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Dynamics of Physicochemical Parameters as Indicator of Water Quality: A Study of Ogun River, Nigeria

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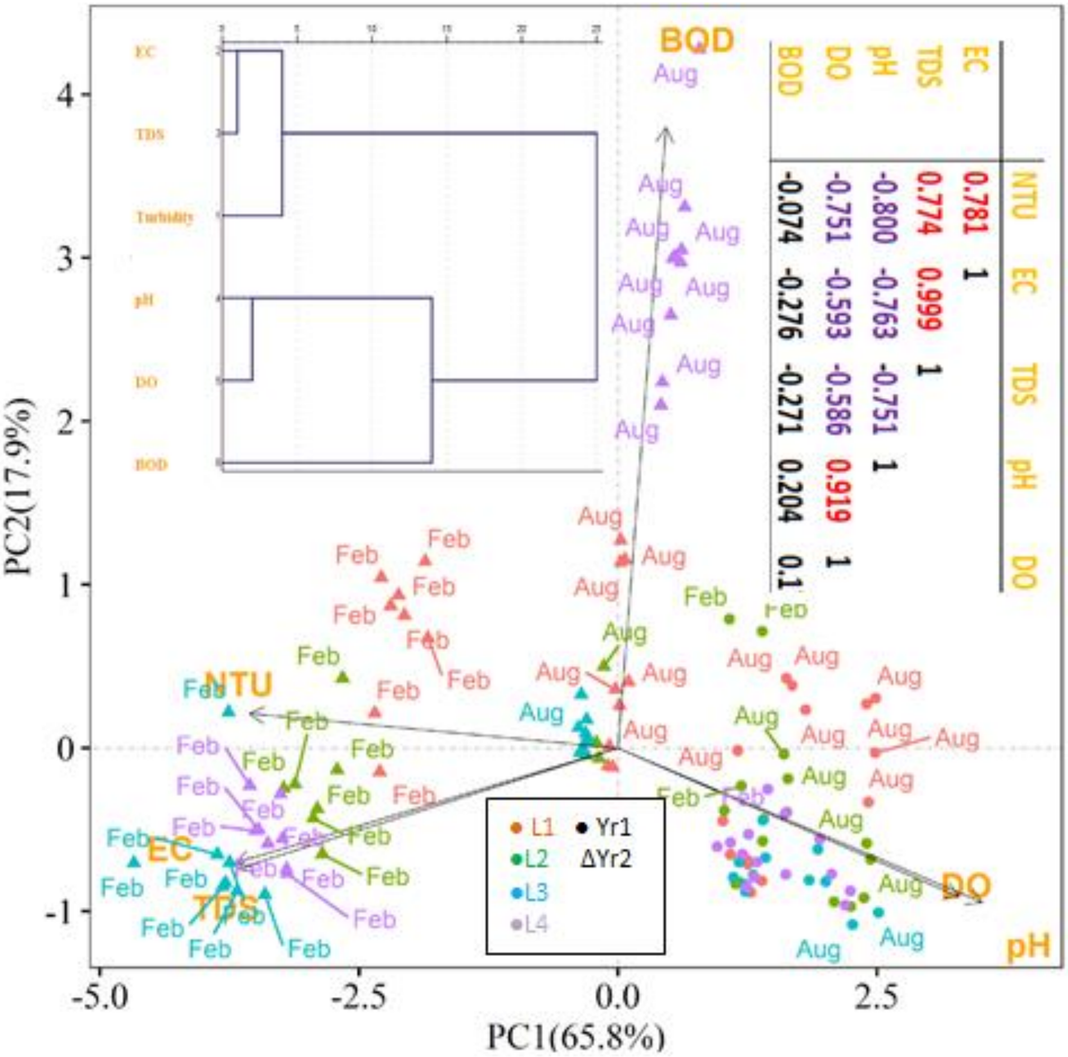
GRAPHICAL ABSTRACT



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ABSTRACT

Environmental pollution is increasingly becoming a major global problem. Surface water pollution impacts human life and the ecosystem, emphasizing the need for water quality assessment and monitoring. In this study, water Samples were collected in Ogun River for two years (twice a year) and analyzed for the physicochemical parameters using standard methods. The results show that there was spatial and seasonal variation in the water quality of the river. The physical parameters Turbidity, EC, and TDS had significant positive correlations with each other but correlated negatively with DO and pH. A significant positive correlation also existed between pH and DO (0.918). Cluster analysis grouped the parameters into three clusters, while the PCA yielded 2-components, which explained 85.61 % of the total variance in the data set. Component 1 accounts for 69.26 % of the total variance and has strong positive loadings for Turbidity, EC, and TDS and strong negative loadings for pH and DO. Component 2 accounts for 16.35 % of the total variance, with strong positive loading for BOD. The results indicate that factors that increase the Turbidity, EC, and TDS levels will decrease the levels of pH and DO while exerting a less significant effect on BOD. This study provides valuable insight into the changes and interactions of parameters that affect the water quality, which is crucial for the sustainability and quality management of the water system.

