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Evaluating quality of water bodies in rural communities in the Southeastern Nigeria and implications to health of the citizen

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Abstract

Access to safe drinking water remains a major public health challenge in rural communities of South-Eastern Nigeria. This study evaluated the quality of water bodies in selected rural areas of Ebonyi, Anambra, and Abia States, assessing contaminant types, concentrations, and potential health implications for residents. A cross-sectional, seasonal field-based approach was adopted, with ninety water samples collected from nine springs during both the dry and rainy seasons. Physicochemical, microbial, and heavy metal parameters including pH, turbidity, total dissolved solids, iron, lead, total coliform, and Escherichia coli were analyzed using standard APHA methods. Statistical analyses, including multiple regression, principal component analysis, and cluster analysis, revealed that microbial contamination (total coliform and E. coli) and physical-chemical factors (turbidity, iron, total dissolved solids) were the dominant contributors to water quality degradation. Significant correlations indicated that lower pH and elevated turbidity and total coliform levels exacerbate contamination, while cluster analysis highlighted spatial heterogeneity and high-risk locations requiring urgent intervention. The findings underscore the serious health risks posed by drinking water in these communities and point to the need for effective monitoring, pollution mitigation, and community-based water treatment strategies to reduce disease burden.

1. Introduction

The indispensable nature of water cannot be over emphasized. Whether water is meant for business purposes, agriculture, domestic purposes, or is used by public municipalities and private homeowners, it must be tested regularly in order to keep the source of water safe and free from environmental risks and potential health disorders. Water testing is carried out to meet the regulatory requirements and adhere to the safety procedures that are needed for pollutant-free water. Water testing is a broad concept that involves several procedures to analyze and evaluate the quality of water. Majority of the people in south eastern Nigeria rely on the private water supply. This includes boreholes, ponds, and wells as well as stream, lake and river water. All these water sources needed to be tested in order to maintain their safety. Tap water is usually tested for chlorine levels, pH in water and bacteria. Despite the importance of water quality testing, many tend to overlook testing until the damage has been done. Tiny microorganisms and substances that naturally get into a water supply may be detrimental to a person's health. Water is rendered unsafe whenever it is contaminated with substances such as chemicals and microorganisms to the extent that is detrimental to human health. Many substances can cause digestive issues, illness, and (in some severe cases) death. These contaminants may be natural or due to anthropological related activities such as in industrial and processing zones, landfills and solid waste processing sites, outlets and confluences of canals as well as deforestation.

Water testing is carried out to meet the regulatory requirements and adhere to the safety procedures that are needed for pollutant-free water. Water testing is a broad concept that involves several procedures to analyze and evaluate the quality of water. Water quality is the chemical, physical, and biological characteristics of water in reference to a set of standards of its usage. The most common standards used to monitor and assess water quality convey the health of ecosystems, safety of human contact, extent of water pollution, and condition of drinking water. Water quality has an important effect on health in whatever purpose it is used for. Water of poor quality can cause disease outbreaks which can contribute to the breakdown rates of diseases manifesting themselves on different time scales (Uzoh et al., 2017). Water is very essential for the stability of ecosystem. Water is colorless, odorless, and tasteless, but due to anthropological activities, water is usually contaminated with human waste, solids, effluents from industries, and dissolved gases. This is the reason for the evaluation of the quality of the available fresh water for the safety of humans and other water bodies which can influence human health through bioaccumulation of some contaminants. Microorganism, toxic chemicals, and some organic compounds are some of the sources of contaminants in water bodies (Verma & Kuila, 2019).

Some of these may be due to anthropological activities or may be product of natural phenomenon such as weathering, volcanic emission, and rock solubilization and so on. It is only of recent that the federal government of Nigeria started showing interest in the mining sector of the economy. This area is one of the generator of contaminant through mine drainage of water that are rich in elements and these has the chances of mixing with the surface water. There are many of these mining activities in many of the rural areas in south eastern of Nigeria without proper monitoring, thus the reason for the research on the evaluating the quality of water in the rural areas of south eastern region. This may be one of the reasons the World Health Organization (WHO & UNICEF, 2021) stated that 26% and 70% of the world and sub-Saharan Africa (SSA) population, respectively, have no access to safely managed water services in 2020. There is the need to know the current level of water services of households in any given area, which will form the basis of service provision monitoring. Some of the rural dwellers are still defecating on open ground (WHO, 2017) in nearby bushes, thus leading to the increase in the chances of contaminating the water bodies during water and/or air erosion. The water bodies needed to be tested in order to maintain their safety for human consumption aquatic lives safety. The mineral content, pH, nitrate, dissolved solids are usually test using biological, chemical, and physical parameters. Despite the importance of water quality testing, many tend to overlook testing until the damage has been done. Uzoh et al. (2017) researched on water quality of the drinking water in state capitals (urban) and found that there are variations in values in the parameters with generally no growth in bacteriological analysis. The turbidity values exceeded WHO standard and some parameters such as phosphate, Mg, and Fe exceeded acceptable limits.

Understanding of the links between water quality and health continues to grow and highlight new potential health crises: from the chronic impacts of infectious diseases on child development through stunting to new evidence on the harms from known contaminants, such as manganese with growing evidence of neurotoxicity in children (Khan, 2023). In natural water bodies such as lakes, rivers, and oceans, various factors can influence water quality. These include natural processes like weathering, erosion, and biological interactions, as well as human activities such as industrial discharges, agricultural runoff, and improper waste disposal. Contaminants commonly found in water include organic and inorganic substances, pathogens, heavy metals, pesticides, and nutrients like nitrogen and phosphorus. Contaminated water can pose serious risks to human health when consumed or used for bathing and irrigation. It can lead to waterborne diseases, reproductive problems, and long-term health issues (Anku et al., 2016). Aquatic organisms and ecosystems can suffer detrimental effects, such as reduced biodiversity, habitat degradation, and the decline of sensitive species. Seventy-three percent of the diarrheal and enteric disease burden as associated with poor access to adequate water sanitation and hygiene, and is disproportionally borne by poorer children.

There are some points to take into account when considering water quality testing: Physical parameters of water quality which determines the senses of sight, smell, taste, and touch. These physical parameters include temperature, color, taste and odor, turbidity, and content of dissolved solids. Chemical parameters of water quality which measures those characteristics which reflect the environment with which water had contacted. These chemical parameters can measure pH, hardness, amount of dissolved oxygen, biochemical oxygen demand (BOD), chemical oxygen demand (COD), and levels of chloride, chlorine residual, sulfate, nitrogen, fluoride, iron and manganese, copper and zinc, toxic inorganic substances, as well as radioactive substances. Biological parameters of water quality are those measurements that reflect the number of bacteria, algae, viruses, and protozoa that are present in water.

