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Full Length Research

Evaluation of surface water quality in Aba Area, Southeastern Nigeria, using multivariate statistical analysis techniques

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ABSTRACT: Aba River in Aba Area is an urban river impacted by anthropogenic activities in the area including industrial, commercial, transportation, agricultural, and recreational activities as well as solid and liquid waste disposal; these are activities which mostly result in water pollution. The objective of this study is to measure the concentration of hydrogeochemical parameters in Aba River, and evaluate their impact on the water quality, trace pollutant sources and principal contaminants and pollutants in the river. In this study, water samples were collected from 7 locations along the river course, starting from the headwaters and the concentration of the following hydrogeochemical parameters were measured: Temperature, T, pH, Electrical Conductivity, EC, Dissolved Oxygen, DO, Chemical Oxygen Demand, COD, Total Dissolved Solid, TDS, Iron, Fe, Aluminum, Al, Cadmium, Cd, Chromium, Cr, Cobalt, Co, Vanadium, V, Zinc, In, Nickel, Ni, Mercury, Hg, Arsenic, As, Manganese Mn, and Cooper, Cu. Using Principal Component Analysis, PCA, Hierarchical Cluster Analysis, HCA, and Correlation Matrix, the data obtained from the measured hydrogeochemical parameters were analyzed. The analyses show the following mean values: pH: 5.7, EC: 42mg/l, DO: 5.8mg/l, COD: 74.3, TDS: 27.4 mg/l. PCA shows 100% positive loading for Principal Component (PC)1 – Principal Component (PC) 4 indicating that Aba River pollution originates from industrial anthropogenic activities. HCA shows one group and one cluster, implying hydrogeochemical contamination from the same source.

Keywords: Anthropogenic activities, correlation coefficient, hydrogeochemical parameters, River water, principal component.

INTRODUCTION

Water is the most abundant natural resource available for human activities (Smith and Edger, 2006). The significance of water in sustaining the life of man, animals and plants, and maintaining balance in the ecosystem cannot be overemphasized; the existence of life will be under severe threat without water (Zhang, 2017). The survival of all forms of life vitally depends on water (Ibiam *et al*., 2024). From the wake of civilization, development and industrialization, the availability and accessibility of water have always been a determining factor in human settlement, choice of location of industries, infrastructure and commercial facilities in a given geographical setting (Ibiam *et al*., 2024).

While water may be one of the very abundant natural resources on the earth, the availability and accessibility of potable water is not a guarantee owing to the recent exponential increase in human population, urbanization and industrialization. Furthermore, as the human population grows, anthropogenic activities multiply. These anthropogenic activities and industrial processes require large volumes of water as well as produce tons of wastewater or used water (Daniels-Azoma *et al.*, 2024).

Figure 1. Photos of heavy pollution sites across Aba River.

Most industrial effluents, urban wastewater, surface runoff, domestic wastewater, and even sewage return to the river as untreated wastewater and sludge thereby contaminating and polluting most surface waters making them unsuitable for drinking and domestic usage, especially, urban surface waters (Daniels-Azoma *et al.,* 2024). According to a 2018 report by the World Health Organization (WHO), about 2 billion of the world's population drink water contaminated with faecal coliform. Thus, accessibility of potable water for all is of premium importance according to the United Nation's Sustainable Development Goal Number Six (SDG6) (2018); Suneela *et al.*, 2020).

Aba River, Southeastern Nigeria is typical of urban surface water on the receiving end of most contaminants and pollutants discharged into it consequent upon the majority of the industrial and commercial anthropogenic activities done in and around the river. Aba River was once a means of potable water supply to the communities around the river until the human population and commercial and industrial activities multiplied in the area (Nwazue, 2021). Most industries, animal farms, and abattoirs in Aba City are situated proximally to the Aba River. Additionally, the topography of the study area makes it easy for drains and sewages to flow down the hill by gravity. Generally, Aba City is characterized by complex drainage issues (Ogbonna *et al.*, 2016). Regrettably, Aba City is one of the commercial cities in Nigeria that has no wastewater treatment plant (Daniels-Azoma *et al.,* 2024; Odurukwe, 2012) and most municipal drainages and industrial wastewater are channeled to empty their contents into the river, causing obvious pollution and contamination of the river. Figure 1 is a set of photos taken during a reconnaissance survey of the study area. These pictures highlight the severity of the impact of the anthropogenic activities taking place in and around the river, thus prompting water quality and health risk assessment of Aba River.

This study assesses the types, concentrations and sources of water pollutants and contaminants in the Aba River. The Principal Component Analysis (PCA), Hierarchical Cluster Analysis (HCA) and Correlation Matrix of data collected from measuring the concentrations of hydrogeochemical parameters in this study help in identifying the principal contributors of pollution of Aba River, their likely sources, the correlation between measured parameters and how they impact the water quality of the river. This is significant because identifying the principal contributors of Aba River pollution, their sources and the impact of their interaction with the environment will provide a guide for sustainable environmental and natural resources management and sustainability. It will also provide a guide for decision-makers on risk assessment of ingestion of water from the Aba River.

STUDY AREA

Location and climate

Aba River popularly known as "waterside" is an urban surface water located in Aba metropolis, the largest commercial city in Abia State, Southeastern Nigeria with a population of 2,534,265 as of 2016 (Nwazue, 2021). Aba City indigenously belongs to the Ngwa people and is usually referred to as "Ala Ngwa" which simply means Ngwa land.

