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Article

Effect of Industrial Effluent on Irrigation Water Quality of Choba River in the Niger Delta Region of Nigeria

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Abstract: Poor irrigation water quality due to oil spillage on surface water can result in food insecurity, health and economic challenges. This paper investigated the effect of total petroleum hydrocarbon (TPHC) and lead (Pb) on irrigation water quality in the oil spill prone area of the Niger Delta region of Nigeria. Water samples were taken from five different sections labelled A, B, C, D, and E along the Choba River, in Rivers State, Nigeria. Sections B, C, D and E were direct industrial effluent discharge points while section A was without direct industrial effluent discharge. Standard methods were employed in the water sampling and analysis. Suitability of Choba river water for irrigation was assessed by comprehensive pollution index (CPI) that incorporated salinity, sodicity, and permeability hazard potentials as well as the specific toxicity hazard potentials of TPHC and Pb. Results showed that all primary water parameters except pH were within the Food and Agriculture Organization (FAO) guidelines. The pH was low, ranging between 4.48 and 5.6. TPHC values for four out of the five samples were greater than the 10mg/l guideline as recommended by the Directorate of Petroleum Resources for surface water. TPHC for the four samples ranged between 14.52 and 174.32mg/l. The parameters with the most impact on CPI include EC, PI and TPHC with TPHC having the most impact. Water samples from sections A, B and E with CPI values 0.14, 0.37, and 0.8 respectively were classified in the clean, sub clean and slightly polluted categories respectively, while water samples from sections C and D with CPI values greater than 1 range from moderately to heavily polluted and not suitable for agricultural irrigation. Only water sample A was found suitable for irrigation.

Keywords: Irrigation; Water Quality Indices; Industrial Effluent; Comprehensive Pollution Index

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1. Introduction

Water is a universal solvent and contains dissolved salts that often remain behind in the soil when water is used up by crops and evaporates from the soil. These dissolved substances that remain in soil, build up over time and could affect both crop growth and yield, as well as soil physiochemical properties even if all the other conditions and cultural practices are optimal. Hence, Irrigation which is the artificial application of water to soils for crop use and crop improvement requires not only good water quantity but also good water quality.

Several indices have been developed by researchers to assess irrigation water quality [1-7]. Most of these indices are based on soil salinity, sodicity and permeability hazards. These indices are used to generate single numeric values that describe the safety level of irrigation water but each index deals with just 2-4 variables of the major cations and anions. A more robust irrigation water quality assessment tool, is the irrigation water quality index (IWQI). The development of this index was based on factor/principal component analysis, quality measurement values and aggregation weight values, thus, provides for the use of several water parameters especially the major ions including Na^+, K^+, Ca^+, Mg^{2+}, SO_4^{2-} and Cl^- in one single index [7].

As industrial activities increase by the years, humans are increasingly exposed to more chemical substances such as heavy metals and petroleum hydrocarbons. Present irrigation water quality indices are not robust enough to access these substances yet studies show that the exposure channels of humans to heavy metals include water, air and food [8] and some of these heavy metals are toxic and carcinogenic [9]. Irrigation system covers water and food channel, as the use of water containing heavy metals results in the accumulation of these heavy metals in the soil and also bioaccumulate in crops grown on such soils [10-14].

Despite the toxicity of heavy metals, they are associated with industrial production such as oil refineries, petrochemical plants, pesticide, batteries, paints, and even solar panels. The Niger Delta region of Nigeria is the hub of oil and gas activities of the nation. Three out of the four petroleum refineries and the only petrochemical company in the country are situated in the Niger Delta region. Consequently, one prominent water contaminant is total petroleum hydrocarbons (TPHC). Report has it that between 2010 and 2016, the region experienced 4,859 incidences of oil spillage involving about 15,0973.96 barrels of crude oil [15]. The impact of these oil spillage incidences is enormous on the population of the host communities of oil wells and oil pipelines; from food insecurity to health and economic challenges. Most of the population are subsistent farmers that rely on the coastal waters for crop production. These farmers are unaware of the dangers of using such polluted water for irrigation and there is a dearth of literatures regarding the irrigation water quality of these oil polluted surface water bodies that is inclusive of salinity, sodicity, permeability, heavy metals and TPHC. There is therefore an urgent need for the assessment of the impact of heavy metals and total petroleum hydrocarbons (TPHC) for areas prone to oil spill like the Niger Delta region of Nigeria. This paper seeks to evaluate the effect of total petroleum hydrocarbon (TPHC) and lead (Pb) on irrigation water quality along the Choba river of Rivers state. The selection of this river was necessitated by the fact that the river serves as an outlet to industrial effluent discharge as well as urban runoff [16] and most of the occupants within the catchment of the river are farmers, as such could use this river as a source of irrigation during the dry seasons of the year.

