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Assessment of the Water Quality of the Benin River, Southern Nigeria, Prior to the Seaport Development Project

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Abstract

Water resources in the form of rivers, oceans and seas are prime natural resources that man has either explored or exploited. The need for clean water is on the increase and water degradation due to industrialization and development has further exacerbated the state of water bodies' degradation. The need to assess the quality status of the Benin River prior to the seaport development was inherent to document the baseline of the physicochemical parameters of the study stretch. Four stations were studied from Ajoki to opposite Young Town between January 2019 and December 2020. Physicochemical parameters and heavy metals for water were collected and analyzed adhering to quality assurance/control measures and standard procedures. Significant spatial variations ($P < 0.001$) were observed in water physicochemical parameters, except pH across the four stations. Principal Component Analysis (PCA), Pollution Load Index and Water Quality Index (WQI) were used to establish a relationship among water quality parameters and determine the water quality status. The first six components of PCA accounted for 87.77% of observed variations. WQI for sampling Station 2 was very poor for drinking (90.46) and Stations 1, 3 and 4 were unsuitable (113.13 - 188.21) for human consumption. PLI showed turbidity as the major pollutant across stations. The concentrations of heavy metals in the Benin River stretch are within background concentration level, except Fe and Cd. The mean dissolved oxygen was below the recommended level of 7 mg/l for aquatic life. The continuous monitoring of this stretch of the River during the seaport development activities and during operational stage is very paramount to prevent further degradation of the environment.

Keywords

Water Quality, Heavy Metals, Principal Component Analysis

1. Introduction

Monitoring and assessment of water quality is a crucial sustainability issue for surface water, especially rivers as they are of vital importance for humans [1]. Water is one of the most important components of life and the functioning of an aquatic ecosystem and, its ability to support life forms depends, to a great extent, on the physicochemical characteristics of the water [2]. The availability of clean water for the complete functioning of an ecosystem is on the decline due to man's ambivalent relationship with this valued natural resource. The continuous degradation of the aquatic ecosystem is further compounded by the fast industrialization of the maritime transport industry. Port development involves the dredging and deepening of channels to maintain navigability. Seaport development is an economically viable project accounting for 70% of global merchandise trade by value [3]. Apart from creating jobs, easing the burden of maritime logistics, bringing about regional connectivity and boosting both the local and national economies, ports can have a wide environmental impact on local ecologies and waterways, most importantly water quality, which can be caused by sediment spills and resurfaced pollutants [3].

The aim of the study is to assess the current status of physicochemical parameters of water before the commencement of seaport development project in the Benin River stretch and also establish baseline data for future comparisons on the Environmental Management Plan for the proposed project and other seaport projects in Nigeria. Water quality of rivers and streams has been reported by different researchers: [4] in 2010, assessed the water quality of river Ethiope in the Niger-delta coast of Nigeria; [5] in 2014, investigated the effects of brewery effluent discharge on the water quality and sediment of the Ikpoba River, Benin City, Nigeria; [6] in 2016, studied the Physicochemical Parameters and Pond Water Quality Assessment by using Water Quality Index at Athiyannoor Panchayath, Kerala, India; [7] in 2019, assessed the water quality and sediment contamination of Pazarsuyu Stream, Türkiye using multivariate statistical methods and pollution indicators; [8] documented the impact of abattoir effluent on the physicochemical and microbiological characteristics of the Effurun River and Eburu Canal, Warri, Nigeria.

2. Materials and Methods

This study covered about 26 km with four sampling stations spanning from Ajoki, through Nana Creek to Benin River (**Figure 1**). It covered the upper freshwater zone, salinity fluctuating zone and the lower coastal zone which is predominately saline [9]. Stations 1 and 2 were within the fresh water zone while Stations 3 and 4 were within the fluctuating zone. The predominant vegetation includes *Pandanus candelabrum*, *Elaeis guineensis*, *Nymphaea lotus*, *Salvinia nymphellula*, and *Eichhornia crassipes*. Many human activities within and around this river include dredging, logging, fishing, boating, watercraft maintenance, transportation, laundering, bathing and swimming. Benin River has a

