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Comparative Assessment of Groundwater and Surface Water Quality for Domestic Water Supply in Rural Areas Surrounding Crude Oil Exploration Facilities

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Abstract The purpose of this study is to assess and compare the quality of groundwater (GW) and surface water (SW) used for domestic purposes in rural areas near crude oil exploration sites in order to determine which source is more susceptible to pollution. Surface water samples were obtained from three (3) distinct locations in the study area, from upstream and downstream of the watercourses, for physicochemical, bacteriological, and heavy metal analysis using conventional laboratory procedures. Similarly, groundwater samples were taken from three (3) separate boreholes in the region for the same analysis, as per American Standard for Testing Materials (ASTM) and American Public Health Association (APHA) procedures. The relative significance of fourteen (14) water quality indicators in defining the quality of water for human consumption was evaluated in this study. The pH of the two water sources was somewhat acidic, with values ranging from 5.19 to 6.24, according to the results of the laboratory analysis. Water quality indicators such as Fe, Pb, TDS, TPC, DO, BOD, F coli, and E coli, on the other hand, were found to be above the permissible tolerance in drinking water, according to the Nigerian Standard for Drinking Water Quality (NSDWQ) and the World Health Organisation (WHO). Pollutant concentrations in surface water were higher than in groundwater, which may be attributable to the presence of humans or animal excrements (from open grazing) as well as offshore activities.

Keywords: *borehole, pollution, groundwater, NSDWQ, surface water, water quality, WHO*

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1. Introduction

Water covers more than 70 percent of the earth's surface and is without a doubt the most valuable natural resource on the planet [1]. Water is an essential resource for human survival, particularly for drinking and irrigation [2]. The distribution of fresh water resources is unequal across the globe, and fresh water availability is becoming increasingly scarce as a result of population expansion and varied human activities. According to the distribution of the world's water, only 2.5 percent and 97.5 percent are fresh water and saltwater water, respectively. 2.5 percent of the world's freshwater, surface water, and groundwater are represented by 0.4 percent, and 30.1 percent, proportionately [3]. The rapid rise in the world population, which is estimated to be above 7 billion and is projected to reach 9 billion by 2045 [4], has put severe strain on the available global fresh water, resulting in a planetary water crisis. In the absence of fresh precipitation, surface water (SW) and groundwater (GW) are used to satisfy the demands of diverse industries. The assessment of the quality of surface and groundwater for any purpose, notably for human consumption and the spatial and temporal variation in the quality water sources in response to local geologic set-up and anthropogenic influences is necessary. Water quality assessment for drinking purposes entails determining the chemical composition of groundwater, and remedial methods for restoring water quality in the event of degradation necessitate the identification of potential sources of groundwater and surface water pollution [5,6,7,8].

1.1. Groundwater

GW is the water trapped beneath the Earth's crust in soil and permeable rock aquifers, and it accounts for up to 33% of total global water withdrawals [9]. Over 2 billion people rely on groundwater as their major water source, and groundwater sources supply half or more of the irrigation water required to cultivate the world's food [9,10]. It is an important supply of water in many parts of Nigeria, Ghana, and India, particularly in semiarid and arid areas [11]. In times of drought, GW also serves as the primary strategic reserve, particularly during lengthy occurrences such as those currently underway in the western United States, northeastern Brazil, and Australia [12]. Groundwater keeps society going during dry spells when there isn't much rain. As a result, without a sustainable approach of mining groundwater, its valuable contents will never be restored [13]. Groundwater is frequently exploited as a supplementary water source in places with recurrent water stress and extensive aquifer systems [14]. Overexploitation or continuous groundwater depletion occurs when groundwater abstraction surpasses natural groundwater recharge across large regions and over extended periods of time [15,16]. Global economic and population development are pushing groundwater, a once-invisible resource, into depletion. Groundwater is essential to most of the world's agriculture and irrigation, as well as many industries [11]. Groundwater shortages and pollution disproportionately impact the poor in developing nations because they are frequently unable to keep up with decreasing groundwater levels or to locate alternate sources when their groundwater supply becomes contaminated. However, in developed nations, groundwater is critical to the economic well-being of large regions. Thus, from the southwestern United States to Mexico, India, and northern China, local groundwater users and governments at all levels are realizing that the once abundant and inexpensive groundwater resource is becoming scarcer and more polluted, limiting opportunities for social and economic growth and development [17]. Groundwater quality is a major concern in many parts of the world, in addition to groundwater depletion.

Groundwater pollution occurs when alien or natural chemicals are discovered in subterranean water at levels that pose a significant risk to the health of humans and/or plants. Domestic, agricultural, and industrial operations have all impaired groundwater quality [18], while hazardous chemicals are occasionally introduced by natural processes [19,20]. However, pollution is almost usually the product of human activities [21]. Groundwater is especially susceptible in regions with high population density and extensive human usage of the land. Almost every operation that involves the deliberate or unintentional release of chemicals or wastes into the environment has the potential to contaminate groundwater. It is difficult and expensive to clean up polluted groundwater. As a result, a full knowledge of the mechanisms that regulate groundwater quality, as well as evaluation of groundwater quality, are critical for the long-term management of groundwater resources [19,22]. Sustainable groundwater management must be focused not only on avoidance of the excessive exploitation of groundwater resources but also on prevention of pollution since unlike treatment at the point of use, prevention protects all of the resource. Groundwater pollution is caused by two sources: point sources and non-point sources. Groundwater and pollutants can travel quickly via rock cracks. Because cracks are typically irregularly distributed and do not follow the contours of the land surface or the hydraulic gradient, fractured rock offers a unique difficulty in identifying and managing pollutants. Pollutants can also enter the groundwater system via macrospore-root networks, animal tunnels, disused wells, and other systems of holes and fractures that provide pollutants with routes.

