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Effects of Seasonality on the Physicochemical, Heavy Metals and Microbial Levels of Water Sources subjected to Gas Flaring in Nigeria.

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ABSTRACT

This study evaluated the influence of seasonal variations on the physicochemical characteristics, heavy metal concentrations, and microbial quality of surface water, groundwater, and rainwater in Okpai and Beneku communities of Ndokwa East Local Government Area, Delta State, Nigeria. Okpai is characterized by active gas flaring and oil exploration activities, while Beneku, located approximately 14 km away, serves as a nearby comparison community. Water samples were collected during the wet season and dry season and analyzed using standard USEPA procedures. Twenty-nine physicochemical, heavy metal, and microbiological parameters were evaluated. Results revealed significant spatial and seasonal variations in water quality across the study area. Surface water and rainwater in Okpai were generally acidic (pH 5.12–5.86), indicating possible atmospheric acidification associated with gas flaring emissions, whereas water sources in Beneku remained near neutral. Wet season conditions generally increased conductivity, biological oxygen demand, phosphate, sulphate, magnesium, and potassium concentrations, while reductions were observed for temperature, turbidity, total dissolved solids, calcium, iron, and copper due to dilution effects. Surface water in Okpai exhibited higher colour, conductivity, sulphate, chloride, chemical oxygen demand, and microbial counts than corresponding water sources in Beneku, suggesting greater contamination from gas-flaring-related activities. Groundwater in Beneku recorded relatively higher concentrations of iron, cadmium, and lead, indicating possible geological and anthropogenic influences. Most heavy metals, including chromium, aluminium, cadmium, and lead, were either absent or detected only at trace levels, while fluoride remained below detection limits in all samples. Coliform bacteria were largely absent, indicating minimal microbial contamination. The findings demonstrate that seasonality significantly influences water quality in gas-flaring environments through dilution, runoff, atmospheric deposition, and geochemical processes. Surface water in Okpai was the most impacted water source, whereas rainwater generally exhibited the best quality despite localized acidification. Continuous environmental monitoring and appropriate water treatment strategies are recommended to safeguard public health and ensure sustainable water resource management in oil- and gas-producing communities of the Niger Delta.

Keywords: Seasonality, gas flaring, water quality, heavy metals, microbial contamination, Niger Delta.

INTRODUCTION

Water is one of the most important resources available to man. Water helps in ensuring the possible existence of most living organisms on earth because all living things are composed of that contain at least 60% water (Akhtar *et al*.,2021).

According to Kumar and Mishra (2024), of the over 70% of the earth's surface covered by water, about 97.6% is salt water from oceans and seas while the remaining less than 3%are contained in soils, rivers, lakes, ground water, as well as ice and glaciers. This implies that usefulness of water depends, to a large extent on whether available water sources are timely, quantitatively and qualitatively ready for man's use. Owing to the fact that salt water sources cannot be readily consumed by humans or freely used for various domestic and industrial processes, humans and other living organisms depend on and compete for the limited fresh water sources available to them.

The availability of quantitative and qualitative fresh water supplies for humans have over the years influenced settlement patterns of people. For water to be adequately utilized, it has to be reasonably free from contaminants as such water sources if contaminated could pose health and environmental threats to man and living organisms that depend on them (Akhtar *et al*., 2021). Water could be harvested as surface water, ground water or rain water sources respectively.

Several factors that fall basically under natural and anthropogenic categories have been found to influence, to a large extent, the level of contaminants in water sources. Notable among these are oil spillage (Bandara & Manage, 2023), gas flaring (Dami *et al.,* 2013), agricultural activities (Akan, 2006), industrial activities (Akhtar *et al.,* 2021), etc. The level of contaminants induced into water bodies could be significantly influenced by seasonality (Quyang *et al.,* 2006). Kurwadkar *et al.,* (2021) reported that seasonal variations significantly affected the concentrations of heavy metals as Cu, Fe, Co, Pb and Au in their study.

It is on the grounds of these that this study was conceived to evaluate the extent of the impacts of seasonal variations between dry and wet on the status of parameters considered for surface water, ground water and rain water sources for both Okpai and Beneku in Ndokwa East Local Government Area of Delta Sate, Nigeria.

MATERIALS AND METHODS

The study area lies within the Niger Delta region, which covers approximately 19,100–30,000 km² and is characterized by low-lying terrain generally less than 3 m above sea level. Located between longitudes 6.40°–6.56°E and latitudes 5.55°–5.69°N, the area consists of freshwater swamps, mangrove forests, lagoonal marshes, tidal channels, beach ridges, and sand bars (Amukali, 2012). Geologically, Okpai and Beneku are situated in the northwestern part of the Niger Delta complex and are associated with listric growth faults, rollover anticlines, and three structural highs within the Kwale region. The area forms part of the Tertiary Niger Delta (Akata–Agbada) Petroleum System, with soils rich in crude oil and gas reserves. The region is traversed by numerous creeks and distributaries, contains extensive floodplains and tidal flats, and is underlain by soft, highly compressible silty clay soils that make it susceptible to natural subsidence (Ibid, 2012). Vegetation is predominantly freshwater forest with swamp forests, lowland rainforests, climbers, ferns, and mangrove species, supporting diverse wildlife, although increasing human activities continue to threaten biodiversity.

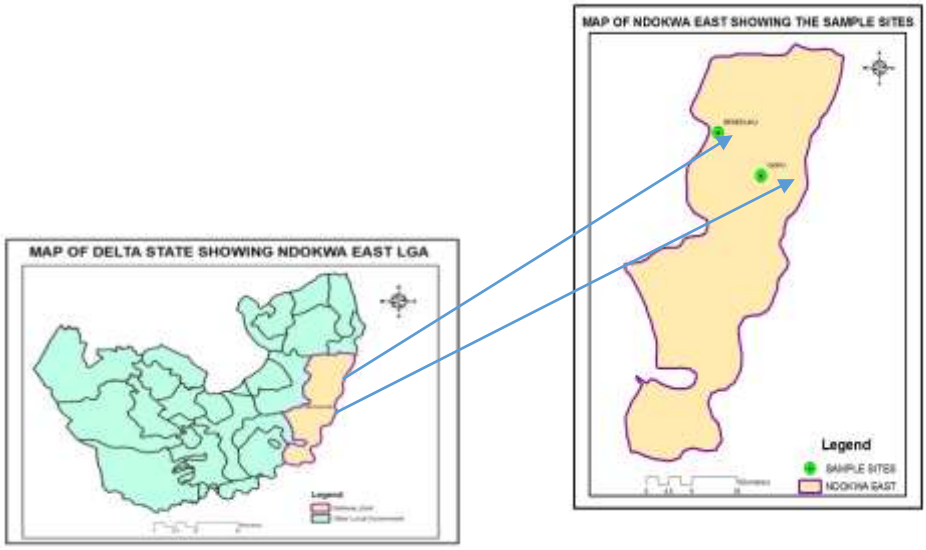

Figure 1: Map showing sampled sites in the study area.

Dami *et al. (*2013) reported that the climate of the study area is tropical and humid, with a rainy season extending from April to November and a dry season from December to March. Annual rainfall ranges from about 1,500 mm to 3,000 mm, averaging approximately 2,500 mm, while temperatures generally range from 24–25°C during the wet season to 27–29°C in the dry season, with extremes of about 21°C and 33°C (Ibid., 2013). Relative humidity is high, averaging around 80%, and surface water temperatures exceed 24°C. The population of the Okpai–Beneku region is estimated at about 242,000 people (NPC, 2006), comprising mainly Ukwuani communities alongside Igbo, Yoruba, Hausa, Urhobo, Ijaw, and Itsekiri groups. Economic activities are dominated by subsistence farming, fishing, hunting, and logging, while many residents also provide skilled and unskilled labour to oil and gas companies operating in the area, particularly the Nigerian Agip Oil Company and its contractors.

