Seasonal variation in water quality of the Cross River, Nigeria

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ABSTRACT

Seasonal fluctuation in water quality of the Cross River (South eastern Nigeria) was studied for 13 months (March, 1988 to March, 1989). Six stations along the main axis of the river channel were identified and used throughout the study.

Significant variations were observed in the seasonal and spatial trends of water temperature, salinity, dissolved oxygen, biochemical oxygen demand, ammonium, nitrite, nitrate, phosphate and silicate. Seasonal variations in Secchi disc transparency and pH were not significant. Variations between surface and bottom levels were not significant except for silicate, phosphate and biochemical oxygen demand.

KEY WORDS : Cross River — Water quality — Estuaries — West Africa.

RÉSUMÉ

LES VARIATIONS SAISONNIÈRES DE LA CHIMIE DE L'EAU DE LA CROSS RIVER, NIGERIA

Six stations ont été échantillonnées pendant 13 mois (mars 1988 à mars 1989) dans la Cross River, dans le sud-est du Nigeria. Les variations saisonnières et spatiales significatives, salinité, température, oxygène dissous et DBO5, ammonium, nitrite, nitrate, phosphore et silice sont décrites. Seuls la transparence et le pH n'ont pas montré de variations saisonnières significatives. Une comparaison surface-fond a mis en évidence des variations pour trois variables : la silice, le phosphate et la DBO5.

MOTS CLÉS : Cross River — Chimie des eaux — Estuaires — Afrique de l'Ouest.

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INTRODUCTION

Since the advent of the Industrial Revolution and mechanized agriculture man is becoming increasingly aware of the worsening conditions of the environment around him.

In Nigeria, the last two decades following the oil boom have witnessed an appreciable increase in industrial activities ranging from agriculture to machinery. River basins have a special attraction for these industries since they serve as a cheap source of water supply and, in most instances, as sink for the waste discharges. Also attracted to the rivers are towns with their associated wastes. Through storm events, rainfall, and surface run-off, most of the wastes end up in the rivers and in the long run could result in irreversible damage to the ecosystem.

The Cross River estuary system is one of the richest sources of inland fisheries in Nigeria. MOSES (1987) reported that the mean annual fish catch from artisanal fisheries in this system within Nigeria is 65000 tonnes. He pointed out that the immediate problem was the management of this fishery to obtain an optimum sustainable yield and avoid over-fishing. He indicated that any management and conservation measures employed must take into account the factors which affect the (biological) production, distribution and abundance of fishes within the ecosystem. One of such factors, the influence of flood regime, has been considered (MOSES, 1987).

Most studies on the Cross River are directed to fisheries ecology (MOSES, 1979, 1987; NAWA, 1982) and water quality studies are very scanty indeed. Recently, some base-line ecological studies on some Nigerian rivers including the Cross River system have been undertaken (Research Planning Institute of USA (-RPI), 1985; ENYENIHI *et al.*, 1987). Heavy metal concentrations in sediment (NTEKIM, 1987) and in the edible Clam *Egeria radiata* (Lamarck) (ETIM and AKPAN, 1991) in the Cross River system have been reported.

The present study is directed to the variability in space and time of those variables which have direct effect on primary production and hence on fisheries production in the river system. A good understanding of the natural variations in the quality of the water is necessary for an understanding of the general dynamics within the system.

MATERIALS AND METHODS

The Cross River basin lies approximately between longitudes 7° 30″ and 10° and latitudes 4° and 8°N, covering an estimated area of 54000 km² of which 14000 km² lie in the Cameroon and 39000 km² lie in Nigeria. The river rises from the Cameroon mountains and flows south-westwards into the Atlantic ocean. The study area extended from Itu bridge (station 1) to Inua-Abasi (station 6), a distance of approximately 100 km (Fig. 1).

