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Application of Principal Component Analysis (PCA) for the Characterization of the Water Quality of Okoro River Estuary, South Eastern Nigeria

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Abstract: *Water quality parameters (pH, salinity, DO, BOD, total suspended solid (TSS), Total dissolved solids (TDS), Total hydrocarbon (THC), water temperature, heavy metals and rainfall) were analyzed from surface water samples collected at Okoro River estuary, Southeastern Nigeria between April 2011 to March 2013. Principal component analysis (PCA) was used in the ordination of physicochemical parameters. The results of the scree plot and eigenvalue decomposition, revealed five significant factors that explained > 75% of the total variance in the complex data set with their eigenvalues >1. The structural resonance of the factor loadings (eigenvectors) followed a decreasing order of hydrological factors (35.30%), oil pollution (16.90%), dissolved salts (12.39%), natural mineralization (8.69%) climatic factors (6.89%) as the major factors responsible for the modification of the surface water quality of the area. This study recommended that PCA is a useful tool for identification, characterization and evaluation of water quality.*

Key words: Anthropogenic transformation, Eigenvalues, Eigenvector, Scree plot.

1. Introduction

Principal component analysis is one of the best multivariate techniques for extracting linear relationship among a set of variables (26). Principal Component Analysis (PCA) is a multivariate eigenvector analytical technique used for the interpretation of the structure within the correlation matrix of variables (15). The ordination technique is capable of generating ecological spaces in which the relationship among the entities in the data set is clearly depicted (15, 2, 33, 31). It reduces the dimensionality of the original data set and minimizes the loss of information about the source component of water quality. The technique has been used for the evaluation and interpretation of large complex data sets with the view to getting better information about the water quality.

Several researchers who were prominent proponents of principal component analysis to evaluate water quality include: (11; 20; 17; 25; 13; 27; 19; 28; 8). Coastal water quality has become a major concern to scientists because of its values for recreation, socioeconomic development, fisheries development and human health. With the growth of human population and the explosion of commercial industries in costal areas, large amounts of pollution from a variety of sources such as oil spill, transport (runoff) and seawater intrusion have been the characteristics of water bodies of the Southeastern Nigeria. (12), (13) have reported that these disturbances have persisted since the advent of oil boom in Nigeria.

However, until now the assessment of the water quality and the variations caused by natural and anthropogenic factors in Okoro River estuary, Southeastern Nigeria has not been documented. Coastal water quality changes with time and space, and water quality measurements and assessments are necessary for effective water quality management. It is therefore essential to diagnose the present condition of the water quality of Okoro River estuary using the principal component analysis (PCA) in order to assess the component factors or sources of fluctuation, sources of perturbation and the effect of environmental degradation in the study area.

2. Materials and Methods

2.1 *Description of the study area*

The study was carried out in Okoro River estuary, Southeastern Nigeria located (4^o 33ʹN - 4^o 55ʹ N; 7^o45ʹE - 7^0 55ʹE about 650 m above sea level in the tropical mangrove forest belt east of the Niger Delta between the lower Imo and Qua Iboe River estuaries (Figure 1). The tidal range in the area is about 0.8 m at neap tides and 2.20 m during spring tides with little fresh water input joined by numerous tributaries as they empty into the Atlantic Ocean (21). The climate of the area is tropical with distinct rainy (April to October) and dry seasons (October to May) with a high annual rainfall averaging 2500 mm (16). The mean water temperature of the study area is 28.2^{o}C (32).

Fig. 1: Okoro River estuary, Southeastern Nigeria (Source: Google earth)

2.2 *Vegetation and Mineral Resources*

The area is characterized by an expensive mangrove swamp dominated with mangrove species: *Rhizohora racemosa*, *Avicennia germinas*, *Conocarpus eractus*, interspersed with *Nypa fruticans* with inter-tidal mud flats influenced by the semi-durnal tidal regime of the estuary. Fishing and farming are the main economic activities in this study area. Oil palm (*Elaeis guineensis*) and coconut palm (*Cocus nucifera*) are also widely distributed in the surrounding villages. The area is also an oil-producing area with several oil exploration wells and oil pipelines.

