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Studies on the physico-chemical characteristics and nutrients of a tropical rainforest river in southeast Nigeria

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Abstract. Investigation of the variations in fifteen physico-chemical variables and three nutrients in three stations along Ikpa River, Nigeria were conducted between March 2009 and February 2010. All the parameters measured showed significantly different ($p<0.05$) spatial and temporal (monthly and seasonally) variability, except transparency and pH ($p>0.05$). Coefficient of variation (%CV) depicted that all the variables varied widely (1.86-68.16%) except total suspended solids and pH. Some parameters showed significant, insignificant and no relationships when the data was subjected to Pearson correlation coefficient analysis and depending on the period of predominance, they were classified as dry, wet, and non-seasonal climax parameters. Parameters such as TDS, TSS, DO, BOD_5, TA, TH, FCO_2, transparency and pH, fell within the range of World Health Organization (WHO) standard for potable drinking water, and adequate for sustaining living aquatic organisms. Of the nutrients, PO_4-P and NO_3-N were higher, while SO_4^{2-} was lower than standards for drinking water. The high nutrient levels render the water quality poor, indicating need for protection from further nutrient load inputs.
Key Words: water quality, ammonia, nitrite, nitrate, phosphate, multiple-use.

Introduction. Water quality attributes are prime factors that influence fish survival, reproduction, growth performance, and overall biological production (King 1998). They affect aquatic biotic integrity by directly causing mortality and/or shifting the equilibrium among species due to subtle influences such as reduced reproductive rates or alternations in competitive ability. A variety of physico-chemical attributes vary in relation to seasonal hydrologic variations in tropical rivers. The nature and concentration of chemical elements and compounds in a freshwater system are subject to change by various types of natural processes i.e. physical, chemical, hydrological and biological. The effects of these factors/processes on water quality depend to a large extent on environmental factors brought about by climate, geographical and geological conditions (Bartram & Balance 1996).

Human anthropogenic activities are on the increase along the Ikpa River, Nigeria as well as most inland waters of Nigeria. Such activities include a large oil-palm processing mill sited along the riverbank at Ikot Ebom, which uses water from the river in its processing activities and discharges the wastewater, untreated, back into the river system; massive road construction work with a new bridge over Ikpa River is on-going at Ntak Inyang, where water from this same river is used in all the construction works with a backwash of cement and coal-tar into the river as surface runoffs. Sand mining and extraction in Ikpa River is equally a booming business, while portions of the river bed have been dredged mechanically by a construction firm. These activities have impacted upon the livelihood of the communities along the river, particularly, women who usually fermented cassava and washed/processed periwinkles in the river water have had to look elsewhere, because of the high turbidity of the water. Further downstream at Nwaniba beach is the popular *Le Meridien* Five Star Hotel and Ibom Golf Resort as well as large dugout canoes ferrying timber from Cameroun to Nigeria, offloading at Oron in addition to large timber mill and busy mammy market sited at the Nwaniba beach.

The recognition of deleterious effects of the destruction and loss of habitat, chemical pollution, eutrophication, and climatic alterations on the aquatic organisms, as a result of human activities, combined with an urgent need of a more environmentally sensitive and ecologically sustainable management of Ikpa River system, gingered the assessment of the water quality of this river. Very little is known about the water quality of Ikpa River, except for the works of King (1989) and Akpan (1995, 2004). In this study, N, S and P and some other physico-chemical factors were investigated with the aim of providing baseline/benchmark information on the river for future environmental impact assessment, conservation, monitoring and management strategies.

Study area. Ikpa River (Figure 1) is situated within the rainforest zone of southeastern Nigeria in Akwa Ibom State. It is a small perennial rainforest tributary stream located west of the lower reaches of the Cross River system. It drains a catchment area of 516.5 km^2, 14.8% (76.5 km^2) of which is prone to annual flooding. The river has a main channel (53.5 km) between its source in Ikono Local Government Area and where it discharges into the Cross River creek close to Nwaniba in Uruan Local Government Area in Akwa Ibom State, Nigeria. It lies at the interface of two different geological deposits: tertiary sedimentary rocks and cretaceous deposits (King 1989). The Eastings and Northings of the three sampling stations selected are as follows: 379437.913mE and 572840.203mN for STN 1 in Ikot Ebom; 380881.324mE and 561822.998mN for STN 2 in Ntak Inyang and 394252.669mE and 558778.199mN for STN 3 in Nwaniba, respectively.

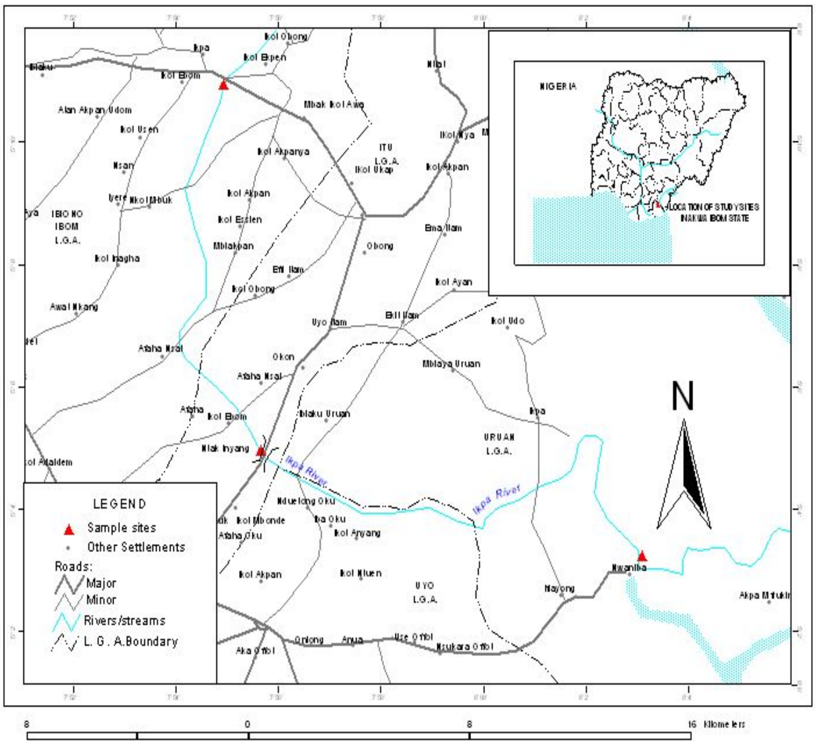

Figure 1. Ikpa River showing locations of sampling sites.

The climate of the study area is typically that of tropical rainforest belt, comprising dry (November-March) and wet (April-October) seasons characterized by long periods of dry continental winds from the Sahara desert and long periods of moist maritime winds from the Atlantic Ocean, respectively. The river is considerably shaded by overhanging, thick canopy of riparian vegetation such as *Elaeis guineensis, Raphia hookeri, R. vinifera,* etc. and the littoral macrophytes are mainly *Nymphaea, Vossia* and *Crinium* species (King 1989 1998).

Materials and methods. Sampling for water quality (physico-chemical and nutrients) parameters was carried out forthnightly for twelve calendar months, from March 2009 to February 2010. The choice of the sampling stations is based on the aforementioned human activities carried out in the river system.

Physical and chemical parameters. Fifteen physico-chemical parameters (current velocity (CV), water level (WL), air temperature (AT), water temperature (WT), transparency, total dissolved solids (TDS), total suspended solids (TSS), total hardness

(TH), total alkalinity (TA), conductivity, dissolved oxygen (DO), biochemical oxygen demand (BOD), chemical oxygen demand (COD), free carbondioxide (free CO_2) and hydrogen ion concentration (pH)) and three nutrients (nitrates-nitrogen (NO_3N), phosphates-phosphorus (PO_4-P) and sulphates (SO_4^{2-}) were sampled and analysed forthnightly using field kit with sensitive probes and standard and analytical methods of water analysis (Hanson 1973; USEPA 1979; Orth 1983; Schlosser 1983, Bartram & Balance 1996; APHA-AWWA-WPCF 1998).

Statistical analysis. Data generated were subjected to Analysis of Variance (ANOVA) at probability level of $p < 0.05$ to test for variations, and Pearson correlation coefficient was calculated to establish relationships among variables, in addition to routine measures of dispersion and central tendency.

Results. The physico-chemical parameters in the three sampling stations in Ikpa River are summarized in Figures 2 to 5. All the parameters measured showed significantly different ($p < 0.05$) spatial and temporal (monthly and seasonally; $F=8.17$; $p < 0.0001$) variability, except transparency and pH ($p > 0.05$). Least square means revealed that only the months July ($t=4.61$; $p > 0.0001$) and September ($t=4.09$; $p < 0.0004$) did not exhibit significant differences in the parameters measured.

