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THE ENVIRONMENTAL IMPACT OF CRUDE OIL FORMATION WATER: A MULTIVARIATE APPROACH

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Water bodies receiving effluents from gas flow stations were sampled for ten months (March to December). Fifteen physicochemical parameters were monitored at six locations. Results obtained were analyzed using principal component analysis and cluster analysis. Five principal components accounting for 72.43 % of total variance were isolated. The first principal component was a measure of sea water intrusion, the second component was a measure of total solids, the third component was a measure of organic pollution while the fourth and fifth principal component depicted the impact of effluent discharges. Effluents from gas flow stations were not the major causes of pollution of water resources in the locations of study. Cluster analysis showed no significant variation in the physicochemical characteristics of water samples based on location. Physicochemical parameters exhibited a seasonal pattern as a result of dilution by rainfall, reduced rate of evaporation in rainy season and dissolution of gaseous products of gas flaring in rain. Metals had no significant effect on the quality of water sampled from the six locations during the period of monitoring.

Keywords: effluents, cluster analysis, formation water, principal components, pollution, rainfall.

Introduction

Water pollution remains an ever increasing problem in developing countries as a result of industrial activities coupled with lack of technical capacity to cope with the negative impacts of these activities. Many industries discharge effluents into nearby water bodies without proper treatment and adherence to effluent discharge standards set by the Ministry of Environment. Some rivers and streams in urban areas are in a permanently polluted state because they receive effluents at multiple points along their reaches so that self-purification process is hardly ever achieved. The Lagos Lagoon is so polluted that it continuously gives out a stench that can be perceived from a distance. Sources of water pollution in Nigeria include industrial effluent discharge, runoff from markets and

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farmlands, raw sewage from overflowing septic tanks, leachates from ubiquitous refuse dumps, abattoir discharges, oil spills, acid rain, debris from construction sites and chemicals used by fishermen. Polluted water is usually high in chemical oxygen demand (COD), biochemical oxygen demand (BOD), suspended and dissolved solids, nutrients, heavy metals and diverse microbial species. Numerous studies on water quality done in Nigeria revealed that effluent discharges into water bodies can have far-reaching effects on water resources and the ecosystem. Arimoro (2009) found that rubber effluent discharge into Adofi River in the Niger Delta caused changes in habitat, water quality and diversity of macro invertebrates. Effluents low in dissolved oxygen (DO) can make serious demands on the oxygen budget and undermine the self-purification process of a river (Eludoyin et al., 2004). Effluents rich in nutrients encourage the multiplication of micro organisms and further depletion of dissolved oxygen, giving rise to the preponderance of pollution tolerant and opportunistic species Arimoro et al. (2007). In developing countries, millions of deaths have been traced to ingestion of water polluted with untreated sewage (Benka-Coker and Ojior, 1995). Diarrhoeal diseases attributed to poor water supply, sanitation and hygiene account for 1.73 million deaths each year and contribute over 54 million Disability Adjusted Life Years, a total equivalent to 3.7% of the global burden of disease (WHO, 2003).

Study Area. The Niger Delta is a wetland through which River Niger discharges into the Atlantic Ocean. The vegetations are mostly saline mangrove, freshwater forest and lowland rainforest. The Niger Delta is dissected by a dense network of rivers and creeks which maintain a delicate but dynamic equilibrium between saline, estuarine and freshwater surface bodies with complex underground extensions (Abam, 2001). It covers an area of 112,000 km² encompassing nine states of the Nigerian Federation with a population of about 27 million people. The area is rich in crude oil with about 1183 oil fields. Shell D'Arcy (Now Shell BP) pioneered oil exploration in Nigeria in 1937. In 1956, the first commercial oil field was discovered at Oloibiri, Niger Delta. Since then oil has become the backbone of the Nigerian economy making up over 92 % of the nation's foreign exchange and 74 % of total revenue. Sadly, oil production has led to a gross bastardization of the Niger Delta environment without adequate efforts to ameliorate these impacts. Agricultural lands have been irreversibly damaged and water resources have been reduced to a state of permanent pollution leaving communities with no lands to cultivate and no water fit for fishing. Several incidents of kidnapping and deliberate damage to oil facilities in the Niger Delta precipitated from the dilapidated state of the environment. Ironically, the Niger delta is nearly submerged in water, yet there is not enough for

drinking and domestic activities. Several studies have shown that water in the Niger Delta is heavily polluted (Adebayo, et al, 2007; Ekiye and Luo, 2010; Yusuf and Sonibare, 2004; Akaninwo, et al, 2007; Asia and Akpohonor, 2007; Okoh et al, 1996; Adakole and Abolude, 2009).

