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Research Article

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Fluxes of Physicochemical Parameters in The Cross River Estuary, Nigeria

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Abstract
Study on the fluxes of physicochemical parameters and nutrients in the Cross River estuary ecosystem was under taken between June, 2016 and April, 2017. Field data were collected bimonthly at five stations and analysed both insitu and in the laboratory using standard methods. The monthly mean surface water temperature ranged from 26.68±0.74 ^{O}C in June 2016 to 33.6±7.84 ^{O}C in October 2016, salinity ranged from 0.10±0.12 ‰ in October 2016 to 10.20±2.80 ‰ in March 2017, and DO from 2.740±0.563 mg/l in June 2016 to a maximum of 5.340±2.152 mg/l in January 2017. Values obtained for PO_4, SO_4, NO_3, DO, and BOD in this study were below the permissible limits [1]. There was significant ($p < 0.05$) temporal variation in all the parameters studied (PO_4, NO_3, SO_4, DO, BOD_5, salinity, temperature and transparency). There was no significant ($p > 0.05$) spatial variation in PO_4, NO_3, SO_4, temperature and transparency. Parameters studied showed both positive and negative correlations. The implications of these findings are discussed.

Introduction

Water serves as a very important medium for aquatic organisms to survive. The quality of water is also important for the health and well-being of numerous fauna and flora. Any negative impact on the water ecosystem by reason of pollution would therefore be detrimental to all the living resources in aquatic environment. Some studies on the water quality and pollution status in the Cross River estuary have been reported [2-9]. A 2-year study of the seasonal variations of Mercury (Hg), Lead (Pb), and Arsenic (As) in the dried tissue of *Egeria radiata* showed Arsenic (As) values to range from a minimum of 1.60 mg/kg to a maximum of 5.02 mg/kg with annual mean of 3.066 mg/kg exceeding WHO maximum permissible limits (1.50 mg/kg) [2]. The concentration of Pb varied between 0.318 and 3.602 mg/kg with annual mean of 0.953 mg/kg. The concentration was below 2.0 mg/kg by WHO standards except for January and December 1988. Hg concentration varied from 0.11 mg/kg to 0.710 mg/kg with annual mean of 0.228 mg/kg. The values were however low throughout the period except in August 1988 when it exceeded WHO permissible limits of 0.5 mg/kg. Temporal trends in some heavy metals concentrations in the dried body tissue of *Egeria radiata* in the estuary was also studied Etim *et al.*, Four heavy metals were studied, they included: Pb, Cd, Ni and Zn and had the following reported minimum, maximum and mean values respectively: Pb (3.6, 0.3, 0.96 mg/kg); Cd (0.6, 0.11, 0.32 mg/kg); Ni (4.5, 0.61, 1.39 mg/kg) and Zn (172, 96, 117 mg/kg). Pb peak values of 3.6 and 3.1 mg/kg (in January and December 1988) were above WHO standard value of 2.0 mg/kg. Cd and Zn concentrations were below WHO permissible limits of 2.0 and 1000 mg/kg respectively for sea food throughout the period of study. It was observed that hydrocarbon levels in the estuary was due to the presence of oil spills and discharges from offshore petroleum facilities located adjacent to the mouth of the estuary, reported habitat degradation of the marine and brackish water ecosystems of Nigeria as a result of frequent oil spillages and marine transportation activities [3, 4]. The consequences of these anthropogenic inputs are death of fish and shell fish as well as destruction of mangroves [5]. Asuquo *et al.* studied the distribution of heavy metals and total hydrocarbon (THC) levels in the coastal waters and sediments of Cross River coastline [6]. There were higher concentrations of heavy metals in coastal waters compared to inland waters. The THC levels (22.0 to 758.4 mg/kg in water and sediments, exceeded 10mg/l limit recommended by the Federal Environmental Protection Agency for nearshore waters [7, 8]. Showell on the study of microbial water quality status of the Calabar River estuary reported a significant impact of fecal coliform and BOD5 on the system, originating from organic matter from untreated garbage dumpsites [9]. This study intends to understand fluxes of some physicochemical parameters on the estuary and their potential impact on aquatic health.

Materials and Methods

Study Area

The Cross River estuary is located in the southeast of Nigeria, with an area of about 580 km2 [10]. It is situated between latitudes

4030’ N and 4058’N and Longitudes 80 09’ and 8030’E (Figure. 1). The Cross River estuary is regarded as an extension of the shallow continental shelf region of Nigeria, classified as a drowned-river-mouth type of estuary [10]. It is the largest estuary on the Gulf of Guinea [4]. The Cross River, Calabar River, Great Kwa River, Akpa-Yale River, the Great-Kwa River and the Mbo River are the main tributaries that empty into the Cross River estuary. The estuary provides habitat for a large number of economically important fish and shellfish species that support a large population of coastal communities, predominantly artisanal fishers. Like most estuaries, the Cross River estuary serves many purposes for marine organisms including long-term residence, breeding and nursery.