1. INTRODUCTION

Water is one of the most abundant resources in the world, covering approximately 71% of the earth's surface and vital for the existence of all living organisms. However, over 1.8 billion people worldwide do not have access to safe drinking water due to increasing pollution of water bodies [1]. In 2016, the United Nations General Assembly declared access to clean and safe water for human consumption a human right [2]. Pollution degrades water quality and limits its use for various purposes [3]. A change in water quality means a change in its physical, chemical, biological, or radiological characteristics [4]. The degradation in water quality has adverse effects on human and animal health and impacts aquatic ecosystems [5, 6].

Water pollution affects both developed and developing countries. However, developing countries are at greater risk of pollution due to inadequate infrastructure and limited resources to combat the problem [7, 8]. In Nigeria, water pollution is a growing concern and poses significant threats to public health, the environment, and the economy. Lagos, Nigeria's largest city and economic capital is one of the most affected areas due to its high population density and industrialization. Lagos, Nigeria, is home to various industries, including textiles, food processing, metallurgy, rubber/plastics, pharmaceuticals, paints, etc. These industries generate significant wastewater, often discharged into nearby water bodies without proper treatment. The Ogun River and its main tributaries serve as a water source for domestic purposes, irrigation, and other general uses in the Southwestern part of Nigeria [9, 10].

Variation in river water quality is a continuous process because rivers are dynamic systems that respond to changes in physicochemical characteristics [3]. Hence, physicochemical parameters have been used by different researchers to evaluate and monitor pollution in water bodies such as dams, rivers, lakes, wastewater, groundwater, etc. [5, 11-16]. It has been reported that pollutants from anthropogenic activities degrade water quality and alter their physicochemical characteristics [17-20]. Therefore, monitoring of the physicochemical parameters of the water is used in water quality assessments as it reflects its water quality, pollution history, and possible human and environmental impact of pollution [21-23]. It has been used for trend analysis and as a baseline for future monitoring [4, 5]. The change in levels of physicochemical parameters has also been used to study the spatial and temporal pattern in water quality [19, 22, 24]. Physicochemical parameters have also been reported to influence the abundance and distribution of aquatic plants and animals [3, 11, 25]. This study aims to assess the level and variations of physicochemical parameters of Ogun River to understand how the interactions and variations between the parameters affect the pollution dynamics. This was achieved using statistical analysis such as correlation analysis, cluster analysis, and principal component analysis. The results will help develop effective pollution management and reduction strategies for the water system.

2. EXPERIMENTAL METHODS

2.1. Sample collection

Polyethylene bottles, thoroughly washed and rinsed with the water to be sampled, were used for sample collection. At each sampling time, nine grab water samples were taken in the morning from four locations or points across the river (L1, L2, L3, and L4 (Figure 1)) below the surface (25 cm) using the grab sampling technique [26]. Samples were collected twice a year (February and August), corresponding to the peak of the dry season and the peak of the rainy (wet) season, over two years (2022 and 2023), resulting in 144 samples. The samples were stored in a mobile cooler with ice packs maintained at ≤ 4°C and immediately transported to the laboratory (Analytical Department, National Research Institute for Chemical Technology (NARICT) Zaria) for analysis within 48 hours.