The final stages of oil production involves separation of oil from formation water. The water separated is usually channelled to the saver pit prior to discharge into streams or rivers. In this study, the impact of such effluent from six flow stations belonging to Shell Nigeria on the physicochemical characteristics of receiving waters was investigated using both descriptive statistics and multivariate analyses – principal component analysis and cluster analysis. The six locations as indicated in Fig. 1 are Benisede, Escravos, Opuama, Otumara, Opukushi and Saghara.

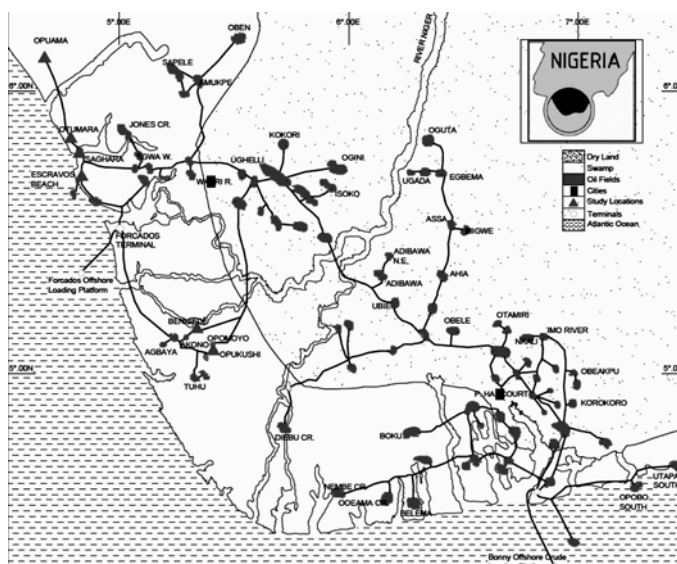


Fig. 1. Niger delta map showing the six locations (shell petroleum development company)

Experimental

Sampling and laboratory analyses. Sampling and laboratory analyses were conducted on the six locations for ten months (march to december). Temperature was measured in situ with a portable thermometer. conductivity was also measured in situ using a conductivity meter. Water samples collected from the six locations were immediately sent to the laboratory for other physicochemical analyses. Samples that could not be analyzed immediately were preserved in the refrigerator prior to analysis. Multiple samples were collected from each location

during each sampling exercise in order to avoid contamination when analyzing for different parameters. All analyses were carried out in strict adherence to the analytical procedures of the Department for Petroleum Resources. All laboratory analyses were carried out by Tudaka Environmental Consultants in accordance with the methods of the American Public Health Association, APHA (1998) and the Recommended Practices of American Petroleum Institute (API-RP). Analytical Methods used have been presented in Table 1.

Table 1. Methods of Sample Analyses

Parameter	Method	Parameter	Method
pH	API RP45	Conductivity ($\mu\text{S}\cdot\text{cm}^{-1}$)	Conductivity Meter
Temperature ($^{\circ}\text{C}$)	Thermometer	Salinity (mg/L)	API-RP45
Turbidity (NTU)	APHA 214A	Nitrate (mg/L)	ASTM D3867
TDS (mg/L)	APHA 209C	Sulphate (mg/L)	APHA 427C
TSS (mg/L)	APHA 209D	Zinc (mg/L)	AAS-SP2900
DO (mg/L)	APHA 422B	Copper (mg/L)	AAS-SP2900
BOD (mg/L)	APHA 507	Iron (mg/L)	AAS-SP2900
COD (mg/L)	APHA 506	Lead (mg/L)	AAS-SP2900
Oil (mg/L)	API-RP45	Chromium (mg/L)	AAS-SP2900

Keys: ASTM –American Society for Testing and Materials; AAS-SP2900 – Atomic Absorption Spectrophotometer, Model SP2900.

Statistical Analyses. SIn water quality monitoring which involves a vast number of parameters with no explicit physical relationships, it is usually necessary to understand which parameters is driving the variations in the characteristics of the water. This implies that, in most cases, not all the parameters measured are useful as some parameters may have very high correlations. Principal component analysis is a non-parametric approach used for reducing the dimensionality of such data in order to render the data amenable to better interpretation. The number of principal components obtained from principal component analysis is usually the same as the number of variables (parameters) measured. However, the first few principal components usually explain a higher percentage of variance than the rest of the principal components. A number of approaches have been proposed to aid the selection of the most important principal components but the user should always be guided by discretion and interpretability of principal components. In this study, the standardized principal component analysis was used

to analyze the data. This approach was useful in this because the parameters have widely differing units and magnitudes. This method involves first standardizing the data thereby converting the covariance matrix to the correlation matrix, before proceeding with principal component analysis. Various methods of standardization exist but in this research, standardization was achieved by subtracting the group mean from each variable and dividing by the group standard deviation so that the all the data had zero mean and a unit variance.