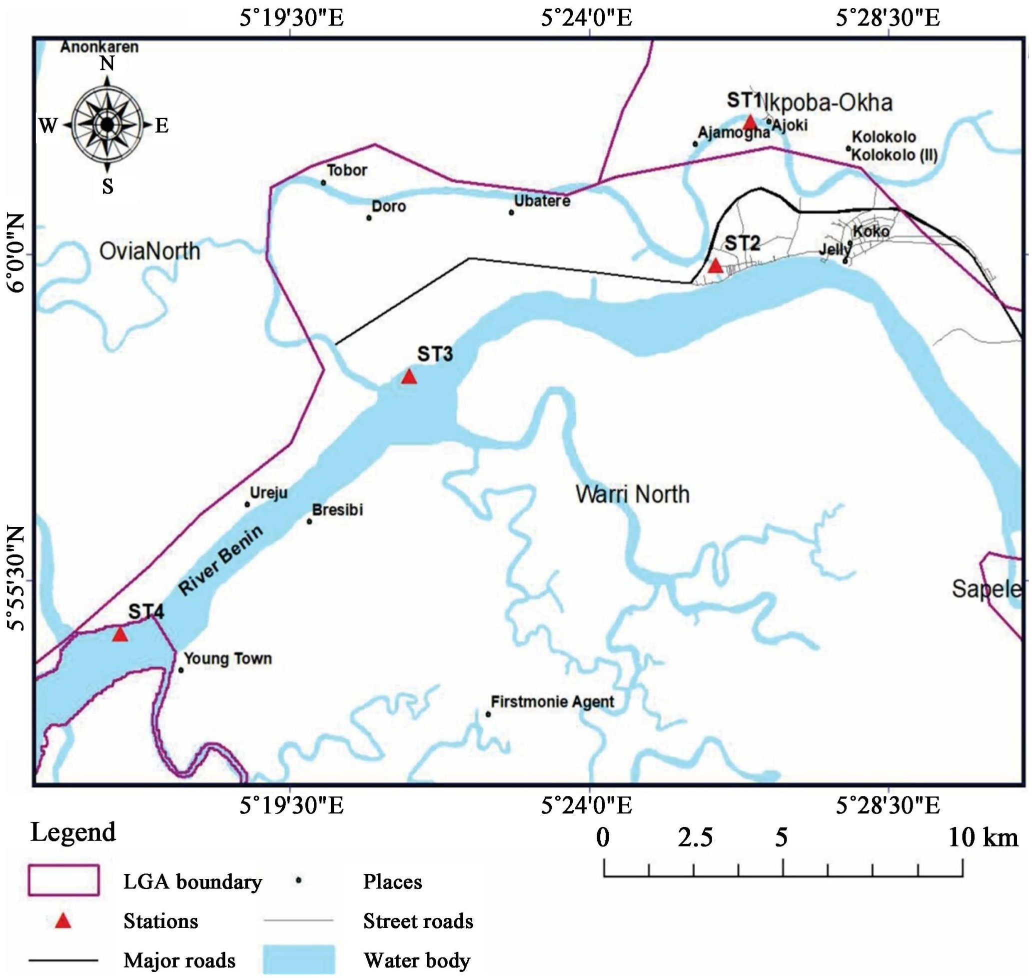

Figure 1. Map of the study area showing the sampling stations.

tropical climate with two seasons: the wet season with an average rainfall of about 2605 mm and relative humidity varying between 50% and 75%.

Ambient air and surface water temperature were measured *in-situ* using mercury-in-glass thermometer. Hydrogen ion concentration and conductivity were similarly measured using HACH digital meter. Dissolved Oxygen and Biochemical Oxygen Demand were estimated using Winkler's method [10]. The BOD was carried out after 5 days incubation at 200˚C. However other physicochemical tests and solids (total, suspended and dissolved solids) salinity, sodium, potassium, calcium, magnesium, chloride, phosphorus, nitrate and sulphate were determined in the laboratory titrimetically. Heavy metals: iron, lead, cadmium, zinc, copper, vanadium, manganese nickel and chromium were determined by preparing standard solutions of known metal concentrations in water. Appropriate lamp of the metal was mounted and the spectrophotometer set at the normal wavelengths and readings recorded [11].

3. Data Analysis

The results of the physicochemical characteristics were analyzed statistically and interstation comparisons were carried out to test for significant differences [12]. Significance between wet and dry season in the four stations combined were analyzed using Mann-Whitney Unpaired t-test. PCA was applied to summarize the statistical correlation among the parameters and further identify the parameters that play significant roles in variations within this sampling location. All statistical analysis was carried out using SPSS version 20.0 and Excel Statistical Tool Pak. Microsoft Word was be used for the graphical representation.

The Water Quality Index (WQI) was calculated using the Weighted Arithmetic Water Quality Index Method [13].

Pollution severity and its variation were determined with the use of Pollution Load Index (PLI). PLI was calculated according to [14]. This contamination factor is the quotient obtained by dividing the concentration of each metal. Assessed as the ration obtained by dividing the concentration of each metal in the water by baseline or background value.

$$CF_{metal} = \frac{C_{metal}}{C_{background}}$$

The reference standard utilized for the water quality index and pollution load index calculation was the water quality criteria of the Nigerian Federal Ministry of Environment (FMEnv).

4. Results and Discussion

Surface Water Characteristics

Table 1 shows the summary of the physical and chemical characteristics of surface water from the Benin River stretch.