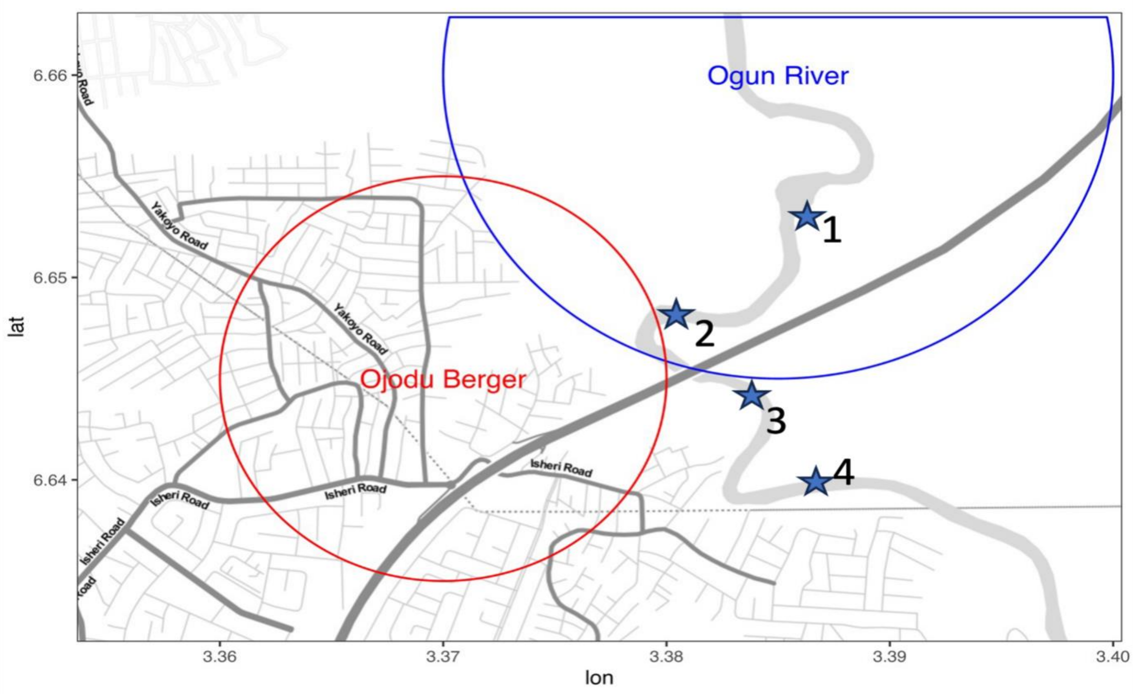

Figure 1. Map of the study area showing the sampling sites.

2.2. Sample analysis

In situ Measurements: In situ measurements were taken for parameters such as pH, temperature, electrical conductivity (EC), total dissolved solids (TDS), and turbidity using a portable digital meter, Hanna Instrument H19813-5 and Turbidimeter 2100P HACH, respectively. The concentrations were measured while the meter was submerged.

Dissolved Oxygen: The water samples were poured gently into a beaker after calibrating an LTLUTRON - 5519 DO meter. The reading was recorded while the probe was inside the beaker.

Biochemical Oxygen Demand (BOD): The BOD was measured using Wrinkler's technique [27]. Water samples were taken using a 125 ml BOD bottle. Manganese sulphate (0.5 ml) was added to the pipette tip, which was submerged in the water. The stopper was changed, and the same quantity of alkaline iodide was added. The reagents were well combined and then given time to settle. Concentrated sulphuric acid (0.5 ml) was added to the mixture, corked, and stirred properly. 100 ml of the sample was transferred into a flask using a measuring cylinder, and sodium thiosulphate was added gradually until a colour change was visible. Four drops of the starch solution were added, and the titration was carried out until another colour change was noticed. BOD was calculated as the difference between the DO content of days one and five.

2.3. Statistical Analysis

The data obtained from the study were summarised using descriptive statistics with the 'summary tools' package in R. Significant differences between the Months, Years, and Sampling stations were determined using Analysis of Variance (ANOVA) with the 'aov' function from the 'stats' package. Tukey's Posthoc HSD test in the 'emmeans' package was applied to separate significantly different means. Correlation analysis and Principal Components Analysis (PCA) were performed with the 'prcomp()' function of the 'stats' package to determine the relationship between physicochemical parameters. Hierarchical clustering was performed with the 'hclust()' function of the 'stats' package to identify patterns in changes in physicochemical parameters.

3. RESULTS AND DISCUSSIONS

3.1. Changes in Physicochemical characteristics of the Ogun River

The results of the variations in the physicochemical parameters of the river are in Table 1. In February year 1, site L4 has the highest turbidity of 193 ± 8.48 NTU. There were little variations in turbidity throughout the sites during August year 1, although there was a general decrease compared to February year 1. The highest turbidity was discovered at site L3 (42.76 ± 8.50 NTU), and the lowest was recorded at site L4 (26.38 ± 2.44 NTU). However, in February year 2, the general turbidity increased compared to year 1, with site L3 having the highest turbidity of 323.67 ± 25.18 NTU and site L2 having the lowest value of 277.67 ± 12.01 NTU. Similar to August year 1, August year 2 saw an overall reduction compared to February year 2, with site L3 having the highest turbidity and site L4 having the lowest. The values of turbidity obtained in this study are generally higher than those reported by [4] in South East Nigeria (3.00±0.48 NTU), [28] (0.45±4.05 – 4.10±1.41 NTU), and [6] (4.33±2.74 NTU) in India. They are however, comparable to those of [23] (28.12±1.31 – 37.83±2.28 NTU), [20] (15.42±3.88 – 36.51±15.36 NTU), and [29] (89.74±307.71 NTU) at Bangladesh, Brazil and Ghana respectively.