Water samples comprising rainwater, surface water, and groundwater were collected simultaneously from Okpai and Beneku in Ndokwa East Local Government Area of Delta State, Nigeria, during both wet (June–August 2010) and dry (December 2010–February 2011) seasons. Okpai hosts oil wells, gas flaring facilities, pipelines, and an Independent Power Plant, while Beneku, located approximately 14 km away, is influenced mainly by oil pipelines and atmospheric transport of pollutants from nearby flaring activities. Rainwater samples were collected directly during rainfall using pre-cleaned plastic containers positioned above ground level to prevent contamination following the method of Oluwafisayo *et al.,* (2026). Surface water samples were collected from rivers and stagnant water bodies within a 100 m radius of the rainwater sampling points, while groundwater samples were obtained from community water supply taps after flushing. All samples were properly labeled according to location, water source, and season, geo-referenced using GPS, and transported to the laboratory for analysis. Monthly values were averaged to obtain representative seasonal data.

Laboratory procedures followed standard methods recommended by USEPA (2020). Following the procedures, stock solutions and working standards for major cations and trace metals were prepared through serial dilution, while water samples were digested using nitric acid and aqua regia prior to analysis. Physicochemical parameters including pH, temperature, taste, colour, conductivity, alkalinity, turbidity, dissolved oxygen, biochemical oxygen demand, chemical oxygen demand, total dissolved solids, and total suspended solids were determined using standard field and laboratory techniques. Nutrients such as sulphate, phosphate, nitrate, chloride, and fluoride were analyzed using spectrophotometric and colorimetric methods, while microbial analyses employed McConkey and

Brilliant Green Lactose Bile broth media. Concentrations of metals including calcium, magnesium, sodium, potassium, iron, copper, zinc, cadmium, lead, chromium, and aluminium were determined using Atomic Absorption Spectrophotometry (AAS). The resulting data were processed and averaged to evaluate seasonal and spatial variations in water quality across the study area.

Results and Discussions

The data contained in Tables 1 and 2 reveal clear variations for the parameters analyzed for surface water, ground water, and rain water sources, when compared between wet and dry seasons at both gas-flaring community of Okpai and Beneku community lying 14km away in Ndokwa East Local Government Area of Delta State, Nigeria. Seasonal rainfall variations have been reported to have influenced to some extents, contamination status of various media (Banerjee *et al.,* 2023). These could be attributable to factors as dilution, runoff, atmospheric deposition, and mineral dissolution processes, with resultant expectation in differences in physicochemical, microbial and heavy metal concentrations. This is the major focus of this work. Below are the results and explanations on the effects of seasonality on the parameters studied in this work.

1. pH

At Okpai, surface water and rainwater samples were observed to be acidic in both seasons with pH ranging from 5.12 to 5.86, while groundwater values were found to be near neutral as pH ranged from 6.56 to 6.81 (figure 2), while at Beneku, all water sources were observed to be near neutral (6.48–6.93), respectively (figure 2) Consistently, lower pH values were observed in Okpai, especially in surface water and rainwater as compared to Beneku, suggesting higher acidification levels, likely associated with gas flaring emissions. This is because, gases emitted from gas flare furnaces, such as SO_2 and NO_x can form acidic compounds in the atmosphere and subsequently end up lowering the pH of precipitation and surface waters (Rezapour *et al*., 2022)

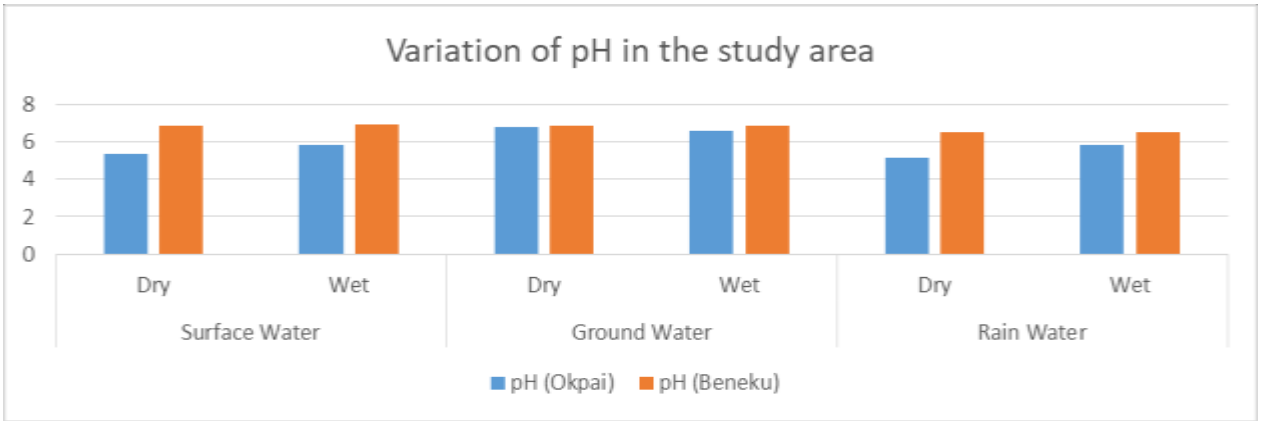

Figure 2: Variation of pH over wet and dry seasons in the study area.

The slightly higher wet-season pH in Okpai rainwater (5.86) and surface water (5.82) could have been possibly influenced by gas flaring. This was in contrast to Beneku where there was no gas flaring, and was observed to have exhibited stable and near-neutral pH values, suggesting minimal atmospheric acidification influences.

2. Temperature

As could be seen from figure 3 below, both communities exhibited temperatures that generally decreased during the wet season. Rainfall, cloud cover, and reduced solar radiation during the wet season must have contributed to lower water temperatures as seen in this particular study.

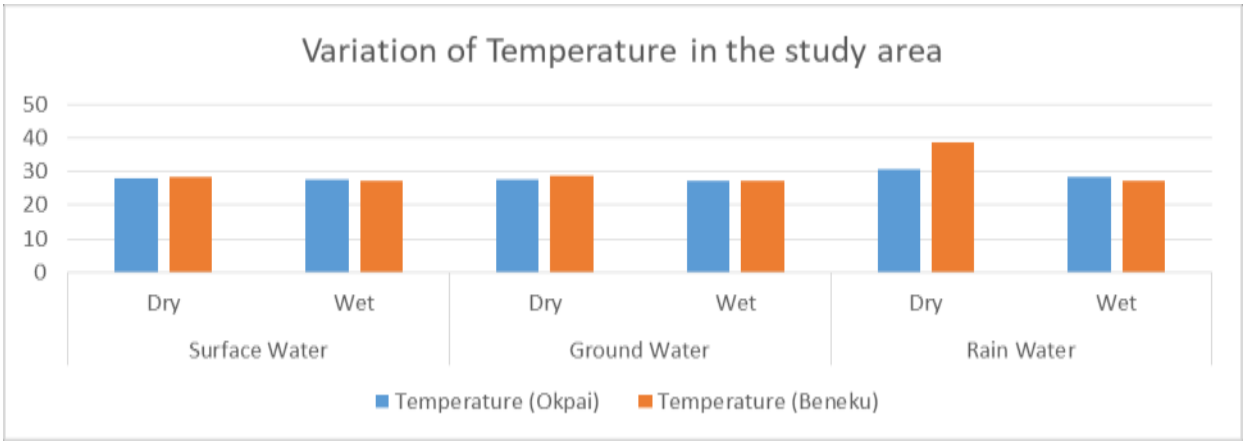

Figure 3: Variation of Temperature over wet and dry seasons in the study area.