2.3 *Physicochemical Analysis of Water*

Surface water temperature, pH (hydrogen ion concentration), salinity and total dissolved solids (TDS) were measured insitu with the multi-parameters monitoring instrument (Model- EXTECH, EC, 500). Dissolved Oxygen was measured with DO meter – Model – EXTECH 11, DO 600, while biochemical oxygen demand (BOD_5) was determined with DO –meter Model – EXTECH 11, DO 600 after 5 days incubation at 20^oC . Similarly, total suspended solids (TSS) was determined using Gravimetric method.. Water hardness was determined by complexometric titration- with EDTA. Total hydrocarbon content (THC) was extracted with carbon tetrachloride (CCL4) in a separating funnel at pH 5 and absorbance read from the Fisher Electrophotometer at 450 nm wave length after appropriate treatment and digestion. Other tests using standard methods and procedures included: sodium and potassium while copper, zinc, nickel was determined using atomic absorption spectro- photometer (AAS)- Perkin- Elmer Model 2380 (7). Rainfall data was collected from the Meteorological Unit, Department of Geography, and University of Uyo.

2.4 *Statistical Techniques*

Statistical analysis was performed using Statistical Package for Social Sciences (SPSS, Version 19.0). Principal Component Analysis was used to decipher interrelationships among the variables and to identify the origin (source components) of environmental stress in the study area. It was also used to explain the total percentage variation among variables of interest.

3. Results

The range, mean and standard deviations of the parameters are given in Table 1.

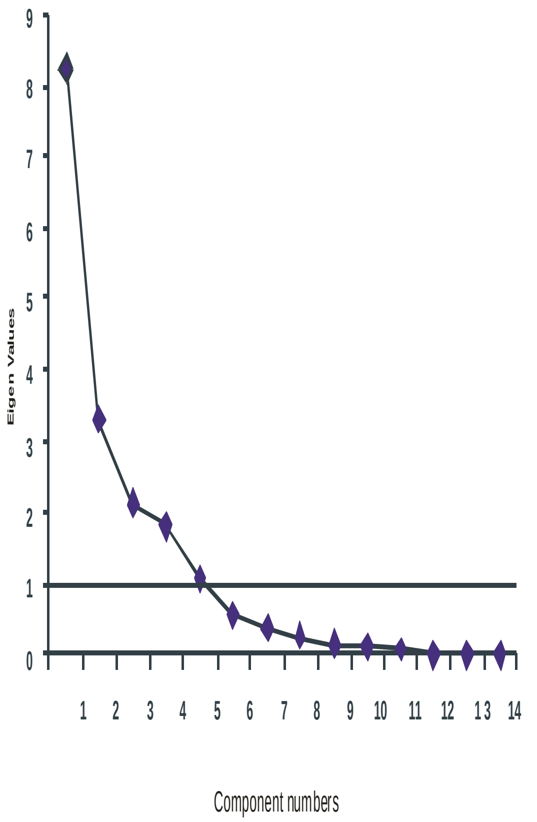
The characterization of the water quality was done with the dominant features from the data set (Table 2). The dominant features were separated from the set and used to obtain the principal component. The five significant factors were ordained as : hydrological regime, pollution, nutrient dynamics, salinity gradient and climatic factors. The Inspection of scree plot spectrum indicated that components with eigenvalues < 1 are outside the break line and were not considered as significant components. The scree plot spectrum of the physicochemical parameters analyzed in this study produced five (dominant) principal components with 35.30% (PC -1), 16.90% (PC -2), 12.39% (PC - 3), 8.69% (PC -4) and 6.89% (PC-5) with their eigenvalues >1 and cumulative percentage of 80.17%. The Eigenvalues measured the strength of the principal component and revealed the natural structure or resonance within the physicochemical parameters and explained quantitatively the variance explained in each component.

