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The Effects of Crude Oil Production Activities on Surface and Groundwater Quality in Sapele, Delta State, Nigeria

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Abstract

The crude oil industry in Nigeria remains a major source of revenue and foreign exchange. However, oil exploration and production activities have the potential of causing a lot of distortions in the environment, affecting the ecosystems and human life. The purpose of this study is to assess the physicochemical status of surface and groundwater in Sapele, Delta State, a region that has witnessed oil exploration and production activities. In carrying out this study, water samples were collected monthly from April to September 2016 from stations 1 and 2 (perturbed locations) and station 3 (control) for analysis of physicochemical parameters including heavy metals. Samples were analyzed using standard procedures and atomic absorption spectrophotometer. At significant level of $P < 0.05$, HCO_3, Na, K, Mg, Cl, SO_4, Mn, Cr, Cd, Pb, EC, Colour, TSS, Turbidity, TDS and Salinity were significantly different across the study stations for surface water. *A posteriori* Duncan's Multiple Range Test revealed that stations 1 and 2 (perturbed stations) had higher mean values than station 3 (control). Results from the study show the average physicochemical parameters in ground and surface water conformed to World Health Organization (WHO) standard with the exception of temperature, electrical conductivity, colour, dissolved oxygen, biological oxygen demand, iron, cadmium and lead which were slightly higher than WHO and Federal Ministry of Environment permissible level for surface and groundwater indicating some level of pollution due to oil exploration activities.

Subject Areas

Hydrology

Keywords

Crude Oil, Exploration/Production, Water Quality, Sapele

1. Introduction

Among all the natural resources, crude oil, its exploration and production activities have had the greatest impact on world polity and environment [1]-[9]. Several materials such as drilling mud, produced water, drill cuttings and hydrocarbons are discharged into the environment during crude oil production [7], with produced water as the major waste stream [8], impacting the water quality and aquatic flora and fauna [9] [10] [11]. Tubonimi *et al.* [12] reported that many inhabitants of regions where oil production takes place are ingesting high and dangerous levels of hydrocarbons.

Sapele, one of the Niger-Delta communities plays host to oil fields, flow station and networks of pipelines within the area. Groundwater remains the primary source of potable water supply for domestic, industrial and agricultural uses in crude oil production zone of Nigeria [13]. Previous investigation in the study area looks at the impact of oil exploration on water quality and vegetal resources [14]. With increasing tempo of oil exploration and production activities, environmental degradation, increasing population and demand on groundwater supply, routine monitoring and evaluation of the water quality in oil producing communities become imperative. Therefore, the present study documents the physicochemical status of surface and groundwater in Sapele, Delta State, to ascertain the potability and possible health risk.

2. Materials and Methods

2.1. Study Area

Sapele, located in Delta State of Nigeria lies between the latitude of 5˚52'30.28"N and a longitude of 5˚41'35.29"E (**Figure 1**). The climate is warm and wet throughout the year, characterized by the sub-equatorial type and marked by the rainy and dry seasons with a brief spell of harmattan in-between.

2.2. Sample Collection

Three sampling stations were selected: Stations 1 (Ugberikoko) and 2 (Shell Road) are the perturbed stations with anthropogenic activities while Station 3 (Ugbeyiyi) serves as the control, 16 km away from perturbations.

Water samples were collected monthly from the sampling stations for six months (April to September). Surface water samples for physicochemical and heavy metal analysis were collected by immersing a 1 litre plastic bottle about 50 cm below the water surface and allowing it to fill while still under water, while groundwater samples were collected by random sampling from different boreholes dug around the study area and were stored at 4˚C and taken to the laboratory. Samples for heavy metal analysis were acidified with 1 ml of HNO_3. For Dissolved Oxygen (DO) and Biochemical Oxygen Demand (BOD) determination, 250 ml reagent bottles (transparent for DO and amber for BOD) with glass stoppers were used for the collection of water samples. The water sample for Dissolved Oxygen (DO) determination was immediately fixed by adding 1 ml

