SEASONALITY IN THE PHYSICAL AND CHEMICAL CHARACTERISTICS OF MBO RIVER, AKWA IBOM STATE, NIGERIA.


ABSTRACT

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The study of the seasonal variations of some physical and chemical characteristics of Mbo River flowing into the Cross River Estuary was carried out between December 2005 and November, 2006. A total of 15 different parameters were investigated. Variations in these physico-chemical attributes were observed both in the dry and rainy seasons. The results revealed that some parameters (TDS, Free CO$_2$, COD, Silicates, Alkalinity, Sulphates and Transparency).

INTRODUCTION

Rivers have rapid turnover of water which is powered by the hydrological cycle. Replenishment of surface water relies on precipitation. According to Giller and Malmqvist (2002), the proportion of this precipitation that ends up as stream flow depends on a number of variables which include meteorological conditions, vegetation, slope of the land, properties of the ground waters, which depends mostly on the nature of the underlying bedrock and other regional and local factors. In the tropical region, rainfall is more important than temperature in determining environment (Webb, 1960). Rainfall causes flooding and surface run-off which results in the transportation of nutrients and domestic and industrial wastes into river.

Lowe-McConnell (1987) and Chapman and Kramer (1991), reported that the onset of the rains signals a radical change in the physico-chemical characteristics of tropical rivers. The input of allochthonous organic materials from the catchment areas during rainfall increases certain physico-chemical parameters. Rainfall thus is one major source of chemical inputs to rivers. However, most rivers and streams contain much more suspended and dissolved materials than is found in rain-water (Allan, 2001). The ions and other substances carried into rivers through surface-runoff may result in poor water quality. Rivers play a major role in the development of Akwa Ibom State. They provide easy means of transportation, occupational activities, source of food and means of waste disposal. Although much literature exists on rivers and estuaries within the state, (Ekwu and Sikoki, 2006; Akpan et. al, 2005; Essien et. al, 2003; Ubom et. al, 2003; Akpan, 2002; 1999, 1998,1994; Moses, 1974), there is not yet any published work on Mbo River.

MATERIALS AND METHODS

Study area: The Mbo River (fig. 1) is one of the major rivers in Akwa Ibom State, Nigeria. Mbo River lies within latitude 4°30’ to 5°30’ North and longitude 7°30’ to 8°20’ East on the South Eastern Nigerian Coastline. It is a coastal river which empties into the Cross River Estuary at Ibaka in the Bight of Bonny. It is a hydrographic feature draining two local government areas of Akwa Ibom State. Mbo River plays a major role in the fisheries resources of the state, transportation and nutrient load of the estuary. Mbo River is located in the Cross River Drainage Basin within the Niger Delta. According to Martins (1988), the Niger Delta is located within the tropical rainforest region with rainfall throughout the year and temperature ranges between 21°C and 31°C. It has a tropical humid climate characterized by distinct dry and wet seasons.

Selection of sampling stations: The River was selected on the basis of the fact that despite its economic and ecological role, no published work is available on it. Sampling stations were selected to represent different environmental and ecological variations within the river. This is to provide an avenue to better understand the effects of natural and anthropogenic factors on the river’s water quality. Sampling station I was located in an area which could be considered to be minimally impaired by human activity. Sampling station II was located by the bridgehead about 500 meters from station I where domestic effluents, petroleum products and other wastes, were discharged directly or carried by surface run-off into the river. This was also a port for the river transportation. Sampling station III, on the other hand, was the jetty at the defunct Ebughu Fishing Terminal, about 500metres to the left of the bridgehead.

Data collection: Sampling was done fortnightly from the three established sites between December 2005, to November 2006, inclusive. Morphometric parameters were measured using appropriate procedures (Orth, 1983;
Schlosser, 1982; Hanson, 1973; and Bartram and Balance, 1996). The water’s chemical analysis was done using standard and analytical methods of water analysis (Bartram and Ballance, 1996; Trivedi and Goyal, 1986; APHA – AWWA – WPCF, 2005; USEPA, 1979). Since the physico-chemical and biological features of a lotic system could vary with time, sampling was done at regular and specific time intervals in the mid-morning hours between the hours of 8a.m and 11a.m. At each sampling location, the surface water samples were collected at the middle of the river and stored in a clean polythene bottles that have been pre-washed with nitric acid and thoroughly rinsed with deionized water (Bartram and Balance, 1996). Non-conservable parameters such as temperature, pH and electrical conductivity were determined, at the time of sampling, in the field (in situ). Water samples were collected approximately 15 – 20cm below the water surface with 125cm$^3$ Nessler bottles for dissolved oxygen (DO), and large-mouthed pre-cleaned and chemically neutral 1 litre plastic vessels for laboratory analysis of other physico-chemical parameters.