1.2. Surface Water

Fresh surface water comes mostly from streams, ponds, rivers, and lakes [23]. Aside from the requirement for drinking water, surface water is essential in a variety of economic sectors such as forestry, industrial operations, hydropower generation, fishing, and other creative activities. Freshwater availability is one of the world's key issues, with surface sources such as rivers, dams, lakes, and canals providing about one-third of the world's drinking water requirements [24]. These water sources are also excellent drains for the disposal of residential and industrial trash [25,26]. Pollution of accessible water resources is the greatest danger to sustainable water supply in Nigeria, South Africa, Ghana, and other developing nations [23]. Many communities in developing countries still rely on untreated or inadequately treated water from surface resources including rivers, streams, ponds, and lakes for their daily supply. They have little or restricted access to appropriate sanitary facilities, putting them at risk of waterborne illnesses [27]. Waterborne illness outbreaks from surface water have increased dramatically in developing countries, particularly in Africa [28].

Humans have used surface water for a variety of purposes. It serves as a supply of drinkable water after treatment as well as a source of household water without treatment, especially in low - income nations' rural regions. Farmers have utilised it for irrigation, and fishermen make a living by spear fishing in so many freshwater bodies. It is utilised for swimming and also acts as a tourist attraction center. As a result, surface water should be safeguarded from pollution. The quality and availability of surface water have worsened as a result of several major causes such as rising population, industrialisation, urbanisation, and so on. Surface water is one of the most impacted natural ecosystem on the planet, and its changes have resulted in extensive environmental degradation such as a downturn in water quality and availability, intense flooding, species loss, and changes in the distribution and structure of the aquatic fauna [29,30], rendering surface water courses unsustainable in terms of providing goods and services. For example, the geomorphology and geological formations, physicochemical and microbiological quality of the water, hydrological regimes, and the type of instream and riparian ecosystems all have an impact on the health of a river system [30]. Surface water in Nigeria, as in most other developing nations, is often used for residential, recreational, and agricultural uses, mostly in rural regions [31,32]. Water quality is influenced by both natural and human factors. Natural water quality varies from place to place due to seasonal and climatic variations, as well as the types of soils, rocks, and surfaces through which it flows [27]. Agricultural activities, urban and industrial growth, mining, and leisure all have a substantial impact on the quality of natural waterways and the capacity for water usage [33].

Assessment and management of surface and groundwater quality are key concerns that have a significant influence on our lives. Continuous crude oil exploration, extraction, and production are currently threatening this vital resource in Nigeria's Niger Delta area. Notwithstanding the region's enormous economic growth potential, its future is imperiled by declining environmental and economic circumstances that are not adequately addressed by current governmental policies and activities. There was no legislation particularly designed to address the region's environmental pollution problem until 1988. As a result, oil firms and oil operation-support industries conducted indiscriminate operations, causing severe damage to surface and groundwater resources. Their hostile environmental operations include unplanned wastewater releases, gas flaring, and, most importantly, oil spills. Analysing chemical constituents linked with oil activities helps determine the level of pollution. pH, temperature, electrical conductivity, biological oxygen demand (BOD), chemical oxygen demand (COD), dissolved oxygen (DO), turbidity, cations, anions, total petroleum hydrocarbon (TPH), and heavy metals such as nickel, lead, and zinc are among the primary physicochemical characteristics of importance.

Decreased water quality can result in higher treatment costs for both potable and industrial process water. The use of low-quality water for agricultural purposes can reduce crop production and lead to food scarcity. Water quality treatments have a significant impact on human health, therefore there has been a surge in attention in water quality control in recent times [34,35]. The deterioration of water quality in developing nations has resulted in diarrhea, hepatitis E, dental caries and poor oral hygiene, anemia in children, decreased Intelligence level in children, and impaired brain functioning and development [36-42]. Water quality encompasses a wide range of physical (EC, TDS), total suspended solids (TSS), hardness, alkalinity, turbidity, dissolved oxygen (DO), heavy metals (pH, Cu, Fe, Mn, Zn, P, Na, and so on), and biological (e.g., coliform) characteristics and constituents of both surface and groundwater sources. [43]. Most trace elements found in drinking water are said to be important for human health. However, high quantities of these metals (Zn, Cu, Fe, Mn, Cd, Ni, and Pb) and their excessive use can cause serious health issues [44,45,46]. The coliform bacterial group primarily infects water used for household, industrial, or other applications, and it reacts to the environment, wastewater treatment, and water treatment in the same way that many pathogens do. As a result, testing for coliform bacteria can provide a good indicator of the presence of other dangerous bacteria. [47].

This research likewise adopts an anthropocentric approach in that it is concerned with the causes/sources of possible pollution that are caused by people, the effects/consequences of pollution on humans, and management solutions that are related to human activity. Water quality in household usage must be evaluated to determine the degree of contamination and suitability for human consumption. It is beneficial to analyze the aforementioned issues in the context of an environmental framework in which the quantity and quality of water resources is a key concern. Therefore, the aim of this study is to assess and compare the drinking water quality in diverse drinking water sources utilised in rural communities near crude oil exploration sites.

To accomplish the aforementioned aim, the following particular objectives were set:

- Determine the quality of ground and surface water in the research region and compare it to national and international drinking water standards.
- Examine the degree of contamination in the study area's ground and surface water.
- Evaluate the water quality of boreholes and streams in the research region.