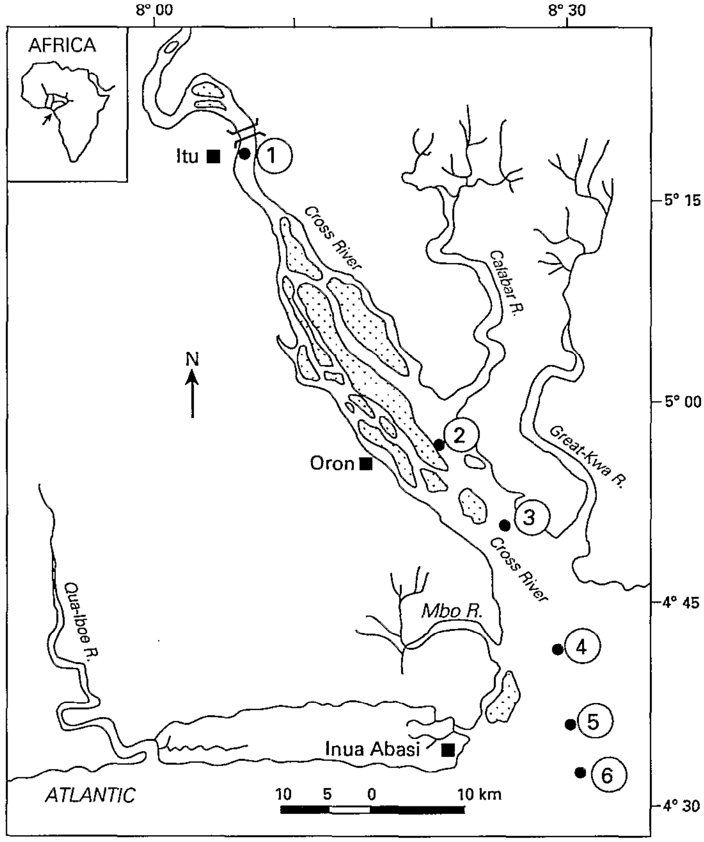

FIG. 1. — Map of the Cross River system showing sampling locations.
Carte de la Cross River et stations de prélèvement.

Water samples were obtained with the aid of a Hydrobios, Nansen type reversible water sampler from the surface (*ca.* 0.5 m below the surface) and bottom (*ca.* 0.5 m above the bottom). Sampling was done only during ebbing tide between the hours of 8 a.m. and 12 noon. This was to eliminate the influence of tide and sampling time on measured parameters. Water samples for laboratory analysis were preserved at 4 °C.

Water temperature was measured using a mercury thermometer; pH was determined by colorimetry using HACH pH (comparator) technique; dissolved oxygen was determined by Winkler method. Salinity was obtained from chlorinity using the relation :

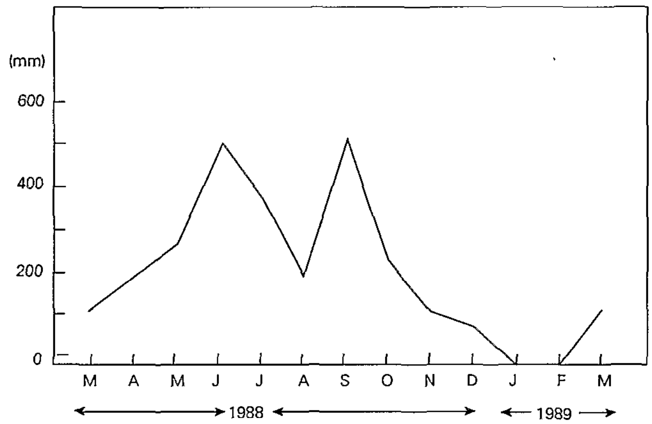

FIG. 2. — Monthly rainfall for Calabar during the sampling period.
Pluies mensuelles à Calabar pendant la période d'étude.

$S_{ppt} = 1.80655 \times Cl_{ppt}$ (Unesco, 1976). Chlorinity was determined by argentometric titration using potassium dichromate as indicator. Biochemical oxygen demand was determined from unseeded water samples after 5 days incubation at 20 °C and transparency was measured *in situ* using a 25 cm-diameter Secchi disc.

Water samples for nutrient analysis were filtered through 0.45 µm Whatman GF/C glass fibre filters. Ammonium was measured in the field by Nesslerization using the HACH colorimetric technique. Nitrate and nitrite were determined by the diazotization method, nitrate after reduction in a cadmium column (PARSONS *et al.*, 1984). Orthophosphate was measured by the molybdenum blue method (PARSONS *et al.*, 1984); total inorganic phosphorus (orthophosphate + hydrolizable phosphates) as orthophosphates after acid mineralization. Reactive silicate was determined spectrophotometrically according to PARSONS *et al.* (1984). Statistical analysis were performed according to SACHS (1984).