The results of the annual means, coefficient of variation (%CV) and ANOVA of the physico-chemical parameters of Ikpa River, Nigeria from the three sampling stations are presented in Table 1. Station effect indicated that STNs 1 and 3 were significantly different ($p < 0.0001$) while STN 2 was not ($p > 0.0010$). The station differences based on differences of least square means showed: STNs 1 and 2 ($t=1.88$; $p > 0.0691$), STNs 1 and 3 ($t=-0.41$; $p > 0.6817$) and STNs 2 and 3 ($t=-2.29$; $p > 0.0284$) were not significantly from each other.

These parameters were characterized into three main groups depending on the period of predominance or seasonal influence as follow: dry season climax referring to those variables which are pronounced during times of low precipitation leading to reduced surface runoff and water level: TDS, COD, TA, FCO_2, SO_4, DO, BOD, TH, air and water temperature. Wet season climax refers to those parameters that were more pronounced as a result of increased precipitation leading to increased surface runoff and water level: NO_3-N, PO_4-P, TSS, pH, current velocity, conductivity and water level. No marked seasonal variation climax is the parameter which was insensitive to dry/wet cycle of the tropics: transparency.

Relationship between physico-chemical characteristics. Pearson correlation coefficient (r) revealed that physico-chemical parameters gave some significant relationships with each other at the probability level of $p < 0.05$ as shown in Table 2. The relationship between water level and current velocity was significantly negative ($r=-0.47$) in STN 1, no significant relationship in STN 2 but was significantly positive in STN 3 ($r=0.26$), and significantly negative ($r=-0.04$) all sampling stations combined. Air temperature, water temperature and total dissolved solids correlated significantly negatively with current velocity and water level in all stations (Table 2). The relationship between total suspended solids with air, water temperature and TDS in STNs 1, 2 and 3 was negative but insignificant except in STN 3 where it was significantly positive with current velocity ($r=0.30$). It correlated significantly positive with current velocity ($r=0.41$) and water level ($r=0.49$) while that with water temperature was significantly negative ($r=-0.41$) in the combined stations. The relationship between transparency with air, water temperature and TSS was significantly positive ($r=0.22$, 0.31, 0.12) respectively in STN 1 whereas there was no significance in STN 2. Water temperature in the relationship was significantly positive but significantly negative with current velocity and water temperature ($r=-0.35$, -0.47) respectively in STN 3. The relationship with current velocity, water level, conductivity and total suspended solids was significantly negative ($r=-0.08$, -0.23, -0.23 and -0.10, respectively) whereas with air temperature, water temperature and total dissolved solids, it was significantly positive ($r=0.13$, 0.04, 0.01) when all the stations were combined. The relationship between total hardness with current velocity, water level, TSS and transparency was significantly negative ($r=-0.45$, -0.25, -0.50, -0.12) whereas it was significantly positive with air temperature and COD (r=29, 0.45) respectively in STN 1. In STN 2, only TSS was significantly negative (r=-0.31) with air temperature and COD (r=-0.29, 0.45) respectively in STN 1. In STN 2, only TSS was significantly negative (r=-0.31) while it was significantly positive with air temperature, water temperature, TDS, DO, BOD, COD and TA (r=0.48, 0.46, 0.46, 0.11, 0.27, 0.15, 0.31) respectively. There was a significantly negative relationship with water level and TSS (r=-0.38, -0.22) and a significantly positive correlation with air temperature, water temperature, DO, COD, FCO_2 and TA (r=0.30, 0.40, 0.41, 0.13, 0.47, 0.35) respectively in STN 3. A combination of all the stations revealed that the relationship with current velocity, water level and total suspended solids (r=-0.47; -0.29; -0.30) was significantly negative but was significantly positive with air temperature, water temperature, transparency, total dissolved solids, dissolved oxygen, biochemical oxygen demand, chemical oxygen demand, free carbondioxide and total alkalinity (r=0.31, 0.28, 0.11, 0.43, 0.38, 0.18, 0.53 and 0.28) respectively.

Conductivity correlated significantly positively with current velocity (r=0.44) and water level (r=0.46) in STN 1 but there was no significant relationship in STN 2. In STN 3, only TSS (r=0.46) was significantly positive. In the combined stations, it correlated significantly positively with water level (r=0.48) but was significantly negative with air temperature, water temperature and transparency with r=-0.56, -0.49 and -0.17, respectively. The dissolved oxygen content of the water showed a significantly negative relationship with current velocity, water level and TSS (r=-0.38, -0.34, -0.27) while it was significantly positive with air temperature, TDS and transparency (r=0.28, 0.44, 0.08) respectively in STN 1. The relationship with current velocity, water level, TSS, conductivity was significantly negative (r=-0.38, -0.04, -0.02, -0.26) but positively significant with air temperature, TDS and transparency (r=0.37, 0.41, 0.34) respectively in STN 2. Water level and TSS with DO correlated significantly and negatively (r=-0.10, -0.25) but was significantly positive with air temperature, water temperature and transparency (r=0.49, 0.50, 0.32) respectively in STN 3. There was a significantly negative relationship with current velocity, water level, total suspended solids and conductivity as follow: r=-0.32, -0.32, -0.21 and -0.50 respectively but was significantly positive with air temperature (r=0.26), water temperature (r=0.41), transparency (r=0.10) and total dissolved solids (r=0.28) when the three stations were combined. Biochemical oxygen demand gave a significantly positive correlation with air temperature and transparency as follow: r=0.48, 0.30 but was negatively significant with current velocity and TSS (r=-0.44, -0.45) respectively in STN 1. It showed a significantly positive relationship with current velocity, water level, conductivity and DO (r=0.09, 0.21, 0.12, 0.41) whereas was significantly negative with air temperature, water temperature, TDS and transparency (r=-0.12, -0.08, -0.10, -0.21) respectively in STN 2. In STN, there was no significant variable though negatively related. All the stations put together gave a significantly positive correlation with air temperature, water temperature, total dissolved solids and transparency as follow: r=0.35, 0.46, 0.47, 0.60 and 0.08 respectively, whereas was negatively significant with current velocity (r=-0.36), water level (r=-0.10), total suspended solids (r=-0.20) and conductivity (r=-0.48). The chemical oxygen demand showed a significantly positive relationship with DO and BOD (r=0.22, 0.30) whereas the relationship was negatively significant with current velocity and transparency (r=-0.19, -0.23) respectively in STN 1. In STN 2, it was significantly positive with water temperature, transparency and DO (r=0.24, 0.36, 0.18) respectively but significantly negative with BOD (r=-0.14). In STN 3, only water temperature and TDS correlated significantly and positively (r=0.34, 0.18) respectively with COD. A combination of all the sites showed that COD correlated positively with air temperature, water temperature, dissolved oxygen, biochemical oxygen demand and total dissolved solids (r=0.46, 0.30, 0.10, 0.11 and 0.44) respectively but showed a negatively significant relationship with current velocity, water level, total suspended solids and conductivity with r=-0.31, -0.32, -0.52 and -0.45, respectively. There was a significantly positive correlation between free carbondioxide with transparency, DO and BOD (r=0.10, 0.33, 0.38) but significantly negative with current velocity and water level (r=-0.23, -0.14) respectively in STN 1. It was significantly positive with water temperature and DO (r=0.47, 0.04) respectively and significantly negative with BOD (r=-0.21) in STN 2. The relationship was significantly positive with COD (r=0.27) in STN 3. In the combined stations, water temperature, transparency, total dissolved solids, dissolved oxygen, biochemical oxygen demand and chemical oxygen demand (r=0.48, 0.16, 0.61, 0.29, 0.29 and 0.47) respectively but significantly and negatively with current velocity and water level and as follow: r=-0.38, -0.37, respectively. Total alkalinity showed a significantly negative relationship with current velocity (r=-0.27) and a significantly positive relationship with DO (r=0.47) in STN 1. It showed a significantly negative relationship with current velocity, TSS, DO and BOD (r=-0.30, -0.46, -0.29, -0.23) but was significantly positive with water temperature, TDS and transparency (r=0.11, 0.46, 0.28) respectively in STN 2. In STN 3, the relationship was significantly negative with water level, TSS and COD (r=-0.39, -0.35, -0.16) whereas was significantly positive with water temperature and transparency (r=0.36, 0.43) respectively. Putting all the stations together, there was a significantly negative correlation with water level, current velocity and total suspended solids (r=-0.11, -0.45, -0.43) respectively and was significantly positive with water temperature, transparency, dissolved oxygen, biochemical oxygen demand and chemical oxygen demand (r=0.39, 0.04, 0.22, 0.45, 0.32) respectively. The relationship of pH with current velocity, water level, TDS, transparency, conductivity and FCO_2 (r=0.21, 0.46, 0.50, 0.17, 0.03, 0.12) in STN 1; water level, TSS, DO, BOD and PO_4P (r=0.50, 0.49, 0.05, 0.23, 0.23) in STN 2; and water level, TSS, conductivity, NO_3-N and PO_4P (r=0.11, 0.07, 0.40, 0.02, 0.25) in STN 3 respectively. Combining all the stations together, current velocity, water level, transparency, conductivity, phosphate-phosphorus and total suspended solids (r=0.29, 0.08, 0.02, 0.17, 0.02, 0.21) was significantly positive while it was significantly negative with water level, air temperature, total dissolved solids, dissolved oxygen, biochemical oxygen demand, chemical oxygen demand, total hardness, nitrate-nitrogen, free carbondioxide, total alkalinity and sulphates (r=-0.10, -0.08, -0.26, -0.16, -0.13, -0.14, -0.09, -0.08, -0.22, -0.30 and -0.29) respectively.