Access to safe drinking water is a fundamental necessity for human health, yet urbanization and population growth increasingly strain land, and freshwater resources in South-Eastern Nigeria (Odimegwu & Anyakora, 2018; Akanwa et al., 2024). Unregulated human activities, such as indiscriminate waste disposal and poor land-use practices, exacerbate water pollution and degrade water quality (Odimegwu, 2020; Oramah et al., 2025). Research emphasizes that regular monitoring of water quality is critical to identifying contaminants and mitigating health risks associated with outbreak of microbial, chemical, and physical pollution (Ikechukwu & Odimegwu, 2021). Seasonal variations, population density, and land-use changes have been shown to influence contamination levels, highlighting the need for continuous assessment. However, proper testing ensures that treatment systems are appropriately designed and potential sources of contamination are addressed (Munonye et al., 2022; Farinmade et al., 2025). Annual standard checks of drinking water, regardless of source, are recommended to maintain safe and reliable water supply for domestic use (Anyakora et al., 2025). Implementing effective monitoring and management strategies is essential to reduce waterborne disease risk and promote community health in rural areas undergoing rapid urbanization.

Drinking water in developing countries especially in Nigeria is susceptible to toxins as a results of effluents and pollutants (Odoh & Jidauna, 2013). The level of water services to a large extent influences household's health and socioeconomic development (Chowdhury et al., 2018; Zerbo et al., 2021. Increase in human population and development in modern technology increases the risk for water contamination. The consumption of unsafe water has been blamed for the high incidence of diarrhea, which has caused preventable deaths, especially among children below the age of five. Prüss-Ustün et al. (2019), reported that in 2016 there were about 485,000 deaths due to diarrhea and which were attributable to poor access to water supply. Bain et al. (2014), also reported that in 2011 the death of about 700,000 children were as a result of diarrhea, which was caused by the consumption of unsafe water.

For microbial water quality, verification is likely to be based on the analysis of faecal indicator microorganisms, with the organism of choice being Escherichia coli or, alternatively, thermotolerant coliforms. Assessment of the adequacy of the chemical quality of drinking-water relies on comparison of the results of water quality analysis with guideline values. These guidelines provide guideline values for many more chemical contaminants than will actually affect any particular water supply, so judicious choices for monitoring and surveillance should be made prior to initiating an analytical chemical assessment. Therefore, in order to determine the constituent responsible for the contamination, it will be necessary to undertake a water quality assessment. Thus, the reason for the study.

Water bodies play a significant role in sustaining human welfare. Water bodies are valuable to human beings from the point of view of ecology, landscape, recreation, heritage, culture, irrigation, and drainage. In 2018, epidemiological surveillance reported 43,996 cases and 836 deaths cross 20 states between January 1st and November 19th with a Case Fatality Ratio (CFR) of 2% in which Anambra and Ebonyi State in the south eastern Nigeria were part of the 20 states. In 2019, Nigeria recorded over 1,585 suspected cases resulting to 22 deaths with Case Fatality Ratio (CFR) of 1.38% across 6 states in Nigeria in which Ebonyi State in the south eastern Nigeria was part of the 6 states. In 2023, Nigeria recorded over 3,683 suspected cases, resulting to 128 deaths with a Case Fatality Ration (CFR) of 3.5% across 9 states in Nigeria in which Ebonyi State in the south eastern Nigeria was part of the 9 states. As of July 21, 2024, Nigeria had recorded over 4,809 suspected cases, resulting in 156 deaths with a Case Fatality Ratio (CFR) of 3.2% across 9 states in Nigeria in which Abia and Ebonyi in the south eastern were part of the 9 states. Cholera flourishes in regions where there is restricted availability of uncontaminated water and unsanitary living conditions that usually coincide with poverty. Cholera cases in Nigeria have been increasing significantly since the 1970's, primarily due to wide spread of poverty. Due to the lack of basic contemporary infrastructure, most of the population residing in rural communities in South Eastern Nigeria are very susceptible to disease outbreaks.

Results shown that PH of all the spring water in Igbo Etiti L.G.A were slightly acidic and were above the guideline values. The water quality index showed that none of the spring water had excellent water status. Probable cancer and non-cancer risk assessment revealed a probable risk associated with the consumption of the spring in Igbo Etiti area, Nigeria. Further survey shown that 80% of people drinking water from the spring water are ulcer patient (Ezea et al., 2022). Uzoh et al (2017), evaluated the quality of urban drinking water in south eastern Nigeria and revealed very high iron (Fe) content in the drinking water which could lead to health problems. The increasing trend necessitates a proactive measure to assess the water bodies in the rural communities in the south eastern Nigeria. Hence, this study focuses on evaluating quality of water bodies in the rural communities in the south eastern Nigeria: Implications to health of the citizens.

The study aims to assess the quality of water bodies in rural communities of southeastern Nigeria and examine their implications for public health by identifying the types and concentrations of contaminants present, analyzing the associated health impacts on residents, and proposing feasible solutions to mitigate health problems arising from the consumption of contaminated water; accordingly, the research is guided by questions concerning what contaminants and quantities exist in these water bodies, how these contaminants affect citizens' health, and what interventions can effectively address the resulting health challenges.

2. Method

The study was conducted in selected rural communities within South-Eastern Nigeria, specifically in Ebonyi, Anambra, and Abia States. These areas depend largely on natural spring water sources for domestic use, making them suitable for assessing water quality and associated health implications. A cross-sectional and seasonal field-based research design was adopted. Water quality was evaluated during both the rainy and dry seasons to capture seasonal variations in contamination levels and potential health risks. Nine (9) sampling locations were identified, and water samples were collected from them seasonally during the dry and rainy seasons. Samples were taken from nine (9) springs located in nine communities across Ebonyi, Anambra, and Abia States. A total of ninety (90) water samples were collected from the nine (9) springs during the dry and rainy seasons. The water samples were collected between May and June 2025 (rainy season) and between December 2025 and January 2026 (dry season).

Each sample was collected using a clean two-liter screw-capped polyethylene container, which was thoroughly washed with detergent, rinsed with analytical-grade 1:1 HCl, and finally rinsed with deionized water. At the point of collecting, the polyethylene containers were rinsed three times with the spring water samples. The containers were positioned directly at the point source of the spring water to minimize contamination by surface films. The polyethylene containers were filled to capacity without leaving air space, immediately covered, and properly labeled. Temperature was determined on-site to prevent sample deterioration. Samples were transported to the laboratory in a cool box maintained at 4 °C to minimize microbial activity that could affect analyte concentrations.

The samples were digested by adding 50 mL of the spring water sample into a beaker, followed by the addition of 30 cm^3 of aqua regia (a mixture of HNO_3 and HCl in a 1:3 ratio). Ten (10) mL of deionized water was also added and left for 24 hours. The mixture was heated at 100 °C until the volume was reduced to 30 cm3. 20 cm3 of deionized water was added to the sample solution and re-heated until no fume was observed coming out of the system. The digest was allowed to cool for about 30 minutes, filtered into a 100 mL standard flask, and made up to the mark with deionized water. Water sources in South-Eastern Nigeria were identified through reconnaissance surveys, and each sampling area was delimited to 200 m × 200 m. The delimited area was divided into grid plots, from which 30% were randomly selected for sample collection. Water samples were subsequently collected from ten (10) water spots. The samples were placed in sample bottles rinsed with the same water, properly labeled, and transported to the laboratory for analysis.