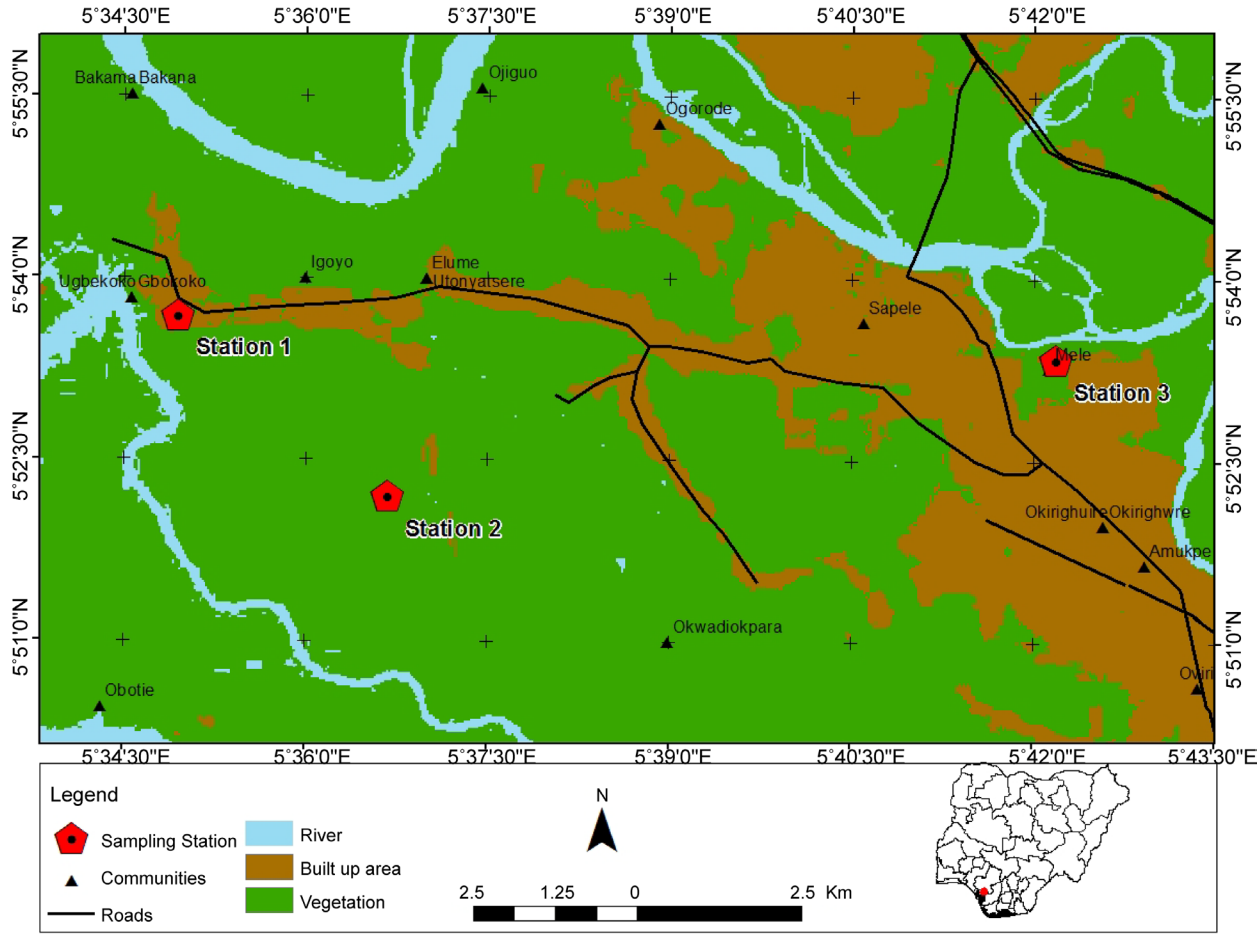

Figure 1. Map of study area indicating study stations.

each of Winkler's solutions A (Manganous sulphate) and B (Potassium hydroxide in Potassium iodide), and the stopper quickly replaced.

2.3. Water Extraction

From the different boreholes/streams, 500 ml of water samples were collected and transferred into 1000 ml separating flask. 30 µg/ml of a surrogate in 1 ml of DCM was transferred into a measuring flask with the water sample, thereafter 20 ml of DCM was put into the flask. To release pressure at intervals, the flask was shaken. Few minutes after shaking was stopped, two layers were formed in the flask. Using a filter paper, the lower layer of the sample was transferred into a beaker [15].

2.4. Laboratory Analysis

Water samples collected were analyzed in the laboratory for physicochemical parameters using standard procedures (Table 1).

2.5. Statistical Analysis

Measures of central tendencies and dispersion (mean, standard error and range)

Table 1. Analysis methods used for physicochemical parameters.

Physicochemical parameters	Analysis method
pH	pH meter
Electrical Conductivity (EC), Total Dissolved Solids (TDS),	Conductivity meter
Total Suspended Solids (TSS)	Gravimetric method
Temperature	Thermometer
Turbidity	Turbidity meter
Total Hydrocarbon Content (THC)	UV fluorescence spectroscopy
Sulphate (SO_4), Nitrate (NO_2), Sodium (Na^+), Potassium (K^+), Phosphorus (P)	UV-Visible Spectrophotometer
Colour	ASTM D1209
Calcium (Ca^{2+}), Magnesium (Mg^{2+}), Salinity, Dissolved Oxygen (DO), Chemical Oxygen Demand (COD), Chloride (Cl), Hydrogen Carbonate (HCO_3)	Titration
Biochemical Oxygen Demand (BOD)	Sawyer and McCarty, 1978
Heavy metals: Iron (Fe), Copper (Cu), Lead (Pb), Manganese (Mn), Nickel (Ni), Cadmium (Cd), Chromium (Cr), etc.	Atomic Absorption Spectrophotometer

were used to summarize the physicochemical parameters of the water samples. Analysis of Variance (ANOVA) was used to test for significant difference across the study stations. The "*a posteriori*" Duncan's Multiple Range (DMR) test was used to ascertain the definite location of means responsible for the observed significant difference wherever the Null Hypothesis (H_o) was rejected ($P < 0.05$) [16].

Water Quality Index (WQI) was computed to establish the potability status of the water samples from different stations.

3. Results and Discussion

Table 2 and Table 3 show the summary of physicochemical conditions of surface and groundwater of the study stations while Figure 2 shows the water quality index for the sampling stations.

The pH of surface and groundwater recorded in this study from the three stations was slightly acidic and ranged from 4.910 - 5.797, below the recommended standard. The mean pH, however, was the lowest in station 2 for groundwater (4.910). The mean pH values in the study area were low when compared with the value of 6.53 recorded by Atubi [17] in Warri. Similar pH range has been recorded in a previous study in Sapele [14].

The temperature of the surface and groundwater samples ranged from 27.75˚C - 29.75˚C (Table 2 and Table 3). All values were within the maximum permissible limit of 25˚C - 30˚C for drinking water [18]. The temperature recorded in this study was in agreement with the result of previous studies reported in the Niger Delta area [19] [20].

Table 2. Surface water physicochemical status of study stations.