Aba River, a tributary of Imo River has its headwater at Mgboko-Umuette autonomous communities Osisioma Ngwa LGA in the Ngwa heartland (Ezeigbo, 1989). The entire Aba River, from the headwater to its confluence with Imo River, is 50.845km, this length extends across the Aba area to some parts of Ukwa East, and Port Harcourt in Rivers State. Aba River is found between Latitude 5°10'30''N and 4°51'0''N and longitude 7°19'30''E and 7°30'0''E. In this study, water samples were collected from 7 sampling locations between latitudes 5°4'30''N and 5°10'30" N and longitudes 7°21'0" E and 7°24'0'E, a distance of 12km. Figure 2 shows the location map of the study area while Table 3 shows names and coordinates of the 7 Water Sampling (WS) Points from where water

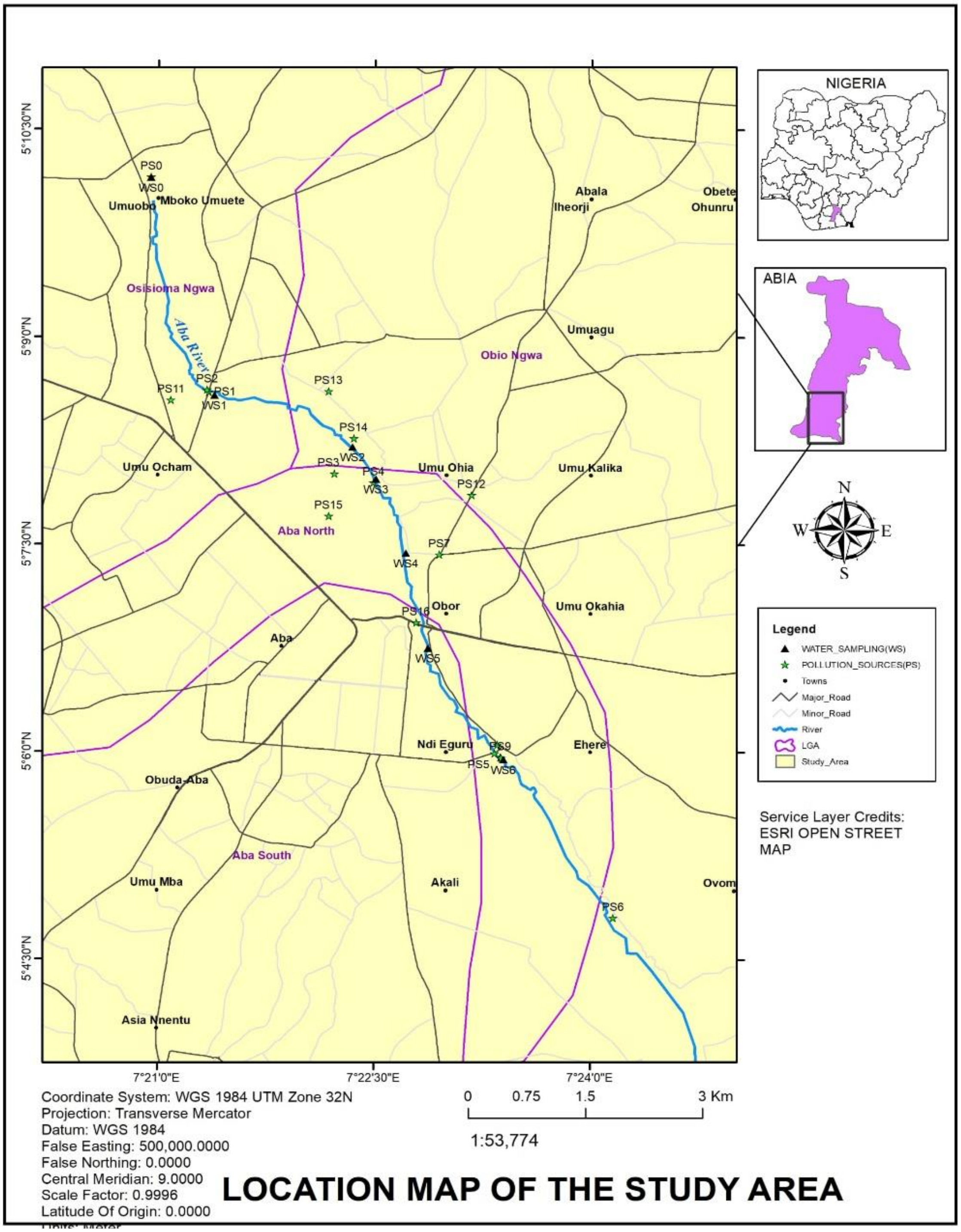

Figure 2. Location map of Study Area showing ABA RIVER, sampling points, and major sources of pollution of the Aba River; World Geodetic System (WGS) 1984; Environmental System Research Institute (ESRI) 2024.

samples were collected for this study.

Aba is a flat coastal terrain; according to Obioha *et al*. (2021), the study area is the Lower Benue Trough extension and an extension of the Coastal Plain from the Bight of Benin. The average relief of the study area is 54m above sea level (Njoku *et al*., 2013). The study area is