All parameters covered in the study were analyzed, including physical parameters (temperature, conductivity/salinity, turbidity, and total dissolved solids), chemical parameters (pH and concentrations of PO_4^{3-}, NH_4^+, dissolved oxygen, biochemical oxygen demand, chemical oxygen demand, and heavy metals such as Pb, Hg, Cd, Cu, Cr, Mn), and biological parameters (Escherichia coli and total coliform). Electrical conductivity, total dissolved solids, and pH were measured immediately after sampling using a model PHS-3D pH meter (Uniscope), after which samples were transferred to the laboratory. Each water sample was analyzed for physicochemical parameters including pH, electrical conductivity, total dissolved solids, turbidity, colour, major cations (Na^+, K^+, Ca^{2+}, and Mg^{2+}), major anions (HCO_3^-, Cl^-, and SO_4^{2-}), minor constituents (NO_3^-, NO_2^-, PO_4^{3-}, and ammonium nitrogen), and heavy metals such as Fe, Mn, Cu, As, Zn, Pb, Cd, and Ni. All analyses followed standard procedures recommended by the American Public Health Association (APHA, 2005).

Statistical analysis was carried out using the Statistical Package for Social Sciences (SPSS version 16.0). The suitability of the water was assessed based on the percentage compliance of measured parameters with the Nigerian Standard for Drinking Water Quality (NSDWQ, 2007) and World Health Organization guidelines (WHO, 2007). The Metal Pollution Index (MPI) was applied, where higher metal concentrations relative to allowable standards indicated poorer water quality (Igbomor, 2019). The MPI represented the sum of the ratios of analyzed metal concentrations to their corresponding national standard values.

$$\text{MPI} = \frac{\sum \text{Ci}}{\text{MACi}} \qquad (1)$$

Where:
MPI = Metal Pollution Index
Ci = the metal concentration in water sample,
MACi = the maximum allowable concentration.

In determining the coliform density in the samples, multiple tube fermentation technique was used in providing the most probable number (MPN). The test will be conducted in three stages, such as presumptive test, confirmatory test, and complete test.

$$\text{MPN per g or mL of sample} = \left(\frac{\text{MPN from table}}{100} \text{ x middle tube dilution rate}\right) \qquad (2)$$

2.1. Sampling Methodology

Table 1. Sample Container Types, Preservation Conditions, Recommended Volumes, and Maximum Holding Duration for Water Quality Parameters

Parameters	Containers	Preservation Conditions	Volume (mL)	Maximum preservation duration
pH	Glass	-	25	Analyze immediately
Temperature	Glass	-	1,000	Analyze immediately
Turbidity	Glass		100	48 hours
TDS	Glass	-	1,000	28 days
DO	Glass	-	300	Analyze immediately
BOD	Glass		1,000	48 hours
COD	Glass		50	28 days
NH_4^+	Glass	H_2SO_4 at pH < 2	400	28 days
PO_4^{3-}	Glass	H_2SO_4 at pH < 2	50	28 days
Cl^-	Glass	-	50	28 days
Pb	Glass	HNO_3 at pH<2	100	6 months
Cd	Glass	HNO_3 at pH<2	100	6 months

Individual parameters were compared with standards. Table 2 is a list of water quality testing parameters and the water quality testing methods which are used to analyse the quality of water.

Table 2. Water Quality Testing Parameters and Corresponding Analytical Methods

No	Water Testing & Analysis Parameter	Water Testing and Analysis Method
1	Colour	Spectrophotmetric method
2	pH	pH meter
3	Turbidity	Meter
4	Pesticide Nitrate	spectrophotometry method
5	Odour	Sensory method
6	Dissolved Oxygen (DO)	Winkler method
7	Biological Oxygen Demand (BOD)	Titrimetric method or Winlier
8	Chloride (Cl)	-
9	Fluoride	-
10	Oil and Grease	Gravimetry method
11	Hardness – Ca and Mg	EDTA method
12	Total Dissolved solids	TDS Meter
13	Sulphate as SO4	Turbidimetric method
14	Nitrate as NO3	Colorimetric method
15	Fe, Cu, Cr, Zn, Mn, Cd, Pb, Hg, As	AAS
16	Na, K	Flame photometry method
17	E.Coli	MPN – completed test for E.coli
18	Total Coliform Bacteria	MPN
19	Faecal Coliform	MPN
20	Temperature	Thermometer

These are some of the common parameters analysed to test the water quality and on comparison with the standards an overall idea of the quality of water can be achieved.

3. Results and Discussion

The results section presents the analysis of water quality in the studied communities. Escherichia coli was the dependent variable, with pH, turbidity, TDS, iron, lead, and total coliform as predictors. Principal Component Analysis identified dominant pollution factors, while K-Means cluster analysis classified sampling locations by pollution risk levels.

Table 3 shows that microbial contaminants, particularly total coliform (mean = 148.51) and Escherichia coli (mean = 35.84), are highly present, indicating significant faecal contamination. Physicochemical contaminants such as turbidity (mean = 12.09) and total dissolved solids (mean = 422.59) suggest moderate water pollution. Trace metals including iron (mean = 0.3871) and lead (mean = 0.0237) were also detected, indicating potential health risks. The results confirm diverse contaminant types in the sampled water bodies.

Table 3. Descriptive Statistics of Contaminant Types and Concentrations in Water Bodies Across Ebonyi, Anambra, and Abia States

	Mean	Std. Deviation	N
Escherichia coli	35.84	22.429	90
potential of Hydrogen	1.5000	.50280	90
Turbidity	12.09	5.266	90
Total Dissolved Solids.	422.59	49.566	90
Iron concentration	.3871	.08635	90
Lead concentration	.0237	.01276	90
Total Coliform	148.51	55.007	90

Table 4 reveals strong positive correlations among most contaminants, particularly between Escherichia coli, turbidity, total dissolved solids, iron, lead, and total coliform, indicating that these contaminants increase simultaneously. Table 4 also shows strong negative correlations between potential of hydrogen and most contaminants, suggesting contamination rises as pH decreases. The statistically significant relationships in Table 4 confirm the coexistence of microbial, chemical, and physical contaminants in the studied water bodies.

