CURRENT STUDIES IN COMPARATIVE EDUCATION,
SCIENCE AND TECHNOLOGY, VOLUME 4,
NUMBER 1, 2017, PP. 141-155

Space and Time Dynamics of Surface Water Quality of an Estuarine creek in the Niger Delta in Nigeria

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Abstract

Azuabie creek receives domestic, municipal and industrial wastes due to human activities from settlements, commerce and industries within its vicinity. The aim of this study was to assess the surface water quality of the creek using the adjacent Okujagu creek as a control location. This was done via evaluation of the physicochemical characteristics of the surface water in space and time and comparing with regulatory limits. Three replicate surface water samples were collected per location on a monthly basis for six months (July – December 2016). Seventy-two samples were collected and analyzed using standard methods as given in APHA. Physicochemical variables examined indicated significant difference between the locations, months and also significant interaction between location and months. Mean pH range (6.5 ± 0.10 – 7.5 ± 0.02) was significantly different between months ($p<0.001$) while alkalinity values (18.0 ± 1.0 – 616.7 ± 60.16 mg/l) showed significant spatial and temporal variations ($p<0.001$), conductivity ((55266.7 ± 290.9 µS/cm), TDS (2494.7 ± 3.7 - 27133.3 ± 176.6 mg/l) and salinity (1.0 ± 0.4 - 11.8 ± 1.0 PSU) had generally higher values at the control location. TSS, colour and turbidity values were higher within Azuabie creek with colour and turbidity showing significant variation ($p<0.01$) in space and time. The values of nitrate (1.2 ± 0.09 – 8.2 ± 0.23 mg/l), sulphate (12.3 ± 1.5 – 2021.7 ± 23.2 mg/l) and phosphate (0.14 ± 0.02 - 2.13 ± 0.10 mg/l) had significant difference ($p<0.001$) between locations, months and significant interaction between location and time. Summarily, conductivity and TDS were high and above permissible limits of FEPA, USEPA and WHO while variables such as pH, salinity, phosphate were within permissble limits but did not show appreciable increase over time compared to previous studies. Values of nitrate indicated increase over time but within regulatory limits while turbidity and TSS had improvement over time compared to previous studies due to reduced dredging operations. Discrete locations of the sites in principal component analysis (PCA) indicated dissimilarity in the water quality parameters due to areas of hotspot within the creek. The study concluded that there was deterioration in surface water quality of the Azuabie creek due to increase in some parameters above permissible values though few, such as turbidity and TSS improved for reasons earlier given, regular monitoring is still necessary to detect signs of water quality changes.

Keywords: Water Quality, Physicochemical parameters, Azuabie Creek, Niger Delta

Introduction

Regular quantitative and qualitative assessment of the physicochemical parameters of surface water bodies is key to detection of water quality changes particularly, in inland creeks and rivers receiving municipal run-offs and industrial wastes discharges. The management and conservation of the aquatic ecosystem would therefore, depend on the knowledge of the physicochemical and biological properties of the surface water body (Moslen *et al*., 2006). The quality of aquatic bionetworks is vital for the productivity, survival and support of aquatic organisms found in them. It is an index of health and well being of the ecosystem and has direct impact on human health. Physicochemical parameters of water provide nutritional balance and ultimately govern the biotic relationships of organisms in an aquatic ecosystem; including ability to withstand pollution load. Industrialization, urbanization and modern agriculture practices directly impact the water resources quantitatively and qualitatively (Udo, *et al*., 2013). Chindah and Braide (2003) stated that in recent years, a number of events affecting water quality has resulted in increased public concern about surface water quality. Such events as increased domestic wastes generation and indiscriminate disposal and discharge of untreated and poorly treated industrial wastes into surface water bodies impact negatively on water quality and lead to water quality deterioration. Water quality monitoring has therefore, become a subject of concern in marine, stream, and river water due to uncontrolled disposal of urban effluents, runoff, atmospheric deposition, municipal, and industrial effluent into these water bodies (Onojake *et al*. 2011). The presence of several companies and the high population density in coastal cities have caused adverse effects in the Niger Delta area (Odu *et al*., 1985; Nwankwo, 1991). Population growth has inadvertently increased effluents and solid wastes generated and discharged into the environment, which finally find their way into the natural water bodies (Chindah *et al*., 2006).

The aquatic system in the Bonny estuary is vulnerable to pollution by organic, industrial and chemical pollutants/wastes from several industries and human habitats located by the banks and water fronts and has been the subject of much research over decades (Chindah *et al*., 1993, Moslen *et al*., 2006; Daka *et al*., 2007; Chindah *et al*., 2009; Ideriah *et al*., 2012; Miebaka and Daka 2013; Moslen and Daka 2014; Moslen and Daka., 2016; Ekweozor and Moslen 2016; Moslen and Miebaka 2017). Daka and Moslen (2013) identified major waste inputs into Aazuabie creek to include run-off from surrounding lands, animal wastes from a major abattoir, human/domestic waste from a high density settlements along the creek and industrial effluents from Trans-Amadi industrial area, hosting a number of manufacturing and oil servicing companies. The aim of this study was to assess the surface water quality of the creek using physicochemical parameters in relation to permissible limits.