A particularly notable observation was Beneku rainwater during dry season showing 38.62°C as compared to wet season where it exhibited 27.26°Crespectively. This substantial reduction could be attributable to intense heating of rain collection surfaces and atmospheric conditions during the dry season (Raad *et al.*, 2021)

3. Taste

It was noticed from figure 4 below that groundwater in both Okpai and Beneku recorded no detectable taste while surface and rainwater showed slight taste perception, especially at Okpai. The presence of taste in surface and rainwater may be related to dissolved minerals, atmospheric contaminants, or organic matter dissolution. The absence of taste in groundwater suggests better natural filtration through soil layers.

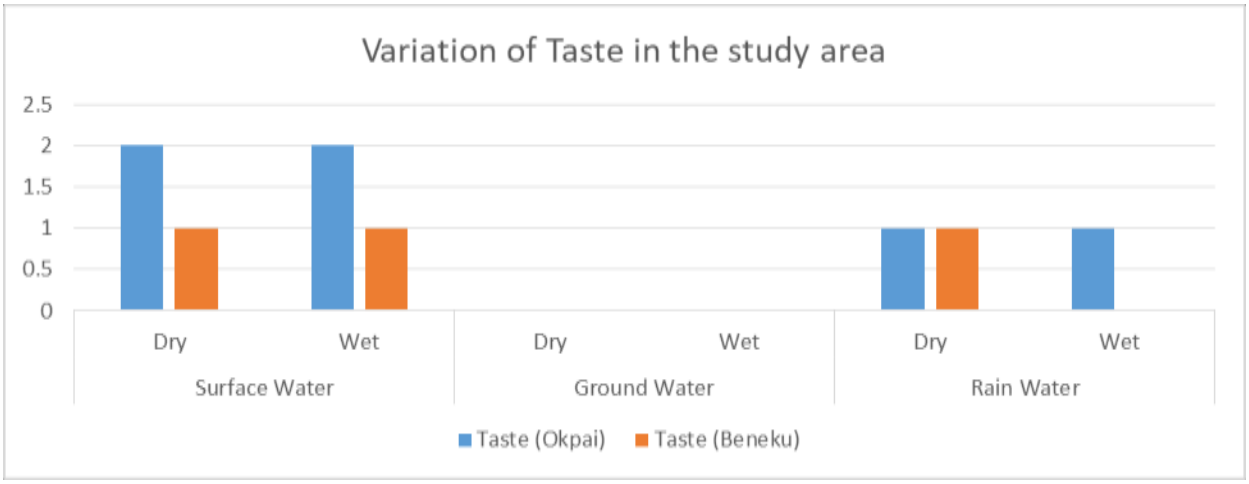

Figure 4: Variation of Taste over wet and dry seasons in the study area.

4. Colour

Surface water increased from 25.33 to 32.50 TCU during wet season while rainwater showed the highest colour values of 48.10 to 52.00 in Okpai (figure 5). Furthermore, figure 5 below showed that colour generally decreased during wet season as compared to dry season.

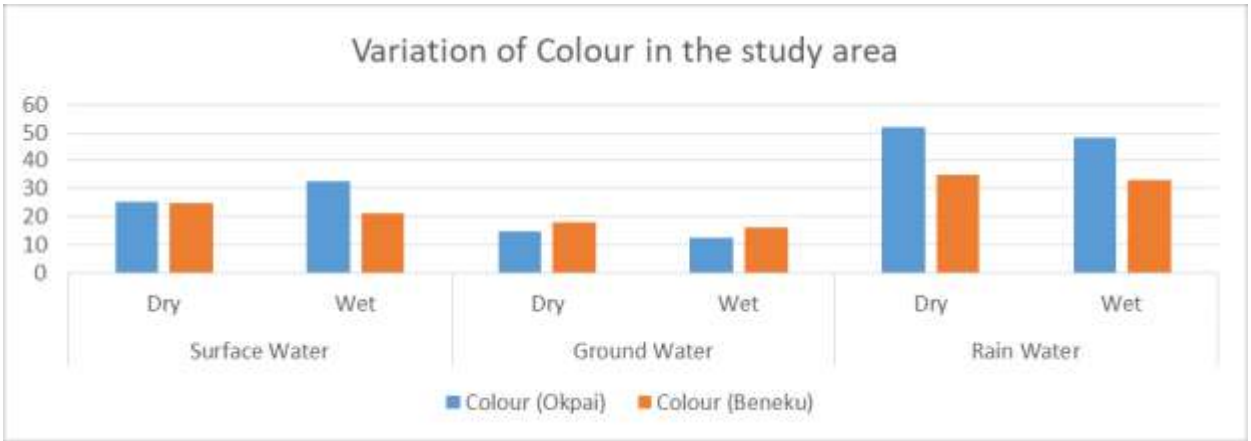

Figure 5: Variation of Colour over wet and dry seasons in the study area.

At Okpai, increased wet-season colour likely resulted from runoff carrying suspended organic materials and particulates into water bodies. The high colour of rainwater may indicate atmospheric deposition of particulates originating from gas flaring activities as suggested by Asibor *et al.*, (2016). Beneku's lower colour values is arguably an indication of reduced pollutant loading.

5. Electrical Conductivity (EC)

Levels of electrical conductivity in surface water sources at Okpai varied significantly between dry season (137.99 µS/cm) and wet season (191.41 µS/cm) as could be seen from figure 6. However, groundwater sources in Beneku showed its highest conductivity value (131 µS/cm) of the water sources in the location. The increase in conductivity during the wet season in Okpai suggests mobilization of dissolved ions through runoff and atmospheric deposition while the high groundwater conductivity in Beneku could be a reflection of natural mineral dissolution from geological formations.

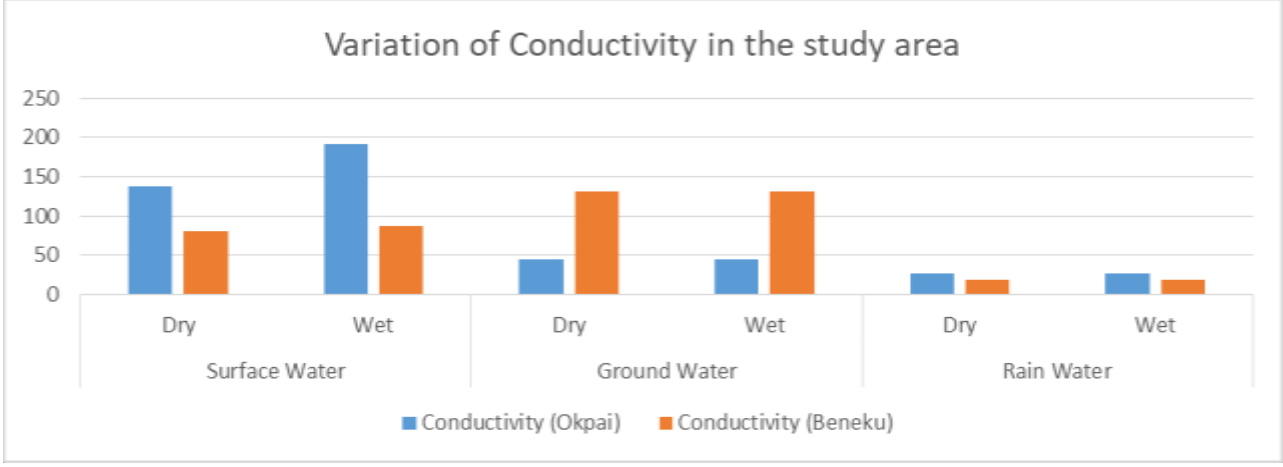

Figure 6: Variation of Electrical over wet and dry seasons in the study area.

6. Alkalinity

A careful look at figure 7 shows that alkalinity was consistently higher in Okpai than Beneku for all water sources and seasons. Higher alkalinity suggests greater buffering capacity against acidification at Okpai than in Beneku. The relatively elevated alkalinity in Okpai may represent a natural response attempting to neutralize acidic inputs associated with gas flaring emissions. In addition, dry season tended to positively

influence alkalinity more than wet season at Beneku. Increased water volume during wet season must have engendered dissolution of salts in such media thereby reducing alkalinity levels during wet season.