PARAMETERS	STATION 1 $\bar{X}$ ± SE (Min-Max)	STATION 2 $\bar{X}$ ± SE (Min-Max)	STATION 3 $\bar{X}$ ± SE (Min-Max)	WHO limit	P-value	Significance
pH	5.797 ± 0.325 (5.00 - 7.13)	5.6367 ± 0.231 (4.90 - 6.62)	5.4233 ± 0.168 (5.09 - 6.18)	6.5 - 8.5	0.582	P > 0.05
Temperature (˚C)	28.750 ± 0.544 (27.0 - 31.0)	27.750 ± 0.528 (26.5 - 29.5)	28.417 ± 0.821 (26.0 - 32.0)	NG	0.550	P > 0.05
EC (µS/cm)	3940.82 ± 1425.87^{a} (281.5 - 9080)	400.80 ± 172.85^{a} (154.1 - 1330)	242.62 ± 110.28^{b} (50.5 - 830)	NG	0.017	**P < 0.05**
Colour (Pt. Co)	6.400 ± 2.069^{b} (0.0 - 13.5)	21.133 ± 3.242^{a} (11.9 - 31.1)	4.233 ± 1.232^{b} (0.0 - 8.5)	5.0	0.000	**P < 0.001**
Turbidity (NTU)	1.783 ± 0.697^{a} (0.0 - 10.6)	0.181 ± 0.084^{b} (9.6 - 28.9)	0.11067 ± 0.055^{b} (0.0 - 7.6)	5.0	0.000	**P < 0.001**
TSS (mg/l)	7.317 ± 1.899^{b} (0.0 - 12.7)	20.367 ± 3.787^{a} (8.4 - 32.7)	6.517 ± 1.675^{b} (0.0 - 11.6)	500 - 1500	0.003	**P < 0.01**
TDS (mg/l)	197.100 ± 774.082^{a} (132.8 - 4550.0)	198.717 ± 94.608^{a} (72.7 - 670.0)	120.183 ± 58.874^{b} (23.1 - 410.0)	500	0.017	**P < 0.05**
Salinity (‰)	1.783 ± 0.697^{a} (0.127 - 4.110)	0.181 ± 0.085^{b} (0.070 - 0.600)	0.111 ± 0.055^{b} (0.023 - 0.380)	200 - 600*	0.017	**P < 0.05**
DO (mg/l)	5.433 ± 0.161 (4.7 - 5.8)	5.100 ± 0.177 (4.6 - 5.9)	5.383 ± 0.312 (4.2 - 6.3)	5	0.548	P > 0.05
BOD_5 (mg/l)	3.383 ± 0.223 (2.7 - 3.9)	3.300 ± 0.249 (2.1 - 3.8)	2.750 ± 0.251 (1.8 - 3.7)	NG	0.166	P > 0.05
COD (mg/l)	15.433 ± 1.33 (11.0 - 18.9)	14.800 ± 1.084 (10.1 - 17.3)	12.233 ± 1.153 (8.7 - 16.7)	NG	0.168	P > 0.05
HCO_3 (mg/l)	132.350 ± 33.763^{a} (35.5 - 255.0)	47.483 ± 6.129^{b} (29.2 - 70.9)	30.267 ± 6.578^{b} (11.7 - 53.8)	NG	0.006	**P < 0.01**
Na (mg/l)	11.773 ± 4.686^{a} (1.16 - 28.40)	1.297 ± 0.227^{b} (0.70 - 2.09)	0.752 ± 0.080^{b} (0.51 - 1.06)	NG	0.019	**P < 0.05**
K (mg/l)	1.880 ± 0.731^{a} (0.25 - 4.72)	0.155 ± 0.155^{b} (0.11 - 0.19)	0.152 ± 0.025^{b} (0.08 - 0.24)	NG	0.015	**P < 0.05**
Ca (mg/l)	16.498 ± 5.563^{a} (3.15 - 38.70)	1.790 ± 0.205^{b} (1.11 - 2.40)	1.200 ± 0.111^{b} (0.84 - 1.63)	NG	0.006	**P < 0.01**
Mg (mg/l)	6.953 ± 2.851^{a} (0.95 - 19.30)	0.922 ± 0.130^{b} (0.56 - 1.40)	0.573 ± 0.064^{b} (0.39 - 0.81)	NG	0.025	**P < 0.05**
Cl (mg/l)	179.367 ± 57.861^{a} (64.5 - 417.1)	55.083 ± 7.404^{b} (34.1 - 82.4)	26.217 ± 3.525^{b} (16.2 - 39.2)	200 - 600	0.013	**P < 0.05**
P (mg/l)	2.458 ± 1.495^{a} (0.26 - 9.85)	4.357 ± 1.032^{a} (1.38 - 8.33)	0.782 ± 0.208^{b} (0.33 - 1.62)	NG	0.088	P > 0.05
NH_4N (mg/l)	0.068 ± 0.018 (0.000 - 0.127)	0.064 ± 0.014 (0.000 - 0.101)	0.031 ± 0.011 (0.000 - 0.071)	NG	0.179	P > 0.05
NO_2 (mg/l)	0.12 ± 0.033 (0.00 - 0.243)	0.14 ± 0.003 (0.00 - 0.217)	0.060 ± 0.013 (0.00 - 0.085	10	0.151	P > 0.05
NO_3 (mg/l)	3.405 ± 1.110 (0.27 - 8.40)	3.268 ± 1.006 (0.01 - 7.10)	1.153 ± 0.387 (0.38 - 2.56)	45	0.170	P > 0.05
SO_4 (mg/l)	3.718 ± 0.874^{a} (1.19 - 7.37)	1.067 ± 0.223^{b} (0.54 - 1.98)	0.552 ± 0.115^{b} (0.22 - 0.98)	200	0.001	**P < 0.01**
THC (mg/l)	1.772 ± 0.843 (0.09 - 4.90)	3.888 ± 2.044 (0.14 - 11.40)	0.683 ± 0.307 (0.02 - 1.80)	10	0.235	P > 0.05

Continued

Fe (mg/l)	2.328 ± 0.937 (0.25 - 6.42)	2.255 ± 0.744 (0.49 - 5.28)	0.6083 ± 0.116 (0.19 - 0.92)	0.3	0.175	P > 0.05
Mn (mg/l)	0.150 ± 0.033[a] (0.064 - 0.296)	0.210 ± 0.029[a] (0.125 - 0.310)	0.053 ± 0.008[b] (0.024 - 0.075)	0.40	0.002	**P < 0.01**
Zn (mg/l)	0.712 ± 0.304 (0.191 - 2.040)	0.689 ± 0.236 (0.280 - 1.583)	0.138 ± 0.016 (0.098 - 0.190)	5	0.153	P > 0.05
Cu (mg/l)	0.057 ± 0.022 (0.007 - 0.148)	0.066 ± 0.014 (0.023 - 0.121)	0.020 ± 0.004 (0.009 - 0.037)	0.5 - 1.5	0.112	P > 0.05
Cr (mg/l)	0.063 ± 0.010[b] (0.029 - 0.099)	0.107 ± 0.020[a] (0.051 - 0.179)	0.035 ± 0.010[b] (0.010 - 0.065)	0.05	0.009	**P < 0.01**
Cd (mg/l)	0.046 ± 0.009[b] (0.024 - 0.084)	0.085 ± 0.011[a] (0.043 - 0.121)	0.022 ± 0.004[b] (0.007 - 0.037)	0.005	0.000	**P < 0.001**
Ni (mg/l)	0.010 ± 0.004 (0.000 - 0.000)	0.030 ± 0.008 (0.000 - 0.000)	0.020 ± 0.005 (0.000 - 0.000)	NG	0.067	P > 0.05
Pb (mg/l)	0.029 ± 0.006[b] (0.010 - 0.045)	0.058 ± 0.011[a] (0.023 - 0.092)	0.020 ± 0.007[b] (0.005 - 0.049)	0.01	0.015	**P < 0.05**
V (mg/l)	0.01 ± 0.003 (0.000 - 0.000)	0.03 ± 0.007 (0.000 - 0.000)	0.01 ± 0.004 (0.000 - 0.000)	NG	0.061	P > 0.05

NOTE: P > 0.05 = No significant difference, P < 0.05 = Significantly different, P < 0.01 = Highly significantly different, P < 0.001 = Very highly significantly different, Similar letters indicate means that are not significantly different, NG = Not Given in the WHO limit.

Table 3. Mean (±SE) values of physical and chemical conditions of groundwater in study stations from April 2016 to September 2016.