RESULTS

The climate of the study area has previously been described (MOSES, 1979; NAWA, 1982). Seasonal variation in rainfall during the study is shown in Fig. 2. Data on rainfall represent monthly mean values obtained from Calabar and is assumed typical of the Cross River catchment. Total annual rainfall for Calabar is approximately 3 000 mm.

Seasonal variations in concentrations of nutrients and other physico-chemical parameters are shown in Fig. 3.

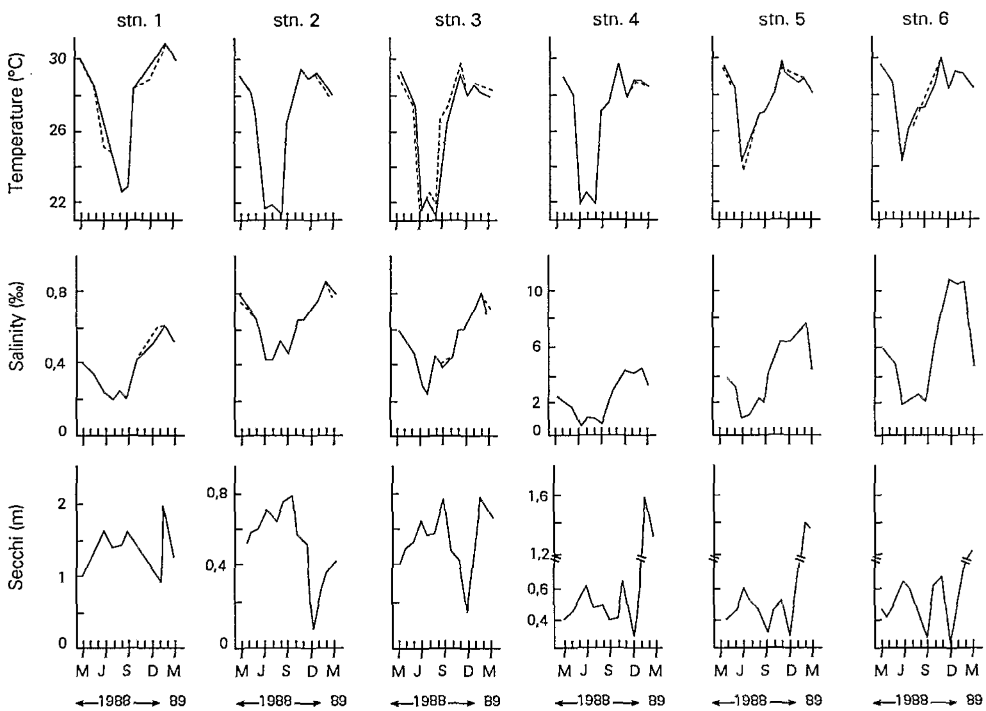

FIG. 3a. — Seasonal variation in water temperature, salinity and Secchi disc transparency in the Cross River.
Variations de la température de l'eau, de la salinité et de la transparence au disque de Secchi dans l'embouchure de la Cross River.

