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Evaluation of the Physicochemical Characteristics and Pollution Source Apportionment of Ojobo Creek Burutu Local Government Area, Delta State, Nigeria

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ABSTRACT: The rapid expansion of industry, agriculture, and urbanization is significantly altering the aquatic environment. To effectively manage and conserve aquatic ecosystems, it is crucial to accurately conduct comprehensive water quality assessments and identify pollution sources. Hence, this study evaluated the physicochemical characteristics and pollution source apportionment of Ojobo Creek, Burutu Local Government Area, Delta State, Nigeria, using a multivariate analytical approach. Surface water samples were collected monthly over a six-month period, from July to December 2024. The water samples were analysed using various standard methods. The results revealed that pH ranged from 6.60 to 6.90, with an average value of 6.73; Turbidity varied between 60.50 and 105.50 NTU, averaging 87.50 NTU; Dissolved Oxygen (DO) ranged from 4.52 to 4.69 mg/L, with a mean value of 4.61; Lead (Pb) concentrations ranged from 0.05 to 0.15 mg/L, averaging 0.09 mg/L; while nickel (Ni) ranged from 0.07 to 0.14 mg/L, with an average of 0.09 mg/L. Notably, Pb, Ni, and turbidity exceeded WHO standard limits, indicating potential health and environmental risks. Cluster analysis and Principal Component Analysis (PCA) revealed both natural and anthropogenic sources of contamination. These findings emphasize the need for effective pollution control measures and sustainable water management strategies to safeguard environmental quality and public health.

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The universal access to water and sanitation by 2030 stands as a pivotal sustainable development goal (Goal 6), which underscores the importance of accessibility and sustainability. Key aims within this objective include enhancing water quality through pollution reduction efforts, instituting integrated water resources management across various scales, and striving for the protection and conservation of water ecosystems (Abulude *et al.* 2023). Water quality refers to any physical, chemical, or biological property determining its appropriateness for activities such as recreation, agriculture, and domestic use (Boyd, 2015). Water quality is intricately shaped by both natural processes and human activities such as the exploration and processing of natural resources. In the absence of human influence, water quality is primarily governed by geological factors such as the weathering of bedrock, which releases minerals and ions into water bodies. Additionally, atmospheric processes like evapotranspiration play a vital role in water quality by influencing the water cycle and mineral deposition. Understanding the interplay between natural processes and human activities is crucial for effectively managing and preserving water

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quality in diverse ecosystems. The aquatic environment is being drastically altered by the fast-paced growth of industry, agriculture, and urbanization, it is critical to precisely identify the sources of pollution and undertake comprehensive assessments of water quality to effectively manage and conserve aquatic systems in the environment (Ren *et al.* 2023).

The substantial volume of data resulting from the analysis of physicochemical parameters in water quality assessments often introduces complexity, impeding straightforward interpretation and posing challenges in drawing conclusive insights (Jebb *et al.* 2017; Junzhao *et al.* 2021). Multivariate techniques present an alternative approach, offering a comprehensive assessment of water quality by identifying hidden factors that elucidate the structure of the database and identifies the potential factors and sources that could impact the water system, leading to variations in water quality (Ustaoglu and Tepe, 2019; Junzhao *et al.* 2021). It helps discern the natural and anthropogenic sources of pollutants influencing the physicochemical parameters of the water body, as well as establishing similarities between sampling stations and identifying variables responsible for spatial and temporal variations in water quality parameters (Abbas *et al.* 2008; Ustaoglu and Tepe, 2019). Evaluating the spatial and temporal variation of the physicochemical characteristics of water is crucial for effective pollution control and water management (Ustaoglu and Tepe, 2019). Principal Component Analysis (PCA), Cluster Analysis (CA), Discriminant Analysis (DA), and Factor Analysis (FA) emerge as examples of multivariate techniques (Abbas *et al.* 2008; Ustaoglu and Tepe, 2019). In recent years, multivariate techniques have found successful application in various studies, contributing to the assessment of water quality in aquatic systems (Okoro and Ikolo, 2005; Adebola *et al.* 2013; Ustaoglu and Tepe, 2019; Wenjie *et al.* 2020; Junzhao *et al.* 2021). Sources of water pollution are commonly classified into point sources and non-point sources (William and Mary, 2018). Point sources are specific locations, such as oil wells, drainages, sewage treatment plants, and industries, from which pollutants are discharged into the environment. On the other hand, non-point sources are not specific locations; they include runoff from farmlands, erosion, and the natural weathering of rocks (William and Mary, 2018; Ghaemi and Noshadi, 2022). Identifying the pollution source is crucial for effective water quality management and environmental conservation (Ghaemi and Noshadi, 2022).