2. Materials and Methods

2.1. Description of study area

Water samples for this study were collected from five different sampling locations along the Choba River, in Rivers State, Nigeria. Choba river is one of the tributaries of the New Calabar River in the Niger Delta Region of Nigeria. It is a low-lying deltaic river which flows southward for roughly 150km before it discharges into the Atlantic Ocean. The river is unidirectional in the upper reach and tidal in the lower reach. Its upstream reach is fresh water with tropical low land, and dense rainforest through secondary forest. The downstream reach is brackish and consist of mangrove swamp forest. The soil of the river basin consists of clays, silts, and sand with high organic matter. It occupies a relief region ranging from 0-50m above sea level at its low zone and 50-100m above sea level at its source [17]. Water samples were labelled A, B, C, D and E against the various locations of the river labelled sections A, B, C, D, and E respectively. Figure 1 shows the sample locations along the Choba river. Four out of the five locations were points of industrial effluent discharge while the remaining location was with little or no industrial effluent discharge. The location without industrial effluent discharge interference was labelled A, while the other four locations were labelled B, C, D, and E. Sections B, C, D, and E were inactive sand dredging site, an artisan crude oil refinery effluent discharge point, a food processing company effluent discharge point, and a pipeline fabrication company effluent discharge point respectively. Due to the nature of the river, the sampling locations were accessed by the use of a paddling boat.

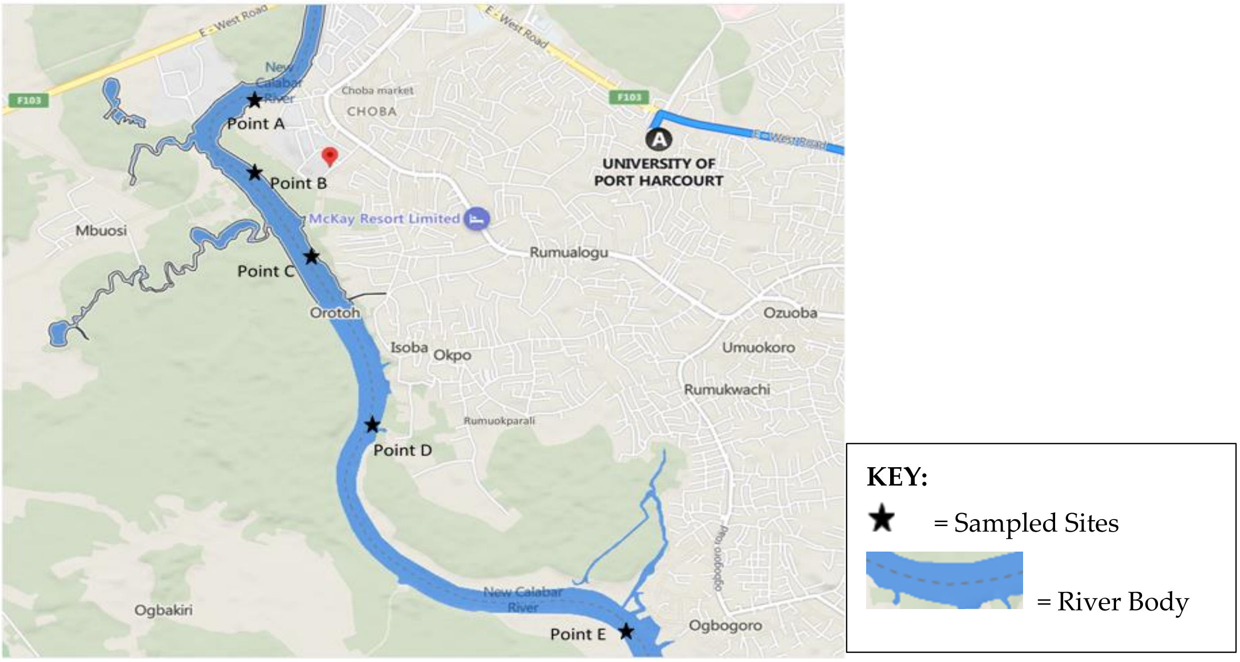

Figure 1. Showing the map of the sample locations.

