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Effects of Industrial Waste Water on the Physical and Chemical Characteristics of a Tropical Coastal River

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Abstract: The effect of industrial wastewater on the physical and chemical characteristics of Warri River, a coastal water body in the Niger Delta area of Nigeria was carried out for eight months spanning from October 2005 to May 2006. Three sampling points were chosen along the river corresponding to the locations were notable industries discharges are drained from the water shed into the river. Two reference points, upstream (Station 1) and downstream (Station 5) were also selected along the watercourse. The effluents discharged into stations 2, 3 and 4 led to slight increase in the acidic pH (6.16-7.73), high BOD values (10.8-54.4 mg L^{-1}), including substantial increase in COD values (20-80 mg L^{-1}), Turbidity values 94.5-18.6 Ntu) and total dissolved solids (165-898 mg L^{-1}). Oil and grease levels were elevated in station 2 (3.42-17.9 mg L^{-1}). This is as expected owing to its location close to a nearby fuel station. Analysis of variance (ANOVA) result revealed that turbidity, TDS, TSS, Electrical conductivity, salinity, BOD, COD, Phosphate, Ammonia, Iron and Copper were significantly different among the various stations sampled. The upstream station and downstream reference sites recorded lower values of these parameters. Seasonality did not affect much of the parameters except for Ammonia, TSS and TDS that were significantly different among the various sampling months. The study underscores the need for immediate remediation programmes to ameliorate the poor water status of the sections of the river sampled.

Key words: Effluents, Niger Delta, physicochemical parameters, Warri River, wastewater

INTRODUCTION

Thousands of residents around the Warri area, Niger Delta rely on water from the river for public use, industrial supplies, power plant cooling and wastewater treatment. Good water quality and a healthy aquatic ecosystem are essential to maintain fish and other aquatic biota (Arimoro and Osakwe, 2006). Similarly, boaters and swimmers enjoy the aesthetic values of a healthy ecosystem.

The Warri River is among the most diverse ecosystem of macroinvertebrates (Olomukoro, 1996) and fish (Ogidiaka, 2006). People always have been closely associated with water sources for drinking, food and transportation and Warri River is no exception. Most Nigerian rivers are generally turbid with a high concentration of suspended silt, particularly during the rainy season (Ita *et al*., 1985). The quality of water, unlike the very obvious physical changes that take place during the development of water resources, is an attribute that affects the biodiversity (flora and fauna) of aquatic systems. The effects are usually subtle and before any obvious changes are noticeable extensive damage would have been done. Nigerian freshwaters are usually very productive at the primary (algae), secondary (zooplankton) and tertiary (fish and other aquatic vertebrate) levels. However, in industrial areas and urban centers there is some pollution with high levels of faecal coliforms (Ogbondeminu, 1986), heavy

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metals, organic wastes and industrial wastes which constitute public health hazards (Arimoro *et al*., 2007). Although, water quality is to some extent an index of water pollution, the indices presently used in Nigeria are inadequate to indicate the damage that is done by heavy metals, metalloids, organic and inorganic compounds and blue green algae. The common indicators for assessing water quality in Nigeria (Ikomi *et al*., 2003) are temperature, pH, biological oxygen demand, turbidity, dissolved oxygen, ammonia, nitrogen and coliform counts.

Studies of the physical and chemical hydrology of water bodies, both lotic and lentic, in many African countries and Nigeria in particular have received considerable attention. Amongst the numerous contributions are the studies of Nwadiaro and Umeham (1985), Onwudinjo (1990), Adeniji and Mbagwu (1990, 1991), Ogbeibu and Victor (1995), Ikomi and Owabor (1997), Jonnalagadda and Mhere (2001), Olomukoro and Egborge (2003), Ikomi *et al*. (2003), Imoobe and Oboh (2003), Olaleye and Adediji (2005), Armah *et al*. (2005) and Fafioye *et al*. (2005) among others.

The Warri River, a coastal river in the Niger Delta affected by various effluents of industries located in the area offers an opportunity to further quantify the impact of such effluents on the water quality which may lead to better understanding of the pollution processes in the river that may lead to improved regulation and policy development.

The present study aims at describing the spatiotemporal variations of water physicochemical parameters as affected by the industrial effluents and to identify the parameter(s) that most influence the variations observed.

MATERIALS AND METHODS

Description of Study Area

Warri River is one of the most important coastal rivers of the Niger Delta area of Nigeria. The river takes its source from a point, 10 km away from Utagba-Uno and lies within 50211-60001 N (Fig. 1), covering a surface area of above 255 km^2 with a length of about 150 km (NEDECO, 1961). From its source, the river flows south-westerly to link the industrial towns of Aladja and Warri. Beyond the Warri port the main channel of the river joins the Forcados estuary, which empties into the Atlantic Ocean. Warri is part of the wettest region of Nigeria and with two recognizable annual seasons of variable duration, the dry and the rainy seasons (NEDECO, 1961; Egborge, 1987). The rainy season lasts for about 8-10 months. The main features of the climate for the period October to May 2006 are shown in Fig. 2 and Table 1. The relevant human activities in the river are commercial sand dredging, production of gravel, fishing, washing and so on. The level of pollution is relatively high in the areas sampled due mainly the effluent coming in from the industries in Warri town.