Surface water pollution represents a significant challenge for water resources management because it is highly vulnerable to contamination from runoff originating from farmlands, as well as municipal and industrial wastewater discharges (Bhuyan *et al.* 2018)). Agricultural practices, sewage runoff, and population growth have significantly raised nutrient levels in water bodies beyond natural thresholds, giving rise to the phenomenon known as eutrophication (Tibebe *et al.* 2022). Eutrophication results from an excess of nutrients, primarily nitrogen and phosphorus, which serve as limiting factors influencing primary production (Alprol *et al.* 2021; Tibebe *et al.* 2022). While the process of eutrophication typically spans thousands of years under natural conditions, anthropogenic activities significantly accelerate nutrient loads in aquatic ecosystems, leading to a rapid increase in photosynthesis, heightened phytoplankton growth, and a subsequent reduction in dissolved oxygen concentrations in the aqueous system (Chislock *et al.* 2013; Alprol *et al.* 2021). Heavy metals such as lead, nickel and chromium pose a significant threat to environmental and biological systems due to their toxic nature and ability to accumulate within organisms (Blewett and Leonard, 2017).

Oil spillage is a recurring issue that inflicts significant environmental harm on the Niger Delta region and its surroundings. Petroleum spillage can stem into the environment from extraction, refining, transportation, storage processes, sabotage, equipment failure, pipeline corrosion, and tanker accidents. These spillages introduce heavy metal and total petroleum hydrocarbons into the environment, these pollutants, pose considerable risks to both human health and the environment due to their detrimental effects (Enegide and Chukwuemeka, 2018). Ojobo community stands as a significant crude oil producer nestled within the Burutu Local Government Area, situated in the heart of the Niger Delta sub-region of Nigeria. This community plays a crucial role in the country's oil industry, contributing to its economic vitality and energy sector (Miebi, 2013). Agricultural activities and dumping of refuse are other anthropogenic activities that can also cause deteriorating effect on the environment (Kuch and Bavumiragira, 2019). To conserve the aquatic lives and for effective environmental management it is therefore paramount to determine the physicochemical characteristics of the surface water in Ojobo creek as well as the various source of pollutants due to anthropogenic activities affecting the water quality. Hence, the objective of this paper is to evaluate the Physicochemical Characteristics and

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MATERIALS AND METHODS

The Study Area: Ojobo Creek is situated in Burutu Local Government Area (LGA), Delta State. Burutu LGA is a major onshore crude oil production centre in the area. The tropical climate is split into two distinct seasons: the rainy season, which lasts from April to October, and the dry season, which lasts from November to March. Burutu LGA is notable for its farming, fishing, and small-scale manufacturing operations. Ojobo Creek passes through several communities before emptying into the Forcardos estuary (Miebi, 2013; Iwegbue *et al.* 2023).