The projection of component loadings and ordination graphs are presented in Fig.3 and 4. The multivariate PCA plots revealed the correlation structure and strength of associations among the physicochemical variables on the plane or ecological hyperspace. The variable lines represent the PCA coefficients (eigenvectors) while the black spots represent the sampling months. The longer the amplitude the higher the factor of influence as can be seen on amplitude of temperature, rainfall, THC which indicated higher influence and prominent factors. Also, the closer the structural angle, the stronger the strength of associations as can be seen with (BOD5 and temperature), and salinity and water hardness. The agglomeration and amalgamation of factors of influence in different quadrant portrayed different ecological condition in the estuary. For instance, Na, Temp, DO, HAD = alkaline condition, Salinity/TDS = mineralization/ salinization process and THC/ Ni = organic matter encroachment

Table 1: Variation of Physicochemical Parameters in Okoro River Estuary, Southeastern Nigeria

S/N	Parameters	Min	Max	Mean±SD	Coefficient of Variation (CV)
1	Temp (^oC)	24.70	34.40	28.00± 1.934	0.069
2	pH	6.12	8.24	7.38± 0.759	0.102
3	TSS (mg/l)	231.20	316.30	289.07± 30.724	0.106
4	TDS (mg/l)	16080.50	25811.00	21879.87± 3300.49	0.150
5	DO (mg/l)	6.10	8.24	7.24± 0.728	0.100
6	BOD_5(mg/l)	2.01	4.22	3.04± 0.545	0.157
7	SAL ‰	24.10	30.90	26.59± 2.299	0.086
8	THC (mg/l)	0.10	2.65	1.07± 0.885	0.826
9	HAR (mg/l)	308.10	596.20	418.68± 90.688	0.216
10	Ni (mg/l)	0.16	0.26	0.21± 0.032	0.117
11	Na (mg/l)	382.00	716.00	574.25± 127.680	0.188
12	K (mg/l)	300.40	605.20	511.68± 96.428	0.222
13	Cu (mg/l)	0.12	0.18	0.15± 0.019	0.128
14	Zn (mg/l)	0.06	0.23	0.17± 0.046	2.56
15	RNF (mm)	0.00	918.10	282.60±84.45	1.006

Keys: Temp= Temperature, pH=Hydrogen Ion, TSS= Total Suspended Solids, TDS= Total Dissolved Solids, BOD_5 = Biological Oxygen Demand, SAL= Salinity, THC= Total hydrocarbon Content, HAR= Water hardness, Ni= Nickel, Na= Sodium, K= Potassium, Cu= Copper, Zn=Zinc, RNF= Rainfall pattern.



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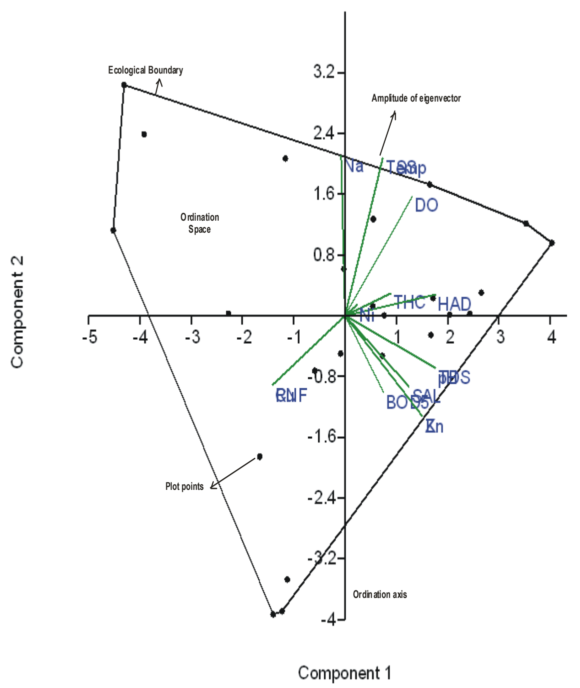

Fig 2: Scree Plot Spectrum of different Principal Components with their Eigenvalues