Parameters	Station 1 X ± SE (Min-Max)	Station 2 X ± SE (Min-Max)	Station 3 X ± SE (Min-Max)	WHO limit	P-value	Significance
pH	5.338 ± 0.331 (4.60 - 6.55)	4.910 ± 0.403 (4.06 - 6.70)	5.050 ± 0.355 (4.27 - 6.37)	6.5 - 8.5	0.703	P > 0.05
Temperature (˚C)	29.417 ± 0.569 (28.0 - 32.00)	28.583 ± 0.664 (26.0 - 31.00)	28.667 ± 0.307 (28.0 - 30.00)	NG	0.495	P > 0.05
EC (µS/cm)	253.467 ± 155.675 (48.3 - 1030.00)	343.333 ± 207.562 (96.7 - 1380.00)	259.517 ± 85.101 (99.0 - 670.00)	NG	0.904	P > 0.05
Colour (Pt. Co)	0.533 ± 0.533 (0.0 - 3.20)	0.000 ± 0.000 (0.0 - 0.00)	0.000 ± 0.000 (0.0 - 0.00)	5.0	0.391	P > 0.05
Turbidity (NTU)	0.400 ± 0.400 (0.0 - 2.40)	0.000 ± 0.000 (0.0 - 0.00)	0.000 ± 0.000 (0.0 - 0.00)	5.0	0.391	P > 0.05
TSS (mg/l)	0.317 ± 0.317 (0.0 - 1.90)	0.000 ± 0.000 (0.0 - 0.00)	0.000 ± 0.000 (0.0 - 0.00)	500 - 1500	0.391	P > 0.05
TDS (mg/l)	127.48 ± 78.722 (22 - 520)	172.35 ± 105.673 (46 - 700)	126.20 ± 42.009 (50 - 330)	500	0.898	P > 0.05
Salinity (‰)	0.116 ± 0.071 (0.022 - 0.47)	0.155 ± 0.093 (0.044 - 0.62)	0.117 ± 0.038 (0.045 - 0.30)	200 - 600*	0.910	P > 0.05
DO (mg/l)	5.967 ± 0.184 (5.4 - 6.60)	5.667 ± 0.265 (4.9 - 6.70)	5.900 ± 0.225 (5.2 - 6.60)	5	0.628	P > 0.05
BOD_5 (mg/l)	1.517 ± 0.135 (1.2 - 1.90)	1.767 ± 0.123 (1.5 - 2.30)	1.517 ± 0.194 (1.1 - 2.40)	NG	0.435	P > 0.05

Continued

COD (mg/l)	6.683 ± 0.429 (5.8 - 8.20)	7.867 ± 0.681 (5.1 - 9.90)	6.883 ± 0.814 (4.9 - 10.10)	NG	0.420	P > 0.05
HCO_3 (mg/l)	24.583 ± 7.940 (9.5 - 62.90)	34.883 ± 8.707 (12.2 - 75.00)	35.000 ± 5.307 (18.3 - 52.80)	NG	0.540	P > 0.05
Na (mg/l)	0.710 ± 0.057 (0.57 - 0.96)	1.347 ± 0.401 (0.74 - 3.31)	1.1917 ± 0.138 (0.81 - 1.60)	NG	0.199	P > 0.05
K (mg/l)	0.123 ± 0.015 (0.07 - 0.18)	0.147 ± 0.027 (0.08 - 0.26)	0.1117 ± 0.008 (0.09 - 0.14)	NG	0.419	P > 0.05
Ca (mg/l)	1.433 ± 0.163 (1.06 - 2.18)	2.823 ± 0.621 (1.47 - 5.41)	2.627 ± 0.497 (1.12 - 4.44)	NG	0.109	P > 0.05
Mg (mg/l)	0.562 ± 0.055 (0.42 - 0.79)	1.138 ± 0.306 (0.60 - 2.25)	0.977 ± 0.067 (0.76 - 1.17)	NG	0.105	P > 0.05
Cl (mg/l)	19.700 ± 1.599 (14.6 - 26.00)	40.750 ± 11.262 (24.6 - 96.40)	32.150 ± 4.495 (15.4 - 42.70)	200 - 600	0.140	P > 0.05
P (mg/l)	0.280 ± 0.075 (0.05 - 0.58)	0.350 ± 0.083 (0.09 - 0.64)	0.598 ± 0.152 (0.01 - 0.98)	NG	0.129	P > 0.05
NH_4N (mg/l)	0.022 ± 0.07 (0.000 - 0.052)	0.0257 ± 0.09 (0.000 - 0.062)	0.034 ± 0.08 (0.000 - 0.053)	NG	0.523	P > 0.05
NO_2 (mg/l)	0.047 ± 0.02 (0.000 - 0.132)	0.056 ± 0.03 (0.000 - 0.164)	0.031 ± 0.01 (0.000 - 0.071)	10	0.728	P > 0.05
NO_3 (mg/l)	1.585 ± 0.54 (0.33 - 3.490)	2.2917 ± 0.72 (0.13 - 5.180)	1.103 ± 0.39 (0.21 - 2.150)	45	0.349	P > 0.05
SO_4 (mg/l)	0.760 ± 0.34 (0.26 - 2.400)	1.153 ± 0.49 (0.37 - 3.540)	0.840 ± 0.17 (0.24 - 1.300)	200	0.716	P > 0.05
THC (mg/l)	0.000 ± 0.00 (0.00 - 0.000)	0.005 ± 0.01 (0.00 - 0.030)	0.000 ± 0.00 (0.00 - 0.000)	10	0.391	P > 0.05
Fe (mg/l)	0.433 ± 0.09 (0.25 - 0.810)	0.398 ± 0.09 (0.19 - 0.730)	0.527 ± 0.11 (0.16 - 0.920)	0.3	0.633	P > 0.05
Mn (mg/l)	0.043 ± 0.02 (0.013 - 0.120)	0.033 ± 0.01 (0.019 - 0.070)	0.029 ± 0.01 (0.011 - 0.050)	0.40	0.618	P > 0.05
Zn (mg/l)	0.124 ± 0.02 (0.090 - 0.190)	0.126 ± 0.02 (0.080 - 0.180)	0.136 ± 0.03 (0.046 - 0.210)	5	0.907	P > 0.05
Cu (mg/l)	0.011 ± 0.00 (0.000 - 0.026)	0.008 ± 0.00 (0.000 - 0.019)	0.009 ± 0.00 (0.000 - 0.018)	0.5 - 1.5	0.790	P > 0.05
Cr (mg/l)	0.000 ± 0.00 (0.00 - 0.000)	0.010 ± 0.01 (0.00 - 0.060)	0.000 ± 0.00 (00.00 - 0.000)	0.05	0.391	P > 0.05
Cd (mg/l)	0.000 ± 0.00 (0.000 - 0.000)	0.000 ± 0.00 (0.000 - 0.002)	0.0000 ± 0.00 (0.000 - 0.000)	0.005	0.391	P > 0.05
Ni (mg/l)	0.00 ± 0.00 (0.000 - 0.000)	0.00 ± 0.00 (0.000 - 0.000)	0.00 ± 0.00 (0.000 - 0.000)	NG	-	P > 0.05
Pb (mg/l)	0.000 ± 0.00 (0.000 - 0.000)	0.001 ± 0.00 (0.000 - 0.008)	0.000 ± 0.00 (0.000 - 0.000)	0.01	0.391	P > 0.05
V (mg/l)	0.00 ± 0.00 (0.000 - 0.000)	0.00 ± 0.00 (0.000 - 0.000)	0.00 ± 0.00 (0.000 - 0.000)	NG	-	P > 0.05

NOTE: P > 0.05 = No significant difference, P < 0.05 = significantly different, P < 0.01 = highly significantly different, P < 0.001 = Very highly significantly different; similar letters indicate means that are not significantly different, NG = Not Given in the WHO limit. *in mg/l (*i.e.* 0.33‰ - 1.05‰).