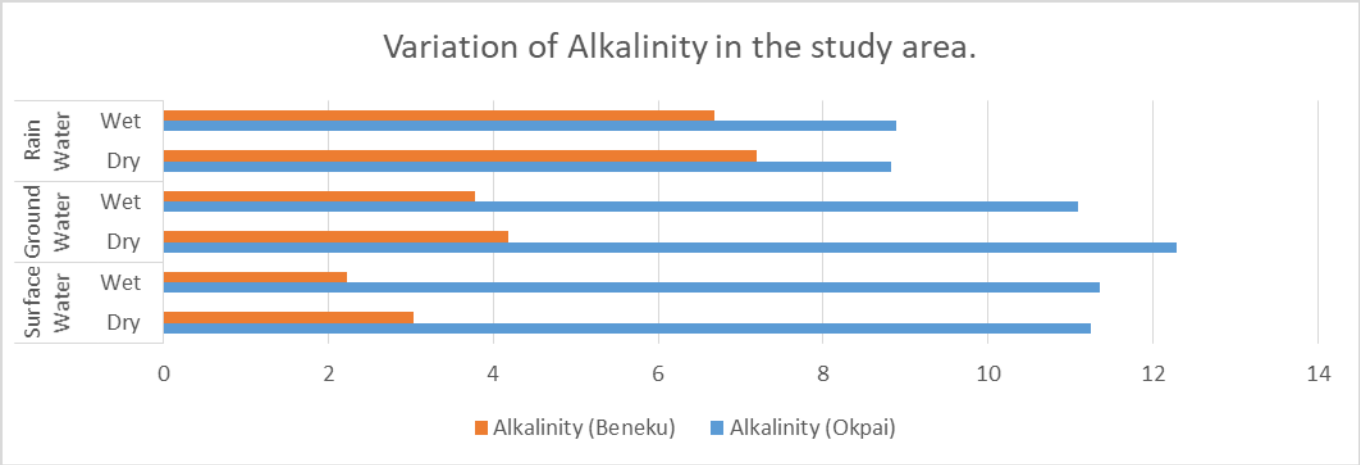

Figure 7: Variation of Alkalinity over wet and dry seasons in the study area.

7. Turbidity

All water sources in this study generally showed lower turbidity during the wet as compared to dry seasons. There was also a general reduction in turbidity in rain water sources as compared to surface and ground water sources and these could be attributable to dilution effects and infiltration of suspended particles orchestrated by heavy rainfall.

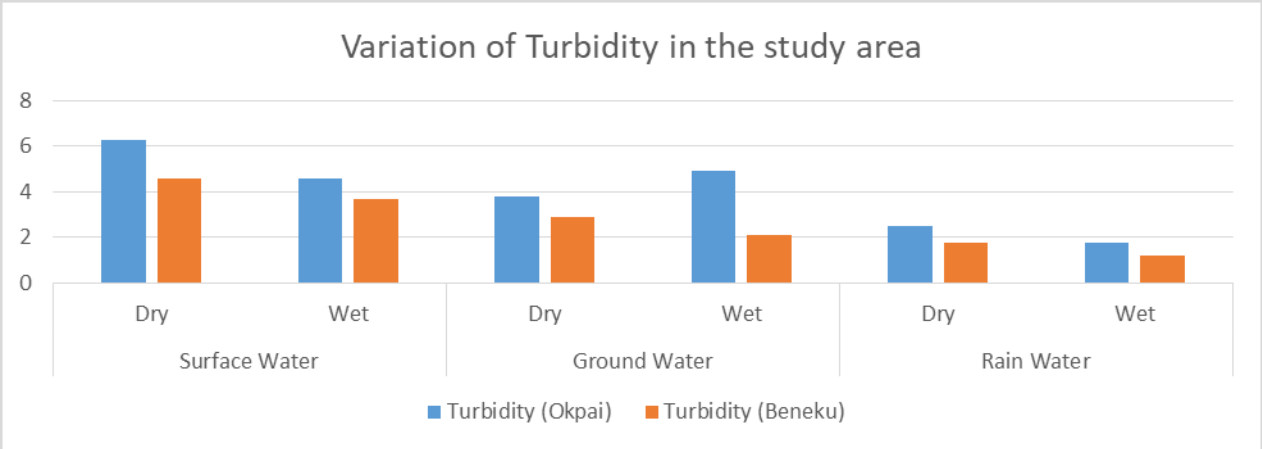

Figure 8: Variation of Turbidity over wet and dry seasons in the study area.

8. Dissolved Oxygen (DO)

DO was observed to have generally higher in all water sources except in groundwater during wet season (figure 9). It could be deduced that cooler temperatures and increased dissolved particulate mixing during rainfall must have enhanced oxygen solubility as suggested by Obayemi and Komolafe (2023). The highest DO values occurred in rainwater probably suggesting situations of well-aerated conditions.

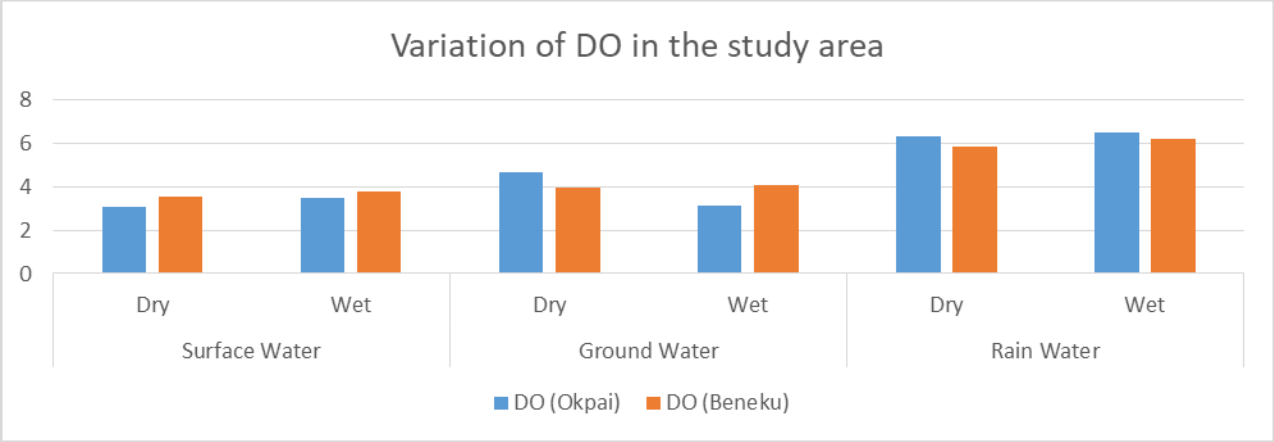

Figure 9: Variation of DO over wet and dry seasons in the study area.

9. Biological Oxygen Demand (BOD)

From figure 10 below, BOD was seen to have increased during the wet season in all water sources. Higher wet-season BOD could be an indication of increased organic matter input from runoff, which ends up stimulating microbial decomposition as earlier opined by Nwalieji *et al*. (2024). Rainwater exhibited the highest BOD values, probably indicating greater activities of biodegradable organic material deposition in the study area.