The observed changes in the turbidity of the Ogun River have significant implications for water quality and ecosystem health. The increase in the Turbidity levels suggests a potential degradation of water quality in the river. Higher turbidity is often associated with an elevated concentration of suspended particles, such as sediments, organic matter, or pollutants [30]. These can harm aquatic ecosystems by reducing light penetration, which also affects photosynthesis and disrupts the balance of the ecosystem [31]. According to Andrew [32] and Jaji et al. [33], the rise in the turbidity level may be due to increased erosion and sedimentation within the catchment area of the Ogun River. Erosion occurs when soil or sediment is washed away from the land into the river, leading to higher levels of suspended particles in the water. Sedimentation refers to the deposition of these particles, resulting in sediment build-up in the riverbed. Both erosion and sedimentation can harm aquatic habitats, alter river flow dynamics, and impact water quality by introducing excess nutrients and pollutants [34].

The observed changes in the Turbidity could also be due to the influence of human activities. Discharge of untreated or poorly treated industrial effluents, agricultural runoff, and improper waste disposal practices can introduce pollutants into the river, leading to an increase in Turbidity [35].

The variations in turbidity between different periods (February and August) suggest potential seasonal influences on water quality. Factors such as rainfall, runoff patterns, and land use changes can vary between seasons, affecting erosion rates, sediment transport, and turbidity levels [36]. Understanding the seasonal dynamics of turbidity is crucial for effective water resource management and conservation efforts.

In February year 1, EC exhibited slight fluctuation among sites, while the overall amount of EC was lower in August than in February (Table 1). There was a general rise in the amount of EC in year 2, compared to the previous year, with site L3 having the most with a value of 2.12 ± 0.01 mS/cm and site L1 having the least with a value of 0.98 ± 0.01 mS/cm. Unlike February, when the amount of EC varied among sites, August had a constant amount of EC with a value of 0.15 ± 0.00 mS/cm across all sites.

The results revealed that the EC levels in February exhibited minimal fluctuation among the different sampling sites, suggesting a relatively consistent conductivity throughout the river. However, there was a noticeable reduction in EC levels in August of year 1, compared to February, indicating a potential decrease in the concentration of dissolved ions. The subsequent increase in EC levels observed in year 2, particularly at site L3, suggests a rise in the concentration of dissolved ions in the water. These variations in EC levels are due to changes in water sources, pollution inputs, or natural processes like evaporation [37, 38]. The EC values in this study are generally higher than the values obtained by [39] (0.028±0.01 mS/cm) but agree with those reported by [28] (0.92±0.04 – 1.34±0.05 mS/cm), [17] (0.544±0.30 mS/cm), and [40] (0.08 – 0.30 mS/cm)

TDS varied slightly across sites in February year 1, with site L2 having the highest TDS with a value of 147.44 ± 0.44 mg/L and site L4 having the lowest TDS with a value of 143.33 ± 1.13 mg/L. August year 1 has generally lower TDS than February year 1, with site L2 having the highest TDS and site L1 having the lowest. Year 2 saw an overall increase in TDS compared to year 1, while samples taken in August from several sites had a lower TDS compared to February of the same year. Despite the fluctuations in the values of TDS in this study, the range of values is lower than that reported by [39] (20707.62±9250 mg/L); falls within the values reported by [23] (519.66±21.81 – 782.08±18.97 mg/L), [4] (83.75±14.75 mg/L), [5] (233.21 – 309 mg/L), and [17] (259.70±156.89 mg/L), but higher than the values reported by [14] (48.80±8.68 – 90.80±3.35 mg/L).

TDS levels indicate the concentration of dissolved solids in the water [37]. The slight variations in TDS levels among sites in February of year 1 suggests differences in the composition and concentration of dissolved solids. Furthermore, the decrease in TDS levels observed in August of year 1 compared to February suggests a potential reduction in dissolved solids, possibly due to dilution or changes in water sources [38]. However, there was an overall increase in TDS levels in year 2 compared to the previous year. The lower TDS levels in August of year 2, compared to February of year 2, may be attributed to seasonal variations or other factors influencing TDS dynamics [41, 42].

In February of year 1, pH varied slightly throughout the locations, with site L4 having the highest pH of 8.68 ± 0.05 and site L1 having the lowest pH of 7.97 ±1 0.1 (Table 1). The pH in August was comparable to February in year 1. There was an overall decline in pH throughout year 2 compared to year 1, although the pH across all locations was higher in August of year 2 compared to February of year 2**.** The pH range in this study is higher than reported by [13] (5.43±0.13 – 5.69±0.11), but in the same range as the study by [14] (7.70±0.15 – 9.10±0.13), [39] (7.64±0.06), [40] (6.89 – 7.53), [5] (7.2 – 8.3), and [28] (7.18±0.14- 9.38±0.13). pH levels indicate the acidity or alkalinity of the water. The variations in pH levels among sites in February of year 1 and the subsequent decline in pH levels observed throughout year 2 compared to year 1 indicates spatiotemporal variations in water quality. The pH measurement enables water quality experts to evaluate the overall health and appropriateness of water for diverse applications, including drinking, agriculture, and sustaining aquatic habitats [43, 44]. Monitoring pH is one of several critical parameters in comprehensive water quality assessment.