Table 4. Pearson Correlation Matrix Showing Relationships Among Water Contaminants in Water Bodies Across Ebonyi, Anambra, and Abia States

		Escherichia coli	potential of Hydrogen	Turbidity	Total Dissolved Solids.	Iron concentration	Lead concentration	Total Coliform
Pearson Correlation	Escherichia coli	1.000	-.900	.996	.966	.972	.917	.986
	potential of Hydrogen	-.900	1.000	-.924	-.796	-.784	-.692	-.818
	Turbidity	.996	-.924	1.000	.953	.954	.892	.973
	Total Dissolved Solids.	.966	-.796	.953	1.000	.986	.920	.985
	Iron concentration	.972	-.784	.954	.986	1.000	.954	.994
	Lead concentration	.917	-.692	.892	.920	.954	1.000	.953
	Total Coliform	.986	-.818	.973	.985	.994	.953	1.000
Sig. (1-tailed)	Escherichia coli	.	.000	.000	.000	.000	.000	.000
	potential of Hydrogen	.000	.	.000	.000	.000	.000	.000
	Turbidity	.000	.000	.	.000	.000	.000	.000
	Total Dissolved Solids.	.000	.000	.000	.	.000	.000	.000
	Iron concentration	.000	.000	.000	.000	.	.000	.000
	Lead concentration	.000	.000	.000	.000	.000	.	.000
	Total Coliform	.000	.000	.000	.000	.000	.000	.
N	Escherichia coli	90	90	90	90	90	90	90
	potential of Hydrogen	90	90	90	90	90	90	90
	Turbidity	90	90	90	90	90	90	90
	Total Dissolved Solids.	90	90	90	90	90	90	90
	Iron concentration	90	90	90	90	90	90	90
	Lead concentration	90	90	90	90	90	90	90
	Total Coliform	90	90	90	90	90	90	90

Table 5 shows that the predictors collectively have an extremely strong relationship with Escherichia coli (R = 0.999). The model explains 99.9% of the variation in Escherichia coli levels ($R^2 = 0.999$), indicating that turbidity, total dissolved solids, iron, lead, pH, and total coliform strongly influence contamination levels. The model is statistically significant (F = 10146.404, $p < 0.05$), while the Durbin Watson value of 1.890 indicates absence of serious autocorrelation.

Table 5. Model Summary of Multiple Regression Analysis Showing the Prediction of *Escherichia coli* Using Selected Water Contaminants

					Change Statistics					
Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	R Square Change	F Change	df1	df2	Sig. F Change	Durbin-Watson
1	.999[a]	.999	.999	.857	.999	10146.404	6	83	.000	1.890

a. Predictors: (Constant), Total Coliform, potential of Hydrogen, Lead concentration, Total Dissolved Solids., Iron concentration, Turbidity

b. Dependent Variable: Escherichia coli

Table 6 shows that the regression model is statistically significant in predicting Escherichia coli contamination in the sampled water bodies. The model produced an F value of 10146.404 with a significance level of $p < 0.05$, indicating that turbidity, total dissolved solids, iron concentration, lead concentration, pH, and total coliform jointly influence Escherichia coli levels. This confirms that the identified contaminants significantly contribute to microbial pollution in the studied communities.

Table 6. ANOVA Result of Multiple Regression Analysis on the Prediction of *Escherichia coli* Using Selected Water Contaminants

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	44712.862	6	7452.144	10146.404	.000[b]
	Residual	60.960	83	.734		
	Total	44773.822	89			

a. Dependent Variable: Escherichia coli

b. Predictors: (Constant), Total Coliform, potential of Hydrogen, Lead concentration, Total Dissolved Solids., Iron concentration, Turbidity

Table 7 shows that potential of hydrogen, turbidity, total dissolved solids, and total coliform significantly predict Escherichia coli contamination ($p < 0.05$). Potential of hydrogen and total dissolved solids have negative effects, indicating contamination increases as these decrease. Turbidity and total coliform show strong positive influence, with total coliform contributing most ($\beta = 0.563$). Iron and lead concentrations were not statistically significant predictors in Table 7.

Table 7. Regression Coefficients Showing the Individual Contribution of Water Contaminants to *Escherichia coli* Levels

	Unstandardized Coefficients		Standardized Coefficients			Correlations			Collinearity Statistics	
Model	B	Std. Error	Beta	t	Sig.	Zero-order	Partial	Part	Tolerance	VIF
1 (Constant)	6.860	4.370		1.570	.120					
potential of Hydrogen	-8.647	1.162	-.194	-7.440	.000	-.900	-.633	-.030	.024	41.371
Turbidity	1.065	.282	.250	3.781	.000	.996	.383	.015	.004	266.788
Total Dissolved Solids.	-.031	.013	-.069	-2.384	.019	.966	-.253	-.010	.020	51.203
Iron concentration	19.613	11.737	.076	1.671	.098	.972	.180	.007	.008	124.483
Lead concentration	26.661	31.205	.015	.854	.395	.917	.093	.003	.052	19.211
Total Coliform	.229	.031	.563	7.434	.000	.986	.632	.030	.003	349.111

a. Dependent Variable: Escherichia coli

Table 8 shows varying relationships among contaminants influencing Escherichia coli levels. Total coliform demonstrates negative correlations with pH, lead, total dissolved solids, iron, and turbidity, indicating interrelated contamination patterns. Potential of hydrogen shows strong positive association with turbidity. Lead concentration and total dissolved solids display moderate positive relationships. The findings in Table 8 confirm the coexistence and interaction of multiple contaminant types affecting water quality across the study areas.

Table 8. Coefficient Correlations Among Water Contaminants Associated with *Escherichia coli* in Water Bodies Across Ebonyi, Anambra, and Abia States

Model			Total Coliform	potential of Hydrogen	Lead concentration	Total Dissolved Solids.	Iron concentration	Turbidity
1	Correlations	Total Coliform	1.000	-.546	-.422	-.322	-.516	-.740
		potential of Hydrogen	-.546	1.000	-.048	.046	.039	.939
		Lead concentration	-.422	-.048	1.000	.490	-.174	.122
		Total Dissolved Solids.	-.322	.046	.490	1.000	-.406	.105
		Iron concentration	-.516	.039	-.174	-.406	1.000	.147
		Turbidity	-.740	.939	.122	.105	.147	1.000
	Covariances	Total Coliform	.001	-.020	-.407	.000	-.187	-.006
		potential of Hydrogen	-.020	1.350	-1.753	.001	.526	.307
		Lead concentration	-.407	-1.753	973.748	.201	-63.584	1.071
		Total Dissolved Solids.	.000	.001	.201	.000	-.062	.000
		Iron concentration	-.187	.526	-63.584	-.062	137.766	.486
		Turbidity	-.006	.307	1.071	.000	.486	.079

a. Dependent Variable: Escherichia coli

Table 9 indicates the presence of multicollinearity among some predictors of Escherichia coli, particularly turbidity, total dissolved solids, and total coliform, as shown by high condition indices (>30) and large variance proportions. This suggests that these contaminants are interrelated and may jointly influence microbial contamination. The results highlight that both chemical and microbial contaminants coexist in the water bodies, complicating efforts to isolate individual effects on water quality.

Table 9. Collinearity Diagnostics for Water Contaminants Influencing Escherichia coli Levels in Water Bodies Across Ebonyi, Anambra, and Abia States

				Variance Proportions						
Model	Dimension	Eigenvalue	Condition Index	(Constant)	potential of Hydrogen	Turbidity	Total Dissolved Solids.	Iron concentration	Lead concentration	Total Coliform
1	1	6.568	1.000	.00	.00	.00	.00	.00	.00	.00
	2	.395	4.080	.00	.00	.00	.00	.00	.01	.00
	3	.034	13.920	.00	.01	.00	.00	.00	.19	.00
	4	.003	48.999	.06	.05	.00	.00	.01	.55	.04
	5	.001	101.404	.00	.51	.36	.06	.18	.02	.00
	6	.000	175.167	.00	.07	.12	.46	.79	.06	.19
	7	.000	218.734	.93	.36	.51	.48	.02	.17	.76

a. Dependent Variable: Escherichia coli

Table 10 shows that the predicted Escherichia coli values closely match observed values, with residuals ranging minimally from -1.733 to 1.945 and standard residuals within ±2. This indicates a good model fit and reliable predictions of microbial contamination. The low Cook's Distance and centered leverage values suggest no influential outliers, confirming that the measured chemical, physical, and microbial contaminants consistently explain the variation in water quality across the studied communities.