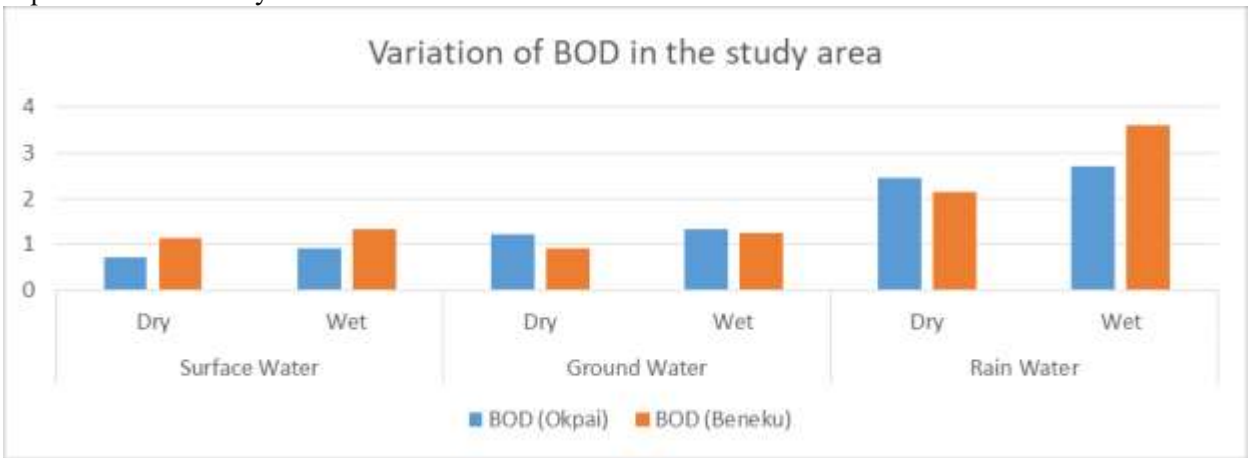

Figure 10: Variation of BOD over wet and dry seasons in the study area.

10. Chemical Oxygen Demand (COD)

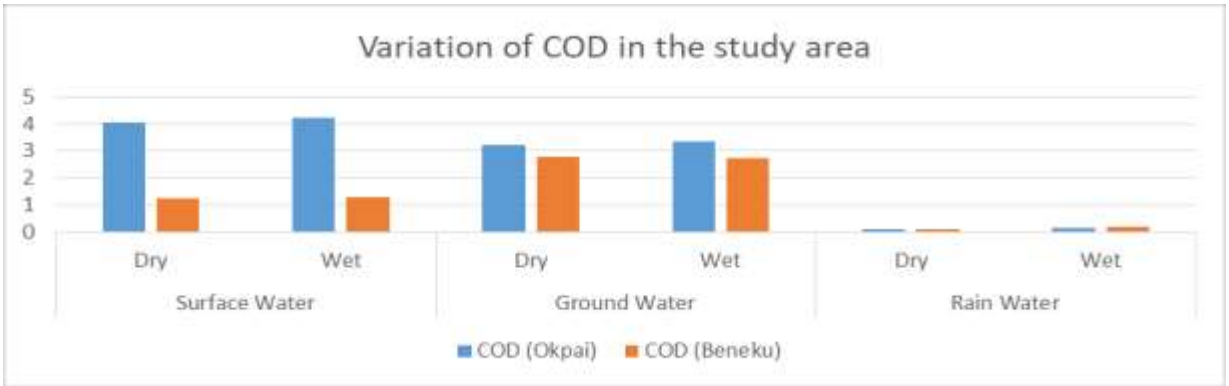

Figure 11: Variation of COD over wet and dry seasons in the study area.

COD values were generally higher in Okpai than Beneku surface and ground waters as compared to rain water where they were comparably very minimal (see figure 11). This suggests a greater presence of oxidizable organic and inorganic substances in Okpai, potentially linked to gas-flaring-related contamination.

11. Total Dissolved Solids (TDS)

TDS was generally higher in surface and rain water sources but surprisingly lower in ground water sources. decreased during wet season (figure 12). The reduction could be attributable to dilution by rainfall.

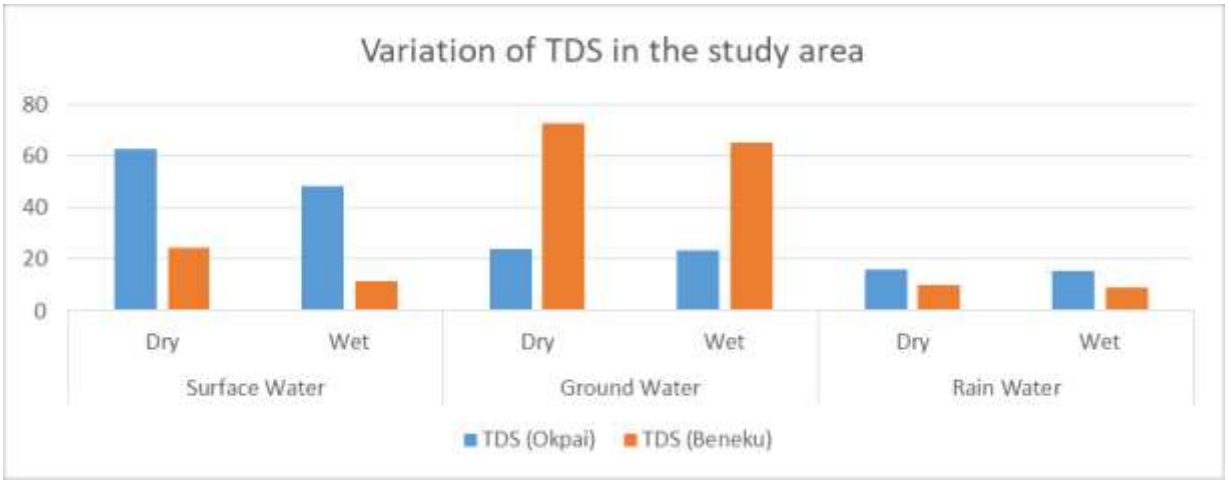

Figure 12: Variation of TDS over wet and dry seasons in the study area.

12. Total Suspended Solids (TSS)

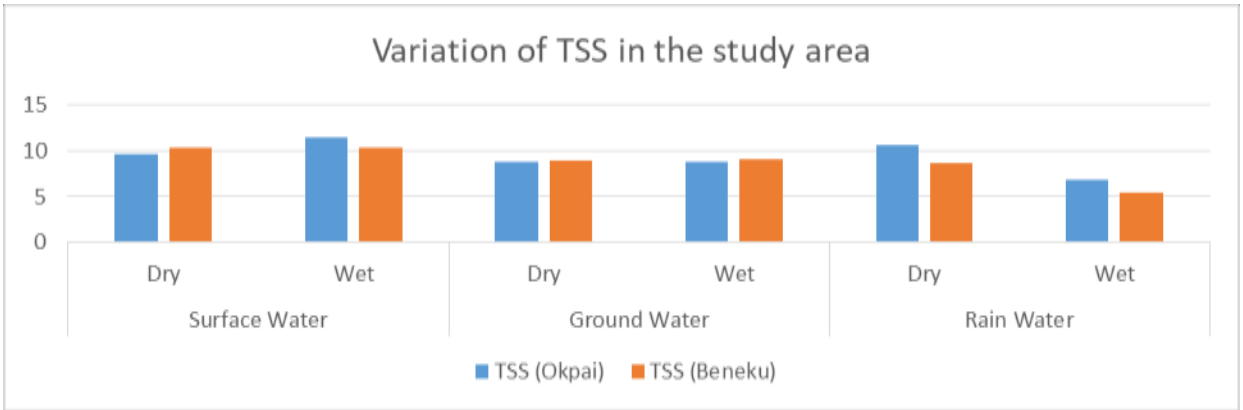

Figure 13: Variation of TSS over wet and dry seasons in the study area.

TSS in surface and ground water sources were observed to have increased slightly during wet season as compared to dry season while rain water sources were observed to have decreased from dry to wet season (figure 13). Rainfall-induced runoff must have probably introduced soil particles and organic debris into surface water bodies that necessitated their showing higher TSS values.

