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Comparative Analysis and Modelling of Rain and Groundwater Qualities in the University of Port Harcourt

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Abstract
This study investigated the comparative water quality of rainwater and groundwater at the Abuja and Delta campuses of the University of Port Harcourt over a twelve-week period. Water samples were collected weekly and analysed for key parameters, including pH, Biological Oxygen Demand (BOD), Total Dissolved Solids (TDS), Total Hardness (THS), bacterial concentration, iron (Fe), and lead (Pb). The Water Quality Index (WQI) was used to assess the overall quality of the water sources and determine their suitability for consumption. The results showed that both rainwater and groundwater generally met acceptable standards, with WQI values ranging from 10.77 to 46.03, indicating "excellent" to "good" water quality according to WHO and Nigerian standards. Groundwater showed greater stability but higher levels of hardness and metal contamination, particularly lead, which ranged from 1.44×10^{-2} mg/l to 3.21×10^{-2} mg/l. Rainwater exhibited higher variability in parameters such as TDS and THS, with THS levels ranging from 324.25 mg/l to 465.12 mg/l. Statistical analysis using ANOVA revealed significant differences between groundwater and rainwater at both campuses, with a p-value of 0.00029 and 0.00752 for Abuja campus and Delta campus, respectively. Regression analysis demonstrated a strong correlation between the Groundwater Quality Index (GWQI) and Rainwater Quality Index (RWQI), with the polynomial model achieving an R^2 value of 91.38% for Abuja and 86.53% for Delta. The study recommended continuous monitoring of water quality, source-specific treatment strategies, and further research to account for seasonal variations and potential anthropogenic impacts.

Keywords: *Water quality, Groundwater, Rainwater, Analysis of variance, Regression modelling, Water Quality index, Groundwater quality index, Rainwater quality index, Exponential regression model*

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1. Introduction

Water, essential for sustaining life and ecosystems, faces global concerns about its quality due to natural processes, human activities, and urbanization (Gleick, 1993; WHO, 2008; Carpenter et al., 1998). Academic institutions like universities must prioritize water quality due to their complex societal roles and diverse water usage (Gupta et al., 2012). The University of Port Harcourt in the Niger Delta faces environmental challenges from industrial activities (Akpoborie et al., 2018; Okonkwo et al., 2016). This research examines water quality within the university, serving as a model for similar settings.

Environmental studies in the Niger Delta have focused on the impact of oil and gas activities on water quality (Akpoborie et al., 2018; Okonkwo et al., 2016). This research uniquely applies these insights to the University of Port Harcourt. Climate change, affecting precipitation patterns and extreme weather, further emphasizes the need to understand water quality impacts (Bates et al., 2008; IPCC, 2014). The study adopts integrated methodologies reflecting the evolving nature of water quality management (Gleick, 1993).

Studies link water quality with environmental sustainability and human health (Gleick, 1993; WHO, 2008; Carpenter et al., 1998). Universities should lead in environmental sustainability practices (Gupta et al., 2012). Understanding water quality challenges within universities can model broader societal changes. This study aims to contribute to the academic discourse on water quality and climate change adaptation.

Advanced statistical methods, such as regression analysis and ANOVA, will be used for a comparative analysis of rainwater and groundwater quality, revealing significant differences from established standards (Montgomery et al., 2006). This research seeks to enhance the understanding of water quality dynamics within the University of Port Harcourt.

Assessing water quality is crucial, yet costly. Water quality models provide cost-effective alternatives to labour-intensive chemical experiments, allowing for effective pollutant flow prediction (Nrunmayee, 2014). Rain and groundwater quality, affected by infiltration and percolation processes, exhibit temporal and spatial heterogeneity, particularly in the Niger Delta due to oil exploration (Majid et al., 2020). This research models water quality indices for rainwater and groundwater at the University of Port Harcourt, employing regression analysis.

The study aims to develop a comparative analysis and modelling of rainwater and groundwater qualities at the Abuja and Delta campuses of the University of Port Harcourt. The objectives are: To assess the current state of rainwater quality within the University of Port Harcourt. To determine water quality indices for rainwater and groundwater samples. To compare rainwater and groundwater, identifying similarities, differences, interdependencies, and comparing them to WHO standards. To develop predictive models using various parameters influencing water quality through regression statistics.

2. Materials and methods

2.1 Research design

The research design for this study involved a meticulous approach to comparative analysis and modelling of rainwater and groundwater characteristics within the University of Port Harcourt's. Samples were collected from two distinct campuses and carefully evaluated for physicochemical properties in a dedicated laboratory, covering parameters like pH, Dissolved Oxygen, Biological Oxygen Demand, Nitrogen ion, Total Dissolved Solid, Total Hardness, and bacteriological components over a three-month period with weekly sampling intervals.

To ensure credibility, the data was benchmarked against WHO standards for safe drinking water. The comparative analysis aimed to identify variations between rain and borehole water sources, contributing to a nuanced understanding of their qualities. Introducing the Water Quality Index (WQI) simplified the complex parameters into a comprehensive metric, aiding comparison and enhancing water quality assessment methodologies. Regression analysis was then used to model water quality, identifying key influencing factors and providing predictive insights.

2.2 Study area

The scope of this investigation covers two campuses of the University of Port Harcourt, situated in Choba, Rivers State, Nigeria, with specific geographical coordinates ranging from Latitude 4º 53' 14" N through 4º 54' 42" N and Longitude 6º 54' 00" E through 6º 55' 50" E. The university comprises three campuses—Abuja, Delta, and Choba—interconnected by road networks, with Choba campus positioned opposite to Abuja and Delta campuses, which are closer to each other along the East-West Road.