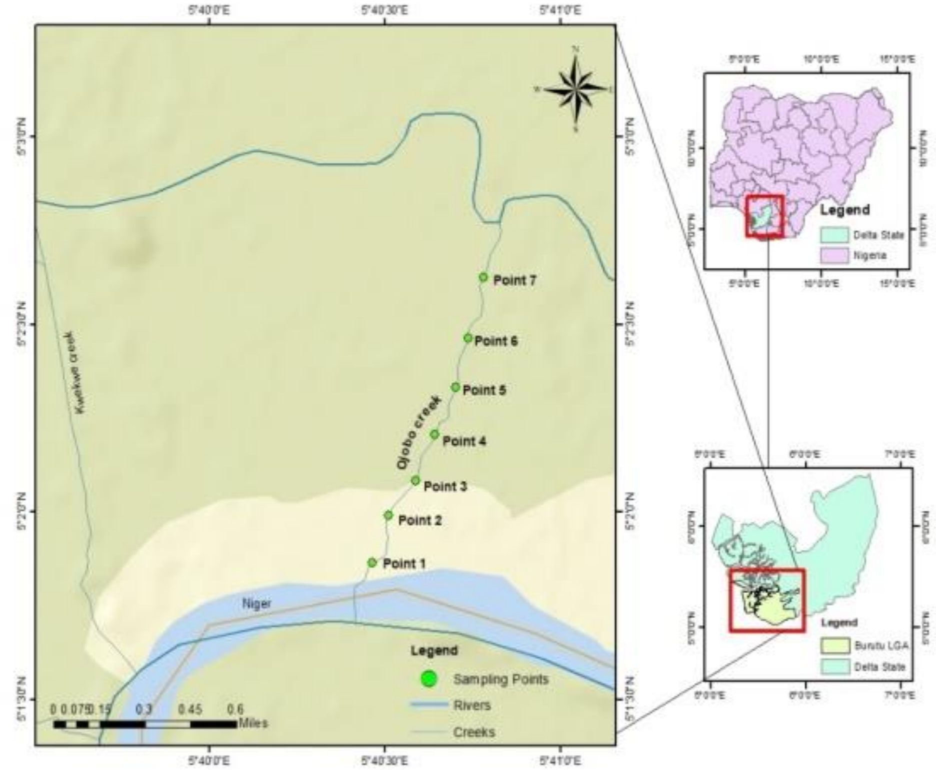

Fig.1: Map of the Study Area showing the Sampling Points.

Sample Collection: Surface water samples were collected monthly over a six-month period, from July 2024 to December 2024, using a water sampler. The sampling period covered both wet and dry seasons, with July to October representing the wet season and November to December marking the dry season (Ekanem and Nwagbara, 2005). A total of 42 samples were collected from 7 sampling stations situated 100 meters apart along the river, following the standard procedures outlined in APHA, (2017). The water samples were collected in two-liter plastic containers. On-site (in-situ) analysis will be conducted to determine pH, conductivity, dissolved oxygen, turbidity, and temperature. 100 mL plastic bottles were used to collect samples for heavy metals while 250 mL BOD bottles were utilized for BOD measurements. For metal analysis, a mixture of 1:1 Nitric acid (HNO_3) at 1 mL was used to preserve and lower the pH of the samples to ≤ 2. All water samples were preserved by cooling at approximately 4°C in an ice box, and all ex-situ analysis were performed according to APHA, (2017) standard procedures and methods at Dukoria Laboratory Ltd in Effurun, Delta State**.**

Statistical Analysis: The data generated were subjected to descriptive statistical analysis. Principal Component Analysis and Hierarchical Cluster Analysis were both computed. The software tools utilized for these analyses encompassed SPSS, Kyplot 5.0, and Microsoft Excel Office 365.

Quality Control and Quality Assurance: The % recovery, limit of detection, and limit of quantification were calculated. By adding a known concentration of analyte to the sample matrix and then analyzing it, the % recovery was ascertained after each ten samples underwent analysis. The recovered percentage fell between 85.1% and 110 %. Continuous dilution and standard solution analysis were used to establish LOD until the lowest concentration was reached at a signal to noise ratio of 3. Likewise, LOQ was ascertained, standard solution was continuously diluted and analyzed until the lowest concentration was found at a signal ratio of 10.

Principal Component Analysis (PCA): PCA is a statistical method used to simplify datasets by identifying directions of maximum variability. The first principal axis captures the greatest variation in the data, and the projections of data points onto this axis form the first principal component (PC1), which explains most of the dataset's variability. A second axis, orthogonal to the first, captures the next largest variation and forms the second principal component (PC2). This process continues to extract components that summarize the original data (Yang *et al.* 2020; Wang *et al.* 2024). The components or clusters are derived through eigenvalue-eigenvector analysis of the similarity coefficient matrix, as expressed in equation 1 (Mahapatra *et al.* 2012). The factor loadings categorized as "strong" (> 0.75), "moderate" (0.50-0.75), and "weak" (0.30-0.50) indicate each variable's influence (Lencha *et al.*, 2021).

$$(S - I\lambda_i)\, Y_i = 0, \quad i = 1,2,\ldots,P \quad (1)$$

Where: S is the P×P Euclidean distance matrix, I is the identity matrix, Λ_i are the eigenvalues (characteristic roots), Y_i are the eigenvectors

Cluster Analysis: Cluster analysis (CA) is an unsupervised method that groups objects into categories based on their similarities; the most used method within CA is hierarchical clustering, which uses Euclidean distance to measure similarity (Singh *et al.* 2015). The analysis is based on the spatial similarity of variables, which are classified using hierarchical clustering with mean linkages (between groups). Significant clusters are identified using a dendrogram at $(D_{link}/D_{max}) \times 100 < 25$. The dendrogram shows how variables are grouped into similar clusters, with the distance between points on the horizontal axis representing their relative proximity (Singh *et al.* 2015).

