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# Delineating Stations along the Coastline of Delta State, Nigeria into Pollution Categories: Multivariate Approach

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***Authors' contributions***

*This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.*

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## ABSTRACT

Aquatic ecosystems disturbance globally are increasing at alarming rate and it has debilitating effects on the ecological balance of the systems. The disturbances experienced by aquatic systems arise mainly from human influences. In this present study, we delineated six stations into pollution categories using multivariate approach (principal component analysis; PCA). The six stations selected were; SW 1- sea water (Benin River mouth/sea), SW2- Benin River (Benin River mouth/sea), SW3- sea water (Escravos River mouth/sea), SW4-River mouth (Escravos River mouth/sea), SW5- sea water (Forcados River mouth/sea) and SW6-River mouth (Forcados River mouth/sea). The PCA we constructed to visualize the relationship between the sampled stations and selected physico-chemical parameters showed that the first PCA component had a variance of 53.29% with an eigenvalue of 6.93 while the second PCA component explained 38.10% with an eigen value of 4.95. SW1 and SW2 were negatively correlated with DO, THC and conductivity, and nitrate, COD, TSS and temperature were negatively correlated with SW5 and SW6. Phosphate, salinity and turbidity were positively correlated with SW3 and SW4. Sulphate, pH and BOD were not associated with any of the stations sampled. Of the six stations we delineated, four were categorized as heavily polluted and they include; SW1, SW2, SW5 and SW6, while SW3 was moderately polluted and SW4 was fairly polluted. This showed that the selected stations within the coastlines of Delta State, Nigeria are heavily impacted by human influences.

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## 1. INTRODUCTION

Urbanisation and industrial developments have been implicated as the major factors aggravating the level of pollution in aquatic systems [1,2]. This is the case of the current study area (coastline of Delta State of Nigeria), due to increasing industrial and urban developments occasioned by rural-urban migration. Delta State is located in the Niger Delta region of Nigeria and it is the oil rich region contributing the largest chunk of economic earnings to the country. Hence, industrial and urban developments are on the rise due to the presence of crude oil deposition in most parts of the state as well as the localization of oil exploration outlets in the region and Delta State inclusive. The activities resulting from the exploration of the crude oil have resulted in the degradation of the environment and the aquatic systems are the most affected.

In assessing, the levels of degradation in aquatic systems, the concentrations of and variations in physico-chemical parameters have been employed. For instance high concentrations of parameters such as nutrients (sulphate, nitrate and phosphate), biochemical oxygen demand (BOD), conductivity and turbidity have been used as measures the level of degradation occurring in an environment spanning from increasing humans activities [3,4]. Following the thinking of previous studies, we analysed selected physico-chemical parameters in the current study area in a bid to assess the level of degradation occurring in the selected stations marked out for this study. In measuring the level of degradation, several statistical tools are been employed and they include descriptive statistics, univariate and multivariate analyses. Among the statistics, descriptive statistics are mostly employed due to their easy interpretation.

Aside the use of descriptive statistics, multivariate approaches such as non-metric multidimensional scaling (NMDS), principal component analysis (PCA), canonical analysis of principal coordinates (CAP) and canonical correspondent analysis (CCA) are also used to determine the level of significance and correlation of selected environmental variables with the stations surveyed [5-7]. The multivariate approaches have been widely used in categorizing and identifying stations into pollution gradients [4,5]. Among the multivariate approaches employed in identifying and categorizing stations into impact categories, the PCA is one of the most employed approaches. The PCA is an ordination analysis used to explain the correlation between environmental parameters and stations [8]. The PCA is a biplot that helps in relating stations with environmental variables as well delineating the stations into level of pollution. Other studies have also employed the PCA and CCA in classifying sites and organisms into impact categories [4-5,9]. For instance, Edegbene et al. [7] recently classified 20 stations in 11 riverine systems into pollution impact categories namely: least impacted sites (LIS), moderately impacted sites (MIS) and heavily impacted sites (HIS). Also, Ogidiaka et al. [6] classified five sites in Farcados Estuary into three potential ecological classes along a pollution gradient namely; least disturbed stations (LDS), moderately disturbed stations (MDS) and heavily disturbed stations (HDS). Following the thinking of these authors, we delineated six stations in the current study area into pollution categories in a bid to using them as ecological gauge to assess the level of degradation in aquatic ecosystems in the Niger Delta region of Nigeria. Therefore, the current is aimed at delineating stations along the coastline of Delta State, Nigeria into pollution categories using multivariate approach.