The study's focus was on Abuja and Delta campuses, chosen for their unique attributes representing the environmental diversity within the University of Port Harcourt, which has a student population exceeding 45,000. Visual representations in Fig. 1 and 2 depict digitalized maps of the selected campuses, including key landmarks. These maps aid in understanding the spatial layout where water samples were collected and subsequent analyses were conducted, crucial for interpreting environmental factors affecting water quality parameters.

By examining these campuses, the research aims to provide a concentrated analysis of localized variations in rainwater and groundwater qualities. Factors such as proximity to water bodies, land use patterns, and potential pollution sources unique to each campus contribute essential data for comprehending water quality dynamics in this geographical region.

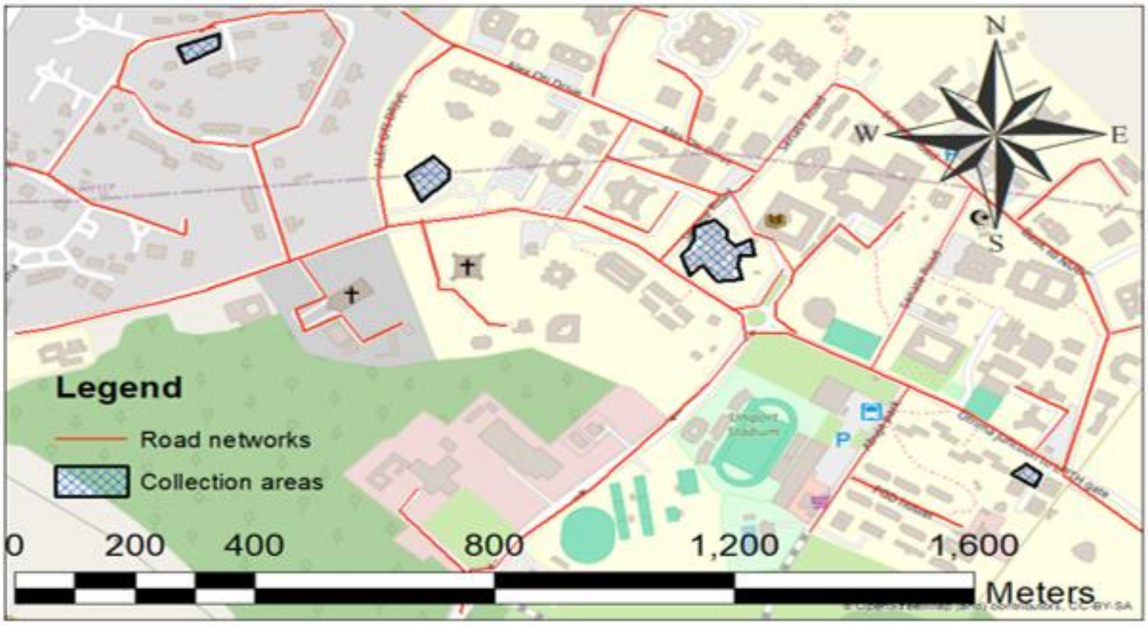

Fig. 1: Digitalize map of the study map for Abuja campus

Fig. 2: Digitalize map of the study map for Delta campus

2.3 Determination of water quality index (WQI)

The calculation of the Water Quality Index (WQI) in this study adhered to the standards set by the World Health Organization for drinking water quality, as recommended by Yu et al. (2013). The WQI serves as a powerful tool for effectively conveying information regarding water quality to concerned citizens and policymakers, offering a consolidated assessment based on various water quality parameters. This approach was first introduced by Horon (1965) and later generalized by Brown et al. (1970).

The WQI is a singular numerical value that provides a rating of water quality by synthesizing multiple water quality parameters. In the context of this study, a lower WQI score signifies better water quality, falling within categories such as "Excellent" or "Good," while a higher score is indicative of degraded water quality, categorized as "Bad" or "Poor." The calculation of WQI involves a systematic process, and the following procedures were meticulously followed:

1. **Selection of Water Quality Parameters:** The relevant water quality parameters, including pH, Dissolved Oxygen (DO), Biochemical Oxygen Demand (BOD5), Electrical Conductivity (EC), Nitrate (NO3^2-), Total Dissolved Solids (TDS), Total Hardness, and bacteriological parameters, were chosen for inclusion in the WQI calculation.
2. **Normalization of Data:** Each water quality parameter was normalized to a scale of 0 to 100, with 100 representing the ideal or permissible level according to the World Health Organization standards. This normalization ensures uniformity in the assessment, regardless of the diverse units or scales associated with individual parameters.
3. **Calculation of Sub-Indices:** Sub-indices were computed for each parameter based on predetermined formulae, reflecting the deviation of each parameter from the ideal value. These sub-indices contribute to the overall WQI calculation.
4. **Aggregation of Sub-Indices:** The individual sub-indices were then aggregated to derive a composite WQI score. This synthesis provides a holistic representation of the overall water quality, considering the collective impact of the chosen parameters.

Classification of WQI Score: The resulting WQI score was classified into distinct categories, such as Excellent, Good, Bad, or Poor, offering a readily understandable depiction of the water quality status. By meticulously following these procedures, the calculated WQI serves as a concise and informative measure, facilitating effective communication of the water quality status to both the public and decision-makers. This systematic approach to WQI calculation enhances the interpretability of the complex dataset, contributing valuable insights to the broader discourse on water quality within the University of Port Harcourt environment.