Description of Study Stations

Station 1

This station is located upstream. Industries are not sited around this station. Human activities are reduced here to bathing and fishing. The vegetation is covered with various plants, fern plants, *Penitum puperium*, oil palm. *Elaeis guineensis*, *Azolla* sp. This station was taken as the reference station owing to the absence of discharge coming into the river from industries.

Station 2

Located close to the Warri town by a site were car is constantly washed. The detergent and other reagents used for washing cars are washed into the river directly without any treatment. The substratum is covered by coarse sand and gravel and the depth is about 1.7 m. This station is sparsely vegetated with such plants as *Azolla* spp., *Pistia* and *Ludwigia* species.

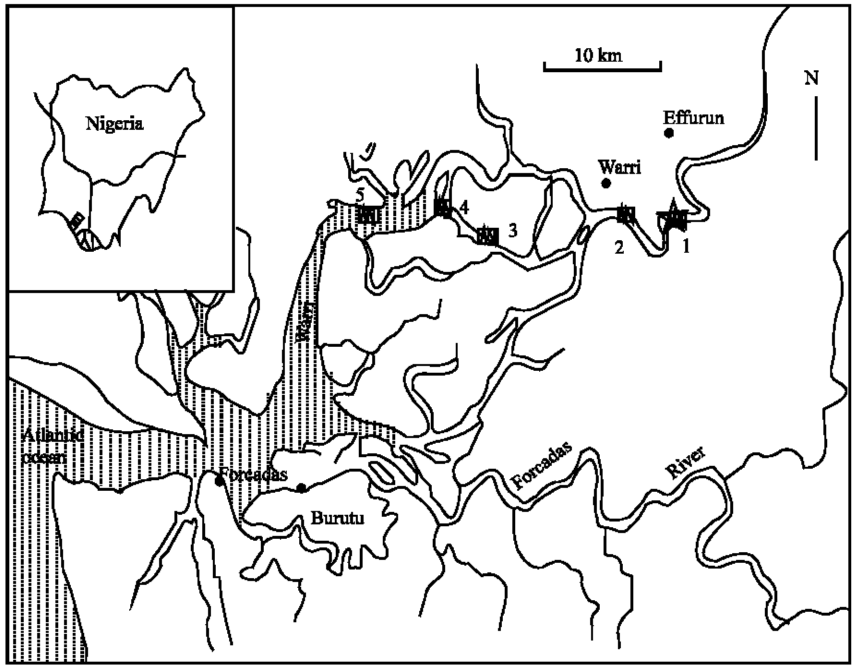

Fig.1: Map of Warri River showing the sampling stations

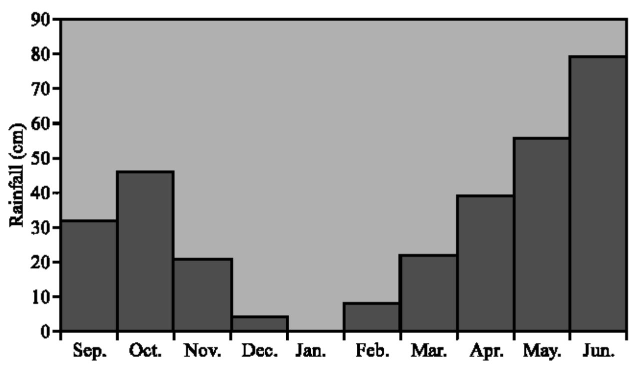

Fig. 2: Rainfall data of Warri area, Nigeria (Sep. 2005-Jun 2006). Source-Meteorological station of Warri Airport, Osubi, Nigeria

Station 3

This station is located in Warri town. The discharges from the fuel filling station are drained into this section of the stream. This station is sparsely vegetated with grasses, few *Pistia* sp. and water hyacinth *Eichhornia crassipes.* It has a low gradient.

Station 4

This station is located in Aladja. At this station effluent samples from the Helipad/Canteen and Maintenance/New PC laboratory discharges are drained into the surface water. This station is relatively

Table 1: Relative Humidity data of Warri area, Nigeria (Sep. 2005-Jun 2006). Source- Meteorological station of Warri Airport, Osubi, Nigeria

Months	Relative humidity (%)
Sep. 05	79
Oct.	82
Nov.	58
Dec.	74
Jan. 06	61
Feb.	65
Mar.	73
Apr.	75
May.	74
Jun.	81

vegetated compared to station 3 with fringing vegetation comprising mainly of *Cyrtosperma senegalens*, *Pandanus candelabrum* and *Anthocleista voeglii.*

Station 5

This station is located at the downstream reaches of the Warri River. The watershed drains through mangrove swamp forest. It has a low gradient and 200-300 m wide with a depth of 7-10 m. The area is not entirely fresh water most of the year. During the dry season months (Dec-Feb) they become brackish due to incursion of marine waters from Forcados (Egborge, 1987).