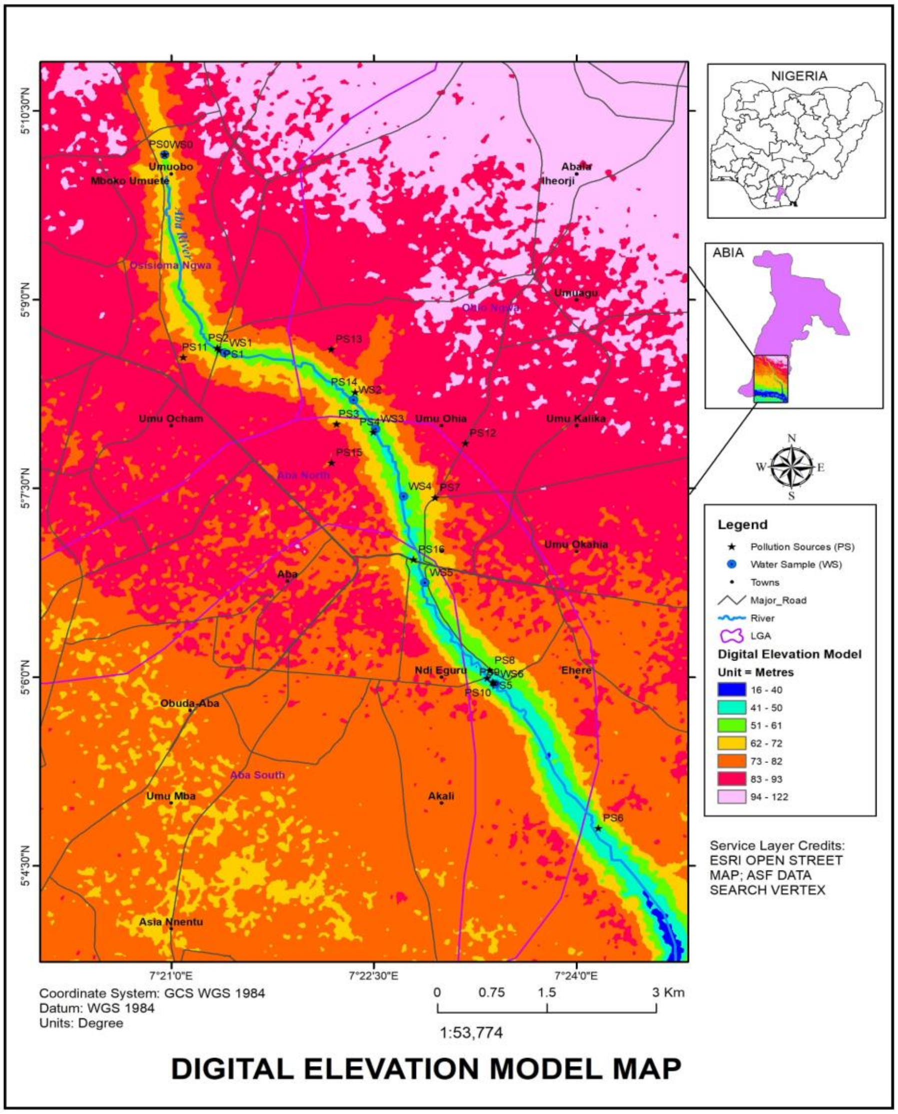

Figure 3. Digital Elevation Model Map of Study Area showing Aba River; Geographic Coordinate System (GCS) 1984, World Geodetic System (WGS) 1984, Environmental System Research Institute (ESRI) 2024.

within the humid tropical rainforest climate zone of south-eastern Nigeria and is located in the Niger Delta tropical rainforest zone (Obioha *et al.*, 2021; Amadi *et al.*, 2010). Its proximity to the equator keeps the city in a summer-like state most of the year. Aba has a significant annual precipitation of about 2500-2747mm. Following the Köppen climate classification system, Aba weather could be classified as 'Am' with a yearly average temperature of 25.6 – 27°C, a relatively high humidity of about 80°, and evergreen vegetation (Obioha *et al.*, 2021)

The direction of the river flow is conditioned by the topography of the study area; thus, the Aba River flows in a North-South direction and joins the Imo River and the Atlantic Ocean (Nwankwoala *et al.,* 2017; Ezeigbo, 1989; Uma, 1989; Amadi *et al.*, 2010). Parts of Aba City outside Ogborhill zone suffer the impact of flood in the rainy season majorly because of the relatively flat terrain of those areas and lack of good drainage system.

Geology and hydrogeology of the study area

The study area is within the Cenozoic Niger Delta basin found in the Gulf of Guinea between latitudes 3°- 6°N and longitudes 5°- 8°E as shown in Figure 3 and covering a total area of over 256,000 km^2 (Nwajide, 2013; Adegoke *et al*., 2017; Izah *et al.,* 2022). The Benin Formation is composed mostly of highly resistant fresh water-bearing