Water temperature is one of the most important parameters for water quality and ecosystem studies, it affects the distribution and the living conditions of aquatic ecosystems as it can affect many chemical and biological processes [15]. During the study period, the water temperature varied between 20˚C and 30˚C with a very high significant difference spatially. There was no significant difference seasonally though higher values were recorded in the dry season. The water temperature did not exceed the limit of 33˚C set by Federal Ministry of Environment for aquatic organisms. The water temperature range observed in this study is similar to that of another stretch of Benin river [16] but higher (25.87˚C to 27.56˚C) than those recorded at Ossiomo [17].

In natural waters, pH is one of the most important chemical and biologically important parameters that may affect the toxicity of some compounds by its fluctuations in water [18]. Hydrogen ion concentration was slightly acidic to being neutral (4.6 to 7.10) without any significant differences between stations ($P > 0.05$). There was a significant difference seasonal as higher values were recorded in the dry season than the wet season. pH values ranged outside the WHO recommended limit (6.5 - 8.5) for aquatic organisms. The range recorded in this study is very close to those recorded in the Niger Delta waters of Nigeria [18] [19] [20].

Electrical conductivity is valuable in assessing the purity of water [21]. The

Table 1. Summary of physical and chemical characteristics of surface water of the study area.

PARAMETERS	STATION 1 $\bar{X} \pm$ SE (Min - Max)	STATION 2 $\bar{X} \pm$ SE (Min - Max)	STATION 3 $\bar{X} \pm$ SE (Min - Max)	STATION 4 $\bar{X} \pm$ SE (Min - Max)	P-value	FMEnv 1999/WHO
Air Temperature (˚C)	28.33 ± 0.422^a (24.00 - 32.00)	30.28 ± 0.464^b (27.00 - 35.00)	28.45 ± 0.341^a (26.00 - 32.20)	30.72 ± 2.018^b (27.10 - 34.00)	$P < 0.001$	25
Water Temperature (˚C)	25.67 ± 0.449^a (20.00 - 25.50)	27.30 ± 0.347^b (24.00 - 29.30)	26.19 ± 0.439^a (21.00 - 29.00)	26.07 ± 0.254^b (26.00 - 30.00)	$P < 0.001$	N/A
Water Level (m)	6.09 ± 1.078^a (4.5 - 9.25)	1.56 ± 0.157^b (1.25 - 2.0)	1.995 ± 0.208^b (1.48 - 2.50)	0.90 ± 0.135^b (0.50 - 1.10)	$P < 0.001$	6.5 - 8.5
pH	5.96 ± 0.127 (5.00 - 7.10)	5.83 ± 0.111 (4.90 - 6.80)	5.71 ± 0.099 (4.60 - 6.40)	5.78 ± 0.111 (4.60 - 6.90)	$P > 0.05$	N/A