Materials and method

Study Site

The study site is an estuarine creek (Azuabie creek) while the Okujagu creek was used as a control location. These creeks are located on the eastern fringes of Port Harcourt city in the upper Bonny estuary of the Niger Delta, Nigeria. The Azuabie creek receives both industrial and domestic wastes from industries and settlements around Trans-Amadi industrial layout. A major abattoir that serves the city is located close to the shore of the Azuabie creek in addition to other anthropogenic activities such as marine boats fabrication/maintenance operations and oil bunkering activities. The Okujagu creek on the adjacent axis has minimal anthropogenic activities compared to the Azuabie creek. Mangroves and Nypa palms that line the shores of the Azuabie creek are fast being cleared for development purposes which further expose the creek to human influence. Three sample locations were taken from the Azuabie creek (AZ1, AZ2 & AZ3) while one point (control) was taken from the Okujagu creek (OK) – Fig. 1.

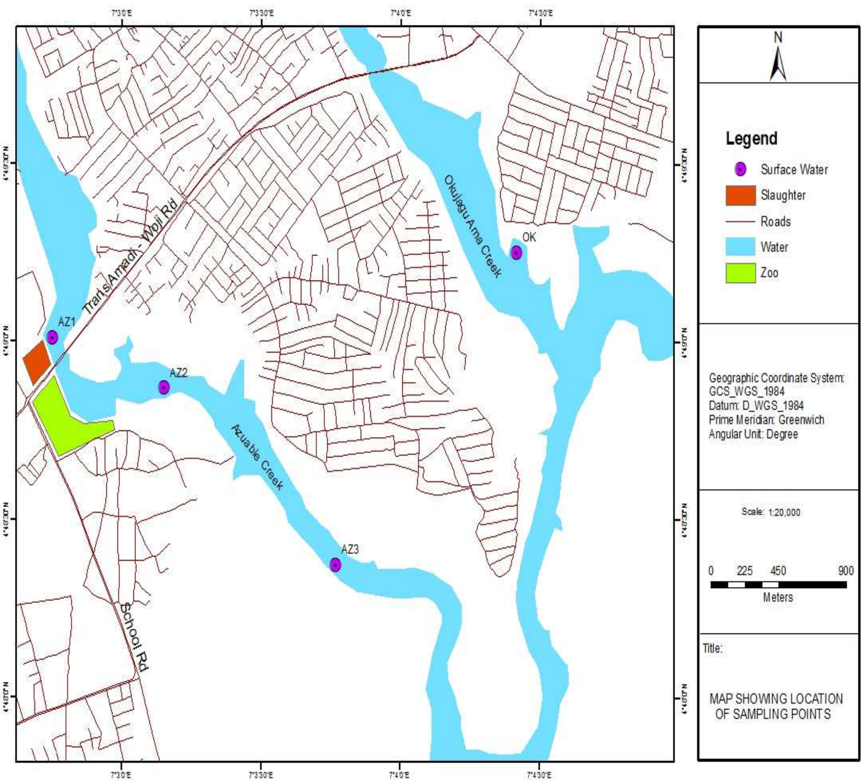


Fig. 1: Location of study sites

Sample Collection and Analysis

Surface water samples were collected at lowest tide in triplicate per station on a monthly basis for six months (July – December 2016). July to December tend to give seasonal (wet and dry) representations with respect to this study. Standard scientific procedures and containers were used to collect samples and preserved in ice chest while in transit to the laboratory. Fast changing parameters such as pH, conductivity, salinity, total dissolved solids, total suspended solids and turbidity were determined *in situ*. Procedures described in Standard Methods for the examination of water and waste water analysis by APHA (1998) were adopted in the analyses of surface water samples.

Data Analysis

Two-way analysis of variance (ANOVA) was used to simultaneously assess the effects of two factors (location and season/period/time) on the variables examined and also how the interaction of the two factors could affect the variable. The two-way ANOVA enabled detection of significant differences between locations, between periods examined and if there was an interaction between location and periods. Post-hoc analysis using Tukey test indicated where actual significant difference occurred either for location or period. Site discrimination based on physicochemicacal variables was achieved via principal component analysis (PCA) after normalization of data. The software packages – MS excel, Minitab R16 and Primer 6 were used.

Results

Spatio-temporal variations of physicochemical variables were illustrated in Figs. 2 – 12 while Table 1 shows the ANOVA results. There were minimal spatial and temporal differences in pH readings with mean values ranging from 6.5 ± 0.10 – 7.5 ± 0.02 (fig 2). The pH values were significantly different ($p<0.001$) between the months and also showed significant interaction ($p<0.05$) between location and time. The significant difference between time occurred as follows: Jul < Dec < Sep < Aug = Oct < Nov meaning that significant difference in pH between months had seasonal implications. Also, the combination of the season and location was significant in its effect on the pH of the study area. The pH values were more acidic at station AZ1 and lesser at stations AZ2 and AZ3 in no particular order. The mean values of alkalinity ranged from 12.3 ± 1.2 – 616.7 ± 60.16 mg/l at AZ2 and AZ1 (Fig.3). The alkalinity values were generally higher during the dry season month of December and showed lower values during the wet season periods. The alkalinity values showed significant variation between locations ($p<0.001$), months ($p<0.001$) and also had a significant interaction between location and time ($p<0.001$). The significant difference between sites occurred as follows: Ok < AZ3 < AZ2 < AZ1 while those between months were Dec < Jul < Sep = Aug = Oct < Nov.

