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The use of multivariate analysis for characterisation and classification of Ikpa River, Nigeria

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ABSTRACT

Water quality parameters from three sampling stations in Ikpa River, Nigeria were investigated for a period of 12 calendar months from March 2009 to February 2010. ANOVA result showed that all the parameters were significantly different ($P<0.05$) except transparency and pH. Sampling station and month effect on the parameters showed significance by LSD means separation in all parameters ($P<0.05$) except air temperature, transparency and pH, thus, some were highly significant while others were significant. pH values in all the stations remained the same indicating uniformity from the upstream to downstream. PC 1 and 2 axes in the combined stations indicated clusters of PO_4-P, NO_3-N and SO_4^{2-} which showed that they have high positive correlations with each other, thus, there is inferred eutrophication and subsequent pollution. AT and WT showed high positive correlation in clustering together in all the stations indicated the effect of climate change which is a global environmental menace due to the increased of the earth's surface. High positive correlation of FCO_2 and BOD indicated low dissolved oxygen which endangers the lives of aquatic fauna. The clustering of TDS and transparency together was an indication of high ionic constituents of the water, thus, inferring nitrification. CCA showed effect of environmental factors on phytoplankton species and the main source of pollution to be from organic materials. Seasonal variability showed higher factor loadings during the dry season than during the wet season ($P<0.05$). Temporal variableness had highest factor loadings occurring in February ($P<0.05$). The total number of families, genera and species of phytoplankton sampled were 7, 67 and 106 respectively.

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Introduction

Clean water is a basically need of both man and the aquatic biota. The alternation of water quality by man had been squealed to socio-economic development (Akin-Oriola and Tayo, 1999). In societies with dense populations, the ill-effects of human impacts on the aquatics include water-borne diseases, pollutions, alternation of aquatic biota composition, eutrophication and reduction or destruction of ecosystem integrity (Sridhar *et al.*, 1981; Egborge, 1991; Oduwole, 1997; Akin-Oriola and Tayo, 1999). Rivers are the most vulnerable water bodies to pollution because of their role in carrying municipal and industrial wastes and runoffs from agricultural lands in their vast drainage basins. Recently, inland water researchers have invested quality time and effort in the assessment of effects of diverse human activities on the water quality status with the view of characterizing and classifying same. Numerous studies have documented changes in river water quality using various approaches. A variety of mathematical assessment models, including water quality index models (Jonnalagadda and Mhere, 2001), structurally dynamic models (Zang *et al.*, 2003), fuzzy synthetic evaluation approach (Liou and Lo, 2003), generalized logistic models (Tan and Beklioglu, 2005), Bayesian models (Borsuk and Stow, 2000), etc. have been used to study the physico-chemical interrelationships and processes (Li *et al.*, 2009).

As a result of the temporal and spatial variations in water qualities, monitoring programmes that involve a large number of physico-chemical parameters and frequently water samplings at various sites are mandatory to produce reliable estimated topographies of surface water qualities. Thus, biomonitoring programmes employ indices and metrics of community structure (King and Akpan, 1998; Udoidiong and King, 2000) or multivariate statistical models (Henrion *et al.*, 1992; Akin-Oriola and Tayo, 1999; Konan *et al.*, 2006; Pinto and Araujo, 2007; Li *et al.*, 2009) to assess the potential impacts or non-impacts on aquatic ecosystems. Recently, studies assessing the interactions and relationships between physico-chemical parameters, with the goal of detecting community changes as a result of human factors, have produced mixed results (Akin-Oriola and Tayo, 1999; Kaller, 2005). Water quality studies usually produce large and diverse data-types which require multivariate analyses to clarify the effects of the interrelationships between factors and associations between different data types (Norris and Georges, 1986; Li *et al.*, 2009). Multivariate statistical analysis methods have the advantage of explaining complex water quality monitoring data to get a better understanding of the ecological status of the studied systems (Vega *et al.*, 1998). It has been successfully applied in a number of hydrogeochemical studies (Simeonov *et al.*, 2003; Singh *et al.*, 2005; Kowalkowskia *et al.*, 2006; Boyacioglu, 2008; Li *et al.*, 2009).

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The microphytes, phytoplankton are among the most common and diverse groups of aquatic flora. They play significant role in ecological processes in rivers and other aquatic ecosystems. As drifters, they accumulate substances that quickly indicate changes in the environment. Hence, they are considered as bio-accumulators and are capable to transfer contaminants to higher trophic levels in the aquatic foodwebs (Kelly and Whitton, 1989; Akin-Oriola and Tayo, 1999). They have been used in water quality monitoring studies (Oduwole, 1997; Nwankwo, 1994; Akin-Oriola and Tayo, 1999).

There is paucity of information on the multivariate analysis of the water quality of Ikpa River, Nigeria. Preliminary studies carried out on Ikpa River were based on either a fish species (King, 1989, 1994, 1996, 1998; Akpan, 1998) or family (Udoidiong, 1988; Udoidiong and King, 2000) or water quality (King and Nkanta, 1991; Udoidiong, 1991). In this study which will serve as a benchmark and a point of future reference, the database analysed was obtained by a combination of the 12 calendar months sampling period together with the three sampling sites, phytoplankton species and the eighteen physicochemistry variables. It was subjected to multivariate statistical technique of Principal Component Analysis (PCA) and Canonical Cluster Analysis (CCA) with a view to extract information about the similarities or dissimilarities among the sampling sites. Latent factors in river water quality were identified and water quality variables responsible for temporal and spatial variations were also explained. Based on these, the water quality parameters were classified and characterized and appropriate recommendations made.