2. Methodology

2.1. Description of Study Area

The research area included three Mkpat Enin Local Government Area communities: Ikot Akpaden, Ikot Ekong, and Ikot Enin. Mkpat Enin is a Local Government Area (LGA) in Akwa Ibom State, Nigeria, and is located on the country's coast. With an area of 322.353 square kilometers, it is the state's second biggest local government area. The region is located between longitudes 4° 44' 1" N and 7° 44' 55" E, at an elevation of about 1,850mm above sea level. The region is typically humid due to its location within the humid tropics and proximity to the sea. The area's climate may be classified as tropical wet, with abundant and intense rainfall. The rainy season lasts around nine to ten months, beginning in March and continuing until the middle of November, with a mean annual rainfall of 2466.6mm. The average annual temperature in the region ranges from 25°C to 29°C, with 1,450 hours of sunlight each year. The region's underlying geology shows a three-tiered lithostratigraphic subdivision, consisting of an upper sand, an intermediate unit of alternating sandstone and shale and a lower shale. These three units span the region and range in date from early Tertiary to recent [48].

The region is rich in crude oil and natural gas; crude oil was discovered in the region in 1953. Crude oil production and export from the Niger Delta earns more than US$14.5 billion each year, accounting for more than 90% of the country's foreign revenue profits and providing more than 70% of the Federal annual budget [49]. Agriculture is the primary occupation of the people that live in this area. It also has a large number of oil fields, an aluminum industry, and a seaport. The region is rich in crude oil and natural gas; crude oil was discovered in the region in 1953. Crude oil production and export from the Niger Delta earns more than US$14.5 billion each year, accounting for more than 90% of the country's foreign revenue profits and providing more than 70% of the Federal annual budget [49]. Agriculture is the primary occupation of the people that live in this area. It also has a large number of oil fields, an aluminum industry, and a seaport.

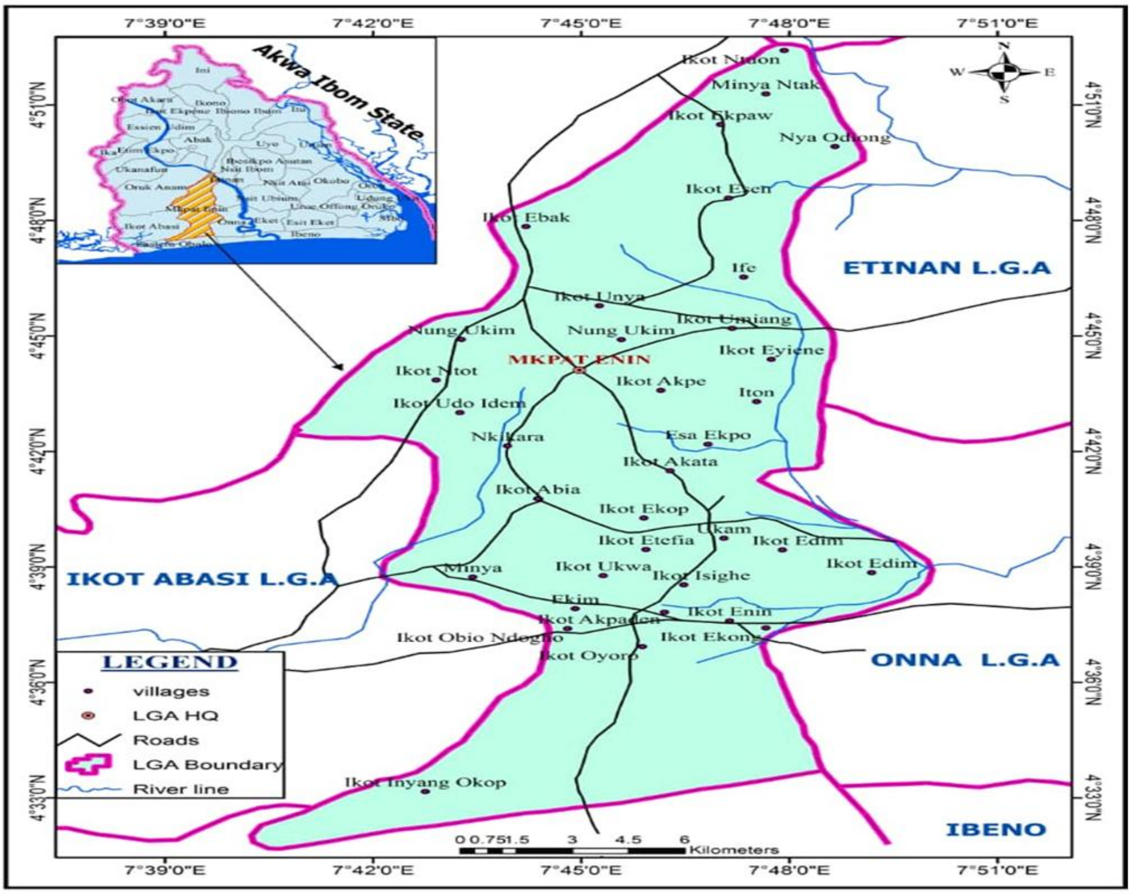

Figure 1. Map of study area

2.2. Data Sampling

The drinking water samples were primarily obtained from bodies of water in rural regions where appropriate facilities for obtaining clean water were well above expectations. The chosen districts border the Atlantic Ocean, where the surface water is often brackish or saline, with a trace of salinity in the groundwater. One of the fundamental criteria of a water quality analysis is the development and implementation of a reliable sampling procedure. It entailed moving a pre-selected small quantity of water from the initial collecting site to another place for evaluation without changing its properties. During sampling, care was taken to avoid contamination of the material being obtained. For the groundwater, three samples of water were collected and analysed from each borehole in the selected communities (Table 1). To avoid contamination, the nozzles of the taps were flamed and sterilised by wiping with cotton wool soaked in methylated spirit before to collecting water samples. The tap was left running for 5-10 minutes to draw up groundwater water rather than water from the distribution pipeline. To lessen contamination from fingers, the new 500mL (polyethylene) bottles were properly closed. Samples were transferred to the laboratory in an ice-packed container and kept cold for physicochemical and bacteriological analysis. Bacteriological samples were analysed within 24 hours. A systematic sampling was conducted in June 2019 to assess the quality of surface water in the research area. Representative surface water samples were obtained from the area's surface water bodies both upstream and downstream (Table 1). After washing the bottles 2 to 3 times with the water to be tested, surface water samples were taken in pre-washed one-litre polyethylene narrow-mouth bottles.