13. Sulphate

Sulphate levels were higher in Okpai surface water (figure 14) than Beneku surface water and these could have originated from oxidation of sulphur-containing gases released during gas flaring. The elevated sulphate concentrations in Okpai support evidence of atmospheric pollution influence. Highest sulphate levels at Beneku ground water sources could be due to its being a natural resource there.

14. Phosphate

Phosphate was found to have generally increased during wet season as compared to dry season. Surface runoff during rainfall must have likely transported phosphate-containing materials from surrounding soils into surface and ground water bodies. Phosphate levels were highest at Beneku ground water (figure 15) than Okpai suggesting probable chances of its being a natural resource in the area.

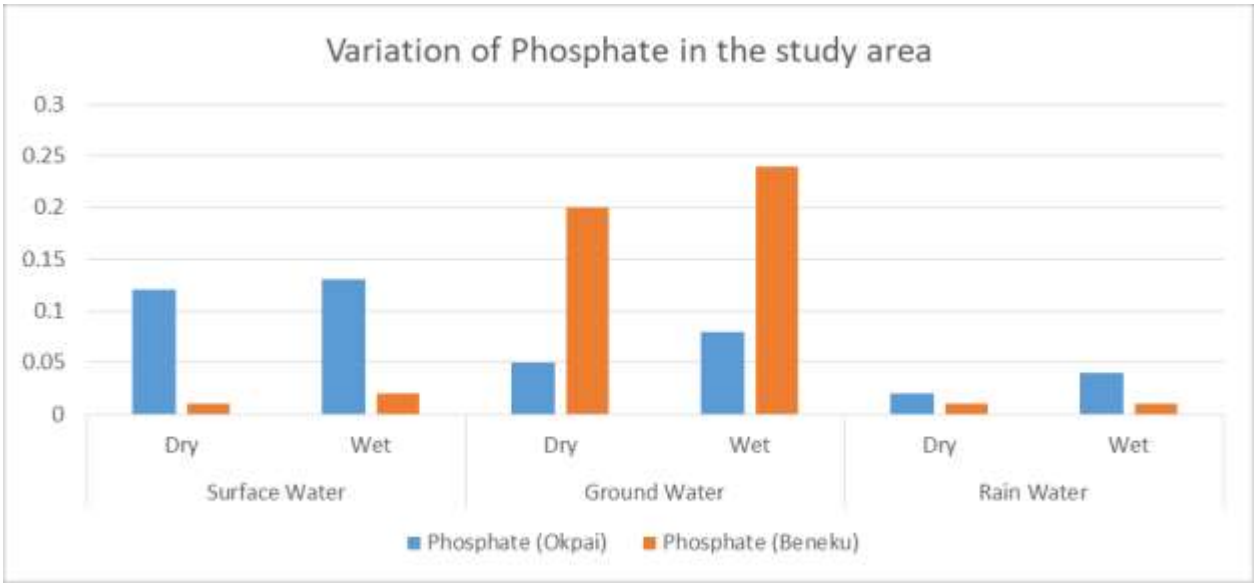

Figure 15: Variation of Phosphate over wet and dry seasons in the study area.

15. Nitrate

Beneku ground water sources showed considerably higher nitrate levels as compared to other water sources in the study area (figure 16). Use of nitrogen-containing fertilizers for crop cultivation within Beneku must have significantly contributed to percolation of nitrates to its underground water aquifers. Low concentrations of nitrates at Okpai could be due to agricultural or sewage contamination as compared to Beneku

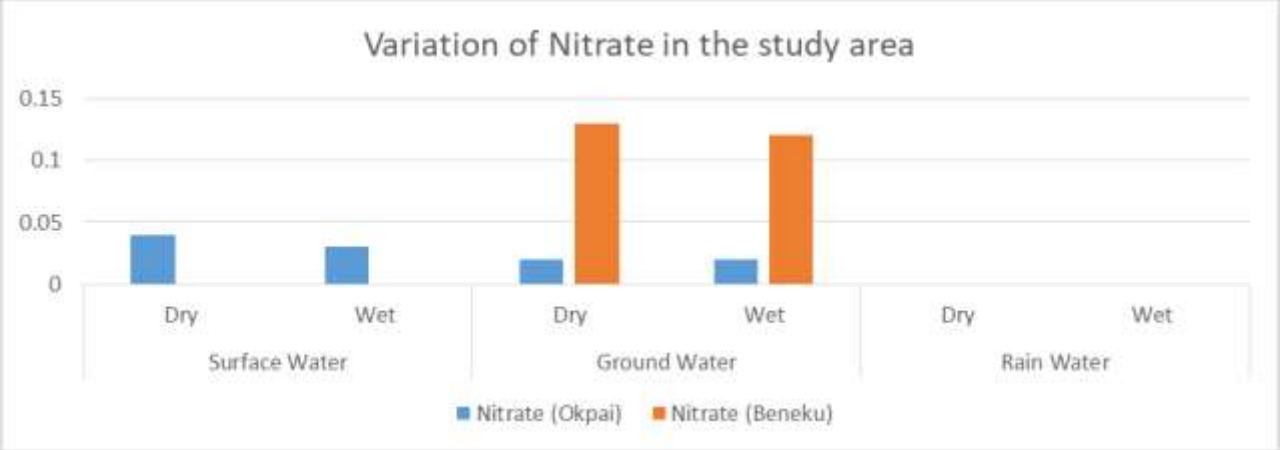

Figure 16: Variation of Nitrate over wet and dry seasons in the study area.

16. Chloride

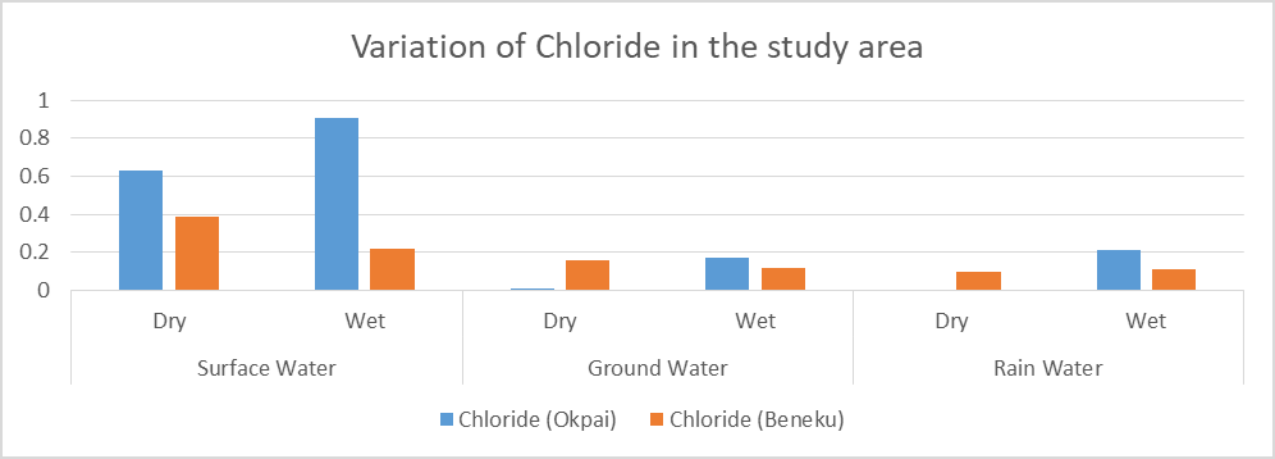

Figure 17: Variation of Chloride over wet and dry seasons in the study area.

Chlorides were significantly higher at Okpai surface water sources over both seasons as compared to Beneku. This could be attributable to gases released through gas flaring interacting with chloride-containing compounds to release chlorides directly into surface waters in the entire area (figure 17). It may also be due to atmospheric deposition and enhanced leaching during rainfall.

17. Fluoride

All water samples recorded concentrations that were below detection limits (<0.01) in this study. Fluoride contamination was absent and posed no water-quality concern in this study.