Study area

The Ikpa River (Fig. 1) is situated in Akwa Ibom State within the rainforest zone of southeastern Nigeria. It is a small perennial rainforest river located west of the lower reaches of the Cross River system. It drains a catchment area of 516.5Km^2, 14.8% (76.5 Km^2) of which is prone to annual flooding. The stream has a main channel with total length of 53.5Km 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. 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 follow: 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. The sampling stations were selected based on the observed human anthropogenic perturbations: in STN 1, a large oil palm processing mill is sited on the riverbank; in STN 2, there is road construction and a new bridge is built over the river and serious riverbed dredging and in STN 3, wastewater from the Five Star Hotels are reintroduced into the river system without any pre-treatment, riverbed dredging, a large timber mill at the bank and large canoes with outboard engines are decked here. From up- to downstream of the river, dry and non-seasonal agricultural practises with organic and inorganic fertilization are continuous.

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 physico-chemical parameters was carried out at forthnightly interval. The sampling period spanned from March 2009 to February 2010 to cover both the dry and wet seasons.

Physical and chemical parameters

Fifteen physico-chemical parameters (current velocity (CV), water level (WL), air temperature (AT), water temperature (WT), transparency (Trans), total dissolved solids (TDS), total suspended solids (TSS), total hardness (TH), total alkalinity (TA), conductivity (Condu), dissolved oxygen (DO), biochemical oxygen demand (BOD), chemical oxygen demand (COD), free carbondioxide (FCO_2) and hydrogen ion concentration (pH)) and three nutrients (nitrates-nitrogen (NO_3-N), 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 and APHA-AWWA-WPCF, 1998, 2005).

Statistical analysis

Generated data were subjected to analysis of variance (ANOVA) to assess the effect of sampling stations and months on the physico-chemical parameters. Fisher's Protected Least Square Difference (LSD) at 5% level of probability was used to separate significant means. Physico-chemical parameter data from each sampling station were analysed separately using PROC Generalized Linear Module (GLM) in Statistical Analysis System (SAS) (1989) because of the number of parameters sampled in each station and the months involved. Multivariate of Principal Component Analysis (PCA) was carried out to segregate and classify the different parameters based on the methods described in (Pinto and Araujo (2007) and Konan *et al.*, (2006).

PCA **is** a method that reduces data dimensionality by performing a covariance analysis between factors and an exploratory tool to uncover unknown trends in the data (SAS, 2003). PCA is designed to transform the original variables into new, uncorrelated variables (axes), called the principal components, which are linear combinations of the original variables (Li *et al.*, 2009). The new axes lie along the directions of the maximum variance. PCA loading is the contribution of each variable in the ecosystem while the eigenvalue (represented by Lambda - λ) is the measure of the variance/dispersion variable scores on the biplot diagram (Jongman *et al.*, 1987) and it decreases downward. The importance of each axis in the diagram was assessed by the magnitude of the λ value for each axis. The percentage variance of each eigenvector (represented by the parameters) was indicated by the cumulative contribution and it increased downward. There were two main axes (PCs 1 and 2) which divided the biplot into four quadrats. An axis was named after the variable with the highest eigenvalue. In a quadrat, variables that lying close to each other indicated a positive correlation or relationship with each other (ter Braak and Prentice, 1988). PCs with eigenvalues $\geq$ 0.30 were selected since the plot of eigenvalues against the PCs showed a trend of gradual tapering of zero values after the PC 2. CCA is also similar in arrangement to PCA, but shows the interactions and interrelationships among abiotic and biotic components in the ecosystems.

Results

ANOVA result showed that all the parameters were significantly different (P<0.05) except transparency and pH. Sampling station effect on the parameters showed significance in all parameters (P<0.05) except air temperature, transparency and pH. LSD means separation also revealed parameter differences as marked with characters (Table 1). pH values in all the stations remained the same indicating uniformity from the upstream to downstream. Monthly effect on all the variables depicted variations with means marked with different characters showing that they were significantly different (Table 2).

PCA of the physico-chemical parameters

The results of the PCA on physico-chemical parameters are presented with all the stations combined (Table 2). PC 1 had the highest factor loading of conductivity with the value of $0.32\mu Scm^{-1}$ at eigenvalue of 0.42; 41.65% explanation of the total variance of the data. On the other hand, PC 2 had the highest loading of NO_3-N with the value of $0.54\mu gL^{-1}$ at eigenvalue of 2.61. Hence, the first and second PC explained 56.08% of the total variance in the data. In PC 3, water level was the most important loading factor contributing 0.47m at a λ value of 0.09. Therefore, PC 2 and 3 explained 65.33% of the total variation in the data. Water temperature (0.43^0 C) and PO_4-P ($0.43\ \mu gL^{-1}$) were the highest loading factor in PC 4 with a corresponding λ value of 0.06. Thus, PC 3and 4 were responsible for 71.79% of the total variance in the data. FCO_2, AT, TH and conductivity were the parameters that formed high loadings in PC1 axis depicting traces of hardness whereas PO_4-P, DO, transparency and NO_3-N had high loadings in PC2 axis indicating nutrification leading to eutrophication. PC 3 and PC 4 had their high loading factors of CV, WL, BOD and pH indicating increased pollution with increased water level and PO_4-P, BOD, transparency, WT and pH indicating eutrophication leading to pollution with increased water temperature respectively (Fig. 5). Four principal components (PC 1-4) were obtained with eigenvalues less than one (<1) summing more than 82% of the total variance in the water data sets in combining all the stations together.