1. Estimating the quality rating (q_i) of each parameter using Equation (1)

$$q_i = 100 * \frac{(v_i - v_{id})}{v_s - v_{id}} \quad (1)$$

where v_i is the actual amount of the ith parameter present, V_{id} is the ideal amount of the ith parameter present = 0 (except ph where it is 7) and V_s is the standard permissible value of the ith parameter present

2. Determination of the unit weight (w_i) of the ith parameter using Equation (2). Theses unit weight transformed all the concerned parameters of different units and dimensions to a common scale.

$$w_i = \frac{k}{v_{si}} \quad (2)$$

Where k is the proportionality constant calculated in accordance to equation (3), V_{si} is the standard permissible value of the ith parameter present

$$k = \frac{1}{\sum_{i=q}^{11}[\frac{1}{v_{si}}]} \quad (3)$$

3. Determination of the sub-index (SI_i) for the ith parameter using Equation (4)

$$SI_i = q_i * w_i \quad (4)$$

4. Determination of WQI using Equation (5)

$$WQI = \sum_{i=1}^{n} SI_I \quad (5)$$

2.4 Water quality comparison

Table 1 in this study provides a comprehensive overview of the permissible values for quality parameters in drinking water, as stipulated by both the World Health Organization (WHO) and the Nigerian Standard for Drinking Water Quality (NSDWQ). These specified values serve as benchmarks against which the obtained water quality parameters were compared. The inclusion of both international and national standards adds a contextual layer to the assessment, considering the specific regulatory framework relevant to the study area.

In conjunction with these permissible values, Table 2.1 displays the ranges of the Water Quality Index (WQI) alongside their corresponding ratings or statuses, as outlined by Brown et al. in 1970. This categorization system allows for a straightforward interpretation of the calculated WQI scores. The comparisons drawn between the actual water quality parameters obtained from the collected samples and the associated WQI values offer a comprehensive assessment of the status of the sampled water.

Table 1: Parameters, WHO Standard Values, Ideal Values and Weightage Factors of Water Quality Parameters

S/N	Standard Value (Si)	Standard Value (Si)	Ideal Value (Vi)	Weightage Factor (Wi)
1	pH	8.5	7	0.1176
2	Electrical conductivity (µmhos/cm)	300	0	0.0033
3	Total Dissolved Solids (mg/l)	1000	0	0.001
4	Total Alkalinity (mg/l)	120	0	0.0083
5	Total Hardness (mg/l)	300	0	0.0033
6	Flourine (mg/l)	1.5	0	0.6666
7	Chlorine (mg/l)	250	0	0.004
8	Nitrate (mg/l)	50	0	0.02
9	Sulphate (mg/l)	250	0	0.004
10	Iron (mg/l)	0.3	0	3.3333
11	Calcium (mg/l)	75	0	0.0133
12	Magnesium (mg/l)	30	0	0.0333
13	Dissolved Oxygen	200	14	0.01

By utilizing this table, the study facilitates a nuanced evaluation of the water quality, taking into account both individual parameter values and the aggregated WQI scores. The incorporation of internationally recognized standards in Table 1 gave a permissible limit of the parameters tested. The process of comparing the observed water quality parameters against established standards and subsequently utilizing WQI values to assess the overall status of the collected water samples enhances the depth and clarity of the research outcomes. This systematic approach contributes to a comprehensive understanding of the suitability of the sampled water for drinking purposes, providing valuable insights for both scientific discourse and practical applications in water resource management.

2.5 Statistical analysis

The following statistical analysis was used to unravel patterns and relationships within the collected data. Analysis of Variance (ANOVA) was utilized to explore variations in water quality parameters among different groups, providing valuable insights into the potential differences between rainwater and groundwater samples. This analysis allows for the identification of significant variations that may influence the overall water quality assessment.

Regression analysis was conducted to establish relationships between rainwater quality (WQI_{RW}) and groundwater quality (WQI_{GW}). Various regression models were employed to capture the nuances of these relationships. The regression models utilized include:

Linear regression model:

$$Y = AX + B \quad (6)$$

Second degree Polynomial model:

$$Y = AX^2 + BX + C \quad (7)$$

Logarithmic model:

$$Y = A\,InX + B \quad (8)$$

Exponential model:

$$Y = Ae^{BX} \quad (9)$$

The regression constants A, B, and C in these equations represent the coefficients determined during the modelling process. The responses Y and independent variable X correspond to WQIRW and WQIGW, respectively. Microsoft Excel software was employed for the regression modelling, leveraging its computational capabilities to derive meaningful insights from the dataset. This comprehensive statistical analysis aims to uncover the underlying trends and associations between rainwater and groundwater quality, contributing to a deeper understanding of the dynamics influencing water quality.

3. Results and discussion

3.1 Comparative plots of parameters for rain and ground water

The water quality indicators considered in this research were grouped into seven categories. Assessment of these indicators was done weekly over a twelve (12) week period for both groundwater and rainwater samples. The comparative analysis of rainwater and groundwater quality at the University of Port Harcourt revealed distinct differences and trends across various parameters. Rainwater generally shows higher variability and higher levels of certain contaminants such as TDS, THS, and bacterial counts, possibly due to atmospheric deposition. Groundwater, while more stable, also shows notable levels of hardness and metal contamination. These findings underscore the need for ongoing monitoring and potential treatment interventions to ensure water safety and quality in both sources.

