Application of Principal Component Analysis in Establishing the Dominant Pollutants in the New Calabar River.

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ABSTRACT

The New Calabar River, an essential water source in Nigeria's Niger Delta region, is facing significant water quality issues due to human activities. This research adopts a comprehensive strategy, integrating field data gathering, statistical analyses, and modeling methods to evaluate and simulate the impact of these activities on water quality. Analysis of Variance (ANOVA) outcomes revealed notable seasonal fluctuations in certain water quality parameters like Water Temperature (F=116.009, p<0.001) and pH levels (F=12.782, p<0.001), indicating clear distinctions between the specified months. Conversely, Total Dissolved Solids (TDS) and Electrical Conductivity (EC) showed insignificant variations (F=0.050, p=0.95 and F=0.036, p=0.96, respectively). Principal Component Analysis (PCA) identified crucial factors influencing water quality variations. The rotated component matrix displayed substantial loadings for parameters such as Turbidity (0.932), Dissolved Oxygen (0.919), and Biological Oxygen Demand (0.912), suggesting their significant impact on water quality dynamics. Employing GIS techniques for spatial mapping of WQI values uncovered pollution hotspots near Points 5 and 6, aligning with the PCA findings. These regions exhibited "Very Bad" water quality status, indicating severe pollution levels. Conversely, Point 3 demonstrated a "Medium" water quality status, implying better water quality conditions. Overall, the study highlights the intricate connection between human activities and water quality in the New Calabar River. The insights gained offer valuable guidance for informed decision-making in water resource management, pollution mitigation strategies, and policy development. Future research endeavors should prioritize continuous monitoring, adaptive management approaches, and community involvement to foster sustainable water quality management practices in the area.

Keywords: New Calabar River, Water quality, Anthropogenic activities, Statistical analyses, Analysis of Variance (ANOVA), Principal Component Analysis (PCA), Spatial mapping, GIS techniques, Water resource management.

INTRODUCTION

The New Calabar River, situated in Nigeria's Niger Delta region, plays a crucial role in supporting various ecological, economic, and social activities within the surrounding communities (Adebayo, 2015). Historically, it has served as a significant water resource for transportation, fishing, agriculture, and domestic water supply, contributing significantly to the livelihoods of the local population and the regional economy (Jones et al., 2005). However, rapid urbanization, industrialization, agricultural intensification, and population growth have escalated anthropogenic pressures on the water quality of the New Calabar River.

These anthropogenic activities, which include industrial discharges, agricultural runoff, domestic sewage, and deforestation, have introduced a diverse range of pollutants into the river ecosystem (Adekola et al., 2015). These pollutants encompass organic matter, heavy metals, nutrients such as nitrogen and phosphorus, pesticides, and other contaminants (Garba et al., 2013). As a result, there are substantial challenges to the ecological integrity and water quality of the river. The cumulative impacts of these activities have raised concerns about the sustainability of water resources and the potential risks to human health and aquatic ecosystems.

The degradation of water quality in the New Calabar River is evident through various indicators, including changes in physicochemical parameters like pH levels, dissolved oxygen (DO) concentrations, turbidity, nutrient levels (nitrogen and phosphorus), and the presence of contaminants such as heavy metals and pathogens (Ogbodo et al., 2020). These alterations not only affect the river's aesthetic value but also have profound ecological consequences, leading to eutrophication, habitat degradation, biodiversity loss, and waterborne diseases.

Furthermore, the New Calabar River is part of a complex hydrological network interconnected with other water bodies, including tributaries, wetlands, and estuarine zones (Smith et al., 2016). This interconnected nature amplifies the challenges of water quality management, as pollutants can travel across spatial scales and affect downstream areas. Consequently, there is a critical need for a holistic and integrated approach to assess and mitigate the impacts of anthropogenic activities on water quality.

In response to these challenges, this study seeks to contribute to the scientific understanding the courses of the pollution in the New Calabar River by modeling the effect of anthropogenic activities (Ibrahim et al., 2020). The study will employ a multidisciplinary approach, integrating field data collection, statistical analysis, modeling techniques (such as GIS-based modeling and regression modeling), and spatial mapping tools (such as ArcGIS) to assess the current water quality status, identify pollutant sources, predict long-term impacts, and propose management recommendations. Through this research endeavor, we aim to inform evidence-based decision-making and promote sustainable water resource management practices in the New

Key issues that need to be addressed include water quality degradation, pollutant sources and pathways, long-term impact assessment, spatial variability and hotspots, integration of data and modeling, and management and policy implications (Jones, 2018).

The New Calabar River is experiencing a decline in water quality parameters such as pH levels, dissolved oxygen (DO) concentrations, turbidity, nutrient levels (nitrogen and phosphorus), and the presence of pollutants such as heavy metals, organic compounds, and pathogens (Adebayo, 2015). These alterations can adversely impact aquatic life, ecosystem functioning, and human health.

The identification and quantification of pollutant sources (e.g., industrial effluents, agricultural runoff, domestic sewage) and their pathways into the New Calabar River are not well-understood (Adekola et al., 2015). Understanding these sources and pathways is crucial for developing targeted pollution control measures and mitigation strategies.

There is a lack of comprehensive long-term studies assessing the cumulative impacts of anthropogenic activities on water quality in the New Calabar River (Brown & Smith, 2019). Predicting the future trends and impacts of ongoing pollution is essential for effective water resource management and sustainable development.

Maintaining healthy water quality is essential for preserving aquatic ecosystems, biodiversity, and ecosystem services (Griffiths, 2008). This study's findings will aid in identifying pollution hotspots, assessing ecological risks, and implementing targeted conservation strategies to protect vulnerable species, habitats, and ecological functions within the New Calabar River basin (Mustapha et al., 2021).

Water quality directly impacts public health outcomes, as contaminated water can lead to waterborne diseases, exposure to toxins, and adverse health effects (Olatunji et al., 2015). By evaluating the water quality parameters and pollutant levels, this study will contribute to safeguarding public health, reducing health risks, and promoting safe water consumption practices among communities relying on the New Calabar River for domestic purposes (Garba et al., 2020).

A. PRINCIPAL COMPONENT ANALYSIS (PCA) IN ENVIRONMENTAL STUDIES

Principal Component Analysis (PCA) is a statistical technique used to reduce the dimensionality of complex datasets while retaining essential information. In environmental studies, PCA helps identify patterns, relationships, and underlying structures within multivariate data, making it valuable for understanding environmental processes and interpreting data variability.

i. Mathematical Formulation of PCA

1. Data Standardization: Standardize the data by subtracting the mean and dividing by the standard deviation for each variable.

$$Zij = \frac{(Xj - \bar{X}j)}{std(Xj)} \qquad 1.1$$

Where Zij is the standardized value, $\bar{X}j$ is the mean of variable j, and std(Xj) is the standard deviation of variable Xj.

2. Covariance Matrix: Calculate the covariance matrix CC for the standardized data.

$$C = \frac{1}{n}\sum_{i=1}^{n} Z_i^T Z_i \qquad 1.2$$

3. Eigen decomposition: Perform eigen decomposition on the covariance matrix to obtain the eigenvectors (V_k) and eigenvalues (λ_k).

$$CV_k = \lambda_k V_k \qquad 1.3$$

4. Principal Components: Obtain the principal components $PCkPCk$ by projecting the standardized data onto the eigenvectors.

$$PC_k = ZV_k \qquad 1.4$$

ii. Interpretation and Applications of PCA

- **Dimensionality Reduction**: PCA simplifies data visualization and analysis by retaining the most informative principal components.
- **Variance Explanation**: Eigenvalues indicate the amount of variance explained by each principal component, helping to identify key factors influencing water quality.

B. ANALYSIS OF VARIANCE (ANOVA)

ANOVA is a statistical method used to compare means among different groups and determine if significant differences exist. In environmental studies, ANOVA helps assess the impact of various factors, such as location and time, on water quality parameters.

i. Application in Water Quality Studies

- **Comparative Analysis**: ANOVA can compare water quality parameters across different locations and time periods, identifying significant variations and interactions. For example, in the New Calabar River study, ANOVA revealed significant differences in water quality parameters based on sampling locations and months, influenced by seasonal changes and hydrological factors.

ii. Geographic Information System (GIS)

GIS is a powerful tool for spatial analysis and mapping in environmental studies. It integrates spatial data with various attributes, allowing for the visualization, analysis, and interpretation of spatial patterns and relationships.

C. GIS APPLICATIONS IN WATER QUALITY MANAGEMENT

- **Spatial Mapping**: GIS can map the distribution of water quality parameters, identify pollution hotspots, and assess spatial variability. This spatial analysis provides insights into localized pollution sources and helps prioritize management interventions.
- **Remote Sensing**: Satellite imagery and remote sensing data can be used to assess land use changes and their impact on water quality, supporting the analysis of anthropogenic influences over time.

MATERIALS AND METHODS

The results of the study focused on examining the changes in water quality in New Calabar River based on the factor causing this change, particularly concerning the effects of human activities as the dry season transitions into the rainy season. The study was conducted over a three-month period from January to February, with sampling conducted at six locations along the river.

Understanding the spatial context of the study area was crucial for accurate data collection and analysis. New Calabar River, a significant water body, is located within the urban area of Port Harcourt, Nigeria. Port Harcourt, serving as the capital of Rivers State, is a major economic and industrial center in the Niger Delta region. Its geographical coordinates are approximately 04°48’56.16” N and 07°2’59.28 E.