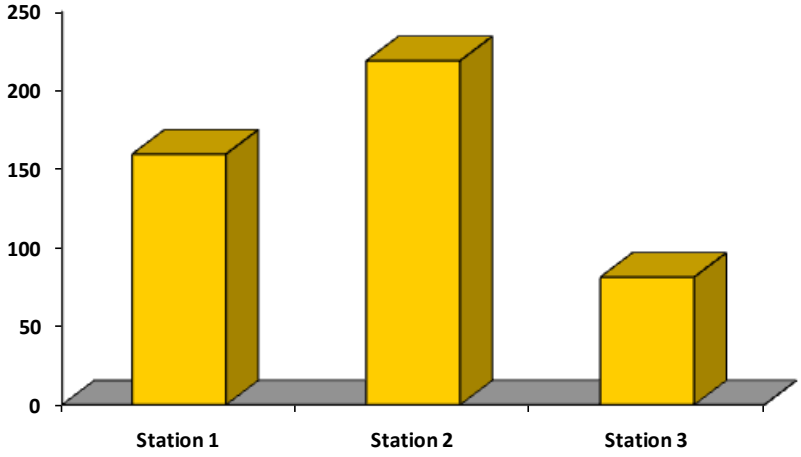

Figure 2. Water Quality Index for stations 1, 2 and 3. Note: <50 = Excellent, 50 - 100 = Good, 100 - 200 = Poor, 200 - 300 = Very poor (bad) water, >300 = Unsuitable for drinking.

Electrical conductivity was significantly different across the stations for both surface and groundwater. It was less than the range of 14 - 41000 μS/cm reported for the New Calabar River [21]. Electrical conductivity values were high in stations 1 (3940.82 μS/cm) and 2 (400.80 μS/cm) for surface water (**Table 2**) and high in station 2 (343.333 μS/cm) for groundwater (**Table 3**). These are environments with gas flaring with high probability of possible contact with inorganic substance coming from the discharges of the flared gas [22].

The maximum permissible value of 15 Pt. Co for water colour was not exceeded by groundwater samples and stations 1 and 3 for surface water; station 2 (21.133 Pt. Co) however, exceeded the permissible limit. For groundwater samples, there was no significant difference across the station for color ranges. At $P < 0.001$ level of significance, there was very highly significant difference in colour across the surface water stations with station 2 being responsible for the difference, as revealed by Duncan's Multiple Range test. Like taste, colour could be an indication of dissolved salts and suspended solids. Akan [23] stated that pure water is colorless, thus, any water with a characteristic colour insinuates contamination.

Turbidity consists of suspended particles in the water and may be caused by organic or inorganic materials. The WHO limit of 5 NTU [18] for turbidity was not exceeded across the stations for both surface and groundwater samples. At $P<0.001$ level of significance, there was very highly significant difference in turbidity across the station for surface water (**Table 2**). Turbidity values obtained were higher in station 1 for surface and groundwater. The high turbidity of surface water in station 1 was observable during sampling and could be attributed to the discharge of crude oil waste or bunkering activities within the area. Boyd [24] reported that turbidities in natural waters seldom exceed 20,000 mg/l and even muddy waters usually have less than 2000 mg/l. The observed turbidity level in this study agrees with the range of 2 NTU to 47 NTU reported by

Asonye *et al.* [25] for the turbidity of Nigerian water bodies. High turbidity waters have been linked to microbial contamination [26].

Groundwater samples showed no significant values across the stations for total suspended solids (TSS). However, there was a significant difference in values obtained from the stations for surface water samples with station 2 having a higher value of TSS which may be as a result of sand dredging done in this station and death and decomposition of plant materials. TSS in water is undesirable since they decrease water transparency, inhibit photosynthesis, increase sediments, smoothen breeding bed of aquatic organisms and eventually lead to an increase of sediments and a decrease of water depth [27].

The maximum permissible value of 1000 mg/l [18] for Total Dissolved Solids (TDS) was not exceeded by ground and surface water samples in all the stations. The TDS in the study shows that the highest value was recorded in station 2 and average readings of 198.717 mg/l and 172.35 mg/l in surface water and groundwater respectively. Result of TDS was below the range of 1235 - 19846 mg/l reported for brackish Elechi Creek in Port-Harcourt Nigeria [28], but within the range of 12 - 490 mg/l reported for the fresh Ikpoba River [29] [30]. All values recorded were below the acceptable limits. The TDS is directly related to the electrical conductivity and salinity of the water.

Salinity was low for all the sampling stations for both groundwater and surface water, and the maximum permissible limit of 200 g/l was not exceeded. Across the stations, there was no significant difference for groundwater, while significant difference was recorded across the stations for surface water with station 1 having the highest value of 1.783 g/l. There was no evidence of salt water intrusion although increase in salinity has been linked to crude oil pollution [31] [32].

Dissolved oxygen was in the range of 6.3 - 8.3 mg/l reported by Idowu and Ugwumba [33]. The minimum permissible value of 5 mg/l [18] was exceeded in all the stations for both ground and surface water samples, making the water oxygenated enough to support aquatic life. DO in station 2 was low and had a mean value of 5.100 mg/l and 5.667 mg/l for surface and groundwater respectively. The reduction in DO concentration could be linked to the breaking down of organic matter by aerobic microorganisms associated with organic pollution. Dissolved oxygen is a useful indicator of water quality, ecological standing, efficiency and health of a river [34]. The maximum permissible value of 1.9 mg/l [18] for BOD was not exceeded in the stations for groundwater samples but was exceeded in the stations by surface water samples. Higher values, therefore, indicate the existence of a large number of organic contaminants and comparatively higher level of microbial activities resulting in the reduction of oxygen content. Value of COD was higher in station 1 (15.433 mg/l) in surface water and higher in station 2 (7.867 mg/l) in groundwater which is in agreement with the values recorded by Uzoekwe and Oghosanine [35] and was attributed to the discharge of pollutant into water bodies. Muoghalu and Omocho [36] reported that when

waste deeply loaded with pollutant and dissolved solids have entry to water bodies, a large volume is required for their decomposition.