2.2. Water sampling, analysis and validation of analysis

Water samples were taken during the dry season in the month of November 2021. Sampling was done by facing the direction of flow of the river and samples taken at a depth of 15cm below the water surface at the different sampling locations with the aid of hand gloves and thoroughly rinsed plastic bottles of one litre capacity. Standard field sampling techniques were adopted in the exercise and samples were taken to the laboratory for further analysis. Standard water quality analysis methods were used to analyze each of the parameters. Concentrations of Sodium (Na^+) and potassium (K^+) ions were analyzed using Flame Photometer, while the UV-VIS spectrophotometer at 420nm wavelength was used to analyze the concentration of sulphate (SO_4^{2-}). Concentrations of calcium (Ca^{2+}), magnesium (Mg^{2+}) and total hardness (TH) were analyzed using volumetric acid (0.005mol/l EDTA) titration method. Chloride (Cl^-) and bicarbonate (HCO_3^-) concentrations were determined using the volumetric titration method with silver nitrate (0.1M) and Sulphuric acid (0.02N) as titrates, respectively. Electrical conductivity (EC), and pH were measured using a conductivitimeter with a pH probe (Hannan, Portugal).

Water quality analysis was validated using the charge balance error (CBE) as shown in "(1)". Water quality analysis result was measured against the Food and Agriculture Organization (FAO) guidelines [18] as displayed in Table 1.

$$CBE = \frac{\sum cations - \sum anions}{\sum cations + \sum anions} \times 100 \quad (1)$$

For total petroleum hydrocarbon (TPHC) the permissible limit of 10mg/l was used in this work. This value was obtained from the guidelines set by the Directorate of Petroleum Resources [19]. This was necessary as no limits were found for TPHC in FAO guidelines for irrigation water.

Table 1. FAO guidelines for irrigation water quality parameters

Parameters	units	FAO guideline
pH		6.5-8.4
Electrical Conductivity (EC)	µS/cm	750
Alkalinity	%	100
Sodium (Na^+)	mg/l	20
Potassium (K^+)	mg/l	10
Calcium (Ca^{2+})	mg/l	200
Magnesium (Mg^{2+})	mg/l	250
Chloride (Cl^-)	mg/l	250
Carbonate (CO_3^-)	mg/l	N/A
Bicarbonate (HCO_3^-)	mg/l	N/A
Nitrate (NO_3^-)	mg/l	45
Sulphate (SO_4^{2+})	mg/l	200
Phosphate (PO_4^{3-})	mg/l	0.07
Iron (Fe^{2+})	mg/l	5
Lead (Pb^{2+})	mg/l	5

2.3. Irrigation water quality indices

Salinity, sodicity and permeability hazard potentials of river water were assessed using EC, sodium adsorption ration (SAR) and permeability index (PI) respectively. While EC is a primary water parameter, SAR and PI are secondary irrigation water parameters calculated from "(2)'' and "(3)'' as shown in Table 2. SAR and PI values of water samples at various sections were measured against standard criteria as indicated in Table 2.

Table 2. Irrigation Water Quality Indices

Indices	Formula	Criteria	References
EC (µS/cm)		$100 < EC \leq 250$ Low (C1) $250 < EC \leq 750$ Medium (C2) $750 < EC \leq 2{,}250$ High (C3) $EC > 2250$ Very high (C4)	[1] Richards (1954)
Sodium adsorption ratio (SAR)	$SAR = \frac{Na^+}{\sqrt{\frac{Ca^{2+} + Mg^{2+}}{2}}}$ (2)	$SAR \leq 10$ Excellent (S1) $10 < SAR \leq 18$ Good (S2) $18 < SAR \leq 26$ Doubtful (S3) $SAR > 26$ Unsuitable (S4)	
Permeability index (PI),	$PI = \frac{Na^+ + \sqrt{HCO_3^-}}{Ca^{2+} + Mg^{2+} + Na^+} \times 100$ (3)	$PI > 75$ Suitable (Class I) $25 < PI < 75$ Good (Class II) $PI < 25$ Unsuitable (Class III)	[3] Doneen (1964)