Sampling occurred twice a month at the selected locations, resulting in a total of 12 samples collected per location over the three-month period. Standard protocols were followed for water sample collection, and analysis of 11 key water quality parameters was conducted at Austine Research Center in Ahiakahia, Rivers State. Here Water samples was collected from the New Calabar River, firstly, consideration was on the necessary equipment and supplies, including sterile sampling bottles, labels, a waterproof marker, a cooler with ice packs, gloves, a field notebook, and portable meters for pH, temperature, and conductivity. The sample bottles were labeled with relevant information such as sample ID, date, time, location, and parameters to be analyzed. All relevant details were recorded in the field notebook, including weather conditions and any potential contamination sources.

Arc Gis was used to choose locations on the river. Gloves were worn and appropriate protective gear, ensuring personal safety when accessing the water body. For surface water, facing upstream, the sampling bottle rinsed three times with the water to be sampled, then the bottle was submerged to a depth of 15cm with the mouth facing upstream. Caped underwater to avoid contamination.

Immediately after collection of sample for each day, they were stored in a cooler with ice packs. Samples where then transported to the laboratory, ideally within 24 hours, maintaining a chain of custody form to

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document sample handling.

These parameters included water temperature, pH, total dissolved solids (TDS), total suspended solids (TSS), electrical conductivity (EC), lead (Pb), sodium (Na), biochemical oxygen demand (BOD), chemical oxygen demand (COD), dissolved oxygen (DO), and iron (Fe).

Data standardization using mean values and standard deviations ensured consistency across parameters and locations. Principal Component Analysis (PCA) was then utilized to analyze the standardized dataset, aiming to reduce dimensionality and uncover underlying patterns. Additionally, Two-way Analysis of Variance (ANOVA) was employed to assess the impact of location and time (months) on water quality parameters. PCA analysis revealed significant patterns and variations in water quality across the six locations, with identified components aiding in understanding the key factors driving these variations. Two-way ANOVA results indicated significant differences attributed to both location and time, highlighting seasonal changes and potential impacts of human activities.

A. STUDY AREA

The New Calabar River is integral to both the ecological balance and socio-economic fabric of Port Harcourt, Nigeria. Serving as a vital water resource, it facilitates activities ranging from agriculture to transportation and industry within the region. Precise knowledge of the river's spatial coordinates is essential not only for geographical accuracy but also for ensuring the reliability of data collection and analysis, especially in environmental science and water quality assessment.

The river traverses a varied landscape characterized by urban settlements, industrial areas, agricultural zones, and natural habitats. Its coordinates, approximately 04°48'56.16" N and 07°2'59.28 E, position it centrally within the biodiverse Niger Delta region.

Port Harcourt, a significant economic and industrial center, owes much of its prosperity to its strategic coastal location and access to waterways like the New Calabar River. However, this development has brought environmental challenges, notably in water quality management.

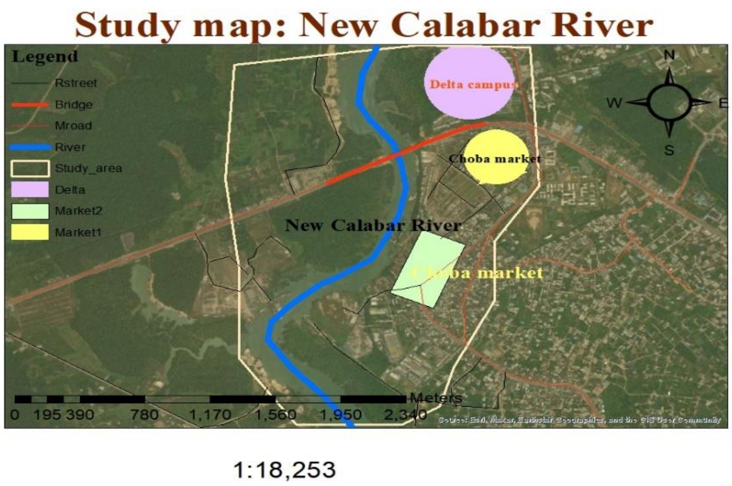

Figure 1 Study map of the New Calabar River

The New Calabar River faces multiple threats from human activities, including pollution from sewage, runoff, and industrial discharges. Agricultural practices, deforestation, and land-use changes in the river's catchment area further exacerbate sedimentation, nutrient runoff, and habitat degradation.

Given these challenges, the river's coordinates play a crucial role in delineating study areas along its course, each presenting unique environmental characteristics and challenges. Accurate data collection and analysis are vital components of water quality assessment efforts, with spatial coordinates enabling the integration of geospatial technologies like GIS and remote sensing into monitoring initiatives.

For the study on water quality variability and its anthropogenic impacts in the New Calabar River, a variety of materials and equipment were indispensable for data collection, analysis, and interpretation:

- Water sampling equipment, including bottles and meters for in-situ measurements.
- Laboratory analysis equipment like spectrophotometers and chemical analysis kits.
- Geospatial tools such as GPS devices and GIS software for spatial analysis.
- Field instruments like temperature probes for on-site measurements.
- Documentation and field supplies, including notebooks, labels, and maps for recording observations and sampling details.

This array of materials ensured comprehensive data collection and analysis, essential for understanding the water quality dynamics in the New Calabar River and formulating effective management strategies.

B. METHODOLOGY

The study embarked on a comprehensive investigation into the abundant component causing the reduction in water quality of the New Calabar River, employing a multifaceted methodology encompassing boat-based water sample collection, laboratory analysis, and spatial mapping using ArcGIS software. This integrated approach aimed to provide a thorough understanding of water quality dynamics and anthropogenic influences in the study area.

A boat was chosen as the primary means to access specific sampling locations along the river, considering its geographical layout and the need to efficiently reach diverse points of interest. Sampling activities were typically conducted during mid-day hours to capture water quality conditions during periods of heightened activity and potential anthropogenic impacts.

Table I Coordinate of sample points

ID	Easting	Northing
1	06° 53' 53.25"	04° 54' 12.01"
2	06° 53' 53.49"	04° 53' 58.73"
3	06° 53' 59.53"	04° 53' 45.45"
4	06° 53' 59.43"	04° 53' 39.65"
5	06° 53' 56.15"	04° 53' 29.99"
6	06° 53' 56.25"	04° 53' 19.85"

Water sampling bottles were utilized for grab sampling, enabling the collection of water samples at various depths to obtain a comprehensive profile of water quality parameters across different layers of the water column. To quantitatively measure standard water quality parameters such as pH, dissolved oxygen, biochemical oxygen demand (BOD), nutrients, heavy metals, and other relevant indicators, specific methods and equipment were used. For pH measurement, a calibrated pH meter like the Hach HQ40d was used. The electrode is rinsed with distilled water, submerged in the water sample, and the reading is recorded once stabilized. Dissolved oxygen (DO) was measured using a dissolved oxygen meter. For the DO meter, the probe is submerged in the sample after calibration and the stabilized reading is recorded. Biochemical

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oxygen demand (BOD) measurement involves using a BOD incubator. Initial DO concentration is measured, samples are incubated in BOD bottles at 20°C in the dark for 5 days, and the final DO concentration is measured. BOD is calculated as the difference between initial and final DO concentrations. For nutrient analysis, a spectrophotometer used. For nitrate (NO^{-3}), the sample is treated with appropriate reagents, and the concentration is measured spectrophotometrically. For phosphate (PO_4^{-3}), similar steps are followed using specific reagents for phosphate detection. Heavy metals like lead (Pb) and iron (Fe) are analyzed using atomic absorption spectrophotometry (AAS). Water samples are acidified with nitric acid, digested if necessary, and analyzed using the appropriate equipment. Total dissolved solids (TDS) and total suspended solids (TSS) are measured using a gravimetric method. For TDS, a known volume of filtered sample is evaporated, and the residue is weighed. For TSS, a known volume of unfiltered sample is filtered, the residue on the filter is dried, and the weight is determined. Electrical conductivity (EC) is measured using a conductivity meter, where the probe is submerged in the sample, and the reading is recorded. All these procedures ensure accurate and reliable measurement of water quality parameters. Most of this test where carried out in the laboratory.

Cutting-edge instrumentation, including spectrophotometers, pH meters, and GPS devices, ensured the accuracy and precision of measurements. Additionally, sophisticated spatial mapping using ArcGIS software facilitated the accurate delineation and identification of specific sampling locations along the river.

After data collection which was being store in a excel spreadsheet, laboratory analysis, and spatial mapping, the study entered the phase of data analysis and interpretation. Statistical techniques using Scientific Package for Social Science (SPSS) was used to carry out the statistical analysis such as Analysis of Variance (ANOVA), correlation analysis, regression analysis, and spatial interpolation were applied to assess relationships between water quality parameters and derive meaningful insights.

Comparative analysis across sampling locations and time intervals revealed spatial heterogeneity in water quality and seasonal trends influenced by anthropogenic activities and environmental factors. Descriptive analysis, including mean values, standard deviations, normalization, and subsequent Principal Component Analysis (PCA), aided in understanding water quality dynamics and underlying patterns.