Nitrate-nitrogen gave a significantly positive correlation with current velocity, air temperature, water temperature, TDS, FCO_2 and TA (r=0.09, 0.43, 0.22, 0.26, 0.45, 0.11) in STN 1; air temperature, TDS, COD and FCO_2 (r=0.22, 0.13, 0.32, 0.36) in STN 2 and current velocity, air temperature, water temperature, TDS, conductivity and FCO_2 (r=0.30, 0.41, 0.17, 0.22, 0.11, 0.25) in STN 3 respectively. However, it was significantly positive with current velocity, air temperature, water temperature, total dissolved solids, conductivity, chemical oxygen demand, free carbondioxide and total alkalinity (r=0.01, 0.25, 0.12, 0.32, 0.04, 0.47, 0.24 and 0.35) respectively whereas a significantly negative relationship with total suspended solids, biochemical oxygen demand, transparency and dissolved oxygen (r=-0.19, -0.012, -0.19 and -0.32) respectively. There was a significantly positive correlation between phosphate-phosphorus with air temperature, TDS, transparency, conductivity, DO, COD, FCO_2, TA, TH and NO_3-N (r-0.09, 0.27, 0.08, 0.08, 0.10, 0.38, 0.25, 0.13, 0.04, 0.37) in STN 1; TSS, conductivity, BOD, TA, TH and NO_3-N (r=0.27, 0.23, 0.12, 0.16, 0.21, 0.25) in STN 2; and water level, conductivity and NO_3-N (r=0.32, 0.50, 0.38) in STN 3. Combining all the stations together, the relationship was significantly positive with current velocity, water level, total dissolved solids, total suspended solids, chemical oxygen demand, total alkalinity, conductivity and nitrate-nitrogen as follow: r=0.09, 0.37, 0.01, 0.08, 0.09, 0.13, 0.28 and 0.43 respectively, but a significantly negative with air temperature, water temperature, transparency, dissolved oxygen, free carbondioxide, total hardness (r=-0.18, -0.11, -0.09, -0.39, -0.13, -0.37). Sulphates correlated significantly and positively with only NO_3-N (r=0.27) in STN 1; water temperature, transparency and TH (r=0.27, 0.43, 0.25) in STN 2; and DO, COD, TH and NO_3-N (r=0.41, 0.23, 0.45, 0.07) in STN 3 respectively. There was a significantly negative relationship with current velocity, water level and phosphate-phosphorus (r=-0.47, -0.23 and -0.15) whereas significantly and positively with water temperature, dissolved oxygen, biochemical oxygen demand, chemical oxygen demand, total hardness and nitrate-nitrogen as follow: r=0.43, 0.21, 0.33, 0.48, 0.39 and 0.38 respectively, when all the stations were considered.

Table 1

Changes in physico-chemical parameters of different sampling stations along Ikpa River, Nigeria, during March 2009 to February 2010

Physico-chemical parameters	*Sampling Stations*			*Range*		*CV (%)*	*ANOVA*	
	1	*2*	*3*					
	Min–Max (Mean ± S.E.)	*Min – Max (Mean ± S.E.)*	*Min–Max (Mean ± S.E.)*	*Min.*	*Max.*		*F-value*	*Prob.*
Current velocity (cm Sec^{-1})	40.10-56.80 (48.13±0.77)	36.30-60.40 (48.26±1.18)	32.00-59.00 (43.2 ±1.37)	32.00	59.00	4.03	37.80*	p<0.0001
Water level (m)	0.18-4.50 (2.76±0.15)	2.10-5.00 (3.33 ±0.13)	3.70-7.00 (5.30±0.17)	0.18	7.00	12.02	25.37*	P<0.0001
Air temperature (^{0}C)	23.00-37.00 (30.80±0.59)	28.00-35.10 (31.62±0.32)	27.00-35.40 (31.0±0.21)	23.00	37.00	5.38	5.06*	P<0.0001
Water temperature (^{0}C)	15.30-35.20 (27.08±0.84)	25.10-31.60 (28.12±0.27)	25.60-30.00 (28.10±0.21)	15.30	35.20	7.38	4.88*	P<0.0001
TDS (mg L^{-1})	117.30-288.00 (180.19±8.27)	91.30-292.00 (176.63±10.27)	115.20-392.50 (231.20±13..58)	91.30	392.50	1.86	1047.54*	P<0.0001
TSS (mg L^{-1})	140.00-430.80 (267.58±15.99)	124.20-397.40 (260.45±13.48)	190.00-455.90 (291.50±12.31)	124.20	455.90	6.68	58.33*	P<0.0001
Transparency (cm)	21.70-41.00 (66.69 ±10.22)	37.40-74.00 (54.98± 2.02)	3.00 - 60.30 (43.80±1.68)	3.00	74.00	68.16	0.97	P>0.52
Conductivity (μS cm^{-1})	218.20-497.30 (366.63±15.05)	216.60-522.60 (388.91±15.13)	224.00-561.30 (406.9±17.94)	216.60	561.30	3.02	191.83*	P<0.0001
DO (mg L^{-1})	2.50-9.20 (5.63 ±0.27)	3.34-7.30 (5.60± 0.18)	2.80 - 7.00 (4.78±0.20)	2.50	9.20	9.22	20.25*	P<0.0001
BOD (mg L^{-1})	0.60-6.70 (3.39 ±0.25)	1.50-4.50 (2.94±0.13)	1.80-5.40 (3.6±0.18)	0.60	6.70	11.90	23.60*	P<0.0001
COD (mg L^{-1})	30.20-55.90 (43.28±1.18)	28.20-57.80 (39.78±1.19)	33.40-59.20 (42.10±1.24)	28.20	59.20	3.73	60.06*	P<0.0001
Free CO_2 (mg L^{-1})	0.07-4.70 (3.05±0.18)	1.20-5.10 (3.29 ±0.18)	1.10-4.00 (2.90±0.14)	0.07	5.10	11.64	20.65*	P<0.0001
Total alkalinity (mg L^{-1})	27.50-50.10 (38.24±1.04)	25.30-50.30 (37.75±1.07)	29.40-56.50 (41.50±1.16)	25.30	56.50	4.77	34.36*	P<0.0001
Total hardness (mg L^{-1})	30.90-46.78 (37.95±0.64)	33.00-46.72 (39.30±0.65)	29.00-47.00 (37.20±0.97)	29.00	47.00	3.41	34.55*	P<0.0001
NO_3N (μg L^{-1})	82.63-202.90 (133.20±5.54)	70.10-220.90 (136.30±6.28)	115.20-244.80 (171.00±7.07)	70.10	244.80	2.10	503.76*	P<0.0001
PO_4P (μg L^{-1})	31.00-61.60 (42.86±1.05)	18.20-50.00 (30.64± 1.55)	29.50-82.00 (51.46±2.26)	18.20	82.00	5.24	101.52*	P<0.0001
SO_4^{2-}(μg L^{-1})	0.70-6.30 (3.15±0.28)	1.00-8.90 (4.33± 0.39)	2.00-8.60 (4.40±0.31)	0.70	8.90	9.10	88.02*	P<0.0001
pH	6.00-8.10 (6.85±0.09)	5.85-7.30 (6.86 ±0.05)	5.30-8.00 (6.80±0.09)	5.30	8.10	6.68	0.92	P>0.60

* Indicates significant difference ($p < 0.05$). Mean values and standard errors of parameter are enclosed in parentheses.