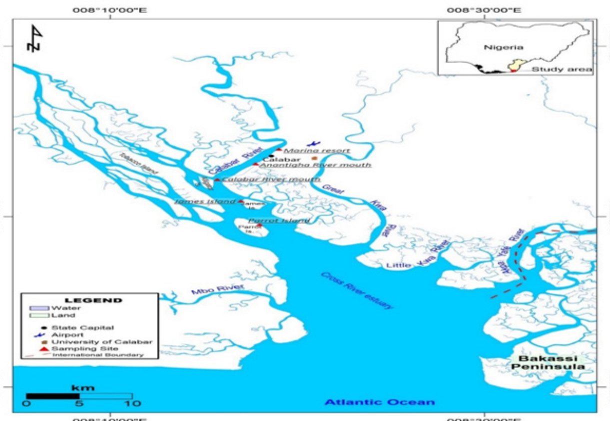

Figure 1: Map of the Cross River estuary and tributaries, showing sampling locations.

Data Collection

A total of thirty (30) surface water samples were collected during this study. Field trips were undertaken for 12 months spanning the wet and dry seasons. Samples were collected bi-monthly at low tides between June, 2016 and April, 2017 at five locations. The locations include, Parrot Island (L1, station 1), James Island (L2, station 2), Calabar River mouth (L3, station 3), Anantigha River mouth (L4, station 4), and Tinapa Resort (L5, station 5) (Figure. 1). Water samples were transported to the Institute of Oceanography Central laboratory, University of Calabar, Nigeria and analyzed for nutrients (Nitrate, Phosphate and Sulphate), and biochemical parameters (Dissolved Oxygen (DO) and Biochemical Oxygen Demand (BOD5). Temperature, salinity and transparency values were measured in situ. Surface water temperature was measured using a mercury-in-glass thermometer. Salinity was also measured with the aid of salinity refractometer with calibrated numbers (2441-W05, Japan), while, transparency was determined using a Secchi Disc. The coordinates of the sampling stations were taken with the aid of global positioning system (GPS).

Results

Nutrients in Cross River Estuary

Phosphate (PO4) concentrations of the Cross River estuary ranged from 0.00 mg/l to 0.245 mg/l. The maximum value of 0.245 mg/l occurred in October 2016 with the highest mean value of 0.093±0.085 mg/l (Table 1). There was a significant ($p < 0.05$) temporal variation (Figure. 2) but no significant ($p > 0.05$) spatial variation in PO_4 concentrations (Figure. 3). There was a strong positive correlation between PO4 and BOD_5 ($r = 0.60$, $n = 30$, $p < 0.05$), and temperature ($r = 0.76$, $n = 30$, $p < 0.05$). Sulphate (SO_4) concentrations ranged from 0.202 mg/l in June 2016 to 183.64 mg/l in January 2017 with the highest mean value of 171.620±4.016 mg/l in March 2017 (Table 1), and a significant ($p < 0.05$) temporal variation (Figure. 4) but no significant ($p > 0.05$) spatial variation (Figure. 5). A strong positive correlation was obtained between SO_4 and DO ($r = 0.84$, $n = 30$, $p < 0.05$), salinity ($r = 0.98$, $n = 30$, $p < 0.05$), and transparency ($r = 0.91$, $n = 30$, $p < 0.05$). Nitrate (NO_4) concentrations ranged between 0.00 mg/l and 1.736 mg/l with the highest mean value of 0.750±0.552 mg/l in June 2016 (Table 1). There was a significant ($p < 0.05$) temporal variation (Figure. 6) but no significant ($p > 0.05$) spatial variation (Figure. 7). A strong correlation was also obtained between NO3 and DO ($r = -0.83$, $n = 30$, $p > 0.05$), salinity ($r = -0.56$, $n = 30$, $p > 0.05$), temperature ($r = -0.66$, $n = 30$, $p > 0.05$), transparency ($r = -0.64$, $n = 30$, $p > 0.05$), and SO4 ($r = -0.64$, $n = 30$, $p > 0.05$) Table 2.

Table 1: Levels of water quality parameters of the surface water of the Cross River estuary; June, 2016 – April, 2017.

Month	PO_4	SO_4	NO3	DO	BOD_5	Salinity	Water Temp	Transpa-rency
June ‘16	0.007± 0.004	10.10± 6.4	0.750±0.55	2.74± 0.64	1.74± 0.541	0.18± 0.249	26.7± 0.844	0.34± 0.096
Aug	0.022± 0.003	12.20± 2.74	0.354±0.11	3.36± 0.18	2.86± 0.270	0.08± 0.110	32-0± 2.828	0.43± 0.047
Oct	0.093± 0.085	12.27± 1.70	0.322±0.14	4.42± 0.67	2.42± 1.123	0.10± 0.141	33.6± 0.894	0.51± 0.095
Jan., ‘17	0.028± 0.043	171.15 ±8.43	0.236±0.14	5.34±2.46	2.50± 0.624	7.40± 2.191	31.0± 0.557	1.10± 0.524
March	0.009± 0.002	171.61 ± 4.0	0.152±0.06	5.02± 2.65	1.62± 0.736	10.20± 3.194	29.8± 0.071	1.74± 0.008
April	0	121.88±21.94	0	5.08± 0.47	1.20± 0.346	6.60± 1.517	29.8± 0.084	1.44± 0.023