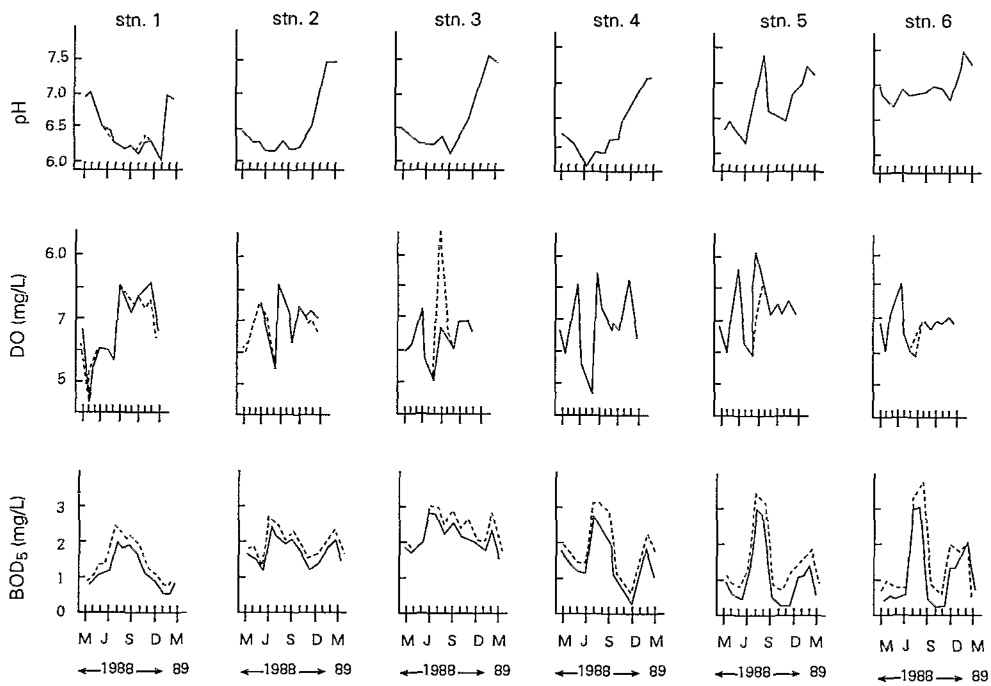

FIG. 3b. — Seasonal variation in pH, DO. and BOD_5 in the Cross River.
Variations du pH, de l'oxygène dissous, de la DBO_5 dans l'embouchure de la Cross River.

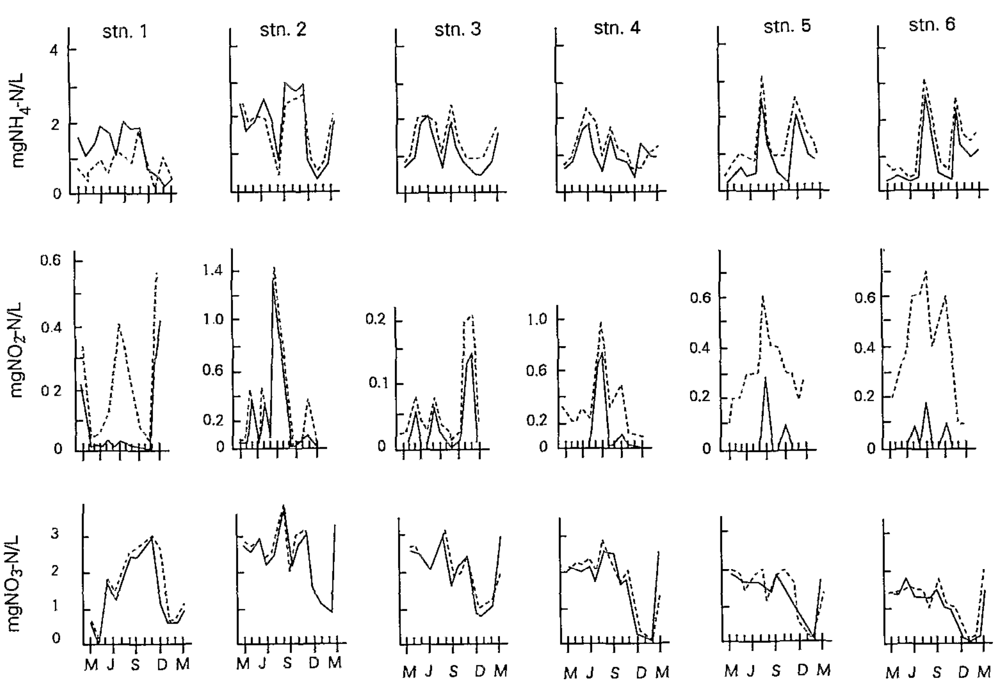

FIG. 3c. — Seasonal variation in concentration of NH_4-N, NO_2-N and NO_3-N in the Cross River.
Variations des concentrations de NH_4-N, NO_2-N et NO_3-N dans l'embouchure de la Cross River.