EC (μS/cm)	143.60 ± 61.634^a (11.70 - 1035.00)	51.31 ± 5.090^a (13.70 - 89.20)	298.5 ± 101.4^a (16.80 - 1732.00)	1021.5 ± 402.4^b (18.90 - 8030.00)	$P < 0.01$	1000
Salinity (g/l)	0.065 ± 0.028^a (0.00 - 0.47)	0.023 ± 0.110^a (0.01 - 0.04)	0.135 ± 0.459^a (0.01 - 0.78)	0.462 ± 0.182^b (0.01 - 3.63)	$P < 0.01$	N/A
Color (Pt.Co)	3.569 ± 0.557^a (0.60 - 8.30)	3.029 ± 0.406^a (0.40 - 6.20)	4.254 ± 0.583^a (0.70 - 9.40)	5.816 ± 0.769^b (0.90 - 13.80)	$P < 0.01$	N/A
Turbidity (NTU)	2.532 ± 0.490^a (0.20 - 6.40)	2.224 ± 0.355^a (0.20 - 5.10)	3.061 ± 0.464^a (0.40 - 7.40)	4.404 ± 0.608^b (0.70 - 10.10)	$P < 0.05$	1, 5
TSS (mg/l)	4.637 ± 0.634^a (0.90 - 9.60)	4.038 ± 0.498^a (0.70 - 8.80)	5.495 ± 0.715^a (1.20 - 11.80)	7.300 ± 0.941^b (1.60 - 18.00)	$P < 0.05$	N/A, 500
TDS (mg/l)	72.25 ± 30.82^a (6.10 - 518.00)	25.95 ± 2.563^a (6.80 - 45.60)	147.3 ± 49.17^a (8.50 - 818.00)	508.0 ± 201.5^b (9.50 - 4030.00)	$P < 0.01$	500
DO (mg/l)	2.200 ± 0.254^a (0.6 - 4.90)	1.833 ± 0.225^a (0.9 - 4.50)	2.543 ± 0.248^a (1.3 - 5.10)	3.186 ± 0.278^b (1.5 - 5.70)	$P < 0.01$	7.5
BOD_5 (mg/l)	0.814 ± 0.069^b (0.4 - 1.90)	0.967 ± 0.076^c (0.4 - 1.80)	0.643 ± 0.061^b (0.3 - 1.40)	0.438 ± 0.036^a (0.2 - 0.80)	$P < 0.001$	N/A
COD (mg/l)	21.28 ± 5.659^a (1.6 - 88.80)	17.34 ± 3.684^a (1.3 - 45.60)	27.89 ± 5.410^a (3.9 - 90.40)	42.04 ± 6.315^b (9.5 - 105.60)	$P < 0.01$	N/A
HCO_3 (mg/l)	41.71 ± 3.822^a (14.4 - 70.20)	34.89 ± 2.579^a (16.6 - 54.90)	52.68 ± 4.185^b (26.6 - 91.00)	76.57 ± 7.416^c (28.8 - 167.10)	$P < 0.001$	N/A
Na (mg/l)	0.099 ± 0.014^a (0.041 - 0.29)	0.063 ± 0.006^a (0.027 - 0.12)	0.179 ± 0.029^b (0.055 - 0.49)	0.291 ± 0.043^c (0.062 - 0.81)	$P < 0.001$	200, <20
K (mg/l)	0.035 ± 0.013^a (0.009 - 0.22)	0.014 ± 0.0012^a (0.007 - 0.04)	0.075 ± 0.018^a (0.009 - 0.23)	0.171 ± 0.036^b (0.02 - 0.61)	$P < 0.001$	N/A, 10
Ca (mg/l)	0.489 ± 0.096^a (0.123 - 1.81)	0.201 ± 0.036^a (0.089 - 0.88)	1.047 ± 0.185^b (0.247 - 2.89)	2.119 ± 0.432^c (0.358 - 7.82)	$P < 0.001$	N/A
Mg (mg/l)	0.207 ± 0.055^a (0.04 - 0.96)	0.090 ± 0.011^a (0.039 - 0.27)	0.263 ± 0.046^a (0.078 - 0.88)	0.839 ± 0.182^b (0.118 - 3.45)	$P < 0.001$	0.1
Cl (mg/l)	72.82 ± 12.68^a (16.1 - 231.80)	52.52 ± 5.691^a (16.1 - 110.30)	129.2 ± 21.72^a (35.5 - 372.20)	269.0 ± 55.11^b (43.2 - 886.30)	$P < 0.001$	250 - 600