The stations examined were significantly different from each other including the control station (OK) suggesting the peculiarity of each site. September, August and October periods showed similarity in alkalinity values but were significantly different from core dry season months of November and December. The mean conductivity value was highest in July (55266.7 ± 290.9 µS/cm) and gradually decreased toward the peak of the wets season and later began to increase as the dry season set in (Fig.4). Significant difference ($p<0.001$) was observed between locations, months and also interaction between location and time. Pairwise comparison for locations indicated that OK = AZ3 < AZ2 < AZ1 while that for periods showed that values in Jul < Aug = Dec < Oct < Nov < Sep. The control station (OK) had similar conductivity values compared to station AZ3 due proximity to the more saline end of the creeks but differed significantly from other sites located inland of the Azuabie creek.

The interaction of the season with location produced higher conductivity values during the dry season months. The values of total dissolved solids (TDS) showed the same pattern as the conductivity. The mean values ranged from 2494.7 ± 3.7 - 27133.3 ± 176.6 mg/l at stations AZ1 and Ok in September and July respectively (Fig.5). The values observed were significantly different ($p<0.001$) between locations, time and also location interaction time. Pairwise comparison for locations indicated that station Ok = AZ3 < AZ2 < AZ1 while those for time showed that values in Jul < Aug < Dec = Oct < Nov < Sep. The total suspended solids (TSS) in the study area was higher in the Azubie creek than the control creek (OK) particularly at AZ2 where values were up to 22.7 ± 17.7 mg/l (Fig. 6) which could be due to increased waste discharge from nearby settlements. The colour of the surface water was generally higher in Azuabie creek compared to the control creek (OK). The mean value of colour ranged from 11.3 ± 4.5 – 44.0 ± 4.4 pt-co (Fig.7). The observed value of colour was significantly different ($p<0.001$) between the stations and also between the periods examined. The actual spatial difference indicated that AZ3 = Ok but significantly different from AZ1 and AZ2 while the actual temporal difference occurred thus: Jul < Aug = Sep = Oct < Nov = Dec. Stations AZ1 and AZ2 were closer to the city abattoir and activities from the slaughter house could be responsible for the significant locational difference compared to sites (OK and AZ1) which were farther away. The turbidity levels in Azuabie creek was generally higher compared to values observed at the control creek location (OK).

The mean values of turbidity ranged from 0.12 ± 0.01 – 1.65 ± 0.25 NTU (Fig.8). The turbidity values observed between locations and months were significantly different ($p<0.01$) with both factor showing significant interactions ($p<0.01$). Pairwise comparison showed that values got from station AZ1 varied significantly with those of AZ2, AZ3 and OK while values obtained in the months of Dec and Sep varied significantly with values obtained in the months of Jul, Oct, Aug and Nov. AZ1 was the closest to the city abattoir and anthropogenic activities from the abattoir could actually cause significant difference between AZ1 and other stations while interaction of season (rains) and the activities at the site significantly affected the turbidity of the area. There were remarkable variations in the salinity values of the study area. The lowest mean value observed was 1.0 ± 0.4 PSU at station AZ1 in the Azuabie creek while the highest mean value was 11.8 ± 1.0 PSU at the control location (OK – Fig.9). The observed spatial and temporal variations were also significantly different ($p<0.001$) between locations, periods and location interaction periods.

Pairwise comparison indicated that station AZ1 was significantly different from all other stations and this was mainly due to dilution effects from fresh water input at the inland part of the creek while the control station (OK) axis had influence of salt water intrusion. The salinity values obtained in July was significantly different from values got in other months suggesting the influence of wet and dry seasons on the salinity of the study area. The nutrient status of the creek also varied across stations and time. The mean value of nitrate ranged from 1.2 ± 0.09 – 8.2 ± 0.23 mg/l (Fig. 10) with no clear trend between the Azuabie creek and the control creek. There were significant difference (p<0.001) between the examined locations, periods and location interacting significantly with periods. The values obtained from stations OK and AZ2 were similar but significantly different from values obtained at AZ3 which also varied significantly with values obtained from AZ1 which is attributable to more anthropogenic activities within the Azuabie creek compared to the control creek. Also the nitrate values obtained in the months of August and December were similar but significantly different from values got in the months of October and November while values obtained in the month of July differed significantly with those observed in the month of September depicting no particular seasonal trend. Sulphate level in surface water was generally lower in Azuabie creek particularly at station AZ2 when compared to the control creek. Mean sulphate value ranged from 12.3 ± 1.5 – 2021.7 ± 23.2 mg/l (fig.11) with significant difference (p<0.001) between the stations examined. There was also significant difference (p<0.001) between months in addition to significant interaction (p<0.001) between locations and months. The significant difference between locations occurred as follows: AZ1 < AZ2 < AZ3 < OK while that between months occurred thus: July < Aug < Sep = Dec < Oct < Nov. The phosphate levels in surface water also varied remarkably across stations and months. The mean values ranged from 0.14 ± 0.02 - 2.13 ± 0.10 mg/l (Fig. 12). The observed variations in phosphate concentrations were significantly different (p<0.001) between locations, months and also between the interaction of location and months. The actual spatial differences occurred thus: AZ3 < AZ1 < AZ2 < OK while the temporal difference occurred thus: Sep = Dec < Aug < Nov < Jul = Oct. The principal component analysis (PCA Fig. 13) indicated that the four stations tested were distinct from each. Stations AZ1 and AZ2 were most dissimilar while station AZ3 and OK had most similarity. The relationship of the physicochemical quality at each station was clearly reflected on the distance between such stations in the PCA output.