2.4. Determination of pollution indices

In order to determine level of pollution and identify polluted sites of water samples, the ecological hazard quotient (EHQ), and comprehensive pollution index (CPI) were employed in this study similar to previous works [20-22]. EHQ and CPI are two of the simplest water pollution indices used in the analysis of degree of pollution with single numeric values. While EHQ is a single factor evaluation index used to assess the degree of water pollution due to TPHC and has two broad categorizations of degree of pollution

[20], CPI is applied to assess the overall status of water pollution and classifies surface water quality into five levels of degree of pollution [21, 22]. In this study, EHQ was therefore used to assess river water pollution by TPHC while CPI was used to assess the totality of the irrigation water quality with respect to salinity, sodicity, and permeability hazard potentials as well as the specific toxicity hazard potentials of TPHC and heavy metals. EHQ is the ratio of the measured concentration of the contaminant to the standard permissible concentration of the contaminant as shown in "(4)". CPI is the sum of the ratio of the measured concentration of each parameter to the corresponding maximum standard permissible concentration of each parameter as shown in "(5)". In this work, the upper limits of $250 \mu S/cm$ for EC, 10 for SAR and 75 for PI for the highest $(C1 - S1)$ irrigation water quality classification as described in Table 2 were used. Pollution indices values obtained were interpreted against the standard interpretation as presented in previous works [20-22] and displayed in Table 3.

Table 3. Pollution Indices

Indices	Formula	Interpretation of values
Ecological hazard quotient (EHQ)	$EHQ = \frac{C_i}{S_p}$ (4)	$EHQ < 1$ no contamination $EHQ > 1$ contamination
Comprehensive Pollution index (CPI)	$CPI = \frac{1}{n}\sum_{i=1}^{n} PI$ (5) $PI = \frac{C_i}{S_p}$ (6)	$CPI \leq 0.2$ Clean $0.2 < CPI \leq 0.4$ Sub clean $0.4 < CPI \leq 1.0$ Slightly polluted $1.0 < CPI \leq 2.0$ moderately polluted $CPI > 2.0$ heavily polluted

3. Results

3.1. Assessment of errors in primary water parameters

Results of the CBE values of the water samples as displayed in Figure 2 explains that water samples of sections A, C and E were cation dominated while locations B and D were anion dominated.

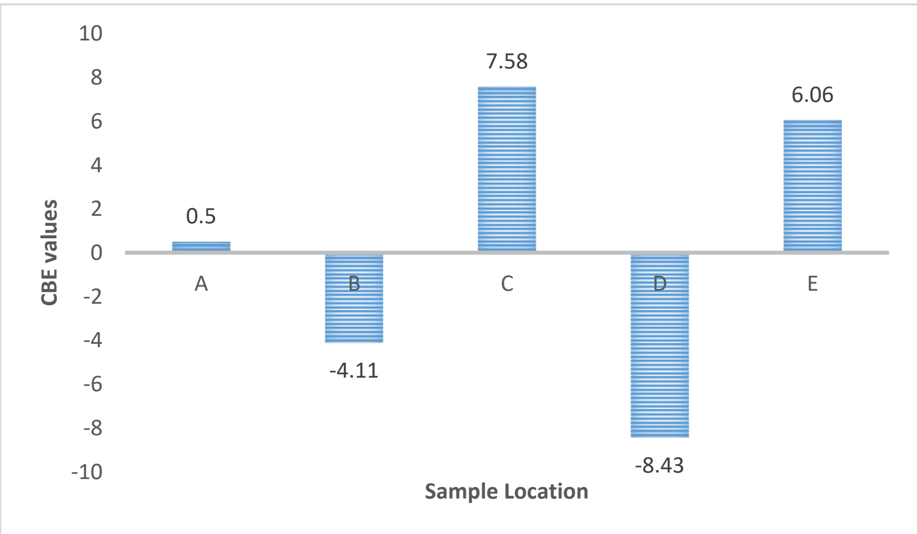

Figure 2. Charge Balance Error (CBE) Analysis display of the water samples

3.2. Primary irrigation water quality parameters

The irrigation primary water parameters of the Choba river along the sections under study are as presented in Table 4. All measured cations and anions analyzed varied along the sections but were within the FAO guidelines for irrigation water quality. The pH values for the different sections were within the acidic range (4.48-5.6) while EC was between 41.33 – 502.33μS/cm. The range of EC values implies that the Choba river water is a low ionic strength water. Also, TPHC and Pb values varied along the sections and TPHC values for all the sections except section A were greater than the recommended limit of 10mg/l for surface water with section C having the highest concentration of 174.32mg/l. The results of the primary water parameters and the values of TPHC indicated that artisan refinery activities had the major impact on the Choba water quality.