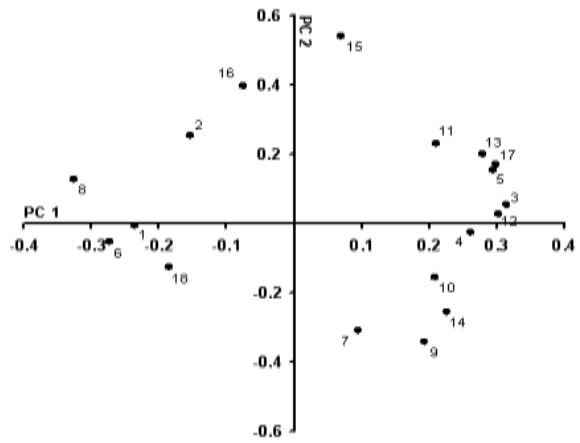

Fig. 2: An ordination of the first two principal components (PCA biplot) constructed from physico-chemical characteristics of the three sampling stations in Ikpa River, Nigeria. Physico-chemical variables are represented with numbers as follow: 1. = Current velocity, 2. = Water level, 3. = Air temperature, 4. = Water temperature, 5. = Total dissolved solids, 6. = Total suspended solids, 7. = Transparency, 8. = Conductivity, 9. = Dissolved oxygen, 10. = Biochemical oxygen demand, 11. = Chemical oxygen demand, 12. = Free carbondioxide, 13. = Total Alkalinity, 14. = Total hardness, 15. = nitrate-nitrogen, 16. = Phosphate-phosphorus, 17. = Sulphates and 18. = pH.

Also, the elements sorted out by each PC had been analysed individually to determine the trend in their temporal and spatial variableness based on months and seasons (Table 4). Generally, lower factor loadings were observed to be during the wet season while higher factor loadings were observed during the dry season apart from two instances in STNs 1 and 3. The same patterns were observed in all the sampling station. In STN 1, the first PC factor loading was lowest in November with the value of -0.80 and highest in September with a value of 4.25; thus, corresponding with the peaks of dry and wet seasons respectively. The second PC factor loading in STN 1 was lowest in August (-0.21) and highest in May (2.75), both in the wet season. In STN 2, PC 1 had factor loading lowest in November with the value of 0.17 and the highest factor of 4.54 was in July which corresponded with dry and wet seasons respectively. In the same station, PC 2 had its lowest factor loading in June (0.02) and highest loading in May (-3.44); the same as in STN 1. In STN 3, the first PC factor loading was lowest in May with the value of -0.13 and highest in February with the value of 4.46; which coincided with the peaks of wet and dry seasons. The second PC had its lowest and highest factor loadings in February (-0.17) and April (2.95) respectively; corresponding with peaks of dry and wet seasons.

Canonical Cluster Analysis (CCA) for phytoplankton species

The result of the CCA for phytoplankton species are presented in Table 5 and the graphical representation is in Fig. 3. In CCV axis 1, which accounted for 31.5% of the total variance in phytoplankton, was positively correlated with pH and AT and was negatively impacted by PO_4-P, BOD, TDS, COD and TA; which represented the 'inorganic' source of variability. In CCV axis 2, which contributed 47.4% of the total variance, was positively influenced by WL, SO_4^{2-}, NO_3-N, conductivity and TSS and negatively loaded with transparency, CV and DO; which represented the 'organic' source of pollution.

In quadrat 1, the most important environmental vector was FCO_2, followed by AT and pH with eigenvalue of 0.53 which were responsible for 31.5% of the total variance in CCV 1. These vectors influenced the following sampling stations: $S_{13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23}$ and $_{24}$, which signifies the middle course of the river i.e. STN 2; where the following phytoplankton species formed clusters: *N. closterium, M. japonica, A. flos-aquae, O. limnetica, P. valderiae, A. racborskii, P. simplex, C. macilentum, N. rostella, C. moniliferium, M. varicans, N. gracilis* and *D. swartzii.* Opposite it was quadrat 3, thus implying negative and inverse relation to quadrat 1. The vector with the longest arrow is PO_4-P, followed by COD, BOD, TA and TDS signifying organic pollutional conditions; being responsible for 51.5% of the observed total variance in CCV 3 with eigenvalue of 0.07. Downstream stations ($S_{26, 32}$ and $_{36}$) which correspond with STN 3 were found to form clusters with these species of phytoplankton: *E. viridis, M. pulverea, A. superbus, C. amoerium, C. parvulum* and *T. fenestrata.* Environmental vectors in order of decreasing importance in quadrat 2 were WL, NO_3-N, SO_4^{2-}, conductivity and TSS, accounted 47.4% of the total variance in CCV 2, whose eigenvalue was 0.27. These were observed in sampling stations: $S_{25, 30, 31}$ and $_{33}$ which correspond with STN 3 also, where the phytoplankters: *G. echinulata, M. aeruginosa, O. lacustris, N. radiosa, A. spiroides, M. granulata* and *S. subtilissima* clustered.