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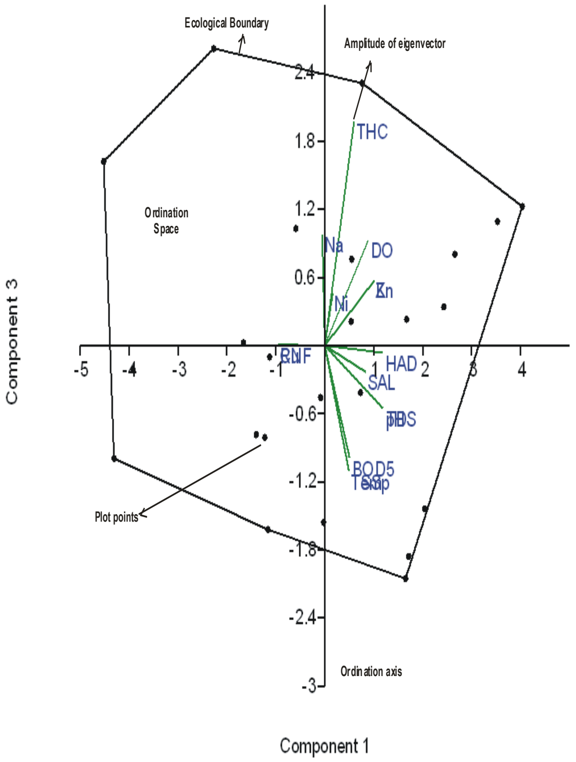


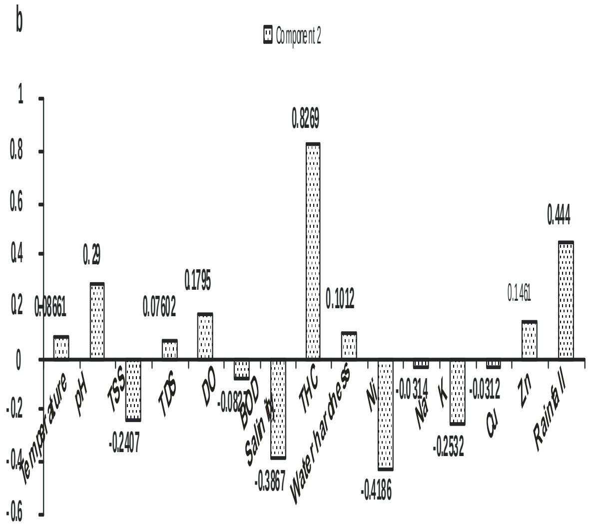
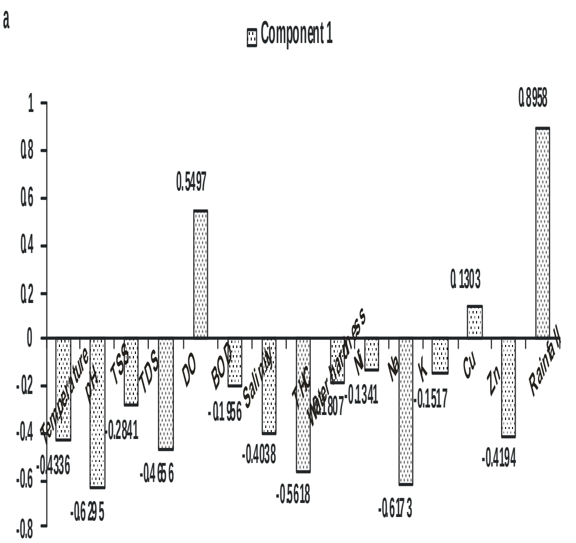


Fig 3. (a): Multivariate Ordination of Physicochemical Variables on Plane Axis 1 (35.30 %) and Plane Axis 2 (16.90%) (b) Multivariate Ordination of Physicochemical Variables on Plane Axis 1 (35.30%) and Plane Axis 3 (12.39%)