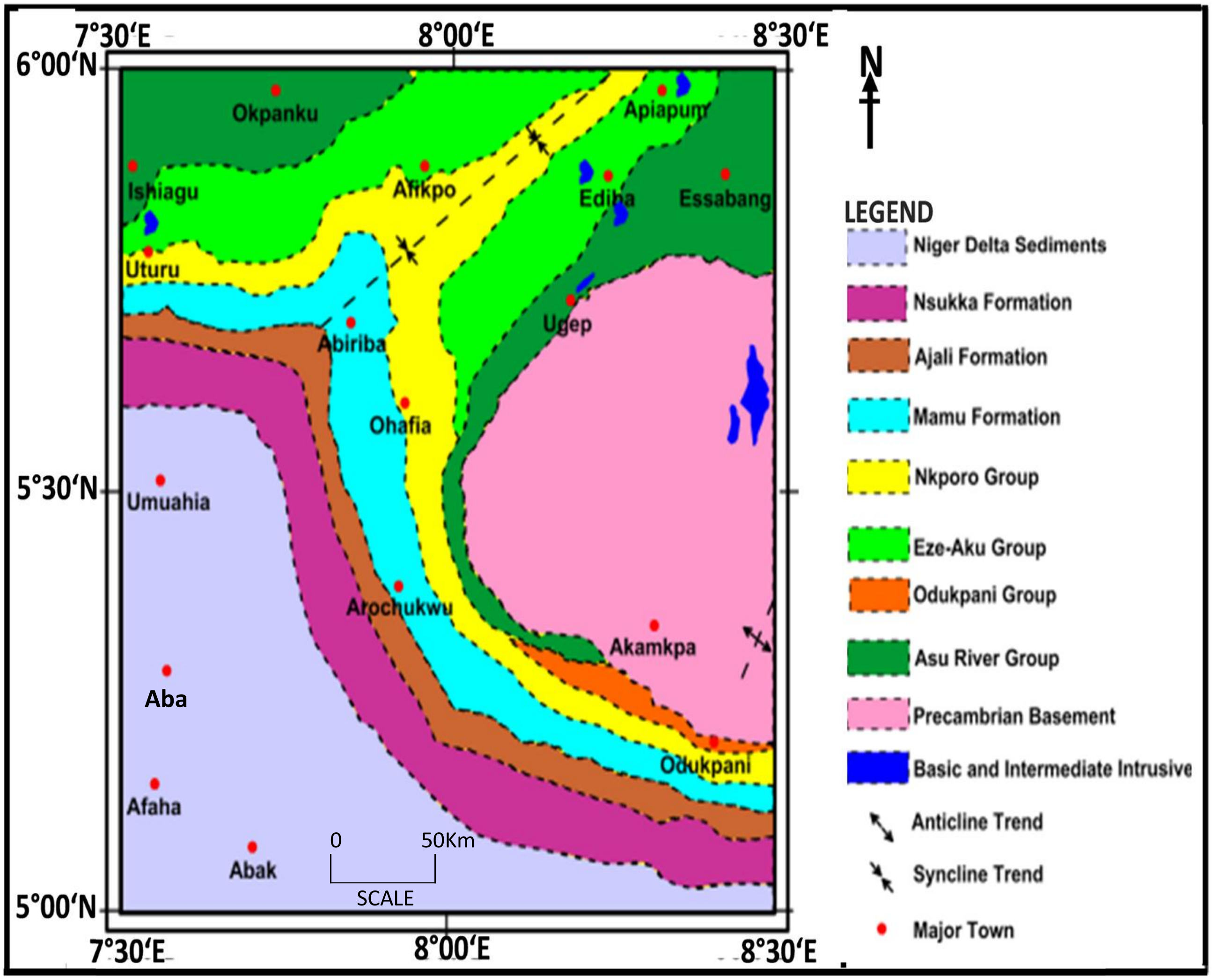

Figure 4. Regional Geologic map of Southeastern Nigeria (Eldosouky *et al*., 2022).

continental sand and gravel with clay and shale intercalations (Onyeagocha, 1980; Agharanya, 2018). The general thickness of the Benin Formation is variable and ranges from 200 m at the North-East end to about 2000 m at the South-west (Avbovbo, 1978). The regional geologic map of the study area as shown in Figure 4 captures the Niger Delta Sediment while Figure 5 is the geologic map of Aba showing the Aba River. Aba River has been a constant source of 'sharp sand' for various building and civil engineering operations in the Aba region and beyond. Besides the Industrial anthropogenic activities in and around the river, 'sharp sand' mining in Aba River has badly defaced and polluted Aba River, especially being unregulated by the environmental protection agency. Table 1 shows the stratigraphy of the Niger Delta Basin and Southeastern Nigeria. Aba River has an average discharge rate of 5.20m^3/s with varying depths of 0.5m-8m (Okeke *et al*., 2005).

MATERIALS AND METHODS

A reconnaissance survey of the study area in this research was first done, a procedure that revealed a lot of details of Aba River such as the rate and degree of the anthropogenic activities that go on in and around the River. This field study also enabled the identification of important pollution spots along the river where samples for water quality parameter analysis were collected. The location map and topographic map of the study area were both prepared for the coordinate data collected via GPS Map camera during the field survey. Figure 6(a,b) shows the headwater of Aba River as discovered during a reconnaissance survey.

Water samples were collected from the seven sampling points already indicated on the location map of Aba River under standard practice and regulation. Water samples were collected by the river bank of each sampling point.