Analytical Methods: The physicochemical parameters of the water samples were analyzed using standardized methods. The pH was determined using the Electronic Method in accordance with APHA 4500-H$^+$. Electrical Conductivity (EC) was measured following the APHA 2510 standard method. Total Suspended Solids (TSS) were quantified using the Gravimetric Method (APHA 2540 D), while Total Dissolved Solids (TDS) were analyzed following the APHA 2540-C procedure. Biological Oxygen Demand (BOD) was assessed through the 5-day BOD test (APHA 5210 B), and Chemical Oxygen Demand (COD) was determined using the Closed Reflux Method (APHA 5220 B). Phosphate concentrations in the water samples were measured using the Ascorbic Acid Method, while Sulphate levels were evaluated through the Turbidity Method (APHA 4500 SO□^{2}□-E). Nitrate concentrations were determined using the Cadmium Reduction Method (ASTM D3867-2016). Metal concentrations were determined in accordance with the APHA 3400 procedure (APHA, 2017).

RESULT AND DISCUSSION

The pH has a significant impact on maintaining the health of aquatic ecosystems since both high and low pH levels affect aquatic life and alters the solubility and availability of nutrients and contaminants (Dewangan *et al.* 2023). The mean pH of 6.73 in this study, which varied from 6.60 to 6.90, was within the WHO-recommended range of 6.5 to 8.5. The pH ranged from almost neutral to slightly acidic. According to Miyittah *et al.* (2020), heavy metals often become less bioavailable in the pH range of 6 to 9 because they tend to form insoluble hydroxides, carbonates, or other complexes at certain pH levels, which lowers the concentration of free ionic forms that are easier for organisms to absorb. The pH found in? this investigation is marginally lower than the 7.38 found in a study on Opa by Akindele and Adeniyi, (2013) in a study conducted on Opa Reservoir catchment area, Ile-Ife, Nigeria. Abali abd *et al.* (2023) reported a lower pH of 5.31 in a study conducted on surface water from Idu Ogba River, Rivers State, Nigeria. Arimieari *et al*. (2014) reported a similar value of 6.97 in some selected location in portharcourt.

The quantity of ions or other dissolved materials in water determines its electrical conductivity, which is a measurement of the water's ability to conduct electricity (Sreenivasulu *et al*. 2015). The water's low ionic content was indicated by the electrical conductivity (EC), which ranged from 55.00 to 180.00 µS/cm with a mean value of 98.85 ± 37.65 µS/cm. This is far lower than the WHO standard of 1000 µS/cm. According to Fanela *et al.* (2019), total suspended solids (TSS) is the concentration of solid particles suspended in water, such as silt, clay, organic matter, algae, plankton, and other fine detritus. The WHO allowed limit of 50 mg/L was not exceeded by the Total Suspended Solids (TSS) levels obtained in this study, which ranged from 17.50 to 43.50 mg/L with a mean value of 31.64 ± 8.67 mg/L, indicating appropriate particle levels. Total dissolved solids are mainly inorganic substances in water bodies that can pass through a filter of 2.0 µm (Boyd, 2015). Minimal dissolved minerals were suggested by the Total Dissolved Solids (TDS) range of 35.20 to 115.20 mg/L, with a mean value of 63.23 ± 20.46 mg/L, much below the WHO recommendation of 500 mg/L. Useh *et al.* (2022) conducted a study on surface water in a specific area in Abuja and reported TDS in the range of 11.68 to 18.64 mg/L with a higher mean value of 110.44 ± 20.46 mg/L. A measure of water's clarity or cloudiness is called turbidity (Edori *et al.* 2019). A decrease in photosynthetic reaction can result from high turbidity, which is caused by suspended and dissolved particles that can reduce light penetration into the water body (Edori *et al.* 2019).