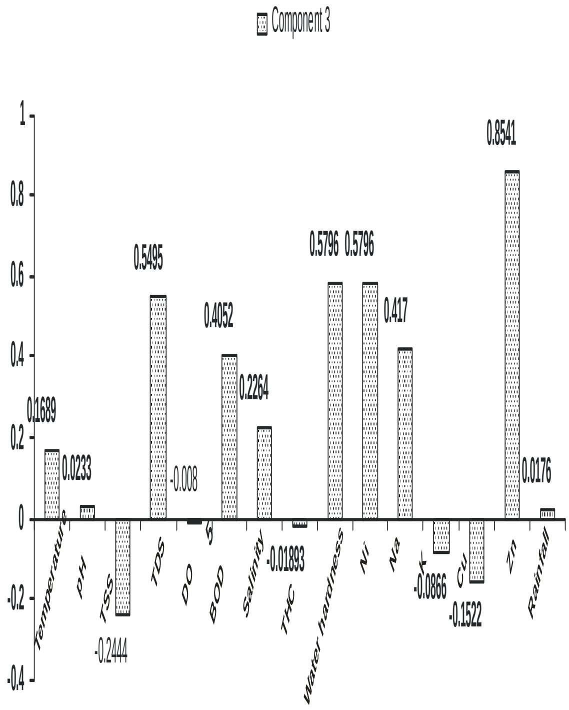
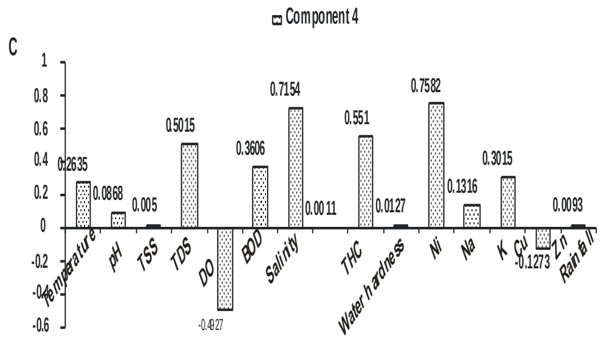


Table 2: Weighted Sums of Variable Scores on Physicochemical Parameters

Parameters	**Component 1 (Hydrological Regime)**	**Component 2 (Pollution)**	**Component 3 (Nutrient Dynamics)**	**Component 4 (Salinity Gradient)**	**Component 5 Climatic factor)**
Temperature	-0.4336	+0.08661	+0.1689	+0.2635	+0.6934*
pH	-0.6295*	+0.2900	+0.0233	+0.0868	+0.5728*
TSS	- 0.2841mmmm	-0.2407	-0.2444	+0.0050	+0.4263
TDS	-0.4656	+0.07602	+0.5495*	+0.5015*	+0.3902
DO	-0.5497*	+0.1795	-0.0080	-0.4927	-0.219
BOD_5	-0.1956	-0.0827	+0.4052	+0.3606	+0.294
Salinity	-0.4038	-0.3867	+0.2264	+0.7154*	+0.1022
THC	-0.5618	+0.8269*	-0.01893	+0.0011	-0.0038
Water hardness	-0.1807	+0.1012	+0.5796*	+0.551*	+0.6496*
Ni	-0.1341	-0.4186*	+0.5394*	+0.0127	-0.4597
Na	-0.6173*	-0.0314	+0.417	+0.7582*	+0.222
K	-0.1517	-0.2532	-0.0866	+0.1316	-0.4726*
Cu	+0.1303	-0.0312	-0.1522	+0.3015	+0.0171
Zn	-0.4194	+0.1461	+0.8541*	-0.1273	-0.0171
Rainfall	+0.8958*	+0.444	+0.0176	+0.0093	-0.0031
Total Variance (%)	**35.30**	**16.90**	**12.39**	**8.69**	**6.89**
Eigenvalues (λ)	**8.238**	**3.283**	**2.125**	**1.816**	**1.072**
Cumlative Percentage (%)	**35.30**	**52.20**	**64.59**	**73.28**	**80.17**

*Component determinant attributes (dominant features)



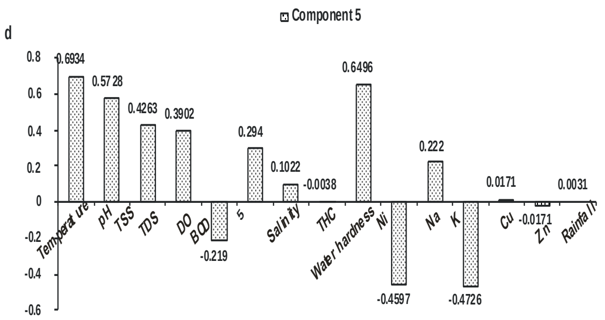


Fig 3 (a-e): Projection of Component Loadings (Eigenvectors) and Significant Components (PC1-PC5)

4. Discussion

The scree plot spectrum of the physicochemical parameters analyzed in this study produced five (dominant) principal components with 35.30% (PC -1), 16.90% (PC -2), 12.39% (PC - 3), 8.69% (PC -4) and 6.89% (PC-5) with their eigenvalues >1 and cumulative percentage of 80.17%. (34) used similar parameters to assess the behaviour of water quality in the Malaysian coastal waters and obtained three (3) Principal Components. These three PCs had eigenvalues greater than one or close to unity and explained 77.0% of the total variance in water quality of Malaysia with PC-1 50.6%, PC-217.7% and PC-38.7%. (34) stressed that principal components should account for approximately 75% of the total variance. The five significant components and the total variation of 80.17% obtained in this study is higher than the results of (34) in Malaysian coast. However, the higher percentage variance supports the position of (31) that the larger the variance the more the features have better discriminate power.