TABLE 2: Linear correlation of water Quality parameters from the Cross River estuary, June, 2016 – April, 2017

	DO	BOD	Salinity	Water Temp	Transparency	PO_4	SO_4	NO_3
DO	0	0.22	0.81	0.36	0.81	0.18	0.84	− 0.83
BOD		0	−0.48	0.63	− 0.58	0.60	− 0.36	− 0.03
Salinity			0	− 0.15	0.97	− 0.33	0.98	− 0.56
W/Temp				0	− 0.09	0.76	− 0.10	− 0.66
Trans					0	− 0.36	0.91	− 0.64
PO_4						0	− 0.24	− 0.17
SO_4							0	− 0.56
NO_3								0

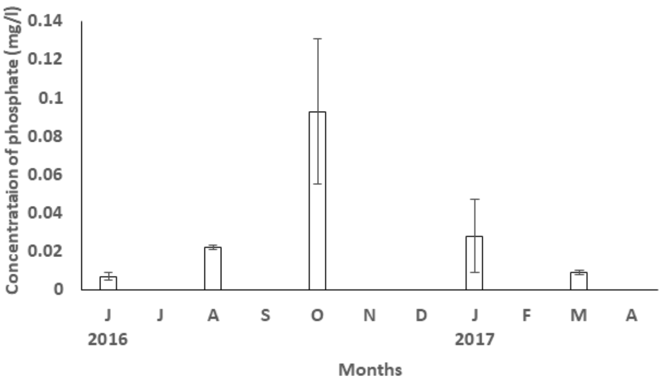

Figure 2: Temporal variation in Phosphate levels (mg/l) of the Cross River estuary (Values were significant difference at P<0.05).

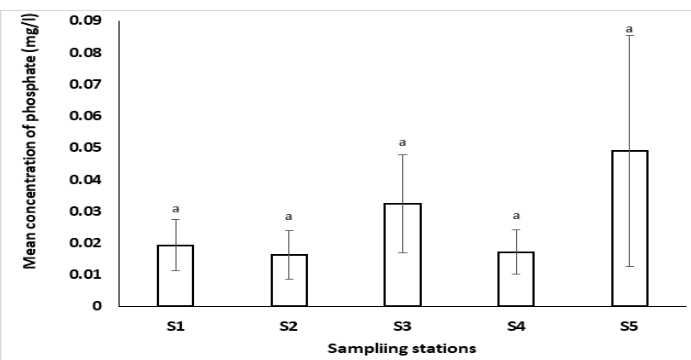

Figure 3: Spatial variation in Phosphate levels (mg/l) of the Cross River estuary (same letter on the error bars indicate no significant difference at P>0.05. This figure shows that phospate concentrations decreased linearly downstream.

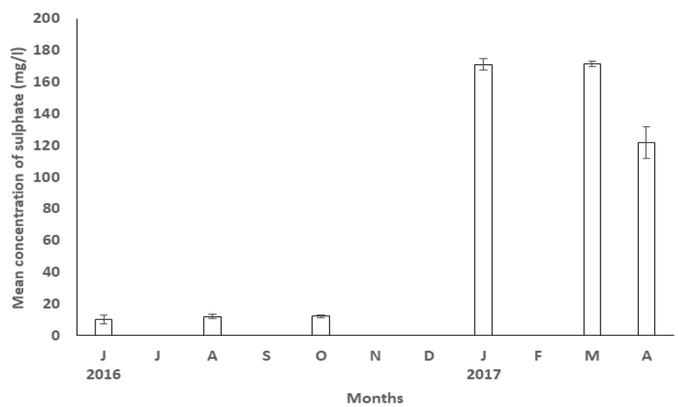

Figure 4: Temporal variation in Sulphate levels (mg/l) of the Cross River estuary. Values very low in the wet season but remarkebly high in the dry season.

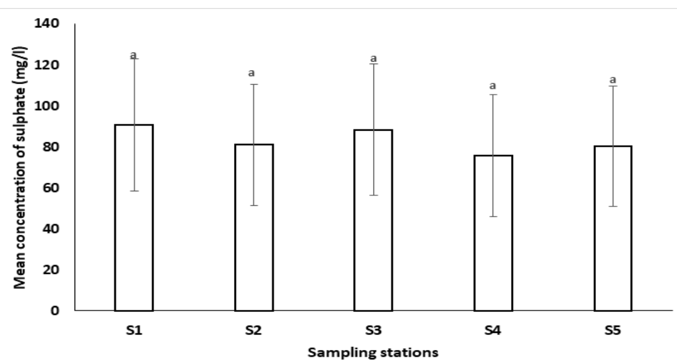

Figure 5: Spatial variation in Sulphate levels (mg/l) of the Cross River estuary. Sulphate variation was almost uniform at all the stations during the period.