Table 2

Pearson correlation coefficient (r) between physico-chemical parameters in all the sampling stations in Ikpa River, Nigeria

Varia-bles	*CV*	*WL*	*AT*	*WT*	*TDS*	*TSS*	*Trans.*	*Cond.*	*DO*	*BOD*	*COD*	*FCO_2*	*TA*	*TH*	*NO_3N*	*PO_4 P*	*SO_4^{2-}*	*pH*
CV	-																	
WL	-0.04*	-																
AT	-0.32*	-0.29*	-															
WT	-0.22*	-0.08*	0.53	-														
TDS	-0.61	-0.10*	0.53	0.39*	-													
TSS	0.41*	0.49*	-0.57	-0.41*	-0.51	-												
Trans	-0.08*	-0.23*	0.13*	0.04*	0.01*	-0.10*	-											
Cond.	0.58	0.48*	-0.56	-0.49*	-0.71	0.65	-0.17*	-										
DO	-0.32*	-0.32*	0.26*	0.41*	0.28*	-0.21*	0.10*	-0.50*	-									
BOD	-0.36*	-0.10*	0.35*	0.46*	0.47*	-0.20*	0.08*	-0.48*	0.60	-								
COD	-0.31*	-0.32*	0.46*	0.30*	0.44*	-0.52	0.00	-0.45*	0.10*	0.11*	-							
FCO_2	-0.38*	-0.37*	0.60	0.48*	0.61	-0.62	0.16*	-0.69	0.29*	0.22*	0.47*	-						
TA	-0.45*	-0.11*	0.54	0.39*	0.71	-0.43*	0.04*	-0.59	0.22*	0.45*	0.32*	0.57	-					
TH	-0.47*	-0.29*	0.31*	0.28*	0.43*	-0.30*	0.11*	-0.65	0.38*	0.41*	0.18*	0.53	0.28*	-				
NO_3N	0.01*	0.12*	0.25*	0.12*	0.32*	-0.19*	-0.19*	0.04*	-0.32*	-0.12*	0.47*	0.24*	0.35*	-0.27*	-			
PO_4P	0.09*	0.37*	-0.18*	-0.11*	-0.01*	0.08*	-0.09*	0.28*	-0.39*	-0.00	0.09*	-0.13*	0.13*	-0.37*	0.43*	-		
SO_4^{2-}	-0.47*	-0.23*	0.60	0.43*	0.68	-0.64	-0.00	-0.65	0.21*	0.33*	0.48*	0.59	0.72	0.39*	0.38*	-0.15*	-	
pH	0.29*	0.08*	-0.08*	-0.10*	-0.26*	0.21*	0.02*	0.17*	-0.16*	-0.13*	-0.14*	-0.22*	-0.30*	-0.09*	-0.08*	0.02*	-0.29*	-

* Indicates significance ($P < 0.05$).

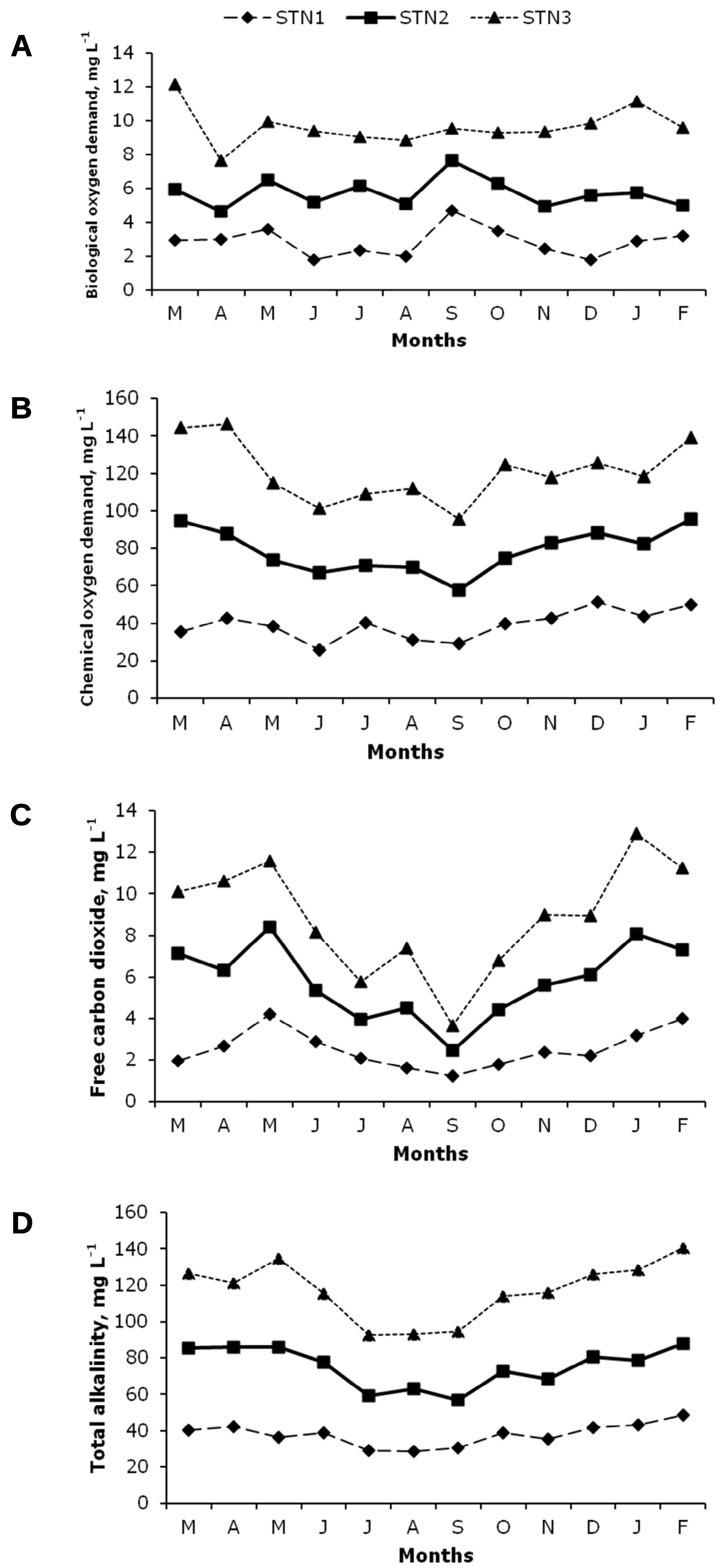

Figure 2. Monthly variations in five-day biological oxygen demand (A), chemical oxygen demand (B), free carbon dioxide (C), and total alkalinity (D) in the three sampling stations in Ikpa River, Nigeria.