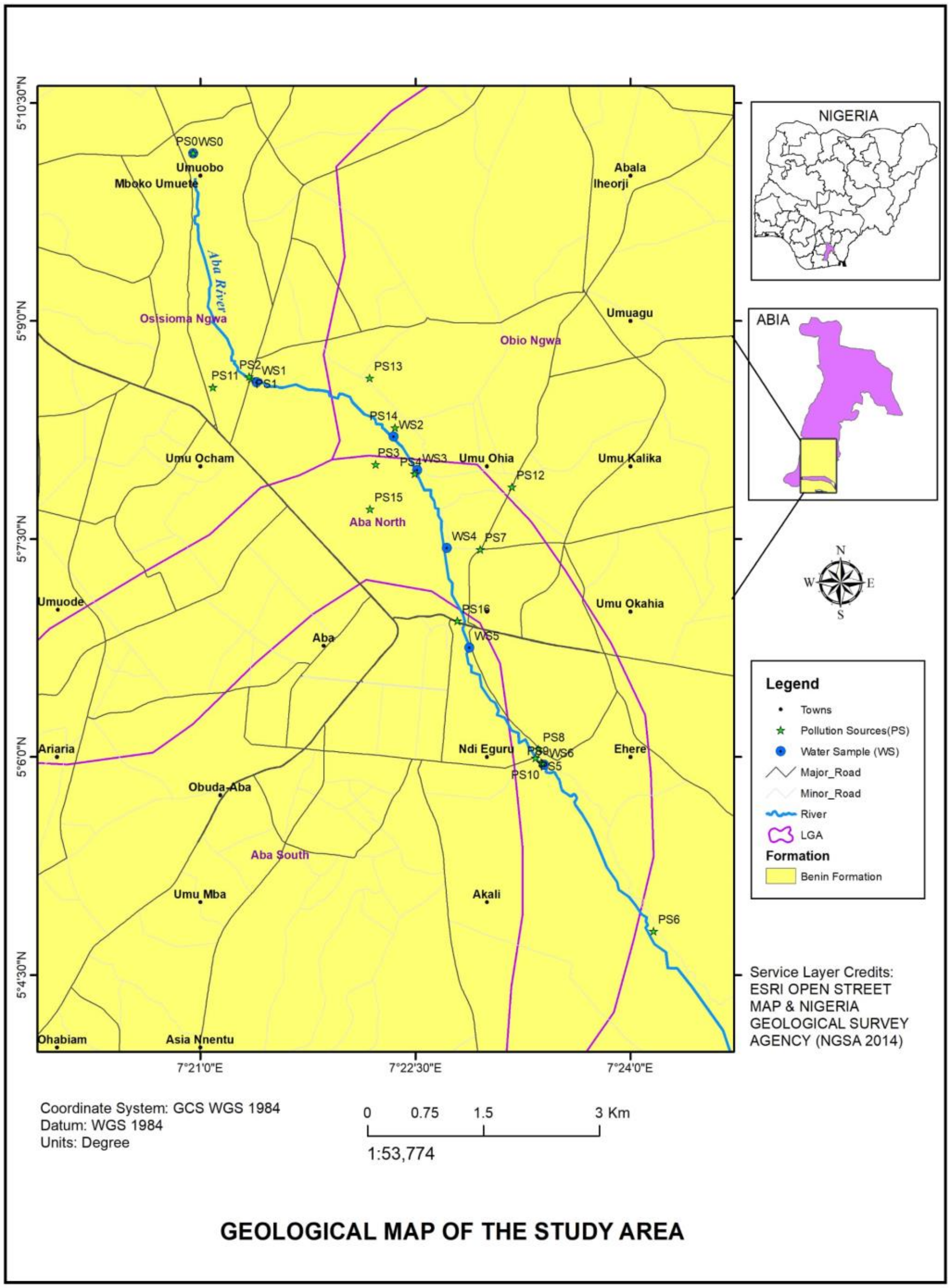

Figure 5. Geologic Map of The Study Area showing Aba River; Geographic Coordinate System (GCS) 1984, World Geodetic System (WGS) 1984, Environmental System Research Institute (ESRI) 2024, & Nigeria Geologic Survey Agency (NGSA) 2014.

Sampling bottles and containers were dipped in water and samples were collected in a way that didn't allow bubbles of atmospheric oxygen to enter the container, especially the samples for COD analysis. Containers and bottles of collected water samples were stored temporarily in an ice cooler while in the field and quickly moved to the fridge in the laboratory for analyses. This procedure is important to ensure that the water is in its original state at the time of laboratory analyses. Some parameters were also measured *in situ* while water samples were being collected; water parameters such as temperature, pH, and DO and the rest were analyzed in standard laboratory

Table 1. Stratigraphic Sequence of Southeastern Nigeria (Okeke and Okogbue, 2010; Ken-Onukuba *et al.,* 2021).

Age	Formation	Lithological Characteristics
Recent	Recent Sediments	Alluvium/Deltaic Plains
Miocene - Recent	Benin Formation	Unconsolidated sandstone with lenses of clay
Oligocene - Miocene	Ogwashi-Asaba Formation	Unconsolidated sandstone, Mudstone, Clay and Lignite Scams
Eocene	Ameki Formation	Grey to green argillaceous sandstone, shale and limestone units
Paleocene	Imo Formation	Fine textured dark-grey shale with arenaceous sandstone member
	Nsukka Formation	Alternating sequence shale, sandstone and coal seams.
Maastrichtian	Ajali Formation	Friable sandstone with Iron stains. Alternating sequence of sandstone, claystone and shale with coal seams
	Mamu Formation	
Campanian	Nkporo Formation/Enugu Shale	Dark grey shale with clayey Mudstone and Shale with thin beds of Sandstone
Santonian	Awgu Formation	Bluish grey Shale with intercalations Sandstone and shaly limestone
Turonian	Ezeaku Formation (Ezeaku Shale)	Black shale with clay and sandstone lenses
Albian	Asu River Group	Black shale and sandstone
Precambrian	Basement Complex	Older Granite and Gneiss

Figure 6 (a and b). Photos showing the Headwater of Aba River with its location coordinates.

under standard conditions. All physicochemical parameters were analyzed using the APHA (2005) standard analytical method. Summarily, the methods used for the analyses of the 18 water quality parameters in the quality assessment of Aba River is summarized in Table 2. Excel 2007 and SPSS were used for all mathematical and statistical computations.

Principle and practice of Multivariate Statistical Analysis (MSA) for surface water quality assessment

Water Quality Assessment involves analyses of multidimensional water parameters; thus, Multivariate Statistical Analysis (MSA) Techniques have been found best for interpreting the data generated (Olubukola, 2021). MSA is a set of data analytical techniques that is under constant development. MSA is a statistical approach to water quality assessment. In this study, the following multivariate analysis techniques are used:

- Principal Component Analysis (PCA)
- Cluster Analysis.
- Pearson Correlation Matrix.

Using these statistical approaches improves the accuracy of the index, reduces subjective assumptions (Tirkey *et al*., 2015) and helps in tracing the source of pollution in the river water.

Principal Component Analysis (PCA)

PCA is an exploratory statistical method for the graphical description of information present in large datasets. It is one of the best-known and most-used MSA in several

Table 2. Summary of materials and methods used for laboratory analysis in this study.

Parameters	Unit	Method	Parameters	Unit	Method
PH		Potentiometric	Chromium, (Cr)	mg/l	AAS
Temperature, (T)	°C	Electrode thermometer	Cobalt, (Co)	mg/l	AAS
Electrical Conductivity,	µS/cm	Potentiometric	Vanadium, (V)	mg/l	AAS
Dissolved Oxygen, DO	mg/l	Electro-membrane	Zinc, (Zn)	mg/l	AAS
Chemical Oxygen Demand, (COD)	mg/l	Titrimetric	Nickel, (Ni)	mg/l	AAS
Total Dissolved Solid, (TDS)	mg/l	Gravimetric	Mercury, (Hg)	mg/l	AAS
Iron, (Fe)	mg/l	AAS	Arsenic, (As)	mg/l	AAS
Aluminum, (Al)	mg/l	AAS	Manganese, (Mn)	mg/l	AAS
Cadmium, (Cd)	mg/l	AAS	Copper, (Cu)	mg/l	AAS

Table 3. Names of Water Sampling (WS) Points and Coordinates of Aba River as shown on the map in Figure 2.