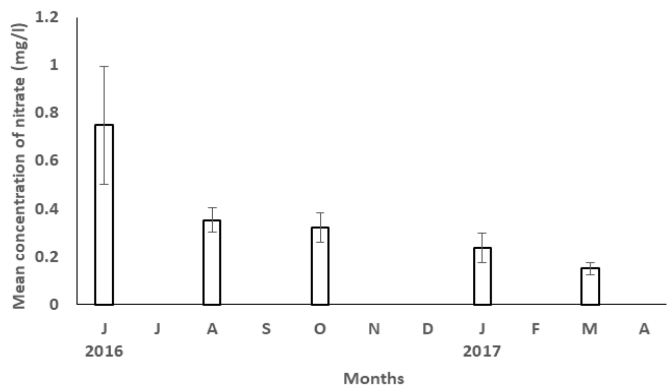

Figure 6: Temporal variation in Nitrate levels (mg/l) of the Cross River estuary. Linear variation decreasing from wet to dry season.

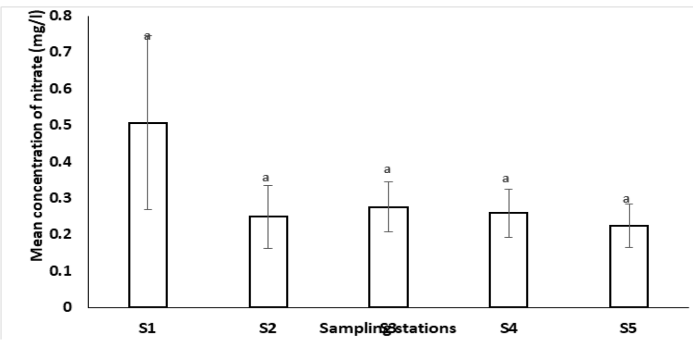

Figure 7: Spatial variation in Nitrate levels (mg/l) of the Cross River estuary. Concentrations decreased upstream

Physicochemical Factors in Cross River Estuary
Dissolved Oxygen and BOD5

Dissolved Oxygen (DO) concentration of the estuary ranged from a minimum of 2.10 to a maximum value of 7.80mg/l in March, 2017. The maximum mean value of 5.340±2.456 mg/l occurred in January 2017 (Table 2). There was a significant ($p < 0.05$) temporal (Figure. 8) and ($p < 0.05$) spatial variations (Figure. 9) in DO concentrations. There was also strong positive correlation between DO and salinity ($r = 0.81$, $n = 30$, $p < 0.05$), transparency ($r = 0.81$, $n = 30$, $p < 0.05$), and SO_4 ($r = 0.84$, $n = 30$, $p < 0.05$). However, DO did not correlate significantly with temperature ($r = 0.36$, $n = 30$, $p > 0.05$). Biochemical Oxygen Demand (BOD_5) concentration of the estuary ranged between 0.800 mg/l and 3.800 mg/l. The maximum value of 3.800 mg/l was obtained in October 2016 with the highest mean value of 2.860±0.270 mg/l in August, 2016 (Table 2). There was significant ($p < 0.05$) temporal (Figure. 10) and spatial ($p < 0.05$) variations (Figure. 11). A strong positive correlation was observed between BOD_5 and temperature ($r = 0.63$, $n = 30$, $p < 0.05$), and PO_4 ($r = 0.60$, $n = 30$, $p < 0.05$), but did not correlate quite significantly with salinity ($r = 0.48$, $n = 30$, $p > 0.05$). There was a strong negative correlation with transparency ($r = 0.58$, $n = 30$, $p > 0.05$).

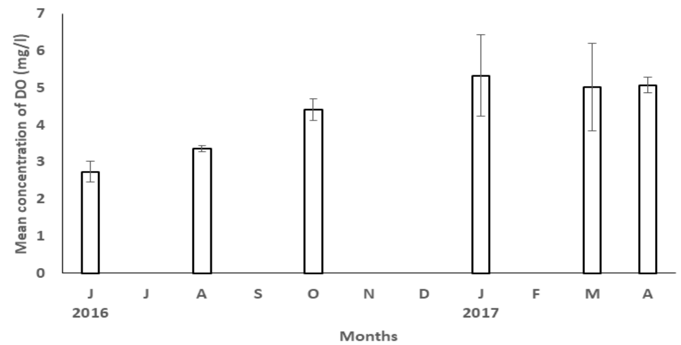

Figure 8: Temporal variation in DO levels (mg/l) of the Cross River estuary. Concentrations decreased markedly from dry to wet season.

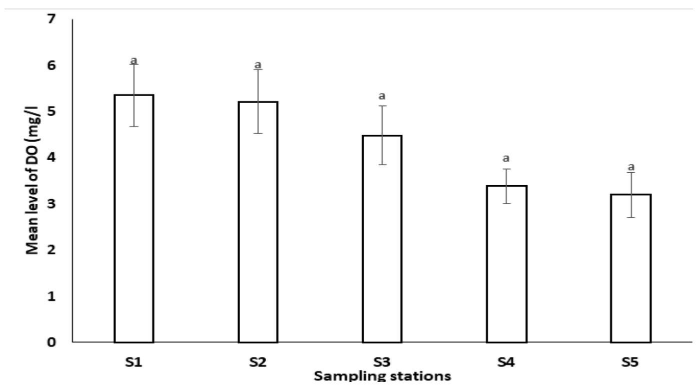

Figure 9: Spatial variation in DO levels (mg/l) of the Cross River estuary. DO levels decreased upstream.