Table 10. Residuals Statistics for the Regression Model Predicting Escherichia coli Levels in Water Bodies Across Ebonyi, Anambra, and Abia States

	Minimum	Maximum	Mean	Std. Deviation	N
Predicted Value	4.88	81.55	35.84	22.414	90
Std. Predicted Value	-1.382	2.039	.000	1.000	90
Standard Error of Predicted Value	.150	.457	.232	.059	90
Adjusted Predicted Value	4.85	81.48	35.84	22.409	90
Residual	-1.733	1.945	.000	.828	90
Std. Residual	-2.022	2.270	.000	.966	90
Stud. Residual	-2.070	2.327	.001	1.006	90
Deleted Residual	-1.872	2.046	.001	.899	90
Stud. Deleted Residual	-2.113	2.392	.002	1.017	90
Mahal. Distance	1.752	24.325	5.933	3.805	90
Cook's Distance	.000	.101	.012	.019	90
Centered Leverage Value	.020	.273	.067	.043	90

a. Dependent Variable: Escherichia coli

Figure 1 shows the distribution of standardized residuals from the regression model predicting Escherichia coli. The residuals are approximately normally distributed around zero, with most values falling between -2 and +2, and the bell-shaped curve closely fitting the histogram. This indicates that the regression model assumptions of normality are met, suggesting reliable predictions. It confirms that microbial contamination in the water bodies is well explained by the selected chemical, physical, and biological predictors in the studied communities.

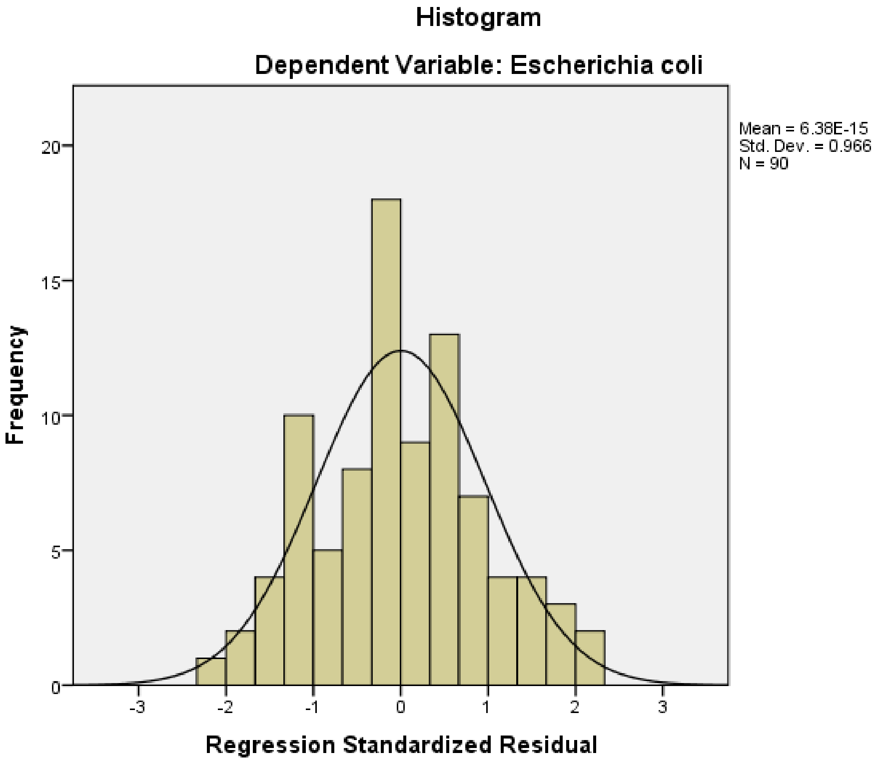

Figure 1. Histogram of Standardized Residuals for Escherichia coli Levels in Water Bodies Across Ebonyi, Anambra, and Abia States

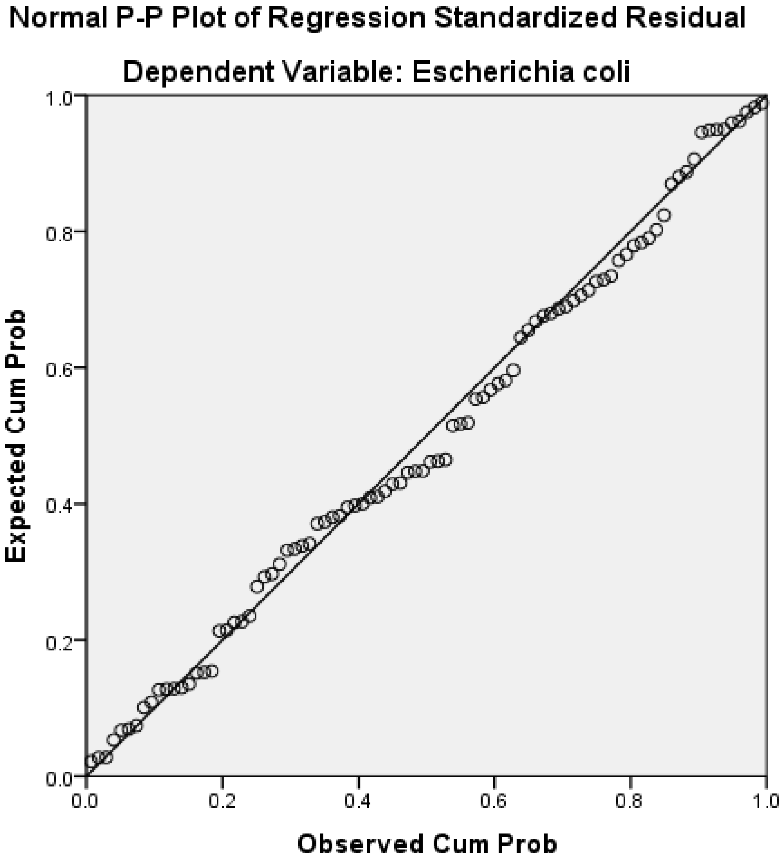

Figure 2. Normal P-P Plot of Regression Standardized Residuals for Escherichia coli Levels in Water Bodies Across Selected Rural Communities in Southeastern Nigeria

The plot in Figure 2 shows that most standardized residuals lie close to the diagonal line, indicating that the residuals are approximately normally distributed. This suggests that the assumptions of normality for the regression analysis are met, supporting the validity of the model used to predict Escherichia coli contamination based on chemical, physical, and microbial water parameters. Minimal deviation from the line indicates reliable predictions and minimal influence of outliers.