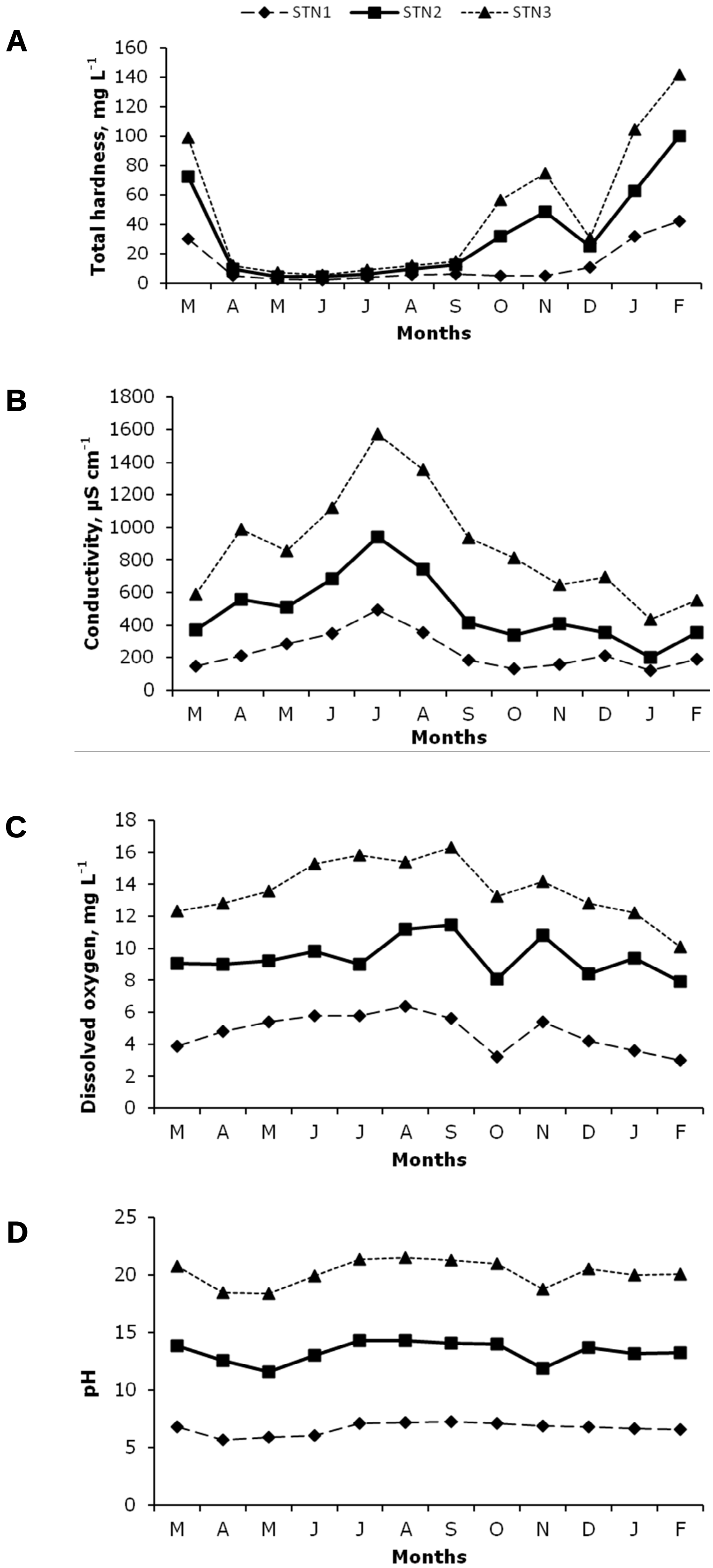

Figure 3. Monthly variations in the total hardness (A), conductivity (B), dissolved oxygen (C), and pH (D) in the three sampling stations in Ikpa River, Nigeria.

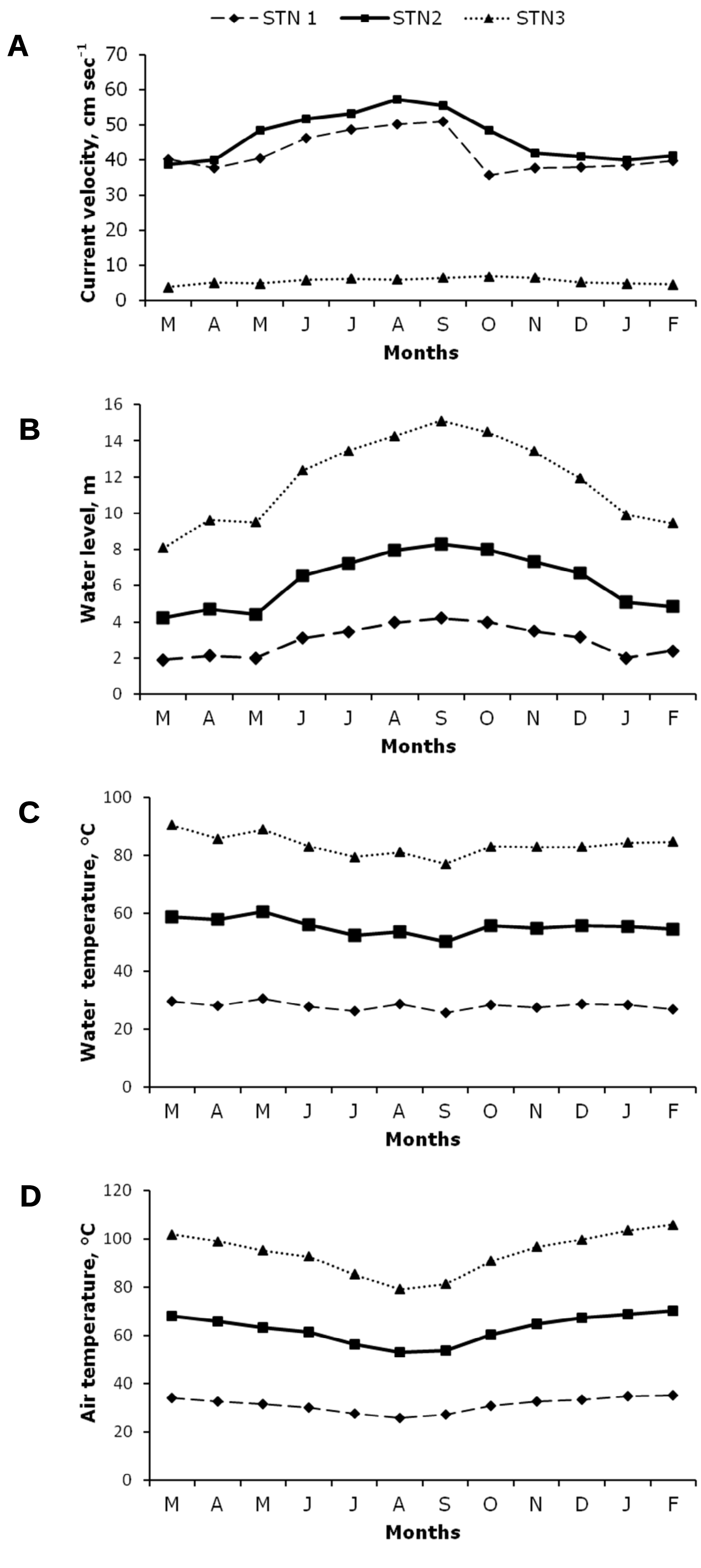

Figure 4. Monthly variations in current velocity (A), water level (B), water temperature (C), and air temperature (D) in the three sampling stations in Ikpa River, Nigeria.

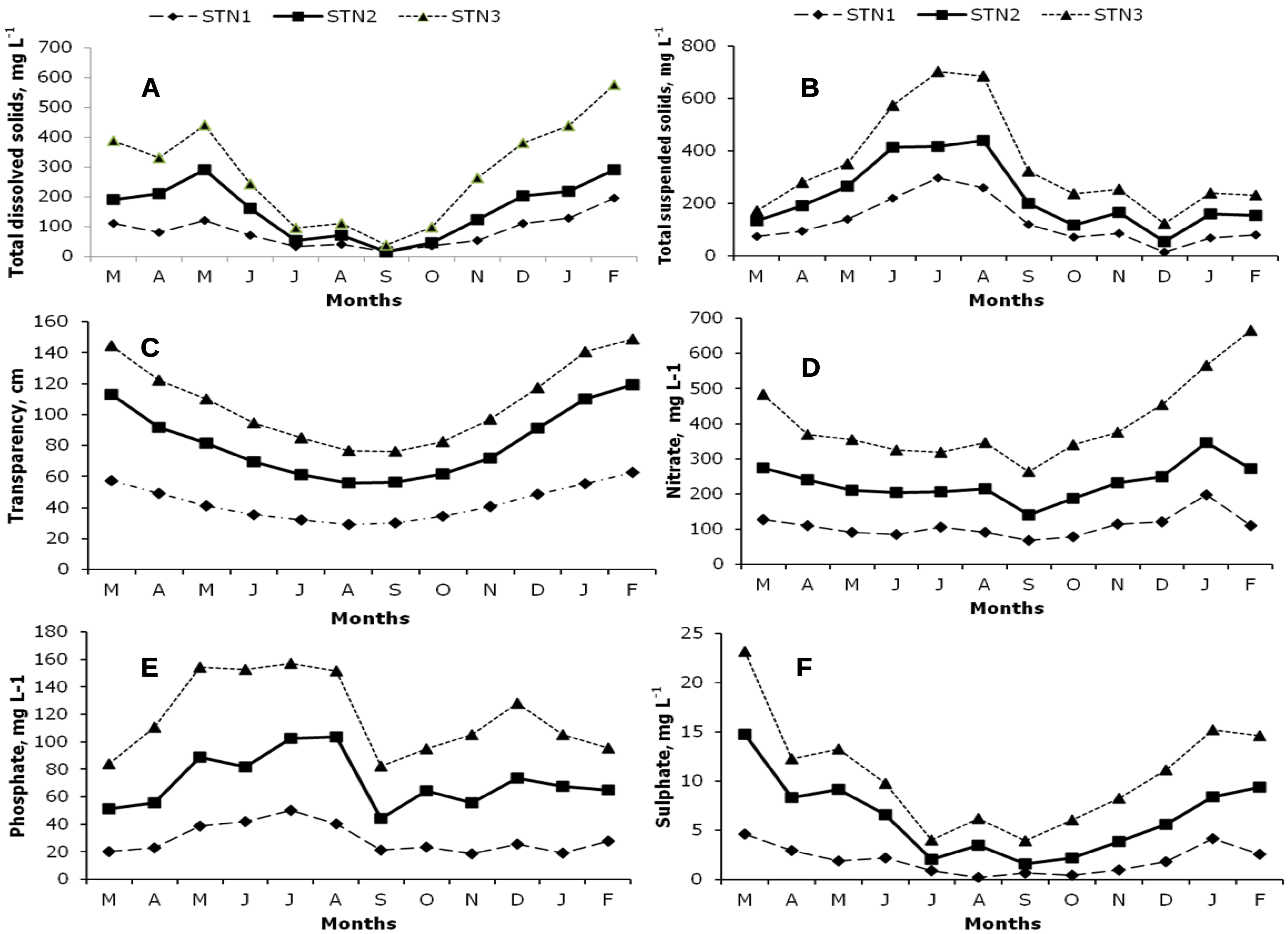

Figure 5. Monthly variations in total dissolved solids (A), total suspended solids (B), transparency (C), nitrate (D), phosphate (E), and sulphate (F) in the three sampling stations in Ikpa River, Nigeria.