Cluster analysis helps in identifying natural groupings among a group of variables or individual measurements that have no straightforward relationship. Vialle et al (2011) observed that cluster analysis nicely complements principal component analysis. This statement was validated by performing cluster analysis on the data. A matrix was first formed with the variables forming the columns while individual sampling results formed the rows and agglomerative hierarchical cluster analysis was performed to search for natural groupings among the physicochemical parameters measured. Another matrix was formed with variables (physicochemical parameters) forming the rows while sampling results formed the columns. Afterwards cluster analysis was performed to search for natural groupings among sampling locations. The method applied was Ward's method using the squared Euclidean distance as a measure of dissimilarity. The columns were labelled to reflect the month of sampling and the sampling location. In order to avoid clumsiness in labelling, the six locations were numbered 1 to 6 to avoid using their names.

Results and discussion

The pH was fairly stable ranging from 6.16 to 7.86. The dissolved oxygen ranged from 0.7 to 7.1 mg/L which signified occasional oxygen deficit. Usually, an oxygen deficit results from the oxygen demand of micro organisms while degrading waste organic matter. But Table 2 shows that BOD values for the five locations were low (0.1 to 5.79) which implied that the oxygen deficit might have been contributed by other factors. The oxygen deficit probably resulted from disruption in re-oxygenation process rather than de-oxygenation resulting from microbial activities. Re-oxygenation can be caused by sealing of the surface of water by grease and oil thereby giving rise to anaerobic conditions. The presence of oil and grease (1.33 mg/L to 58.27mg/L) in the sampling locations was due to the discharge of effluents resulting from oil production activities and occasional spills (224 cases in 2005 and 241 cases in 2006). The water samples were high in total dissolved solids (TDS), salinity and conductivity.

For metals, chromium and lead were below the limits of the Department for Petroleum Resources (DPR) for all samples. However, copper, zinc and iron occasionally exceeded the limits. Pearson correlations between all pairs of parameters have been presented in Table 3. There was high correlation between nitrate and salinity ($R = 0.718$, $p < 0.01$), BOD and dissolved oxygen ($R = 0.789$, $p < 0.01$), conductivity and total dissolved solids ($R = 0.877$, $p < 0.01$), salinity and sulphate ($R = 0.645$, $p < 0.01$), temperature and pH ($R = 0.627$, $p < 0.01$). R is the coefficient of correlation while p is the level of significance. There was no significant correlation between any pairs of metals (see Table 3). The correlation between ammonium and some parameters may not be reliable due to the prevalence of missing data for ammonium. For instance, the correlation between ammonium and lead was 0 and that was also the case for the correlation between oil and ammonium. The correlation coefficient between ammonium and copper was 1.0. Obviously, these values cannot be taken seriously as there is no known plausible explanation for such perfect correlations.

Table 2. Descriptive Statistics of Physicochemical Parameters Monitored

Parameter	Number of samples	Minimum	Maximum	Mean	Standard Deviation	Median
pH	41	6.16	7.86	6.97	0.41	6.9
Temperature (°C)	41	18.80	37.00	28.37	4.78	28.7
Turbidity (NTU)	41	1.35	62.85	30.44	14.42	29.9
TDS (mg/L)	41	43.00	96928	5849	15503.41	974
TSS (mg/L)	41	10.00	300	52.93	50.95	40
DO (mg/L)	41	0.70	7.10	4.07	2.02	4.6
BOD (mg/L)	41	0.10	5.79	2.33	1.64	2.8
COD (mg/L)	39	0.10	420	78.69	103.74	40
Oil (mg/L)	41	1.33	58.27	15.12	12.20	12.36
Conductivity ($\mu\text{S}\cdot\text{cm}^{-1}$)	41	21.25	63000	3307	10070.23	400
Salinity (mg/L)	41	61.50	36676	5737	9894.94	995
Nitrate (mg/L)	41	0.01	1	0.11	0.23	0.1
Sulphate (mg/L)	39	0.01	120	22.93	29.97	8.15
Zinc (mg/L)	41	0.02	20	0.67	03.1	0.15
Copper (mg/l)	41	0.01	3	0.13	0.48309	0.03

Cont.

Iron (mg/L)	41	0.06	2.31	0.68	0.40062	0.64
Lead (mg/L)	32	0.01	0.04	0.018	0.00833	0.02
Chromium (mg/L)	29	0.01	0.03	0.02	0.00704	0.02

Principal Components. Before proceeding with the analysis, the data were checked for sampling adequacy using the Kaiser-Meyer-Oilkin measure of sampling adequacy. A value of 0.62 was obtained signifying that the data were adequate for principal component analysis. Ammonium, nitrate, chromium and lead were excluded from the analysis because of prevalence of missing data thus reducing the variables from nineteen to fifteen. There were also sporadic cases of missing data in the residual data. This was handled by a listwise exclusion of such points. Table 4 shows five principal components that explained 72.43 % of the total variance whereas the other ten contributed only 27.57 % of the total variance. Hence, the variability in the data lies in far less than fifteen components.