Table II Test result of Water Quality Parameters from January to March

WATER SAMPLE RESULTS FROM JAN - MAR

		January						Febuary						March					
s/n	Parameters	Point 1	point 2	point 3	point 4	point 5	point 6	Point 1	point 2	point 3	point 4	point 5	point 6	Point 1	point 2	point 3	point 4	point 5	point 6
1	Water Temp (°C)	29.55	28.6	29.12	29.01	30.24	29.48	29.35	28.4	28.92	28.81	30.04	29.28	29.15	28.2	28.72	28.61	29.84	29.08
2	pH	5.69	5.65	5.77	5.61	5.83	5.8	5.27	5.23	5.35	5.19	5.41	5.38	4.85	4.81	4.93	4.77	4.99	4.96
3	TDS (mg/l)	25.78	27.06	26.48	122.25	255.6	240.59	23.78	25.06	24.48	114.25	247.6	232.59	22.58	23.86	23.28	106.25	239.6	224.59
5	EC (µS/cm)	48.26	55.42	53.76	72.86	82.65	90.1	57.26	64.42	62.76	81.86	385.86	532.64	45.26	52.42	50.76	69.86	373.86	520.64
6	DO (mg/l)	6.2	5.78	5.65	5.2	6.34	5.93	6.67	6.25	6.12	5.67	6.81	6.4	5.28	4.86	4.73	4.28	5.42	5.01
7	COD (mg/l)	20.15	26.56	22.44	120.65	115.78	98.48	23.49	29.9	25.78	133.85	128.98	111.68	12.15	18.56	17.22	111.43	106.56	89.26
8	Na (mg/l)	2.21	2.5	2.61	2.44	30.12	25.7	1.89	2.18	2.29	2.12	32.66	28.24	3.02	3.31	3.42	3.25	34.55	30.13
9	BOD (mg/l)	2.24	2.21	3	2.54	3.62	3.28	1.51	1.48	2.27	1.81	2.89	2.55	2.84	2.81	3.6	3.14	4.22	3.88
10	Fe (mg/l)	0.52	0.64	0.58	1.6	2.86	2.52	0.44	0.56	0.5	1.52	2.78	2.44	0.47	0.59	0.53	1.55	2.81	2.47
11	Ca (mg/l)	0.64	0.89	0.82	1.1	2.65	1.42	0.81	1.06	0.99	1.27	2.82	1.59	0.51	0.76	0.69	0.97	2.52	1.29
12	Pb (mg/l)	0.09	0.09	0.05	0.11	0.18	0.17	0.07	0.07	0.03	0.09	0.16	0.15	0.06	0.06	0.02	0.08	0.15	0.14

The study conducted a two-way ANOVA to examine the impact of sampling locations and months on various water quality parameters, revealing significant interactions and variations. PCA, coupled with Varimax rotation, identified key factors driving variations in water quality and facilitated a clearer interpretation of the dataset.

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Spatial mapping using ArcGIS software and the Inverse Distance Weighting (IDW) interpolation method visualized the spatial distribution and impact of water quality parameters, providing insights into temporal trends and spatial variations. These spatial maps supported informed decision-making and management strategies for enhancing water quality and ecosystem health in the New Calabar River.

The calculation of the Water Quality Index (WQI) in this study adhered to the standards set by the World Health Organization for drinking water quality, as recommended by Yu et al. (2013). The WQI serves as a powerful tool for effectively conveying information regarding water quality to concerned citizens and policymakers, offering a consolidated assessment based on various water quality parameters. This approach was first introduced by Horon in 1965 and later generalized by Brown et al. in 1970.

The WQI is a singular numerical value that provides a rating of water quality by synthesizing multiple water quality parameters. In the context of this study, a lower WQI score signifies better water quality, falling within categories such as “Excellent” or “Good,” while a higher score is indicative of degraded water quality, categorized as “Bad” or “Poor.”

The calculation of WQI involves a systematic process, and the following procedures were meticulously followed:

1. **Selection of Water Quality Parameters:** The relevant water quality parameters, including but not limited to pH, Dissolved Oxygen (DO), Biochemical Oxygen Demand (BOD5), Electrical Conductivity (EC), Nitrate (NO3^2-), Total Dissolved Solids (TDS), Total Hardness, and bacteriological parameters, were chosen for inclusion in the WQI calculation.
2. **Normalization of Data:** Each water quality parameter was normalized to a scale of 0 to 100, with 100 representing the ideal or permissible level according to the World Health Organization standards. This normalization ensures uniformity in the assessment, regardless of the diverse units or scales associated with individual parameters.
3. **Calculation of Sub-Indices:** Sub-indices were computed for each parameter based on predetermined formulae, reflecting the deviation of each parameter from the ideal value. These sub-indices contribute to the overall WQI calculation.
4. **Aggregation of Sub-Indices:** The individual sub-indices were then aggregated to derive a composite WQI score. This synthesis provides a holistic representation of the overall water quality, considering the collective impact of the chosen parameters.
5. **Classification of WQI Score:** The resulting WQI score was classified into distinct categories, such as Excellent, Good, Bad, or Poor, offering a readily understandable depiction of the water quality status.

By following these procedures, the calculated WQI serves as a concise and informative measure, facilitating effective communication of the water quality status to both the public and decision-makers. This systematic approach to WQI calculation enhances the interpretability of the complex dataset, contributing valuable insights to the broader discourse on water quality within the New Calabar River.

1. Estimating the quality rating (q_i) of each parameter using equation 3.1

$$q_i = 100 * \frac{(v_i - v_{id})}{v_s - v_{id}} \qquad 3.1$$

Where; v_i = actual amount of the ith parameter present

V_{id} = ideal amount of the ith parameter present = 0 (except ph where it is 7)

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V_s = standard permissible value of the ith parameter present

2. Determination of the unit weight (w_i) of the ith parameter using equation (3.2). theses unit weight transformed all the concerned parameters of different units and dimensions to a common scale.

$$w_i = \frac{k}{v_{si}} \qquad 3.2$$

Where; k = proportionality constant calculated in accordance to equation (3.3)

V_{si} = standard permissible value of the ith parameter present

$$k = \frac{1}{\sum_{i=q}^{11}[\frac{1}{v_{si}}]} \qquad 3.3$$

3. Determination of the sub-index (SI_i) for the ith parameter using Equation (3.4)

$$SI_i = q_i * w_i \qquad 3.4$$

4. Determination of wqi using equation (3.5)

$$WQI = \sum_{i=1}^{n} SI_I \qquad 3.5$$

Table III in this study provides a comprehensive overview of the permissible values for quality parameters in drinking water, as stipulated by both the World Health Organization (WHO) and the Nigerian Standard for Drinking Water Quality (NSDWQ). These specified values serve as benchmarks against which the obtained water quality parameters were compared. The inclusion of both international and national standards adds a contextual layer to the assessment, considering the specific regulatory framework relevant to the study area.

In conjunction with these permissible values, Table IV displays the ranges of the Water Quality Index (WQI) alongside their corresponding ratings or statuses, as outlined by Brown et al. in 1970. This categorization system allows for a straightforward interpretation of the calculated WQI scores. The comparisons drawn between the actual water quality parameters obtained from the collected samples and the associated WQI values offer a comprehensive assessment of the status of the sampled water.

Table III WHO standard for water quality

Sl. No	Parameter	Standard Value (S_i)	Ideal Value (V_i)	Weightage Factor (W_i)
1	pH	8.5	7	0.1176
2	Electrical Conductivity (µmhos/cm)	300	0	0.0033
3	Total Dissolved Solids (mg/l)	1000	0	0.0010
4	Total Alkalinity (mg/l)	120	0	0.0083
5	Total Hardness (mg/l)	300	0	0.0033
6	Fluoride (mg/l)	1.5	0	0.6666
7	Chloride (mg/l)	250	0	0.0040
8	Nitrate (mg/l)	50	0	0.0200
9	Sulphate (mg/l)	250	0	0.0040
10	Iron (mg/l)	0.3	0	3.3333
11	Calcium (mg/l)	75	0	0.0133
12	Magnesium (mg/l)	30	0	0.0333

Figure: Water Quality Parameters, WHO Standard Values, Ideal Values and Weightage Factors of Water Quality Parameters

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Table IV Water quality index (WQI) and its representative status

Concentration	Quality
0 – 25	Excellent
26 – 50	Good
51 – 75	Medium
76 – 100	Bad
> 100	Very bad

By utilizing these tables, the study facilitates a nuanced evaluation of the water quality, taking into account both individual parameter values and the aggregated WQI scores. The incorporation of internationally recognized standards in Table III and the WQI rating system in Table IV provides a robust framework for contextualizing the findings within the broader context of global and national water quality guidelines.

The process of comparing the observed water quality parameters against established standards and subsequently utilizing WQI values to assess the overall status of the collected water samples enhances the depth and clarity of the research outcomes. This systematic approach contributes to a comprehensive understanding of the suitability of the sampled water for drinking purposes, providing valuable insights for both scientific discourse and practical applications in water resource management.