Table 4. Primary water parameters at varying locations along the Choba river

Parameters	Units	SECTIONS ALONG CHOBA RIVER				
		A	B	C	D	E
pH		5.6	5.5	4.48	5.23	5.33
Electrical Conductivity (EC)	μS/cm	77	41.33	181	502.33	56.33
Alkalinity	%	35.67	64	27.68	25.33	86
Sodium (Na^+)	mg/l	13.285	17.285	16.685	17.485	18.285
Potassium (K^+)	mg/l	2.706	1.6	1.41	0.984	4.109
Calcium (Ca^{2+})	mg/l	80.45	79.8	74.6	90.01	85.37
Magnesium (Mg^{2+})	mg/l	8.6	14.01	6.01	3.13	12.53
Chloride (Cl^-)	mg/l	122.77	197.08	116.35	185.54	149.17
Carbonate (CO_3^-)	mg/l	4.77	2.47	10.07	5	2.67
Bicarbonate (HCO_3^-)	mg/l	59.38	78.31	33.75	30.9	105.6
Nitrate (NO_3^-)	mg/l	0.58	0.57	0.94	0.95	0.53
Sulphate (SO_4^{2+})	mg/l	7.68	4. 67	5.06	4.78	4.78
Phosphate (PO_4^{3-})	mg/l	0.036	0.017	0.022	0.023	0.022
Iron (Fe^{2+})	mg/l	0.2	0.18	0.33	0.22	0.19
Lead (Pb^{2+})	mg/l	0.23	0.3	0.33	0.18	0.09
Total Petroleum Hydrocarbon (TPHC)	mg/l	0	14.52	174.32	80.39	39.02

3.3. Effect of TPHC on Pb and pH

The effect of TPHC on Pb as displayed in Figure 3 shows an increase in concentration of Pb from location A to C followed by a rapid decline from location C to E. The correlation matrix presented in Table 5 showed that a direct relation exists between TPHC and Pb with $r = 0.29$. On the contrary, an inverse correlation between TPHC and pH with $r = -0.99$ was observed as shown in Table 5 and Figure 4.

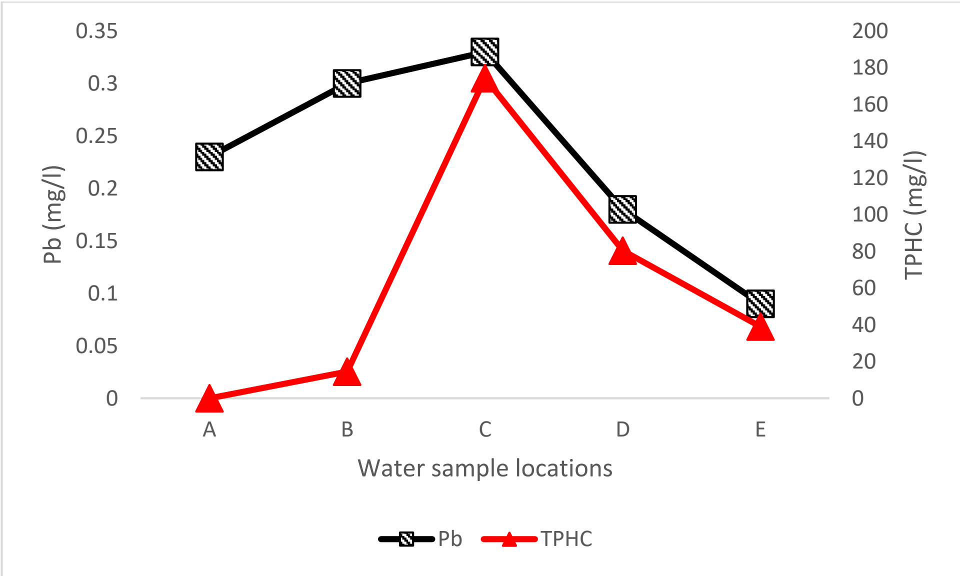

Figure 3. Characteristics of Pb and TPHC along various sections of the Choba river