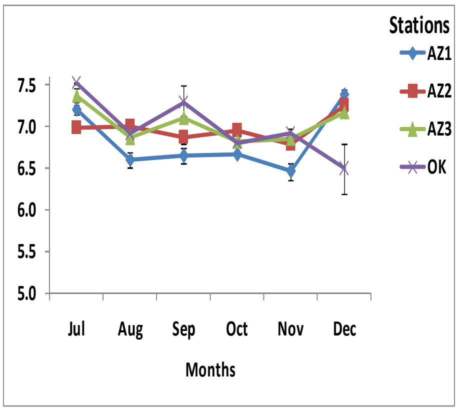


Fig. 2: Variation in pH of the study area

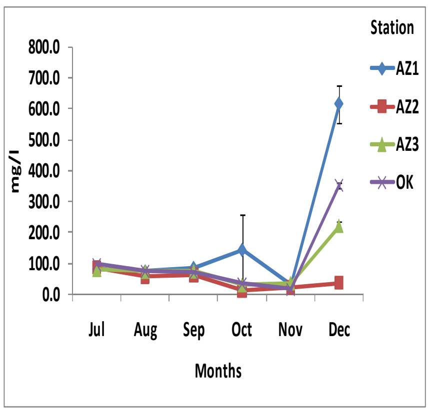


Fig. 3: Variations of alkalinity in the study area

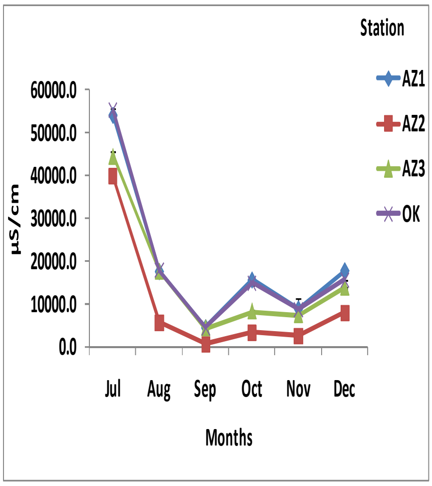


Fig.4: Variation in Conductivity of the study area

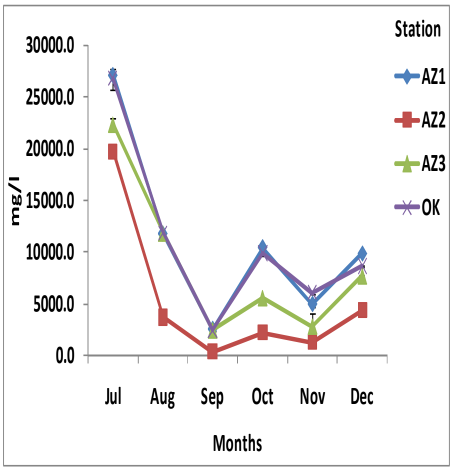


Fig. 5: Variations of TDS in the study area

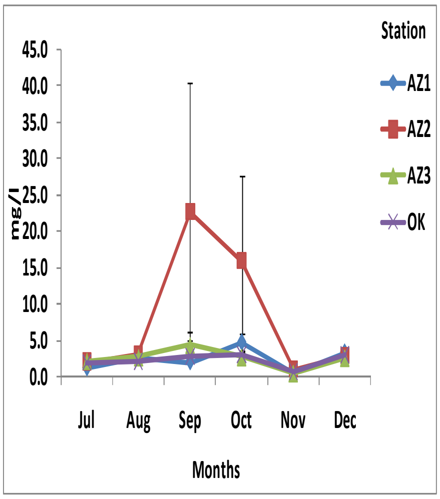


Fig. 6: Variations of TSS in the study area

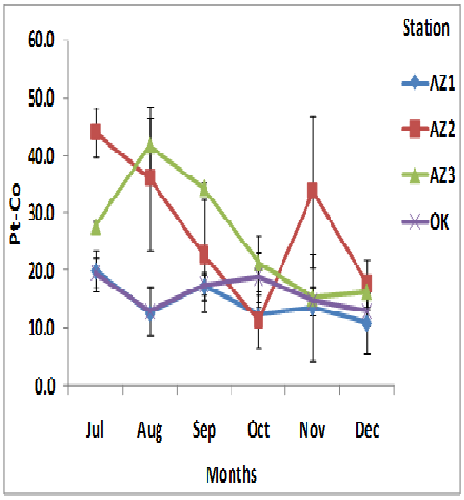
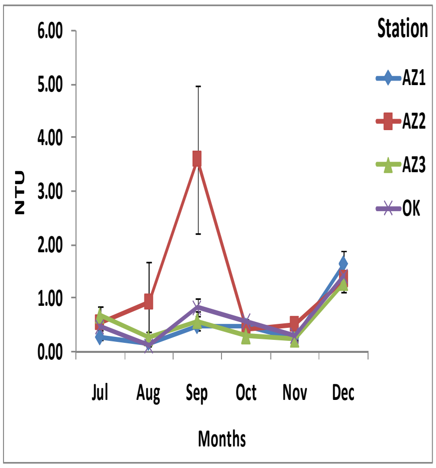