RESULTS AND DISCUSSIONS

A. COMPARATION OF WATER QUALITY PARAMETERS FOR THE THREE MONTHS

Table V pH water quality values

Ph						
	Point 1	point 2	point 3	point 4	point 5	point 6
January	5.69	5.65	5.77	5.61	5.83	5.8
Feburary	5.27	5.23	5.35	5.19	5.41	5.38
March	4.85	4.81	4.93	4.77	4.99	4.96

Table VI Total dissolved solids water quality values

TDS (mg/l)						
	Point 1	point 2	point 3	point 4	point 5	point 6
January	25.78	27.06	26.48	122.25	255.6	240.59
Feburary	23.78	25.06	24.48	114.25	247.6	232.59
March	22.58	23.86	23.28	106.25	239.6	224.59

Table VI Electrical Conductivity water quality values

EC (µS/cm)						
	Point 1	point 2	point 3	point 4	point 5	point 6
January	48.26	55.42	53.76	72.86	376.86	523.64
Feburary	57.26	64.42	62.76	81.86	385.86	532.64
March	45.26	52.42	50.76	69.86	373.86	520.64

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Table VII Dissolved Oxygen water quality parameters

DO (mg/l)						
	Point 1	point 2	point 3	point 4	point 5	point 6
January	6.2	5.78	5.65	5.2	6.34	5.93
February	6.67	6.25	6.12	5.67	6.81	6.4
March	5.28	4.86	4.73	4.28	5.42	5.01

Table VIII Chemical Oxygen Demand water quality parameters

COD (mg/l)						
	Point 1	point 2	point 3	point 4	point 5	point 6
January	20.15	26.56	22.44	120.65	115.78	98.48
Feburary	23.49	29.9	25.78	133.85	128.98	111.68
March	12.15	18.56	17.22	111.43	106.56	89.26

Table IX Sodium water quality vaalues

Na (mg/l)						
	Point 1	point 2	point 3	point 4	point 5	point 6
January	2.21	2.5	2.61	2.44	30.12	25.7
Feburary	1.89	2.18	2.29	2.12	32.66	28.24
March	3.02	3.31	3.42	3.25	34.55	30.13

Table X Biological Oxygen Demand of water quality value

BOD (mg/l)						
	Point 1	point 2	point 3	point 4	point 5	point 6
January	2.24	2.21	3	2.54	3.62	3.28
Feburary	1.51	1.48	2.27	1.81	2.89	2.55
March	2.84	2.81	3.6	3.14	4.22	3.88

Table X Iron water quality values

Fe (mg/l)						
	Point 1	point 2	point 3	point 4	point 5	point 6
January	0.52	0.64	0.58	1.6	2.86	2.52
Feburary	0.44	0.56	0.5	1.52	2.78	2.44
March	0.47	0.59	0.53	1.55	2.81	2.47

Table XII Calcium water quality values

Ca (mg/l)						
	Point 1	point 2	point 3	point 4	point 5	point 6
January	0.64	0.89	0.82	1.1	2.65	1.42

Feburary	0.81	1.06	0.99	1.27	2.82	1.59
March	0.51	0.76	0.69	0.97	2.52	1.29

Table XIII Lead water quality values

Pb (mg/l)						
	Point 1	point 2	point 3	point 4	point 5	point 6
January	0.09	0.09	0.05	0.11	0.18	0.17
Feburary	0.07	0.07	0.03	0.09	0.16	0.15
March	0.06	0.06	0.02	0.08	0.15	0.14

Table XIV Water temperature values

	Water Temp (°C)					
	Point 1	point 2	point 3	point 4	point 5	point 6
January	29.55	28.6	29.12	29.01	30.24	29.48
Feburary	29.35	28.4	28.92	28.81	30.04	29.28
March	29.15	28.2	28.72	28.61	29.84	29.08

The comparative analysis of water quality parameters across the three months provides valuable insights into temporal variations and potential trends in the New Calabar River.

1. **Water Temperature (Table IV)**

Generally, there was a decrease in water temperature from January to February, followed by a slight increase or stabilization in March. Points with higher anthropogenic activities tended to show higher water temperatures throughout the months, indicating potential human influence on water temperature.

2. **pH Levels (Table V)**

There was a noticeable decrease in pH levels from January to March across all points, suggesting a potential increase in acidity or decrease in alkalinity during this period. Points with higher anthropogenic activities tended to have lower pH values, especially in March, indicating a potential impact of human activities on pH levels.

3. **Total Dissolved Solids (TDS) (Table VI)**

There was a general decrease in TDS levels from January to March across all points, indicating a reduction in dissolved solids in the water during this period. Points with higher anthropogenic activities consistently exhibited significantly higher TDS levels throughout the months, indicating potential pollution sources.

4. **Electrical Conductivity (EC) (Table VII)**

Overall, EC values showed fluctuations from January to March, with some points displaying increases while others exhibited decreases. Points with higher anthropogenic activities consistently exhibited significantly higher EC values throughout the months, indicating potential pollution sources.

There was a noticeable variation in DO levels between January and March at most points, with some points showing decreases. Points with higher anthropogenic activities tended to show lower DO levels, especially

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in March, indicating potential oxygen depletion due to pollution.

5. **Chemical Oxygen Demand (COD) (Table VIII)**

Generally, there was a decrease in COD levels from January to March at most points, suggesting a potential reduction in organic pollutant levels. Points with higher anthropogenic activities consistently exhibited higher COD levels, especially in January and February, indicating potential pollution sources.

6. **Sodium (Na) (Table IX)**

Points 1-4 generally exhibited lower Na levels compared to Points 5 and 6, suggesting fewer anthropogenic influences. Points 5 and 6 consistently showed significantly higher Na levels throughout the months, likely due to anthropogenic activities.

7. **Biological Oxygen Demand (BOD) (Table X)**

Points 1-4 generally exhibited relatively stable BOD levels, while Points 5 and 6 consistently demonstrated higher BOD levels, indicating higher organic pollutant influx.

8. **Iron (Fe) (Table XI)**

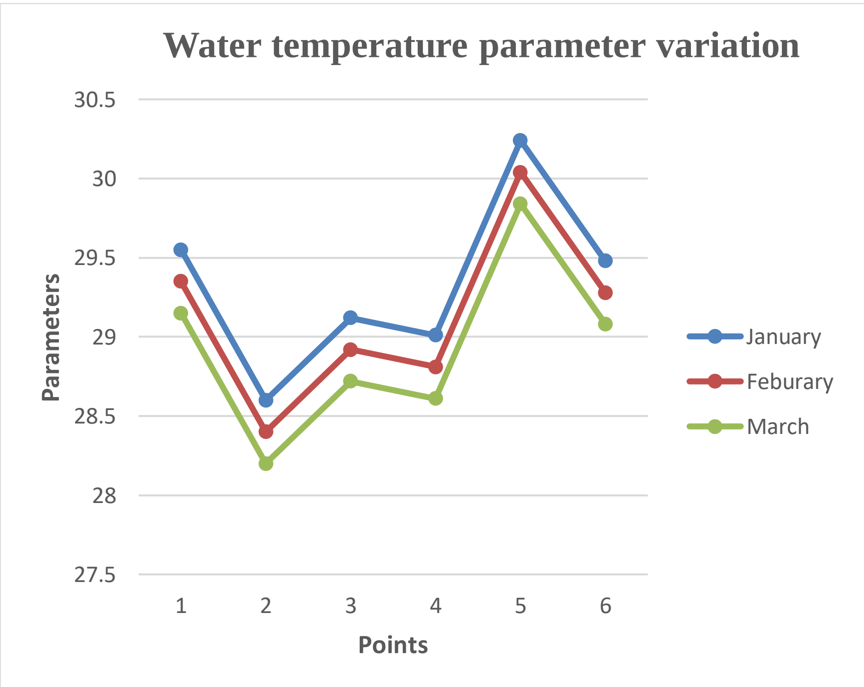
Points 1-3 generally showed relatively consistent Fe levels, while Points 4-6 consistently exhibited higher Fe levels, suggesting different sources of contamination.

9. **Calcium (Ca) (Table XII)**

Points 1-4 generally exhibited relatively consistent Ca levels, while Points 5 and 6 consistently showed higher Ca levels, likely from geological or anthropogenic sources.

11. **Lead (Pb) (Table XIII)**

Points 1-3 generally exhibited relatively consistent Pb levels, while Points 4-6 consistently demonstrated higher Pb levels, indicating potential industrial or anthropogenic inputs.