Transparency contributed most to the observed variation in quadrat 4 with eigenvalue of 0.05 and 54.4% of total variance in CCV 4; this was followed by current velocity and DO. Upstream stations ($S_{1,\ 2,\ 8,\ 9}$ and $_{12}$) which correspond with STN 1 were found to have the clusters of the following algal populations: *T. armata, D. sociale* and *C. hirundinella.* Test of significance for all the four CCA axes was positive at 0.005 level of probability (Trace=1.21; F=2.12; P<0.01). The species and sampling stations not seen were hidden as a result of the overlaps observed in each quadrant. The total number of genera and species of phytoplankton sampled were 67 and 106 respectively as presented in Table 5.

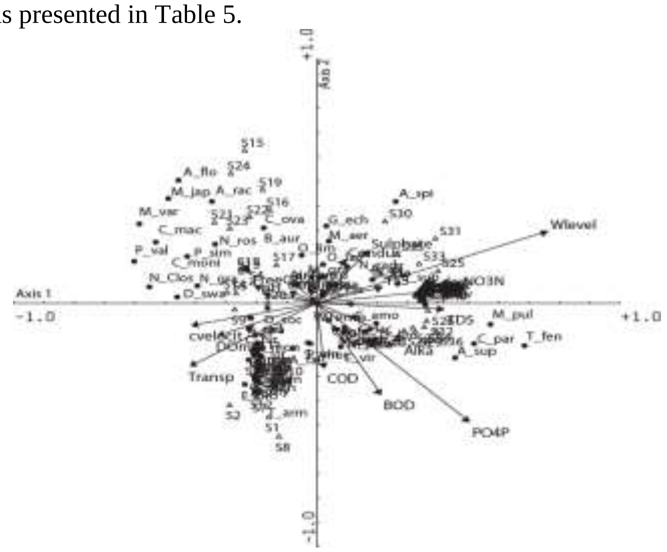

Fig. 3: An ordination diagram of the first two CCA triplot for phytoplankton species illustrating substantial taxonomic overlap among sampling stations (sites) as Δ, phytoplankton species as ● and physico-chemical parameters as arrows. First axis (Axis 1) is horizontal and the second axis (Axis 2) is vertical. See Table 5 for phytoplankton species abbreviations.

Discussion

Multivariate statistical analysis had been used to investigate relationships among variables and factors controlling such variables, to interpret complex data sets, to assess water quality, to explain the correlation among a large number of variables without losing much information and to compress data from the original to gain some useful information (Norris and Georges, 1986; Akin-Oriola and Tayo, 1999; Simeonov *et al.,* 2003; Singh *et al.,* 2005; Kowalkowskia *et al.,* 2006; Boyacioglu *et al*., 2008; Yang *et al*.,2008 and Li *et al.,* 2009). From the result of this research, the multivariate statistical analysis (PC 1-2) showed that the AT, conductivity, FCO_2, transparency, DO and the nutrients (mainly NO_3-N and PO_4-P) were the major natural and anthropogenic factors affecting the temporal and spatial variations in the water quality. WT follows closely to AT, thus, the former fluctuates depending on the later. The environmental vectors influencing the clustering of the various phytoplankton species vary from one sampling station to another and were found to be dependent on the water quality. The upstream station is characterised by clean water as depicted by high transparency, current velocity and dissolved oxygen. Thus, species such as *T. armata, D. sociale* and *C. hirundinella* were found. The less clean middle course was influenced by FCO_2, AT and pH. Hence, species such as *N. closterium, N. rostella, M. japonica, O. limnetica, M. varicans* and many others clustered there. The deteriorated water quality in STN 3 i.e. downstream divided environmental factors and phytoplankton species into two: the initial stations were affected by WL, NO_3-N, SO_4^{2-}, conductivity and TSS; which had the clusters of *G. echinulata, M. aeruginosa, M. grandulata* and others. The final stations were influenced by PO_4-P, COD, BOD, TA and TDS, thus, the species encountered were *M. pulverea, E. viridis, C. parvulum, T. fenestrata,* among others. From the foregoing, it could be derived that there are two major sources of pollution in the river course: organic factor can be interpreted as influences from point sources such as discharges from wastewater treatment plants, domestic wastewater and industrial effluents as observed by other author such as Borsuk and Stow (2000), Simeonov *et al.,* (2003), Singh *et al.,* (2005) and Li *et al.,* 2009. The water quality in STN 3 i.e. the downstream may be rated as 'polluted' due to the pollutions from domestic wastewater, wastewater treatment plants, municipal sewage, timber chippings and industrial effluents located around this site. This fact is further strengthened by the species considered as pollution tolerant or indicator. Similar observations have been made by some other researchers confirming the presence of such species as organic pollutants: Onuoha, (1994); Akin-Oriola and Tayo (1999); Akin-Oriola (2002, 2003); Ekwu and Sikoki (2006). A river system can suffer from the effect of more than one type or source of pollution. Thus, pollution can either be point-source or non-point source (King and Jonathan, 2003). The second and less important source is inorganic factor.