The calcium level of both surface and groundwater ranged between 0.84 mg/l and 38.70 mg/l. Higher calcium values were recorded in station 1 with a mean value of 16.4983 mg/l for surface water and 2.823 mg/l for groundwater. Calcium is metallic cation usually present in fresh surface water and among the most commonly found in groundwater [37]. Its quantities in natural water depend upon the type of rocks and nearness to the coast. The range reported for the Okhuaihe River in the more inland Edo State was far lower (1.73 - 2.65 mg/l) than the values reported in this study. The magnesium level of both surface and groundwater reported for this study lies between 0.42 - 19.30 mg/l. This is lower when compared to the levels of 0.1 - 72.9 mg/l for River Jamieson [38]. The values of calcium and magnesium recorded indicate that all the samples lie within the desirable limit (50 mg/l and 37 - 150 mg/l respectively) for drinking water [39]. The concentration of sodium varied from 0.51 - 28.40 mg/l across the stations. The spatial variation in the concentration of sodium was not significant in the groundwater. In the surface water, the spatial variation was significant with station 1 having the highest mean value of 11.773 mg/l. Increase in sodium concentration has been linked to crude oil leakage [40]. Sodium concentration of more than 50 mg/l makes the water unsuitable for drinking [39]. The potassium level of surface and groundwater ranged from 0.07 - 4.75 mg/l. These values were low when compared with the level in River Sokoto (2.8 to 13.2 mg/l) as reported by Holden and Green [41]. Potassium was within the WHO limit. The cations in the water samples are in the order Ca > Na > Mg > K.

Chloride level of both surface and groundwater recorded in this study ranged between 14.6 - 64.5 mg/l which is below the WHO permissible level of 250 mg/l. In pristine freshwaters chloride concentrations are usually lower than 10 mg/l and sometimes less than 2 mg/l [42]. Chloride is not considered as being harmful to human health. Chloride values above 250 mg/l impart a salty taste which makes the water unpalatable. The presence of Bicarbonates (HCO_3^-) influences the hardness and alkalinity of water. The relative amounts of bicarbonates are related to pH. Bicarbonate concentrations in surface waters are usually < 500 mg/l, and commonly < 25 mg/l [42]. There was a significant difference in the bicarbonate concentration in the surface water with station 1 having the highest with a mean value of 132.350 mg/l followed by station 2 with a mean value of 47.483 mg/l.

Nitrogenous compounds are of interest to environmentalists because they are essential nutrients which are beneficial to living organisms and also become pollutants with potentially harmful consequences when present in excess amount. Ammonium nitrogen, nitrate and nitrite are indicators of nitrogen loading of waters. Ammonium nitrogen was low and ranged from 0.00 - 0.127 mg/l in the surface water and 0.00 - 0.062 mg/l in the groundwater. The nitrite and nitrate values recorded in this study ranged from 0.00 - 0.243 mg/l and 0.01 - 8.40 mg/l

respectively in the surface water, and in the groundwater, 0.00 - 0.164 and 0.13 - 5.18 mg/l respectively. Unpolluted water usually contains little amount of nitrate [43]. The leaching of plants and dry leaf litter is another source of nitrate in water bodies [44] [45]. The values of the Nitrogenous compounds in both surface and groundwaters are within acceptable limits.

The addition of phosphate to natural waters in one of the most serious environmental problems because its contribution to eutrophication. Although, nitrate also contributes to eutrophication, phosphate is the major culprit in freshwaters. It is required by plants in very low quantities. The phosphate content of the waters in this study ranged between 0.26 - 9.85 mg/l for surface water and 0.01 - 0.98 mg/l for groundwater. The concentrations of available phosphorous at all stations differed insignificantly. Phosphorus was highest in Station 2 with an average mean value of 4.357 mg/l. Excess phosphorus in water is considered a pollutant [46] and may be due to enrichment from allochthonous phosphorus-containing substances rather than oil exploration and production activities [47]. The values recorded in this study are within acceptable limits.

Sulphate concentrations in natural water are usually between 2 and 80 mg/l; high concentration (>400 mg/l) may make water unpleasant to drink. Sulphate is one of the least toxic anions in drinking water, but catharsis, dehydration, and gastrointestinal irritation have been linked to high sulphate concentrations in drinking water. WHO recommends an urgent action by health agencies when sulphate in drinkable water exceeds 200 mg/l. In the present study, the sulphate values were far below the 200 mg/l maximum allowable limit.

THC for both surface and groundwater in all the stations showed no significant difference at $P < 0.05$. The FMEnv's maximum discharge limit of 10 mg/l THC/oil and grease into inland waters was not exceeded in this study. The low level of Total Hydrocarbon Content (THC) of less than < 10 mg/l, being limitation standards for FMEnv/DPR, is a good indication that the water samples are not polluted with hydrocarbons. The variation in the pattern of the total hydrocarbon within the study area suggests that most of the hydrocarbons in water samples were of anthropogenic origin. In the groundwater samples, the level of THC contamination decreased significantly. In addition, various chemical, physical and biological processes that are known to degrade petroleum hydrocarbon in water may undoubtedly have contributed to the general decrease in the hydrocarbon levels observed.

Natural waters contain very small quantities of essential metals such as zinc (Zn), copper (Cu), Cadmium (Cd), lead (Pb), iron (Fe), Nickel (Ni), cobalt (Co), manganese (Mn), Barium (Ba) and Silver (Ag). These metals, also called trace or heavy metals, are required by organisms in minute quantities, toxic in relatively high concentrations and non-biodegradable and easily assimilated and bio-accumulated in the protoplasm of aquatic organisms. Non-essential heavy metals of particular concern to surface water systems are cadmium, chromium, mercury, lead, arsenic, and antimony [19]. The concentrations of heavy metals in the sur-

face water samples were generally low but some (Fe, Cr, Cd and Pb) slightly exceeded the WHO limits in the perturbed stations 1 and 2 but not in the control station 3 (**Table 2**). This could be attributed to the impact of anthropogenic activities associated with oil exploration and production activities. The heavy metals contained in the water samples could have emanated from runoff or leachate from drilling fluids components of mud, diesel, bit lube, caustic lignosulphonate, and water-based drilling mud thinner, which contains chrome, ferrochrome and spilled hydrocarbon from drilling operations that find their way to surface and groundwater. Low heavy metal accumulation has been reported in Nigerian water bodies by previous studies [3] [28] [48]. Due to its high toxicity to aquatic life and man, heavy metals have been used as an indicator of pollution [3].