Continued

P (mg/l)	0.064 ± 0.009^{a} (0.011 - 0.14)	0.047 ± 0.005^{a} (0.022 - 0.11)	0.086 ± 0.007^{a} (0.03 - 0.16)	0.233 ± 0.079^{b} (0.034 - 1.77)	P < 0.01	N/A
NH_4N (mg/l)	0.119 ± 0.018^{a} (0.033 - 0.29)	0.100 ± 0.015^{a} (0.04 - 0.28)	0.171 ± 0.015^{b} (0.064 - 0.30)	0.231 ± 0.023^{c} (0.081 - 0.43)	P < 0.001	N/A
NO_2 (mg/l)	0.037 ± 0.005^{a} (0.009 - 0.09)	0.030 ± 0.004^{a} (0.011 - 0.07)	0.049 ± 0.006^{b} (0.017 - 0.12)	0.069 ± 0.008^{c} (0.021 - 0.16)	P < 0.001	10
NO_3 (mg/l)	0.143 ± 0.018^{a} (0.03 - 0.32)	0.103 ± 0.013^{a} (0.033 - 0.23)	0.213 ± 0.028^{a} (0.045 - 0.55)	0.441 ± 0.080^{b} (0.069 - 1.37)	P < 0.001	50
SO_4 (mg/l)	0.136 ± 0.019^{a} (0.049 - 0.33)	0.097 ± 0.010^{a} (0.041 - 0.21)	0.186 ± 0.021^{b} (0.066 - 0.38)	0.283 ± 0.032^{c} (0.084 - 0.61)	P < 0.001	200
Fe (mg/l)	1.470 ± 0.154^{a} (0.106 - 2.80)	1.263 ± 0.139^{a} (0.065 - 2.40)	1.749 ± 0.171^{a} (0.201 - 2.78)	2.347 ± 0.252^{b} (0.345 - 5.12)	P < 0.01	0.3
Mn (mg/l)	0.062 ± 0.006^{a} (0.022 - 0.11)	0.052 ± 0.005^{a} (0.018 - 0.12)	0.089 ± 0.007^{a} (0.042 - 0.18)	0.168 ± 0.027^{b} (0.054 - 0.54)	P < 0.001	N/A
Zn (mg/l)	0.282 ± 0.043^{a} (0.067 - 0.17)	0.174 ± 0.021^{a} (0.05 - 0.43)	0.579 ± 0.070^{b} (0.088 - 1.20)	0.963 ± 0.093^{c} (0.163 - 1.70)	P < 0.001	5.0
Cu (mg/l)	0.032 ± 0.003^{a} (0.009 - 0.05)	0.025 ± 0.003^{a} (0.008 - 0.06)	0.041 ± 0.003^{b} (0.017 - 0.08)	0.071 ± 0.006^{c} (0.033 - 0.16)	P < 0.001	0.05 - 1.5
Cr (mg/l)	0.018 ± 0.001^{a} (0.007 - 0.03)	0.016 ± 0.002^{a} (0.005 - 0.04)	0.022 ± 0.002^{a} (0.008 - 0.04)	0.038 ± 0.004^{b} (0.017 - 0.09)	P < 0.001	0.05
Cd (mg/l)	0.013 ± 0.001^{a} (0.004 - 0.03)	0.012 ± 0.001^{a} (0.004 - 0.04)	0.018 ± 0.002^{b} (0.006 - 0.05)	0.024 ± 0.002^{c} (0.011 - 0.06)	P < 0.001	0.01
Ni (mg/l)	0.008 ± 0.001^{a} (0.003 - 0.015)	0.007 ± 0.001^{a} (0.003 - 0.02)	0.012 ± 0.001^{b} (0.004 - 0.03)	0.018 ± 0.002^{c} (0.008 - 0.03)	P < 0.001	0.05
Pb (mg/l)	0.021 ± 0.002^{a} (0.008 - 0.038)	0.018 ± 0.002^{a} (0.006 - 0.038)	0.028 ± 0.002^{b} (0.01 - 0.05)	0.042 ± 0.003^{c} (0.021 - 0.07)	P < 0.001	0.05
V (mg/l)	0.004 ± 0.001^{a} (0.001 - 0.009)	0.003 ± 0.000^{a} (0.001 - 0.009)	0.006 ± 0.001^{b} (0.002 - 0.013)	0.008 ± 0.001^{c} (0.002 - 0.02)	P < 0.001	0.01
Total Hardness (mg/l)	2.068 ± 0.461^{a} (0.55 - 8.50)	0.799 ± 0.057^{a} (0.42 - 1.38)	3.677 ± 0.596^{a} (0.94 - 10.78)	8.284 ± 1.817^{b} (1.38 - 33.73)	P < 0.001	N/A
THC (mg/l)	0.000 ± 0.000 (0.00 - 0.00)	0.000 ± 0.000 (0.00 - 0.00)	0.000 ± 0.000 (0.00 - 0.00)	0.000 ± 0.000 (0.00 - 0.00)	ND	ND

Note: P < 0.001 = very high significant difference, P < 0.01 = high significance difference, ND = Not Detected, N/A = Not Available, superscripts connote similar environment.

electrical conductivity during this study showed significant spatial and seasonal variation and was between (18.90 - 8030.00 µS/cm). The arbitrary high electrical values were as a result of tidal influence, without which electrical conductivity ranged from 11.7 to 584.6 µS/cm. The concentrations of electrical conductivity in the present study were less than 14 - 41,000 µS/cm for New Calabar River [22], but without tidal influence were relatively similar to the range of 6 - 643 µS/cm recorded for other tropical water [23]. Higher electrical conductivity values recorded during the dry season could be attributed to the effects of evaporation which concentrates ions and increases mineralization of organic matter. The electrical conductivity contents on tidal days were above the WHO limit.

Salinity is one of the most important parameters affecting dissolved oxygen concentration in water [7]. This Benin River stretch has a salinity range of 0.005 - 3.63 g/l. Salinity influences the abundance and distribution of organisms [24]. Though tidal influence was observed but the salinity content in the present study were within the recommended limit for drinking water. Salinity varied significantly spatially and seasonally. The range of conductivity and salinity values recorded in this study showed a progressive increase from the downstream stations towards the upstream stretch of the river (3 and 4).

Turbidity measures the optical ability of sediments suspended to inhibit the penetration of light which is a result of colloidal and extremely fine dispersion which affects aquatic invertebrate fauna. The turbidity profiles for this study ranged from 0.2 to 10.10 NTU and were above the WHO standard for drinking water in Stations 1, 3 and 4. It differs spatially and seasonally. It has been reported that high turbidity levels are often associated with high levels of disease-causing microorganisms. Therefore domestic/drinking water should have low turbidity level since suspended particulates provides suitable sites for the growth of microorganisms which have health risk consequences [25].