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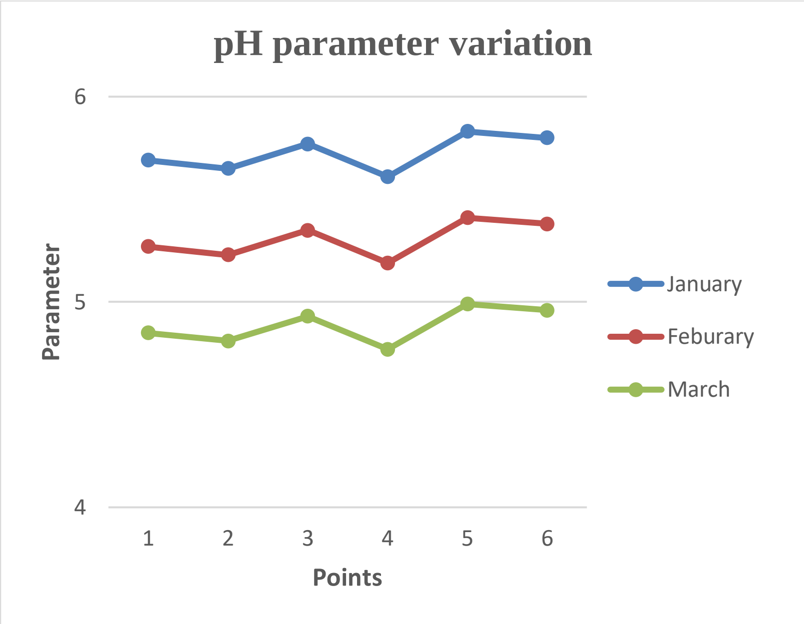
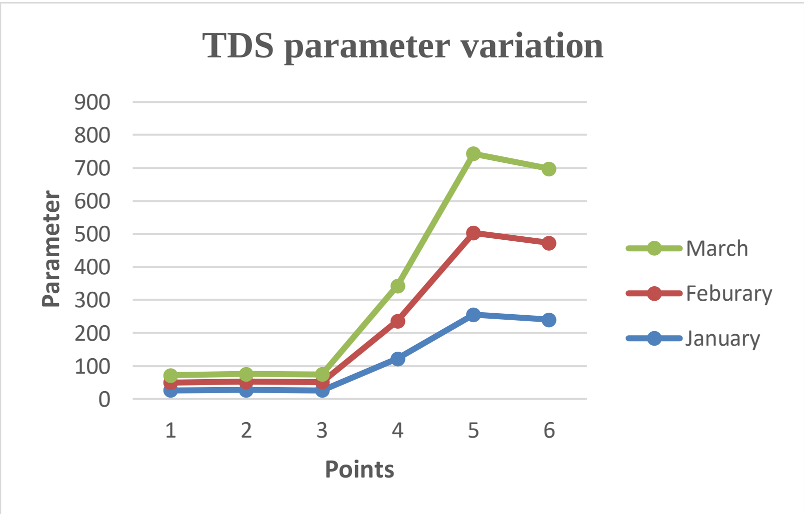
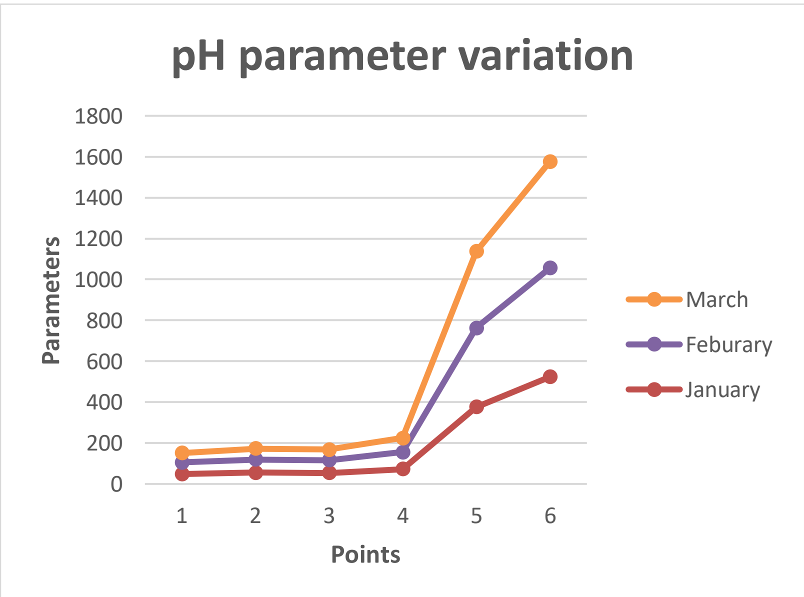
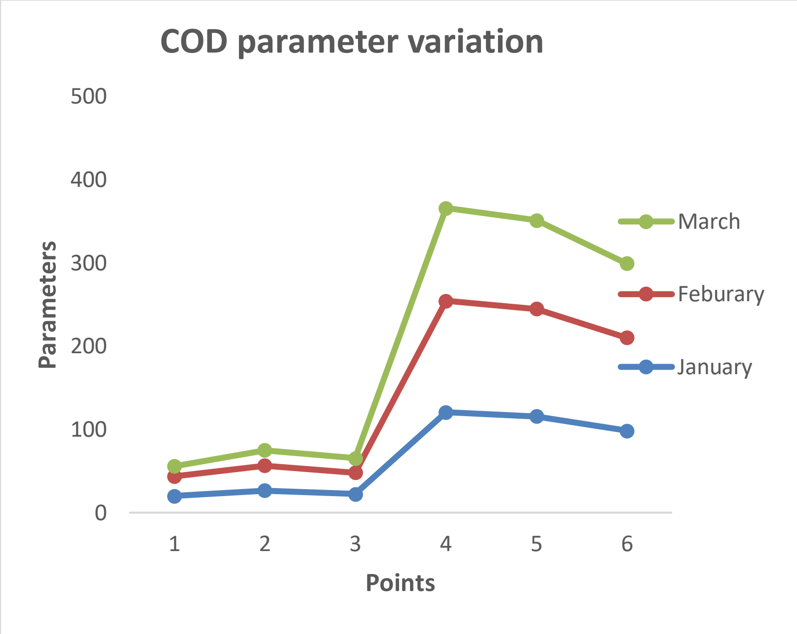
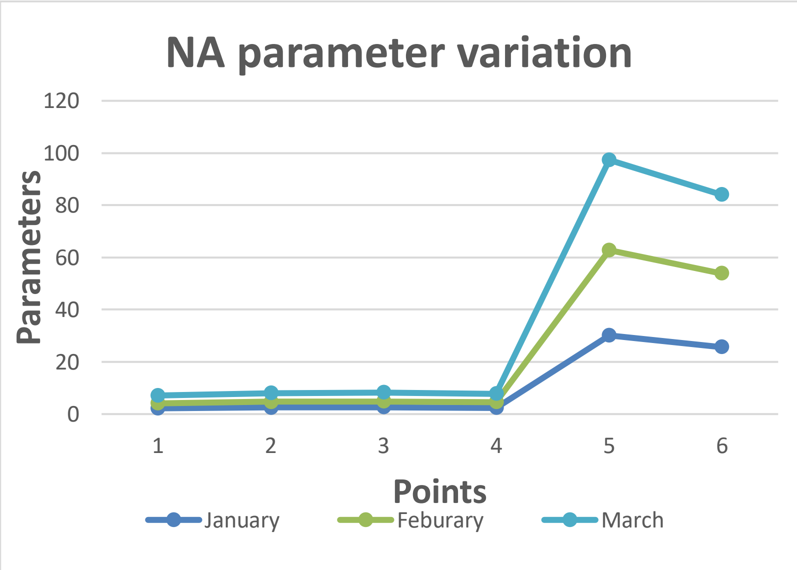
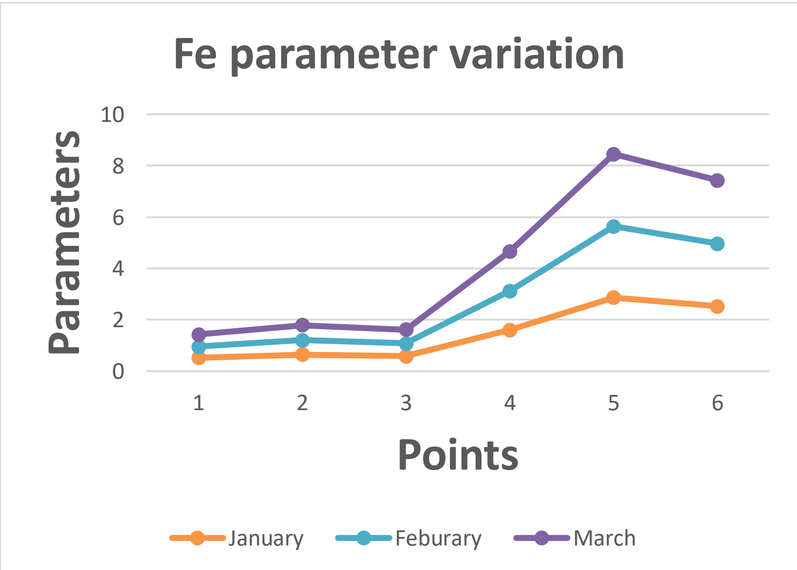







COD parameter variation
Parameters
Points
March
Feburary
January


NA parameter variation
Parameters
Points
January
Feburary
March


Fe parameter variation
Parameters
Points
January
Feburary
March

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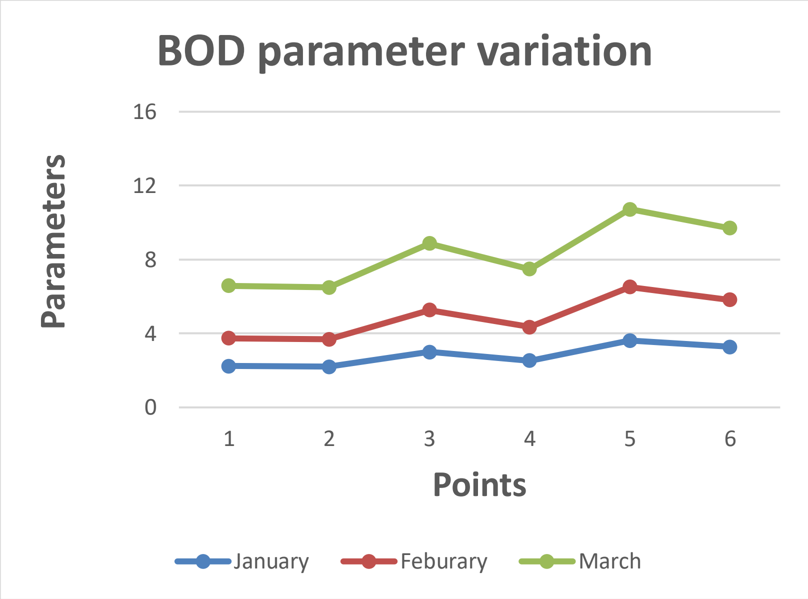