The values of heavy metals in the groundwater (with the exception of Fe) were very low and in most cases below detection limits. Iron is usually high in Nigerian soil and waters as has been reported in earlier studies [49] [50]. The concentration of heavy metals was of the order: Fe > Zn > Mn > Cu > Cr > Pb > Cd > Ni > V.

The water quality index (WQI) was computed for the three stations. Station 1 had a WQI value of 159.42, station 2, 218.81 and station 3, 81.24 (**Figure 2**). Station 3 has the lowest WQI value of 81.24 making it suitable for drinking, while stations 2 and 3 are poor and very poor respectively from rating of the water quality index. The poor water quality of stations 1 and 2 can be attributed to anthropogenic activities from crude oil production.

4. Conclusion

The average physicochemical parameters in surface water conformed to WHO standard with the exception of temperature, electrical conductivity, colour, dissolved oxygen, biological oxygen demand, iron, cadmium and lead. Water quality index shows that water from station 1 and 2 is poor for drinking compared to station 3 (control). Level of heavy metals in groundwater does not exceed WHO standard, indicating any health risk. However, there is heavy metal contamination of surface water in Sapele possibly through oil spillage, gas flaring, drilling, bunkering related activities from crude oil exploration and production operations in the area as crude oil exploration and production activities are a primary source of heavy metal pollution to surface water in crude oil producing area.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

[1] Forsythe, R. (1996) The Politics of Oil in the Caucasus and Central Asia: Prospects for Oil Exploitation and Export in the Caspian Basin. Oxford University Press, Oxford.

[2] Ogbeibu, A.E. and Omoigberale, M.O. (2005) Environmental Impacts of Oil Explo-

ration and Production on the Rotifers of Osse River, Southern Nigeria. *African Journal of Environmental Pollution and Health*, **4**, 72-80.

[3] Omoigberale, M.O. and Ogbeibu, A.E. (2005) Assessing the Environmental Impacts of Oil Exploration and Production on the Osse River, Southern Nigeria, I. Heavy Metals. *African Journal of Environmental Pollution and Health*, **4**, 27-32.

[4] Omoigberale, M.O. and Ogbeibu, A.E. (2007) Assessing the Environmental Impacts of Oil Exploration and Production on the Water Quality of Osse River, Southern Nigeria. *Global Journal of Environmental Sciences*, **6**, 1-13. https://doi.org/10.4314/gjes.v6i1.2484

[5] Omofonmwan, S.I. and Odia, L.O. (2009) Oil Exploitation and Conflict in the Niger-Delta Region of Nigeria. *Journal of Human Ecology*, **26**, 25-30. https://doi.org/10.1080/09709274.2009.11906161

[6] Omoigberale, M.O. and Ogbeibu, A.E. (2010) Environmental Impacts of Oil Exploration and Production on the Macrobenthic Invertebrate Fauna of Osse River, Southern Nigeria. *Research Journal of Environmental Sciences*, **4**, 101-114. https://doi.org/10.3923/rjes.2010.101.114

[7] Nwankwo, N. and Ifeadi, C.N. (1988) Case Studies on the Environmental Impact of Oil Production and Marketing in Nigeria. In: Sada, P.O. and Odemerho, F.O., Eds., *Environmental Issues and Management in Nigerian Development*, Evans Brothers (Nigeria Publishers) Limited, Ibadan, 208-223.

[8] Zheng, J., Chen, B., Thanyamanta, W., Hawboldt, K. and Zhang, B. (2016) Offshore Produced Water Management: A Review of Current Practice and Challenges in Harsh/Arctic Environments. *Marine Pollution Bulletin*, **104**, 7-19. https://doi.org/10.1016/j.marpolbul.2016.01.004

[9] Ayotamuno, M.J., Kogbara, R.B., Ogaji, S.O.T. and Probert, S.D. (2006) Petroleum Contaminated Groundwater: Remediation Using Activated Carbon. *Applied Energy*, **83**, 1258-1264. https://doi.org/10.1016/j.apenergy.2006.01.004

[10] Alinnor, I.J. and Nwachukwu, M.A. (2013) Determination of Total Petroleum Hydrocarbon in Soil and Groundwater Samples in Some Communities in Rivers State, Nigeria. *Journal of Environmental Chemistry and Toxicology*, **5**, 292-297.

[11] Allen, L., Michael, J.C., David, A. and Bart, M. (2014) Fossil Fuels and Water Quality. *The Worlds Water*, **74**, 1-5.

[12] Tubonimi, J.K.I., Omubo, A. and Herbert, O.S. (2010) Assessment of Water Quality along Amadi Creek in Port Harcourt, Nigeria. *Scientia Africana*, **9**, 150-162.

[13] Odukoya, O.O., Arowolo, T.A. and Bamgbose, O. (2002) Effect of Solid Waste. Landfill on Underground and Surface Water Quality at Ring Road, Ibadan. *Global Journal of Environmental Sciences*, **2**, 235-242. https://doi.org/10.4314/gjes.v1i1.2396

[14] Mogborukor, J.O.A. (2014) The Impact of Oil Exploration and Exploitation on Water Quality and Vegetal Resources in a Rain Forest Ecosystem of Nigeria. *Mediterranean Journal of Social Sciences*, **5**, 1678-1685. https://doi.org/10.5901/mjss.2014.v5n27p1678

[15] Laboratory Analytical Work Instruction (LAWI) (2011) Determination of Total Petroleum Hydrocarbon in Soil/Sediment/Sludge in Gas Chromatography. Fugro Nigeria Limited, Lagos.

[16] Ogbeibu, A.E. (2014) Biostatistics: A Practical Approach to Research and Data Handling. 2nd Edition, Mindex Publishing Company, Benin City.

[17] Atubi, A.O. (2011) Effects of Warri Refinery Effluents on Water Quality from the

Iffie River, Delta State, Nigeria. *American Review of Political Economy*, **9**, 45-56.

[18] WHO (1996) World Health Organisation's Guidelines for Drinking Water. 3rd Edition, Geneva.

[19] Ogbeibu, A.E., Oriabure, P.A., Oboh, I.P. and Edogun, I.S. (2014) The Effects of Brewery Effluent Discharge on the Water Quality and Sediment of the Ikpoba River, Benin City, Nigeria. *Journal of Aquatic Sciences*, **29**, 43-58.

[20] Dami, A., Ayuba, H.K. and Amukali, O. (2012) Effects of Gas Flaring and Oil Spillage on Rainwater Collected for Drinking in Okpai and Beneku, Delta State, Nigeria. *Global Journal of Human Social Science Geography & Environmental GeoScience*, **12**, 25-29.

[21] Ekeh, I.B. and Sikoki, F.D. (2003) The State and Seasonal Variability of Some Physicochemical Parameters in the New Calabar River, Nigeria. *Suplementa ad Acta Hydrobiologica*, **5**, 45-60.