Table 1. Distribution of data collection

Sources	**Locations**				
	Ikot Akpaden	**Ikot Ekong**	**Ikot Enin**	**Total**	**Percentage (%)**
Borehole water	4	4	4	12	67
Stream water	2	2	2	6	33
Total	6	6	6	18	100

A questionnaire was designed to interview people from target communities using the water bodies to understand about their concerns about the severity of the drinking water quality problem, as well as ideas for improving access to clean water for the community. The questionnaire included questions on the water bodies, its location, depth, the population of the hamlet, frequent illnesses in the area, and the availability and quality of drinking water.

2.3. Data Analysis

The laboratory techniques employed to analyse the water samples were similar to those used by ASTM 2001[50] and APHA 1995 [51]. The water samples were analysed in the laboratory at the Akwa Ibom State Ministry of Science and Technology's Quality Control Department. The pH and turbidity of the samples were determined using the pH meter model HACH SENSION 3 and the turbid meter model 2100P TURBIDIMETER. Before using the pH meter, it was warmed for around 15-

20 minutes. Total dissolve solid was measured using a conductivity meter model HACH SENSION 5. Dissolve oxygen (DO) was measured using a dissolve oxygen meter type JYD-IA. The heavy metal characteristics were determined using a spectrophotometer type DR 2010 HACHSENSONS. In the statistical analysis, Excel was used to compute and Coefficient of Variation (CV), Correlation Coefficient ANOVA. The results of the different factors were compared to the WHO 2004 and 2011 recommendations, as well as the NSDWQ 2007.

3. Results and Discussion

3.1. Results

The quality of drinking water and the level of water bodies pollution were assessed using the quality standards proposed by ASTM and APHA based on NSDWQ and WHO guidelines. Table 2 and Table 3 show the findings of physiochemical, bacteriological, and heavy metal analyses for surface (streams) and groundwater (boreholes), respectively, while Table 4 – Table 10 present the statistical analysis. Figure 2 and Figure 3 show the comparison of surface water and groundwater quality within the sample locations.

The pH of surface water ranged from 5.19 to 7.12, with water samples from locations A and C having pH values less than 6.0. The pH values in groundwater ranged from 5.38 to 6.24, with water samples from borehole B at location 2 having a pH value more than 6.0, which is beyond the permitted limit. Surface water samples obtained in three sites showed temperatures ranging from 27.4^{o}C to 28.8^{o}C, while groundwater had slightly higher temperatures ranging from 28.11^{o}C to 29.4^{o}C. All of the water bodies had turbidity levels that were less than 5.0 NTU. Groundwater had a greater turbidity concentration (2.81-4.02 NTU) than surface water (1.07-1.54 NTU). The dissolved oxygen levels in the water samples (18) varied from 6.01 to 7.95, which was all above the NSDQW and WHO standard of 5.0. Almost all of the water samples had BOD levels that above the allowable limit for drinking water. One hundred percent of surface water samples exceeded the allowed limit, whereas eighty-three percent of groundwater samples were within the acceptable range. TDS levels in 15 of the 18 water samples collected in the study area ranged from 5.65 to 11.67 mg/L, above the higher desired limit of 5mg/L. Twelve of the 15 polluted water samples were from groundwater, with only three from surface water. TSS levels were generally satisfactory, ranging from 0.001 to 0.009 mg/L.

Table 2. Comparison of surface water with drinking water standards

Parameters	Location A		Location B		Location C		NSDWQ [52]	WHO [53]
	US	DS	US	DW	US	DS		
pH	6.15	5.19	7.12	6.15	6.03	5.83	6.0-8.5	6.0-8.5
Temperature	28.8	27.4	28.03	27.9	27.8	27.4	29.80	29.8
Turbidity (NTU)	1.14	1.42	1.16	1.94	1.07	1.54	5.0	5.0
DO	6.01	7.05	6.55	6.60	7.65	7.80	5.0	5.0
BOD	3.32	3.56	3.41	3.43	3.67	3.68	3.0	3.0
TDS	4.18	5.65	3.88	4.57	5.76	5.85	5.0	5.0
TSS	0.006	0.008	0.004	0.006	0.007	0.009	5.0	5.0
Sulphate	1.021	1.187	1.151	1.253	1.112	1.208	2.0	2.0
Pb	0.314	0.528	0.097	0.313	0.196	0.526	0.01	0.01
Fe	1.251	0.890	1.147	1.301	1.099	1.482	0.3	0.3
Zn	0.385	0.414	0.811	0.536	0.433	0.327	3.0	3.0
TPC (CFU)	36	34	33	34.33	37	36	0	0
F. coliform (CFU)	11	6	9	8.70	14.6	19	0	0
E. coli (CFU)	2	2	1	1.67	2	2.3	0	0

US-upstream; DS-downstream.