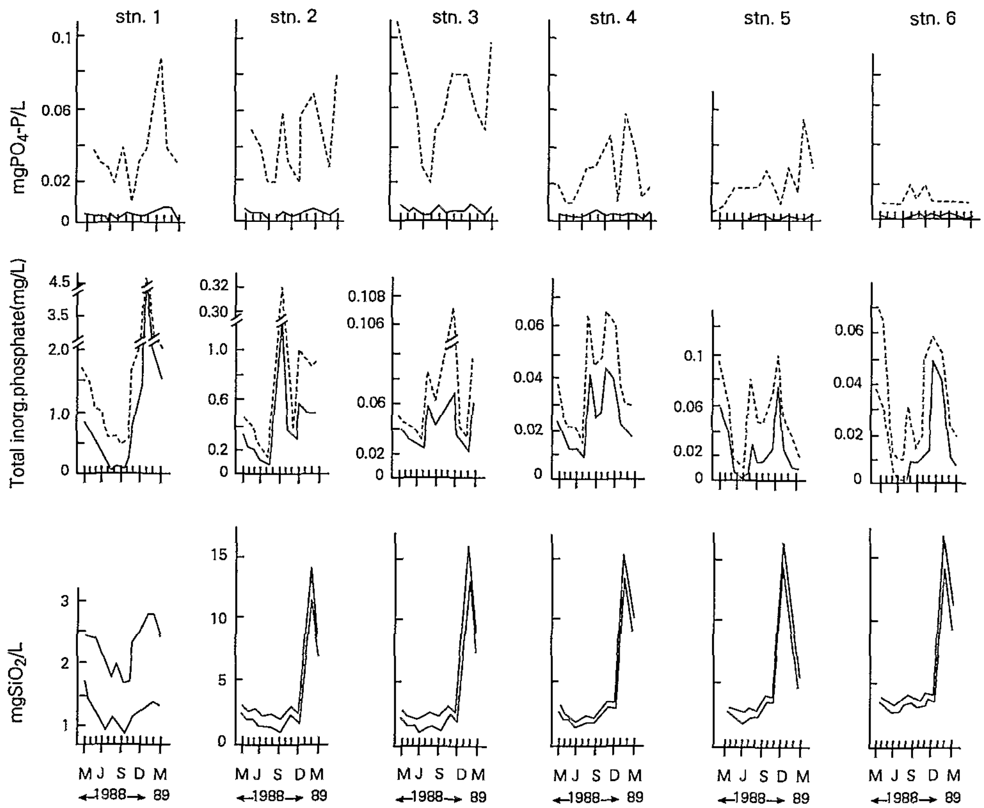

FIG. 3d. — Seasonal variation in concentration of orthophosphate, total inorganic phosphorus and silicate in the Cross River.
Variations des concentrations d'orthophosphate, de phosphore minéral total, et de la silice dissoute dans l'embouchure de la Cross River.

Water temperature varied widely during the study ranging between 21 °C during the wet season and 31 °C in the dry season. Mean temperatures varied between 26.7 °C in stations 2 and 3, and 27.9 °C in station 6. There was no significant variation between surface and bottom values (anova).

Seasonal trend in salinity was similar to that of temperature and there was a significant positive correlation between both variables ($r = 0.63$, $n = 26$, $P << 0.01$). Salinity varied between 0.2 ppt in the wet season and 8.65 ppt in the dry season. Mean salinities ranged from 0.38 ppt in station 1 to 5.46 ppt in station 6. There was no significant variation in salinity between surface and bottom values.

Hydrogen ion concentration reported as pH varied between 6.0 and 8.5 during the study. There was a significant positive relationship between pH and Secchi disc transparency ($r = 0.59$, $n = 26$, $P << 0.1$) and between pH and salinity ($r = 0.66$, $n = 26$, $P << 0.01$). Mean pH values ranged between 6.5 in station 1 and 7.6 in station 6. There was no significant difference between surface and bottom values.

Water transparency varied widely throughout the study ranging between 0.08 m in December, 1988 and 1.95 m in February, 1989. Sampling in December was done soon after a storm event, so that the extremely low transparency obtained is not typical of the period. Mean transparencies varied between 0.53 m at station 2 and 1.30 m at station 1. There was no significant seasonal variation in transparency, but dry season values were relatively higher than those of the wet season.