Dissolved oxygen, which is a measure of the amount of oxygen that is freely available in water essential for sustaining aquatic life in any ecosystem, was low throughout the study period. Dissolved oxygen is an important indicator of water quality, ecological status, productivity and health of a river. This is due to its importance as a respiratory gas, and its use in biological and chemical reactions [26]. The dissolved oxygen concentrations obtained during the sampling period fluctuated between 0.6 mg/l and 5.7 mg/l. The average value obtained in this study is lower than that obtained in other tropical rivers [26] [27]. This value is slightly less than the permissible limit (7.5 mg/l) necessary to sustain aquatic life, an indication that the water quality is starting to deteriorate. The major factors responsible for the low levels of dissolved oxygen in the water are the inflow of discharge of waste and wastewater from most surrounding communities, market and industries.

The amount of oxygen essential for an organism to break down or utilize the organic matter present in a water body over a period of time at a specific temperature is regarded as Biochemical Oxygen Demand. It is important for determining organic health and cleanliness of any water. Unpolluted waters typically have BOD values of 2 mg/l or less, whereas water bodies receiving wastewater may have BOD values up to 10 mg/l or more [28]. The values obtained in this study range from 0.2 to 1.9 mg/l, comparatively; the water body is rated clean. The low values recorded in this study were lower than that recorded for another stretch in the Benin River system [16].

Total Suspended Solid (TSS) is solid materials which comprise organic and in-organic substances suspended in water, while Total Dissolved Solid (TDS) consists of carbonates, sodium, potassium and other substances. When at high concentrations suspended solids and dissolved solids can lower water quality and lessen the ability of water to hold oxygen necessary for aquatic life, by hindering photosynthesis [29]. TDS in water is caused by natural sources, sewage wastes, surface rain water and industrial wastewater [30]. TDS values of this study increased from downstream stations to upstream stations with a high significant difference among stations and between seasons ($P < 0.01$). TDS ranged from 6.10 - 4030 mg/l and the values exceeded WHO limit in Stations 1, 3 and 4. Total suspended solid determination is extremely useful in assessment of polluted water, it is use to determine the strength of domestic wastewaters and to evaluate the efficiency of water treatment process [31]. The concentrations of Total Suspended Solid (TSS) obtained from the sampling ranged from 0.7 - 18 mg/l. Seasons and locations played significant role and higher values were recorded in dry season than in the wet season which may be caused by the transportation and industrial activities.

Nitrate is a form of Nitrogen and vital nutrient for growth, reproduction and survival for aquatic invertebrate fauna. The values of nitrate obtained ranged from 0.03 mg/l to 1.37 mg/l and were within acceptable limit for aquatic life. Nitrite ranged from 0.009 to 0.16 mg/l, with both having high significant difference spatially and seasonally ($P < 0.001$). The low levels of nitrate observed in this study is relatively similar to that recorded for another stretch of Benin River [9].

The alkali metals (Sodium and Potassium, Calcium and Magnesium) total absence in water body limits the growth and distribution of aquatic invertebrate fauna. Alkali metals are interpreted in relation to range of concentration; as such, low concentration enhances biomass, while higher concentration inhibits biomass [32]. The values obtained ranged from 0.027 to 0.81 mg/l for sodium and 0.007 to 0.61 mg/l for potassium. The concentration of calcium and magnesium ranged from 0.089 to 7.82 and 0.039 to 3.45 mg/l respectively. Similar low values were reported by for Ossiomo River [17]. The alkali earth metals level for the Benin River stretch exhibited significant spatial and seasonal variation with observed higher values in the dry than in the wet season. The cations in the study area were in this order Ca > Mg > Na > K. Calcium values are relatively similar compared to 1.11 mg/l to 9.62 mg/l for Osse River [33]. Higher values have also been recorded in some Nigerian waters; [34] recorded a range of 4.80 mg/l to 25.0 mg/l in Ikpoba River and [35] reported values of 0.40 mg/l to 19.24 mg/l for Utor River.

Phosphorus is an essential nutrient for algal productivity of a water body. The values obtained in this study ranged from 0.011 to 0.14 mg/l. Previous studies in a different stretch of Benin River revealed a higher range of 0.01 to 3.66 mg/l [16]. Phosphorus in this Benin River stretch exhibited significant spatial and seasonal variation with observed higher values in the dry than in the wet season. Ammonium nitrogen is one of the forms of nitrogen in water. The values obtained in this study range from 0.033 mg/l to 0.43 mg/l. This value is low compared to the range of 14.25 mg/l to 43.58 mg/l reported in Adofi River Niger Delta area of Nigeria [36]. There was significant spatial and seasonal variation with observed higher values in the dry than in the wet season.