Table 11 indicates that total coliform, iron, total dissolved solids, and turbidity are strongly positively correlated, identifying them as dominant pollution factors in the water bodies. Potential of hydrogen (pH) is negatively correlated with these contaminants, showing that acidic conditions exacerbate pollution levels. Lead shows moderate positive correlations, suggesting secondary influence. The results highlight that microbial contamination (total coliform) and physical-chemical factors (iron, TDS, turbidity) are the primary drivers of water quality degradation in the studied communities.

Table 11. Correlation Matrix of Water Contaminants in Water Bodies Across Ebonyi, Anambra, and Abia States

		Potential of Hydrogen	Turbidity	Total Dissolved Solids.	Iron concentration	Lead concentration	Total Coliform
Correlation	Potential of Hydrogen	1.000	-.924	-.796	-.784	-.692	-.818
	Turbidity	-.924	1.000	.953	.954	.892	.973
	Total Dissolved Solids.	-.796	.953	1.000	.986	.920	.985
	Iron concentration	-.784	.954	.986	1.000	.954	.994
	Lead concentration	-.692	.892	.920	.954	1.000	.953
	Total Coliform	-.818	.973	.985	.994	.953	1.000
Sig. (1-tailed)	Potential of Hydrogen		.000	.000	.000	.000	.000
	Turbidity	.000		.000	.000	.000	.000
	Total Dissolved Solids.	.000	.000		.000	.000	.000
	Iron concentration	.000	.000	.000		.000	.000
	Lead concentration	.000	.000	.000	.000		.000
	Total Coliform	.000	.000	.000	.000	.000	

a. Determinant = 1.700E-8

Table 12 highlights the dominant contributors to water pollution. Large values for total coliform, turbidity, and iron indicate they are the primary factors influencing contamination levels. Potential of hydrogen (pH) also shows substantial influence, negatively affecting other contaminants. Lead and total dissolved solids have smaller relative contributions. These results suggest that microbial contamination and certain physical-chemical factors are the key drivers of water quality degradation in the studied communities.

Table 12. Inverse of Correlation Matrix Showing Dominant Pollution Factors in Water Bodies Across Ebonyi, Anambra, and Abia States

	Potential of Hydrogen	Turbidity	Total Dissolved Solids.	Iron concentration	Lead concentration	Total Coliform
Potential of Hydrogen	41.371	98.630	2.124	2.770	-1.363	-65.648
Turbidity	98.630	266.788	12.226	26.783	8.720	-225.801
Total Dissolved Solids.	2.124	12.226	51.203	-32.388	15.368	-43.028
Iron concentration	2.770	26.783	-32.388	124.483	-8.490	-107.510
Lead concentration	-1.363	8.720	15.368	-8.490	19.211	-34.596
Total Coliform	-65.648	-225.801	-43.028	-107.510	-34.596	349.111

Table 13 shows a Kaiser-Meyer-Olkin (KMO) value of 0.818, indicating that the sample size is adequate for factor analysis. Bartlett's Test of Sphericity is significant ($\chi^2 = 1541.543$, df = 15, $p < 0.001$), confirming that the variables are sufficiently correlated. These results validate the dataset for identifying dominant pollution factors, highlighting that microbial, chemical, and physical contaminants can be meaningfully grouped to determine key contributors to water pollution.

Table 13. KMO and Bartlett's Test for Sampling Adequacy in Identifying Dominant Pollution Factors in Water Bodies Across Ebonyi, Anambra, and Abia States

Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		.818
Bartlett's Test of Sphericity	Approx. Chi-Square	1541.543
	df	15
	Sig.	.000

Table 14 shows that all variables have acceptable Measures of Sampling Adequacy (MSA > 0.7), with potential of hydrogen (0.733), turbidity (0.749), total dissolved solids (0.893), iron (0.901), lead (0.894), and total coliform (0.763) suitable for factor analysis. This indicates that each contaminant contributes meaningfully to identifying dominant pollution factors, confirming that microbial, chemical, and physical parameters collectively drive water quality deterioration in the studied communities.

Table 14. Anti-Image Matrices Showing Measures of Sampling Adequacy for Identifying Dominant Pollution Factors in Water Bodies Across Ebonyi, Anambra, and Abia States

		Potential of Hydrogen	Turbidity	Total Dissolved Solids.	Iron concentration	Lead concentration	Total Coliform
Anti-image Covariance	Potential of Hydrogen	.024	.009	.001	.001	-.002	-.005
	Turbidity	.009	.004	.001	.001	.002	-.002
	Total Dissolved Solids.	.001	.001	.020	-.005	.016	-.002
	Iron concentration	.001	.001	-.005	.008	-.004	-.002
	Lead concentration	-.002	.002	.016	-.004	.052	-.005
	Total Coliform	-.005	-.002	-.002	-.002	-.005	.003
Anti-image Correlation	Potential of Hydrogen	.733[a]	.939	.046	.039	-.048	-.546
	Turbidity	.939	.749[a]	.105	.147	.122	-.740
	Total Dissolved Solids.	.046	.105	.893[a]	-.406	.490	-.322
	Iron concentration	.039	.147	-.406	.901[a]	-.174	-.516
	Lead concentration	-.048	.122	.490	-.174	.894[a]	-.422
	Total Coliform	-.546	-.740	-.322	-.516	-.422	.763[a]

a. Measures of Sampling Adequacy(MSA)

Table 15 shows the proportion of each contaminant's variance explained by the extracted factors. High extraction values indicate that turbidity (0.976), total dissolved solids (0.962), iron (0.973), total coliform (0.989), lead (0.886), and potential of hydrogen (0.751) are well represented in the factor solution. These results suggest that microbial, chemical, and physical contaminants are the dominant pollution factors driving water quality degradation in the studied communities.

Table 15. Communalities of Water Contaminants in Identifying Dominant Pollution Factors in Water Bodies Across Ebonyi, Anambra, and Abia States

	Initial	Extraction
Potential of Hydrogen	1.000	.751
Turbidity	1.000	.976
Total Dissolved Solids.	1.000	.962
Iron concentration	1.000	.973
Lead concentration	1.000	.886
Total Coliform	1.000	.989

Extraction Method: Principal Component Analysis.

Table 16 shows that the first principal component accounts for 92.29% of the total variance, indicating that a single factor strongly explains contamination in the water bodies. Subsequent components contribute minimally. This suggests that microbial, chemical, and physical contaminants, primarily total coliform, turbidity, iron, and total dissolved solids, collectively act as dominant pollution factors, driving most of the water quality degradation observed in the studied communities.

Table 16. Total Variance Explained by Dominant Pollution Factors in Water Bodies Across Ebonyi, Anambra, and Abia States

	Initial Eigenvalues			Extraction Sums of Squared Loadings		
Component	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	5.537	92.287	92.287	5.537	92.287	92.287
2	.374	6.234	98.521			
3	.070	1.166	99.687			
4	.011	.176	99.863			
5	.007	.108	99.972			
6	.002	.028	100.000			

Extraction Method: Principal Component Analysis.