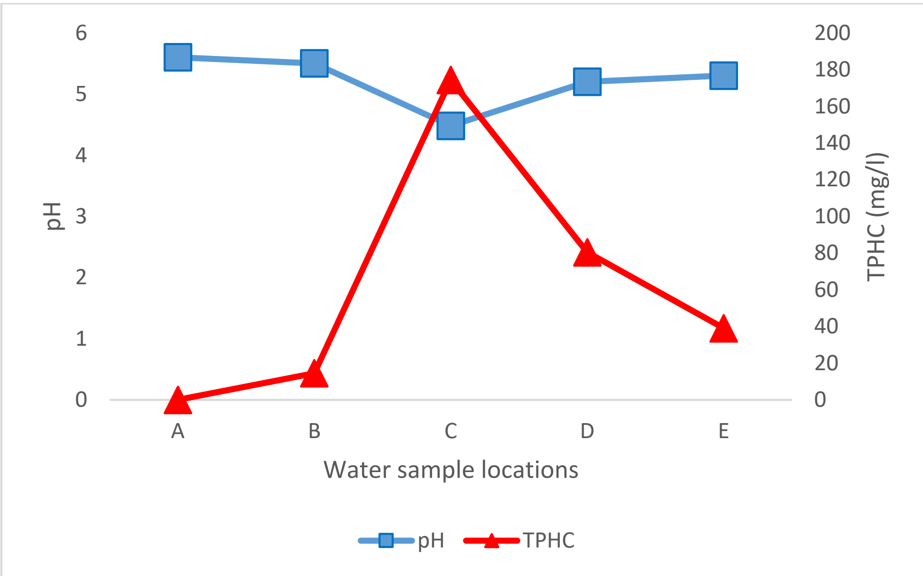

Figure 4. pH and TPHC values of varying locations along the Choba river

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Table 5. Correlation matrix of Choba River water samples parameters

	pH	*EC*	*Na^+*	*K^+*	*Ca^{2+}*	*Mg^{2+}*	*Fe^{2+}*	*Pb^{2+}*	*Cl^-*	*SO_4^{2+}*	*CO^{3-}*	*HCO^{3-}*	*NO^{3-}*	*PO_4^{3-}*	*TPHC*
pH	1														
EC	-0.3199	1													
Na^+	-0.2727	0.3545	1												
K^+	0.3625	-0.6208	-0.0014	1											
Ca^{2+}	0.4551	0.5726	0.3462	0.1043	1										
Mg^{2+}	0.4772	-0.8098	0.1505	0.5730	-0.2214	1									
Fe^{2+}	-0.9595	0.2673	-0.0051	-0.42062	-0.5564	-0.5679	1								
Pb^{2+}	-0.3255	-0.1427	-0.2569	-0.6739	-0.7502	0.0030	0.4299	1							
Cl^-	0.4336	0.3455	0.5307	-0.3249	0.5506	0.2125	-0.5752	-0.0073	1						
SO_4^{2+}	0.369	-0.4015	-0.9689	0.2205	-0.2145	-0.0910	-0.1117	0.0217	-0.5701	1					
CO_3^-	-0.8859	0.2735	-0.1875	-0.4563	-0.5487	-0.6518	0.9795	0.4474	-0.6326	0.0662	1				
HCO_3^-	0.5221	-0.6757	0.2601	0.8354	0.1021	0.8912	-0.6532	-0.4460	0.1442	-0.0993	-0.7420	1			
NO_3^-	-0.73787	0.8246	0.1603	-0.7477	0.0246	-0.8864	0.7505	0.2510	-0.0714	-0.2841	0.7587	-0.8935	1		
PO_4^{3-}	0.30627	-0.2074	-0.8876	0.2582	-0.0189	-0.2742	-0.0691	-0.1955	-0.6039	0.9577	0.1087	-0.1628	-0.1529	1	
TPHC	-0.9882	0.4601	0.2946	-0.4477	-0.3417	-0.5862	0.9473	0.2918	-0.3591	-0.3947	0.8829	-0.6103	0.8286	-0.3061	1

3.4. Secondary Irrigation water quality parameters

SAR and PI values are irrigation water quality indices derived from the primary parameters (cations and anions). SAR values for all locations were less than 10 (see Table 6) indicating excellent irrigation water quality with respect to sodicity. On the other hand, PI values ranged between 23 and 42 indicating good ($25 < PI < 75$) for irrigation purpose for all samples except sample D with $PI < 25$ and is interpreted as not suitable for irrigation.