Fig. 7: Variations of colour in the study area



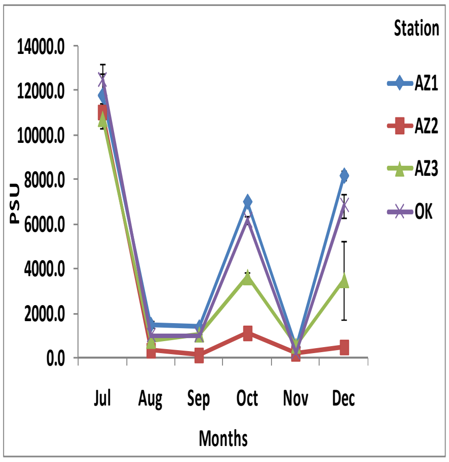
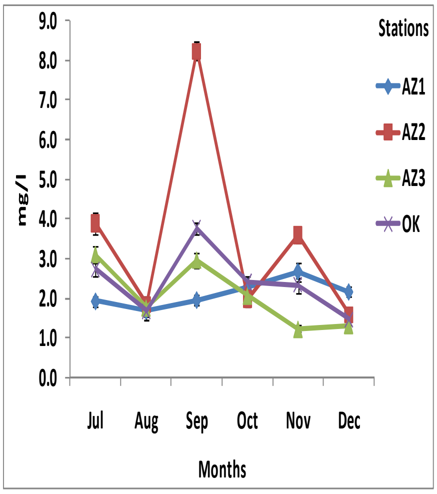


Fig. 8: Variations of turbidity in the study area Fig. 9: Variations of salinity in the study area



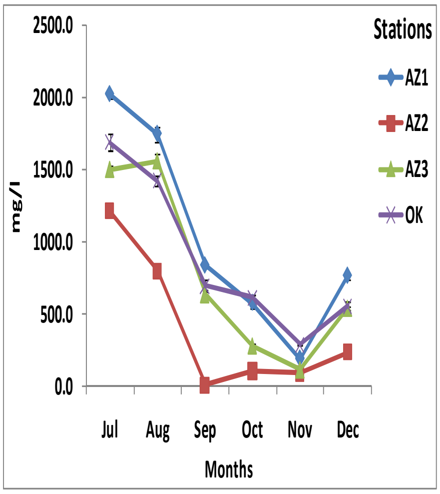
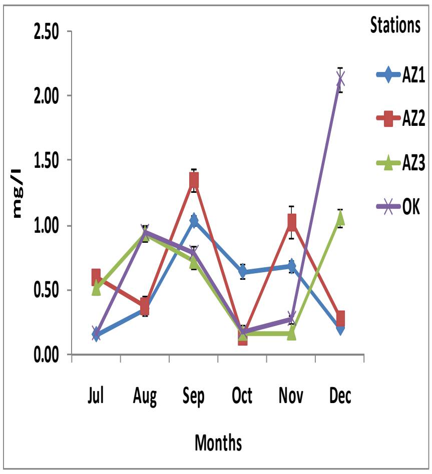


Fig. 10: Variations of NO_3 in the study area   Fig. 11: Variations of SO_4 in the study area



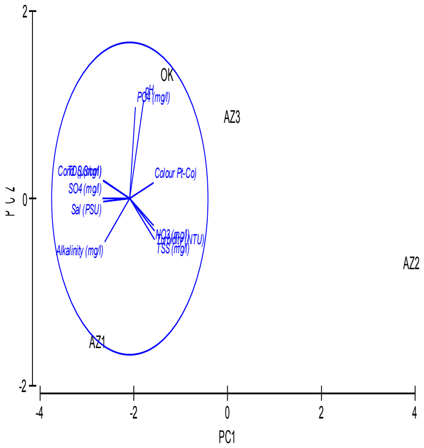


Fig. 12: Variations of PO_4 in the study area *Fig. 13: Principal Component Analysis*