Water Quality Analysis

Sampling for water quality parameters was carried out in the five study stations at monthly intervals between Oct 2005 and June 2006, covering both dry and rainy seasons. Surface water temperatures were recorded with a thermometer. Conductivity, pH, total alkalinity, Dissolved Oxygen (DO) and Biochemical Oxygen Demand (BOD_5), total suspended solids were determined according to APHA (1985) methods. Monthly rainfall data were obtained from the meteorological station in Warri. Ammonia and Phosphate-phosphorus (PO_4-P) were measured spectrophotometrically after reduction with appropriate solutions (APHA, 1985). Chemical Oxygen Demand (COD) was determined after oxidation of organic matter in strong Tetraoxosulphate VI acid medium by $K_2Cr_2O_7$ at 148°C, with back titration. Total Dissolved Solid (TDS) was estimated by multiplying specific conductance by factor of 0.65. Others such as Iron, Copper and Salinity were determined using methods described by APHA (1985). To measure the oil and grease content of the water samples, the colouration of solvent (Xylene) was measured with a UV/Visible spectrophotometer.

RESULTS

A summary of the physicochemical parameters obtained in Warri River for the different stations are shown in Table 2. Also indicated are Means±standard error values and the maximum and minimum values for each parameter in parentheses. ANOVA is included to detect a significant difference among each station, while the monthly variations are given in Table 3.

pH

Temporal variation in Hydrogen ion concentration and the variations between stations is shown in Table 3. pH fluctuated between 6.16 and 8.22 in all the stations sampled. Station 3 recorded more neutral values in pH and tended to be more alkaline than the other stations. The highest pH value of 8.22 was recorded for this station in October. There were no significant difference in pH among the stations sampled ($p>0.05$). Also, there were no seasonal patterns in pH. It did not vary between the various months sampled as indicated by Analysis of variance (ANOVA).

Table 2: Physicochemical Parameters of the section of Warri River receiving waste water from industries (Oct 2005-May 2006)

Parameters	Station 1	Station 2	Station 3	Station 4	Station 5	F-ANOVA =2.36 monthl variation	F-ANOVA =2.71 P between station	DPR Limit	WHO Limit
pH	6.82±0.07 (6.58-7.23)	6.97±0.07 (6.67-7.28)	6.89±0.197 (6.51-8.22)	6.77±0.161 (6.16-7.73)	6.90±0.124 (6.54-7.71)	1.95	0.39	6.5-8.5	6.5-8.0
Temp. (°C)	28.49±0.39 (27.0-30.0)	29.38±0.29 (27.9-30.3)	28.4±0.39 (26.9-30.3)	28.91±0.38 (26.6-30.2)	28.48±0.41 (26.3-30.2)	3.69	1.86	30	27
Turbidity (NTU)	8.85±0.36 (7.9-10.5)	16.08±0.57 (13.2-18.6)	5.41±0.18 (4.5-6.1)	7.56±0.90 (5.6-12.6)	8.75±0.38 (7.7-10.1)	3.07	78.89**	15	N/A
Total dissolved solid (mg L^{-1})	82.13±35.47 (23.0-27.7)	287.63±14.49 (244-361)	225.50±12.54 (165-273)	448±91.71 (221-898)	51.13±12.78 (27-124)	0.81	12.28**	5000	1000
Total suspended solid (mg L^{-1})	5.56±0.49 (4.1-8.1)	9.2±0.47 (7.2-10.9)	3.36±0.139 (2.7-3.9)	455±0.71 (2.9-7.8)	5.49±0.53 (3.9-8.1)	8.32*	46.75**	30	N/A
Electrical conductivity (µS cm^{-1})	157.84±68.3 (45.5-532)	522.38±19.94 (449-598)	433.63±24.31 (315-524)	852.38±177.97 (140-1735)	98.48±24.45 (52.7-238)	0.93	12.02*	N/A	N/A
Salinity (mg L^{-1})	49.74±20.59 (13.65-165)	155.13±5.97 (134.66-179.3)	131.99±7.31 (94.47-157.2)	261.91±55.94 (128.9-520.5)	30.13±7.62 (15.7-74.5)	0.94	11.47*	2000	250
Dissolved oxygen (mg L^{-1})	3.1±0.39 (1.8-4.6)	2.64±0.35 (1.4-3.6)	3.26±0.58 (1.4-6.5)	4.08±0.54 (2.2-6.7)	3.08±0.33 (1.7-4.2)	4.79*	2.38	N/A	6.2
BOD (mg L^{-1})	11.39±1.61 (10.3-13.8)	26.28±6.29 (10.8-54.4)	18.65±3.24 (4.0-30.2)	10.3±0.82 (6.2-14.8)	11.9±1.88 (0.8-18.0)	2.20	1.98*	126	6
COD (mg L^{-1})	25±6.81 (10-70)	43.75±5.65 (20-60)	32.5±5.90 (10-70)	28.75±6.39 (20-70)	27.5±7.96 (10-80)	13.74	4.42	125	N/A
Oil and grease (mg L^{-1})	1.57±0.23 (0.49-2.45)	7.49±1.79 (3.42-17.9)	4.12±0.63 (1.05-5.86)	1.88±0.31 (1.02-3.56)	1.47±0.41 (0.01-3.65)	0.19	7.10	20	N/A
Phosphate (mg L^{-1})	0.0174±0.0037 (0.009-0.04)	1.25±0.14 (0.51-1.88)	0.048±0.0135 (0.01-0.12)	0.020±0.0037 (0.10-0.04)	0.025±0.008 (0.01-0.08)	1.19	77.53*	N/A	0.26
Ammonia NH_4 (mg L^{-1})	1.65±0.53 (0.51-5.13)	4.34±0.33 (3.24-6.315)	1.32±0.08 (1.01-1.62)	0.29±0.025 (0.156-0.37)	1.208±0.32 (0.32-3.26)	3.32*	33.99*	N/A	N/A
Fe (mg L^{-1})	0.844±0.082 (0.48-1.05)	0.896±0.075 (0.64-1.3)	8.288±0.028 (0.10-0.42)	3.413±0.385 (2.53-6.03)	0.53±0.119 (0.31-1.24)	1.43	49.56*	N/A	0.30
Cu (mg L^{-1})	0.0113±0.0023 (0-0.02)	0.038±0.0045 (0.02-0.06)	0.023±0.0031 (0.01-0.04)	0.02-±0.0019 (0.01-0.03)	0.015±0.0019 (0.01-0.02)	0.79	11.43*	N/A	1.00