As measured in this study, the mean turbidity value was 87.50 ± 13.57 NTU, with a range of 60.50 to 105.50 NTU; which was far higher than the WHO acceptable limit of 5 NTU.

One important measure of water quality is dissolved oxygen (DO), which is the amount of oxygen present in aquatic system that is essential for fish, invertebrates, and other creatures to survive. Fish may die at levels below 3 mg/L (Ija *et al.* 2022). The mean DO levels in this study were 4.61 ± 0.06 mg/L, with a range of 4.52 to 4.69 mg/L. In research carried out in Port Harcourt, Rivers State, Nigeria's Nta-Wogba Stream, Friday *et al.* (2020) observed a comparable DO value of 4.01±0.44 mg/L. According to Friday *et al.* (2020), the creek receives drainages from Ikwerre Road and other significant commercial highways, sewages are sometimes directly discharged into it, and the stream receives effluents from abattoirs, hence the low DO value was anticipated. The levels of dissolved salts in water are indicated by its salinity. Sodium chloride, magnesium sulphate, calcium sulphate, potassium chloride, and bicarbonate are among the salts that contribute to the salinity of water bodies (Makinde *et al.* 2015). In this study salinity ranged from 2.99 to 63.98 mg/L with a mean salinity value of 16.63 ± 18.25 mg/L, falling well under the WHO limit of 1000 mg/L.

The amount of oxygen consumed by microorganisms during the breakdown of organic materials in a body of water is estimated by biological oxygen demand (BOD)(Aina, 2016). According to Ioryue *et al.* (2018), the BOD of unpolluted aquatic systems is typically 5 mg/L or less. In this study a low BOD values which ranged from 0.00 to 4.52 mg/L with a mean value of 2.74 ± 1.53 mg/L was obtained. The amount of oxygen needed to oxidize the organic and inorganic compounds present in water bodies is represented by the COD value (Omar *et al.* 2022). Surface water COD levels can vary from less than 20 mg/L in uncontaminated aquatic systems to more than 200 mg/L in contaminated water bodies (Chapman, 1996). In this study, COD in the range of 7.40 to 8.30 mg/L with an average value of 7.80 ± 0.28 mg/L showed low quantities of oxidizable chemicals in the water. Useh *et al*. (2022) reported a higher COD value of 15.19 ± 2.04.

Calcium and magnesium concentrations are the primary determinants of water hardness (Chapman, 1996). Soft water has a hardness of less than 50 mg/L, moderately hard water has a hardness of 50 to 150 mg/L, and hard water has a hardness of more than 150 mg/L (Onwughara *et al.* 2013). Total hardness obtained in this study ranged from 41.00 to 198.00 mg/L, with a mean value of 69.57 ± 43.29 mg/L, reflecting moderately hard water. Total Hydrocarbon Content (THC) was not detected (N.D.), suggesting no measurable hydrocarbon pollution in the sample.

Sulphate, phosphate, and nitrate are crucial macronutrients in water bodies (Tajudeen *et al.* 2015). Aquatic organisms need nutrients to reproduce and thrive in an aqueous system (Smith and Smith, 1998). In this study, Sulphate (SO_4^{2-}) concentrations ranged from 19.44 to 27.17 mg/L, with a mean value of 22.39 ± 2.90 mg/L, well below the WHO limit of 250 mg/L. Nitrate (NO_3^-) concentrations were between 0.004 and 0.024 mg/L, with a mean value of 0.01 ± 0.01 mg/L, significantly below the WHO permissible limit of 50 mg/L. Phosphate (PO_4^{3-}) was observed at a range of 0.74 to 1.29 mg/L, with a mean value of 1.29 mg/L. Iyama *et al.* (2018) reported similar low values of 69.20± 16.27 for sulphate, 0.48± 0.19 for phosphate and 3.20± 2.85 for nitrate in a study carried out n Sagbama creek in Bayelsa State, Nigeria.