**Statistical analysis:** Analysis of variance (ANOVA) was used to test for site differences in the values of the physico-chemical parameters in the water bodies. Paired t-test was used to evaluate seasonal differences in the values of the physico-chemical variables. Correlation coefficients were calculated to establish significant relationship between the physico-chemical parameters and some hydrological variables e.g. depth and rainfall. Coefficient of variation was analysed to evaluate intra-seasonal variability.

## RESULTS

Temporal dynamics in the physico-chemical parameters of water from the three sites as depicted by the coefficient of variation (CV) are shown in Tables 1, 2 and 3.

**Water level:** The seasonal variations in depth for the three stations during the one year of study (Fig. 2) showed that the highest levels of depth were recorded between July, August and September. By October in stations 1 and 2, the water level (depth) had started to decrease while for station 3 the highest water level was recorded in the month of October. The lowest water levels were recorded between January and March. The water depth at the three sites varied more in the wet season than in the dry season with coefficient of variation of 41.62% in the former and 23.43% in the later. Level for the second station 47.23% and 29.65%, and 49.43% and 25.69% for wet and dry seasons respectively. Coefficient of variation showed higher intra-seasonal variation during the rainy season in the water level values. From the coefficient of variation (CV) there was greater variability in the wet season than in the dry season with the highest coefficient of variability of 49.43% being recorded in the wet season for Station 3.

**Current velocity:** Maximum current velocities for the three stations were recorded in June to September which are regarded as the peak of the rainy season while minimum levels were recorded between December and March (dry season). Current velocities recorded greater variability in the wet season (CV = 16.56%) than dry season (CV = 11.29%) indicating greater variability in the former. There was also no significant difference in the variation between the wet and dry season’s coefficient of variation values but the values for Station 2 showed remarkable variation in the values (t = 13.94, df = 11, p < 0.001).

**Transparency:** Seasonal variations in transparency for the 3 stations showed greater variability in the wet season (Fig. 3 ) with higher coefficients of variation than in the dry season. The lowest values of transparency (40,20cm) was recorded in October in Station 3 while the highest value of 70,20cm was recorded in station 1 in August. Generally the lowest values were recorded for the months of July to October in the three stations.

**Total suspended solids (TSS):** Values of Total suspended solid were higher in the wet season than in dry season (Fig. 3 ) with the highest value of 495.40mg/l recorded in June in Station 2 and the least value of 155.2mg/l recorded in April in station 1. There was greater variability in the wet season than in the dry season for all stations. The difference in the seasonal levels of the sample water were statistically significant as depicted by the t-test values (t = 10.82, df = 11, p < 0.01), (t = 12.94, df = 11, p < 0.01), (t = 10.39; df = 11, p < 0.01) for stations 1, 2 and 3 respectively.
Fig. 2: Temporal variation in water level, current velocity, Colour, Air and Water temperatures in Mbo River east of the Niger Delta.
Total dissolved solids (TDS): Concentrations of total dissolved solids were higher in the dry season than in the wet season. There was significant difference in the values of TDS between the dry and the wet season in the 3 stations (Fig. 3) with t-test values being as follows: Station 1 (t = 9.64, df = 11, p < 0.01), Station 2 (t = 18.79, df = 11, p < 0.01) and Station 3 (t = 25.42, df = 11, p < 0.01).

pH: Temporal variations in the pH values in the station showed greater variability in the wet season than in the dry season (Fig. 3) with a coefficient of variation (CV) of 9.22% for the former and 5.97% for the latter. There was no significant difference in the wet and dry season values for pH in the three sampling sites.

Dissolved oxygen (DO): Dissolved oxygen showed temporal variations with coefficient of variation being higher in the wet than in the dry season for the 3 stations (Fig. 4). Higher DO values were obtained in the peak of the wet season (June – October) than in the dry season (November – March). There was significant difference in the values between the seasons in the Stations 1 and 3 but none in Station 2.