*: Indicates that it is significantly different ($p<0.05$), **: Significantly different at $p<0.001$. values are mean ± Standard Error, minimum and maximum values are given in parentheses)

Surface Water Temperature

Surface water temperatures were consistently high between 26.3 and 30.3°C during the entire period of study. There was no significant difference ($p>0.05$) in surface water temperatures recorded between the months and between the different sampling stations. Lower temperatures were recorded in the month of January for all sampling stations.

Turbidity

Turbidity measured in NTU was significantly higher in station 2 than all the other stations sampled. Analysis of various results indicated that turbidity significantly varied among the various sampling stations. The highest turbidity value (18.6 NTU) was recorded in station 2 in January 2006 and the lowest value (4.5 NTU) was recorded in October 2005 in station 3. Generally stations 1, 4 and 5 recorded similar fluctuations in turbidity. Station 2 on the other hand recorded fairly higher values. Analysis of variance result also showed that there were no significant monthly variations observed among the various sampling stations. In addition, no clear seasonal pattern in Turbidity was observed.

Total Dissolved Solids (TDS)

The value of TDS was significantly higher in stations 2, 3 and 4. Stations 1 and 5 recorded lower TDS values. The highest TDS value (898 mg L^{-1}) was recorded in station 4 in March 2006. The lowest value of mg L^{-1} was recorded in station 1 in November 2005. Statistical analysis using ANOVA indicated that TDS was significantly different ($p<0.05$) among the stations sampled. TDS did not however show any marked temporal or seasonal variation although relatively higher values were measured in the dry season month of March in all the stations it did not vary significantly ($p>0.05$).

Table 3: Temporal and spatial variation in some physical and chemical characteristics of Lower Warri River from October 2005 to May 2006