The first five principal components were selected by examining the scree plots (Fig. 2). The scree plot is a plot of eigenvalue versus principal component number and is normally used for determining the number of principal components to be selected. However, sometimes it can be difficult to select principal components based on scree plot as there may be no distinct change of slope. In some cases as in Fig. 2, the change in slope may be gradual (starting from PC5 and ending at PC8) rather than instantaneous.

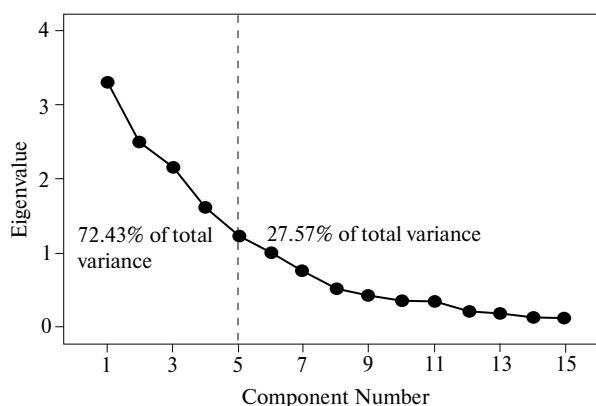


Fig. 2. Scree plots of principal components.

Table 3. Pearson Correlation Matrix for all Nineteen Parameters

Parameter	pH	Temperature	Turbidity	TDS	TSS	DO	BOD	COD	Oil	Salinity	Conductivity	NH ₄	NO ₃	SO ₄	Sn	Zn	Cu	Fe	Cr
pH	1																		
Temperature	0.627**	1																	
Turbidity	-0.169	-0.208	1																
TDS	0.217	0.233	-0.199	1															
TSS	0.352*	0.361*	0.488**	0.331*	1														
DO	-0.205	-0.244	0.173	-0.051	-0.183	1													
BOD	-0.082	-0.098	0.064	-0.125	-0.227	0.789**	1												
COD	0.178	0.146	-0.175	0.278	0.006	0.223	0.254	1											
Oil	0.150	0.183	-0.052	0.010	0.004	-0.107	-0.141	0.099	1										
Salinity	0.345*	0.319*	-0.228	0.267	0.221	-0.313*	-0.293*	-0.073	-0.126	1									
Conductivity	0.163	0.212	-0.126	0.877**	0.396**	-0.164	-0.184	0.062	-0.003	0.297*	1								
Ammonium	0.057	0.028	0.140	-0.143	-0.179	0.010	0.274	-0.174	0.000	-0.174	-0.125	1							
Nitrate	0.071	0.083	-0.034	-0.108	-0.018	-0.225	-0.309	-0.228	0.258	0.718**	-0.059	-0.316	1						
Sulphate	0.286	0.265	-0.268	0.249	0.105	-0.104	-0.039	0.148	-0.185	0.645**	0.161	0.377	0.532**	1					
Lead	-0.006	-0.005	0.028	0.199	0.179	0.304	0.288	-0.181	-0.246	0.000	0.191	0.000	-0.212	-0.163	1				
Zinc	0.084	0.109	-0.069	-0.008	0.021	0.086	0.237	0.497**	-0.067	-0.020	-0.017	-0.005	-0.082	0.263	0.022	1			
Copper	-0.034	0.002	0.205	-0.054	-0.012	-0.069	0.001	-0.067	-0.040	-0.041	-0.036	1.000**	0.552**	0.122	0.015	-0.029	1		
Iron	0.108	0.038	-0.072	-0.106	-0.003	-0.274	-0.295*	0.058	0.488**	-0.145	-0.125	-0.126	0.033	-0.091	-0.259	0.072	0.004	1	
Chromium	-0.046	-0.243	0.124	0.254	0.087	0.100	0.154	-0.124	-0.224	0.219	0.186	0.414	-0.180	0.331*	0.328	0.002	0.226	0.303	1

*Correlation is significant at 0.05, **Correlation is Significant at 0.01.

