an index for determining sodicity hazard in irrigation water (Schwab *et al*., 1993). However, it was observed that most of the SAR values recorded were close to the guideline limit of 15 given by FAO for irrigation water quality standard (Table 2). This implies that the river water may posed a potential sodicity problem when used as irrigation water source.

Nutrients: The mean values for the respective nutrient elements from the sampled river water are also presented in Table 2. Location 3 had significantly ($p \leq 0.05$) the highest concentration of nitrite-nitrogen compared with the other locations. The least nitrite-nitrogen contents were recorded in locations 5, 6 and 15 and differed significantly from the other locations. Nitrate-nitrogen recorded the highest value of 5.42 mg L^{-1} in location 1. Phosphate-phosphorus was high in locations 1 and 2 and significantly differed from the other locations. There were no significant differences ($p \leq 0.05$) among the locations with respect to ammonia-nitrogen. However, location 9 recorded the highest value of 0.97 mg L^{-1}, while location 5 had the least value of 0.39 mg L^{-1}. Considering the WHO drinking water quality guidelines (Table 2), all the measured nutrient elements were low, except for the ammonia-nitrogen. The values for the ammonia-nitrogen were equal to or greater than the WHO guidelines in most of the locations, suggesting high level of nitrogen from domestic and agricultural origin. However, the nutrient level in all the locations were lower than the FAO recommended guidelines (Table 2) for irrigation water. The level of these nutrient elements in the river water may not cause health problem in human (Baird, 1995) and might supplement the cost of inorganic fertilizer when used as irrigation water source.

Heavy metals: Iron concentration did not vary significantly ($p \leq 0.05$) among the different locations of the river (Table 2). However, location 2 recorded the highest value and is closely followed by location 13. The lowest Fe value was recorded in location 5. It was observed that the concentration of Fe in all the locations was lower than the WHO threshold value of 0.3 mg L^{-1}, for drinking water (Table 2), except for locations 2 and 3, suggesting that the water may not stain laundry and plumbing fixtures (WHO, 2006). Manganese concentration was high in locations 1 and 10 and differed significantly from the other locations of the river. Considering the WHO guideline (Table 2) value of 0.1 mg L^{-1}, the river water might be considered wholesome with respect to manganese content. This finding is at variance with that reported by Ayeni *et al.* (2011) for Ala River in Southwestern Nigeria. This could be attributed to the difference in industrial and agricultural activities that characterized the respective location. The heavy metals determined in all the locations of the river were also below the limits set by FAO irrigation water quality guidelines (Table 2). This implies that the river water may be safe from these metals toxicity probably due to lack of anthropogenic or industrial activities near the Okpauku river.

Microbiology: Total coliform counts per 100 mL of the water sample collected differed significantly ($p \leq 0.05$) among the locations of the river (Fig. 2). Location 14 had significantly the highest coliform count compared with the other locations except for the locations 1, 4, 15 and 17. The least coliform count was recorded in locations 11 and 12, which differed significantly from the other locations. Considering the WHO standard for drinking water, the river water is not wholesome for drinking. This result apparently indicates contamination especially by faecal matter probably from in discriminate disposal of domestic wastes directly into the river or on the bank, which eventually gets into the river by runoff from rainfall. However, for irrigation purposes, water from locations 10, 11 and 12 could be used to irrigate crops that are not to be consumed raw (Lazarova *et al.*, 2005) as they met the standard stipulated by FAO irrigation water guidelines (Table 3) with respect to coliform count.

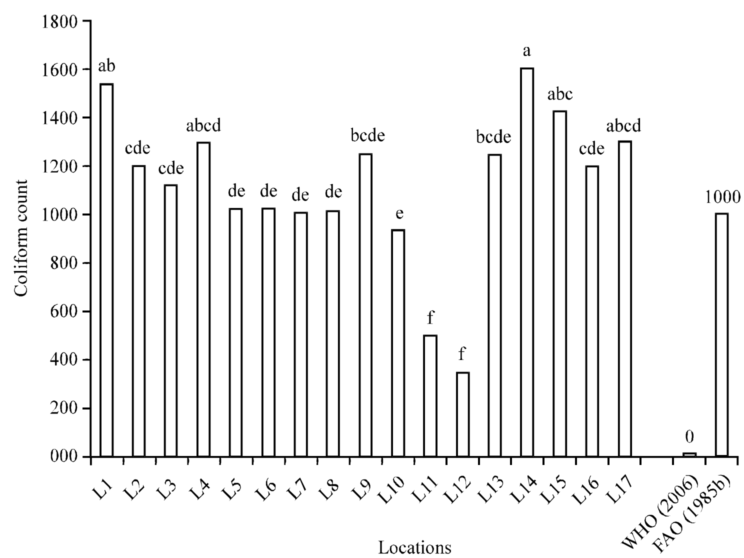

Fig. 2: Coliform count of water samples collected from Okpauku river, Bars followed by the same letter are not significantly different at 5% level of probability as determined by the DNMRT

Table 3: Mean microbiological parameters of water samples collected from Okpaku river