Productivity by aquatic microflora (phytoplankton) increases with increase in temperature upto a certain threshold. The product of carbon synthesis (i.e. photosynthesis) is the liberation of dissolved oxygen. Correspondingly, nutrients with favourable temperature, leads to increased DO content and high ionic constituents. CCA result also revealed that apart from PO_4-P, BOD and COD; WL was another most important environmental vector in the downstream (STN 3) station, (S_{25-36}) affecting the clustering of the various species as obtained from the results. Lowe-McConnell (1987), Chapman and Kramer (1991) and Wetzel (2001) reports were similar to those observed in this work that onset of the rains signals a radical change in the physico-chemical characteristics of the river and the inputs of allochthonous organic materials from the catchment areas during rainfall increases conductivity, pH, TA, TDS and BOD. This was followed by PO_4-P and then transparency. The method showed heterogeneity in the grouping of the species together. This demonstrated that most of the species collected from the same location were not clustered together especially for seasonal variation, whose major influence was water level caused by precipitation. These results prove that the major source of anthropogenic perturbation in Ikpa River is nutrients (inputs) enrichment. Morgan and Cushman (2003); Young *et al.,* (2004); Muwanga and Barifaijo (2006) observed that the discharge of organic matter into water is an important source of plant nutrient since aerobic decomposition of organic matter result in the release of phosphate, nitrate, and other nutrients. Also, domestic sewage contains high levels of phosphate because detergent washing powder formations normally contain high levels of phosphate. Other sources of nutrients include food processing effluents, agricultural practices, intensive livestock rearing, precipitation, urban and rural runoffs, groundwater, nitrogen fixation, among others (Lowe-McConnell, 1975; Welcomme, 1979, 1985; Moss, 1998; King and Jonathan, 2003). It had been observed that in tropical rivers, the ionic composition of water is derived primarily from rain, the bedrock over which the river flows and aquatic plants i.e. phytoplankton and macrophytes

(Welcomme, 1985; Allan, 2001). Apart from these aquatic plants, secondary influences on the ionic composition of lotic systems are the various industrial, agricultural and domestic activities. Human pollutants enter river water through precipitation and dry deposition by storm water transport of fertilizers and road salts and by direct disposal (Welcomme, 1985; Giller and Malmqvist, 2002; Li *et al.,* 2009). Giller and Malmqvist (2002) attribute the autochthonous sources of nutrients in a river to decomposition of plant and animal remains and sediment-water exchanges. Nutrients move unidirectionally within running waters as observed in this work (higher values in STN 1 and 3, but lower value in STN 2). Dissolved substances move downstream, may be bound or assimilated for a period of time, and later released for further movement down the gradient (Giller and Malmqvist, 2002). Areas of high rainfall and surface runoff usually have less concentrated stream water compared with arid areas where evaporation is greater and dilution is less. There was an inverse relationship between temperature and DO, which had been observed by Li *et al.,* (2009) and they ascribed it to natural process because warmer water become more easily saturated with oxygen and it can hold less DO.

In unpolluted systems, ecological indicators show discrete arrangement or pattern downstream with the concentrations of most dissolved salts, levels of most nutrients and number of species tending to increase progressively downstream (Giller and Malmqvist, 2002; Vannote *et al.,* 1980). However, the observed trends/patterns in this present study deviate remarkably from those previously established. Such deviations could be attributed to anthropogenic perturbations in STN 2 which alter the ecosystem stability and cause a shift in the longitudinal pattern downstream. Lower values were therefore, observed in TDS, TSS, BOD, COD, TA and PO_4-P whereas higher values were observed in CV, WT, FCO_2, TH and pH in STN 2 than in the other two stations. A pollution indicator species (*M. varicans*) was also observed in STN 2. These parameters are pollution indicators (Allan, 2001). This suggests that the river at STN 2 is impacted by human interferences more than STNs 1 and 3. Also, there was reduction in number of species composition of phytoplankton in this station than in other stations. These microphytes are known to posses no ability to move on their own. Thus, they are often referred to as 'drifters', and are dependent on water current. Welcomme (1985) and Akpan and Ufodike (1995) had observed that fish eggs and other aquatic biotas (including phytoplankton) are disturbed by human activities when the environments are impacted. Thus, the riverbed dredging, new bridge construction and the associated activities in STN 2 could have probably contributed to these deviations from the normal trend. Ogbeibu and Oribhabor (2008) reported on the species reduction in STN 2 and attributed it to anthropogenic activities in the aquatic system. In the CCA for all the species, WL was the most important environmental vector influencing the biotas. Plankton which do not possess ability for movement would have been found clustering around this vector but a deviation was observed.