Table 4. Loadings of First Five Principal Components

Parameter	PC1 (22.10%)	PC2 (16.76%)	PC3 (14.45%)	PC4 (10.9%)	PC5 (8.23%)
Salinity	0.853	0.098	0.018	0.177	0.053
Sulphate	0.839	0.043	0.038	0.060	0.267
Conductivity	0.836	0.002	-0.150	0.097	-0.112
TDS	0.033	0.903	-0.040	0.126	-0.056
TSS	0.142	0.880	-0.230	0.183	0.057
BOD	-0.105	-0.154	0.876	0.111	0.277
DO	-0.128	-0.237	0.859	-0.059	0.078
Iron	-0.294	-0.225	-0.580	0.338	0.232
pH	0.265	0.297	-0.029	0.741	0.054
Temp	0.218	0.308	0.037	0.736	0.067
Oil	-0.350	-0.317	-0.388	0.630	0.070
Turbidity	-0.303	0.523	-0.062	-0.561	-0.081
Zinc	0.121	0.053	0.070	-0.070	0.884
COD	0.001	-0.069	0.104	0.216	0.789
Copper	0.038	-0.016	-0.007	-0.032	-0.065

This dilemma was resolved by ensuring that the selected principal components explained up to 70 % of the total variance as clearly indicated in Fig. 2. The first principal component (PC1) explained 22.1 %, the second principal component (PC2) explained 16.76 %, the third component explained 14.45 %, the fourth component explained 10.9 % and the fifth component explained 8.23 %. A three dimensional representation of PC1, PC2 and PC3 in rotated space was shown in Fig. 3. The method of component rotation applied was varimax rotation. Fig. 3 clearly shows that PC1 has a high loading on conductivity, salinity and sulphate; PC2 has a high loading on TDS, total suspended solids (TSS) and Turbidity; and PC3 has a high loading on BOD and COD. These three principal components together explained 53.31 % of the total variance.

Having reduced the dimensionality of the data from fifteen to five, we proceed with interpretation. The first principal component had high positive loadings on conductivity, salinity and sulphate. Hence the first principal component can be said to represent sea water intrusion from the Atlantic Ocean. All six locations are adjacent to the Atlantic Ocean. During high tide, water from the Atlantic Ocean overflows into adjoining creeks and rivers. Saline water

intrusion has been exacerbated by the proliferation of canals constructed by oil companies to gain access to their offshore facilities. Abam (2001) reported that canal construction and the attendant dredging activities have given rise to saline water intrusion heralded by the disappearance of freshwater vegetation and the emergence of mangrove vegetation. He further stated that the dredging of an upstream channel or construction of a new dam upstream could affect downstream discharges and sediment transport, which may invariably alter the location of the saline water–freshwater interface at the estuary. Aghalino and Eyinla (2009) also reported that the excessive abstraction of groundwater through boreholes in the Niger Delta cities of Port Harcourt and Warri has often caused a reversal of hydraulic gradient, leading to saline water intrusion. The second principal component has high positive loadings on turbidity, TDS and TSS and a negative loading on dissolved oxygen, oil and BOD. This component represents the total inorganic solid content of water. Sediment transport is a key phenomenon in the Niger Delta estuary as the River Niger delivers about 50mg/L (Gibbs et al., 1978) of sediment to the Atlantic Ocean via the estuary.

The construction of navigation canals in recent years has increased the sediment load of the estuary by freeing up soil particles. However, due to high sediment load, these canals are soon silted up prompting the owners to dredge them. The dredge spoils are often deposited on the river bank and are returned to water bodies by runoff during the rainy season.

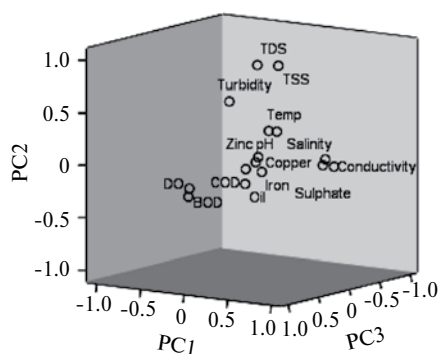


Fig. 3. Component plot in three dimensional rotated space.

Ohimain et al. (2008) reported an increase in turbidity from 20 nephelometric turbidity units (NTU) to 11398 NTU and an increase in TSS from 20mg/l to 8200mg/l after the dredging of an oil well access canal in the Niger Delta. They also observed a corresponding increase in TDS accompanied by

re-suspension of heavy metals, increased acidity, vegetation damage, fish kills and reduction in the population of phytoplankton. Hence, the second principal component is driven by both anthropogenic activities and the dynamics of the hydrogeology of the Niger Delta estuaries. A greater proportion of sediment generated in the Niger Delta estuaries results from urbanization and oil exploration (Dike, 2010) accompanied by borehole drilling, dam construction and canalization. A two-dimensional plot of PC1 and PC2 was presented in Fig. 4. The sampling sessions were numbered to enable ease of detection of groupings. The third component has a high positive loading of BOD, dissolved oxygen, and hence, represents organic pollution of water. Organic pollution of water results from discharge of sewage from riverine communities and dredging house boats, dredged materials, municipal drains and public toilets. A major contributor to the organic loads of water in the Niger Delta is oil spillage resulting from failure of machine parts, bilge and effluent discharges, pipeline wreckage, seepage and leakages from oil tankers. Between 1976 and 1996 a total of 4647 incidents resulted in the spill of approximately 2,369,470 barrels of oil in the Niger Delta (Egberongbe et al, 2006). McCauley (1966) observed that oil has a high oxygen demand ranging from 3.1 to 3.5 mg of oxygen per mg of oil decomposed. The fourth and fifth principal components have a high loading on pH, temperature and oil, COD and zinc.