	Parameters		
Locations	Coliform (count/100 mL)	Total heterotrophic bacteria (CFU mL^{-1})$\times 10^4$	Total heterotrophic fungi (CFU mL^{-1})$\times 10^3$
1	1535^{ab}	6.44^{a}	5.50^{a}
2	1200^{cde}	5.25^{b}	4.00^{c}
3	1121^{cde}	3.35^{e}	4.50^{b}
4	1297^{abcd}	4.15^{c}	3.00^{e}
5	1025^{de}	1.10^{h}	2.00^{h}
6	1025^{de}	1.20^{h}	2.00^{h}
7	1010^{de}	1.15^{h}	1.55^{hij}
8	1020^{de}	1.03^{h}	1.10^{j}
9	1250^{bcde}	2.05^{f}	2.50^{g}
10	938^{e}	4.15^{c}	3.25^{de}
11	500^{f}	1.65^{g}	1.20^{j}
12	350^{f}	1.49^{g}	1.25^{ij}
13	1250^{bcde}	3.18^{e}	1.65^{hi}
14	1600^{a}	6.40^{a}	3.55^{d}
15	1425^{abc}	5.15^{b}	3.50^{d}
16	1200^{cde}	1.20^{h}	1.05^{j}
17	1300^{abcd}	3.60^{d}	2.55^{fg}
[1]WHO	0	0	0
[2]FAO	1000/100 mL	500/100 mL	500/100 mL

Means followed by the same letter are not significantly different at 5% level of probability as determined by the DNMRT, [1]World Health Organization (WHO, 2006), Drinking water quality standard, [2]Food and Agricultural Organization (Ayers and Wescot, 1985). Irrigation water quality standard

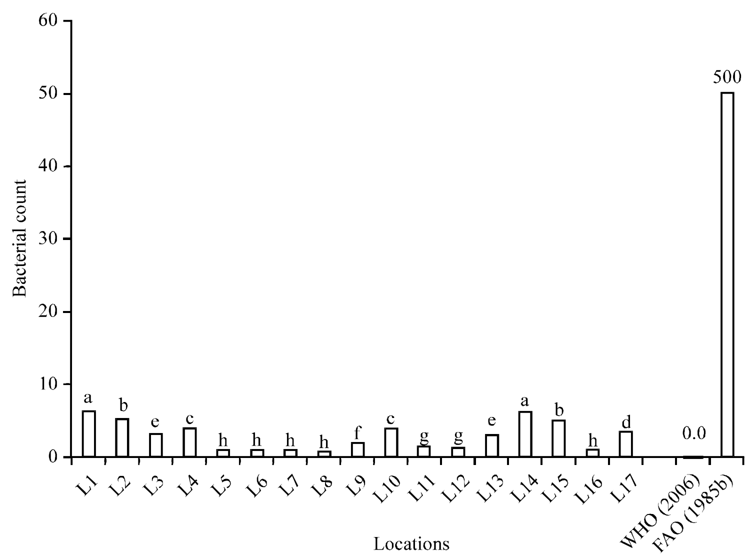

Fig. 3: Total heterotrophic bacteria count of water samples collected from Okpauku river, Bars followed by the same letter are not significantly different at 5% level of probability as determined by the DNMRT

Total aerobic heterotrophic bacteria (THB) (Fig. 3) and fungi (THF) (Fig. 4) differed significantly among the different locations of the river. Incidentally, location 1 had the highest THB

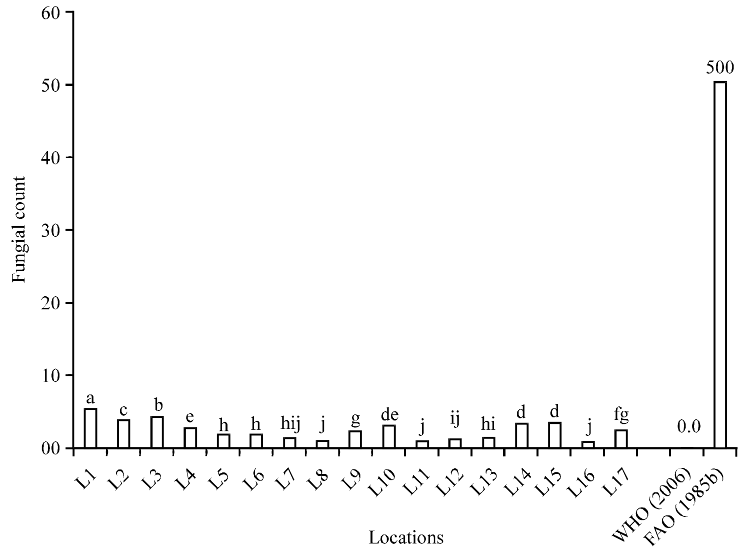

Fig. 4: Total heterotrophic fungi count of water samples collected from Okpauku river, Bars followed by the same letter are not significantly different at 5% level of probability as determined by the DNMRT

and THF and differed significantly from the other locations. The values for THB and THF in all the locations exceeded the WHO and FAO standards for drinking and irrigation water quality, respectively.

CONCLUSION

The assessment of water quality from Okpauku river in Yala Local Government Area of Cross River State, Nigeria for irrigation and drinking purposes showed a significant variation amongst the different locations in some of the parameters evaluated. In most of the locations of the river, the water could be considered suitable for domestic uses, but not wholesome for drinking due to contaminations by some microbes. Similarly, many locations of the river may provide a good source of irrigation water for some agricultural crops especially those that are not to be consumed raw.

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