Figure 3 shows the eigenvalues of each principal component. The steep decline after the first component indicates that the first component explains the majority of variance in contaminant levels. Subsequent components contribute minimally. This “elbow” pattern confirms that a single factor dominated by total coliform, turbidity, iron, and total dissolved solids which captures most of the variability, identifying it as the primary driver of water pollution in the studied communities.

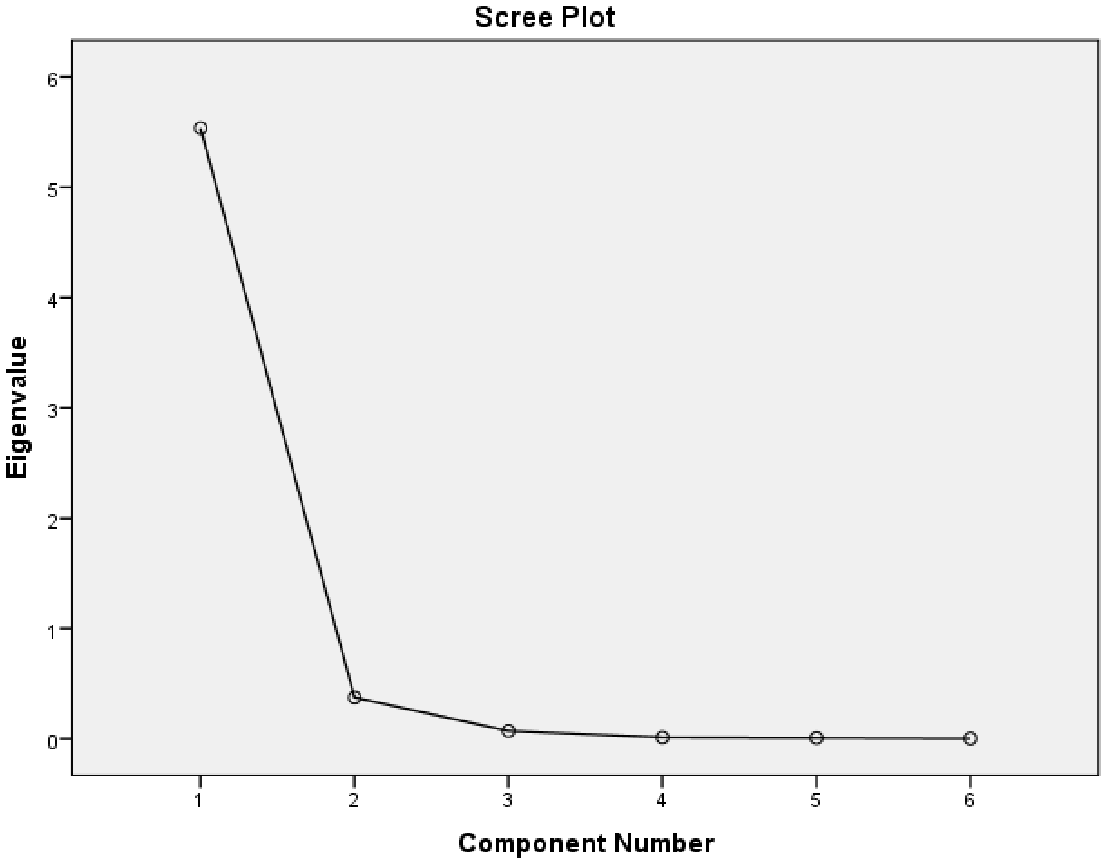

Figure 3. Scree Plot of Principal Components for Identifying Dominant Pollution Factors in Water Bodies Across Ebonyi, Anambra, and Abia States

Table 17 shows the factor loadings of contaminants on the first principal component. High positive loadings for total coliform (0.995), turbidity (0.988), iron (0.986), total dissolved solids (0.981), and lead (0.941) indicate they are the dominant pollution factors. Potential of hydrogen has a strong negative loading (-0.867), suggesting that lower pH intensifies contamination. These results confirm that microbial and physical-chemical contaminants collectively drive water quality degradation in the studied communities.

Table 17. Component Matrix Showing Dominant Pollution Factors in Water Bodies Across Ebonyi, Anambra, and Abia States

	Component
	1
Potential of Hydrogen	-.867
Turbidity	.988
Total Dissolved Solids.	.981
Iron concentration	.986
Lead concentration	.941
Total Coliform	.995

Extraction Method: Principal Component Analysis.
a. 1 components extracted.

Table 18 shows that the principal component model successfully reproduces the observed correlations among contaminants, with high reproduced correlations for total coliform (0.989), turbidity (0.976), iron (0.973), and total dissolved solids (0.962). Residuals are mostly small, with only 26% exceeding ±0.05, indicating an adequate model fit. This confirms that microbial contamination and physical-chemical factors are the dominant pollution factors influencing water quality in the studied communities.

Table 18. Reproduced Correlations and Residuals of Water Contaminants in Identifying Dominant Pollution Factors Across Ebonyi, Anambra, and Abia States

		Potential of Hydrogen	Turbidity	Total Dissolved Solids.	Iron concentration	Lead concentration	Total Coliform
Reproduced Correlation	Potential of Hydrogen	.751a	-.856	-.850	-.855	-.816	-.862
	Turbidity	-.856	.976a	.969	.975	.930	.983
	Total Dissolved Solids.	-.850	.969	.962a	.967	.923	.975
	Iron concentration	-.855	.975	.967	.973a	.929	.981
	Lead concentration	-.816	.930	.923	.929	.886a	.936
	Total Coliform	-.862	.983	.975	.981	.936	.989a
Residualb	Potential of Hydrogen		-.068	.053	.071	.124	.044
	Turbidity	-.068		-.016	-.020	-.039	-.010
	Total Dissolved Solids.	.053	-.016		.019	-.003	.009
	Iron concentration	.071	-.020	.019		.025	.013
	Lead concentration	.124	-.039	-.003	.025		.017
	Total Coliform	.044	-.010	.009	.013	.017	

Extraction Method: Principal Component Analysis.
a. Reproduced communalities
b. Residuals are computed between observed and reproduced correlations. There are 4 (26.0%) nonredundant residuals with absolute values greater than 0.05.

The bar chart in Figure 4 shows the distribution of sampling locations (cases) across a range of clusters, representing varying pollution risk levels. Each bar corresponds to a case, with the height indicating the number of clusters it belongs to. Locations with taller bars are associated with higher pollution risk, suggesting multiple contributing factors or contaminants, while shorter bars indicate lower risk. The variability across cases highlights spatial heterogeneity in pollution exposure among sampling sites. This classification allows environmental managers to identify high-risk areas requiring urgent intervention and low-risk areas for routine monitoring, supporting targeted pollution mitigation strategies.