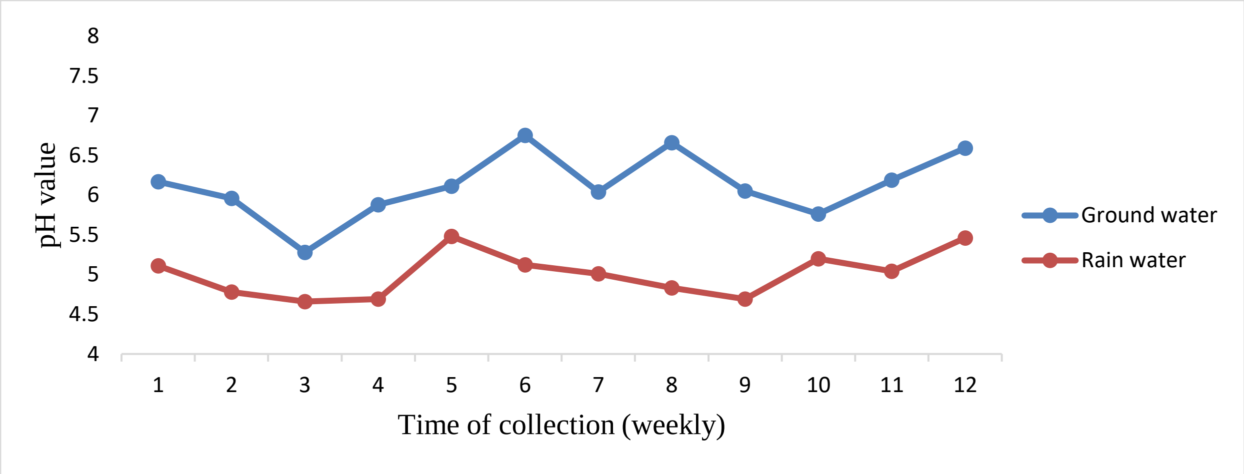

Fig. 3: pH comparative parameters for Abuja campus

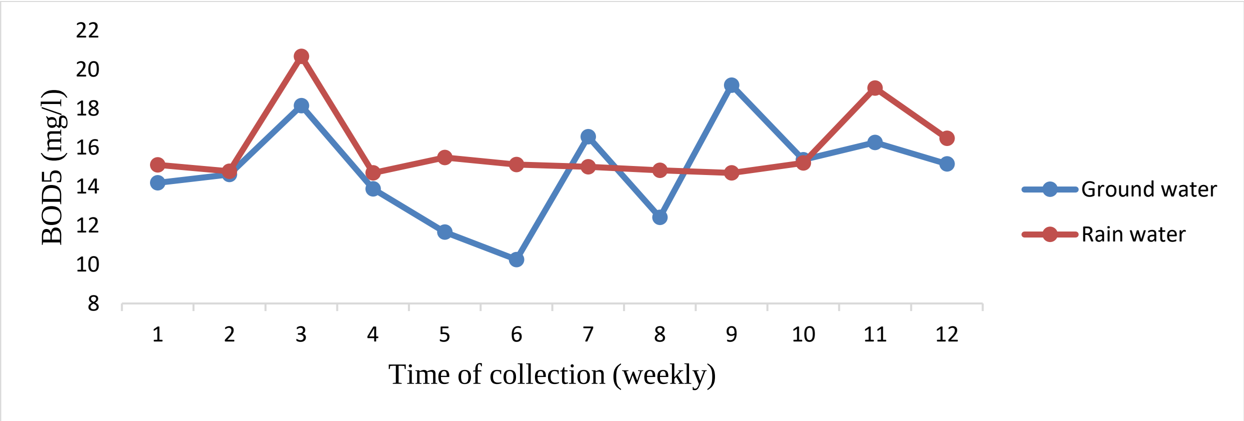

Fig. 4: BOD comparative parameters for Abuja campus

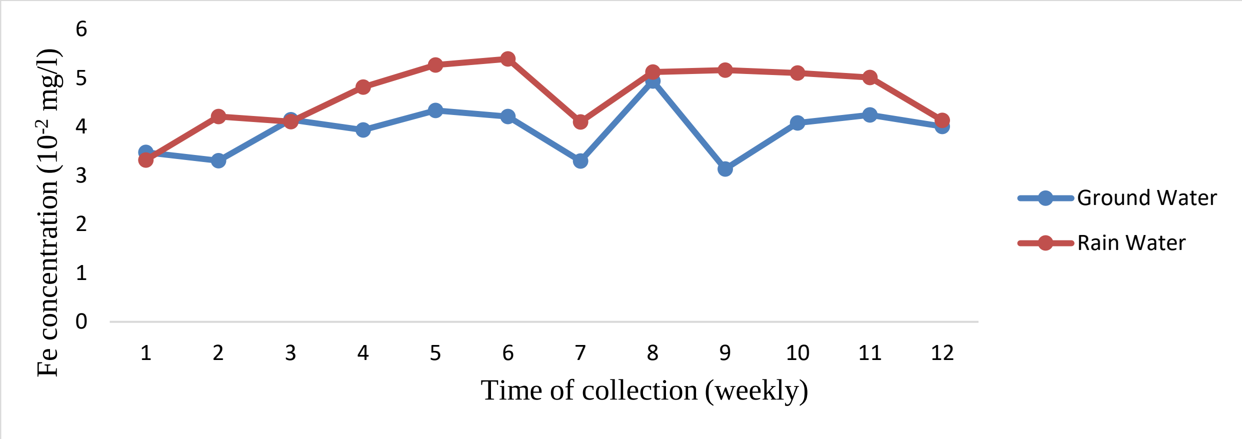

Fig. 5: Fe comparative parameters for Abuja campus

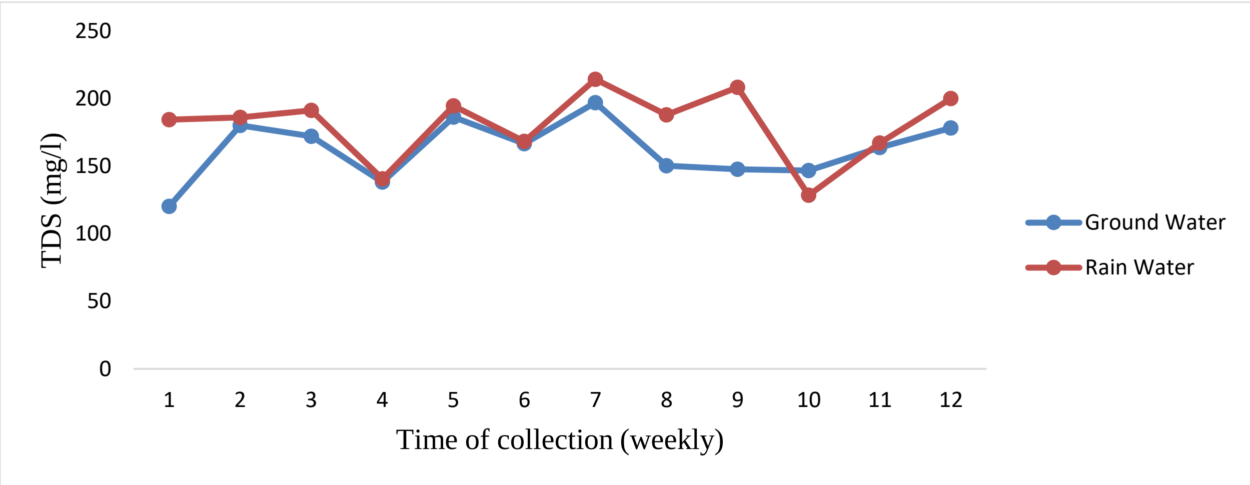