DO exhibits differences between year 1 and year 2, with more consistent values between sites each year. The highest DO was from site L2 in August year 1 with a value of 7.44 ± 0.09 mg/L and the lowest DO was from site L3 in August year 2 with a value of 1.72 ± 0.05 mg/L**.** These values are similar to what was obtained by [25] (1.64±0.37 – 10.88±0.35 mg/L), [20] (4.60±0.42 – 6.78±0.53 mg/L), and [5] (2.80±1.95 – 7.70±0.09 mg/L) Variations in DO levels could be influenced by factors such as temperature, photosynthesis, respiration, and the presence of aquatic plants and algae [45, 46].

Understanding the dynamics of DO is crucial for assessing water quality, as it directly affects the survival and well-being of aquatic organisms. The significant differences in DO levels among sites and over time suggest potential variations in oxygen availability and ecosystem health within the Ogun River.

Aquatic organisms, such as fish, invertebrates, and aquatic plants, rely on adequate dissolved oxygen in the water to survive [47-49]. DO is essential for the respiration process, allowing organisms to extract oxygen from the water and release carbon dioxide. Insufficient DO levels can lead to hypoxia, where oxygen deprivation occurs, resulting in stress or even death for aquatic organisms [49, 50]. Low DO levels negatively affect the metabolism and overall health of organisms. It can impair their growth, reproduction, and immune system, making them more susceptible to diseases. Fish and other organisms may exhibit reduced feeding activity, impaired reproduction, and altered behaviour. Moreover, lower DO levels can disrupt the balance of the ecosystem, favouring less oxygen-demanding species and potentially leading to a decline in biodiversity [49].

BOD levels varied slightly across sites for the entire length (month and year), with site L4 having the highest BOD of 10.57 ± 0.70 mg/L in August of year 2 and site L2 having the lowest BOD of 0.64 ± 0.13 mg/L in February of year 2 (Table 1). The BOD values in this study are generally lower than the result in the study by [23] (28.08±45.66 mg/L), in the same range as reported by [20] (6.88±1.19 – 8.56±1.07 mg/L), [17] (3.75±0.28 mg/L), [6] (9.41±3.75 mg/L), but higher than that of [39] (0.33±0.04 mg/L). BOD reflects the amount of oxygen used by microorganisms for the decomposition of organic materials in water. Higher BOD levels indicate higher organic pollution, suggesting potential inputs of organic waste or pollutants into the river. When organic pollutants enter a river or water body, microorganisms break down these organic materials using up oxygen in the process [51]. As a result, the level of dissolved oxygen in the water decreases. Lower dissolved oxygen can lead to the depletion of oxygen necessary for aquatic life to thrive [49]. There was a statistically significant difference in the values of BOD in both February and August indicating the non-random nature of the observed variations in BOD levels.

TABLE I. Mean concentrations of the physicochemical parameters.

Year	Month	Location	Turbidity (NTU)	EC (mS/cm)	TDS (mg/L)	pH	DO (mg/L)	BOD (mg/L)
1	FEB.	L1	153.49 ± 5.01	0.20 ± 0.00	145.33 ± 0.73	7.97 ± 0.12	7.27 ± 0.07	0.71 ± 0.10
		L2	172.78 ± 3.69	9.15 ± 0.00	147.44 ± 0.44	8.20 ± 0.07	7.03 ± 0.12	3.96 ± 0.64
		L3	173.13 ± 4.29	0.18 ± 0.00	146.00 ± 0.93	8.41 ± 0.05	6.91 ± 0.11	3.08 ± 0.51
		L4	193.01 ± 8.48	0.18 ± 0.00	143.33 ± 1.13	8.68 ± 0.05	6.58 ± 0.14	2.21 ± 0.58
	AUG.	L1	31.78 ± 6.87	0.07 ± 0.01	58.11 ± 5.00	8.11 ± 0.26	6.99 ± 0.62	2.33 ± 0.78
		L2	31.54 ± 3.47	0.09 ± 0.01	69.33 ± 7.98	8.11 ± 0.25	7.44 ± 0.09	1.18 ± 0.26
		L3	42.76 ± 8.50	0.08 ± 0.01	60.78 ± 5.59	8.58 ± 0.18	7.34 ± 0.07	1.37 ± 0.41
		L4	26.38 ± 2.44	0.08 ± 0.00	60.56 ± 2.87	8.31 ± 0.19	6.44 ± 0.17	0.78 ± 0.34
2	FEB.	L1	303.89 ± 8.74	0.98 ± 0.01	684.67 ± 3.53	6.17 ± 0.06	1.93 ± 0.04	0.76 ± 0.17
		L2	277.67 ± 12.0	1.62 ± 0.02	1225.78 ± 0.8	6.30 ± 0.08	1.83 ± 0.03	0.64 ± 0.13
		L3	323.67 ± 25.2	2.12 ± 0.01	1665.56 ± 0.8	6.33 ± 0.05	1.87 ± 0.02	0.85 ± 0.39
		L4	317.89 ± 11.4	1.86 ± 0.02	1423.00 ± 1.4	6.41 ± 0.05	1.90 ± 0.03	0.71 ± 0.12
	AUG.	L1	166.22 ± 3.09	0.15 ± 0.00	112.78 ± 1.39	7.21 ± 0.02	1.83 ± 0.05	1.12 ± 0.19
		L2	191.00 ± 3.61	0.15 ± 0.00	114.00 ± 0.46	7.04 ± 0.03	1.77 ± 0.06	0.83 ± 0.12
		L3	202.67 ± 2.34	0.15 ± 0.00	114.78 ± 0.15	6.97 ± 0.03	1.72 ± 0.05	0.92 ± 0.17
		L4	181.89 ± 3.03	0.15 ± 0.00	114.89 ± 0.92	7.42 ± 0.03	4.11 ± 0.17	10.57 ± 0.7