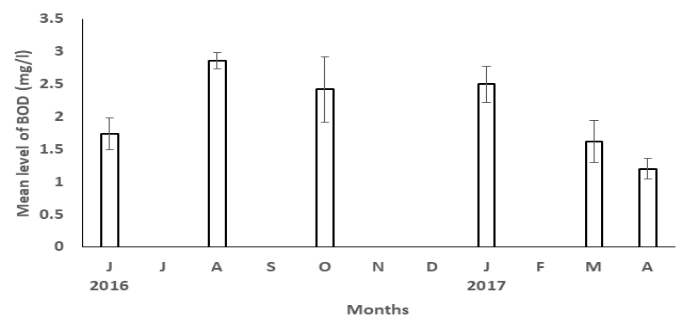

Figure 10: Temporal variation in BOD levels (mg/l) of the Cross River estuary. BOD exhibited haphazard temporal variation during the period

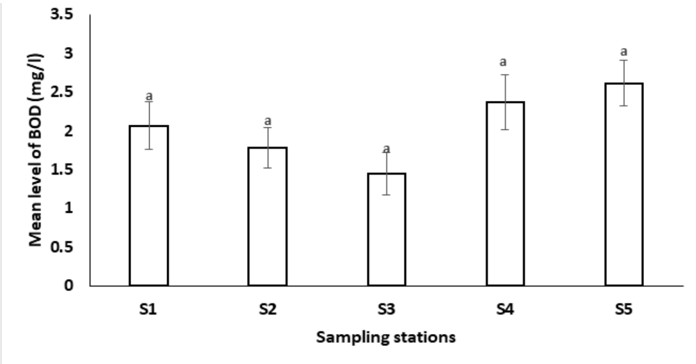

Figure 11: Spatial variation in BOD levels (mg/l) of the Cross River estuary. Bimodal spatial variation

Salinity

Salinity (0/00) of the estuary ranged from 0.00 mg/l at some stations in rainy season months (June, August and October 2016) to a maximum of 15.00 mg/l in March 2017. The highest mean values of 10.20±3.194 mg/l (Table 2) was also recorded in March 2017. There was significant ($p<0.05$) temporal (Figure. 12) and ($p<0.05$) spatial variations (Figure. 13). A strong positive correlation was observed between salinity and transparency ($r = 0.97$, $n = 30$, $p < 0.05$), and SO4 ($r = 0.56$, $n = 30$, $p < 0.05$). There was a strong negative correlation with NO_3 ($r = 0.56$, $n = 30$, $p > 0.05$).

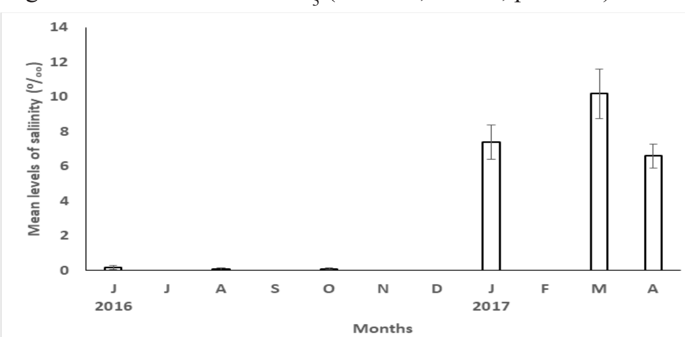

Figure 12: Temporal variation in Salinity levels (mg/l) of the Cross River estuary. Values very low in the wet season but remarkebly high in the dry season.SO4 and Salinity exhibits the same temporal variation.

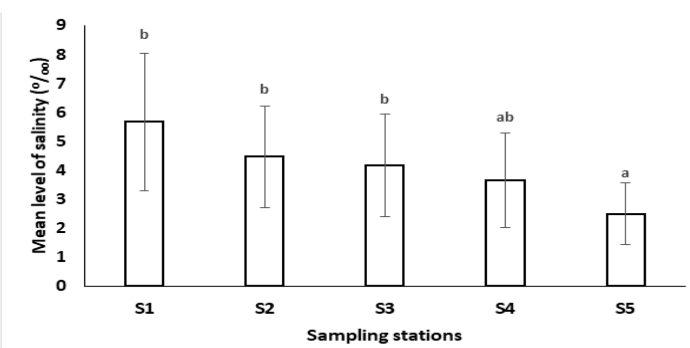

Figure 13: Spatial variation in Salinity levels (o/oo) in Cross River estuary. Salinity increased linearly downstream