Fig. 6: TDS comparative parameters for Abuja campus

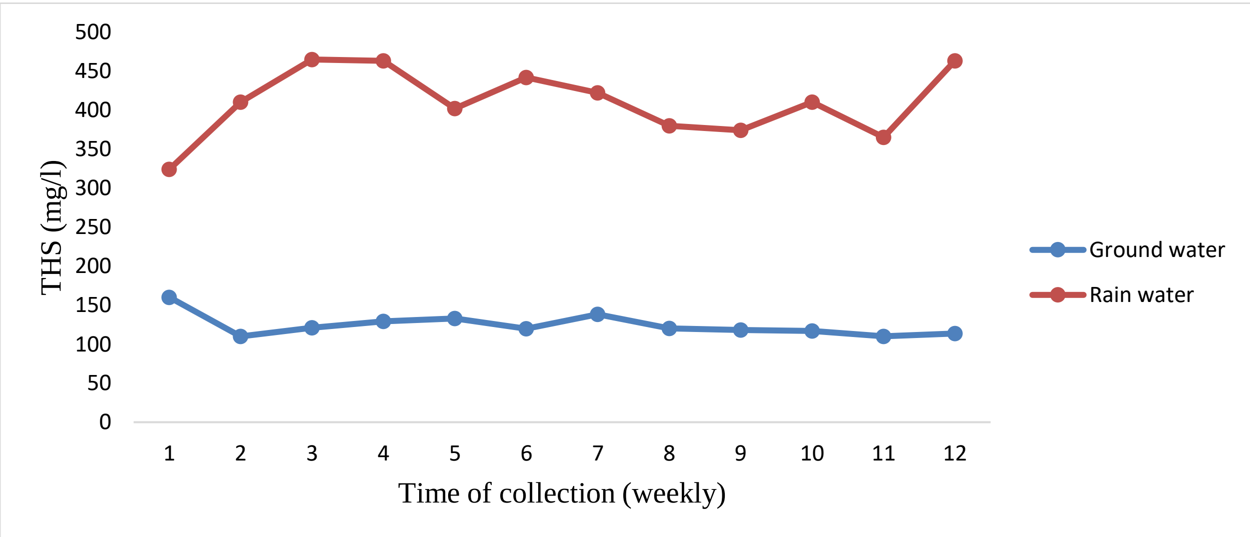

Fig. 7: THS comparative parameters for Abuja campus

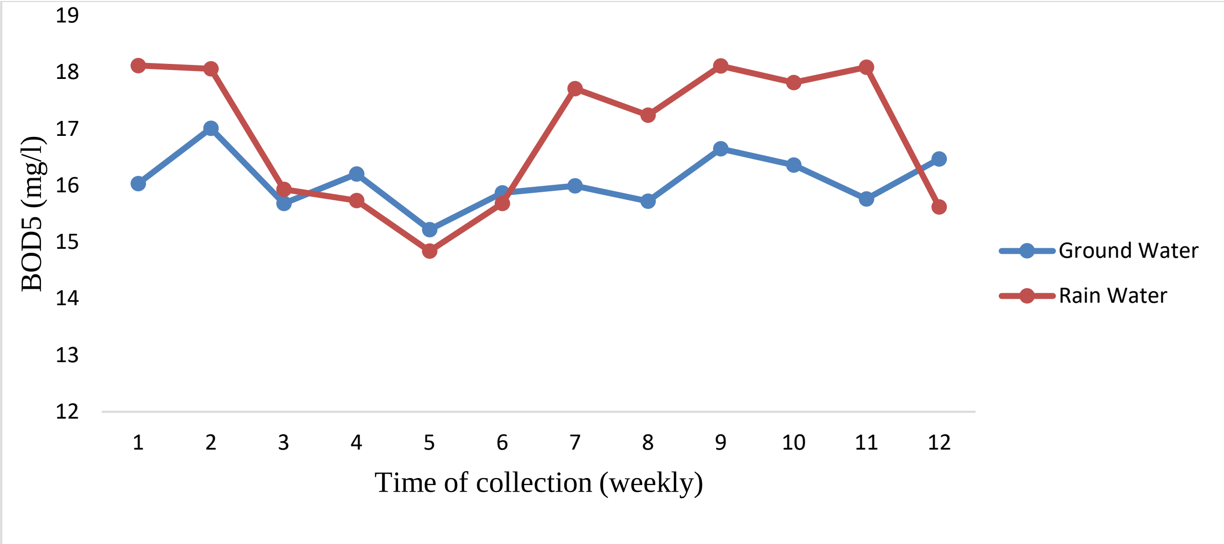

Fig. 8: BOD comparative parameters for Abuja campus

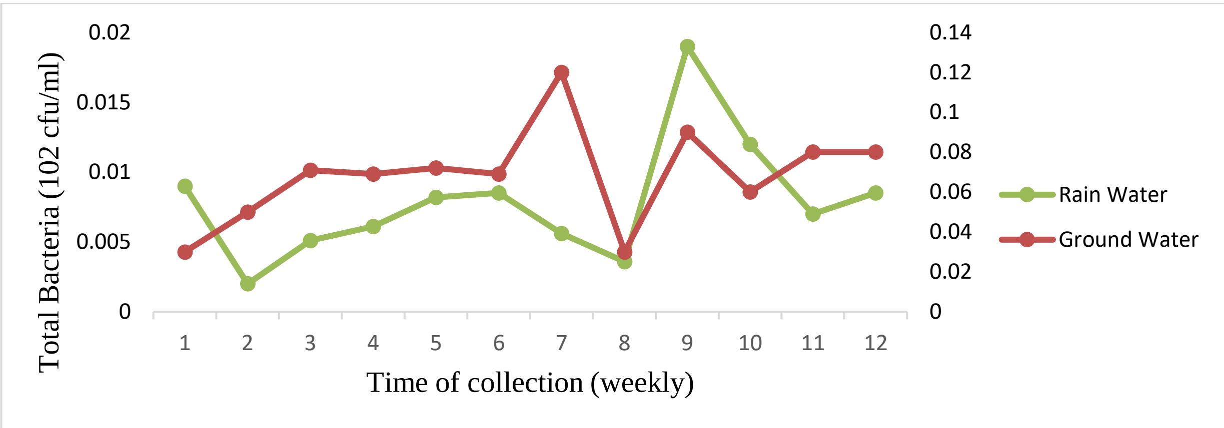

Fig. 9: Total Bacterial comparative parameters for Abuja campus

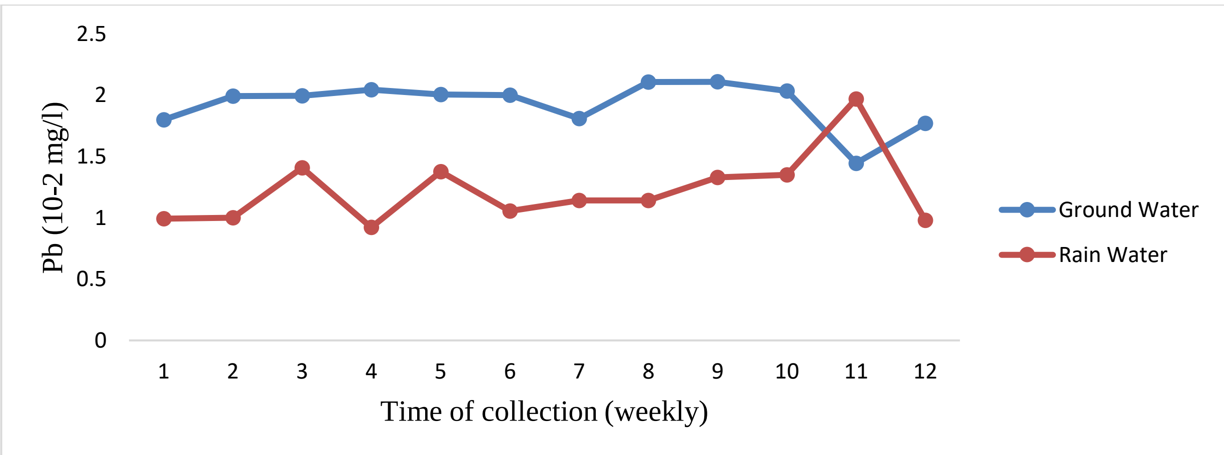