The five significant components with eigenvalues > 1 and the 80.17% variance recorded in this study is in consonance with the results of (19) on the multivariate analysis of hydrochemical component of Central Ganga Basin, India, showed that the principal component analysis identified five factors that are responsible for the hydrochemical structure of coastal water of India and explained 83.49% variance in the data set. The result of this study is also closer to the report by (30) who identified four significant components that together accounted for 84.11% of the total variance with component PC (I -4) accounting for 38.06%. 20.00%, 15.46% and 10.59% respectively with eigenvalues greater than 1 in the water quality of Mumbai coast through multivariate analysis techniques. Principal Component Analysis (PCA) was also carried out on the dataset of physicochemical parameters obtained during the rainy and the dry season to determine the contribution and significant variation of season on the water quality of Okoro River Estuary.

The PCA ordination also showed that hydrological regime has (35.30%) influence on the water quality of Okoro River Estuary. This implies that the seasonal variations of abiotic factors in the Okoro River Estuary are driven by hydrological regime. The hydrological variability between the dry and rainy seasons is influenced by rainfall that triggers river discharge. This is considered very important in producing mobility of the brackish zones. In the rainy season, the major part of the estuarine zone exhibits the hydrochemical characteristics of a river, and is slowly occupied by freshwater species. Thus, rainfall is one of the determinant factors that affects productivity in the Okoro River estuary. A negative sign of the temperature weight indicates its reciprocal relation to rainfall pattern in the area.

Compare with results from other estuaries along the Gulf of Guinea, (10;13;1;14) Lower Cross River estuary, Nigeria, seawater intrusion and tidal action are sources of perturbation in the estuary. This explains the high loading of sodium and potassium in the water column. The annual hydrological regime of the area affects the concentrations of dissolved materials and drives material interchange between aquatic and terrestrial systems. The hydrodynamic transport affects the shorelines which are often broken in the process, increasing the turbidity of the water in the estuary. The frequency and intensity of such disturbance can be stressful to aquatic species which may lead to significant shifts in species composition and could erode the biotic integrity of the ecosystem.

The positive loading of dissolved oxygen in Okoro River estuary, Southeastern Nigeria suggests ecological wellbeing of the water body and its suitability for sustaining fish, crayfish (shrimps) and other aquatic life and it is also suitable for the maintenance of biological function.

However, the explanation for high BOD concentration in Okoro River estuary could be that the area in recent years, had suffered massive mangrove die-off and exploitation, which may have increased the BOD from the decomposition of organic matter. Increase in BOD concentration during the dry season may have resulted from augmentation in production of phytoplankton from strong and longer light period during the dry season months.

The PCA showed that oil pollution has 16.10% influence on the characteristics of water quality of Okoro River estuary. The anthropogenic organic input as fallout from oil exploitation and exploration were clearly observed in the Okoro River estuary. Thus, organic matter encroachment as a result of industrial, photo degradation of organic carbon (THC) and chemical transfer from oil terminals influenced the ordination of the water quality of Okoro River estuary. Anthropogenic transformations as a source component are linked to oil discharges from outboard engines, sea trucks or oil pipelines which are indicators of participation of THC in the water component of Okoro River estuary. The oil activities in the study area are capable of changing the ecological regimes of the water ecosystem both in terms of the physical structure and chemical quality, which invariably may threaten the health status of the water, resulting in changes in the fishery resource base of the area.Spilled oil may affect shrimp production in the form of lowered fertility and abnormal offspring, the oil on the water as evidenced by the high loading of THC ($\alpha = 0.678$). It may also prevent natural procreation and causes suffocation and natural mortality of juveniles trapped under benthic water level. The result of this finding agrees with the assertion by (3) that the major proportion of all water quality degradation worldwide is due to anthropogenic causes.