Dissolved oxygen concentrations ranged from 4.5 mgl^{-1} in August to 9.90 mgl^{-1} in September, 1988. Mean values varied between 6.28 mgl^{-1} in station 3 and 7.28 mgl^{-1} in station 5. Generally, DO saturation values were confined between 53.2 % in station 4 (August) and 110 % in station 1 (February). There was no significant variation between surface and bottom values (anova).

Biochemical oxygen demand (BOD_5) varied between 0.2 mgl^{-1} and 3.8 mgl^{-1} during the study. The extreme value of 3.8 mgl^{-1} was measured in August, 1988, in station 6 (bottom). Mean values ranged from 1.03 mgl^{-1} in station 6 to 2.35 mgl^{-1} in station 3.

Significant variations were observed between surface and bottom concentrations (anova). A strong negative correlation was obtained between BOD and temperature ($r = -0.79$, $n = 26$, $p << 0.01$) but BOD did not correlate significantly with DO.

Ammonium concentrations varied widely throughout the study, with values ranging from indetectable levels to 3.41 mgl^{-1} which coincided with BOD peak in August, 1988. Mean values ranged from 0.93 mgl^{-1} in station 1 (bottom) to 1.84 mgl^{-1} in station 2 (surface). There was no significant variation between surface and bottom concentrations (anova). A strong negative relationship was observed between ammonium and temperature ($r = -0.66$, $P << 0.01$) and between ammonium and salinity ($r = -0.74$, $P << 0.01$).

At many stations, nitrite concentrations were below the limit of detection (0.5 μgl^{-1}). The maximum concentration of 1.44 mgl^{-1} was measured in station 2 (September). Mean values ranged between 0.003 mgl^{-1} in station 3 (surface) and 0.33 mgl^{-1} in station 2 (bottom). Nitrite showed significant seasonal and spatial variations but variation between surface and bottom values was not significant (anova). Nitrite showed a positive correlation with ammonium during study ($r = 0.52$, $P << 0.01$).

Nitrate ranged from indetectable levels in the dry season to the extreme value of 3.74 mgl^{-1} observed in August. Mean concentrations ranged from 1.02 mgl^{-1} in station 6 to 2.51 mgl^{-1} in station 2. There was no significant variation between surface and bottom values. Nitrate showed significant relationships with ammonium ($r = 0.61$, $P << 0.01$), salinity ($r = -0.71$, $P << 0.01$) and DO ($r = -0.41$, $P < 0.01$).

Orthophosphate concentrations remained low throughout the period with values ranging from indetectable levels to 0.11 mgl^{-1} obtained in March, 1988. Mean concentrations varied between 0.001 mgl^{-1} in station 6 to 0.007 mgl^{-1} in station 3. There was no significant seasonal variation in concentrations of orthophosphate but a significant variation occurred between surface and bottom values (anova). Orthophosphate values were, however, relatively higher in the dry season than in the wet season and gave a significant correlation with salinity ($r = 0.51$, $P < 0.01$).

Total inorganic phosphate concentrations ranged from 0.002 mgl^{-1} in the wet season to 4.49 mgl^{-1} obtained in January, 1989. Mean concentrations varied between 0.01 mgl^{-1} in station 6 and 1.65 mgl^{-1} in station 1. Total inorganic phosphate values showed significant seasonal and spatial variations but there was no significant variation between surface and bottom concentrations.(anova). Significant positive relationships occurred between total phosphate and salinity ($r = 0.80$, $P << 0.01$), pH ($r = 0.65$, $P << 0.01$) but negative correlation was found with nitrate ($r = -0.77$, $P << 0.01$).

Silicate concentrations ranged between 0.82 mgl^{-1} in the wet season and 16.73 mgl^{-1} during the dry season. Mean concentrations varied between 1.21 mgl^{-1} in station 1 and 5.90 mgl^{-1} in station 6. Bottom values were higher than surface concentrations at all stations. Significant positive correlations were observed between silicate and salinity ($r = 0.76$, $P << 0.01$), pH ($r = 0.88$, $P << 0.01$) but silicate correlated negatively with nitrate ($r = -0.74$, $P << 0.01$).