## 2. MATERIAL AND METHODS

### 2.1 The Study Area

The study area is located along the coastline of Delta State within the Niger Delta region of Nigeria. The Niger Delta region occupies an approximate area of 70, 000 km$^2$ and it is located at the southern tip of Nigeria [10]. The region is the third largest wetland system in the world [11,12]. The area is characterised by mangrove swamps, wetlands, inland waters, brackish waters, vegetation, and an extensive tropical rain forest [13,14]. Two seasons characterised the study area: wet and dry seasons, the wet season is between March and October, and the dry season is between November and February. Three riverine systems namely: Benin, Escravos and Forcados Rivers were marked out for this study. Two stations each were selected for each of the rivers. Table 1 below shows the six stations sampled, their geographical location, features of reach of the stations, assessment by community and activities along each stations.

**Table 1. The coastlines of Delta State, Nigeria, geographical locations, features, communities and activities at the sampling stations**

| Stations | Coastline and sand beaches | GPS Location | Features | Community | Activities |
|---|---|---|---|---|---|
| **SW1** | Seawater | 4.954592, 5.823057 | 5km into the Atlantic | Ogheye | Maritime |
| **SW2** | Benin River | 5.072377, 5.757282 | 500m Benin River | Orere | Local fishing |
| **SW3** | Seawater | 5.05861, 5.622671 | 5km into the Atlantic | Aruton | Oil and gas platforms |
| **SW4** | Escravos River | 5.174864, 5.573722 | 500m Escravos River | Ogidigben | Chevron Terminal |
| **SW5** | Seawater | 5.151919, 5.440641 | 5km into the Atlantic | Forcados | Oil and gas logistics |
| **SW6** | Forcados River | 5.311005, 5.385573 | 500m Forcados River | Beniboye/ Ogulagha | Shell Terminal |