Free carbon-dioxide (CO₂): Free Carbon-dioxide showed greater variability in the dry season in the three stations than in the wet season (Fig. 4). The lowest value of 1.20mgl⁻¹ was recorded in the month of September for the three stations while the highest value (5.20ml⁻¹) was recorded in the month of March in Station 2. In general, the highest values of free CO₂ were recorded towards the end of the dry season and the onset of the rains in all the Stations.

Biochemical oxygen demand (BOD): Concentrations of BOD showed no significant difference in the coefficient of variation between the two seasons (Table 4, 5 and 6).

Chemical oxygen demand (COD): Seasonality regime in COD concentrations in the three sampling stations indicated consistently higher values in the dry season, the values decreasing as the rains increase in the three sampling stations with a peak just before the rains (Fig. 4). The coefficient of variation depicted a greater variability in the wet season than in the dry season. Levels of COD were significantly different between the seasons with (t = 5.93, df = 11, p < 0.05), (t = 6.87, df = 11, p < 0.01), (t = 4.67, df = 11, p < 0.01), for Stations 1, 2 and 3 respectively.
Fig. 3: Temporal variation in Transparency, pH, Conductivity, Total Suspended Solid and Total Dissolved Solid in Mbo River east of the Niger Delta.
Fig. 4: Temporal variation in Free Carbon (iv) oxide, Dissolved Oxygen, Biochemical Oxygen Demand and Chemical Oxygen Demand in Mbo River east of the Niger Delta.
Fig. 6: Temporal variation in Silicate, Sulphate, Alkalinity and THC Mbo River east of the Niger Delta.
Silicate: Concentrations of silicate were higher in the dry season than in the wet season with the dry season showing more variability than the wet season. The seasonal variability was not significant except in Station 3 (t-test, t = 5.49, p < 0.05).

Sulphate: Sulphate showed remarkable seasonal variation (Fig. 6) with dry season concentrations being significantly higher (t-test p < 0.05) than wet season concentrations for the different sampling sites.

Alkalinity: Total alkalinity concentrations showed very narrow variations (Fig. 6) but with dry season values being significantly higher (t-test, p < 0.05) for Station 1 and 2 and p < 0.01 for station 3. Coefficient of variation showed a higher degree of variability in the dry season than in the wet season in the three stations.

THC: The total hydrocarbon concentrations were slightly higher in the dry season than in the wet seasons but no significant difference was observed between seasons. Coefficient of variation showed a higher variability in the wet season than in the dry season for all the sampling stations.

The Relationship between the physico-chemical parameters and some hydrological variables

The physico-chemical parameters gave significant relationships within each other and with some of the hydrological variables. Conductivity values showed significant positive correlation with pH, (r=0.59, p<0.05) (Table 4). DO values gave significant negative correlation with BOD (r = -0.69, p<0.05) and water temperature (r = -0.48, p<0.01).

Conductivity values also showed a significant negative correlation with rainfall (r = -0.81, p<0.001).

Water level on the other hand showed a significant positive correlation with pH (r = 0.76, p< 0.001) and rainfall (r = 0.85, p<0.001), significant negative correlation with conductivity (r = -0.70, p<0.001) and total alkalinity (r = -0.55, p < 0.01). Water temperature showed a significant positive correlation with pH (r=0.43, p<0.05) and significant negative correlation with dissolved oxygen (r=-0.48, p<0.05) and rainfall (r = -0.62, p<0.01).

The relationship between air and water temperature was significantly positive (r=0.75, p<0.001) while the relationship with rainfall was significantly negative (r = 0.92, p<0.001).

The relationship between total alkalinity and pH and conductivity was significantly positive (r=0.42, p<0.05; r=0.53, p<0.01 respectively). TA also gave a significant correlation with rainfall (r=-0.88, p<0.001). The pH of the water showed a significantly positive relationship with conductivity (r=0.59, p<0.05); TA (r=0.47, p<0.05); rainfall (r=0.67, p<0.01), and water temperature (r=0.43, p<0.05). Salinity on the other hand, gave a significantly positive correlation with conductivity (r=0.89, p<0.001) and TA (r=0.53, p<0.01).