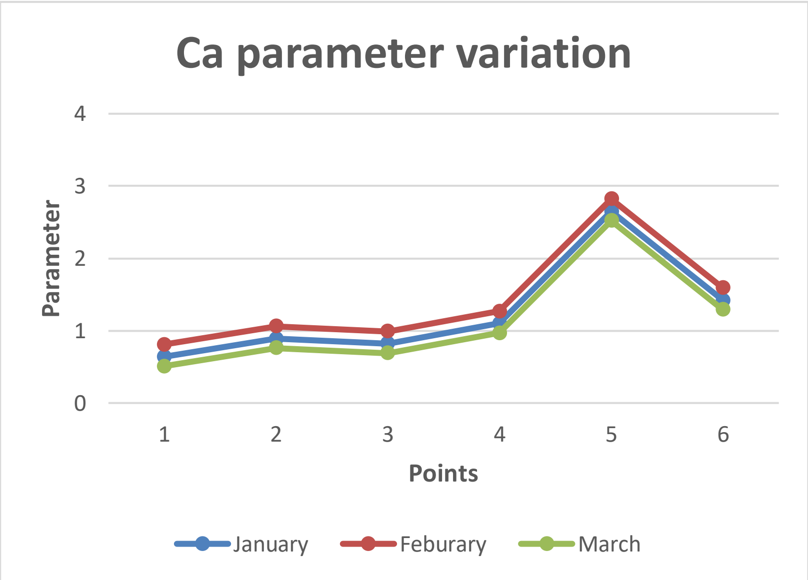

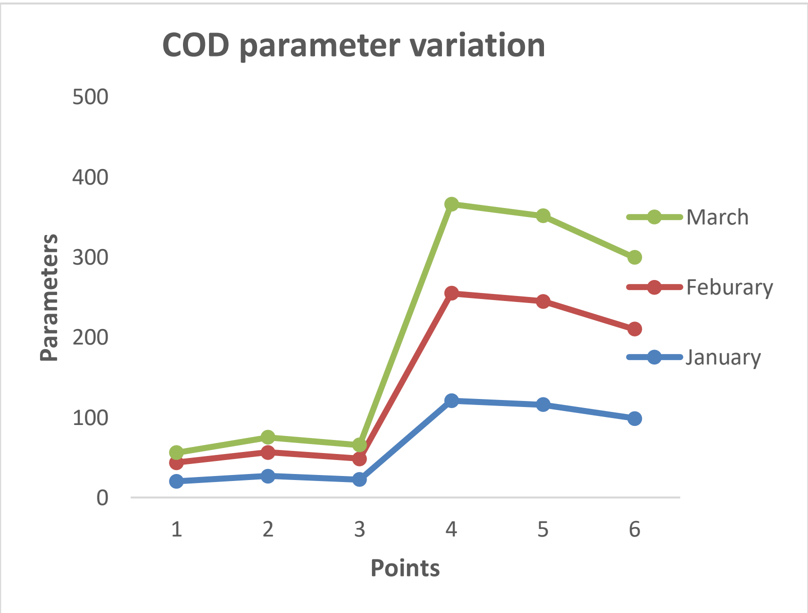

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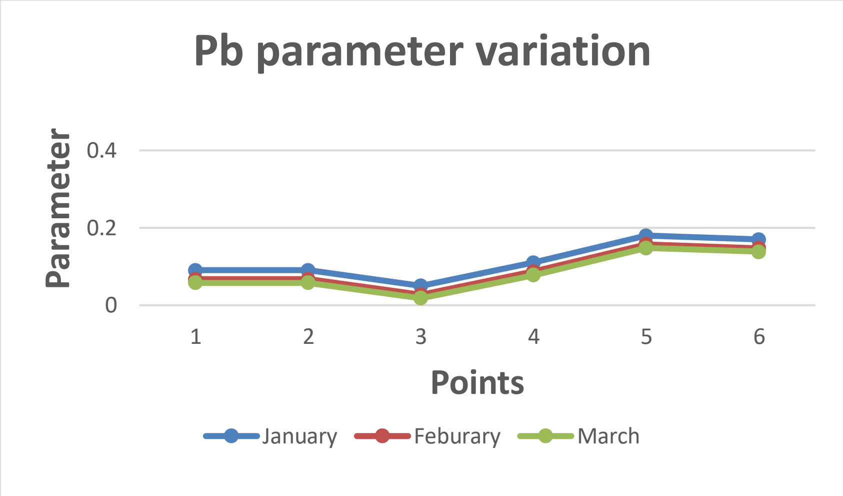

Figure 2. Comparative plots of water quality parameters

B. ANALYSIS OF VARIANCE

The two-way analysis of variance (ANOVA) conducted to assess water quality variations based on both months and points along the New Calabar River provides valuable insights into the spatial-temporal dynamics of various parameters.

Table XV Month and point two-way ANOVA

Tests of Between-Subjects Effects						
Source		Type III Sum of Squares	df	Mean Square	F	Sig.
Month	Water Temp (°C)	97.937	2	48.968	116.009	<0.001
	pH	2.329	2	1.165	12.782	<0.001
	TDS (mg/l)	647.418	2	323.709	0.050	0.95
	EC (µS/cm)	1739.409	2	869.704	0.036	0.96
	DO (mg/l)	2.078	2	1.039	1.568	0.24
	COD (mg/l)	1522.586	2	761.293	0.388	0.68
	Na (mg/l)	27.383	2	13.692	0.108	0.90
	BOD (mg/l)	2.349	2	1.175	2.480	0.11
	Fe (mg/l)	0.022	2	0.011	0.016	0.98
	Ca (mg/l)	0.178	2	0.089	0.297	0.75
	Pb (mg/l)	0.003	2	0.002	0.977	0.40
Points	Water Temp (°C)	9.707	5	1.941	4.599	0.01
	pH	0.049	5	0.010	0.108	0.99
	TDS (mg/l)	126978.240	5	25395.648	3.939	0.01
	EC (µS/cm)	523785.842	5	104757.168	4.333	0.01
	DO (mg/l)	3.233	5	0.647	0.976	0.46
	COD (mg/l)	25246.318	5	5049.264	2.572	0.06
	Na (mg/l)	2300.521	5	460.104	3.615	0.02
	BOD (mg/l)	5.348	5	1.070	2.258	0.09
	Fe (mg/l)	12.794	5	2.559	3.655	0.02
	Ca (mg/l)	6.815	5	1.363	4.559	0.01
	Pb (mg/l)	0.031	5	0.006	3.738	0.02

Here's a summary of the ANOVA results:

I. Month-wise ANOVA

1. Water Temperature and pH: Significant differences were observed between months for water temperature and pH levels, indicating substantial variations over the study period influenced by seasonal changes and environmental factors.
2. Total Dissolved Solids (TDS) and Electrical Conductivity (EC): TDS and EC did not show significant differences between months, suggesting relatively stable concentrations and conductivity over the sampled months.
3. Other Parameters (DO, COD, Na, BOD, Fe, Ca, Pb): These parameters did not exhibit significant differences between months, except for BOD, which showed a trend towards significance. This indicates that these parameters maintained relatively consistent levels over the study period, with minor variations in BOD that could be further investigated.

II. Point-wise ANOVA

1. Water Temperature: Significant differences were observed across the sampled points, indicating spatial variability influenced by factors such as pollution sources, flow dynamics, and local conditions.
2. TDS, EC, Na, BOD, Fe, Ca, Pb: These parameters showed significant differences between points, suggesting spatial variations in water quality influenced by different sources or activities at each point.
3. Other Parameters (pH, DO, COD): These parameters did not exhibit significant differences between points, indicating relatively uniform levels across the sampled points.

C. PRINCIPAL COMPONENT ANALYSIS (PCA)

The Principal Component Analysis (PCA) utilized a comprehensive set of water quality parameters, including water temperature, pH levels, total dissolved solids (TDS), electrical conductivity (EC), dissolved oxygen (DO), biochemical oxygen demand (BOD), and concentrations of ions such as sodium (Na), iron (Fe), calcium (Ca), and lead (Pb). A Varimax rotation was applied to the PCA components to maximize the variance of the loadings, thereby facilitating a clearer interpretation of the underlying factors.

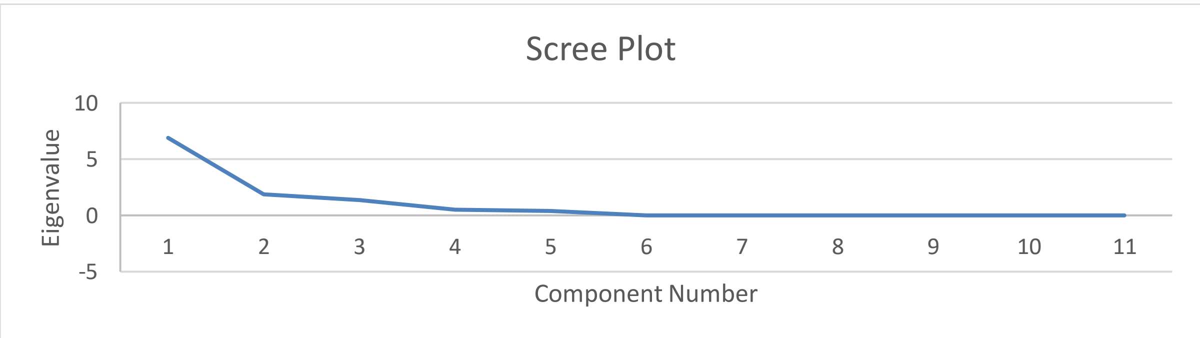

Figure 3 Scree Plot Based on Eigenvalues < 1

The Scree plot (Figure 3.3) provides a visual depiction of the eigenvalues in descending order, helping to identify the "elbow point" where the eigenvalues start to level off. This elbow point is crucial in determining the number of components that capture the most significant variance in the data, ensuring a balance between capturing essential patterns and avoiding overfitting.

Upon examining the Scree plot, a clear elbow point is observed after the initial few components, indicating that these initial components explain a substantial amount of the variance. In contrast, subsequent

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components contribute less to the overall variability. This finding suggests that retaining the key initial components is sufficient to capture the essential patterns and relationships within the water quality data.