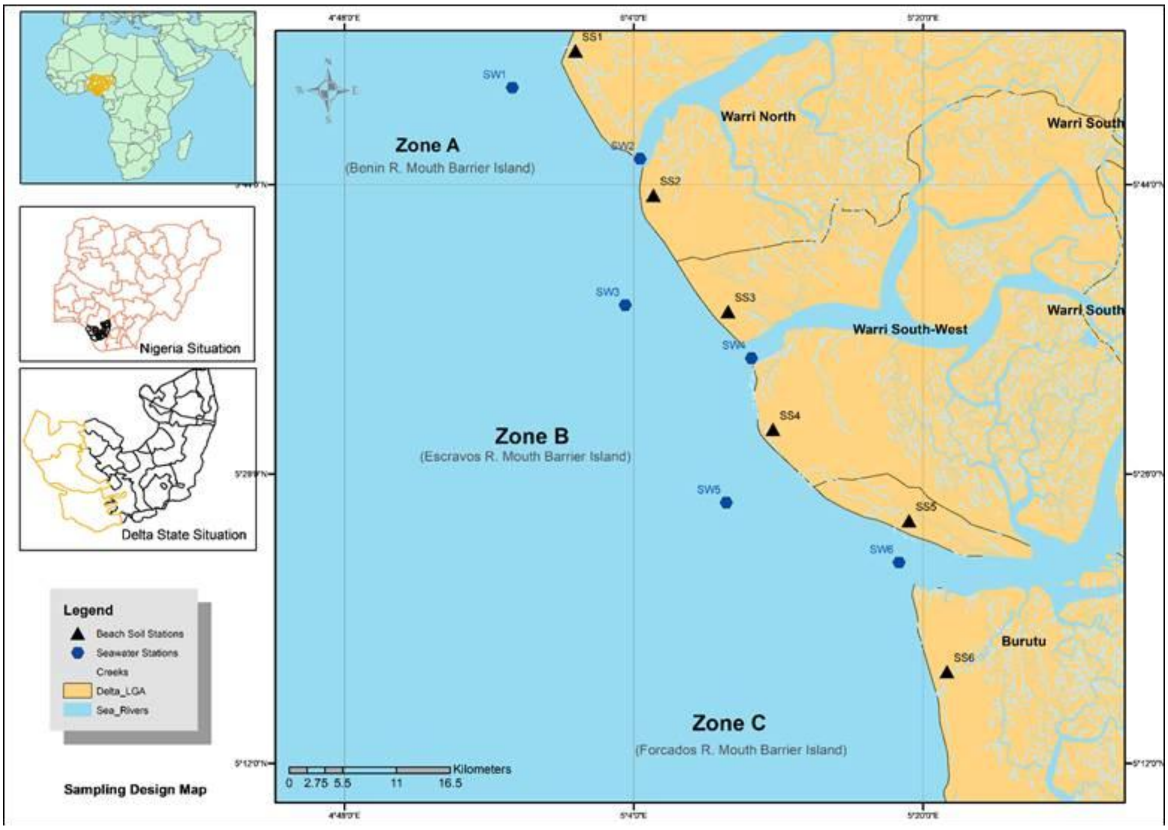


**Fig. 1. Map of the study area showing the sampling stations along the coastline of Delta State, Nigeria**

## 2.2 Sampling and Analysis of Physico-Chemical Parameters

Surface water physico-chemical parameters were collected and analysed for a period of 22 months between November 2019 and August 2021. The following physico-chemical parameters were analyzed in the course of the present study: pH, temperature, conductivity, salinity, dissolved oxygen (DO), turbidity, total suspended solids (TSS), total hydrocarbon (THC), biological demand oxygen (BOD), chemical oxygen demand (COD), nitrate, sulphate and phosphate. pH was measured using pH meter (model: HANNA HI 9828), temperature was measured using mercury-in-glass thermometer. Conductivity and TSS were measured using conductivity meter (model: DDSJ-308A). Turbidity was measured using turbidity meter (model: WGZ-B) and it was measured in nephelometric turbidity unit (NTU). THC, BOD, COD, nitrate and phosphate were determined following APHA [15] methods.

## 2.3 Data Analysis

Mean, standard error and range of physicochemical variables were calculated per station using the Univariate function on Palaentological Statistical package (PAST) [16]. Two-Way Analysis of Variance (ANOVA) without replicate was used to test for differences ($P < 0.05$) in the means of the measured water physico-chemical parameters between the six stations sampled [6]. When ANOVA indicated significant differences, a post-hoc test, the Tukey's Honest Significant Different (HSD) test was computed to indicate station mean that showed significant difference.

We used principal component analysis (PCA) to correlate selected physico-chemical parameters with the six sampled stations. Station pollution category was undertaken by first extricating the coordinate's score loadings from the first component of the PCA. The first component of the PCA was used because it explained the highest variance (53.29%) among the six PCA components visualized. The PCA was constructed using PAST [16].

We categorized the six stations into pollution categories by following the thinking of Edegbene [4] who used the first axis of PCA to delineate sites into pollution gradient based on the following procedures: (i) the coordinate scores of the six stations were extricated, (ii) the extricated scores were used to calculate inter-station distance of each station by subtracting the lowest scoring station from the remaining stations one after the other, (iii) we converted the inter-station distance to percentages, and (iv) we used three particle distribution to delineate the stations into pollution categories; 100% (fairly polluted, FP), 50%-99.99% (moderately polluted, MP), 0-<50% (heavily polluted; HP). The PCA was constructed using PAST [16].

## 3. RESULTS AND DISCUSSION

### 3.1 Results

The mean, standard error, minimum and maximum values, ANOVA (F-values, p-values) of the physico-chemical parameters in the stations sampled along the coastline of Delta State, Nigeria as well as the Turkey Honest significant differences (HSD) among stations means are summarized in Table 2.