This component represents the impact of gas flow effluent discharge on the characteristics of receiving water. The final stage in oil production involves separation of oil from constituent water (formation water) which makes up about 50 % of the total volume. In addition to polluting water with oil, Okoh et al. (1996) noted that gas flow station effluent can cause thermal pollution and alter the pH of receiving water.

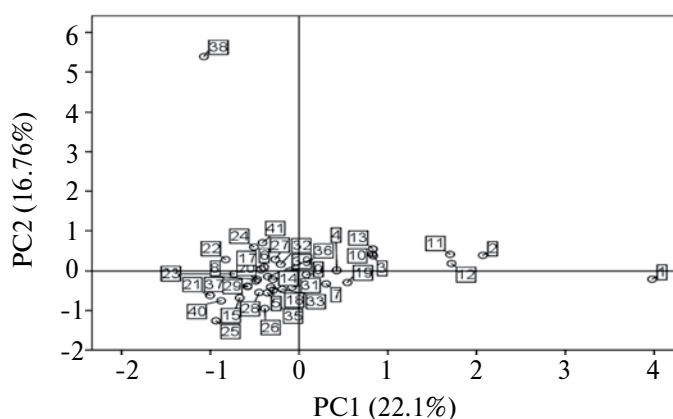


Fig. 4. Two dimensional representation of sampling data.

Cluster Analysis. The data was standardized as previously described to equalize the importance of all parameters involved, before performing cluster analysis. The result of the principal component analysis was fairly reproduced by cluster analysis with minor variations as can be seen from Fig. 5. Fig. 5 shows the cluster groupings of physicochemical parameters regardless of location or season of sampling. A broken line was used to delineate the cluster groupings such that they approximately agree with the principal components. Group A comprises DO and BOD and hence corresponds to PC3. Group B corresponds to PC5, group C corresponds to PC1, group D corresponds to PC2 and group E corresponds to PC4. There are other two groups which do not correspond to any of the selected five principal components. These groups correspond to two of the principal components which were not selected. Hence cluster analysis has been used to validate the results obtained from principal component analysis.

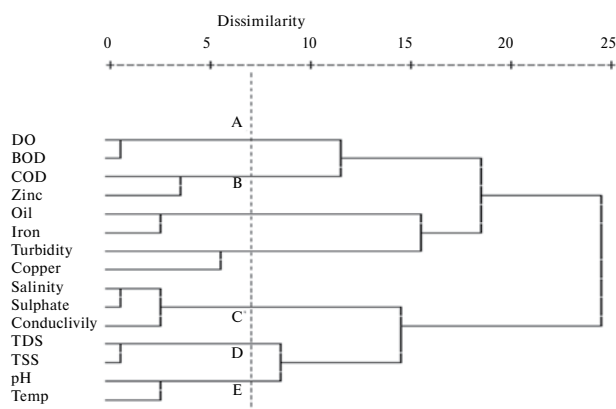


Fig. 5. Cluster groupings for physicochemical parameters.

The second cluster analysis was performed in order to search for natural groupings among sampling locations and season. Fig. 6 shows the result of cluster analysis based on sampling location and season.

Each sampling session was labelled to reflect the location and month of sampling. In a bid to minimize clumsiness, the six locations were designated as locations 1 to 6 as shown in Fig. 6. For instance, the sampling session labelled Oct3 refers to sampling done at Escravos in October. The broken line shown in Fig. 6 was used to indicate the groupings. Five major groupings designated as F to J are evident. Groups F and J do not portray any immediate pattern and hence can be considered as outliers because the two extreme sessions, March1 and March5

respectively correspond to the outliers numbered 1 and 38 in Fig. 4. A very keen observation of groups G, H and I reveals a pattern which has been brought to the fore by summarizing the result of the cluster analysis in Tables 5 and 6 based on months and locations respectively. This was done by noting the number of times a location or month appeared in a particular cluster. There were no marked differences among the sampling locations as they were somewhat uniformly distributed across all the cluster groups. The cluster number of cases in Table 5 refers to the numbers of times a location appeared in a particular cluster. Similarly, the cluster number of cases in Table 6 refers to the number of times a particular month appeared in a particular cluster. This was further buttressed by the two-dimensional plot of the data on PC 1 and PC 2 in Fig. 3 showing that the points are evenly distributed except for a few outliers. The fact that the locations seemed to fall under one group showed that their commonalities outweighed their differences. The six locations mutually share proximity to the sea, discharge of gas flow effluents, location within the Niger Delta estuary, occasional oil spillage and high sediment loads.