Names of points	Point No.	Location ID	Latitude (°) N	Longitude (°) E	Altitude (M)
Headwaters/Control	1	WS1	5.16918	7.34919	43
Okpu Umuobo Bridge	2	WS2	5.14296	7.35655	36
Glass Industry area	4	WS3	5.13674	7.37249	34
Ohuru Isimiri UmuOhia	4	WS4	5.13287	7.37522	31
Hill Top by PZ	5	WS5	5.12396	7.37867	29
Aba River Layout	6	WS6	5.11251	7.38128	28
Emelogu/Slaughter	7	WS7	5.09909	7.38999	22

scientific disciplines (Saporta *et al.,* 2009; Abdi *et al.,* 2010). The central idea of the analysis is to reduce the dimensionality of a dataset where there are a large number of interrelated variables, keeping as much of the variation present in the dataset as possible (Jolliffe *et al.*, 2016). The analysis is designed to transform the original variables into new uncorrelated variables (axes), called principal components (PC), which are linear combinations of the original variables. PCA explains the variance in the data while reducing the quantity of the parameters to a few uncorrelated components whereas the PC provides information on the most significant variables, which represent a matrix with data reduction and minimal loss of original information (Holland, 2019).

Cluster Analysis (CA)

CA is the formal study of methods and algorithms in order to group objects according to measured or perceived intrinsic characteristics, or similarities (Jain; 2010). In general, the objective of cluster analysis is to identify groups, or clusters, of similar objects, where elements in a cluster are more similar to each other than elements in different clusters (Govender and Sivakumar; 2020). In cluster analysis, objects are classified based on their similarities. There are three main types of Cluster Analysis:

1. The Hierarchical methods, HCA
2. The Partitioning methods
3. The Methods that allow overlapping clusters.

However, in this research, Hierarchical Cluster Analysis (HCA) approach shall be used.

Correlation Matrix

Correlation Matrix is a statistical tool that helps a data analyst determine the connection between two or more variables in a given data set. It also shows the degree of such correlation, dependence and interdependence between variables (in this case of the current study, parameters). Correlation Matrix shows the correlation existing between all possible pairs of values in a matrix format (Wagavkar, 2023). The correlation matrix is a table comprising rows and columns showing the variables of a data set. Each cell in a correlation matrix table contains the correlation coefficient which is calculated using Pearson's correlation coefficient equation (Wagavkar, 2023).

$$R = \frac{n(Exy)-(Ex)(Ey)}{\sqrt{[nEx^2-(Ex)^2][nEy^2-(Ey)^2]}} \quad \ldots\ldots\ldots\ldots (1)$$

Where r has values ranging from -1 to +1. When r is -1, it implies perfect negative correlation, when it is +1, it means perfect positive correlation, and when 0, it implies that no correlation exists between the variables of a given data set.

Table 4. Result of measurement of physicochemical and hydrogeochemical parameters from the 7 sampling points of Aba River.

Parameters	FMEnv (2011)	WS1	WS2	WS23	WS4	WS5	WS6	WS7
PH	6.50-8.50	5.8 ± 0	6.1 ± 0	5.8 ± 0	5.85 ± 0.07	5.95 ± 0.07	4.95 ± 0.07	5.5 ± 0
T °C	30	28.05 ± 0.78	9.05 ± 0.07	29.65 ± 0.35	29.75 ± 0.07	29.6 ± 0	28.7 ± 0.14	28.5 ± 1.41
EC µS/cm	1000	21 ± 0	25 ± 0	45 ± 0	37 ± 0	41 ± 1.41	44 ±0	81.5 ± 2.12
DO mg/l	>7.50	3.85 ±0.07	9.05 ± 0.07	4.85 ± 0.07	7.15 ± 0.07	5.35 ± 0.07	5.8 ± 0.28	4.45 ±0.07
COD mg/l	NS	96 ± 0	64 ± 0	32 ± 0	208 ± 0	32 ± 0	64 ± 0	48 ± 0
TDS mg/l	500	13.65 ± 0	16.25 ± 0	29.25 ± 0	24.05 ± 0	26.65 ± 0.92	28.6 ± 0	53.48 ± 0.67
Fe mg/l	0.3	3.44 ± 0	0.98 ± 0.01	0.92 ±0.01	0.61 ± 0.01	0.72 ± 0	0.715 ± 0.01	1.21 ± 0.028
Al mg/l	0.2	43.19 ± 0.64	21.82 ± 0	40.46 ± 0.64	24.55 ± 0	43.64 ± 0	53.64 ± 0	45 ± 0.64
Cd mg/l	0.003	0.33 ± 0	0.195 ± 0.01	0.18 ± 0.01	0.15 ± 0.014	0.31 ± 0	0.165 ± 0.01	0.195 ± 0.01
Cr mg/l	0.03	0.41 ± 0.007	0.31 ± 0	0.26 ± 0	0.32 ± 0.014	0.22 ± 0.01	0.11 ± 0	0.29 ± 0
Co mg/l	NS	0.02 ± 0	0.02 ± 0.01	0.05 ± 0.01	0.11 ± 0	0.05 ± 0.01	0.135 ± 0.01	0.17 ± 0
V mg/l	NS	0.01 ± 0	0.01 ± 0	0.003 ±0	0.01 ± 0	0.02 ± 0	0.02 ± 0.	0.01 ± 0
Zn mg/l	0.01	0.37 ± 0.028	2.57 ± 0	0.28 ±0	1.01 ± 0	0.63 ± 0	0.085 ± 0.02	0.19 ± 0.03
Ni mg/l	0.02	ND ± 0	0.12 ± 0	0.53 ± 0.084	0.47 ± 0	0.88 ± 0.085	0.53 ± 0	2.41 ± 0.08
Hg mg/l	0.001	0.02 ± 0	0.02 ± 0.01	0.05 ± 0	0.02 ± 0	0.06 ± 0	0.03 ± 0	0.05 ± 0.01
As mg/l	0.01	0.13 ± 0	0.2 ± 0	0.29 ± 0.01	0.18 ± 0.01	0.24 ± 0	0.19 ± 0	0.12 ± 0.01
Mn mg/l	0.05	0.05 ± 0	0.14 ± 0.01	0.18 ± 0	0.17 ± 0	0.13 ± 0	0.145 ± 0.01	0.15 ± 0
Cu mg/l	1	ND ± 0	ND ± ND	0.01 ±0	0.01 ± 0	ND ± ND	ND ± ND	0.002 ± 0