The highest mean dissolved oxygen (DO) ($6.57 \pm 0.028$) was recorded in SW1, and the highest conductivity ($425.09 \pm 8.69$) and total hydrocarbon (THC) ($0.84 \pm 0.038$) were recorded in SW2 (Table 2). pH ($7.39 \pm 0.046$), salinity ($21.59 \pm 0.89$), sulphate ($1.67 \pm 0.066$) and phosphate ($0.26 \pm 0.02$) highest mean values were recorded in SW3 (Table 2). Turbidity ($6.26 \pm 0.41$) was highest in SW4, and biochemical oxygen demand (BOD) ($2.89 \pm 0.38$) were highest in SW5 (Table 2). Total suspended solids (TSS) ($24.01 \pm 1.66$), temperature ($31.20 \pm 0.66$), chemical oxygen demand (COD) ($6.86 \pm 0.50$) and nitrate ($2.11 \pm 0.44$) were highest in SW6 (Table 2). pH, temperature, conductivity, turbidity, chemical oxygen demand, nitrate, sulphate and phosphate were significantly different in both the stations and months sampled ($P<0.05$). Salinity, dissolved oxygen, total hydrocarbon and biochemical oxygen demand were only significantly different among the stations sampled ($P<0.05$), while salinity, DO, total suspend solids, THC and BOD were not significantly different among the months sampled ($P>0.05$).

The PCA we constructed to visualize the correlation between the sampled stations and selected physico-chemical parameters revealed component 1 to have variance of 53.29% with an eigenvalue of 6.93 while component 2 explained 38.10% with an eigen value of 4.95 (Fig. 2).

SW1 and SW2 were negatively correlated with DO, THC and conductivity, and nitrate, COD, TSS while temperature were negatively correlated with SW5 and SW6 (Fig. 2). Phosphate, salinity and turbidity were positively correlated with SW3 and SW4, and sulphate, pH and BOD were not associated with any of the stations (Fig. 2).