The water quality statuses of Ikpa River, Nigeria revealed human anthropogenic perturbation effect. The continual input of oil palm untreated waste-water, surface runoffs laden with cement and coal-tar, serious riverbed dredging, frequent non-season and fertilized farming impact, washing and bathing, introduction of hot wastewater from generating sets, incessant dumping of refuge, hydrocarbon oil-films from automobile water-crafts, timber chippings from the mill, transportation of passengers between fishing and farming communities, transportation of timber from Cameroun and Oron and riparian shoreline clearing are some of the daily activities that are undertaken directly on the river system. The water is also used for domestic purposes especially in STN 1 where there is no other source of drinking water without any kind of treatment. From the above obtained results from this research, the following conclusions can be drawn: the mean levels of physico-chemical variables of water were, therefore, compared with drinking water and aquatic life guideline standards. Almost all of them were within the allowable limit with the exception of PO_4-P which was higher. The physico-chemical variables were further characterized into three main groups depending on the type of seasonal influence as follow: dry season climax referring to those variables which resulted 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; wet season climax referring 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. There was no marked seasonal variation climax in the parameter which was insensitive to dry / wet cycle typical of the tropical zone e.g. transparency.

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Table 1: Annual mean variations of physico-chemical parameters in the three sampling stations of Ikpa River, Nigeria

Physico-chemical parameters	STN 1	STN 2	STN 3	Range		CV (%)	ANOVA	
	Min–Max Mean ± S.E	Min – Max Mean ± S.E	Min–Max Mean ± S.E	Min.	Max.		F.value	Probability
Current velocity($CmSec^{-1}$)	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(^0C)	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(^0C)	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(μScm^{-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
D0($mg\ L^{-1}$)	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(μgL^{-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(μgL^{-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-}(μgL^{-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

Table 2: Factor loadings of the principal components (PC 1 - 4) for physico-chemical parameters showing the percentage variance and eigenvalues at the three sampling and the combined stations in Ikpa River, Nigeria. Loadings equal to or greater (≥) 0.30 indicated significance. Significant factor loadings are boldfaced.

Physico-chemical parameters	Sampling Stations 1, 2 & 3 combined			
	PC 1	PC 2	PC 3	PC 4
CV	-0.24	-0.01	-0.33	0.20
WL	-0.15	0.25	0.47	0.15
AT	0.31	0.05	-0.21	0.17
WT	0.26	-0.03	-0.05	0.43
TDS	0.29	0.15	0.18	-0.05
TSS	-0.27	-0.05	0.28	0.09
Trans	0.09	-0.31	-0.22	0.38
Condu	-0.32	0.13	0.02	0.06
D0	0.19	-0.34	0.21	0.12
BOD	0.21	-0.16	0.35	0.42
COD	0.21	0.23	-0.28	-0.05
FCO_2	0.30	0.03	-0.17	-0.02
TA	0.28	0.20	0.18	0.08
TH	0.23	-0.26	0.14	-0.23
NO_3N	0.07	0.54	-0.15	0.05
PO_4P	-0.07	0.40	0.11	0.43
SO_4^{2-}	0.29	0.17	-0.00	-0.17
pH	-0.18	-0.13	-0.32	0.31
Eigenvalue (λ)	0.42	0.15	0.09	0.06
% Variance explained	41.56	56.08	65.33	71.79

Table 4: Monthly variations of first two principal component loadings (PC 1 - 2) of the various physico-chemical parameters showing station effect in the three sampling stations in Ikpa River, Nigeria. Loadings equal to or greater 0.20 indicated significance.

Station	PC axis	Months											
		M	A	M	J	J	A	S	O	N	D	J	F
1	1	3.53	1.38	0.90	-1.12	-3.94	-3.35	-4.29	-1.73	-0.80	1.46	3.82	4.15
	2	-1.11	0.56	2.75	2.27	0.82	-0.21	-1.37	-2.60	-0.53	1.13	-1.32	-0.40
2	1	4.24	1.17	0.95	-1.66	-4.54	-2.75	-4.32	-1.89	0.17	1.88	2.79	3.98
	2	-0.58	-2.64	-3.44	0.02	-1.05	-0.89	2.02	0.51	1.91	1.77	1.43	0.93
3	1	2.41	0.67	-0.13	-2.51	-4.96	-1.94	-4.29	-0.89	1.89	1.19	4.01	4.46
	2	2.02	2.95	1.56	1.76	0.29	-0.92	-2.06	-1.09	-1.28	-1.13	-1.93	-0.17

Table 5: Canonical variables (CV 1-4) of Cumulative fit per species as fraction of variance of species constructed from the combined sites, months and phytoplankton species data showing phytoplankton species and their abbreviations, weights (loadings) and canonical variates in Ikpa River, Nigeria between March 2009–February 2010. Significant loadings equals to or greater than 0.30 are boldfaced.