Table 3. Comparison of groundwater with drinking water standards

Parameters	Location 1		Location 2		Location 3		NSDWQ	WHO
	A	B	A	B	A	B		
pH	5.38	5.72	6.24	5.78	5.25	5.82	6.0-8.5	6.0-8.5
Temperature	29.2	28.8	28.11	28.7	28.13	29.4	29.8	29.8
Turbidity (NTU)	3.21	3.08	2.81	3.03	3.86	4.02	5.0	5.0
DO	6.99	7.44	6.87	7.10	7.56	7.95	5.0	5.0
BOD	1.23	2.82	0.89	1.65	2.67	3.52	3.0	3.0
TDS	10.97	8.81	8.43	9.40	11.67	10.42	5.0	5.0
TSS	0.001	0.001	0.001	0.001	0.001	0.001	5.0	5.0
Sulphate	0.003	0.006	0.082	0.030	0.009	0.010	2.0	2.0
Pb	0.001	0.001	0.001	0.001	0.001	0.001	0.01	0.01
Fe	0.213	0.198	1.001	0.47	0.329	0.802	0.3	0.3
Zn	0.054	0.136	0.061	0.084	0.093	0.107	3.0	3.0
TPC (CFU)	12	9	15	12	18	14	0	0
F. coliform (CFU)	3	2	2	2.3	4.6	3.4	0	0
E. coli (CFU)	0	0	0	0	0	0	0	0

A-average result in borehole A; B- average result in borehole B.