**Table 2. Summary of physico-chemical parameters of the stations sampled along the coastline of Delta State, Nigeria**

| Parameters | SW1 | SW2 | SW3 | SW4 | SW5 | SW6 | Months | | Stations | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | F-value | P-value | F-value | P-value |
| pH | 7.39±0.046 (7.07-7.72)$^{abd}$ | 7.27±0.033 (7.1- 7.61)$^{abd}$ | 7.92±0.083 (7.19- 7.61)$^{bc}$ | 7.67±0.065 (7.06- 8.1)$^{cd}$ | 7.77±0.098 (5.98- 8.32)$^{cd}$ | 7.83±0.054 (6.88- 8.14)$^{cd}$ | 2.60 | 0.00076 | 18.86 | 2.42E-13 |
| Temperature (°C) | 28.29±0.15 (27.0 – 30.0)$^{abc}$ | 28.52±0.24 (25.3- 29.9)$^{abc}$ | 27.22±0.39 (20.9-29.98)$^{abc}$ | 8.16±0.11 (27.48 – 29.05)$^{bc}$ | 30.0±0.70 (25.3- 38.6)$^{bc}$ | 31.20±0.66 (26.9 – 37.4)$^{c}$ | 2.76 | 0.00035 | 13.71 | 2.69E-10 |
| Conductivity (µS/cm) | 391.77±10.11 (320- 469)$^{abc}$ | 425.09±8.69 (321- 473)$^{bc}$ | 34.23±1.28 (13.4- 39.0)$^{c}$ | 35.49±1.00 (16.8- 39.4)$^{c}$ | 28.11±1.42 (18.4- 39.2)$^{c}$ | 28.11±1.42 (18.4- 39.2)$^{c}$ | 1.53 | 0.083 | 1350.71 | 1.48E-93 |
| Salinity (g/L) | 14.24±0.85 (10.0-23.13)$^{ab}$ | 14.46±1.057 (8.1- 23)$^{ab}$ | 21.59±0.89 (7.7- 29)$^{b}$ | 2.27±1.12 (10.0- 31.8)$^{b}$ | 14.16±1.33 (2.85- 23.4)$^{a}$ | 14.58±1.44 (2.88- 27.1)$^{a}$ | 0.49 | 0.97 | 11.05 | 1.46E-08 |
| DO (mg/L) | 6.57±0.028 (6.40-6.80)$^{abc}$ | 6.55±0.030 (6.30- 6.78)$^{abc}$ | 3.97±0.15 (2.99- 5.20)$^{bc}$ | 3.87±0.11 (3.00 – 5.00)$^{bc}$ | 3.48±0.11 (2.68- 4.30)$^{c}$ | 3.59±0.16 (2.90- 6.30)$^{bc}$ | 0.58 | 0.92 | 165.86 | 3.62E-48 |
| Turbidity (NTU) | 4.29±0.41 (1.60- 8.18)$^{ac}$ | 5.32±0.49 (1.65- 8.50)$^{abc}$ | 5.46±0.47 (1.69- 8.00)$^{ac}$ | 6.26±0.41 (2.40- 9.00)$^{c}$ | 5.48±0.35 (3.15- 8.20)$^{ac}$ | 4.02±0.26 (2.70- 7.90)$^{ac}$ | 7.31 | 1.07E-12 | 8.66 | 6.74E-07 |
| TSS (mg/L) | 15.45±1.67 (4.97-31.0)$^{abc}$ | 15.07±1.97 (4.96- 31.4)$^{abc}$ | 13.30±1.67 (4.00- 42.00)$^{bc}$ | 12.70±0.54 (6.10- 20.0)$^{ab}$ | 22.91±3.89 (10.50- 70.00)$^{ac}$ | 24.01±1.66 (10.50-35.00)$^{c}$ | 0.91 | 0.57 | 5.39 | 0.000109 |
| THC (mg/L) | 0.82±0.039 (0.49- 1.20)$^{ab}$ | 0.84±0.038 (0.45- 1.30)ab | 0.28±0.023 (0.10- 0.61)$^{b}$ | 0.29±0.013 (0.17- 0.43)$^{b}$ | 0.28±0.017 (0.12- 0.49)$^{b}$ | 0.28±0.017 (0.12- 0.43)$^{b}$ | 1.24 | 0.23 | 118.66 | 1.47E-41 |
| BOD (mg/L) | 1.10±0.20 (0.11- 2.80)$^{a}$ | 1.42±0.18 (0.40- 3.50)$^{a}$ | 1.63±0.13 (0.56- 2.60)$^{abc}$ | 2.57±0.25 (1.02-5.69)$^{b}$ | 2.89±0.38 (1.02-6.50)$^{abc}$ | 2.64±0.38 (0.80- 6.54)$^{ab}$ | 1.036 | 0.43 | 7.59 | 4.03E-06 |
| COD (mg/L) | 2.35±0.30 (1.01- 5.15)$^{a}$ | 4.04±0.32 (1.02- 6.8)$^{ab}$ | 3.23±0.38 (1.00- 5.90)$^{ab}$ | 3.00±0.34 (1.02- 5.80)$^{ab}$ | 4.46±0.69 (0.40- 10.00)$^{bc}$ | 6.86±0.50 (1.14- 10.00)$^{c}$ | 0.70 | 0.82 | 12.23 | 2.37E-09 |
| Nitrate (mg/L) | 0.15±0.037 (0.06-0.9)$^{ab}$ | 0.087±0.01 (0.02-0.17)$^{ab}$ | 0.088±0.06 (0.02-0.12)$^{ab}$ | 0.11±0.03 (0.02-0.7)$^{ab}$ | 1.91±0.39 (0.08-5.0)$^{b}$ | 2.11±0.44 (0.04-5.5)$^{b}$ | 2.62 | 0.00069 | 20.96 | 1.77E14 |
| Sulphate (mg/L) | 0.25±0.006 (0.20- 0.30)$^{ab}$ | 0.24±0.0056 (0.21- 0.29)$^{ab}$ | 1.67±0.066 (0.59- 2.00)$^{b}$ | 1.58±0.059 (0.77- 2.00)$^{bc}$ | 1.25±0.12 (0.08- 2.00)$^{bc}$ | 1.33±0.12 (0.06- 2.00)$^{b}$ | 1.56 | 0.074 | 70.61 | 5.24E-32 |
| Phosphate (mg/L) | 0.23±0.034 (0.09-0.86)$^{a}$ | 0.25±0.029 (0.04-0.49)$^{a}$ | 0.26±0.02 (0.02-0.4)$^{a}$ | 0.29±0.025 (0.02-0.44)$^{a}$ | 0.19±0.048 (0.008-1.01)a | 0.14±0.021 (0.01-0.31)$^{ab}$ | 1.52 | 0.085 | 3.075 | 0.012 |