3.2. Interrelation between the parameters

Knowledge of the interactions between the various parameters is essential as it can be used to predict the water quality for sustainability and quality management of the water system [42]. The results of the bivariate correlations of the parameters are in Table 2. Significant correlations between parameters indicate that they may have similar sources or similar controlling factors and may have predictable variations over space and time [20, 52]. Significant positive correlations exist between turbidity and TDS (0.781); and between turbidity and EC (0.781). Turbidity in water is caused by suspended and dissolved solids (including coloured dissolved organic matter, fluorescent dissolved organic matter, and other dyes) [53]. TDS constitute positive and negative ions that increase the conductive ability of water [54]; hence positive correlations were observed between turbidity and TDS and EC. Due to the same reason, there was a significant positive correlation between TDS and EC (0.999). Because conductive ions come from dissolved solids and inorganic materials, TDS measurements are derived from conductivity using a TDS factor [55, 56]. Correlations between EC and TDS are not always linear; however, the strongest correlations observed in this study are consistent with natural waters [16, 42]. These results imply that factors that affect turbidity, such as water flow, point source of pollution, land use, and re-suspension [55], will also similarly affect EC and TDS.

A significant positive correlation also exists between pH and DO (0.918). The most common factor that affects water pH is CO_2. Factors that affect CO_2, such as photosynthesis, respiration, and decomposition, will also affect DO [57, 58]. For instance, increasing pollution reduces the level of DO and also lowers pH. The decomposition of organic pollutants lowers the amount of DO while increasing the amount of CO_2. CO_2 forms carbonic acid with water, which reduces the water's pH [21, 15].

On the other hand, there were significant negative correlations between pH and the following: turbidity (-0.800), EC (-0.763), and TDS (-0.751). Significant negative correlations also existed between DO and Turbidity (-0.751), TDS (-0.586), and EC (-0.593). Turbidity, TDS, and EC are interrelated. Suspended and dissolved solids, which contribute to turbidity, are also responsible for EC. These solids also mediate the association between turbidity and pH [29]. Dissolved organic matter can release H^+ through the process of decomposition, which in turn leads to lower pH [21, 15]. An increase in pH can lead to a decrease in the solubility of the suspended solids, the precipitation of solutes, and consequently lower TDS [40].

The negative correlation between Turbidity and DO is due to the effect of turbidity on photosynthesis. DO in water is a product of photosynthesis from aquatic plants [59]. An increase in turbidity reduces light penetration in water, which adversely affects aquatic photosynthesis, leading to a reduction in DO [60]. Higher Turbidity also increases water temperature and reduces the concentration of DO (increase in temperature leads to lower solubility of oxygen in water) [45, 61]. On the other hand, high TDS in water reduces the solubility of oxygen. As TDS in water increases, the capacity of water to hold DO decreases. TDS occupies space in the water, reducing the available space for oxygen molecules to dissolve [21, 15, 62]. This also explains the negative correlation of DO with EC, as EC is an estimate of TDS.

TABLE II. Bivariate correlations of the physicochemical parameters.