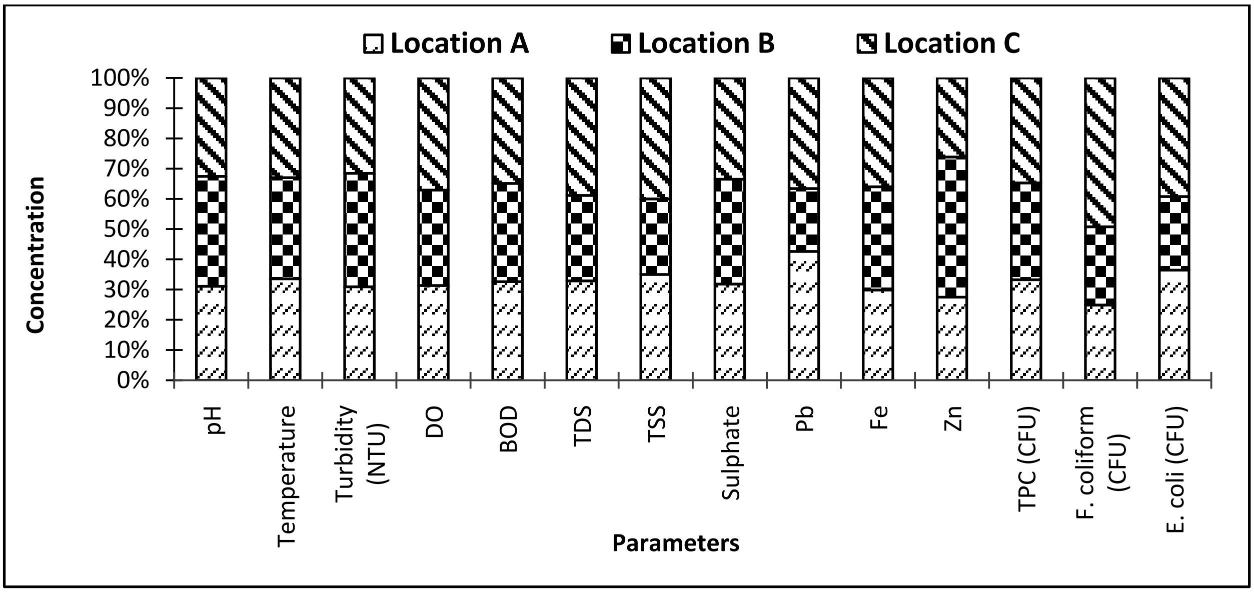

Figure 2. Comparison of surface water within the study area

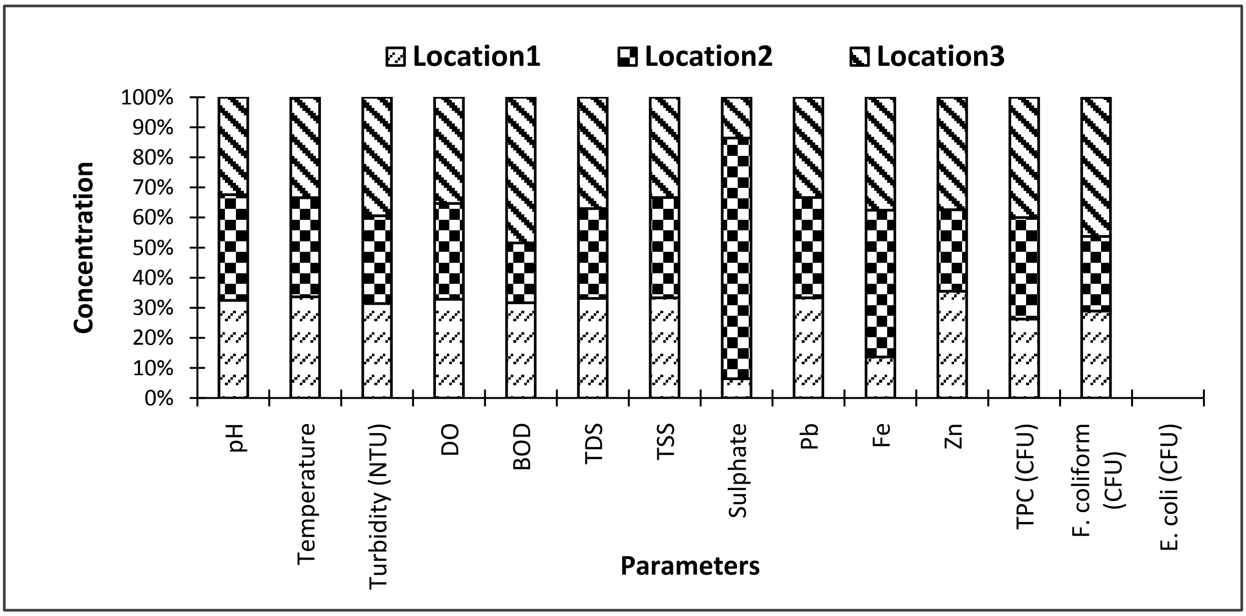

Figure 3. Comparison of groundwater within the study area

Sulphate found in all water samples were less than the allowable limit of 2.0mg/L, with a greater concentration level in surface water. The concentration of lead in drinking water ranged from 0.001 to 0.528mg/L, with six samples, all from surface water, exhibiting greater concentrations above the NSDWQ and WHO of 0.01mg/L Pb in drinking water. The iron concentration in drinking water samples varied from 0.198.1 to 1.482mg/L, with 14 samples above the desired limit of 0.3mg/L and four samples falling within the limit. Zinc concentrations in all samples ranged from 0.054 to 0.811mg/L, well within the NSDQW and WHO standards of 3.0mg/L. The total plate count (TPC) values for all of the water show significant levels of pollution and were beyond allowable limit in drinkable water. The concentration levels in groundwater ranged from 9 to 18CUF and from 33 to 37CUF in surface water. For faecal coliform, the similar pattern of findings was found. The concentrations ranged from 2 to 19 CUF, significantly above the NSDWQ and WHO standards of zero in drinking water. There was no E. coli in any of the groundwater samples. The test results show that the concentration of this parameter in surface water varied from 1.0 to 2.3CUF, which is above the permissible limit in drinking water.

3.2. Statistical Analysis

Table 4 and Table 5 show the findings of the correlation in surface and ground water quality parameters. In surface water samples, there was a strong positive correlation between DO and BOD (0.994), TDS and BOD (0.928), E. coli. and TSS (0.906), and TSS and TDS (0.903), indicating that their distribution was highly associated, r>0.5. There was a strong negative correlation coefficient between E. coli. and Zn (-0.993), Pb and pH (-0.856), TSS and pH (-0.851), and E. coli. and pH (-0.851). (-0.808). In contrast, substantial positive correlations were detected in groundwater samples between BOD and DO (0.980), F. coli. and TDS (0.927), DO and Turb. (0.876), and F. coli. and Turb, (0.852), indicating that their distribution was highly associated, r>0.5. TDS and pH had a high negative correlation coefficient (-0.862), as did F coli. and pH (-0.724). Pb (52.72 percent), F coli. (41.27 percent), Zn (35.95 percent), TSS (26.27 percent), E coli. (24.73 percent), and Turb. (23.906 percent) had high coefficients of variation in surface water, whereas DO (9.95 percent), Sulp (7.06 percent), TPC (4.31 percent), BOD (4.21 percent), and Temp. (1.85 percent) had low and narrow coefficients. However, in groundwater, Sulp (129.76 percent), Fe (65.80 percent), BOD (48.24 percent), F coli. (35.12 percent), Zn (33.95 percent), and DO (5.56 percent) were found to be low and narrow, whereas DO (5.56 percent) and Temp. (1.86 percent) were found to be high and narrow. If F > F crit, the null hypothesis of the analysis of variance is rejected. Table 8 – Table 10 provide the results of the variance analysis between surface and groundwater quality parameters in the region. As a result, we reject the null hypothesis in all three locations where F > Fcrit. However, this implies that there was a significant difference in the study area's surface water and groundwater quality parameters.

Table 4. Correlation coefficients of surface water quality parameters

	pH	*Temp.*	*Turb.*	*DO*	*BOD*	*TDS*	*TSS*	*Sulp*	*Pb*	*Fe*	*Zn*	*TPC*	*F. coli.*	*E. coli.*
pH	1.000													
Temp.	0.479	1.000												
Turb.	-0.259	-0.368	1.000											
DO	-0.391	-0.808	0.036	1.000										
BOD	-0.472	-0.810	0.010	0.994	1.000									
TDS	-0.762	-0.756	0.089	0.889	0.928	1.000								
TSS	-0.851	-0.622	0.241	0.707	0.744	0.903	1.000							
Sulp	-0.182	-0.756	0.826	0.395	0.360	0.295	0.261	1.000						
Pb	-0.856	-0.509	0.442	0.345	0.386	0.625	0.869	0.338	1.000					
Fe	0.265	0.121	0.363	0.109	0.026	-0.074	0.143	0.155	0.099	1.000				
Zn	0.811	0.160	-0.109	-0.386	-0.438	-0.689	-0.864	0.122	-0.750	-0.198	1.000			
TPC	-0.321	0.114	-0.271	0.430	0.450	0.519	0.512	-0.416	0.146	0.317	-0.742	1.000		
F. coli.	0.002	-0.172	-0.114	0.643	0.594	0.465	0.488	-0.057	0.148	0.706	-0.456	0.721	1.000	
E. coli.	-0.808	-0.250	0.109	0.489	0.535	0.757	0.906	-0.066	0.756	0.219	-0.993	0.754	0.523	1.000

Table 5. Correlation coefficients of groundwater quality parameters

	Ph	*Temp.*	*Turb.*	*DO*	*BOD*	*TDS*	*TSS*	*Sulp*	*Pb*	*Fe*	*Zn*	*TPC*	*F. coli.*	*E. coli.*
pH	1.000													
Temp.	-0.145	1.000												
Turb.	-0.497	0.309	1.000											
DO	-0.259	0.384	0.876	1.000										
BOD	-0.267	0.371	0.785	0.980	1.000									
TDS	-0.862	0.189	0.755	0.401	0.309	1.000								
TSS	0.000	0.000	0.000	0.000	0.000	0.000	1.000							
Sulp	0.812	-0.591	-0.575	-0.569	-0.616	-0.646	0.000	1.000						
Pb	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.000					
Fe	0.804	-0.183	-0.030	-0.017	-0.135	-0.401	0.000	0.773	0.000	1.000				
Zn	-0.057	0.174	0.312	0.701	0.825	-0.148	0.000	-0.453	0.000	-0.265	1.000			
TPC	-0.164	-0.522	0.493	0.160	0.015	0.516	0.000	0.248	0.000	0.387	-0.357	1.000		
F. coli.	-0.724	-0.047	0.852	0.543	0.443	0.927	0.000	-0.484	0.000	-0.197	-0.012	0.727	1.000	
E. coli.	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.000