[22] Etu-Efeotor, J.O. (1998) Hydrochemical Analysis of Surface and Groundwater of Gwagwalada Area of Central Nigeria. *Global Journal of Pure and Applied Sciences*, **4**, 153-162.

[23] Akan, J.C. (2006) Determination of Pollutant Levels in Some Surface and Water Waste Samples from Kano Metropolis, Nigeria. An M.Sc. Dissertation, University of Maiduguri, Maiduguri.

[24] Boyd, C.E. (1981) Water Quality in Warm Water Fish Ponds. 2nd Edition, Craftmaster, Printers Inc., Auburn.

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

[26] DWAF (1998) Quality of Domestic Water Supplies Assessment Guide 1 (2nd Edition). Department of Water Affairs and Forestry, Department of Health and Water Research Commission.

[27] Ogbeibu, A.E. and Anagboso, M.U. (2004) Baseline Limnological Investigation of the Utor River in Esan South-East, Edo State, Southern Nigeria: 1. Physical and Chemical Hydrology. *Tropical Freshwater Biology*, **12**, 45-62. https://doi.org/10.4314/tfb.v12i1.20875

[28] Obire, O., Tamuno, D.C. and Wemedo, S.A. (2003) Physicochemical Quality of Elechi Creek in Port Harcourt, Nigeria. *Journal of Applied Sciences and Environmental Management*, **7**, 43-49. https://doi.org/10.4314/jasem.v7i1.17164

[29] Ogbeibu, A.E. and Edutie, L.O. (2002) Impact of Brewery Effluent on the Water Quality and Rotifers of Ikpoba River, Southern Nigeria. *African Journal of Environmental Pollution and Health*, **1**, 1-12.

[30] Ogbeibu, A.E. and Ezeunara, P.U. (2002) Ecological Impact of Brewery Effluent on the Ikpoba River, Using the Fish Communities as Bioindicators. *Journal of Aquatic Sciences*, **17**, 35-44. https://doi.org/10.4314/jas.v17i1.19908

[31] Rhykered, R.I., Weaver, R.W. and McLnnes, K.J. (1995) Influence of Salinity on Bioremediation of Oil in Soil. *Environmental Pollution*, **90**, 127-130. https://doi.org/10.1016/0269-7491(94)00087-T

[32] Ward, D.M., Atlas, R.M., Boehm, P.D. and Calder, J.A. (1980) Microbial Biodegradation and the Chemical Evolution of Amoco Cadiz Oil Pollutants. *Ambio*, **9**, 277-283.

[33] Idowu, R.T. and Ugwumba, A.A. (2005) Physical, Chemical and Benthic Characteristics of a Southern Nigeria Reservoir. *The Zoologist*, **3**, 15-28.

[34] Moshood, K.M. (2008) Assessment of the Water Quality of Oyun Reservoir, Offa, Nigeria, Using Selected Physicochemical Parameters. *Turkish Journal of Fisheries and Aquatic Sciences*, **8**, 309-319.

[35] Uzoekwe, S.A. and Oghosanine, F.A. (2011) The Effect of Refinery and Petrochemical Effluent on Water Quality of Ubeji Creek Warri, Southern Nigeria. *Ethiopian Journal of Environmental Studies and Management*, **4**, 107-116. https://doi.org/10.4314/ejesm.v4i2.12

[36] Muoghalu, L.N. and Omocho, V. (2000) Environmental Health Hazards Resulting from Awka Abattoir. *Africa Journal of Environmental Studies*, **2**, 72-73.

[37] Iorwua, M., Onyebuchi, M., Tiza, M. and Iorwua, J. (2018) Physico-Chemical Analysis of Some Wells and Streams in North Bank, Makurdi-Benue State, Nigeria. *International Journal for Research in Engineering Application and Management*, **4**, 84-89.

[38] Imoobe, T.O.T. and Oboh, I.P. (2003) Physical and Chemical Hydrology of River Jamieson, Delta State, Nigeria. *Benin Science Digest*, **1**, 105-119.

[39] WHO (1999) Guidelines for Drinking Water Quality. 2nd Edition, Vol. 2, Health Criteria and Other Supporting Information. World Health Organization, Geneva.

[40] Callot, H. and Ocampo, R. (2000) Wetlands and Water Pollution. *Boston College Environmental Affairs Law Review*, **23**, 885-919.

[41] Holden, M.J. and Green, J.E. (1960) The Hydrology and Plankton of the River Sokoto. *Journal of Animal Ecology*, **29**, 65-84. https://doi.org/10.2307/2271

[42] Chapman, D.V. (1996) Water Quality Assessments: A Guide to Use of Biota, Sediments and Water "Environmental Monitoring". 2nd Edition, UNESCO, WHO, and UNEP, E. and F.N. Spon, London. https://doi.org/10.4324/NOE0419216001

[43] Jaji, M., Bamgbose, O., Arowolo, T. and Odukoya, O. (2007) Water Quality Assessment of Ogun River, South West Nigeria. *Environmental Monitoring and Assessment*, **133**, 447-482. https://doi.org/10.1007/s10661-006-9602-1

[44] Hynes, H.B.N. (1970) The Ecology of Running Waters. Liverpool Univ. Press, Liverpool.

[45] Wetzel, R.G. (1974) Review of: A Guide to the Measurement of Marine Primary Production under Some Special Conditions. (UNESCO, Paris, 1973). *Transactions of the American Fisheries Society*, **103**, 416-417.

[46] Odiete, W.O. (1999) Environmental Physiology of Animals and Pollution. Diversified Resources, Lagos.

[47] Ogbeibu, A.E. and Victor, R. (1995) Hydroblological Studies of Water Bodies in Okomu Forest Reserve (Sanctuary) in Southern Nigeria 1: Distribution and Diversity of the Invertebrate Fauna. *Tropical Freshwater Biology*, **4**, 1-19.

[48] Chindah, A.C. and Braide, S.A. (2004) The Physicochemical Quality and Phytoplankton Community of Tropical Waters: A Case of 4 Biotopes in the Lower Bonny River, Niger Delta, Nigeria. *Caderno de Pesquisa. Série Biologia*, **16**, 7-35.

[49] Nikoladze, G., Mintis, D. and Kastalsky, A. (1989) Water Treatment for Public and Industrial Supply. English Edition, MIR Publishers, Moscow, 51-70, 89-107, and 213-224.

[50] Omoigberale, M.O., Ogbeibu, A.E. and Olotu, N.O. (2009) Assessment of Groundwater Quality of Benin City, Edo State, Nigeria. *Tropical Freshwater Biology*, **18**, 15-35. https://doi.org/10.4314/tfb.v18i2.63289