	Turbidity	EC	TDS	pH	DO	BOD
Turbidity	1					
EC	0.781**	1				
TDS	0.774**	0.999**	1			
pH	-0.800**	-0.763**	-0.751**	1		
DO	-0.751**	-0.593*	-0.586*	0.919**	1	
BOD	-0.074	-0.276	-0.271	0.204	0.177	1

**Correlation is significant at 0.01 level (2-tailed). *Correlation is significant at 0.05 level (2-tailed)

Cluster analysis classifies parameters with similar characteristics and variations. A dendrogram is a useful graphical tool that helps to decide the number of clusters [63]. The dendrogram of the hierarchical cluster analysis presented in Figure 2 identified three (3) clusters: cluster 1 (turbidity, EC, TDS), cluster 2 (pH, DO), and cluster 3 (BOD). Parameters in cluster 1 are positively correlated with each other while negatively correlated with cluster 2 and with no significant correlation with cluster 3. Likewise, cluster 2 parameters are positively correlated but with no significant correlation with cluster 3.

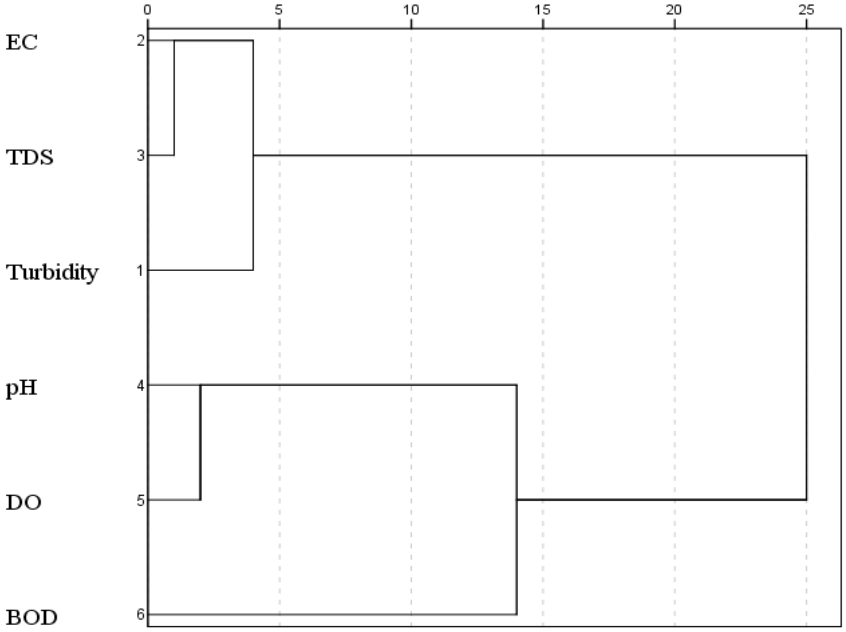

Figure 2. Dendrogram of the cluster analysis of the physicochemical parameters.

However, the PCA yielded 2-components that explained 85.61 % of the total variance in the data set (Table 3). Component 1 accounts for 69.26 % of the total variance and has strong positive loadings for turbidity, EC, and TDS; also, strong negative loadings for pH and DO. Component 2 accounts for 16.35 % of the total variance, with strong positive loading for BOD. The positive relationships between Turbidity, EC, and TDS indicate that higher turbidity levels are associated with increased EC and TDS concentrations. This further shows that factors that increase turbidity, EC, and TDS will decrease the levels of pH and DO. However, BOD in component 2, which exists alone in Cluster 3, is controlled by more complex factors. Although the level of BOD in rivers has been used to assess the level of pollutants such as sewage and industrial effluents [17, 64], its variation depends on complex factors including temperature, biochemical activities, level of organic matter, flow rate, weather events, etc. [39].

TABLE III. Principal component loadings for the water quality parameters.

Parameters	Components	
	1	2
Turbidity	0.897	0.225
EC	0.921	-0.088
TDS	0.915	-0.087
pH	-0.932	-0.106
DO	-0.844	-0.154
BOD	-0.288	0.938
%Variance	69.26	16.35
Cumulative %	69.26	85.61

The interrelationships revealed by the PCA analysis have important implications for understanding the dynamics of water quality in the Ogun River. The strong positive relationship between BOD and samples from August of year 2 (Figure 3) indicates elevated organic pollution levels during that period [17]. This finding suggests a potential increase in organic waste inputs, such as untreated sewage or agricultural runoff, which can lead to oxygen depletion and negatively impact aquatic organisms. Previous studies have emphasised the adverse effects of organic pollution on water quality and aquatic ecosystems [48, 51, 65-67]. The consistently high positive correlation between BOD and samples from all seasons in year 1 indicates persistently elevated organic pollution levels throughout that year.

Understanding the interrelationships between water quality parameters, such as Turbidity, EC, TDS, pH, DO, and BOD, provides valuable insights for water resource management in the Ogun River. These findings can guide efforts to identify pollution sources, develop appropriate mitigation strategies, and implement effective measures to improve water quality. Implementing measures to reduce sedimentation, erosion, and pollution inputs, as well as enhancing wastewater treatment processes, can help maintain and restore the health of the river ecosystem and safeguard the well-being of the community dependent on its resources.