Table 5. Summary of Cluster Analysis Based on Location

Cluster No of Cases	Otumara	Saghara	Escravos	Opukushi	Opuama	Benisede
1	1	0	0	0	1	1
2	2	5	2	1	1	2
3	4	3	6	3	0	2
4	3	2	1	3	2	1
5	0	0	0	0	0	2

However, very distinct patterns were observed when the clusters were considered on monthly basis regardless of sampling location as depicted in Table 6. Discarding clusters F and J for having very few number of cases, group G seemed to cover the months starting from the onset of rainy season to the peak of the season, group H seemed to cover the months starting from the peak of rainy season to the recession, while group I covered the months in the middle of rainy season. This indicates that the variation in the characteristics of these locations was affected most by climatic conditions (rainfall).

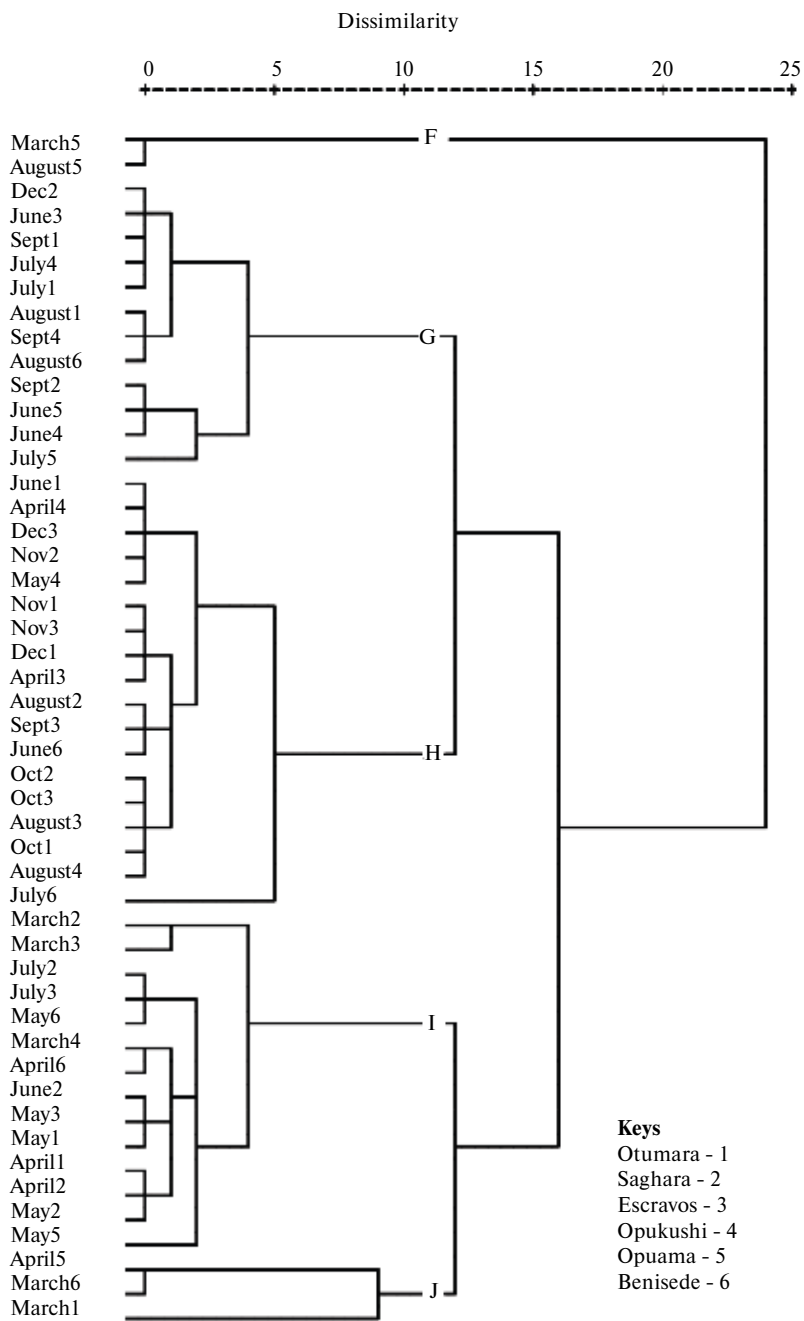


Fig. 6. Cluster groupings for season and location

The Niger Delta has the highest annual rainfall in Nigeria, ranging between 2000 mm and 4000 mm. Rainfall in the Niger Delta has a bimodal pattern with maximum rainfall occurring in July and September. Though there are two seasons (dry and rainy) in principle, rain falls in the Niger Delta all year round (Fig. 7). Effectively, rainfall starts in March and ends in November with both months recording just about 150mm of rainfall individually.