Table 6. Coefficient of variation for surface water quality parameters

Variable	Mean	SE Mean	S.D	Variance	C.V	Min.	Max.
pH	6.078	0.395	0.624	0.390	10.270	5.190	7.120
Temp.	27.888	0.355	0.517	0.267	1.854	27.400	28.800
Turb.	1.378	0.255	0.330	0.109	23.906	1.070	1.940
DO	6.943	0.557	0.691	0.478	9.954	6.010	7.800
BOD	3.512	0.125	0.148	0.022	4.214	3.320	3.680
TDS	4.982	0.772	0.875	0.766	17.574	3.880	5.850
TSS	0.007	0.001	0.002	0.000	26.268	0.004	0.009
Sulp	1.155	0.061	0.082	0.007	7.059	1.021	1.253
Pb	0.329	0.132	0.173	0.030	52.717	0.097	0.528
Fe	1.195	0.150	0.201	0.040	16.790	0.890	1.482
Zn	0.484	0.126	0.174	0.030	35.950	0.327	0.811
TPC	35.055	1.278	1.512	2.286	4.313	33.000	37.000
F. coli.	11.383	3.611	4.698	22.074	41.273	6.000	19.000
E. coli.	1.828	0.329	0.452	0.204	24.729	1.000	2.300

Table 7. Coefficient of variation for groundwater quality parameters

Variable	Mean	SE Mean	S.D	Variance	C.V	Min.	Max.
pH	5.698	0.256	0.351	0.124	6.168	5.250	6.240
Temp.	28.723	0.410	0.533	0.284	1.855	28.110	29.400
Turb.	3.335	0.403	0.489	0.239	14.654	2.810	4.020
DO	7.318	0.332	0.407	0.166	5.563	6.870	7.950
BOD	2.130	0.873	1.027	1.056	48.235	0.890	3.520
TDS	9.950	1.070	1.275	1.626	12.817	8.430	11.670
TSS	0.001	0.000	0.000	0.000	0.000	0.001	0.001
Sulp	0.023	0.022	0.030	0.001	129.756	0.003	0.082
Pb	0.001	0.000	0.000	0.000	0.000	0.001	0.001
Fe	0.502	0.266	0.330	0.109	65.799	0.198	1.001
Zn	0.089	0.023	0.030	0.001	33.953	0.054	0.136
TPC	13.333	2.333	3.077	9.467	23.076	9.000	18.000
F. coli.	2.883	0.783	1.013	1.026	35.124	2.000	4.600
E. coli.	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Table 8. Anova single factor for surface and groundwater in Ikot Akpaden

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	2030.045	13	156.1573	9.0245	0.000108	2.507263
Within Groups	242.251	14	17.30364			
Total	2272.296	27				

Table 9. Anova single factor for surface and groundwater in Ikot Ekong

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	2242.277	13	172.4829	7.7023	0.000265	2.507263
Within Groups	313.5106	14	22.39361			
Total	2555.788	27				

Table 10. Anova single factor for surface and groundwater in Ikot Enin

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	2006.354	13	154.335	6.4115	0.000719	2.507263
Within Groups	337.0005	14	24.07146			
Total	2343.355	27				

3.3. Discussion

The pH indicated that the highest and lowest pH values in the water sources from all sample locations are below the allowable thresholds of National and International regulatory organisations. The recommended pH range for lengthy living is 6.5-8.2 [54]. The collected pH values of the samples are found to be rather low, implying acidic deposition in the nearby surroundings of the natural gas processing facility [55]. Water that is excessively acidic or too alkaline can be harmful to human health and causes nutritional imbalances, as proven in an oil spilt region where both pH extremes are hazardous [56]. Acidic rainfall is recognised to endanger a variety of economic resources, including fisheries, agriculture, and wildlife [57]. Toxic metals may leak from watersheds and water distribution networks into acidified waterways, and the accumulation of these metals in potable water can have a range of significant human health consequences [55].

Turbidity in groundwater samples was greater than in surface water samples, reaching 4.02 NTU. The turbidity readings, however, are within the maximum allowable limit of 5 NTU for drinking water [53]. In contrast, the moderate range of turbidity caused by oil-related activities such as gas flaring and oil spillage may have significant health consequences for people in the researched regions, which may be connected to the presence of clay, silt, organic components, and other microscopic elements [58]. This is also consistent with the results of Longe and Enekwechi (2007) [59] who concluded that it is due to leaching from oil operations and pipeline vandalism in the research region.

Dissolved oxygen (DO) analysis is used to determine the quantity of gaseous oxygen dissolved in water, which is critical for all forms of life since oxygen (O_2) is involved in almost all chemical and biological activities inside water bodies [60]. The greatest mean value of DO was found in both stream and borehole water samples, which were above the NSDQW and WHO acceptable limits. When the concentration of DO in liquid is high, it offers a source of oxygen required for the oxidation of organic matter, and its absence leads the water body to become lifeless or devoid of aquatic life [61].