Table 4: Correlation coefficient (r) values between some physico-chemical parameters and some hydrological variables

<table>
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<tr>
<th></th>
<th>pH</th>
<th>Conductivity</th>
<th>DO</th>
<th>BOD</th>
<th>TA</th>
<th>Salinity</th>
<th>Rainfall</th>
<th>Water Level</th>
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<td>0.21</td>
<td>0.22</td>
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<td>0.10</td>
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<td>0.76***</td>
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<tr>
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<td>0.21</td>
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<td>0.53**</td>
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</tr>
<tr>
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<td></td>
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<td>0.15</td>
<td>0.12</td>
<td>0.53**</td>
<td>0.45*</td>
<td>0.45*</td>
<td>0.41*</td>
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</tr>
<tr>
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<td>-0.15</td>
<td>0.12</td>
<td>0.53**</td>
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<td>0.55**</td>
<td>0.31</td>
<td>0.11</td>
</tr>
<tr>
<td>Rainfall</td>
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<td>0.61**</td>
<td>0.45*</td>
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<td>0.45*</td>
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<td>Water level</td>
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<td>-0.70***</td>
<td>0.22</td>
<td>0.41*</td>
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<td>0.45*</td>
<td>0.45*</td>
<td>0.31</td>
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<tr>
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<td>0.25</td>
<td>0.25</td>
<td>-0.92***</td>
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</table>
| Level of Significance: * p < 0.05; **p < 0.01; *** p < 0.001

DISCUSSION

The significant increase during the wet season is attributable to increased precipitation and increased inflow of surface run-off into the river channel. The higher coefficient of variation during the wet season and the fact that water level correlated positively with rainfall (r=0.85, p < 0.001) indicates that rainfall is the predominant factor contributing to the rise in water level during the wet season. This seasonality regime in water level is in agreement with works reported for other water bodies by Akpan, (1991) and Adebisi, (1981). The mean surface temperatures were high and nearly uniform. The ambient temperatures of the water body are believed to have been influenced by the intensity of sunlight as temperature rose from 28°C to 31°C particularly in the months of the dry season and lower during the months of rainy season. In addition, the similarities in variation trends between surface water and air temperatures suggest a relationship between them. This lack of differences in trends between the air and water temperatures is consistent with findings of Obire et al., (2003) who observed a similar trend in Elechi Creek in
Port Harcourt, Nigeria. Akpan (2004) working on tropical fresh water bodies in Uyo, also noted the seasonal difference in temperature which he attributed to the effect of the prevailing air-masses. Studies by Smith and Lavis (1975) indicate that there is a great modification of the water temperature by rainfall. This is particularly so in the study area as it was greatly influenced by rainfall and cloud cover as noted especially during the rainy season. This is corroborated by the significant negative correlation between rainfall and air temperature \( (r = -0.92, p < 0.01) \) and surface water temperature \( (r = -0.62, p < 0.01) \). On the other hand, air temperature gave a high positive correlation with surface water temperature \( (r = 0.75, p < 0.001) \) showing a close and positive relationship between them. Thus a decrease or increase in air temperature results in a corresponding decrease or increase in surface water temperature in Mbo River. A similar result was reported for Qua Iboe River (Akpan, 1991). The limited variation in temperature and lack of significant seasonality variation can be attributed to the limited changes associated with the equatorial tropical area (Gobo, 1988, Chindah and Pudo, 1991).

The decreasing transparency, downstream, in Mbo River may be attributed to increased tributary input of suspended materials and increased surface run-off from the drainage basin. It could also probably be attributed to increased plankton abundance downstream. From this study, transparency decreased markedly in the wet season (April – October). This could be due to the heavy load of organic matter carried into the river by surface run-off and also by silt generated by the disturbance of the river bottom (sediment) by the greater turbulence of flood water which comes after heavy rains. This is consistent with the observations of Adebisi (1981), for Ogun River, Akpan (2004) for some tropical freshwater bodies in Uyo, Anadu et al (1990) for two mine lakes in Jos, Akpan (1995) for a pond in Uyo, all in Nigeria. There was a highly significant positive correlation between transparency and water level \( (r = 0.761, p < 0.01) \), pH \( (r = 0.680, p < 0.05) \) and dissolved oxygen (DO) \( (r = 0.820, p < 0.01) \), indicating that an increase in transparency results in a corresponding increase in pH and DO. On the other hand Pearson correlation coefficient indicates a negative but strongly significant relationship between transparency and conductivity \( (r = -0.709, P < 0.01) \). total dissolved solid (TDS) \( (r = -0.711, p < 0.01) \) and chemical oxygen demand (COD) \( (r = -0.719, p < 0.01) \). The negatively significant correlation values for silicate, sulphate and total alkalinity indicates that when transparency is high, conductivity, total dissolved solids, silicates sulphates and alkalinity will be low. The high significant difference between the seasons indicates that transparency is dependent greatly upon precipitation. This corroborates the evidence of Akpan (2004). Conductivity (electrical conductance), is strongly influenced by the concentration of dissolved constituents. The remarkable increase in conductivity in the dry season is possibly due to high evapo-transpiration process which resulted in the concentration of the ions in the water (Allan, 2001; Wetzel, 2001). There was a high significant difference between the values in the seasons with greater coefficient of variation in the dry season for the three stations. This intra-seasonal variability indicates a strong influence of hydrometeorological factors on conductivity levels in the river. Similar influence has been reported by Adebisi (1981) in Ogun River, Nigeria. This seasonality regime is consistent with those of other tropical rivers (Welcombe, 1985; Wright, 1982; King and Ekeh, 1990; Akpan and Ufodike, 2005). Conductivity gave a significant positive correlation with pH, salinity and parameters known as conducting species (Sulphate, chloride and phosphate, (Fakayode, 2005)), indicating that an increase in these variables results in a corresponding increase in the electrical conductance of the water. The negative correlation between conductivity and rainfall and water level indicates that an increase in these parameters leads to a corresponding decrease in conductivity. The significant negative correlation with rainfall strongly signifies that rainfall has a major influence on the ionic composition of the river. This view is consistent with the report of Akpan (1993, 2004, 2005) on Qua Iboe River.