*Note: Values are mean±SE; (minimum values-maximum values) in parenthesis. Different superscript letters in a row show significant differences ($p<0.05$) indicated by Tukey Honest Significant Difference (HSD) tests. SW abbreviations: SW 1- sea water (Benin River mouth/sea), SW2- Benin River (Benin River mouth/sea), SW3- sea water (Escravos River mouth/sea), SW4-River mouth (Escravos River mouth/sea), SW5- sea water (Forcados River mouth/sea) and SW6-River mouth (Forcados River mouth/sea)*

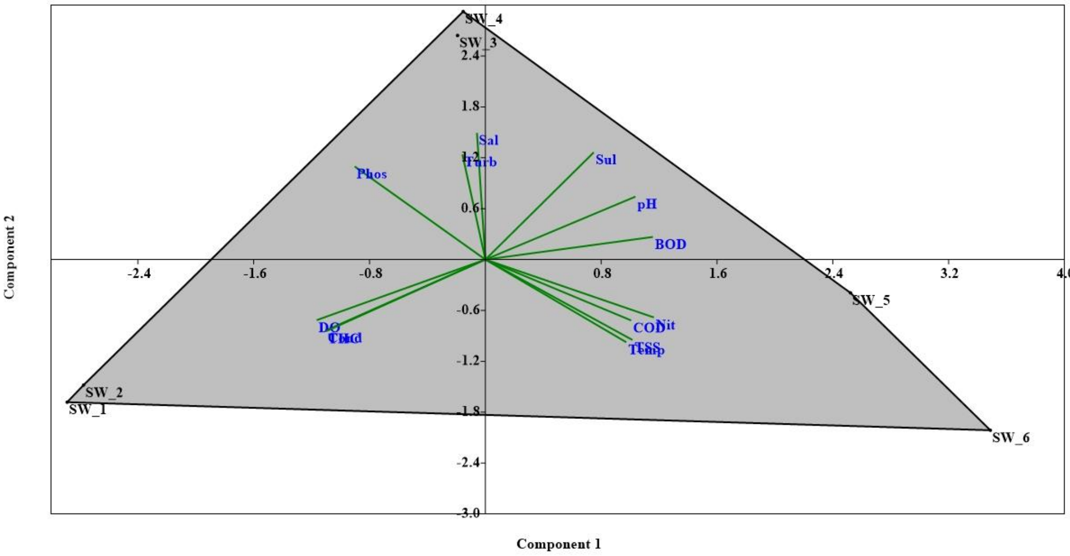


**Fig. 2. Principal component analysis (PCA) based on correlation matrix showing the correlation between selected physico-chemical parameters and stations sampled along the coastline of Delta State, Nigeria**

*Physico-chemical variables abbreviations: Temp = temperature, Cond = conductivity, Sal = salinity, DO = dissolved oxygen, Turb = turbidity, TSS= total suspended solids, THC =total hydrocarbon, BOD = biochemical oxygen demand, COD = chemical oxygen demand, Nit =nitrate, Sul= sulphate, Phos =phosphate.*