S/N	Phytoplankton species	Species abbre.	CV 1	CV 2	CV 3	CV 4	Var (y)	% Expl
1	*Amphora ovata*	A_ova	0.01	0.10	0.10	0.24	0.37	65.27
2	*Asterionella formosa*	A_for	0.16	0.45	0.46	0.48	0.29	54.35
3	*A. gracilluna*	A_gra	0.34	0.37	0.56	0.57	1.79	69.49
4	*Biddulphia aurita*	B_aur	0.34	0.65	0.65	0.65	2.17	69.52
5	*Coscinodiscus lacustris*	C_lac	0.31	0.37	0.39	0.40	0.68	49.17
6	*C. radiata*	C_rad	0.46	0.49	0.57	0.58	1.37	74.84
7	*Cyclotella glomerata*	C_glo	0.09	0.37	0.43	0.44	0.22	58.15
8	*C. striata*	C_str	0.36	0.61	0.73	0.74	1.35	84.19
9	*Gyrosigma attenuatum*	G_att	0.30	0.40	0.45	0.45	1.40	80.98
10	*Melosira granulata*	M_gra	0.01	0.26	0.30	0.30	0.63	59.57
11	*M. moniliformes*	M_mon	0.26	0.36	0.73	0.73	2.05	79.22
12	*Navicula cuspidata*	N_cus	0.07	0.26	0.56	0.56	0.70	62.73
13	*N. placentula*	N_Pla	0.01	0.03	0.06	0.06	0.65	42.96
14	*N. rhynchocephala*	N_rhy	0.16	0.56	0.57	0.61	3.28	78.31
15	*N. rostella*	N_ros	0.47	0.63	0.64	0.64	1.45	71.01
16	*Nitzschia closterium*	N_Clos	0.39	0.66	0.67	0.67	1.74	73.75
17	*N. filiforms*	N_fil	0.19	0.49	0.49	0.49	2.45	62.16
18	*N. gracilis*	N_gra	0.52	0.73	0.73	0.74	0.68	81.53
19	*N. paradoxa*	N_par	0.19	0.51	0.52	0.56	0.57	72.53
20	*Pinularia divergens*	P_div	0.10	0.25	0.25	0.25	4.49	48.77
21	*Rhizosolenia longiseta*	R_lon	0.19	0.42	0.47	0.48	0.76	75.48
22	*Surirella robusta*	S_rob	0.15	0.28	0.42	0.42	3.42	53.40
23	*Synedra ulna*	S_uln	0.01	0.33	0.42	0.43	1.07	58.94
24	*Akinstrodesmus falcalus*	A_fal	0.06	0.42	0.44	0.46	1.27	59.74
25	*Chlamydomonas atactogam*	C_ata	0.14	0.31	0.31	0.31	3.43	45.98
26	*C. elliptica*	C_ell	0.21	0.57	0.58	0.59	2.19	63.22
27	*Chlorococcum humicolum*	C_hum	0.19	0.57	0.57	0.59	2.38	70.39
28	*Chlorogonium elongatum*	C_elo	0.10	0.22	0.44	0.44	1.13	67.40
29	*Closterium lanceolatum*	C_lan	0.20	0.63	0.66	0.66	2.27	73.57
30	*C. moniliferium*	C_mon	0.13	0.39	0.39	0.45	4.46	63.25