Sulphate occurs naturally in water and is an essential primary productivity nutrient. The values obtained in this study range from 0.041 to 0.61 mg/l and there was a high significant difference spatially and seasonally. This is rather low compared to sulphate values obtained by [9] [16] in a different stretch of Benin River. Recommended limit is not available for sulphate in drinking water because it is said to be one of the least toxic anions; yet, dehydration, gastrointestinal irritation and catharsis are associated with high sulphate concentrations in drinking water. In the present study, the sulphate values were within the recommended limit (500 mg/l) in drinking water by WHO [37].

Heavy metals concentrations were generally low. Heavy metals are vital sources of pollution, not just because they are noxious to aquatic invertebrate fauna at a relatively low concentration but also because they are persistent within the environment long after the source of pollution has been removed [38] [39]. Cadmium ranged from 0.004 to 0.06 mg/l and it exceeded the recommended limit of 0.01 mg/l set by [37] in Stations 3 and 4. Fe ranged from 0.065 to 5.12 mg/l and had mean values exceeding 0.3 set by WHO. Mn ranged from 0.018 to 0.58 mg/l with levels above recommended limit in Station 4. Zinc ranged from 0.05 to 1.70 mg/l, though values were within limit set for portable water but was above the recommended limit (0.03) for aquatic organisms. The level of lead (0.021 - 0.071) obtained from the Station 4 exceeded the World Health Organization recommended maximum concentration (0.01 mg/l) for portable water. The concentrations of heavy metals in the different stations differed significantly. [9] reported similar values for some heavy metals exceeding recommended limit set by WHO for another stretch of the Benin River. The Heavy metal concentrations below recommended limits have been reported for water bodies in Nigeria by some researchers [22] [38] [40] for lower Bonny River, Osse River, Southern Nigeria and Mangrove Creek in the Niger Delta respectively. The high toxicity of heavy metals to aquatic life and humans make them important indices of pollution [38]. Higher values of heavy metals were recorded in the dry season and this could be due to the effect of evaporation resulting in the concentration of these metals in the water. The order of dominancy of the heavy metal is as follows Fe > Zn > Mn > Cu > Pb > Cr > Ni > V. [9] in their study of water quality of upstream of Benin River recorded Fe and Mn as the most and least concentrated heavy metals respectively. The range of heavy metals values recorded in this study showed a progressive increase from the downstream stations towards the upstream stretch of the river with Station 4 recording the highest level.

Principal Component: The principal component analysis revealed the significance of individual parameters in the total variability using Eigen value which decreases in order of importance. It simplifies and reduces high dimensional data while retaining important information of the large data set which determines the principal factors controlling or determining the quality of water. High loadings having correlation coefficients not less than 0.564 denote significant variables in various components. The principal component in this Benin river stretch revealed EC, Salinity, TDS, Total hardness, Mg, Ca, K, Cl, Na, and SO_4 as the major components influencing the environment (Table 2). These significant variables when altered can bring about spontaneous changes in the water characteristics and composition.

Table 2. Varimax rotated matrix of water quality data shows eigenvalue, cumulative proportion and variability principal component.

Parameters	PC1	PC2	PC3	PC4	PC5	PC6
EC	**0.921**	0.202	0.193	0.081	−0.043	−0.019
Salinity	**0.921**	0.202	0.193	0.081	−0.043	−0.019
TDS	**0.920**	0.197	0.192	0.084	−0.043	−0.017
Total Hardness	**0.905**	0.304	0.195	0.142	0.062	0.081
Mg	**0.885**	0.317	0.175	0.165	0.059	0.025
Ca	**0.881**	0.310	0.227	0.153	0.024	0.166
K	**0.869**	0.229	0.259	0.170	−0.010	0.222
Cl	**0.834**	0.378	0.249	0.114	0.066	0.097
Na	**0.782**	0.314	0.228	0.313	0.000	0.273
Cd	0.169	**0.874**	0.167	0.228	−0.181	0.068
Ni	0.287	**0.861**	0.175	0.247	−0.110	0.135
Cu	0.377	**0.850**	0.081	0.194	0.077	0.112
Pb	0.285	**0.826**	0.251	0.248	−0.079	0.202
Cr	0.409	**0.824**	0.026	0.228	0.057	0.066
Zn	0.249	**0.797**	0.239	0.118	0.119	0.264
Mn	0.539	**0.650**	0.242	0.008	0.281	−0.115
Fe	0.316	**0.639**	**0.598**	0.003	0.032	−0.031
HNO_3	0.532	**0.584**	0.382	0.349	0.075	−0.067
V	0.413	**0.578**	0.335	0.166	−0.258	0.172
Turbidity	0.467	0.169	**0.830**	−0.082	−0.056	0.150
Color	0.498	0.219	**0.814**	−0.044	−0.053	0.124
TSS	0.533	0.227	**0.787**	−0.078	−0.068	0.076
SO_4	0.570	0.435	**0.597**	0.113	0.069	0.176
P	0.026	0.218	0.545	0.323	0.338	−0.159
NO_2	0.141	0.422	−0.068	**0.842**	0.158	0.098
NO_3	0.196	0.338	0.020	**0.773**	0.186	0.168
NH_4N	0.261	0.436	0.039	**0.772**	0.189	0.071