Physical Parameters

Surface water temperature (^{O}C) of the estuary ranged from 26.0 ^{O}C in June, 2016 to 34.0 ^{O}C in August and September, 2016 with the highest mean value 33.60±0.894 ^{O}C in October, 2016 (Table 1). There was a significant ($p < 0.05$) temporal variation (Figure. 14). Temperature of the estuary did not display any significant ($p > 0.05$) spatial variation (Figure. 15). There was a strong positive correlation between temperature and SO_4 ($r = 0.76$, $n = 30$, $p < 0.05$), and temperature correlate not significantly with DO ($r = 0.36$, $n = 30$, $p < 0.05$), and with salinity ($r = 0.15$, $n = 30$, $p > 0.05$). However, there was a strong negative correlation of temperature with NO_3 ($r = 0.66$, $n = 30$, $p > 0.05$). Transparency (m) of the estuary ranged from 0.17m in June, 2016 to 1.75m in March, 2017 with a maximum mean value of 1.742±0.008 mg/l also in March, 2017 (Table 1). There was a significant ($p < 0.05$) temporal variation (Figure. 16). Transparency of the Cross River estuary did not display any significant ($p > 0.05$) spatial variation (Figure. 17). There was strong positive correlation between Transparency and SO_4 ($r = 0.91$, $n = 30$, $p < 0.05$) and negative correlation with NO3 ($r = 0.64$, $n = 30$, $p > 0.05$).

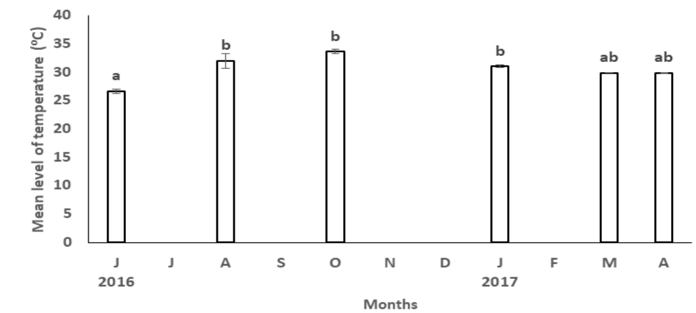

Figure 14: Temporal variation in surface water temperature (^{0}C) of the Cross River estuary. Temperature variation was almost uniform throughout the year..

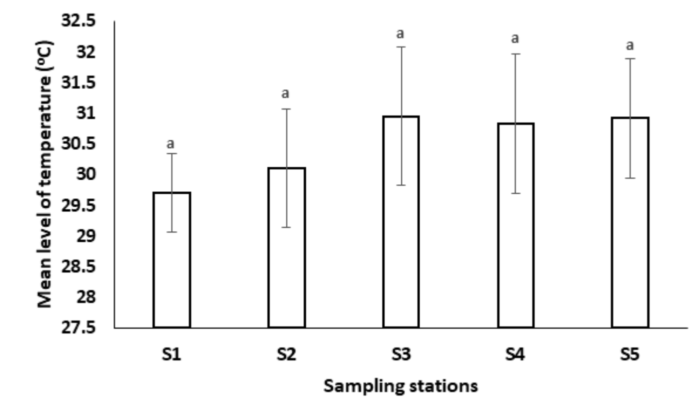

Figure 15: Spatial variation in surface water temperature (^{0}C) of the Cross River estuary Linear variation increasing from wet upstream.

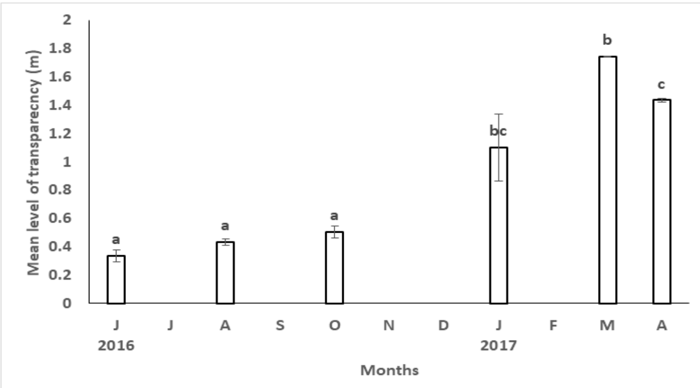

Figure 16: Temporal variation in Transparency (mg/l) of the Cross River estuary. Transparency increased towards the dry.

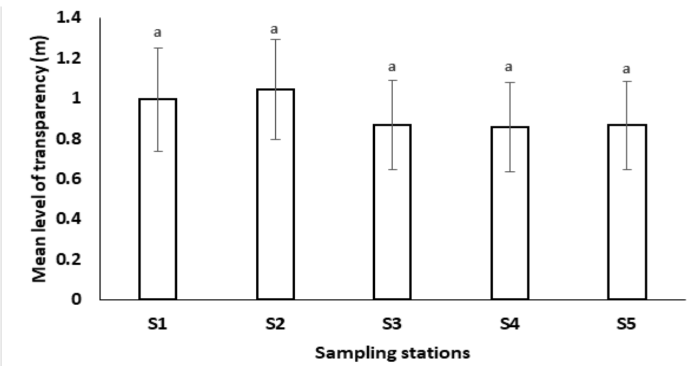

Figure 17: Spatial variation in Transparency (mg/l) of the Cross River estuary. Transparency variation was almost uniform at all the stations during the period.