The correlation coefficient, R, is symmetric, thus Rij =Rji for two variables. Also, the correlation coefficient, R = 2 for a variable with itself, that is, the diagonal values of ‘R’ are 1. Eigenvalues which are variances of the variables (parameters) are also calculated. All true eigenvalues of the correlation matrix must be positive.

RESULTS AND DISCUSSION

Table 4 shows the result of the measurement of the hydrogeochemical parameters analyzed from water samples collected from 7 locations along the Aba River. Using the data shown in Table 4, Principal Component Analysis, Hierarchical Custer Analysis and Correlation Matrix of the concentration of measured hydrogeo-chemical parameters in Aba River was performed.

Principal Component Analysis (PCA)

PCA attempts to explain the variance of observed variables (Wang *et al*., 2023). The measured water parameter data were put into different multivariate statistical techniques to discover the parameters responsible for the water quality variation at different points along the stretch of Aba River. Principal Component Analysis describes the connection between the characteristics to pinpoint the most likely sources of water contamination in the review area. Principal component analysis shows 4 Principal Components, PC1 to PC4 all have 100% positive loading; of all the 12 hydro geochemical parameters analyzed for Principal Component Analysis in this study, all have 100% positive loading all through as shown in Table 5. This result indicates that anthropogenic activities related to industrial activities in the study area is responsible for the water pollution in the Area. Component Analysis is a data analysis method that majors on the collection of certain variables with common factors. A component plot in rotated space is shown in Figure 7.

Cluster Analysis (CA)

Cluster analysis (CA) as an analytical tool groups water parameter data on the bases of similarity

Table 5. Principal component extraction method factor loadings for different parameters.

Parameter	Component Matrix[a]			
	1	2	3	4
Cr	-0.850	-0.033	0.450	-0.186
Hg	0.806	0.204	0.084	0.543
Co	0.780	-0.069	0.246	-0.543
Mn	0.563	-0.820	-0.041	0.093
Cu	0.038	-0.787	0.419	0.111
Cd	-0.427	0.749	0.100	0.407
Al	0.621	0.677	0.261	0.155
Fe	-0.615	0.633	0.413	-0.142
Zn	-0.580	-0.406	-0.609	-0.116
V	0.456	0.563	-0.593	0.023
Ni	0.436	-0.087	0.531	-0.094
As	-0.369	-0.509	0.134	0.745
Eigen Values	4.113	3.507	1.718	1.433
% of Variance	34.277	29.228	14.320	11.938
Cumulative %	34.277	63.504	77.825	89.763

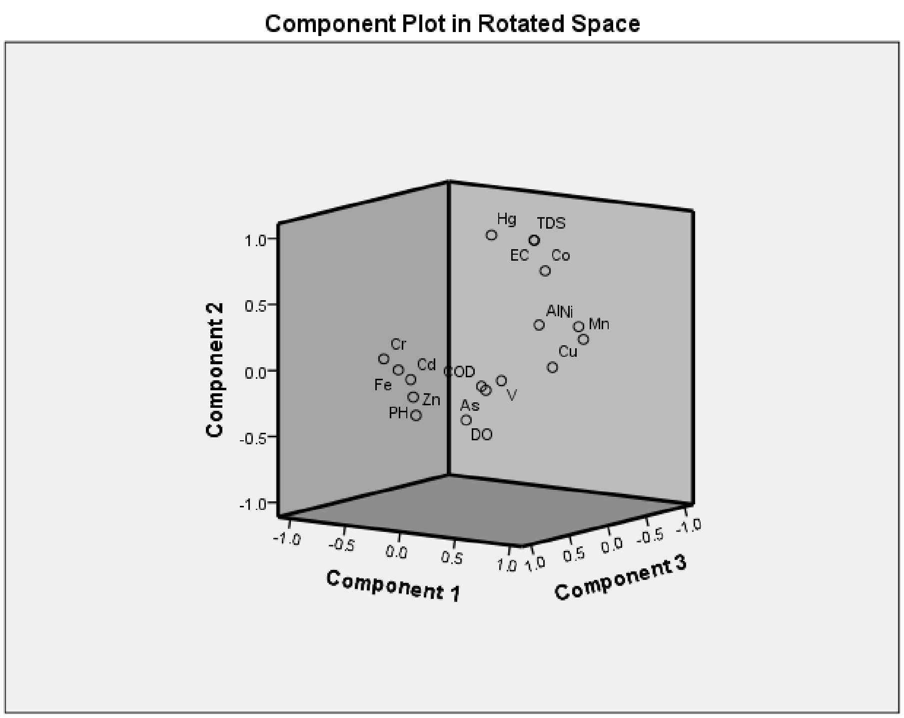

Figure 7. Principal Component Plot.

among their attributes. To identify the components of the various sources in the samples, a hierarchical cluster analysis (HCA) of the parameters was performed. The goal of the HCA was to classify the contaminants according to potential similarities or differences in the sources of their prevalence in the water samples. In this study, 12 hydrogeochemical water quality parameters were used to perform hierarchical Cluster Analysis. According to Ward's Method adopted in this research, the distance between the metallic pollutants indicates their degree of association (Akakuru *et al.*, 2022; Ajayi and Okeke, 2024). The Hierarchical Cluster Analysis (HCA)