Table 6. SAR and PI values for various sections of the Choba river.

Water samples	SAR	PI (%)
A	0.38	29
B	0.47	35
C	0.5	26
D	0.49	23
E	0.49	42

Results of water sample pollution level are as shown in Table 7. The single factor evaluation index (EHQ = PI) used to assess water pollution along the entire study sections showed that PI for all parameters were less than 1 except for TPHC. PI values of TPHC for all samples were greater than 1 except for sample A while the CPI values of the water samples varied between 0.14-3.12 (Table 7). The results indicated that the measured values of all primary water parameters did not exceed the maximum permissible value except for TPHC at sections B, C, D, and E. This means that the river was polluted by TPHC and that the degree of pollution varied along the stretch of the Choba river.

Table 7. Degree of toxicity of Choba river water samples at various sections

Parameters	Units	**PI values along the sections of CHOBA RIVER**				
		A	B	C	D	E
Electrical Conductivity (EC)	µS/cm	0.31	0.17	0.72	2.01	0.23
SAR	-	0.04	0.05	0.05	0.05	0.05
PI	%	0.39	0.47	0.35	0.31	0.56
TPHC	mg/l	0	1.45	17.43	8.04	3.90
Pb	mg/l	0.05	0.07	0.07	0.04	0.02
Fe	mg/l	0.04	0.04	0.07	0.04	0.04
Sum	-	0.83	2.25	18.69	10.49	4.80
CPI	-	0.14	0.38	3.12	1.75	0.80

PI=EHQ; PI is the single factor evaluation index

4. Discussion

The CBE values of water samples of sections A to E of the Choba river ranges between absolute values of 0.5 and 8.43, an indication that the accuracy of primary water analysis was ≥90%. The results of the measured primary water parameters (cations and anions) are considered acceptable for low ionic strength water [23]. All the major cations and anions as shown in Table 4 were observed to be within the FAO guidelines permissible zone for irrigation water as indicated in Table 1. However, pH and TPHC did not meet the FAO and DPR standards respectively. Choba river water samples showed low pH values between 4.48 and 5.6 similar to the findings of previous works [16,17]. The low pH values were attributed to anthropogenic activities. Section C with the lowest pH value of 4.48

had the highest TPHC value of 174.32mg/l and was associated with the runoff from artisan crude oil refining activities. The runoff is often a mixture of crude and refined oil as evident in the high TPHC value.

A common impact of TPHC on primary water parameter has been reported in previous works as the suppressing of water pH value [24, 25] and this was observed as shown in Figure 4 and the correlation matrix value of $r = -0.99$ between TPHC and pH. The negative r value implies inverse linear relationship between pH and TPHC while the high value of 0.99 explains a high impact of TPHC on pH. However, pH value of sample A (5.6) with zero TPHC as shown in Table 4 suggests that Choba river water without crude oil contamination was slightly acidic but decreased with crude oil contamination. The slight acidity was attributed to acidic rain due to gas flaring which is another common occurrence in the Niger Delta region of Nigeria [26, 27].

The spatial distribution of Pb along the study sections of the Choba river was within the FAO guidelines for irrigation water but exceeded the permissible limit of surface water as a source of potable water according to World Health Organization guidelines [28]. The Pb content along the various sections showed that $C > B > A > D > E$. This suggests that the source of Pb at the various sections were different and that artisan crude oil refining activities produced the highest amount of Pb, followed by corrosion of inactive sand dredging equipment and urban runoff. The relation between TPHC and Pb as displayed in Figure 3 is similar to other works [29, 30]. The correlation value (r = 0.29) between TPHC and Pb as displayed in Table 5 explains that the impact of TPHC on Pb along the entire stretch of Choba river under investigation was low supporting the fact that the source of Pb contamination along the Choba river was site specific.

Soil salinity potential hazard due to irrigation water quality was measured by water sample EC values which ranged between 41.33 to 502.33μS/cm. Measuring these values against the standard criteria as shown in Table 2; water sample C belonged to the class C1 while sample D belonged to class C2 similar to previous works [31]. This implies that the use of water samples C and D for agricultural irrigation has low and medium tendencies of causing soil salinity hazards respectively. Water samples A, B and E, with $\mathrm{EC} < 100\mu\mathrm{S/cm}$ is termed fresh water suitable for drinking and irrigation [32] hence, has no potential of causing soil salinity hazard. Although, no criteria for EC values $< 100\mu\mathrm{S/cm}$ was defined in Table 2, samples A, B and E were classified as C0 referring to excellent water quality based on salinity hazard description of a previous work [32].