Spatio-Temporal Variations in Water Quality parameters

The spatio-temporal variations in water quality parameters during this study are presented in Figures. 2-17.

Discussion

The concentrations of Phosphate (PO_4), (NO_3) and sulphate (SO_4) were higher than the values reported by Asuquo and Akpan and Offem in Cross River estuary [11, 12]. This implies an increased nutrient concentration over time in the system. Similar studies in Imo River Estuary and Amadi-Ama Creek, Port Harcourt, Nigeria showed higher nitrate (NO_3) and sulphate (SO_4) concentrations indicating that the Cross River estuary has lower nutrient concentrations [13, 14]. Generally, most Nigerian and African rivers have been reported to be poor in nitrate, phosphate and sulphate [13]. Nitrate values recorded in this study, were below the statutory limits of 25 – 50 mg/l and 20 mg/l recommended by European Economic Community and United States Environmental Protection Agency respectively [1, 15]. The higher values of nitrate recorded in the wet season of this study however agrees with the report of Akpan and Offem, and is due to increased input of surface water run-off enriched with nutrients [12]. Ebere studies also attributed occurrence of higher concentration of nitrate during the rainy season to high anthropogenic inputs [16]. The decrease on the other hand, during the dry season was attributed to high uptake of nitrate by phytoplankton and epipelagic algae as a result of increased photosynthetic activities. The present study showed a marked increase of nitrate downstream. This trend differed from the results of Akpan and Offem who reported decrease in nitrate values towards the sea as a result of possible dilution effect of the sea water [12]. The reason for this marked increase is attributed to inputs of nitrates from upstream.

The reported phosphate concentrations were higher than the acceptable limits of 0.10 mg/l in running waters as recommended by USGS [17]. Seasonal variation in phosphate concentration was largely due to input of organic matter through rainfall. The highest concentration of 0.245 mg/l was measured in October followed by 0.125 mg/l in August 2016 at the peak of the rainy season. This agrees with the finding of Akpan and Offem that during the rainy season, the Cross River estuary is rich in organic matter due to input from water runoff. Similarly, high concentration of phosphate (0.245 mg/l) at station 5 (Figure. 5) could be a result point source of waste discharge from the Calabar metropolis [12]. However, phosphate maximum mean concentrations in the estuary were within the permissible limits (Table 1). Reported that phosphate exists in water bodies either in isolation as particles, loose fragrant or in the body of aquatic organisms causing digestive problems when in excess of permissible limits [18]. The strong positive correlation between PO_4 and BOD_5 ($r = 0.60$, $n = 30$, $p < 0.05$) indicates external introduction from decomposable organic matter brought in by surface run off. The observed SO_4 maximum value (183.64 mg/l) is below 250mg/l and 265 mg/l standard values respectively [19, 20]. The highest sulphate (SO_4) value of 183.64 mg/l recorded in January, 2017 could also be attributed to high evaporation of the sea water during the peak of dry season [12]. This also is evident as the values in dry season months were markedly different from that of rainy season months ($p<0.05$) suggesting its possible intrusion from the sea coupled with evaporation. This result is in contrast to Ekeh who attributed increase in sulphate concentration (in Amadi Creek) to leachates and water run-off during the rains. However, SO4 concentration correlated positively with salinity during the study ($r = 0.91$, $n = 30$, $p < 0.05$) suggesting SO4 contributed salinity concentration [21]. Higher concentration in the dry season is evident that SO_4 did not emanate from external sources.