Fig. 10: Pb comparative parameters for Abuja campus

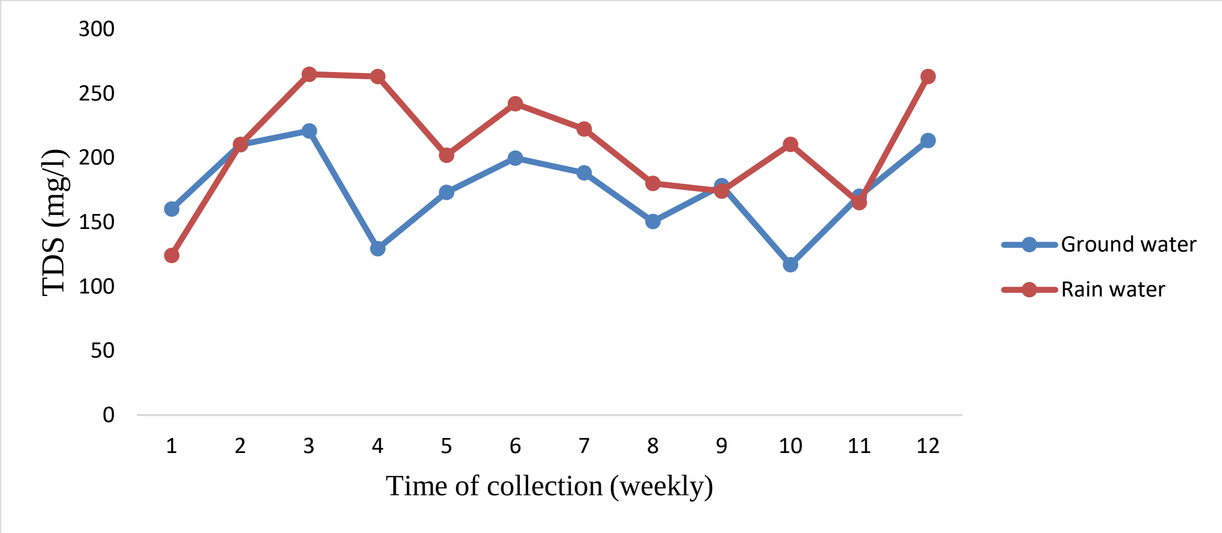

Fig. 11: TDS comparative parameters for Delta campus

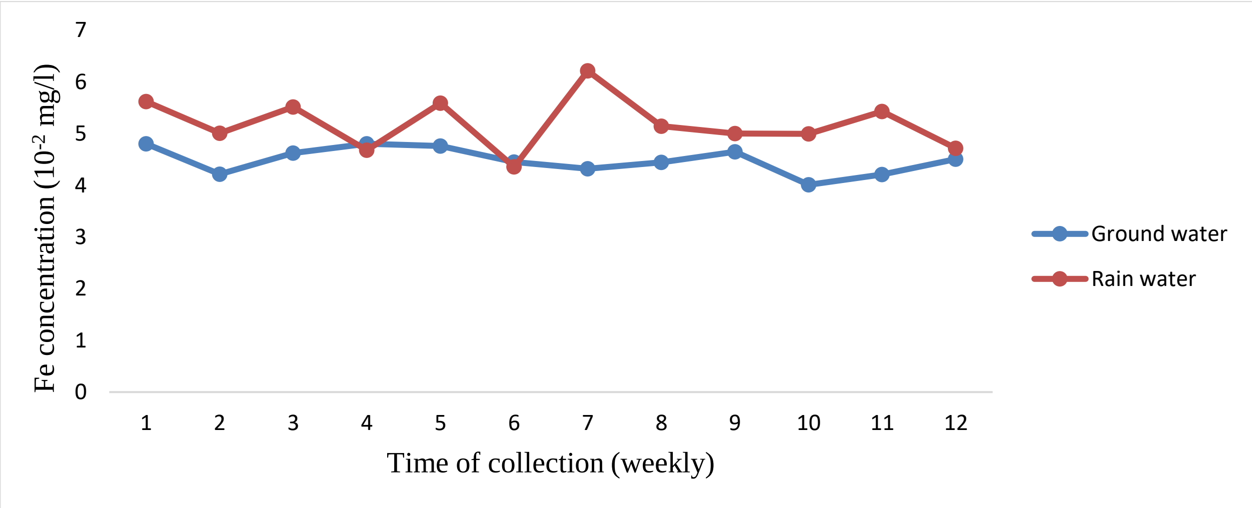

Fig. 12: Fe comparative parameters for Delta campus

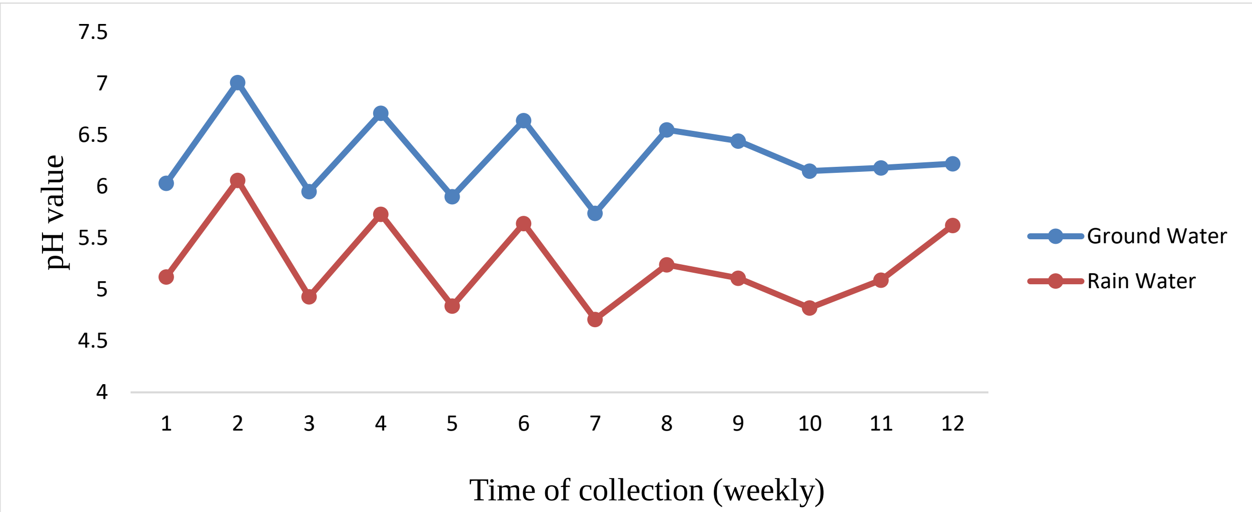

Fig. 13: pH comparative parameters for Delta campus