Discussion. The water quality of Ikpa River, Nigeria has been characterized based on the levels of the different physico-chemical parameters as compared with the existing standards and was observed that there are many factors affecting it. It has been shown that the onset of rains signals a radical change in physico-chemical characteristics of tropical rivers (Lowe-McConnell 1987; Chapman & Kramer 1991; Adeyemo et al 2008). Also, the input of allochthonous organic materials from the catchment area during rainfall increases conductivity, pH, alkalinity, total dissolved solids and biochemical oxygen demand (Akin-Oriola 2003).

Current velocity. Values of current velocity (Figure 4A) were higher during the wet season than the dry season. The wet season is a period of high precipitation which is accompanied by increased surface runoff. It is often referred to as the flood season. Factors such as gradient, vegetation cover, organic matter load, suspended matter, water width, sediment type and meanders affect the speed at which water flows. Current velocity decreased downstream; being highest in sampling STN 2 than in 1 and was significantly different in all the stations. This high current velocity may probably be due to the increased dredging of the river bottom at STN 2. Pearson correlation coefficient revealed that there was a positively significant relationship between current velocity and TSS, NO_3-N, PO_4-P and pH; hence increases in current velocity results in corresponding increases in these other parameters. Current velocity also showed a negative significant correlation with all other parameters except total dissolved solids and conductivity indicating that increases in current velocity will not necessary bring about corresponding increases in those parameters.

Water level. Water level (depth, Figure 4B) was higher during the wet than the dry season. The wet season corresponds to the period of torrential and continuous rainfall (increased precipitation and inflow of surface runoff) known to be peculiar to the rainforest zone of the tropics. This seasonality in the water level is in agreement with the findings of other researchers such as Adebisi (1981), Akpan (1991) and Essien-Ibok et al (2010) where the authors reported of a positive correlation between water level and rainfall. Water level increased steadily and progressively downstream. The upstream has high gradient indicating shallow depth which slopes to the downstream with formation of floodplains, where the water during the flood phase (wet season) inundates the surrounding lands, indicating deeper depth. The increased water level downstream may also be occasioned by the dredging activities and provision of berth for the powered large dugout canoes which land timber at this beach. Pearson correlation coefficient showed that water level established a positive relationship with and positively correlated with TSS, conductivity, NO_3N, PO_4-P and pH.

Water temperature. Seasonal variability of temperature (Figure 4C) showed higher temperatures during the dry than the wet season. The surface water temperature closely followed same pattern with the air/ambient temperature reflecting general trend in the tropics and the study area as reported by Welcomme (1975) and Aguigwo (1998). The periods of low and high temperatures coincided with the peaks of wet and dry seasons, respectively. This corresponds to the lowering of solar heat radiation during the cloudy rainy months and accumulation of runoff water into the stream resulting in high increase in conductivity and simultaneous increase in total suspended solids concentrations, respectively as explained in the findings of Aguigwo (1998), and Ezra & Nwankwo (2001). The temperature of river water may be influenced by a whole lot of factors including latitude, altitude, degree of insulation, substrate composition, turbidity, ground/rain water inflows, wind, and vegetation cover.

Air temperature. Air temperature (Figure 4D) correlated significantly with the water temperature; rises in air temperature result in corresponding rises in water temperature. Surface water temperatures follow the pattern of ambient air temperature as explained earlier (Welcomme, 1975), although under hot conditions (dry season) this is more likely to be correlated with air temperature minima due to the cooling effect of evaporation. Water level (depth) was also influenced by temperature with fluctuations in shallow waters, indicating effect of heating. There was a decrease in temperature values in January, during the harmattan (characterized by dry wind) when the cold dry air from the Sahara desert region blow southwards (from December to mid-February), covering the area with large amount of dust particles, tending to reduce the amount of solar radiation (Khan & Ejike 1984; Ezra & Nwankwo 2001; Akpan 2004). Spatial variation in temperature recorded between sites may probably be due to differences in macrophyte shading, precipitation, humidity and the degree of ambient temperature. The water temperature values were however within the acceptable limit adequate for aquatic organisms especially fish (Boyd & Lichtkoppler 1979).

Dissolved oxygen. DO was higher during the dry than during the wet season (Figure 3C). This may be due to high photosynthetic activities by green plants which release oxygen into the water. Plimmer (1978), Aguigwo (1998), Kemdirim & Ejike (1992), and Ezra & Nwankwo (2001) observed that dry months exhibit high DO concentration due to the high photosynthetic activities of the phytoplankton during this period. DO concentration, in this study also followed the temperature pattern. Seasonal fluctuations in DO concentrations may also be attributed to reduced solubility of DO due to the effect of temperature on its solubility in water as confirmed by the observations of Plimmer (1978), and Izonfuo & Bariweni (2001). However, Hall et al (1977), Welcomme (1979), King & Ekeh (1990), Akpan (1993) and Essien-Ibok et al (2010) had findings which contrast with this present work. These authors obtained higher dissolved oxygen during the wet season which they attributed to increased flow that enabled diffusion and mixing of atmospheric oxygen into the water, as opposed to stagnation and increased organic load (mainly as leaf litter) into the water whose decomposition increase oxygen depletion and reduced temperature during the wet season. According to Aguigwo (1998) low dissolved oxygen concentration during the rainy months is likely caused by high phytoplankton blooms and other aquatic vegetational covers which flourish favourably during the rainy months at the expense of the dissolved oxygen used in respiration. Also the excessive runoff water carrying various types of inorganic chemicals which may likely ionize with dissolved oxygen of water may cause low level of dissolved oxygen. Pearson correlation coefficient showed that dissolved oxygen correlated positively with biochemical oxygen demand implying that increases in dissolved oxygen leads to a corresponding increases in biochemical oxygen demand. However, Essien-Ibok et al (2010) obtained a significant negative correlation between these two parameters. Welcomme (1985) observed that in the dry season dissolved oxygen concentrations are linked to a number of factors including the size of the water body, biochemical oxygen demand of organic detritus or pollutants, vegetation cover, phytoplankton development and wind action. During the dry season, some collections of water are in pools and in the main channels which may become deoxygenated or anoxic due to the decomposition of organic material, the oxygen demand of fish and to the increased temperature. As the floodwater invades the floodplain and the water level increase during the wet season, there is an initial rise in dissolved oxygen concentrations in open water and floating vegetation. During the wet season floodwater may flush deoxygenated water remaining from the preceding dry season, out of the swamps and pools. The oxygen becomes rapidly depleted in the lower layers and hydrogen sulphide accumulates. Beadle (1974) and Welcomme (1985) noted that the general effect of plant cover is to reduce dissolved oxygen concentration with a coincident development and release of H_2S. Considering Boyd & Lichtkoppler (1979), WHO (1984) and Udoessien (2003) standards for aquatic organisms and drinking, optimum levels of dissolved oxygen in this work are conducive, except the lower value, downstream.

Biochemical oxygen demand. BOD (after 5 days) indicates the degree of microbial mediated oxygen consumption by contaminants in water. BOD was higher during the dry season than during the wet season (Figure 2A). The increased level during the dry season might have resulted from reduced water level due to increased evapo-transpiration rate occasioned by the high temperature. Thus, the organic matter in the water becomes concentrated and with favourable conditions in the environment, bacteria and other decomposers increase degradation process utilizing oxygen. Thus, BOD indicates the amount of dissolved oxygen used in the oxidation process to produce carbon dioxide and water. Oxygen depletion brings about the growth of anaerobes which can breakdown organic matter in the absence of dissolved oxygen using sulphates and nitrates to release hydrogen sulphide and ammonia gases. The findings of Akpan (1993), Akpan & Akpan (1994), and Essien-Ibok et al (2010) are at variance with this study. They observed high BOD concentration during the wet season which they attributed to increased input of decomposable organic matter, requiring oxygen for their biodegradation, into the river through surface runoff. This occurred highest in the downstream station in their study. This may probably be due to the pooled effect of surface runoff which cause great deposition of organic matter, accumulated nutrient load and dead macrophytes. There was a significant negative correlation between biochemical BOD and conductivity indicating an inverse but a positive significant relationship with dissolved oxygen and water temperature indicating that increases in BOD also increases these parameters. However, Essien-Ibok et al (2010) showed a negative correlation between BOD and dissolved oxygen suggesting an inverse relationship between the two parameters. The BOD level in this study was low and within the limit permissible for aquatic organisms but too high for drinking water level according to WHO (1984) and Udoessien (2003).