The present study showed that Cross River estuary ecosystem is relatively poor in nutrient compared to other nearby ecosystems. However, there was an increase in concentration of phosphate and decrease in nitrate when compared with previous studies in the estuary. The estuary's low nutrients concentration may be responsible for low primary productivity as indicated by low occurrence of chlorophyll a and carotenoids [22]. Dissolved Oxygen (DO) levels observed were normal except for some few locations in the estuary. According to Baden et al. oxygen concentration as low as 3.0-4.3 mg/l could cause ecological harm in some estuarine and coastal waters including low survival of fish larvae, mortality of some benthic invertebrates as well as loss of habitat to some fishes [23]. The reduction in DO in stations 4 and 5 could be attributed to reduce mixing and tidal influence upstream and possible influx of fresh nutrients discharged from the Calabar metropolis during flooding. The trend of concentration with higher values in dry season and lower values in rainy season agrees with the report of Lowenberg and Kunzel, Akpan and Offem, and Akpan [12, 24, 25]. Lowenberg and Kunzel and Akpan and Offem reported high saturation values of 54-114% and 53.2 -110% (4.5 to 9.9 mg/l) in dry season respectively [12, 24]. These values were relatively higher than those obtained in this study. The reason for the difference could be due to increased discharge of excess nutrients coming from human activities such as metropolitan wastes and agricultural inputs from the land with the resultant higher microbial activities. Showell also showed that increased activities of micro-organisms can lead to depletion of dissolved oxygen in the marine environment [9]. Microbial studies in Calabar River (stations 4 and 5) showed no significant variation of DO on microbial contamination of the surface water [9]. The significant temporal variation reported in DO could be due to the higher nutrient load in the rainy season as compared to the dry season. This was evident with a significant positive correlation between DO and transparency ($r = 0.81$, $n = 30$, $p < 0.05$). Salinity is the measure of salt content of the sea/estuary. In this study, the trend of variations showed an increase towards the sea and high values in the dry season with the peak value of 150/00 at Parrot Island (station 1) in March. These variations is attributed to freshwater discharge during the raining season and seawater intrusion in the dry season. According to Akpan and Offem, and Akpan, salinity variation in the estuary is mainly controlled by freshwater inflow and high input of freshwater during the rainy season results in a remarkable dilution of the estuarine salinity and vice versa [12, 25]. Salinity values at stations 4 and 5 (Anantigha River Mouth and Marina Resort) were very low due to significant influence of tidal flows most part of the year. The maximum value of 150/00 recorded in the dry season, is at variance with higher values (26.90/00, 210/00) reported by Nawa, and Lowenberg and Kunzel, and lower values (10.70/00, 8.650/00) reported by Ama-Abasi and Akpan respectively [10, 24-26]. The high values recorded could be attributed to location specific. Nawa sampled at the outer estuary while the present study sampled from mid/central estuary- the mid-point between the two divisions; the ocean water and river water upstream [10, 24-26]. The same is the case of Lowenberg and Kunzel as two out of the three stations sampled were at the outer estuary [24]. On the other hand, the lower values recorded could be due to high volume influx of the rains exacerbated by climate change. During the rains, the estuary salinity is highly depressed by high volume of runoff water leading to flooding of adjacent plains at the peak of raining season [26]. However, the salinity value of 150/00 from this study and values from other studies from the estuary, except Nawa, Akpan and Offem, Akpan, and Ama-Abasi, were lower than salinity values from nearby ecosystems in the Niger Delta region [10, 12, 25, 26]. Francis et al. in the study of physical parameters of Andoni River system, reported salinity range from 5.5 0/00 to 22 0/00, while Akoma reported a range between 0-220/00 [13, 27]. The reason could be greater tidal influence on the Imo and Andoni Rivers as compared to the influence on the Cross River estuary. Biochemical Oxygen Demand (BOD) measures the amount of oxygen (O_2) micro-organisms consume while decomposing organic matter. BOD Values with a maximum of 3.8mg/l, observed in this study were lower than the bench mark value (≥5.0) for unpolluted estuarine waters [28]. However, BOD was higher in the wet season attributed to the inputs of decomposing organic materials from the river tributaries through surface runoff, which agrees with the observation by Akpan and Offem [12]. There were low values of BOD5 in stations 2 (James Island) and 3 (Calabar River Mouth). It is believed that freshwater discharge from the Cross River channel is less likely to be polluted due to little or no municipal discharge. Enin (1997) considered the Cross River estuary as a microcosm model for integrated coastal management in Nigeria, reported pollution from discharge of untreated industrial effluent and municipal sewage into the estuary. Showell reported microbial contamination on surface waters reported a significant impact of faecal coliform on BOD5 [10]. According to Showell, Calabar River is fed directly by organic matter from untreated garbage of dumpsites, through seepage and leaching [10]. Industrial activities, farming and unregulated Abattoir activities as some factors responsible for high BOD5. The higher the BOD measure, the greater is the chance that dissolved oxygen will be depleted in the course of breaking it down, with attendant negative impact on aquatic life.

The present study showed a relative increase in surface water temperature compared to previous studies to a peak value of 34.0 ^{0}C with a lowest value of 26.0 ^{0}C both at Calabar River Mouth. Climate is the sole reason responsible in the fluctuation in temperature. Recent report by Asuquo and Chovwen indicates the occurrence of marine heat waves in the adjacent Gulf of Guinea [29]. These heat waves which prevail mostly during the dry season (winter period) are driven by oceanographic factors such as currents and tides into the nearby estuaries and coastal systems. The peak value of 34.0 ^{0}C observed in this study is very remarkable as it could signal the beginning of ecological consequences such as the depletion of marine flora and fauna, as well as coastal fisheries or shrimp stock, which are the associated effects with marine heat waves [29]. This observation also explains the marked difference in temporal distribution during the period. The transparency result agrees with Akpan in relation to the noticeable differences in the rate of primary production in the ecosystem [25-49].

Conclusion

This study summaries the spatio-temporal fluctuations in PO_4, NO_3 and SO_4, and in several physicochemical parameters in the Cross River estuary, Nigeria. Physico-chemical parameters values obtained were within the range that support live and maintain ecosystem health. The study revealed higher concentration in nutrients, reduced DO, and increased BOD_5 compared to previous studies in the estuary. Though the ecosystem remains unpolluted, it is evident that it has received increased waste load of extraneous substances. The higher water temperatures recorded has some link with marine heat waves which could be enhanced by the prevailing global warming with its deleterious consequences on the estuarine living resources.

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