Classes of metals or metalloids with a particular density higher than 5g/cm3 are known as heavy metals (Sarmistha *et al.* 2021). At trace amounts of 10 to 15 parts per million, essential heavy metals such as copper (Cu), manganese (Mn), zinc (Zn), iron (Fe), cobalt (Co), and nickel (Ni) are vital for human physiological and biological processes (Tchounwou *et al.* 2012; Sarmistha *et al.* 2021). According to Ali and Khan, (2018), non-essential heavy metals include lead (Pb), mercury (Hg), cadmium (Cd), aluminium (Al), and arsenic (As). Since heavy metals are extremely persistent and tend to bioaccumulate in the food chain, they pose a serious threat to the aquatic environment (El Ati-Hellal *et al*. 2021). For heavy metals, iron (Fe) concentrations ranged from 0.12 to 0.76 mg/L, with a mean value of 0.33 ± 0.20 mg/L, slightly exceeding the WHO permissible limit of 0.3 mg/L. Lead (Pb) ranged from 0.05 to 0.15 mg/L, with a mean value of 0.09 ± 0.04 mg/L, exceeding the WHO limit of 0.01 mg/L. Copper (Cu) levels ranged from 0.11 to 0.74 mg/L, with a mean of 0.39 ± 0.22 mg/L, below the WHO limit of 2.0 mg/L. Chromium concentrations were recorded between 0.29 and 0.77 mg/L, with a mean value of 0.51 ± 0.17 mg/L, exceeding WHO limits. Nickel levels ranged from 0.07 to 0.14 mg/L, with a mean value of 0.09 ± 0.03 mg/L, surpassing the WHO limit of 0.07 mg/L. Heavy metals observed in this study were in the order of magnitude Cr > Cu > Ni > Fe > Pb. Iyama *et al.* (2018) higher values of 5.96 ± 5.01 for Fe; and similar mean values 0.045 ± 0.01for Pb. According to Iyama *et al.* (2018), inappropriate disposal of dry cell batteries and tires has been linked to the Pb levels in Niger Delta waters. Pb negatively impacts aquatic creatures by causing developmental issues, decreased capacity, and sodium loss. (Onojake *et al.* 2017).

Table 1: Physicochemical characteristics of surface water in the study area

Physicochemical Parameters	Range	Mean	WHO, 2017
pH	6.60 – 6.90	6.73	6.5 – 8.5
Electrical Conductivity, µS/cm	55.00 – 180.00	98.85	1000
Total Suspended Solids (TSS), mg/L	17.50 – 43.50	31.64	50
Total Dissolved Solids (TDS), mg/L	35.20 – 115.20	63.23	500
Dissolved Oxygen (DO), mg/L	4.52 – 4.69	4.61	
Salinity, mg/L	2.99 – 63.98	16.63	1000
Biochemical Oxygen Demand (BOD), mg/L	0.00 – 4.52	2.74	
Chemical Oxygen Demand (COD), mg/L	7.40 – 8.30	7.80	
Turbidity, NTU	60.50 – 105.50	87.50	5
Total Hardness, mg/L	41.00 – 198.00	69.57	
Total Hydrocarbon Content, (THC)	N. D	N. D	
Sulphate, (SO_4^{2-})	19.44 – 27.17	22.39	250
Nitrate, (NO_3^-)	0.004 - 0.024	0.01	50
Phosphate, (PO42+)	0.74	1.29	
Heavy Metals (mg/L)			
Iron, (Fe)	0.12 – 0.76	0.33	0.3
Lead, (Pb)	0.05 – 0.15	0.09	0.01
Copper, (Cu)	0.11 - 0.74	0.39	2.0
Chromium	0.29 – 0.77	0.51	
Nickel	0.07 – 0.14	0.9	0.07

Note: WHO – World Health Organization.

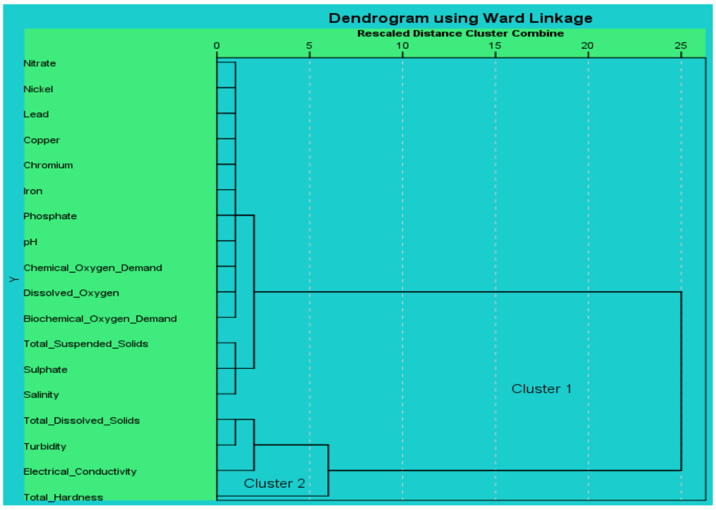

Fig.2: Dendogram of Ojobo surface water parameters.