	pH					Temperature (°C)					Turbidity (NTU)				
	Stn. 1	Stn. 2	Stn. 3	Stn. 4	Stn. 5	Stn. 1	Stn. 2	Stn. 3	Stn. 4	Stn. 5	Stn. 1	Stn. 2	Stn. 3	Stn. 4	Stn. 5
Oct 05	6.58	7.28	8.22	6.41	6.75	27.8	27.9	26.9	26.6	27.7	9.8	16.8	4.5	9.6	9.9
Nov	6.86	7.20	7.05	6.79	6.79	30.0	29.2	27.4	28.8	29.2	9.8	15.3	5.1	8.9	10.1
Dec	6.58	6.88	6.51	6.16	6.54	29.4	29.9	29.1	29.3	29.1	10.5	17.2	5.2	12.6	10.1
Jan 06	6.69	6.94	6.60	6.68	6.68	27.4	29.0	28.5	29.2	28.7	8.4	18.6	5.6	6.4	8.0
Feb	7.23	6.89	6.74	7.73	7.71	28.6	30.3	28.4	29.7	28.2	8.4	16.4	6.1	5.8	8.2
Mar	6.89	6.97	6.74	6.78	6.91	27.0	30.2	30.3	28.8	26.3	7.9	15.9	5.8	5.6	7.7
Apr	6.85	6.67	6.69	6.89	6.93	28.0	28.7	27.5	28.7	28.4	8.1	15.2	5.8	5.7	8.0
May	6.90	6.90	6.60	6.70	6.90	29.7	29.8	29.1	30.2	30.2	7.9	13.2	5.2	5.9	8.0

	Total Dissolved Solids (TDS) (mg L^{-1})					Total suspended solids (mg L^{-1})					Electrical conductivity (µS cm^{-1})				
	Stn. 1	Stn. 2	Stn. 3	Stn. 4	Stn. 5	Stn. 1	Stn. 2	Stn. 3	Stn. 4	Stn. 5	Stn. 1	Stn. 2	Stn. 3	Stn. 4	Stn. 5
Oct 05	31	361	165	674	38	8.1	10.9	3.1	7.8	8.1	59.4	590	315	1270	73.7
Nov	23	323	216	221	31	7.4	10.2	3.2	6.4	7.5	45.5	449	416	430	59.2
Dec	24	281	214	675	29	5.2	10.2	3.5	6.5	5.1	45.7	539	413	1300	55.9
Jan 06	29	246	225	284	30	5.1	9.8	3.8	3.3	5.0	56.0	469	433	547	58.0
Feb	27	244	199	283	27	5.0	9.1	3.9	3.2	5.0	52.3	46	382	483	52.7
Mar	40	269	249	898	39	4.7	8.6	3.5	2.9	4.5	76.8	518	479	1735	75.8
Apr	206	265	273	270	124	4.9	7.6	3.2	3.3	4.8	395.0	547	524	519	238.0
May	277	312	263	279	91	4.1	7.2	2.7	3.0	3.9	532.0	598	507	535	174.5

	Salinity (mg L^{-1})					Dissolved oxygen (mg L^{-1})					Biochemical oxygen demand (mg L^{-1})				
	Stn. 1	Stn. 2	Stn. 3	Stn. 4	Stn. 5	Stn. 1	Stn. 2	Stn. 3	Stn. 4	Stn. 5	Stn. 1	Stn. 2	Stn. 3	Stn. 4	Stn. 5
Oct 05	22.1	177.0	94.47	380.8	17.81	2.6	3.6	6.5	4.0	3.2	13.80	15.6	14.8	10.1	12.60
Nov	13.6	134.6	124.76	128.9	17.75	4.6	3.6	4.5	3.3	4.2	12.50	54.4	30.2	10.5	15.20
Dec	16.8	140.7	129.90	164.1	17.50	1.8	1.4	2.0	2.2	1.9	12.40	10.8	25.6	14.8	8.20
Jan 06	15.7	140.2	114.60	144.9	15.70	1.8	1.9	1.4	2.6	1.7	13.80	18.6	14.8	10.2	12.60
Feb	23.1	155.4	143.70	520.5	22.70	3.6	3.6	2.6	4.9	3.1	12.00	16.0	4.0	10.0	18.00
Mar	118.5	163.6	157.20	155.7	74.50	2.3	2.1	2.9	3.4	2.8	0.30	24.8	14.8	6.2	0.80
Apr	165.0	179.3	152.10	160.4	52.40	4.4	3.4	2.3	5.5	4.2	12.50	54.4	30.2	10.5	15.20
May	23.1	149.7	139.20	440.0	22.70	3.7	1.5	3.9	6.7	3.5	13.80	15.6	14.8	10.1	12.60

	Chemical oxygen demand (mg L^{-1})					Oil and grease (mg L^{-1})					Phosphate (mg L^{-1})				
	Stn. 1	Stn. 2	Stn. 3	Stn. 4	Stn. 5	Stn. 1	Stn. 2	Stn. 3	Stn. 4	Stn. 5	Stn. 1	Stn. 2	Stn. 3	Stn. 4	Stn. 5
Oct 05	70	60	70	70	80	0.79	12.12	1.05	1.02	0.52	0.010	0.51	0.01	0.02	0.02
Nov	30	60	30	40	30	2.15	7.45	4.52	1.21	1.45	0.040	1.52	0.12	0.02	0.02
Dec	20	40	30	20	20	2.45	3.42	4.96	1.56	1.23	0.020	1.88	0.05	0.02	0.02
Jan 06	20	30	30	20	20	1.86	3.86	5.62	2.15	1.42	0.020	1.42	0.08	0.03	0.02
Feb	20	20	10	20	30	0.49	17.99	1.95	1.46	0.01	0.009	1.09	0.01	0.01	0.08
Mar	10	50	30	20	10	1.45	4.96	5.86	1.32	0.86	0.010	1.06	0.02	0.01	0.01
Apr	10	60	30	20	10	1.49	5.21	3.52	3.56	2.65	0.010	1.23	0.03	0.01	0.01
May	20	30	30	20	20	1.86	4.96	5.45	2.74	3.65	0.020	1.33	0.06	0.04	0.02