31	*Cosmarium amoerium*	C_amo	0.20	0.20	0.22	0.30	0.85	44.45
32	*C. moniliforme*	C_moni	0.52	0.60	0.63	0.63	1.29	77.47
33	*Desmidium swartzii*	D_swa	0.49	0.53	0.54	0.56	1.25	67.50
34	*Eudorina illinoisensis*	E_ill	0.13	0.25	0.36	0.38	4.41	50.78
35	*Pandorina elegans*	P_ele	0.11	0.25	0.25	0.25	4.11	49.30
36	*P. morum*	P_mor	0.00	0.27	0.29	0.32	1.30	63.57
37	*Pediastrum boryanum*	P_bor	0.08	0.24	0.32	0.34	5.44	52.72
38	*P. simplex*	P_sim	0.32	0.46	0.46	0.47	2.12	59.22
39	*Scenedesmus quadricauda*	S_qua	0.03	0.16	0.16	0.24	0.23	71.90
40	*Schroederia setigera*	S_set	0.07	0.14	0.30	0.30	5.93	42.45
41	*Spirotaenia condensata*	S_con	0.21	0.43	0.45	0.45	2.63	57.02
42	*Sphaerocystis schroeteri*	S_sch	0.08	0.16	0.17	0.21	8.54	58.27
43	*Staurastrum paradoxum*	S_par	0.19	0.62	0.63	0.63	2.30	72.88
44	*Volvox aureus*	V_aur	0.22	0.69	0.70	0.70	2.30	75.73
45	*Dinobyron divergens*	D_div	0.10	0.34	0.38	0.38	5.17	51.23
46	*D. sociale*	D_soc	0.59	0.59	0.59	0.59	0.57	78.19
47	*Uroglenopsis botrys*	U_bot	0.11	0.33	0.56	0.57	4.36	70.10
48	*Geotrichia echinulata*	G_ech	0.01	0.19	0.19	0.24	0.89	71.35
49	*Microcystis aeruginosa*	M_aer	0.01	0.05	0.10	0.11	0.37	46.98
50	*Euglena acus*	E_acu	0.30	0.45	0.47	0.50	1.12	68.06
51	*E. viridis*	E_vir	0.04	0.22	0.44	0.46	2.24	69.30
52	*E. proxima*	E_pro	0.10	0.29	0.34	0.40	7.37	73.33
53	*Phacus caudatus*	P_cau	0.09	0.19	0.26	0.28	5.44	54.82
54	*Trachelomonas armata*	T_arm	0.04	0.17	0.46	0.46	12.66	67.52
55	*Ceratium candelatum*	C_can	0.13	0.26	0.63	0.63	0.94	77.94
56	*C. hirundinella*	C_hir	0.19	0.23	0.24	0.30	3.38	61.92
57	*Gymnodinium aeruginosum*	G_ae	0.01	0.07	0.07	0.12	0.69	46.46
58	*Peridinium depressum*	P_dep	0.07	0.24	0.36	0.37	0.86	59.41
59	*P. latum*	P_lat	0.00	0.00	0.04	0.16	1.23	47.01
60	*Gloeobotrys limnetica*	G_lim	0.34	0.40	0.48	0.51	1.49	79.77
61	*Melosira japonica*	M_jap	0.24	0.61	0.61	0.61	3.25	65.45
62	*M. varicans*	M_var	0.22	0.51	0.51	0.51	3.43	59.84
63	*Navicula radiosa*	N_rad	0.17	0.36	0.36	0.37	1.23	57.62
64	*Closterium macilentum*	C_mac	0.16	0.45	0.46	0.46	4.20	53.51
65	*Anabaena affinis*	A_aff	0.17	0.25	0.25	0.31	2.08	72.72
66	*A. spiroides*	A_spi	0.11	0.37	0.38	0.59	1.59	72.87
67	*Anabaenopsis racborskii*	A_rac	0.16	0.43	0.44	0.45	5.32	61.70
68	*Aphanizomenon flos-aquae*	A_flo	0.15	0.40	0.40	0.44	5.41	75.57
69	*Dactylococcopsis irregularis*	D_irr	0.25	0.33	0.34	0.35	1.54	59.58
70	*Oscillatoria lacustris*	O_lac	0.00	0.19	0.19	0.22	1.85	48.21
71	*O. limnetica*	O_lim	0.11	0.23	0.23	0.24	2.40	43.18
72	*Phormidium valderiae*	P_val	0.08	0.16	0.17	0.17	7.89	32.62
73	*Rivularia plantonica*	R_pla	0.25	0.32	0.33	0.33	1.82	65.13
74	*Spirulina subtilissima*	S_sub	0.66	0.72	0.74	0.75	1.43	86.24
75	*Cryptomonas ovata*	C_ova	0.07	0.31	0.31	0.34	5.23	42.95
76	*Attheya zachariasi*	A_zac	0.61	0.62	0.63	0.79	2.55	8995
77	*Chaetoceros decipiens*	C_dec	0.48	0.49	0.51	0.61	3.29	75.74
78	*Fragilaria crotonensis*	F_cro	0.74	0.75	0.76	0.76	2.25	91.29
79	*F. intermedia*	F_int	0.49	0.49	0.50	0.52	2.89	80.99
80	*Melosira distans*	M_dis	0.80	0.81	0.81	0.81	1.93	95.47
81	*Nitzschia longissima*	N_lon	0.26	0.26	0.27	0.27	6.20	78.61
82	*Stauroneis phoenicenteron*	S_pho	0.72	0.73	0.73	0.83	2.26	91.42
83	*Stephanodiscus astraea*	S_ast	0.58	0.58	0.58	0.68	2.74	91.81
84	*Synedra acus*	S_acu						
85	*Tabellaria binalis*	T_bin	0.51	0.51	0.51	0.78	3.26	92.02
86	*T. fenestrata*	T_fen	0.54	0.54	0.56	0.68	3.11	82.44
87	*Asterococcus superbus*	A_sup	0.30	0.30	0.32	0.32	5.06	76.35
88	*Closterium parvulum*	C_parv	0.68	0.68	0.68	0.68	2.43	92.20
89	*Gloeocystis gigas*	G_gig	0.83	0.84	0.84	0.85	1.83	92.02
90	*Pediastrum clathratum*	P_cla	0.79	0.70	0.70	0.70	2.50	89.46
91	*Aphanothece stagnina*	A_sta	0.87	0.87	0.87	0.87	1.78	91.11
92	*Lyngbya limnetica*	L_lim	0.60	0.60	0.60	0.61	2.62	87.38
93	*Merismopedia punctata*	M_pun	0.51	0.53	0.53	0.54	3.04	77.40
94	*Microcystis pulverea*	M_pul	0.49	0.49	0.51	0.53	3.30	82.11
95	*Phormidium tenue*	P_ten	0.64	0.65	0.65	0.72	2.30	79.22
96	*Raphidiopsis curvata*	R_cur	0.60	0.60	0.61	0.61	2.73	72.93
97	*Euglena gracilis*	E_grac	0.71	0.73	0.73	0.84	2.12	90.26
98	*Phacus curvicauda*	P_cur	0.30	0.31	0.32	0.54	5.15	74.67
99	*Chilomonas paramecium*	C_par	0.63	0.63	0.63	0.65	2.58	87.11
100	*Gymnodinium neglectum*	G_neg	0.77	0.78	0.79	0.80	2.30	89.45
101	*Bostrycoccus braunii*	B_bra	0.41	0.41	0.43	0.43	4.11	82.64
102	*Tribonema viride*	T_vir	0.53	0.53	0.54	0.66	2.81	75.88
103	*Amphora ovalis*	A_ova	0.78	0.79	0.79	0.80	1.97	89.20
104	*Aulacosirra granulata*	A_gra	0.46	0.47	0.47	0.53	3.57	72.15

	Eigenvalue	0.53	0.27	0.07	0.05
	Sp-env correlation	0.99	0.82	0.97	0.95
	Cum % var of sp data	31.5	47.4	51.6	54.4
	Cum % var of sp-env relation	43.9	66.2	72.1	76.0
	FR EXTRACTED	0.11	0.03	0.14	0.19