Table 1: ANOVA Table with F-values

Parameters	Location (F-values)	Season (F-values)	Location inter-action Months (F-values)
pH	2.34ns	7.02***	2.28*
Alkalinity	23.89***	58.46***	13.12***
Conductivity	300.39***	2581.61***	15.85***
TDS	287.17***	1615.30***	14.76***
TSS	2.46^{ns}	1.73^{ns}	0.98^{ns}
Colour	8.82***	3.78**	1.83^{ns}
Turbidity	5.70**	9.35***	3.19***
Salinity	43.24***	305.71***	8.88***
Nitrate	90.50***	119.76***	43.66***
Sulphate	505.07***	1658.26***	29.63***
Phosphate	19.09***	112.47***	83.26***
Key	* = $P \leq 0.05$; ** = $P \leq 0.01$; *** = $P \leq 0.001$; ns (not significant)		

Discussion

Generally the pH readings observed in the Azuabie creek were more acidic compared to the values measured at the control station (OK). This may not be unconnected with salinity intrusion on the Okujagu (control) axis of the creeks. The pH values were within the regulatory limits (6.5 – 8.5) of WHO (1984) and FEPA (1991) and USEPA (2006). Moslen *et al*. (2006) recorded pH ranges of 6.5 – 7.5 in the Azuabie creek and 6.4 – 7.2 in the Okujagu creek which served as control point of this study. This was lower than 7.9 - 8.0 recorded by Inyang *et al*. (2006) in the Azuabie creek. The findings of this study therefore, show that there had not been a significant change in the pH of the creeks over time irrespective of the anthropogenic activities in the study area. The pH value observed in this study is also in consonant with readings observed in other parts of the Niger Delta (Daka and Moslen 2013; Marcus and Ekpete, 2014 and Makinde *et al*., 2015). The spatial and temporal variations in alkalinity of the surface water of Azuabie creek showed significant difference ($p<0.001$). Combination of anthropogenic activities and environmental factors in the creek could have impacted discretely on the alkalinity of the water body giving rise to the observed differences.

The impact of season was also obvious with alkalinity increasing during the dry season period particular to locations which interacted significantly with periods. The alkalinity values obtained in this study was more compared to the reports (6.5 – 10.3 mg/l) of Makinde *et al*., (2015) but falls within the values (30.0 mg/l) reported by Olorode *et al*. (2015) and (66.66 ± 5.77 - 217.5 ± 187.38 mg/l) by Moslen and Daka (2016) recorded in similar areas of the Niger Delta. The conductivity values of this study were generally above the permissible limit (4000 µS/cm) of the USEPA (2006) but showed a clear pattern with reduced values at the less saline end of the creek (AZ1 & AZ2) and increased towards the more saline end of the creeks (AZ3 & OK) during the wet and dry season periods respectively. The influence of fresh water greatly affected conductivity at AZ1 and AZ2 which were significantly different ($p<0.001$) from locations AZ3 and OK.

This study observed higher values of conductivity in the Azuabie and Okujagu creek (control station) compared to values (1200 – 23000 µs/cm) obtained by Moslen *et al*. (2006), and that (18400 µs/cm) obtained by Inyang (2006) but corroborates that of Makinde *et al*. (2015) in the Bonny estuary. This suggests slight increase in the conductivity of the study area over time. The total dissolved solids of the study area were above the regulatory limits (2000 mg/l) of the USEPA (2006) and also showed the same pattern with the conductivity values in a proportional relationship. The TDS values observed in this study were comparable to values obtained by Ogamba *et al*. (2005), Marcus and Ekpete, (2014) but above 70 – 190 mg/l recorded by Makinde *et al*. (2015). The total suspended solid (TSS) was generally higher in Azuabie creek compared to the control creek location with values comparatively less than the permissible limit (<500 mg/l) of FEPA (1991). The range of TSS value observed in this study agrees with the records of Marcus and Ekpete (2014) but significantly lower compared to those (735.66 ± 64.47 - 1251.66 ± 75 mg/l) obtained by Moslen and Daka (2016) in similar environments. The colour of the water was generally higher in the Azuabie creek compared to the control creek station.

Station OK and AZ3 were akin but significantly different from the colour observed at AZ1 and AZ2 which was traceable to domestic and abattoir wastes inputs exerting reasonable influence over AZ1 and AZ2. The turbidity values were below the permissible limit (5.10) of USEPA. The significant difference between AZ1 and the rest of the sites examined suggest significant impact of abattoir wastes discharged close to station AZ1. Turbidity results obtained in this study indicate a significant improvement in the study area compared to Moslen *et al*. (2006) who recorded 1.0 – 19.0 NTU in the Azuabie creek and 0.0 – 9.0 NTU within the control station creek.