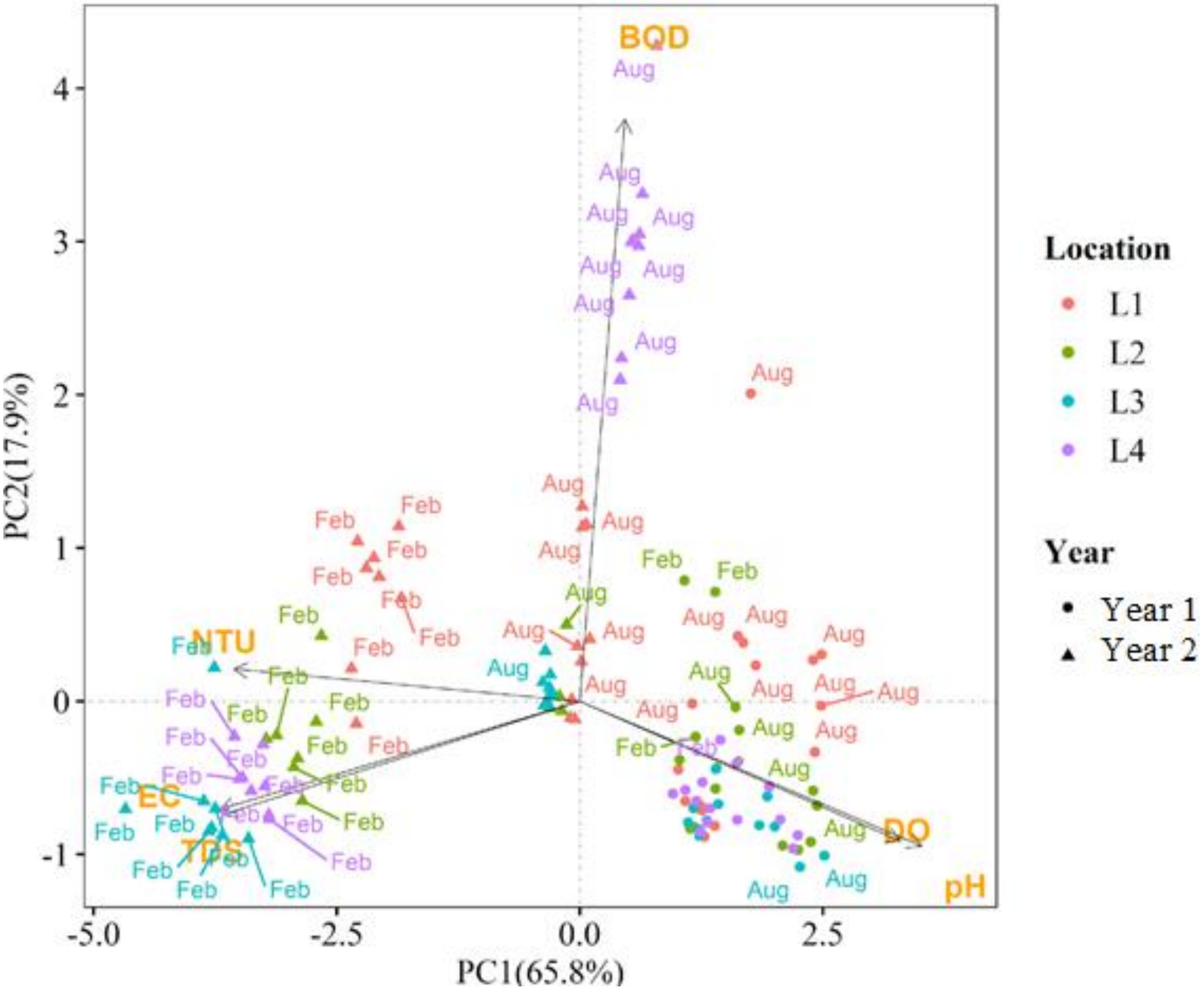

Figure 3. Relationship between all the physiochemical parameters using PCA.

4. CONCLUSIONS

The results of the study showed that the levels of the physicochemical parameters changed across sites and seasons or years, corresponding to the change in the water quality. There were positive correlations between turbidity, EC, and TDS, indicating that these parameters have similar sources, the same controlling factors, and variations with time. If pollution increases, turbidity, EC, and TDS will increase, while DO and pH will decrease, as seen in the negative correlations observed with them. These relationships were emphasized by PCA, which grouped turbidity, EC, TDS, DO, and pH under one component but with negative loadings for pH and DO. Only BOD existed as a separate cluster in Cluster analysis and on different components in PCA, suggesting a more complex relationship with other parameters. The study shows that monitoring the changes in the physicochemical parameters of a river is important for assessing water quality and understanding and managing the river environment.

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