The detection of Nickel (Ni) in the water samples with higher eigenvector (component loading) on component 3 thereforesuggests the presence of crude oil pollution in the Okoro River system. The implication here is that oil pollution in the Okoro River Estuary can be blamed on the activities of the oil companies operating in the area. This result is in line with the report of (12) that oil pollution is a major component of the water of the coastal region of Nigeria. The result also supports the report of (23) that Nickel (Ni) is a crude oil pollution indicator and that high value of Nickel may be related to oil pollution. Okoro River has been suffering from oil spillages from oil terminals and flow stations. This implies that anthropogenic disturbances are prominent in the area and can modify the water quality and can also affect benthic community structure in the area.

The distribution of dissolved salts in the estuary may be due to much influence of tidal action that carrier dissolved particles from mud flat and sea water into the estuary. Contributions from natural sources, such as weathering of rocks and degradation of mudflat which eventually get eroded through surface runoff into the estuary influence water system. The freshwater runoff may result in colloidal rock particles in the exchange zone of the estuary which contributed to high loading of potassium (K) in the water quality of Okoro River Estuary, Nigeria.

The water quality of Okoro River estuary was largely influenced by heavy metal concentration and mineral-related parameters such as TDS and water hardness (12.39%). Total Dissolved Solids (TDS), water hardness, Zn and Ni loaded significantly on the water column with positive eigenvectors ($\alpha = 0.576$ for water hardness, $\alpha = 0.5495$ for TDS, $\alpha = 0.5394$ for Ni and $\alpha = 0.8541$ for Zn. Therefore, the impact of trace metals with mineralization processes influenced the behaviour of this component. The finding is in strong agreement with the findings of (9) who opined that an estuary is the main entry for nutrients coming from continental drainage to the marine environment. The behaviour of dissolved nutrients in the estuary contributes to the overall performance of this component. (29) claimed that the increase of nutrient concentrations in estuarine and coastal waters causes several environmental disturbances, such as increases in productivity and fishing yields as a result of varying river flows and nutrient budget. The addition of nutrients and suspended solids to the coastal waters due to weathering and riverine transport and natural sources also influences the characterization of the Okoro River Estuary. Similar observations had been made from other estuarine water bodies: (24) coastal water off Devi estuary India; (22), west coast of India. The indicator parameters which loaded highly on component 4 were TDS, Na, and salinity. This indicates that in the Okoro River estuary, salinization processes (seawater intrusion and freshwater incursion) is prominent as evidenced in the high loading of sodium, salinity and TDS. Besides, fresh water incursion and seawater intrusion bring the allocation of organic and inorganic materials or loads from the surrounding catchments area into the estuary, resulting in the mineralization and salinization of the water of the area.

The high positive loading of temperature and inverse loading of rainfall on component 5 indicated that climatic factor plays an active role in the water quality of the Okoro River. Temperature is an important factor affecting ions and phase equlibria and influencing the rates of biochemical processes which accompany the mineral substances.

Water temperature is an essential parameter that influences photosynthesis in water, physiological responses in aquatic organisms as well as the decomposition of organic matter and subsequent biochemcial reactions. It is one of the factors controlling the growth and distribution of marine shrimps (29). Temperature variation is one of the factors in the estuarine system which may influence the physicocheimcal characteristics and also influence the distribution and abundance of flora and fauna in estuarine system.

5. Conclusion

Principal component analysis (PCA) applied to the physicochemical datasets indicated various factors during the whole study period influencing variability in the water to the extent of 75%. The distribution of nutrients in the area is influenced by factors like salinity regime and anthropogenic activities (oil pollution). Principal axis factoring have been used to observe the mode of association of parameters and their interrelationships for evaluating water quality. Hydrological regime, ocean surging and industrial wastes contribute to the current condition of Okoro River Estuary, Nigeria. Oil pollution is a major organic contaminant in the estuarine ecosystem in the South Eastern region of Nigeria. Salinization and mineralization processes, climatic factors and anthropogenic transformations are among major factors that regulate the integrity and behavioral pattern of the Okoro River estuary. Degradation of mudflats and organic matter encroachment from anthropogenic sources are contributory factors that influence the water quality of Okoro River estuary, South Eastern Nigeria.

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