The concentration of Sulphate in surface water is found to be considerably greater than in groundwater. The extremely high SO_4^{2-} levels in streams might be attributable to agricultural pollution from fertilisers washed into these water bodies after rainfall. Furthermore, sulphate is extremely volatile in the atmosphere, where it is transformed into forms appropriate for survival in surface waters.

TDS concentrations in the study area's surface and ground water were generally attributable to naturally existing minerals in the soil. Furthermore, the high TDS levels might be attributable to dissolved solid waste coming from the discharge of wastewater from the oil and gas industry, which causes surface and ground water contamination. A high TDS measurement implies that the water is heavily mineralised. Similar results were observed by Soylak et al. (2001) [62], Turkey drinking water and Olalekan et al. (2018) [63]. TDS levels in water are typically not hazardous to humans, although high concentrations may impact those suffering from renal and heart problems [64].

Iron concentrations in groundwater and borehole water were higher than in well water, which is typically within the maximum acceptable level set by national and international regulatory agencies. This implies that iron (Fe) has dissolved inside the soil particles. It might be related to the impacts of gas flaring. The iron levels in the borehole waters were substantially higher than those reported in the region [65]. The high percentage of iron in groundwater can also be attributed to a high rate of evaporation, which left less water in the borehole, resulting in a higher concentration of iron. It may also be related to the degree of ferruganisation of the aquifer materials, the quality of ground/borehole water materials, and poor borehole construction. Borehole materials may be of poor quality and hence prone to corrosion, while incorrect borehole design may enable extraneous fluids such as oxygen to feed the well [66]. Iron shortage in human blood can cause anemia, while excess iron can introduce free radicals into the system, hastening the aging process [67].

The analysis also revealed that trace metals (Pb and Zn) were present in low concentrations in groundwater samples but in significant concentrations in surface water in the study region. Metal traces are prevalent in water, and they are usually not detrimental to our health. Drinking water with excessive amounts of Pb or Zn may be harmful to human health [55]. The mean Pb concentrations in the surface water samples tested were all found to be over the allowable limit set by national and international regulatory organisations. However, Pb in groundwater and Zn in both water bodies were within the permitted limits. This points to a good heavy metal remediation installation at crude oil processing units operated by oil companies in the research region. At this concentrations, zinc has no negative health or environmental consequences [67,68]. Although the zinc content measured may appear small, the long term effect may be detrimental to health. Long-term exposure to lead, as in over-dependence on water sources, may result in decreased performance in some tests that measure nervous system functions, weakness in fingers and wrists, the emergence of wrinkles, small increases in blood pressure, and anemia, whereas exposure to high levels of lead may result in severe brain and kidney damage, miscarriage, and death.

The total coliform group has been chosen as the major indicator bacteria for the presence of pathogens in drinking water. It is a major indication of water's compatibility for human consumption. If a significant number of coliforms are discovered in water, it is quite likely that additional harmful bacteria or organisms present. The absence of coliform in home drinking water sources is required by the NSDWQ and WHO drinking water guidelines. In this investigation, faecal coliform bacteria were found in significant concentrations in both surface and ground water samples. The presence of E coliform was found in high concentrations in surface water but not in groundwater. Only groundwater samples passed the WHO guideline and NSDWQ criteria for E. coli based on the analysis results.

3.3.1. Health Effect of Water Quality On Residence

Table 11 lists the most frequent human ailments identified in three communities in the research area. Diseases caused by contaminated drinking water place a significant cost on human wellbeing. Actions aimed at improving the quality of drinking water provide substantial health benefits [69]. Improving access to safe drinking water can have a direct impact on health. Every attempt should be taken to ensure that drinking water is as safe as possible. Microbial (bacteriological, viral, protozoan, or other biological) pollution causes the vast majority of obvious water-related health issues [69]. Excessive accumulation of physical, chemical, and biological parameters in drinking water sources has an adverse effect on human health.

Table 11. Common ailments in the study area

Ailment	Locations						Total	Percentage (%)
	Ikot Akpaden		Ikot Ekong		Ikot Enin			
	SW	GW	SW	GW	SW	GW		
Fever	29	21	27	23	24	25	149	33
Cholera	10	3	11	4	12	6	46	10
Dysentery	9	4	14	3	8	5	43	9
Skin infection	18	10	19	13	21	14	95	21
Food poisoning	21	10	23	16	29	21	120	27
Total	87	48	94	59	94	71	453	100

SW-surface water; GW-groundwater.

The total coliform count is not related with sickness [70], but the presence of coliform in water indicates the presence of highly hazardous kinds of disease-causing organisms [71]. Water pollution is caused mostly by microbial pathogens, which can cause gastrointestinal infections such as fevers, cholera, dysentery, food poisoning, and even a range of skin disorders [g 11(Farah et al. 2002)]. As mentioned in the results, sixty-four percent of surface water water quality parameters and fifty percent of groundwater water quality parameters were not below the permissible level of NSDWQ and WHO guideline criteria. As a result, the high concentrations of these pollutants may be linked to the prevalence of human ailments seen in the present study area.

4. Conclusion

All of the water sources in the area are somewhat acidic, with low pH values in all borehole water samples, according to the findings. The analysis also revealed that water quality parameters such as Fe, Pb, TDS, TPC, DO, BOD, F coli., and E coli. determined from samples of stream water in three communities did not fall within the recommended NSDWQ and WHO values, indicating that the water was polluted by physicochemical, bacteriological, and heavy metal contaminants. The pH, DO, TDS, TPC, and F coli levels in borehole water samples from the research region were not within the tolerable limits set by national and international regulatory organisations. In addition, surface water samples were much more polluted than borehole water samples. This is substantial evidence that the effluent released during offshore crude oil operations has led to the pollution of the area's surface water bodies. The frequent ailments fever, cholera, dysentery, skin infection, and food poisoning may well be connected to the area's poor water quality.

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