The salinity values showed a clear pattern with a gradient from the inland part of the Azuabie creek to the outwards due to sea water inflow. The salinity values obtained in this study were comparable to those (1.45 – 12.1 PSU) within the Azuabie Creek and (2.2 – 13.6 PSU) within the control creek recorded as found by Moslen *et al*. (2006) and those (2.5 – 15.5 PSU) observed by George *et al*. (2009) on the distributary Okpoka River. Observed salinity values were relatively stable over time but within regulatory limit (<10 – 25 PSU) of WHO (1984). Data obtained in this study was consistent with the findings of some studies in the Bonny estuary (Marcus and Ekpete, 2014 and Makinde *et al*., 2015). The nitrate values (0.3 – 1.2 mg/l) earlier recorded in the Azuabie creek and those (0.27 – 0.97 mg/l) for the Okujagu creek (control point) by Moslen *et al*. (2006) were quite lower than values (1.2 – 8.4mg/l) obtained in this study. This shows an increase in the concentration of nitrate over time in the study area but values were below the 10.0 mg/l regulatory limit of FEPA (1991). The increase could be attributed to increased waste load into the Azuabie creek. Nitrate values obtained in this study were higher than values (0.23 – 0.67 mg/l) recorded by Ogamba *et al*. (2005) and Makinde *et al*., (2015) in the Bonny estuary. The concentration of sulphate in the study area was generally high particularly at location AZ1. The drains of most companies in Trans-Amadi Industrial layout including a soap making factory finally empty into the Azuabie creek.

The result of this study agrees with the findings of values (501.32 mg/l) recorded by Olorode *et al*. (2015) but remarkably different from 22.4 ± 3.4 mg/l noticed by Marcus and Ekpete (2014) in the Niger Delta. The phosphate concentration in surface water was generally higher in the Azuabie Creek compared to the control creek except in the month of December but all the stations differed significantly ($p<0.001$) in terms of their phosphate levels. Phosphate values obtained in this study were all below the regulatory limit (5.0 mg/l) of FEPA (1991). Moslen *et al*. (2006) had recorded phosphate ranges of 0.6 - 1.9 mg/l within the Azuabie creek and 0.6 – 1.6 mg/l within the control creek which also compared favourably with the findings of Inyang (2006) in the study area. Compared to values obtained in this study, there had been no significant change in the concentration of phosphate over time within the two creeks examined. The phosphate values obtained in this study favourably compared with values (0.15 – 0.59 mg/l) reported by Marcus and Ekpete (2014) and (0.03 ± 0.01 - 3.4 ± 2.40 mg/l) reported by Moslen and Daka (2016). In view of the fact that regular monitoring studies is required in order to detect changes in such pollution prone creeks, this study found that water quality parameters like turbidity relatively improved compared to previous studies due to reduced dredging activities within the creeks at the time of the study.

The study also found that variables such as TDS and conductivity had values above regulatory limits while nitrate values also increased significantly over time but within permissible values. It was also clear from the study that TDS, salinity, conductivity and sulphate accounted for the locational separation of site AZ1 while pH and phosphate accounted for the distinction of location Ok in the PCA. Nitrate, TSS and turbidity mainly accounted for the dissimilarity in station AZ2 while colour was in no particular order. This finding indicates the water quality status of the creeks at the time of this study and serves as reference for future studies and regulation for such municipal creeks receiving waste discharge.

Conclusion

Discrete locations of the sites examined indicate dissimilarity in the water quality parameters within the Azuabie creek. Water quality parameters examined indicated that some variable exceeded permissible limits while others were with such limits. Findings indicated the creek was prone to pollution, further deterioration of the water quality of the study area may pose health risk of significant concern to those using the creek for fishing and other economic activities – the need for regular monitoring of the creek is necessary to prompt changes in the water quality condition.

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References

American Public Health Association (APHA). (1998). Standard Methods for the examination of water and wastewater, 20th ed. American Public Health Association, Inc. New York.

Chindah, A.C., Braide, S.A., Amadi, A. and Osuamkpe, A. (1993). Investigations into the
epipelic algal community of Elechi Creek in the Bonny Estuary, Niger Delta, Nigeria. *Int. J. Biochemphysics* (2): 119 - 124.

Chindah, A. C, Braide, S. A. (2003); Cadmium and Lead concentrations in fish species of a brackish wetland / upper Bonny Estuary, Niger Delta. *J. Nig. Environ. Soc. (JNES)* 1(3):399-405.

Chindah, A.C., Braide, S.A., Obianefo, F. and Obunwo, C. C. (2006). Water quality and periphyton community of stream system receiving municipal wastes discharges in Rivers State, Niger Delta, Nigeria. *Estud. Biol*. (28): 73-89.

Chindah, A. C.1., Braide, S. A., Amakiri, J. and Chikwendu, S.O.N (2009). Heavy Metal Concnetrations in Sediment and Periwinkle -Tympanotonus fuscastus in the Different Ecological Zones of Bonny River System, Niger Delta, Nigeria. *The Open Environmental Pollution & Toxicology Journal*, (1): 93-106.

Daka, E.R., Moslen, M., Ekeh, C. A. and Ekweozor, I. K. E. (2007). Sediment quality status of two creeks in the upper Bonny estuary, Niger Delta, in relation to rban/ industrial activities. *Bull. Environ. Contam.Toxicol.* (78): 151-521.