Chemical oxygen demand. The levels of chemical oxygen demand, COD, were higher during the dry season than during the wet season as indicated by the highest monthly occurrence in March and the lowest in September (Figure 2B). This may be attributed to increased temperature during this season leading to reduced water level in the river system which might have resulted in increased evapo-transpiration and crystallization of salts. Similar pattern was observed in BOD. The after effect of the wet season is the mass movement and deposition of dead and decaying organic matter downstream which are soon degraded by bacteria and other decomposers. This process of breakdown of organic matter continues even after the rains releasing chemicals into the system as reported in Essien-Ibok et al (2010). Variability with respect to station effect did not show any particular pattern, however, it was highest in sampling STN 1 (upstream) and lowest in STN 2 (middle course). COD showed significant positive correlation with air temperature which implies that increases in air temperature (leading to a corresponding increase in water temperature) bring about increases in COD. But this parameter also showed a negative significant correlation with total suspended solids, indicating that increased values of COD will not necessary bring about corresponding increase in the values of total suspended solids.

pH. Higher pH values were observed during the wet months than the dry season and fluctuated between narrow limits (Figure 3D). This is an all important physico-chemical characteristic whose low values indicate acidic conditions while high values indicate alkaline or basic conditions. At low pH, the degree of ionization, speciation and precipitation may increase leading to bioaccumulations and biomagnifications in macrophytes, fish and other aquatic organisms, because it regulates the chemical and biological processes in natural waters. Low pH values in water also corrode metal pipes and ustensils while high pH values may precipitate calcium carbonates from solutions to form scales on pipes. In conformity with these observations, Welcomme (1979) noted that forest rivers with their characteristics blackwaters and abundant humic materials are slightly to very acidic with pH ranging from 4 to neutrality while Adebisi (1981), King & Ekeh (1990), Mama & Ado (2003), Akpan (1991), Akpan (2004) and Essien-Ibok et al (2010) attribute variations in pH to evapo-transpiration process, rainfall causing dilution of chemical substances and chemical and biological processes in water. However, on the contrary Aguigwo (1998) and Egborge (1971) obtained alkaline pH throughout the year, fluctuating between pH 7.2 in March and 9.10 in August and concluded that the high pH values indicated good buffering capacity of the water making it fully adequate for aquatic life including fish. The sudden increase in the pH of river water may be attributed to cow dung (Blanc et al 1955), under the floating vegetation (DÁubenton, 1963) while application of laterite could reduce it (Mizuno & Mori 1970). The lower pH values in swamps usually cause a general drop in pH throughout the system when the acid waters are flushed out by rain or flood water with poor buffering capacity early in the flood season. In evaluating the effect of road and bridge construction across a stream, Victor & Onomivbori (1996) reported that there was a significant difference in all the physico-chemical parameters except in temperature and pH; thus, conforming with the present finding in sampling STN 2 where there is an on-going road and bridge construction. pH results show that the river water became more acidic downstream. The pH of 5.30–8.10 obtained in this present work is within the range for inland waters as reported by Boyd & Lichtkoppler (1979), Antoine & Al-Saadi (1982), Ezra & Nwankwo (2001) and Fakayode (2005). The slight acidity during the dry season and at the on-set of wet season could be attributed to the drainage of the catchment basin which is typical of the tropical rainforest. Pearson correlation coefficient showed positive relationship with current velocity but negatively correlation with total alkalinity indicating that increases in pH lead to corresponding increases in current velocity but might not result in increased total alkalinity. Akin-Oriola (2003) reported that the input of allochthonous organic materials from the catchment area during rainfall increases pH, the buffering capacity factor is a direct response to rainfall due to its high contribution to variations in rivers.

Conductivity. Conductivity, which is a measure of the total amount of ions present in a body of water and useful in approximating chemical richness, was lower during the dry than the wet season (Figure 3B). The high wet season conductivity value obtained in this work may be caused by the positive effect of rainfall and subsequent nutrient-load of surface runoffs together with the high organic matter contents brought into the aquatic system; as well as, wash out of nutrient-rich ground waters and solution of salts from inundated lands which according to Schmidt (1972), Junk (1973), Welcomme (1979) cause local rises in conductivity in streams during the rains. Higher conductivities during the dry season have been reported by many authors: Oshun River (Egborge 1971; Gaudet & Melack 1973), Ogun River (Adebisi 1981), Kafue River (Carey 1971), Senegal River (Reizer 1974; Allan 2001; Ezra & Nwankwo 2001; Wetzel 2001) and Mbo River (Essien-Ibok et al 2010) which they attributed to high evapo-transpiration rates resulting in concentration of ions (dissolved solids) in the water. In addition, conductivity steadily increased downstream. This may be caused by the accumulated effect of surface runoffs with high nutrient-load of the flood water. Conductivities are less variable in river waters and changes throughout the year in one system. Broadly speaking, Gibbs (1970) and Welcomme (1979) noted that the ionic composition of water is determined by three processes: precipitation, nature of the bedrock and evaporation-crystallization. Pearson correlation coefficient indicates its negative but strongly significant relationship with dissolved oxygen, biochemical oxygen demand, free carbondioxide, total alkalinity and total hardness indicating that an increase in conductivity does not bring about increases in these parameters.

Total dissolved solids. TDS is a convenient measure of the total ionic concentration in water. Dry month values of TDS were higher than the wet (Figure 5A). This may be due to sedimentation as a result of reduced current velocity and water levels, implying reduced flood waters. It may have also resulted from evapo-crystallization process and low rainfall leading to low dilution of the river water. Therefore, large amount of dissolved solids can lead to increased mineralization of the receiving waterway with the consequent of dissolved oxygen depletion. This is in agreement with the reports of Akpan (1991) and Essien-Ibok et al (2010) but different from the findings of Fatoki et al (2001) on Umtata River (South Africa) and Akpan (2004) in which higher TDS values were obtained during the wet season, attributed to increased precipitation and subsequent runoffs from the surrounding lands. TDS increased progressively downstream. Naturally, the concentration and relative abundance of ions in river water is highly variable (Welcomme 1979) and while there is considerable spread in total dissolved solids for any particular runoff, the increase in concentration with decreasing runoff is unmistakeable (Holland 1978). Tropical rainforest rivers arise on very poor, leached, podsolitic soils (Welcomme 1979) and such waters had been described as more or less transparent, devoid of significant amounts of inorganic particles but with very poor light penetration because of the brown colour imparted by dissolved humic substances. In such waters, the pH is usually very low and the dissolved nutrient concentration poor as was observed with the negative relationship with TDS and conductivity in this work. Such low pH values are raised in the presence of organic pollution from urban sources as human settlement of these areas become more intense and heavy silt loads in order to maintain the productivity of the water. However, the observed TDS range were within the acceptable limit adopted by

WHO (1984) and Federal Ministry for Environment, Nigeria (Udoessien 2003) for aquatic organisms.

Total suspended solids. TSS values were seasonally higher during the wet than the dry seasons (Figure 5B). High values of total suspended solids during the rainy months may be due to influx of allochthonous materials and organic matter debris into the system through surface runoffs. It may also be due to large amounts of silts and debris held in suspension just before the commencement of the wet season. This is consistent with works carried out in other rivers such as River Zambezi in Hall et al (1977), Ogun River in Adebisi (1981), Qua Iboe River in Akpan (2004) and Mbo River in Essien-Ibok et al (2010). TSS correlated significantly with conductivity and sulphates indicating the high nutrient level of the water. Ogbeibu & Oribhabor (2001) observed that siltation increases the amount of suspended solids in water, which in turn reduces light penetration and water transparency. The range of TSS obtained falls within the acceptable permissible limit for fish (FWPCA 1968) and drinking water standard (WHO 1984).

Free carbondioxide. FCO_2 was higher during the dry season than during the wet season (Figure 2C). This high FCO_2 level during the dry season may be caused by the reduced populations of aquatic fauna which utilize FCO_2 for respiratory purposes, in conformity with the findings of Adebisi (1981), Wright (1982), King & Nkanta (1991) and Aguigwo (1998). The observed reduction in the levels of FCO_2 during the wet season may be attributable to its utilization by phytoplankton for photosynthetic activities and low temperatures during this period. FCO_2 correlated positively with total alkalinity, total hardness and sulphates. The monthly variation of FCO_2 follows the pattern as reported in Aguigwo (1998), declining during the wet months due to the utilization of the FCO_2 by phytoplankton bloom during this period.