The seasonality profile of total suspended solids in Mbo River indicated that wet season levels were higher than dry season values. Higher wet season values in these attributes may be due to the influx of allochthonous materials into the river through surface run-off. The greater wet season value of coefficient of variations for the three stations than the dry season values indicate a strong influence of rainfall on total suspended solids. This is consistent with works carried out in other rivers: Akpan, 2004 for Qua Iboe River; King and Nkanta for Mfangmfang pond, Hall et al., 1977, for River Zambezi. The wet season increase in total suspended solids in Mbo River was probably due to large amount of silt and debris held in suspension just before the rains (Adebisi, 1981).

The dry season decrease in the level of total suspended solids was probably due to sedimentation when the current velocity and water level is reduced, and low tributary inputs. TDS was higher in downstream site because of salt intrusion from the sea and with a significant difference between the seasons \( (t = 9.64, p < 0.01) \). The high dry season value is probably as a result of evapo-crystallisation process and low precipitation signifying low dilution. This result is consistent with the report of Akpan (1991) but not with his work on water bodies in Uyo (Akpan, 2004) where he observed an increase in dissolved load with a corresponding increase in precipitation. Fatoki et al (2001) also noted an increase in total dissolved solids in Umtata River (South Africa) from contributions from runoff from the settlements during the summer rains.
Comparatively, higher values were considerably observed for all the stations in the wet than dry season. However, the seasonal variation was not significant. The variation in pH could probably be due to evapo-transpiration process, rainfall and the chemical and biological processes in the water (Mama and Ado, 2003). The lower pH recorded in all the stations during dry season with low flow, is probably due to the concentration of dissolved substances as a result of evapo-transpiration. Likewise, the pH increased during the rains as a result of dilution of the chemical substances by increased base flow. This is consistent with the report of Akpan (2004) and Adebisi (1981). pH range of 6.6 – 7.3 reported for Mbo River could be considered to be within the range considered as normal for unpolluted fresh water (Kudryavtseva, 1999; Chrenyavskaya et al., 1993; Fakayode, 2005). The slight acidity of the sampling stations especially during the dry season and early rains could be attributed to the fact that Mbo River drains a catchment area with thick tropical rainforest.

The seasonality pattern in the pH of Mbo River is similar to that reported by Akpan (1991) for Qua Iboe River and King and Ekhe (1990) for Nworie stream. However, it is at variance with the patterns found in some other African rivers in which pH increases during the dry season and reduces during the raining season (Egborge, 1971; Adebisi, 1981). The significant positive correlation between pH and water temperature (r = 0.45, p < 0.05) TA (r = 0.47, p < 0.05) show that an increase in these parameters results in a corresponding increase in pH. Also the highly significant and positive correlation with rainfall (r = 0.67, p < 0.01) suggests that increase in rainfall attributed to increase in pH.