Soil sodicity and permeability hazard potentials as expressed in numeric values of SAR and PI respectively and displayed in Table 6 showed that SAR values of sections A to E were far less than 10 (0.38-0.5). This means that the Choba river along the stretch of investigation was in the S1 Class and also that the Choba river water along sections A to E will not lead to soil dispersion. The higher concentration of Calcium ion (80.45 – 90.01mg/l) compared to sodium ion (13.29 – 18.29mg/l) was responsible for the very low SAR values. A combination of salinity and sodicity categorization, gives water samples A, B, and E a C0-S1 (excellent) classification, water sample C a C1-S1 (very good) classification and water sample D a C2-S1 (good) classification. The PI values of the samples were in the ranges of 23% – 42%. Based on these values, the Choba river along the study sections can be classified as Class II (25<PI< 75) for sections A, B, C, and E while section D was classified as Class III. This implies that water from all sections of the study area except section D was good for irrigation and will not impair the movement of water through the soil pores thus, preventing flooding while that of section D is not suitable for irrigation purpose and could cause impermeability problems if such water is used over a long period of time. The varying conditions of the irrigation water quality along the Choba river is similar to previous works [33, 34].

The spatial distribution of TPHC pollution and the classified pollution degree referred to as EHQ and CPI are as displayed in Table 7. The parameters with the most impact on CPI include EC, PI and TPHC with TPHC having the most impact. Measuring the

CPI values of sections, A to E against the standard criteria for degree of contamination as shown in Table 3 explains that the larger the CPI value the greater the degree of pollution and the smaller the CPI value the better the water quality. Water samples from sections A, B and E with CPI values 0.14, 0.37, and 0.8 respectively were classified in the clean, sub clean and slightly polluted categories respectively. Water samples from sections C and D with CPI values greater than 1 range from moderately to heavily polluted. Based on the direct relationship between TPHC concentration and degree of toxicity of petroleum hydrocarbon on plant and soil biota [35] only water from sections A was good enough for irrigation purpose, water from sections B and E can be used with caution while water from sections C and D should be avoided.

5. Conclusion

The Choba river, which is a possible source of irrigation water supply has low ionic strength, and was slightly acidic. Low pH value for irrigation water, poses little or no threat because of the soil buffering capacity but is an indication of pollution/contamination. The major cations and anions for irrigation water quality analysis are within permissible limit. Choba river water suitability for agricultural irrigation based on SAR, PI and EC classification, has spatial variation. With the PI index classification, water from sections A, B, C, and E, were all good for irrigation while water from section D was not suitable. For SAR water from all sections were excellent for irrigation while for EC water from all sections except section D were suitable. In terms of toxicity due to crude oil pollution, only water from section A was safe for irrigation. Withdrawal of water for irrigation purpose at section A should be done with care to avoid interference from other sections of the river. The most impactful point source of TPHC, Pb and Fe contamination are the artisan crude oil refining sites and inactive sand dredging effluent points. Artisan refining should be replaced with modular refineries with proper environmental assessment. Also, industrial effluent should be properly treated before discharging into the river. Gas flaring should be minimized to reduce acidic rain.

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Author Contributions

Merit Leyiga Kornebari Bestmann collected the water samples and analyzed the samples with the help of the Laboratory attendants as part of her final year project work in the Department of Agricultural and Environmental Engineering.

Dr. Erewari Ukoha-Onuoha co-supervised the student under the general guidance of the Head of the Soil and Water Engineering option in the Agricultural and Environmental Engineering Department. She compiled the water sample data, analyzed same and wrote the manuscript.

Prof. Isoteim Fubara-Manuel, the Head of the Soil and Water Engineering Option of the Agricultural and Environmental Engineering Department, gave the frame work of project to the student and had a general oversight of the field work as well as the writing of the manuscript. He proofread the manuscript, and made necessary corrections.

Conflict of Interest

The authors declare that there was no conflict of interest. They have also read and agreed with the contents of the manuscript, with no financial interest to report. We certify that the submission is an original work and is not under review at any other publication

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