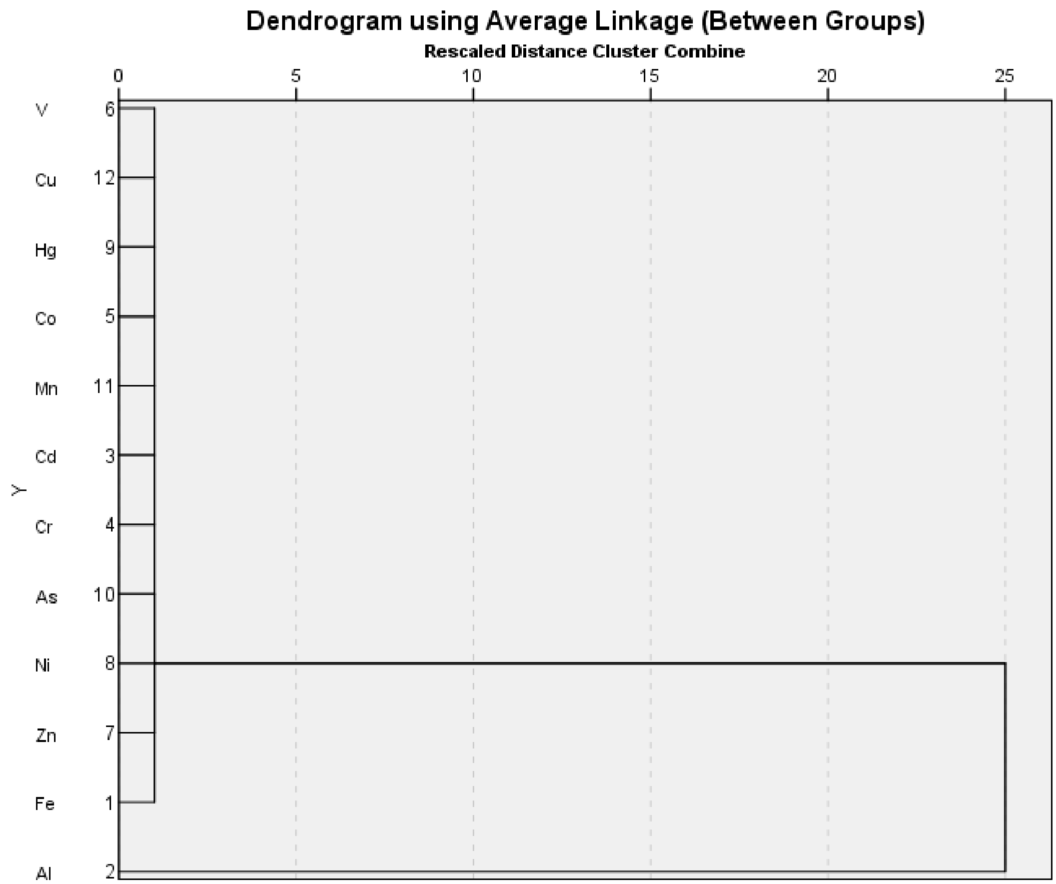

Figure 8. Dendrogram.

Table 6. Correlation matrix analysis (Correlation Matrix[a])

	FE	AL	D	CR	CO	V	ZN	NI	HG	AS	MN	CU
FE	1.000	.176	**.671**	**.680**	-.375	-.218	-.172	-.198	-.410	-.175	**-.894**	-.330
AL		1.000	.260	**-.512**	.371	.435	**-.851**	.201	**.747**	-.462	-.198	-.353
CD			1.000	.363	**-.530**	.264	-.119	-.085	.035	.137	**-.824**	**-.553**
CR				1.000	-.413	**-.618**	.286	-.003	**-.757**	.283	-.490	.136
CO					1.000	.216	-.487	**.616**	.337	**-.598**	.432	.111
V						1.000	-.136	-.086	.427	-.485	-.188	**-.637**
ZN							1.000	-.302	**-.639**	.305	.027	-.116
NI								1.000	.362	.010	.294	.033
HG									1.000	.020	.336	-.069
AS										1.000	.274	.469
MN											1.000	**.649**
CU												**1.000**

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

result is displayed as a dendrogram in Figure 8. One group with only one cluster is shown by the dendrogram in Figure 8. This implies that comparable anthropogenic activities in the research area have an impact on the pollution of the water in the study area.

Correlation Matrix Analysis

In evaluating the origin, correlation and interaction between hydrogeochemical parameters in a given water body, correlation matrix analysis is a trustworthy method (Akakuru *et al.*, 2022; Akakuru *et al.,* 2021a; Akakuru *et al*., 2021b; Ajayi and Okeke, 2024). Correlation Coefficients with a value of more than 0.7 indicate a strong relationship between the two parameters, and correlation coefficients between 0.5 and 0.7 indicate a shaky relationship and suggest a moderate correlation between parameters. The majority of the parameters in this study show a strong correlation suggesting that the same kind of anthropogenic activities could be the source of water pollution of Aba River. Table 6 is a correlation matrix for the hydrogeochemical parameters analyzed for the evaluation of the water quality of the Aba River.

Conclusion

Principal Component Analysis, Custer Analysis and correlation Matrix of data collected from Aba River in this research clearly show that the numerous anthropogenic activities, especially industrial operations, in and around Aba River are major sources of pollution of the river. Thus, the activities of the industries and commercial outfits located around the river should be regulated to ensure that there is no indiscriminate disposal of harmful industrial waste into the river. Based on the findings of this study, it is recommended that wastewater treatment plants be built in the Aba area to ensure that municipal wastewater does not drain into the river untreated. Also, the industries located around the Aba River should ensure that they do not discharge untreated effluents into the river.

CONFLICT OF INTEREST

The authors declare the they have no conflict of interest.

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