18. Calcium and Magnesium

Calcium generally decreased during wet season in all water sources while magnesium exhibited a contrary trend (figures 18 & 19). These could be owing to calcium dilution occurring due to rainfall input, whereas magnesium may have increased through enhanced weathering and runoff processes (Akhtar *et al.,* 2021).

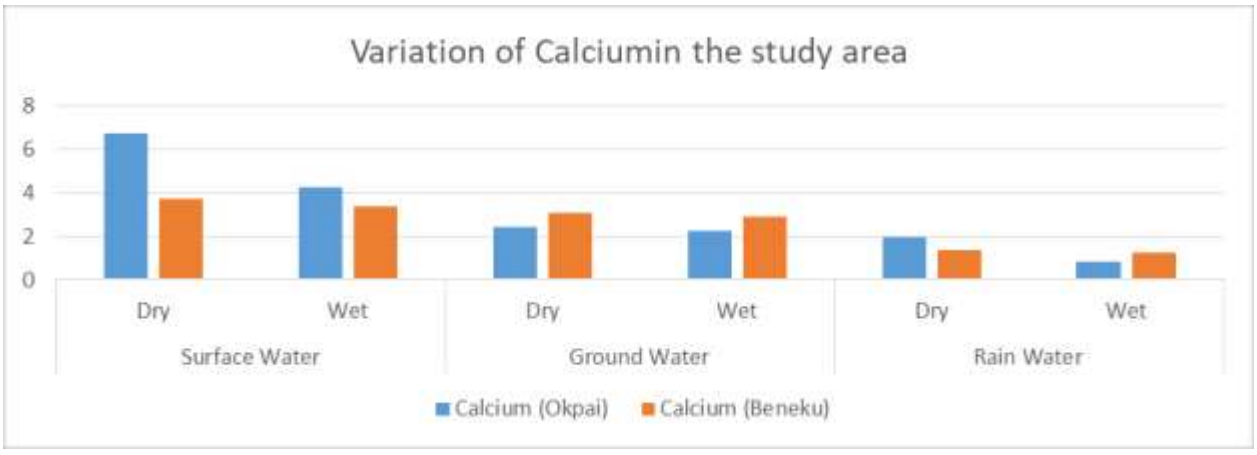

Figure 18: Variation of Calcium over wet and dry seasons in the study area.

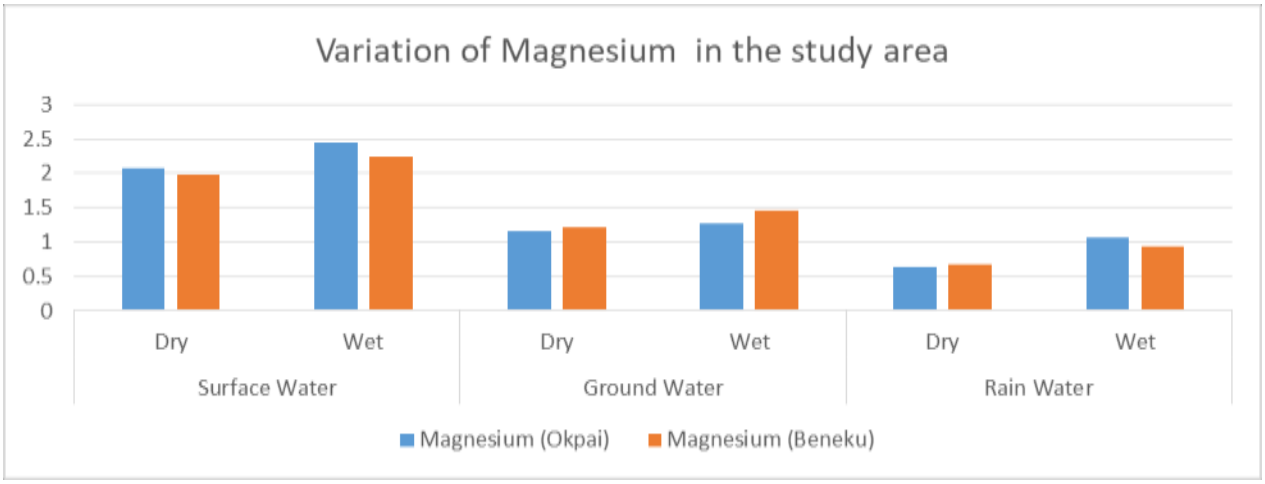

Figure 19: Variation of Magnesium over wet and dry seasons in the study area.

19. Sodium

There were no significant differences between sodium levels in rain water sources in the area between both seasons and sampled areas. However, while sodium levels increased from dry to wet season at Okpai, it decreased from same dry to wet season Beneku ground water (figure 20). This could due to gas flaring effects at Okpai and enhanced agricultural-oriented activities leading to increased soluble salt transports at Beneku respectively.

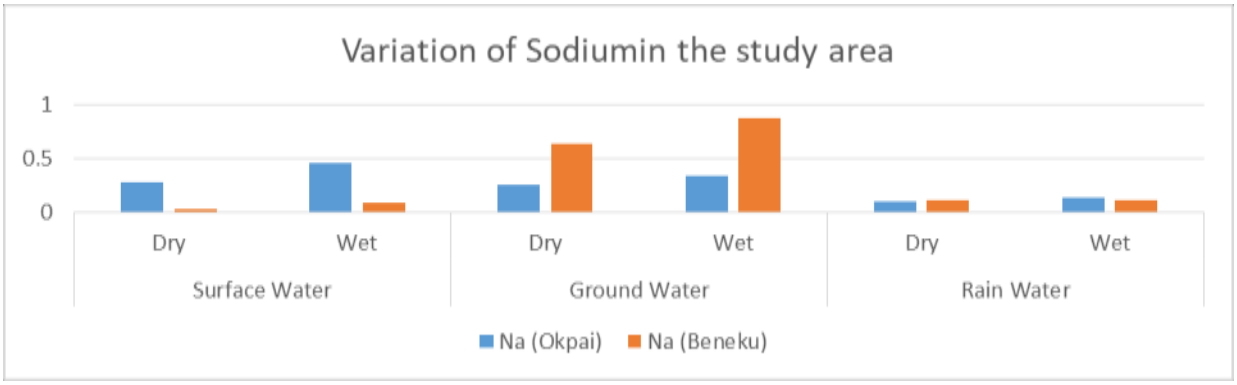

Figure 20: Variation of Sodium over wet and dry seasons in the study area.

20. Potassium

Most Okpai water sources showed wet-season increases as compared to the dry season values (figure 21). This could be due to Potassium enrichment likely originating from soil leaching and runoff during rainfall.

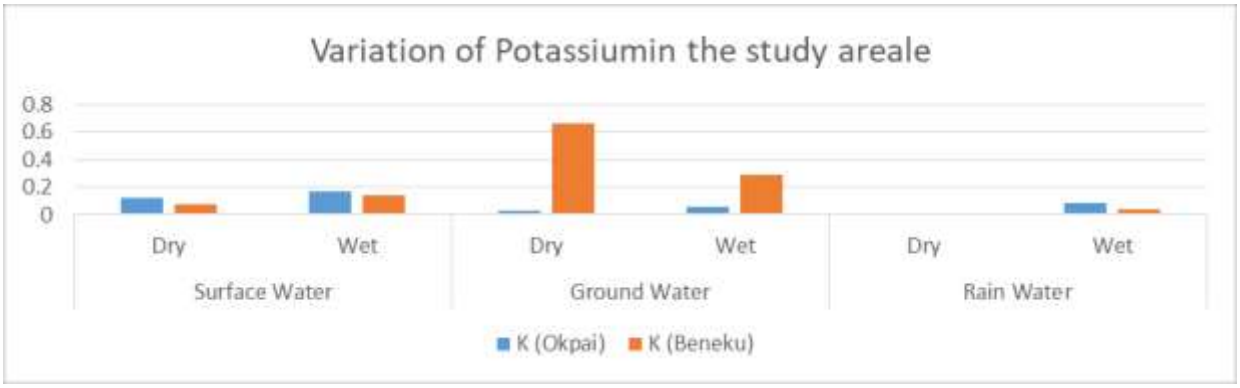

Figure 21: Variation of Potassium over wet and dry seasons in the study area.