	Ammonium (NH_4) (mg L^{-1})					Iron (mg L^{-1})					Copper (mg L^{-1})				
	Stn. 1	Stn. 2	Stn. 3	Stn. 4	Stn. 5	Stn. 1	Stn. 2	Stn. 3	Stn. 4	Stn. 5	Stn. 1	Stn. 2	Stn. 3	Stn. 4	Stn. 5
Oct 05	2.20	4.32	1.02	0.25	1.26	0.68	0.96	0.26	3.16	0.84	0.01	0.03	0.02	0.01	0.01
Nov	1.42	4.15	1.01	0.25	1.08	0.48	0.64	0.31	3.26	0.31	0.02	0.03	0.01	0.02	0.01
Dec	1.05	3.56	1.23	0.29	1.08	0.96	0.86	0.42	3.06	0.31	0.01	0.04	0.02	0.02	0.01
Jan 06	0.56	4.85	1.46	0.36	0.32	0.56	0.68	0.38	2.88	0.42	0.01	0.06	0.02	0.02	0.01
Feb	5.13	6.32	1.26	0.16	3.26	0.98	0.76	0.19	6.03	1.24	0.00	0.02	0.04	0.02	0.01
Mar	1.25	3.95	1.56	0.32	1.15	1.02	0.96	0.26	3.36	0.31	0.02	0.05	0.02	0.02	0.02
Apr	1.09	3.24	1.62	0.34	1.19	1.05	1.01	0.28	3.02	0.38	0.01	0.04	0.03	0.02	0.02
May	0.51	4.34	1.41	0.37	0.33	1.02	1.30	0.20	2.53	0.42	0.01	0.03	0.02	0.03	0.02

Total Suspended Solids

TSS values were lower than the TDS values in all the stations sampled and in all sampling months. Generally TSS fluctuated between 2.7 and 10.9 mg L^{-1}. There was significant difference ($p<0.05$) using ANOVA in the value of TSS among the different sampling stations. Also relatively higher values of TSS were recorded during the months of October to January 2006 as compared to the months of February to May 2006. Station 2 recorded relatively higher values of TSS as compared to the other stations sampled. The lowest mean TSS value of 3.36 mg L^{-1} was recorded in the month of May for station 3.

Electrical Conductivity

Electrical conductivity (EC) fluctuated between 45.5 and 1735 μS cm^{-1}. There was significant difference ($p<0.05$) in EC among the various stations sampled. Station 4 recorded relatively higher values in electrical conductivity in most of the months sampled. Station 5 recorded relatively lower electrical conductivity values of 52.7 to 238.0 μS cm^{-1} as compared with the other stations sampled. Analysis of variance (ANOVA) result also indicated that the electrical mean values of conductivity did not vary between within months and did not show any seasonal pattern.

Salinity

Salinity varied between 13.65 and 520.5 mg L^{-1}. There was no significant difference (ANOVA) in salinity measured monthly although relatively higher values of salinity were measured in the dry season months. There were marked differences in salinity measured among the various sampling stations. Station 4 recorded higher values in salinity followed by station 2 and 3 in that order. Station 5 with a mean salinity value of 48.48 mg L^{-1} recorded a range of 15.7 to 74.5 mg L^{-1} and accounted for the lowest salinity values. Generally, the highest value of 520.5 mg L^{-1} was recorded in station 4 in the month of February.

Dissolved Oxygen

Dissolved oxygen values were consistently low in all the stations and in all the months sampled. Dissolved oxygen value fluctuated between 1.4 to 6.7 mg L^{-1}. Station 1 and 4 recorded relatively higher oxygen values. There were no marked or distinct variations in dissolved oxygen among the different sampling months neither was there any marked seasonal variation. Analysis of variance (ANOVA) result indicated that dissolved oxygen values among the various sampling stations were not significant ($p>0.05$).

Biochemical Oxygen Demand

Biochemical oxygen demand fluctuated between 0.3 and 54.4 mg L^{-1}. The upstream station recorded lower values of BOD. Station 2 and 3 recorded relatively high values of mean 26.28 and 18.65 mg L^{-1}, respectively showing high organic burden load. Analysis of variance result showed that BOD was significantly different ($p<0.05$) among the various stations sampled. There were no marked temporal variation observed neither was there any seasonal pattern in BOD. The lowest BOD value of 0.3 mg L^{-1} was recorded in the upstream station 1 in the month of March. Again, low BOD value of 0.8 mg L^{-1} was recorded in the downstream station. A very high BOD value was recorded in the month of November as well as in the month of April for station 2.