**Table 3. Categorizing selected stations along the coastline of Delta State, Nigeria**

| Stations | Extracted coordinates from PCA component 1 | Inter-station distance | Inter-station distance (%) | Pollution category |
|---|---|---|---|---|
| SW1 | -2.889 | 0.00 | 0.00 | heavily polluted (HP) |
| SW2 | -2.7755 | 0.1135 | 4.12 | heavily polluted (HP) |
| SW3 | -0.192 | 2.697 | 98.59 | moderately polluted (MP) |
| SW4 | -0.15331 | 2.73569 | 100 | fairly polluted (FP) |
| SW5 | 2.5215 | -0.3675 | -13.43 | heavily polluted (HP) |
| SW6 | 3.4883 | 0.5993 | 21.9 | heavily polluted (HP) |

Based on the visualization from the PCA, we further delineated the six stations into pollution categories, and four out of the six stations were categorized as heavily polluted and they include; SW1, SW2, SW5 and SW6, while SW3 was moderately polluted and SW4 was fairly polluted (Table 3).

### 3.2 Discussion

We delineated selected stations into pollution categories along the coastline of Delta State, Nigeria using multivariate approach in the current study. Results of the analyses of physico-chemical parameters showed an environment typical of afrotropical aquatic systems. For instance, the pH along the six stations showed an alkaline nature of the water. This is as expected as most of the sites are within the marine ecosystem. The salinity concentration further buttress the salty water nature of the study area, as mean values of salinity were relatively high with the following values; 14.24±0.85g/L, 14.46+1.44g/l, 21.59+0.89g/L, 14.16+1.33g/l and 14.58+1.44g/L recorded in SW, SW2, SW3, SW5 and SW6, respectively (Table 2). Similarly, findings with regards to alkaline pH and relatively high saline water had earlier been reported in the studies they conducted in salt water bodies in the Niger Delta region of Nigeria [16,17]. Most recently, Ogidiaka [6] reported a relatively alkaline water system in their study at the Forcados Estuary, Delta State, Nigeria. Furthermore, most of the parameters showed a degrading ecosystem sites judging from the high concentrations of some physico-chemical parameters such as conductivity, BOD and nutrients. Similar studies had reported concomitantly high concentrations of pollution indicating variables such as BOD, nitrate, phosphate and conductivity [e.g. 5,18]. These they attributed to increasing urban development, industrialization and agricultural activities which are also the case in the current study area. Urban settlements and oil exploration firms dominate most of the stations catchments we sampled. This might probably be the reason high concentrations of some pollution indicating physico-chemical parameters were recorded in most of the stations.

In delineating the stations into pollution categories, we constructed a PCA, and the PCA first two axes accounted for 91.39% of the total variance of the entire PCA variance, and this showed a good ordination. Other studies had showed that a PCA variance of 70%-90% are considered good enough to decide the reliability of environmental variables used in constructing ordination plots [19]. On the PCA ordination we constructed, parameters such as turbidity, COD, nitrate and conductivity correlated with SW5 and SW6. This showed the level of degradation these stations have been subjected. Further, we categorised and classified SW1, SW2, SW5 and SW6 as heavily impacted stations. On the other hand, SW3 and SW4 were classified as moderately and fairly polluted, respectively. This result revealed that most of the stations in the systems sampled are subjected to high level of anthropogenic influences. This is expected owing to the growing urban settlements as well as industrial developments (e.g. the presence of oil exploration outlets in most reaches of the aquatic systems) within the Niger Delta area of Nigeria.

## 4. CONCLUSION

This current study, present a baseline information on the health of the coastlines of Delta State, Nigeria. Key physico-chemical parameters such as conductivity, BOD, DO and nutrients were used to delineate stations into pollution categories using multivariate approach (PCA). The PCA result showed that selected pollution indicating physico-chemical parameters such as THC, conductivity, and nitrate, COD and TSS and temperature correlated with SW1 and SW2. Of the six station delineated, four were heavily polluted and they include, SW1, SW2, SW5 and SW6 while SW3 was moderately polluted and SW4 was fairly polluted. This confirms the level of deterioration the coastlines of Delta State of Nigeria coastline are subject to. We recommend more stations to be sampled along the coastlines of Niger Delta region of Nigeria to confirm the result of the present study.

## COMPETING INTERESTS

Authors have declared that no competing interests exist.

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