Dissolved oxygen levels were higher in the wet season than in the dry season due to the increased current flow that enables the diffusion and mixing of atmospheric oxygen into the water. This finding is consistent with those reported for River Osun (Welcomme, 1979), Zambezi River (Hall et al., 1977), Qua Iboe River (Akpan, 1993) who observed that tropical African aquatic systems generally have low DO in the dry season than the wet season. King and Ekhe (1990) in their work on Nworie Stream, Nigeria, attributed the dry season decline in dissolved oxygen concentration to stream stagnation and increased input of organic load into the water (mainly as leaf litter), whose decomposition increases oxygen depletion. On the other hand, some authors have argued the fact that dissolved oxygen does not increase with the rains. Aguiwo (1998) working on Nnamdi Azikiwe University stream, and Kemdirin and Ejike (1992) argued that dissolved oxygen concentration is high in the dry seasons due to high photosynthetic activities of the phytoplankton at this period. They argued that low DO levels during rainy months is likely caused by high aquatic vegetation cover that flourish favourably in the rainy months at the expense of dissolved oxygen used in respiration.

On the other hand, the high levels of dissolved oxygen observed in the wet season in all the stations in Mbo River is consistent with the work of Chindah and Braide (2004) in Bonny River, in the Niger Delta who observed that DO concentrations were consistently variable between seasons with wet season concentration significantly higher than that of dry season (ANOVA, p < 0.01). Also in the Niger Delta, Izonfuo and Barwini (2001), while working in Epipe Creek, observed average DO levels of 4.45 mg l\(^{-1}\) in the wet season higher than 3.35 mg l\(^{-1}\) obtained in the dry season. They attributed this seasonal fluctuation to the effect of temperature on the solubility of oxygen in water. At high temperature, the solubility of oxygen decreases while at lower temperature, it increases (Plimmer, 1978).

The significant negative correlation between dissolved oxygen and biological oxygen demand (r = 0.69, p < 0.01) and water temperature (r = -0.48, p < 0.05) shows that there is an inverse relationship between these parameters. On the other hand, a positive relationship was observed between dissolved oxygen and rainfall (r = 0.61, p < 0.01) indicating the influence of rainfall on DO concentrations in Mbo River. This conforms to the earlier results and observations made that DO is rainfall-dependent and increases with the rains. The coefficient of variation was higher in the rainy season than dry season (ANOVA, p < 0.05) show that an increase in these parameters results in a corresponding increase in pH. Also the highly significant and positive correlation with rainfall (r = 0.67, p < 0.01) suggests that increase in rainfall attributed to increase in pH.

Dissolved oxygen levels were higher in the wet season than in the dry season due to the increased current flow that enables the diffusion and mixing of atmospheric oxygen into the water. This finding is consistent with those reported for River Osun (Welcomme, 1979), Zambezi River (Hall et al., 1977), Qua Iboe River (Akpan, 1993) who observed that tropical African aquatic systems generally have low DO in the dry season than the wet season. King and Ekhe (1990) in their work on Nworie Stream, Nigeria, attributed the dry season decline in dissolved oxygen concentration to stream stagnation and increased input of organic load into the water (mainly as leaf litter), whose decomposition increases oxygen depletion. On the other hand, some authors have argued the fact that dissolved oxygen does not increase with the rains. Aguiwo (1998) working on Nnamdi Azikiwe University stream, and Kemdirin and Ejike (1992) argued that dissolved oxygen concentration is high in the dry seasons due to high photosynthetic activities of the phytoplankton at this period. They argued that low DO levels during rainy months is likely caused by high aquatic vegetation cover that flourish favourably in the rainy months at the expense of dissolved oxygen used in respiration.

On the other hand, the high levels of dissolved oxygen observed in the wet season in all the stations in Mbo River is consistent with the work of Chindah and Braide (2004) in Bonny River, in the Niger Delta who observed that DO concentrations were consistently variable between seasons with wet season concentration significantly higher than that of dry season (ANOVA, p < 0.01). Also in the Niger Delta, Izonfuo and Barwini (2001), while working in Epipe Creek, observed average DO levels of 4.45 mg l\(^{-1}\) in the wet season higher than 3.35 mg l\(^{-1}\) obtained in the dry season. They attributed this seasonal fluctuation to the effect of temperature on the solubility of oxygen in water. At high temperature, the solubility of oxygen decreases while at lower temperature, it increases (Plimmer, 1978).