Cluster Analysis: The results of the cluster analysis conducted on the physicochemical parameters in this study are presented in the dendrogram in Fig.2, which reveals two distinct clusters. The larger cluster (Cluster 1) comprises most of the water quality parameters, including heavy metals such as nickel, lead, copper, chromium, and iron, as well as nutrients like phosphate and nitrate. It also encompasses key water quality indicators, including pH, chemical oxygen demand (COD), dissolved oxygen (DO), biochemical oxygen demand (BOD), total suspended solids (TSS), sulphate, and salinity. The strong association among these parameters suggests that their concentrations in the water are influenced by similar anthropogenic activities, particularly pollution from industrial discharge, agricultural runoff, and domestic waste.

This smaller cluster, referred to as Cluster 2, comprises Total Dissolved Solids (TDS), Turbidity, Electrical Conductivity (EC), and Total Hardness. These parameters are more indicative of natural water characteristics, primarily influenced by geological processes such as erosion and rock weathering. A similar clustering pattern was observed in a study conducted by Ajayi and Okeke, (2024) on Kolo Creek in the Niger Delta, Nigeria, where a comparable dendrogram was reported.

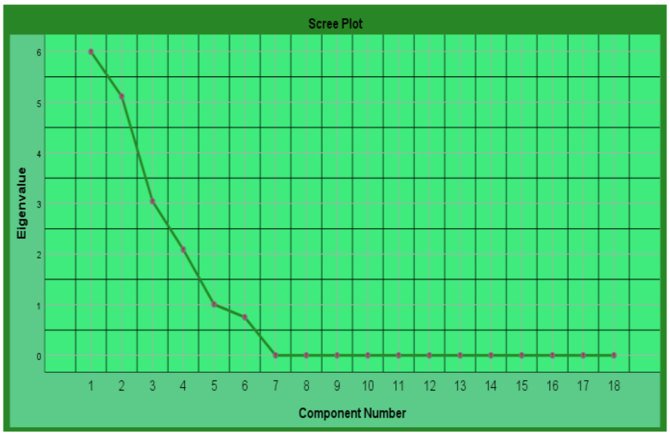

Fig.3: Screen plot result of the surface water

Table 2: Principal component analysis of result for the surface water in the study area

	Component				
Component Matrix	1	2	3	4	5
pH	**-.582**	-.051	**.639**	**.493**	-.066
Electrical Conductivity, µS/cm	**.863**	.229	.027	.227	.359
Total Suspended Solids (TSS), mg/L	**.566**	-.007	-.096	**-.749**	.256
Total Dissolved Solids (TDS), mg/L	**.862**	.231	.027	.228	.358
Dissolved Oxygen (DO), mg/L	.197	**.958**	-.198	.005	-.060
Salinity, mg/L	.598	-.184	.359	**.578**	-.243
Biochemical Oxygen Demand (BOD), mg/L	-.278	-**.580**	**.574**	.236	.317
Chemical Oxygen Demand (COD), mg/L	.132	**.813**	**-.402**	.355	-.024
Turbidity, NTU	**.623**	-.238	**-.667**	.264	-.192
Total Hardness, mg/L	**-.583**	.607	.464	.218	.088
Sulphate, ($SO_4^{2-)}$	**-.642**	.222	**-.634**	.321	-.162
Nitrate, (NO_3^-)	-.161	**-.910**	-.151	-.022	-.215
Phosphate, ($PO_4^{2+)}$	-.244	**-.403**	**-.742**	.285	.300075
Iron, (Fe)	-**.538**	**.827**	.054	-.021	.062
Lead, (Pb)	-.328	**.886**	.042	-.123	.064
Copper, (Cu)	**.858**	**.077**	**.490**	.066	.042
Chromium	**.585**	.309	.281	-.398	**-.470**
Nickel	**.810**	.145	**-.063**	**.431**	-.168
Eigen Value Total	5.994	5.113	3.044	2.090	1.007
Initial Eigen Value % of Variance	33.303	28.405	16.909	11.610	5.592
Cumulative %	33.303	61.708	78.62	90.226	95.818

Principal Component Analysis (PCA): Principal Component Analysis (PCA) was conducted on twenty parameters, leading to the selection of five principal components (PCs) based on their eigenvalues. These five PCs account for 95.82% of the total variance. The extracted components are illustrated in the scree plot presented in Fig.3. According to Lencha *et al.* (2021), factor loadings are categorized based on their values as "strong" (> 0.75), "moderate" (0.50–0.75), and "weak" (0.30–0.50).