Table 6. Summary of Cluster Analysis Based on Season

Cluster No of Cases	March	April	May	June	July	August	September	October	November	December
1	2	1								
2	3	3	5	1	2					
3		2	1	2	1	3	1	3	3	2
4				3	3	2	2			1
5	1					1				

Several researchers have reported the dilution effects of intense rainfall on the physicochemical characteristics of water bodies in the Niger Delta. Eludoyin et al.,(2004) observed the same trend in a reservoir receiving market effluent in Ile-Ife, Nigeria. Sampling done during the rainy season usually yields results that diminish the level of pollution, hence water quality surveys must cover both rainy and dry seasons for a true picture to be obtained. Fig. 7 was used to buttress the effect of rainfall on key physicochemical parameters such as pH, salinity, conductivity, oil and grease.

The bars represent annual rainfall depths (twenty-two years average) plotted on the primary axis while the lines represent the standard score of the aforementioned physicochemical parameters plotted on the secondary axis. Fig. 7 reveals a marked reduction in salinity, conductivity, pH, oil and grease contents resulting from the dilution effect of rainfall.

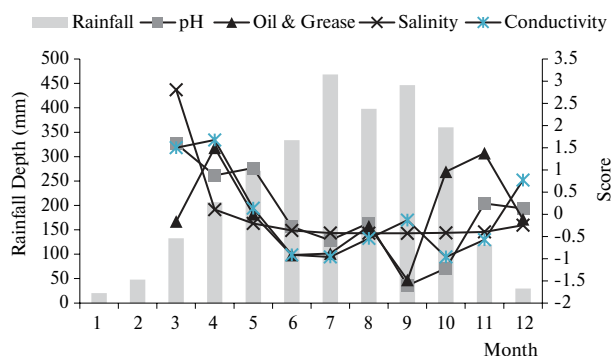


Fig. 7. Plot of parameter scores and twenty-two years (1980 – 2001) average rainfall.

The greatest effects of dilution were observed between the months of June and September after which this effect started to diminish. The rainy season in the Niger Delta is usually accompanied by reduced evaporation rates due to relatively low temperatures and high humidity. As rain recedes, temperature begins to rise and consequently evaporation rate increases causing a high concentration of pollutants in water. The coldest month was August during which a temperature reduction of about 50 % was recorded. There is deception hidden in the overall effect of rainfall on water quality in the Niger Delta. It would seem that the water bodies are less polluted in the rainy season. However, the overall pollutant transported into the Ocean is more in rainy season than in the dry season despite the dilution effect. Rainfall is an additional source of pollution if gas flaring is taken into consideration. Gas flaring releases acidic and toxic oxides into the atmosphere which dissolve readily in rainwater. This was evident as the pH fell from a near neutral state to acidic condition. The lowest pH of 6.16 was recorded at the peak of the rainy season in the month of July.

Conclusion

Fig. 8 was used to clearly illustrate and summarize the process of water pollution in the six study locations. The characteristics of water sampled from the six locations were found to be composed of five principal components. These principal components represent the effects of saline water intrusion from the Atlantic Ocean; hydro geological effect embodied in transport, deposition and dissolution of solids; organic pollution and gas flow stations effluent discharge.

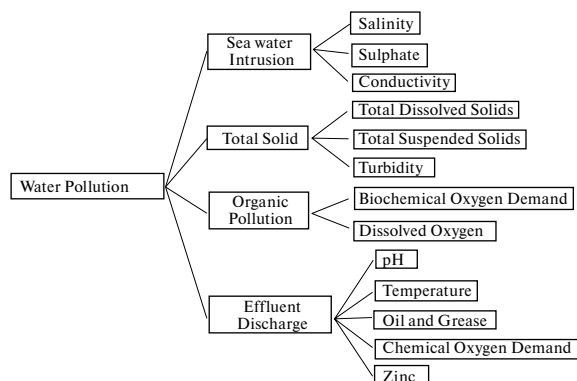


Fig. 8. Flow chart of water pollution in study locations.

The fourth and fifth principal components together represent the impact of gas flow stations effluent. These principal components explained 72.43 % of the total variance associated with the data. Cluster analysis showed that the characteristics of water sampled from the six locations were largely dependent on season but independent of location of sampling. Hence, the similarity between the water samples were informed by the dilution effect of rainfall, reduced evaporation rate during the rainy season and dissolution of gas flaring fumes in rain water. Though gas flow station effluent reduced the quality of receiving water, it was not the leading cause of water quality variations in the study area.

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Recieved 18.10.2011