Table XVI Rotated Varimax PCA values

Rotated Component Matrix[a]			
	Component		
	1	2	3
Water Temp (°C)	-.163	.715	.632
Ph	-.174	-.919	.036
TDS (mg/l)	.868	.445	.219
EC (µS/cm)	.932	.180	.070
DO (mg/l)	.294	.039	.919
COD (mg/l)	.490	.774	.095
BOD (mg/l)	.912	.095	-.079
Fe (mg/l)	.887	.372	.258
Ca (mg/l)	.648	.188	.660
Pb (mg/l)	.897	.045	.324
Na (mg/l)	.857	-.158	.455
Extraction Method: Principal Component Analysis. Rotation Method: Varimax without Kaiser Normalization.[a]			
a. Rotation converged in 8 iterations.			

In the analysis of water quality parameters along the New Calabar River using Principal Component Analysis (PCA), three distinct components were identified. These components provide valuable insights into the variations and underlying factors affecting water quality.

I. Component 1

Variance Explained: Approximately 43%

This component represents the overall water quality status of the samples, strongly influenced by parameters indicative of pollution. Higher values on this component suggest elevated concentrations of TDS, EC, BOD, Fe, Pb, and Na, pointing to potential pollution sources from industrial activities, agricultural runoff, and urban inputs.

II. Component 2

Variance Explained: About 28%

This component contrasts natural factors with acidity levels. It is primarily influenced by pH, indicating more acidic water, and water temperature. The negative loading on pH suggests that higher acidity levels are inversely related to the water's temperature and sodium content. This component highlights variations influenced by natural processes such as temperature fluctuations and oxygen levels, along with acidity affected by soil composition or vegetation in the river's ecosystem.

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III. Component 3

This component combines aspects of temperature, acidity (pH), and dissolved solids (TDS). It indicates that certain samples exhibited a combination of temperature changes, acidity variations, and varying amounts of dissolved solids. This component suggests potential influences from seasonal effects or localized pollution sources along the river.

These components offer a detailed understanding of the water quality dynamics in the New Calabar River, delineating between overall pollution levels, natural variations, and specific combinations of environmental factors affecting water quality.

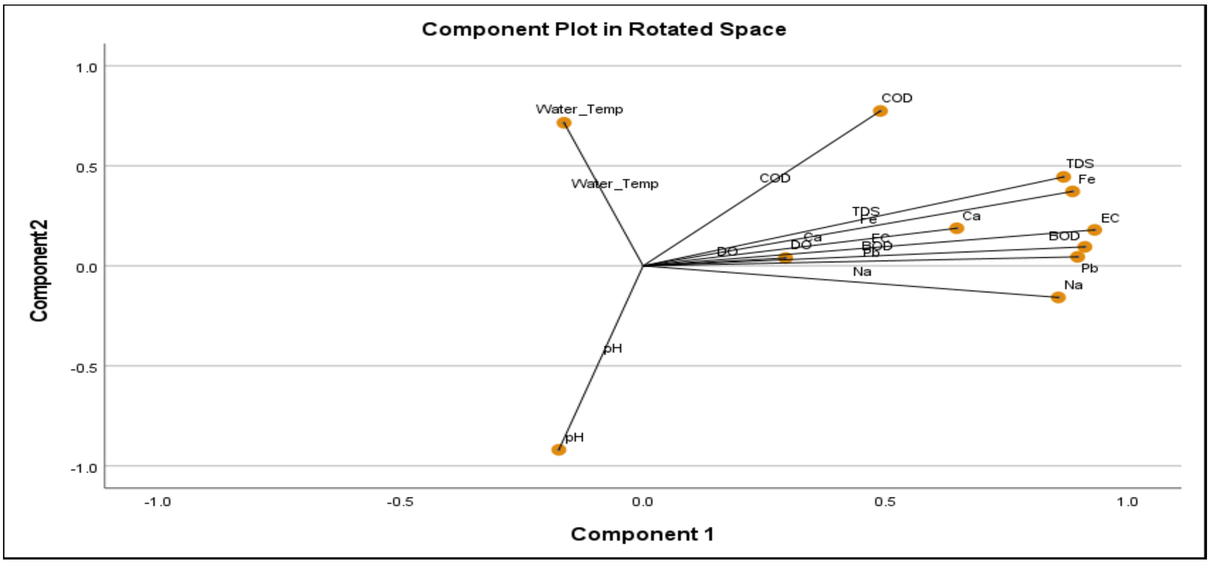

Figure 4 Rotated component plot

The rotated plot of Component 1 and Component 2, as shown in Figure 3.4, provides valuable insights into the relationships among water quality parameters along the New Calabar River. The plot reveals distinct clusters of parameters based on their loadings on Component 1 and Component 2, helping to elucidate the factors influencing water quality in the river.

Component 1, representing parameters such as Total Dissolved Solids (TDS), Electrical Conductivity (EC), Biochemical Oxygen Demand (BOD), Iron (Fe), Lead (Pb), and Sodium (Na), forms a cohesive cluster. This cluster represents water quality parameters associated with pollution sources, industrial activities, and dissolved substances. The close grouping of these parameters suggests a shared influence or common sources contributing to water pollution along the river. Elevated concentrations of these substances indicate significant contributions from industrial activities, agricultural runoff, and urban pollution.

Component 2 includes parameters such as pH (Acidity), Water Temperature, and Dissolved Oxygen (DO). These parameters are grouped together, reflecting natural factors and variations in water quality driven by temperature, oxygen levels, and acidity. The proximity of these parameters in the plot indicates their interconnectedness and the influence of environmental processes on water quality dynamics. This cluster highlights the impact of natural conditions such as climate, seasonal changes, and the river's ecosystem dynamics, rather than direct anthropogenic pollution.

D. SPATIAL MAPS FROM ARCGIS

The spatial maps created through ArcGIS provide a visual representation of the spatial distribution of water quality indices (WQI) using Arithmetic Mean Method along the New Calabar River.

Table XVII Water Quality Index of various points

WATER QUALITY INDEX OF THE VARIOUS POINTS						
Water quality Indicators	Point 1	Point 2	Point 3	Point 4	Point 5	Point 6
Water Temp (°C)	0.03867	0.03742	0.03811	0.03796	0.03958	0.03858
pH	-0.20773	-0.21253	-0.19812	-0.21733	-0.19092	-0.19452
TDS (mg/l)	0.00009	0.00010	0.00010	0.00044	0.00095	0.00089
EC (µS/cm)	5.36434	6.12854	5.95137	7.98995	40.43643	56.10254
DO (mg/l)	0.17110	0.17951	0.18211	0.19112	0.16830	0.17651
COD (mg/l)	0.00029	0.00038	0.00034	0.00187	0.00180	0.00153
Na (mg/l)	0.00006	0.00006	0.00007	0.00006	0.00078	0.00067
BOD (mg/l)	0.00528	0.00520	0.00710	0.00600	0.00859	0.00777
Fe (mg/l)	5.08755	6.36833	5.72794	16.61459	30.06281	26.43392
Ca (mg/l)	0.00011	0.00015	0.00014	0.00019	0.00045	0.00024
Pb (mg/l)	688.42052	688.42052	304.18581	880.53787	1552.94861	1456.88993
WQI	698.88029	700.92770	315.89496	905.16272	1623.47740	1539.45808

Points	WQI
1	698.88
2	700.93
3	315.89
4	905.16
5	1623.48
6	1539.46

By georeferencing sampling points and attributing them with corresponding WQI values, as shown in Figure 5 for the three months, these spatial maps offer insights into pollution hotspots, areas of concern, and potential sources of contamination.