Daka, E.R. and Moslen, M. (2013). Spatial and temporal variation of physicochemical parameters of sediment from Azuabie creek of the upper Bonny estuary, Niger Delta. *Research Journal of Environmental and Earth Sciences* 5(4):291-228.
Ekweozor, I. K. E. and Moslen, M. (2016). Abundance and Diversity of Plankton of Ekerekana and Okochiri Creeks in the Upper Bonny Estuary. *Nigeria. Nigerian Journal of Oil and Gas Technology* (2): 144-155.

FEPA (1991). Interim Guidelines and Standards Industrial effluents gaseous emission and Hazards waste management in Nigeria. Federal Environmental protection Agency publication, Lagos, Nigeria, 210p.

George, A. D. I., Abowei, J, F, N. and Daka E. R. (2009).Benthic macro invertebrate fauna and physic-chemical parameters in Okpoka creek sediment, Niger Delta, Nigeria. International *Journal of Animal and Veterinary Advances* 1(2) 59 – 65.

Ideriah T. J. K., David-Omiema S. , Ogbonna D. N. (2012). Distribution of Heavy Metals in Water and Sediment along Abonnema Shoreline, Nigeria. *Resources and Environment*, 2(1):33-40.

Inyang, I. R., Ekweozor, I. K. E. and Daka, E.R. (2006). Macroscopic ectoparasites commonly associated with some fishes in the upper Bonny estuary. *J. Appl. Sci. Environ Manage*. 10 (4):31–35.

Marcus A. C. and Ekpete O. A. (2014). Impact of Discharged Process Wastewater from an Oil Refinery on the Physicochemical Quality of a Receiving Waterbody in Rivers State, Nigeria. *Journal of Applied Chemistry.*7(12):01

Makinde, O. O., Edun, O. M. and Akinrotimi O. A. (2015). Comparative Assessment of Physical and Chemical characteristics of Water in Ekerekana and Buguma Creeks, Niger Delta Nigeria. *Journal of Environment Protection and Sustainable Development* 1(3):126 -133

Miebaka, C. A. and Daka, E. R. (2013). Dynamics of Zooplankton of Azuabie Creek in the Upper Bonny Estuary of the Niger Delta. *International Journal of Fisheries and Aquatic Sciences* 2(2): 29-37.

Moslen, M., Daka, E.R.,Ekeh, C.A. and Ekweozor, I.K.E. (2006).Physicochemical properties of two estuarine creeks in the Niger Delta in relation to urban/industrial activities. *Niger Delta Biologia* 5(2):115-122.

Moslen, M**.** and Daka, E. R. (2014). Effects of aggregate extraction on the physicochemical variables of surface water of Orashi River in the Niger Delta, Nigeria. The Proceedings of the International Conference on Oceanography, Calabar, 12-14 November 2013.Pp 272 – 284.

Moslen, M. and Daka, E. R. (2016): Spatio-Temporal Differences of Physicochemical Variables in Relation to Industrial Effluent Discharges into Ekerekana and Okochiri creeks, Bonny Estuary of the Niger Delta, Nigeria. *J. of Nig Environ Socie (JNES*) 10(2): 152 – 167.

Moslen, M. and Miebaka, C. A. (2017). Concentration of Heavy Metals and Health Risk Assessment of Consumption of Fish (Sarotherodon melanotheron) from an Estuarine Creek in the Niger Delta, Nigeria. *IOSR Journal of Environmental Science, Toxicology and Food Technology* 11(3): 68-73

Nwankwo, D.I.(1991). Periphyton algae on fish fences (Acadja) in a tropical open lagoon. Intern. *J. Ecol. Environ. Sci.* (17):1-10.
Odu, C. I. I., Esuruoso, O. F., Nwoboshi, L.C and Ogunwale, J.A. (1985). Environmental study of the Agip oil operational areas. Proceeding of Soil, Water and Forest Vegetation, Millan, Italy, pp: 176-181.

Ogamba, E. N., Ekweozor, I. K. E. and Daka, E. R. (2005). The influence of human activities on the zooplankton of Elechi complex in the Niger Delta. *Afr. J. Environ. Pollut. Health* 4(2) 3 – 38.

Olorode, O. A., Bamigbola, E. A. and Ogba, O. M. (2015). Comparative Studies of some River waters in Port Harcourt based on their physico - chemical and microbiological analysis, Niger Delta Region of Nigeria. *International Journal of Basic and Applied Sciences* 3(3): 29 -37.

Onojake M.C., Ukerun, S. O., Iwuoha, G. (2011). A statistical approach for *evaluation of the effects of industrial and municipal wastes on Warri Rivers, Niger Delta, Nigeria. Water Qual Expo Health* 3:91–99.

Udoh, J. P., Ukpatu, J. E. and Otoh, A. J. (2013). Spatial Variation in Physico-Chemical Parameters of Eastern Obolo Estuary, Niger Delta, Nigeria. *Journal of Environment and Earth Science.* 3(12) 163 -171.

USEPA. 2006. Quality Criteria for Water. Environmental Protection Agency, Washington, D.C.

WHO, World Health Organization (1984). Guideline for drinking water quality, health criteria and other information Vol.2, Geneva Publication, 306p.