21. Iron

Elevated Fe (figure 22) in groundwater sources at Beneku could be owing to dissolution of iron-bearing minerals under reducing subsurface conditions. In contrast, Okpai showed declining iron concentrations during wet season due to dilution.

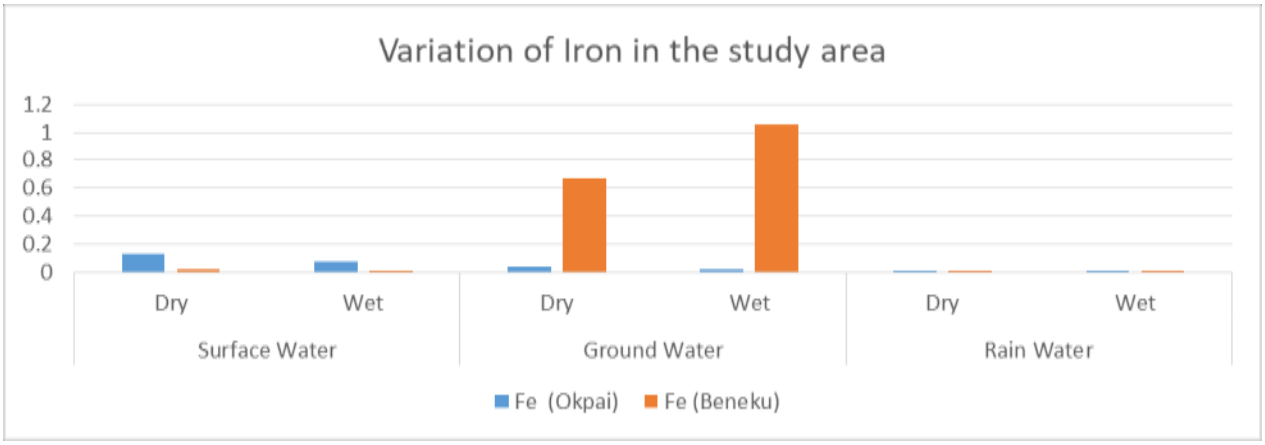

Figure 22: Variation of Iron over wet and dry seasons in the study area.

22. Copper

Table 1: Variation of Copper in the study area

Parameters	Surface Water		Ground Water		Rain Water	
	Dry	Wet	Dry	Wet	Dry	Wet
Cu (Okpai)	0.02	0.01	0.02	0.01	<0.01	<0.01
Cu (Beneku)	0.01	0.01	0.03	0.01	<0.01	<0.01

Copper concentrations were relatively very low and generally decreased during wet season in this study (table 1). Dilution by rainfall could have caused the reduced concentrations observed in this case.

23. Zinc

Low concentrations of zinc were observed across all water sources in this study (table 2). No evidence of significant zinc contamination could be ascertained even over both wet and dry seasons in this study.

Table 2: Variation of Zinc in the study area

Parameters	Surface Water		Ground Water		Rain Water	
	Dry	Wet	Dry	Wet	Dry	Wet
Zn (Okpai)	0.04	0.02	0.01	0.01	0.03	0.01
Zn (Beneku)	0.01	0.01	0.02	0.02	0.01	<0.01

24. Cadmium, Lead, Chromium and Aluminium

As could be seen from tables 3, it was observed that values for cadmium, lead, chromium and aluminium were mostly below detection limits with very few exceptions. Cadmium contamination was negligible.

Table 3: Variation of Cadmium, Lead, Chromium and Aluminium in the study area

Parameters	Surface Water		Ground Water		Rain Water	
	Dry	Wet	Dry	Wet	Dry	Wet
Cd(Okpai)	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Cd (Beneku)	<0.01	<0.01	0.01	0.01	<0.01	<0.01
Parameters	Surface Water		Ground Water		Rain Water	
	Dry	Wet	Dry	Wet	Dry	Wet
Pb (Okpai)	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Pb (Beneku)	<0.01	<0.01	0.01	0.04	<0.01	0.01
Parameters	Surface Water		Ground Water		Rain Water	
	Dry	Wet	Dry	Wet	Dry	Wet
Cr (Okpai)	<0.01	<0.01	<0.01	<0.01	0.01	0.01
Cr (Beneku)	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Parameters	Surface Water		Ground Water		Rain Water	
	Dry	Wet	Dry	Wet	Dry	Wet
Al (Okpai)	<0.01	<0.01	<0.01	0.01	0.01	0.02
Al (Beneku)	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01

25. Lead

It was seen from table 3 that Pb was detected only at Beneku groundwater and rainwater. The occurrence of Pb at Beneku groundwater may be linked to geological sources or localized anthropogenic activities rather than gas flaring.

26. Chromium

It was also seen from table 3 that Cr was almost entirely below detection limits, as such safe to state that Cr contamination could be said to be absent in the study area.

27. Aluminium

Al was detected only at trace levels at Okpai (table 3) with slightly elevated concentrations during wet season and this could be suggestive of runoff-mediated transport of alumino-silicate particles.

28. Coliform Bacteria

No coliform contamination was detected in ground water or rain water (table 4).

Table 4: Variation of Zinc in the study area

Parameters	Surface Water		Ground Water		Rain Water	
	Dry	Wet	Dry	Wet	Dry	Wet
Coliform (Okpai)	<2.00	<2.00	0.00	0.00	0.00	0.00
Coliform (Beneku)	0.00	0.00	0.00	0.00	0.00	0.00

However, surface water at Okpai was observed to have recorded <2 CFU, indicating a general absence of microbial contamination in the study area. This particular situation could be an indication of good sanitary conditions in the entire study area over wet and dry seasons.

CONCLUSION

The study assessed the seasonal quality of rainwater, surface water, and groundwater in Okpai and Beneku communities using twenty-nine physicochemical and biological parameters compared against established national and international water quality standards. Results revealed significant spatial and seasonal variations in water quality between the two study areas. Rainwater generally exhibited the least contamination, although parameters such as pH, taste, colour, alkalinity, biochemical oxygen demand (BOD), phosphate, fluoride, magnesium, and potassium frequently fell outside recommended limits in both seasons. Surface water showed greater levels of contamination, particularly in Okpai, where elevated turbidity and coliform counts indicated microbial pollution in addition to chemical and physical deterioration. Groundwater quality also varied between seasons and locations, with Beneku recording higher concentrations of iron, cadmium, and lead, especially during certain seasons, suggesting a greater susceptibility to heavy metal contamination. Across all water sources, chemical parameters contributed more significantly to water quality degradation than physical or biological indicators.

Comparative analysis showed that water quality generally fluctuated between the wet and dry seasons, reflecting the influence of environmental conditions and anthropogenic activities such as oil exploration, gas flaring, and agricultural practices. Rainwater was found to be the safest natural water source in both communities despite minor seasonal variations and deficiencies in some chemical constituents. Surface water in Okpai was more polluted than that of Beneku due to higher microbial contamination and poorer physicochemical quality, making treatment essential before domestic use. Groundwater in Okpai was comparatively safer, whereas Beneku groundwater posed greater health concerns because of elevated heavy metal concentrations, particularly iron, cadmium, and lead. Overall, the findings indicate that water quality in both communities is affected by seasonal changes and local environmental pressures, with Okpai exhibiting greater surface water pollution and Beneku showing more pronounced groundwater contamination, underscoring the need for regular monitoring and appropriate water treatment measures.

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