The significant negative correlation between dissolved oxygen and biological oxygen demand (r = 0.69, p < 0.01) and water temperature (r = -0.48, p < 0.05) shows that there is an inverse relationship between these parameters. On the other hand, a positive relationship was observed between dissolved oxygen and rainfall (r = 0.61, p < 0.01) indicating the influence of rainfall on DO concentrations in Mbo River. This conforms to the earlier results and observations made that DO is rainfall-dependent and increases with the rains. The coefficient of variation was higher in the rainy season than dry season. The trend of seasonality in BOD followed that of DO concentration with higher values and variability in Stations 1 and 2 during the rainy season and in the dry season. The wet season increase in BOD values was probably due to the increased input of decomposable organic matter into the river through surface runoff. These organic matter require oxygen for their biodegradation. This wet season high in BOD levels is in accordance with those reported by Akpan and Offem (1993) for Cross River Estuary; Akpan (1993) for Qua Iboe River, Nigeria, and Akpan and Akpan (1994). BOD was positively correlated with water level (r=0.41, p < 0.05) signifying that an increase in rainfall and subsequently water level, resulted in an increase in BOD as a result of increased organic load brought into the river by surface runoff. The negative correlation between BOD and DO indicates an inverse relationship between the two parameters. Moore and Moore (1976) reported that BOD has been a fair measure of cleanliness of any water on the basis that values less than 1-2 mg l\(^{-1}\) are considered clean, 3 mg l\(^{-1}\) fairly clean, 5 mg l\(^{-1}\) doubtful and 10 mg l\(^{-1}\) definitely bad and polluted. The results, therefore, show that the Mbo River is cleaner in the dry season than rainy season.

The levels of free carbon dioxide (CO\(_2\)) at the three sites were higher in the dry season than in the rainy season. This is in agreement with findings of King and Nkanta (1991) in Mfangmang pond, Nigeria, who reported higher free carbon dioxide in the dry season than in the rainy season and Aguiwo (1998) who reported same seasonality.
trend in Nnamdi Azikiwe University stream, Nigeria. This higher dry season levels in free carbon dioxide is inconsistent with the reports of Adebisi (1981) and Wright (1982) who reported lower levels in the dry season than in the wet season in River Ogun and Jong, respectively.

The pronounced decline of free carbon dioxide level in the rainy season reported in this study may be attributed to the utilization of free carbon dioxide by the phytoplankton. The marked seasonality trend in the levels of total alkalinity (TA) of the river with the three sites showing greater values just before the rains (dry season) than wet season values. This seasonality regime is consistent with those reported for some tropical freshwater bodies; Zambesi River (Hall et al., 1977), Upper Ogun River (Adebisi, 1981) Qua Iboe River (Akpan, 1993), Epic Creek (Izonfuo and Bariwendi, 2002). The lower value of total alkalinity in the wet season suggests that runoff water contributed to dilution of this parameter in the wet season.

From this study, alkalinity showed a high correlation with pH (r = 0.47, p < 0.05), conductivity (r = 0.53, p < 0.01) and salinity (r = 0.53, p < 0.01). This indicates that a rise in pH, conductivity and salinity results in a corresponding rise in the level of total alkalinity. On the other hand total alkalinity correlated negatively with biochemical oxygen demand, although insignificantly.

The seasonality regime in the levels of sulphate was characterized by higher dry season levels than the wet season in the river. This means that runoff water dilutes the sulphate ions in the river system and that through evapo-crystallization process sulphate was concentrated in the water during the dry season.

There was slight seasonality regime in the upstream and downstream stations with higher dry season values in both sites showing that rain water contributed to the dilution of ammonia in the wet season in these two sites. On the other hand, in station 2, ammonia levels were lower in the dry season and higher in the wet season. This means that runoff water contributed a significant proportion of this constituent into this station mainly from sewage input.

This study has revealed that the general effect of precipitation and associated differences in the river volume and input of surface runoff from the drainage basin / watershed were the major determinants of the total levels and trends of monthly and seasonal variations in the water quality attributes. The physico-chemical components can be divided into three classes in relations to the type of seasonal influence:

Dry season maximum, resulting from low rainfall and a reduction in water level and surface runoff e.g. TDS, Free CO₂, COD, Silicates, Nitrates, Alkalinity, Sulphates and Transparency.

Wet season maximum are those that occur as a result of increased rainfall which results in increase water level and input by surface runoff e.g. Conductivity, TSS, DO, pH, Current velocity and Water level.

No marked seasonal variation are those insensitive to the dry-wet cycle of the tropics e.g. ammonia and water temperature.

REFERENCES