DISCUSSION

The climate of the Cross River catchment is dominated by the wet (April to November) and dry (November to March) seasons. During the wet season, South West Trade Winds prevail and bring about high rainfall and reduced temperatures. During the dry season, the North East Trade Winds, characterized by drought and high temperatures prevail. A short period of drought, termed "August drought", lasting about 2 weeks is common in late July or August.

Temperature fluctuations observed in the present study are mainly controlled by climate. The observed temperature range of 21 °C to 31 °C is within the range reported previously in the Cross River system (Moses, 1979; Nawa, 1982) and in the Niger Delta area (Ewa, 1988). Although previous studies in the Cross River system were confined to surface measurements (Moses, 1979; Nawa, 1982), no significant difference was observed between surface and bottom temperatures during the present study. This vertical homogeneity is mainly attributed to tidal mixing. Lowest temperatures were observed in stations 2 and 3 within the mid-estuary. Low temperatures at these stations are attributable to the influence of water discharge from the Calabar and Great Kwa Rivers as well as to lateral water movements leading to mixing with colder waters from the shallow intertidal zone. The dense growth of mangrove at these stations which shaded the water from solar radiation is also partly responsible for the observed drop in temperatures.

Salinity variations in the Cross River are mainly controlled by freshwater inflow. The high input of freshwater during the wet season led to marked dilutions of the river resulting in significant drop in salinity. The reverse occurred in the dry season when saltwater intrusion became dominant. Seasonal variation in salinity was less pronounced at the upper reaches of the river where the dominant influence of freshwater discharge maintained a relatively stable salinity in the water. Seasonal variability in salinity was highest in station 4, within the mid-estuary, due to wide fluctuations in freshwater inflow and saltwater intrusion. LOEWENBERG and KUENZEL (1992) found salinities lower than 0.5ppt at station 4 during the wet season while salinities remained brackish during the dry season. At station 6, seasonal variability in salinity dropped markedly in comparison to station 4. At this station, the influence of freshwater inflow is highly reduced leading to a more stable salinity distribution. Similarly, NAWA (1982) did not observe any significant seasonal variation in salinity within the outer estuary of the Cross River (beyond station 6).

Hydrogen ion concentration (pH) correlated positively with salinity during the present study ($r = 0.66$, $P << 0.01$) so that the seasonal variation in pH could also be attributable to the interplay of freshwater inflow and saltwater intrusion. However, seasonal variability in pH was low at all stations indicating the higth buffering capacity of the water.

Secchi disc transparency was also significantly correlated with pH ($r = 0.59$, $P << 0.01$). Seasonal variation in transparency was also related to seasonal regimes of freshwater inflow. Although there was no significant seasonal variations in transparency, dry season values were relatively higher than those of the wet season. A similar result has been reported previously in the Cross River (RPI, 1985), where values of 0.36 and 2.5 m were recorded for the wet and dry seasons respectively in station 1.

Although riverine input of materials may be the dominant factor, tidal activity (POWELL *et al.*, 1989) and resuspension due to strong winds (PEJRUP, 1986; DEMERS *et al.*, 1987) may contribute significantly to fluctuations in transparency, especially during the dry season. For instance, the extremely low transparency of 0.08 m measured in December was attributed both to wind resuspension and riverine input of turbid water following a storm event which preceded the sampling. Lowest transparencies were measured in stations 2 and 3 which receive drainage water from the Calabar and great Kwa Rivers respectively (Fig. 1).

During the present study DO concentrations were confined between 4.5 and 9.9 mgl^{-1}, corresponding to saturation values of 53 % at station 4 in August and 110 % at station 1 in February. Similarly, LOEWENBERG and KUENZEL (1992) found DO saturation values of 54 to 114 % for the Cross River system with highest values occurring during the dry season in conformity with the present study. The observed seasonal variations in DO concentrations are attributable to riverine input of oxygen demanding wastes. BOD_5 was higher during the west season due to input of decomposing organic matter through surface run-off water.