The first principal component (PC1) accounted for 33.30% of the total variance in the dataset. The strong positive loadings of EC (+0.863), TDS (+0.862), copper (+0.858), and nickel (+0.810) and a moderate positive loading of turbidity (+0.623) and chromium ((+0.585) (Table 2) suggest that these parameters likely originate from the same source (Mustapha & Nabegu, 2011; Fonfo *et al.* 2022). Conversely, the moderate negative loadings of pH, total hardness, sulfate, iron, and lead indicate that these variables are influenced by different factors, distinct from those affecting the positively loaded parameters in PC1 (Fonfo *et al.* 2022). The significant positive loadings of EC and TDS indicates dissolved ions that may be associated with natural processes such as soil erosion and rock weathering (Elemile *et al.* 2021; Roy *et al.* 2024).

The second principal component (PC2) exhibited strong positive loadings for dissolved oxygen (DO) (+0.958), chemical oxygen demand (COD) (+0.813), lead (+0.886), and iron (+0.827). In contrast, PC2 showed negative loadings for biological oxygen demand (BOD) (-0.580), nitrate (-0.910), and phosphate (-0.403). According to Ukpatu and Udoinyan, (2015), the positive loading of dissolved oxygen in the Okoro River estuary, Southeastern Nigeria, suggests the ecological well-being of the water body and its suitability for sustaining aquatic life, as well as maintaining essential biological functions. Hamed, (2019) and Raimi *et al.* (2022) identified domestic and industrial waste as major contributors to the positive loadings of COD. Okoro *et al.* (2021) attributed to the increasing untreated industrial discharge and municipal solid waste disposed may be the major factor influencing the levels of Lead and iron in surface water. Negative loading of BOD, nitrate and phosphate is an indication that they contribute significantly to oxygen depletion in the study area.

PC3 shows moderate negative loading of COD, turbidity, phosphate and sulphate with values – 0.402, – 0.667, – 0.742, and – 0.634 respectively. pH and BOD showed moderate positive loading with values + 0.639, + 0.574 and weak positive loading of copper with values + 0.490 in PC3. The moderate positive loading of COD, turbidity, phosphate and sulphate suggest similar sources and similar factors may be contributing to their concentration. Phosphate, sulphate and turbidity may be contributing COD levels in the water body. Domestic waste discharge and agricultural waste are major sources of sulphate and phosphate in the environment (Kipngetich *et al.* 2013).

PC4 showed a weak positive loading of pH and nickel with values of + 0.493 and – 0.431 respectively. The weak positive loading of pH and nickel suggest that pH influences the concentration of nickel in the surface water. The moderate negative loading of TDS (- 0.749) suggests that different factors may be influencing its concentration from the factor affecting the concentration of nickel in the study area. The significant loading of nickel in PC1, PC3 and PC4 infers that there are different sources of nickel in the study area. Domestic and industrial effluents are sources of nickel in the environment (Begum *et al.* 2022). Chromium was the only parameter that showed significant loading of - 0.470 in PC5. The significant loading of chromium in PC1 and PC5 is an indication that different sources may be influencing the concentration of chromium in the surface water.

Conclusion: The analysis of surface water quality in the study area indicated that all heavy metal concentrations complied with the World Health Organization (WHO) drinking water quality standards, except for turbidity, lead (Pb), and nickel (Ni). The elevated concentration of these parameters indicates contamination. The results of Principal Component Analysis (PCA) and Cluster Analysis (CA) suggest that domestic and anthropogenic activities have significantly influenced the water quality. Potential sources of contamination include industrial discharge, domestic waste, and agricultural runoff, which contribute to the degradation of water quality. Regular assessment of key water quality parameters will help identify potential contamination trends and guide appropriate mitigation strategies to prevent further environmental and health risks.
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