Continued

Air Temperature	−0.015	−0.070	−0.029	0.114	**0.805**	−0.078
Water Temperature	0.120	−0.057	0.079	0.342	**0.744**	0.007
pH	0.255	−0.185	0.112	0.513	**−0.599**	−0.276
COD	0.017	0.233	0.169	0.180	−0.302	**0.800**
BOD_5	−0.196	−0.135	0.031	0.030	−0.373	**−0.693**
DO	0.267	0.169	0.498	0.378	−0.266	**0.509**
Eigen Value	17.984	3.508	2.509	1.952	1.583	1.430
% of Variance	54.498	10.631	7.604	5.914	4.796	4.334

Water Quality Index: Figure 2 shows the water quality index in the study area. Values recorded are 113.13 (unfit), 90.46 (very poor), 129.02 (unfit), and 188.21 (unfit) for Stations 1, 2, 3 and 4 respectively (Figure 2). Stations 1, 3 and 4 were unfit for drinking while Station 2 was of poor quality. There was no station that was within the good water quality category. The water quality index of the study area was in this order; Station 2 > Station 1 > Station 3 > Station 4. This collaborates with the findings of [9] for the same Benin River. He reported high cumulative Water Quality Index (WQI) observed in five stations as 234.45, 315.26, 295.09, 1710.49 and 1421.06 respectively and rated the water as unfit for drinking.

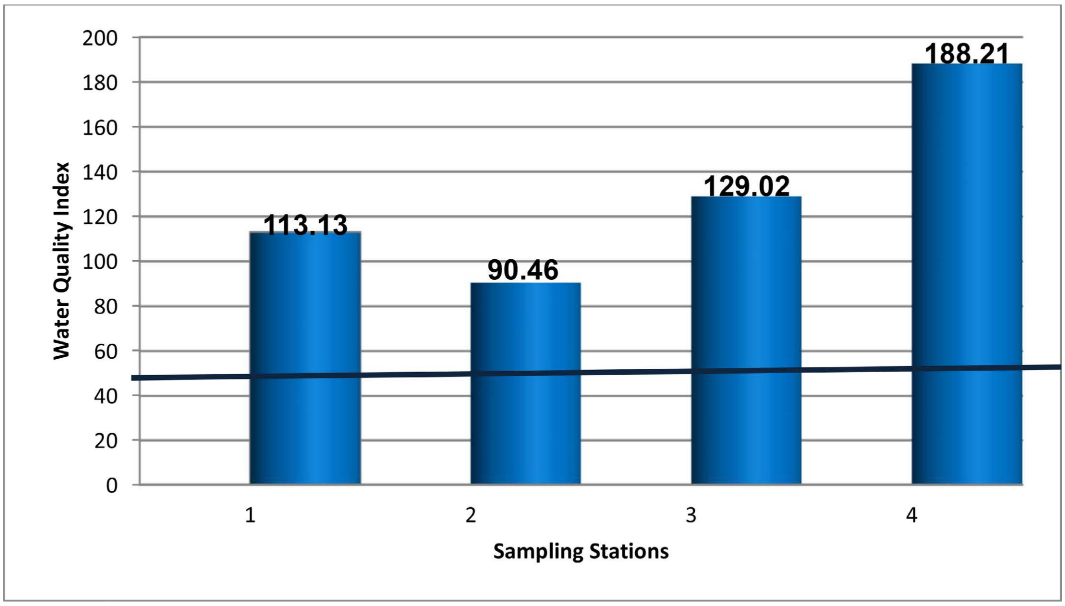

Figure 2. Water quality index of the study area.

Comprehensive Pollution Index: The Comprehensive Pollution Index shows that Stations 1, 3 and 4 are slightly polluted while Station 2 is of the sub-cleanness category. Major pollutant parameters include turbidity, TSS, Cl, Cd and Fe. Others were Pb, V, Cu and Cr. Turbidity was a major pollutant in all the study locations, this could be as a result of runoff. Station 2 was devoid of Pb and V pollutants while Stations 3 and 4 in addition to Pb and V, had Cu and Cr as pollutants. The heavy pollutant in Station 4 is Cd, which is probably due to industrial discharges, waste disposal or leaching of agricultural fertilizers.

5. Conclusion

It has provided comprehensive information on the physicochemical properties and water quality of the Benin River stretch before the seaport development project. The water is unfit for drinking with Fe, Cd, Zn and Pb at certain times and at different study locations that were above the regulated limit.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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