Seasonal variation in concentration of inorganic nitrogen nutrients were similar to that of BOD : maximum concentrations in the wet season and markedly reduced values in the dry season. The wet season is characterized by increased inputs of surface run-off water enriched with nutrients which is mainly responsible for the increase in concentration of inorganic nitrogen in the river during this season. In the Blue Nile, which is slow flowing, TALLING and RZOSKA (1967) measured high amounts of nitrate-nitrogen occasionnally exceeding 500 μgl^{-1} in the flood water and levels below 20 μgl^{-1} when floodwater subsided. During the present study, a sharp drop was observed in the values of ammonium and nitrate-nitrogen between November and February. This decline is mainly due to the subsiding of floodwater but phytoplankton assimilation is also important during this season. AKPAN and OFFEM (1993) reported maximum phytoplankton densities in the Cross River in February. During the study, concentrations of ammonium and nitrate were found to decrease towards the sea, indicating the possible diluting effect of sea water on the nutrient concentrations.

Seasonal variations in concentration of orthophosphate is attributed to fluctuations in riverine input of organic matter, bacterial mineralization/assimilation and phytoplankton assimilation. The highest concentration of 0.11 mgl^{-1} was measured in March, 1988 while the lowest value occurred in February, 1989. High density of phytoplankton in February (AKPAN and OFFEM, 1993) is partly responsible for the low concentrations of orthophosphate observed while zooplankton grazing activity (AKPAN, 1991) is mainly responsible for the increase in March. ANTIA *et al.* (1963) showed that in the absence of zooplankton, phosphate concentrations could decrease markedly during a phytoplankton bloom. BUTTLER *et al.* (1970) found that grazing activity of Calanus effectively returned more than 80 % of the phytoplankton phosphorus to the environment. NAWA (1982) reported that the zooplankton of the Cross River was dominated by Crustacea, mainly composed of larval stages of Calanus species. Low concentrations of orthophosphate observed during the wet season between April and July, may be attributed to dilution from rainfall since, unlike nitrogen, little phosphorus appears to be added to the marine environment from rainfall (PARSONS and HARRISON, 1983). HARRISON *et al.* (1977) found that in coastal waters (where organic substrate for heterotrophic production may be high) at least 50 % of the inorganic phosphorus uptake could be attributable to bacterial assimilation.

During the rainy season, the Cross River is rich in organic matter, which could promote heterotrophic production and thus bacterial assimilation of inorganic phosphorus. In comparison to most of the other variables measured, phosphate showed significant differences between surface and bottom values. Although the causes of such variations are not completely known, higher bottom values observed are associated with sediment regeneration due to herbivore grazing and tidal activities.

During the present study, silicate concentrations increased significantly towards the sea and except for station 1, dry season values were markedly higher than those of the wet season. A significant positive correlation was observed between silicate and salinity during the period. Silicate mineralization is very slow compared to those of nitrogen and phosphorus (DUGDALE, 1972). Accordingly, silicate becomes incorporated into the sediment due to rapid sedimentation of silica via diatom frustules packaged together in relatively large faecal pellets. Sedimentation is expected to be higher during the wet season in the Cross River system due to low tidal activity. Low concentrations of silicate during the wet season is also attributed to dilution from rainfall.

River waters frequently contain higher concentrations of reactive silicate than coastal seawaters, and silicate is thought of as being removed during estuarine mixing (FAXI, 1980; VAN BENNEKOM and SALOMONS, 1980). However, during the present study, silicate concentrations increased markedly towards the sea indicating no chemical removal. Although intances exist where silicate concentrations increase in estuaries compared to riverine parts (VAN BENNEKOM and SALOMONS, 1980), the case of the Cross River is mainly due to silicate input from tributaries such as the Calabar, Great Kwa, Mbo and other coastal rivers (Fig. 1). Markedly lower concentrations of silicate in station 1 compared to the other stations is also partly due to uptake by phytoplankton (mainly diatoms) especially during the dry season diatom bloom (AKPAN and OFFEM, 1993).

CONCLUSION

Almost every process or property studied in the estuary has a component of variability related to seasonal variation of riverflow. The increase in riverflow during the wet season has been associated with the reduction in salinity and pH of the water and also with the variation in concentration of organic matter and nutrients.

Although the present paper has thrown some light on natural fluctuations in the quality of the river water, large gaps still remain in our understanding of the chemical and biological dynamics within the system. In the light of the present study, factors such as winds and mostly rainfall are among the most important physical variables which influence the water quality of the Cross River system, but biological cycles may play a prime role on the chemical solutes.

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