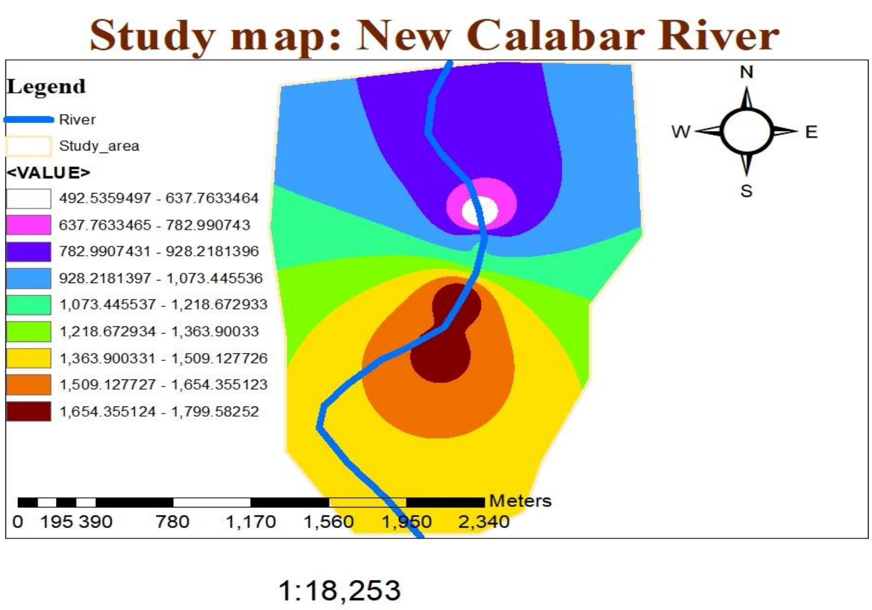

Figure 5a January spatial map

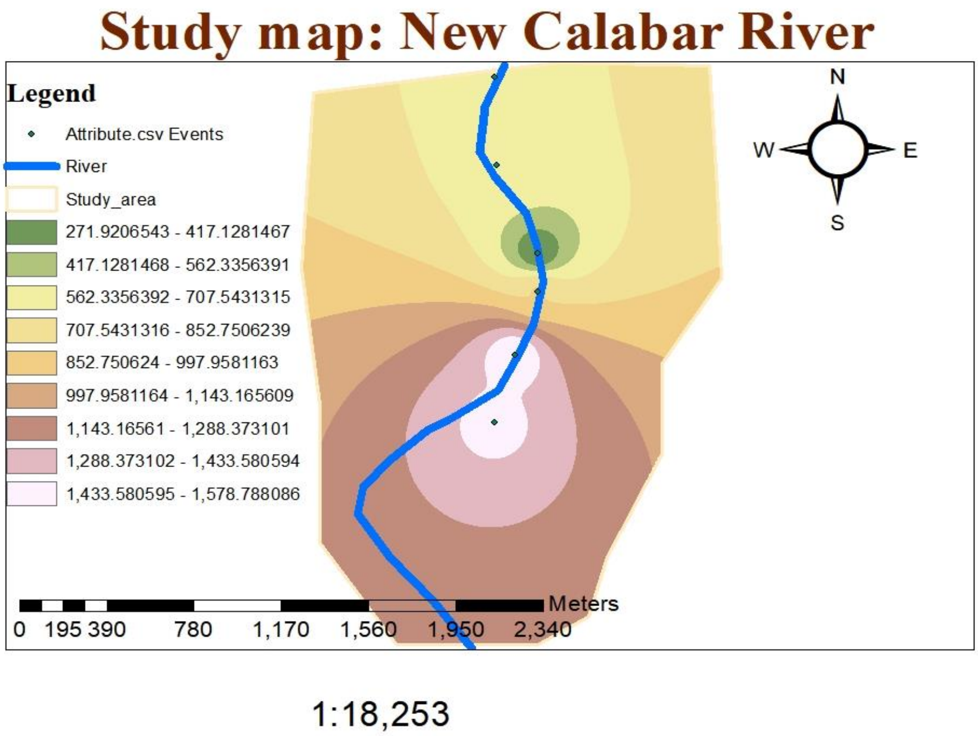

Figure 5b Fabuary spatial map

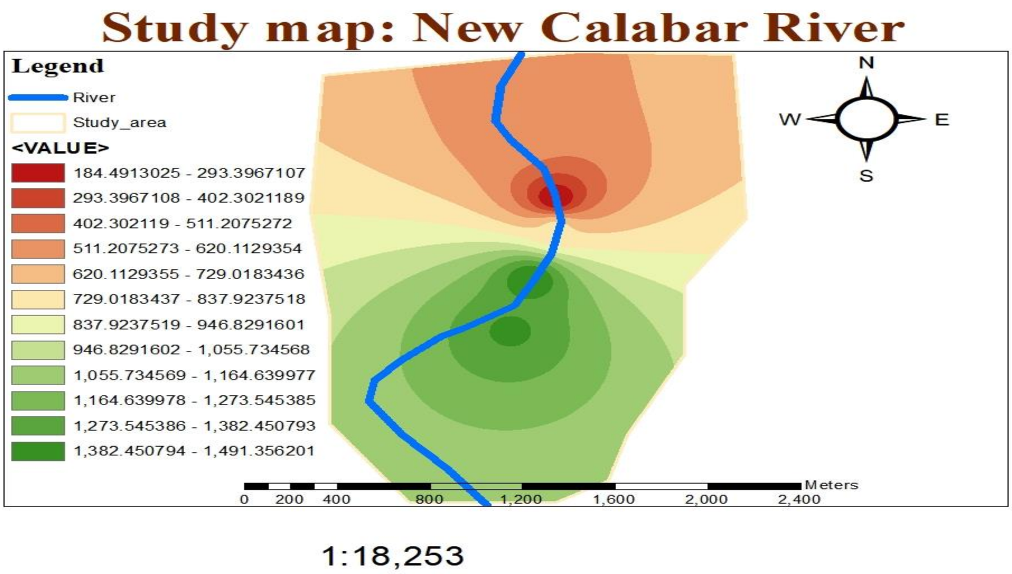

Figure 5c March spatial map

The observations in Figure 5 indicate recurring patterns in water quality dynamics along the New Calabar River across the three-month study period. The spatial maps and corresponding WQI values consistently reflect higher pollution levels at Points 5 and 6, which can be attributed to their proximity to anthropogenic activities, such as markets and abattoirs. Point 3 consistently exhibits reduced pollution levels due to its location under a bridge, which offers a protective barrier against direct pollution inputs. Conversely, Points 4, 1, and 2 consistently show similar variations in water quality, implying common pollution sources or environmental influences affecting these areas.

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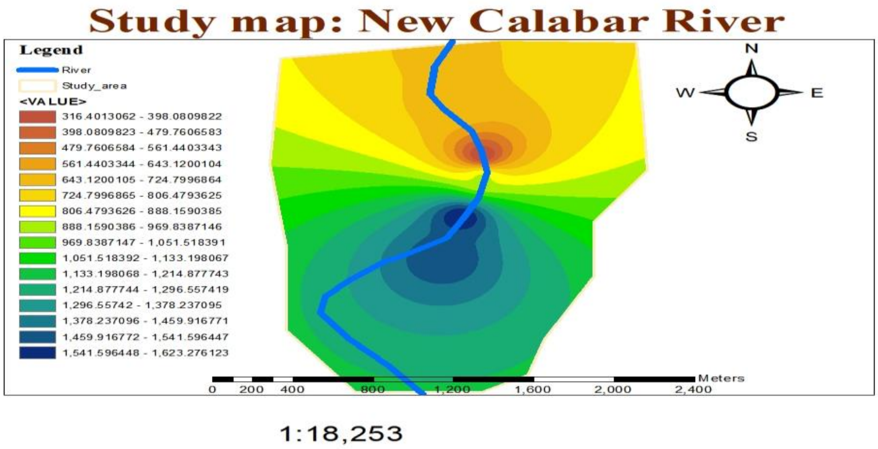

Figure 6 Spatial map for New Calabar River

The general spatial map, representing the mean WQI of all sampling points along the New Calabar River, as shown in Figure 6, provides a comprehensive visual overview of pollution trends across the study area. Consistent with previous observations, this map reveals distinct spatial patterns in water quality, with certain areas showing higher pollution levels than others. Specifically, points near anthropogenic sources, such as markets and abattoirs, consistently exhibit elevated pollution, reflected in higher WQI values. Conversely, areas under natural or structural protections, such as Point 3 located under a bridge, demonstrate relatively lower pollution levels.

This spatial variation underscores the localized impact of human activities on water quality and emphasizes the importance of targeted pollution control measures and ecosystem conservation efforts in the New Calabar River. The utilization of ArcGIS for spatial mapping of WQI values significantly enhances the understanding of the spatial dynamics of water quality along the river, providing valuable insights for environmental monitoring and management strategies.

CONCLUSION

The comprehensive study on the New Calabar River has revealed significant insights into water quality dynamics. Key findings include:

1. **Seasonal Variations**: There were notable seasonal variations in key water quality parameters. Temperature ranged from 28.2°C to 30.24°C, and pH levels fluctuated between 4.77 and 5.83, reflecting the dynamic nature of water quality in response to environmental factors.
2. **Statistical Analysis**: ANOVA indicated substantial differences in water quality metrics between months. Total Dissolved Solids (TDS) ranged from 22.58 mg/L to 255.6 mg/L, and Electrical Conductivity (EC) values ranged from 45.26 µS/cm to 523.64 µS/cm, indicating varying pollutant concentrations influenced by seasonal activities and land use changes.
3. **Principal Component Analysis (PCA)**: PCA identified the influence of industrial effluents, agricultural runoff, and domestic waste on pollutant concentrations. Significant anthropogenic influences were noted, particularly in Iron (Fe) and Lead (Pb) levels, which varied across sampling points and months.
4. **Spatial Mapping and GIS Analysis**: Spatial mapping techniques and GIS analyses identified pollution hotspots correlated with anthropogenic activities. Points near markets and abattoirs showed elevated pollution levels, while a point shielded by a bridge demonstrated improved water quality, highlighting the protective role of natural barriers.

These findings emphasize the impact of seasonal and human activities on water quality, providing a foundation for targeted interventions and management strategies.

RECOMMENDATION

The study amalgamates quantitative analyses, spatial mapping, and statistical insights to provide a holistic understanding of water quality in the New Calabar River. The identified seasonal variations, significant differences, WQI assessments, and spatial map discoveries collectively underscore the need for proactive management strategies, pollution control measures, and community engagement initiatives to safeguard water resources and promote sustainable river ecosystems in the region. The following recommendation:

1. Implement regular and systematic water quality monitoring programs, including continuous data collection for key parameters such as temperature, pH, Total Dissolved Solids (TDS), Electrical Conductivity (EC), Dissolved Oxygen (DO), and pollutants like Chemical Oxygen Demand (COD) and heavy metals. Long-term data collection efforts will facilitate trend analysis, early detection of anomalies, and informed decision-making.
2. Conduct detailed assessments to identify specific sources of pollution, including industrial effluents, agricultural runoff, domestic waste, and urban discharges. Develop and enforce stringent regulations, pollution control measures, and wastewater treatment standards to mitigate pollutant inputs into the river system. Collaborate with industries, local authorities, and community stakeholders to promote responsible waste management practices.
3. Adopt an integrated approach to water quality management, combining pollution prevention strategies, land use planning, and ecosystem-based approaches. Implement best management practices (BMPs) such as riparian buffer zones, green infrastructure, and sustainable agriculture practices to reduce nonpoint source pollution and protect water quality at its source.

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