Chemical Oxygen Demand

Chemical oxygen demand fluctuated between 10 and 80 mg L^{-1}. The value of COD was nearly uniform in all the stations sampled except again for station 2 with a mean of 43.75 mg L^{-1} which was significantly higher than the means recorded for the other stations sampled. Analysis of variance

(ANOVA) was slightly significant ($F = 4.42$, $p>0.05$) among the various sampling stations. A post hoc test using Duncan multiple range tests showed that the means of station 2 was different from that of the other stations which were not different from each other. There were no significant differences in the monthly values of COD neither were there any marked seasonal pattern observed.

Oil and Grease (OG)

Oil and grease fluctuated between 0.01 and 17.9 mg L^{-1}. The upstream (station 1) and downstream (station 5) recorded considerably lower oil and grease values. Station 2 recorded relatively higher values of OG. It had a mean of 7.49 mg L^{-1} and was the cause of the observed differences among the stations sampled ($p<0.05$). Station 3 also recorded relatively higher values of OG but not up to the range obtained in station 2. There were no significant differences in OG measured in the different months ($p>0.05$) neither was there any seasonal pattern observed in the value of OG.

Phosphate

Phosphates in the surface water sampled fluctuated between 0.009 and 1.88. Again station 2 recorded considerably higher values of phosphates in all the months sampled. A mean of 1.25 mg L^{-1} was recorded for this station. The upstream and downstream stations recorded much lower phosphates values in all the months sampled. Analysis of variance showed that there were significant differences ($p<0.01$) in the value of phosphates recorded among the stations. The values of phosphates were uniform in station 3 and 4. Station 3 varied from 0.01 mg L^{-1} recorded in October to 0.12 mg L^{-1} recorded in November 2005. Station 4 on the other hand fluctuated from 0.01 mg L^{-1} recorded in the months of March and April 2006 to 0.04 mg L^{-1} recorded in May 2006. Analysis of variance did not detect any significant difference ($p>0.05$) in phosphates value recorded monthly neither was there any seasonal patter in phosphates observed.

Ammonium (NH_4)

Ammonium fluctuated between a low value of 0.32 mg L^{-1} recorded in the month of January in station 5 to 6.315 mg L^{-1} recorded in the month of February in station 2. Station 4 recorded relatively lower values of ammonia throughout the months of sampling. The values of ammonium recorded in station 1, 3 and 5 were uniform and not too different from each other. Analysis of variance result showed that there was significant difference ($p<0.05$) in the values of ammonium recorded among the stations. This test also revealed that ammonium varied slightly within the months sampled. A relatively higher value was recorded in the month of February in all the stations sampled except in station 4 and was also generally high in January 2006

Iron

Iron fluctuated between 0.19 and 6.03 mg L^{-1} in station 3 and 4 respectively. The downstream station recorded considerably lower. Iron values of between 0.31 to 1.24 mg L^{-1}. This range was also similar to that obtained in Station 1 (0.48-1.05 mg L^{-1}) and Station 3 (0.19-0.42 mg L^{-1}). Station 4 recorded relatively higher values of Iron in all the months sampled with the highest value of 6.03 mg L^{-1} recorded in the month of February 2006. Analysis of variance result showed that there was significant variation ($p<0.05$) in the values of Iron recorded among the various sampling stations. There was no significant difference in the values of Iron observed monthly. Again there was no clear seasonal pattern observed.

Copper

The values of copper were significantly ($p<0.05$) higher in stations 2 and 3 as compared with the upstream and downstream stations. Generally copper fluctuated between 0.00 mg L^{-1} recorded in the month of February in Station 1 to 0.06 mg L^{-1} recorded in month of January in Station 2. Stations 1, 4 and 5 recorded uniform values in copper fluctuating from 0.00 to 0.02 mg L^{-1}. Analysis of variance result showed that the values of copper was significantly ($p<0.05$) different among the sampling stations but not different among the different sampling months ($p>0.05$). Again, there was no observed seasonal pattern of variation in copper.

DISCUSSION

The rainfall and relative humidity regimes during the period of study were typical of the deltaic area of Nigeria with relatively high values of these parameters in the months of May and July (Ikomi *et al*., 2003).

The pH range of 6.60-8.22 recorded in the study indicates that the water was slightly acidic with occasional slight alkaline condition. Generally rivers flowing through forest are acidic with pH ranging from 4 to neutrality (Welcomme, 1975). The range recorded in this study is very close to those recorded in many Nigerian and other African water bodies (Egborge *et al*., 1986; Onwudinjo, 1990; Ogbeibu and Victor, 1995; Jonalagadda and Mhere, 2001). Like the observations of Egborge *et al*. (1986) and Odum (1992) there was no discernible seasonal pattern in the pH.