Total alkalinity. TA was higher during the dry season than during the wet season. The lower value in the wet season suggests that runoff water contributes to dilution of this parameter then in conformity with the findings of Hall et al (1977), Adebisi (1981), Akpan (1993), Aguigwo (1998), Izonfuo & Bariweni (2001) and Essien-Ibok et al (2010) confirming the current trend stated that alkalinity is indicative of high FCO_2 values and probably high content of allochthonous and autochthonous organic materials in the stream. TA was highest downstream and correlated positively with sulphates and pH which implies that increases in TA values have corresponding increases in sulphates and pH values, in agreement with this observation Essien-Ibok et al (2010). The total TA in the river system is within the allowable limit for fish as reported in Boyd & Lichtkoppler (1979).

Total hardness. TH was higher during the dry season than during wet. The least significant difference evaluation revealed that there were significant differences in all the sampling stations, though in no definite pattern (Figure 2D). Pearson correlation coefficient showed that TH negatively but significantly relate with conductivity indicating that rises in one parameter will not lead to the rises in the other. It also showed a positive significant relationship with free carbondioxide which indicates that increase in total hardness will lead to corresponding increase in free carbondioxide. Comparison of the obtained levels of this parameter with WHO (1984) and Udoessien (2003) guidelines on drinking water standards shows the water is soft enough for consumption by humans.

Transparency. Transparency was higher during the dry season than during the wet one (Figure 5C); probably due to heavy load of organic matter carried into the river by surface runoff, silt generated by the disturbance of the bottom of the river by the great turbulence of flood water coming after heavy rains and increased zooplankton abundance observed in the wet season. For the survival of aquatic organisms especially fish and plankton, water transparency must be high. Low transparency (i.e. high turbidity) reduces light penetration into the aquatic system which in turn is capable of leading to the migration of these organisms to more conducive habitats. Apart from determining the survival of aquatic organisms, highly turbid water could become hard, contaminated and hence unsuitable for domestic consumption, laundry and some industrial processes. In conformity to the present findings, Adebisi (1981), Anadu et al (1990), Aguigwo (1998), Ezra & Nwankwo (2001) and Akpan (2004) noted that the low turbidity in the rainy months tends to show high suspended matter giving little opportunity for light penetration into the water during the rainy months. Low turbidity may also serve as adaptive feature enabling the free floating biota and fish eggs to become attached to suspended solids. It may also aid in complete reduction of solar radiation to bottom dwellers and so help in eliminating or reducing their communities particularly the eggs of predatory organisms (Boyd 1979). Transparency was observed to decrease downstream. This may be attributed to increased tributary input of suspended materials, increased plankton abundance downstream and increased surface runoffs from the basins draining the river. The growth of plants and plankton will be stimulated by nutrient enrichment of the system which together with surface runoff may cause sediments in suspension. As these organisms die and sink to the bottom, they are decomposed by bacteria and fungi which need oxygen for the process, thus, making oxygen to become limited and unavailable to fish and other aquatic life to survive. Transparency did not show any Pearson correlation with any other parameters but it had been shown to have a negative but strongly significant relationship with conductivity, total dissolved solids and chemical oxygen demand, indicating that an increase in transparency resulted in a corresponding decrease in conductivity, total dissolved solids and chemical oxygen demand (Essien-Ibok et al 2010). However, the levels of transparency were within allowable limits of Boyd & Lichtkoppler (1979) and WHO (1984), except in sampling STN 1 where it was little higher.

Nitrate-nitrogen and phosphate-phosphorus nutrients. NO_3-N and PO_4-P levels were higher during the wet season than the dry season (Figure 5D,E) in conformity with the findings of Aguigwo (1998), and Ezra & Nwankwo (2001) who further asserted that such nutrient levels lie favourably to high nutrient production level which also favours high plankton production, runoffs from agricultural lands, livestock and human wastes. The low levels during the dry season could probably be as a result of the absence of above factors and may be, their utilization by aquatic biota. Welcomme (1985) remarked that runoffs into water due to excessive land-use strongly influence the amount of nutrients that enter the receiving water. These nutrients result in increased amount of energy input (of allochthonous organic origin) into the water system. Nitrate salts enter natural water sources through domestic effluents, sewage sludge, industrial discharges, leachates from refuse dumps, runoff through fertilized farmlands, leguminous soil, decayed vegetables and animal matter. They could be either direct or indirect contamination and also by percolation over a period of time. Water containing high concentration of nitrates is injurious to health because it encourages eutrophication and increases biochemical oxygen demand. In contrast to the observation of increased nutrient levels during the wet season, Akpan & Akpan (1994) reported that the low nitrate-nitrogen and phosphate-phosphorus levels in the dry season coincided with high plankton density during the same period indicating high utilization of the nutrients. The findings in this research revealed that both nutrients increased downstream, suggesting downstream accumulation of organic matter leading to increased eutrophication of the water. Pearson correlation coefficient however, did not show any relationship between these nutrients and other parameters. The banks and the land fringing the river system are heavily exploited for agricultural activities contributing to the increasing organic matter content, free carbondioxide values and the increased primary productivity (Aguigwo 1998). The wet and dry season farming activities entail the utilization of agricultural inputs in the form of organic and inorganic fertilizers and even the grazing effect of cattle, as a result of surface runoffs are washed back into the aquatic system; hence, increasing the water nutrient levels, alternation of the water quality and leading to anthropogenic degradation of the aquatic system. Hence, the levels of nitrate-nitrogen and phosphate-phosphorus obtained were higher than the allowable standards for drinking water (WHO 1984; Udoessien 2003), rendering the water quality low.

Sulphates. SO_4^2 concentrations were highest in the dry season and lowest during the wet season (Figure 5F). This may probably be due to evapo-crystallization process of sulphate ions in the water during the dry season. There are two sources of sulphate dissolved in water: the cretaceous aquifer and soil within the catchment area. The main source of sulphate in spring water is oxidizing processes using the same source of oxygen in every location. The sulphate concentrations were diluted by surface runoff and precipitation during the rainy periods, thus, leading to low sulphate levels during the wet season, probably due to evapo-crystallization as a result of dry season high temperatures (Essien-Ibok et al 2010). Sulphate concentrations showed steady and progressive increase downstream, probably caused by the pooled effect of surface runoff, contributions from additional tributaries and increased nutrient load downstream (Trembaczowski et al 2004; Essien-Ibok et al 2010) attributed to deficiency of oxygen in the mud, reduction in bacterial activity and salt intrusion into the aquatic environment from the sea, in addition to input from the underlying bedrock and watershed. The high sulphate content suggests that the sulphate from cretaceous aquifer were mixed with sulphate dissolved from the soil. This parameter showed significant negative correlation with water level, total suspended solids and conductivity which indicates that sulphates inversely with these parameters. Also, there was a significant positive correlation between sulphates and air and water temperatures, total dissolved solids, free carbondioxide and total alkalinity implying that increases in sulphates concentrations result in a corresponding rise in these parameters. Sulphate levels in this water body were low compared to allowable standards, good for drinking (WHO 1984; Udoessien 2003).

Conclusions. This study revealed that most parameters varied greatly: monthly and seasonally among the stations and a great number of them were within allowable levels, thus indicating water quality is good. But the nutrient levels mainly phosphate and nitrate levels were higher than allowable limits, indicating water is polluted. From the foregoing, a few of the water quality variables are unsuitable for human consumption and aquatic organisms. The various human anthropogenic activities may probably have contributed to the various alternations in the water quality of the river system. Therefore, the water quality of Ikpa River, Nigeria can be improved by pre-treatment of wastewater from the palm-oil processing mill in STN 1; supervision and advice to the road construction company at STN 2 and prohibition of the discharge and dumping of refuge into the river water at STN 3. Also, riparian zone crop farming whose yield is boosted with application of fertilizers and manure should be stopped with penalties/fines attached. Moreover, the physico-chemical variables of Ikpa River, Nigeria can be characterized into three main groups depending on the type of seasonal influence as follow: dry season climax referring to those variables which result from low precipitation leading to reduced surface runoff and water level e.g. TDS, COD, TA, FCO_2, SO_4, DO, BOD, TH, air and water temperature, then wet season climax refers to those parameters that were more pronounced as a result of increased precipitation leading to increased surface runoff and water level e.g. NO_3-N, PO_4-P, TSS, pH, current velocity, conductivity and water level. No marked seasonal variation climax is the parameter which was insensitive to dry/wet cycle of the tropics e.g. transparency.

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