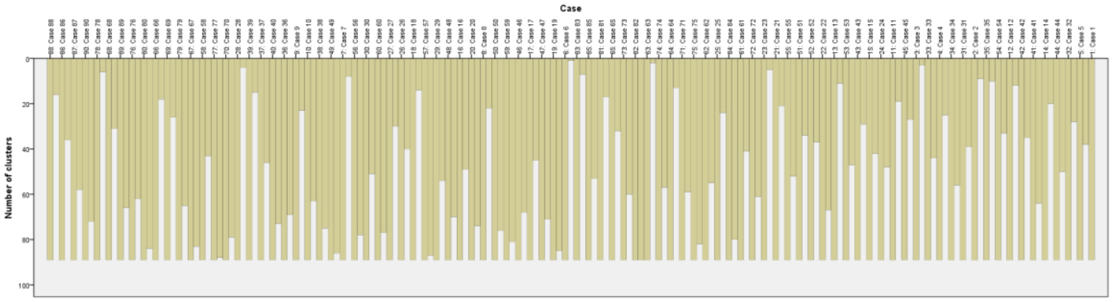

Figure 4. Cluster Analysis of Sampling Locations (Cases) Across a Range of Clusters, Representing Varying Pollution Risk Levels

Research question 1 covered various types and quantity of contaminants in the water bodies. From the analysis, the high presence of microbial contaminants, particularly Escherichia coli and total coliform, observed in the sampled water bodies indicates substantial faecal pollution. This finding agreed with the study by Debela et al. (2018), who reported widespread faecal contamination in surface and groundwater sources across sub-Saharan Africa due to poor sanitation and agricultural runoff. In contrast, some urban-focused studies have reported lower microbial loads where centralized water treatment systems exist (McDonald et al., 2014), highlighting infrastructural disparities between rural and urban water systems. The observed turbidity and total dissolved solids (TDS) levels suggest moderate physicochemical pollution. In a related study, Adjovu et al. (2023) found that elevated turbidity often co-occurs with microbial contamination because suspended particles provide attachment sites for bacteria. This finding agreed with the strong positive correlations identified between turbidity, TDS, and microbial indicators in the present study. In contrast, groundwater-dominated systems with low surface interaction tend to show weaker turbidity–microbial relationships (Qiao et al., 2025).

Trace metals such as iron and lead were detected, indicating potential chronic health risks. This result aligned with findings by Isah et al. (2025), who linked metal contamination in Nigerian water bodies to natural geological formations and anthropogenic activities such as mining and waste disposal. However, studies in highly industrialized regions have reported significantly higher lead contributions relative to microbial pollutants (Sevak et al., 2021), suggesting differing pollution sources across regions. The strong negative correlation between pH and most contaminants suggests that acidic conditions exacerbate pollution levels. This observation agreed with research by Yang et al. (2025), which demonstrated that lower pH enhances metal solubility and microbial survival in aquatic environments. In contrast, alkaline waters have been shown to suppress microbial growth under certain conditions (Wu et al., 2022).

Regression analysis revealed that turbidity, TDS, pH, and total coliform significantly predict E. coli levels. This finding agreed with Li et al. (2023), who identified turbidity and coliform counts as robust predictors of microbial risk. In contrast, iron and lead were not statistically significant predictors individually, supporting studies suggesting that metals often act indirectly by modifying water chemistry rather than directly driving microbial abundance (Hu et al., 2024). Principal Component Analysis further demonstrated that a single dominant factor driven by microbial and physicochemical contaminants which explains most water quality degradation. This finding agreed with recent multivariate studies emphasizing the clustering of pollution sources rather than isolated effects (Kumar et al., 2022). Cluster analysis also revealed spatial variability in pollution risk, consistent with findings by Goodkind et al. (2023), underscoring the need for location-specific interventions.

Research question 2 was on the implication of the contaminants to health of the citizen. The presence of Escherichia coli and total coliform in the water sources implies significant faecal contamination, exposing citizens to waterborne diseases such as diarrhoea, typhoid fever, and cholera. This finding agreed with Akinyemi et al. (2022), who reported that microbial contamination remains a major contributor to gastrointestinal infections in sub-Saharan Africa. In contrast, Alver (2019) observed lower health risks in regions with effective water treatment systems, underscoring the role of infrastructure in mitigating microbial exposure. Elevated turbidity and total dissolved solids further increase health risks by shielding pathogens from disinfection and facilitating their survival. In a related study, Hui (2018) found that high turbidity was strongly associated with increased incidence of gastrointestinal illness due to reduced treatment efficiency. This finding agreed with the present result, as turbidity often co-occurs with microbial contamination, compounding health impacts. The detection of trace metals such as lead poses chronic health concerns. This finding agreed with Olufemi et al. (2022), who reported that prolonged exposure to lead-contaminated water can impair neurological development in children and increase cardiovascular risks in adults. In contrast to microbial contaminants that cause acute illness, metal exposure results in long-term health effects due to bioaccumulation.

Research question 3 covered possible solution to health challenges gotten as a result of drinking contaminated water. Addressing health challenges associated with drinking contaminated water requires a combination of treatment, infrastructure improvement, and public health interventions. Household-level water treatment methods such as boiling, chlorination, and filtration are effective in reducing microbial pathogens, particularly Escherichia coli and total coliform, which are responsible for many waterborne diseases (Messner et al., 2017). These low-cost approaches are especially valuable in resource-limited communities where access to treated water is inadequate. Improving water supply infrastructure and protecting water sources are also essential for long-term health protection. Effective management of catchment areas, reduction of open defecation, and control of agricultural runoff can significantly lower microbial and physicochemical contamination, including turbidity and total dissolved solids (Hidayana et al., 2024). Strengthening centralized water treatment facilities further enhances pathogen removal and improves overall water quality (Sawyer et al., 2025). Chemical contaminants such as lead require regulatory enforcement and continuous monitoring to prevent chronic exposure. Replacing old pipelines, enforcing drinking-water quality standards, and routine testing have been shown to reduce long-term health risks associated with heavy metals. Public health education on safe water handling and storage complements these measures by reducing recontamination at the household level.

4. Conclusion

This study evaluated the quality of water bodies in rural communities of South-Eastern Nigeria and examined the implications for citizens' health. The findings demonstrate that the assessed water sources are compromised by microbial, physicochemical, and chemical contaminants, rendering them unsuitable for direct consumption without treatment. The dominance of faecal indicator organisms highlights persistent sanitation challenges and exposes residents to significant risks of waterborne diseases, while the presence of physicochemical parameters and trace metals suggests additional long-term health concerns. These conditions reflect systemic gaps in water infrastructure, source protection, and regulatory monitoring in rural settings. The study underscores the urgent need for integrated interventions, including improved water treatment systems, protection of water sources, enforcement of water quality standards, and community-based health education. Strengthening routine monitoring and investing in sustainable rural water supply infrastructure are essential to reducing disease burden and improving public health outcomes.

Data Availability

The datasets generated during and/or analysed during the current study are available from the corresponding author on reasonable request.

Conflicts of Interest

All authors in this publication declare no conflict of interest regarding the title, data, location, and results of the research.

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Supplementary Materials

This study does not include any supplementary materials.

Declaration on AI Use

The authors declare that no artificial intelligence (AI) or AI-assisted tools were used in the preparation of this manuscript. AI were used only to improve readability and language under strict human oversight; no content, ideas, analyses, or conclusions were generated by AI.

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