Water temperature did not show any seasonal variations. The absence of seasonal variations in the water temperature is explained by the fact that water has great specific heat capacity. Hence the radiation received by the water body hardly brings about serious fluctuation on a daily basis. However, the effects of cloud cover and river flow on the ambient and water temperature must not be ignored (Imoobe and Oboh, 2003). Thus it seems that the response to the major changes in ambient temperature is slow since a body of water must absorb vast quantities of heat in order to increase or decrease its temperature by 10°C.

Turbidity is a measure of the ability of a water to received light and is caused by small particles in the various stations were turbidity exist. Station 2 was significantly more turbid than all the other stations examined. This can be attributed to the compounds discharge from the near by fuel oiling station into the river.

The influxes of industrial effluents significantly lead to the increase in total dissolved solids in station 2, 3 and 4. Station 1 and 5 recorded lower values. Dissolved solids values were high during the dry season period and low in the rainy season, thus reflecting a seasonal pattern of variation. High dissolved solids (<600 mg L^{-1}) as the ones recorded in station 4 may be harmful to aquatic life (Velz, 1985).

Conductivity values from this study show that the sections of the Warri River sampled contain appreciable amount of dissolved ions thus forming a saline barrier for the survival of sensitive organisms. The values recorded for station 1, 2 and 5 is similar to that reported by Egborge *et al*. 1986 in Bench river, Adebisi 1981 in Upper Ogun River, Nigeria. Station 4 recorded remarkably high conductivity values as a result of the nature of effluents discharge from helipad canteen and New PC laboratory. These discharges thus contain significantly high amounts of ions that exceed the recommended standard by EPA. Salinity values recorded in this study stations also indicates that station 2, 3 and 4 had significantly higher amount of salt contents. On the other hand the upstream and down stream stations had lower salt content.

The dissolved oxygen concentration of the section of the river examined showed that the river was poorly aerated, irrespective of season and station. The low mean values of dissolved oxygen recorded falls short of the relatively higher values reported by Egborge *et al*. (1986) and Umeham (1989). These low values observed may be as a result of the nature of the effluents discharge into the water that places a high demand on the dissolved oxygen. Again, the raw effluents discharge into the water resulted to high COD and BOD values.

The colloidal suspension in the effluent discharges may have likely increase turbidity and reduce transparency of the water body. This finding is consistent with the reported work of Olaleye and Adedeji (2005) of Oluwa River receiving palm oil effluent in Ondo state, Nigeria.

In addition, the high levels of dissolved oxygen and suspended solids in the water systems increased the BOD and COD, which depleted the dissolved oxygen in the water system. The levels of TDS in a broad sense therefore reflect the pollutant burden on the aquatic system.

Oil and grease values were high in the sampled stations especially in station 2 which normally receive effluents discharge into the stream from a nearby filing station. Studies of the aquatic ecosystems in the Niger Delta have also indicated high levels of oil and grease in areas prone to oil spills (Ibiebele *et al*., 1983; Dahlin *et al*., 1985).

The monthly variation pattern and the mean values recorded for some nutrients (phosphate and ammonium) are similar to those waters in Nigeria receiving effluents of various sorts from industries and domestic activities (Olaleye and Adedeji, 2005; Adebisi, 1981; Ogbondeminu, 1986). The heavy or trace metals (Iron, Copper, Chromium, Lead) were usually present in the waters examined particularly at much lower concentrations. Many of the trace metals like lead (Pb) and Cadmium (Cd) are highly toxic to humans and other living organisms and their presence in surface water above background concentration is undesirable (Velz, 1985). Unlike many organic pollutants, metals are not chemically or biologically degradable, but may be bioconcentrated in the food chain.

This process of biomagnification, biomagnifications or bioaccumulation has been responsible for major pollution indicators in the past (Radojevie and Bashkin, 1999). The concentrations of heavy metals recorded in this study were high although not up to the maximum allocable limits set by Federal Ministry of Environment, Nigeria.

CONCLUSIONS

From the data collated in this research, the physicochemical parameters monitored in station 2, 3 and 4 showed high levels of dissolved and suspended solids. This must have been as a result of the nature of the effluents discharged from the watershed into the river. Station 2 particularly in some months sampled exceeded the limits set by Federal Ministry of Environment and International Bodies. Staff of the various industries located along the sketch of the river should avoid the discharge of wastes that are not environmental friendly. Regular flushing and maintenance of the saver pit is recommended. Accordingly, water from these sample stations is not entirely free from gross pollution and cannot be used for domestic purposes and drinking without treatment.

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