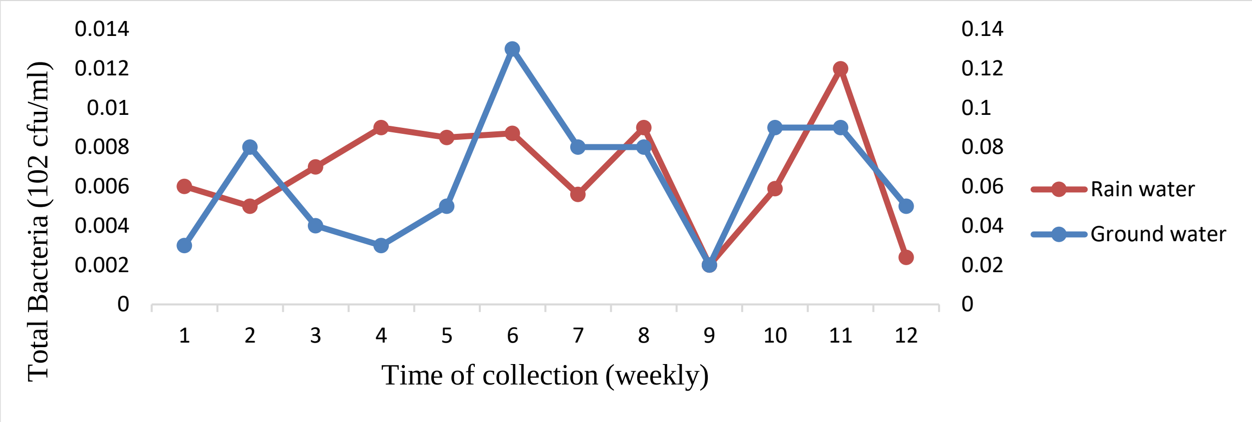

Fig. 14: Total bacterial comparative parameters for Delta campus

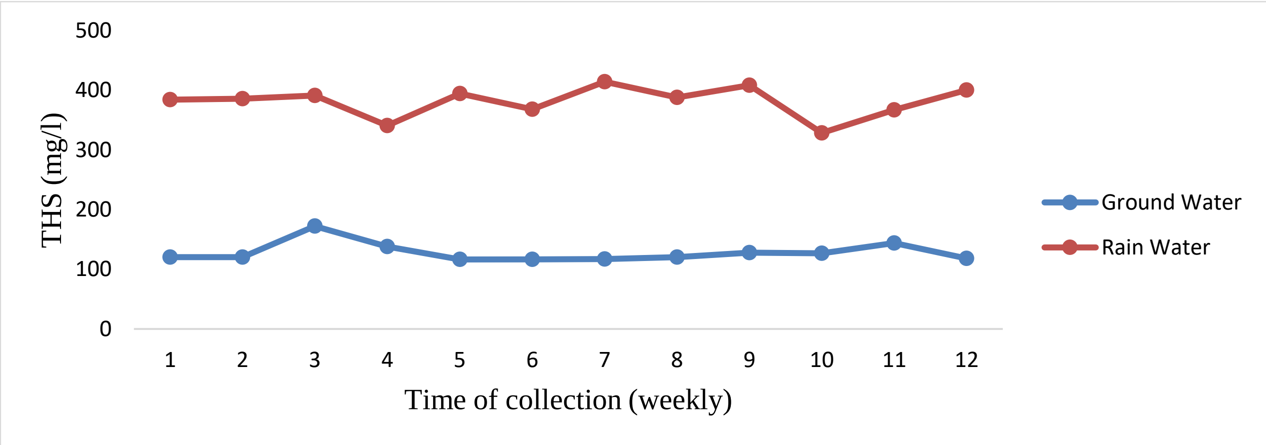

Fig. 15: THS comparative parameters for Delta campus

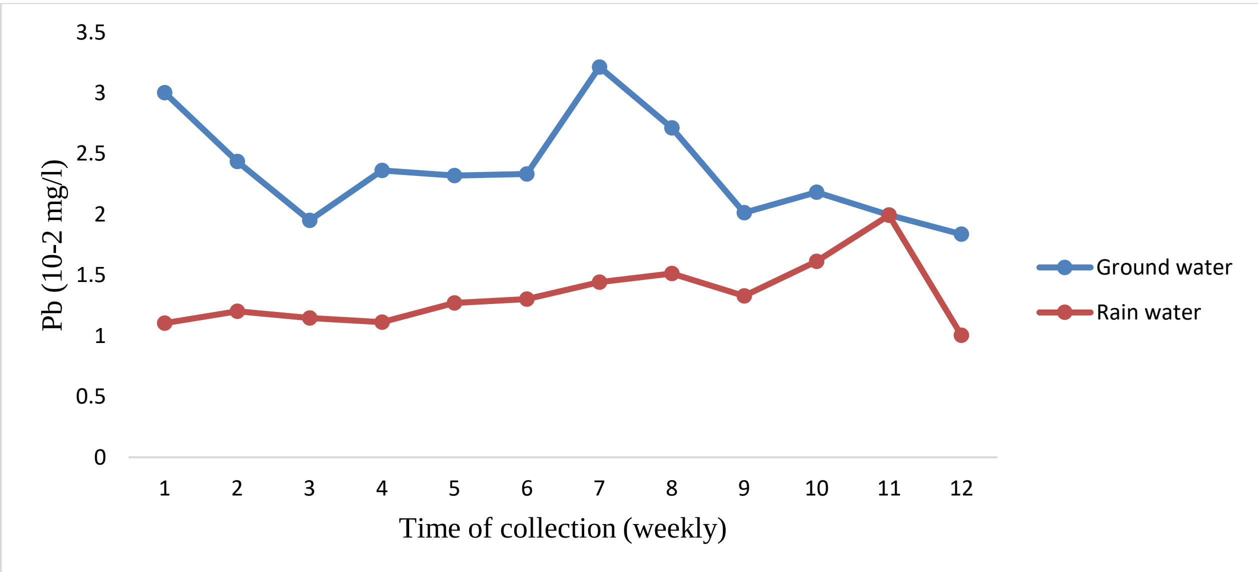

Fig. 16: Pb comparative parameters for Delta campus

3.1.1 pH

The pH values of groundwater on both campuses mostly fall within the slightly acidic to neutral range, with occasional fluctuations. Rainwater, however, tends to be more acidic, reflecting common patterns due to atmospheric carbon dioxide and other pollutants dissolving into rainwater. The pH of rainwater is consistently lower than that of groundwater, indicating higher acidity. Groundwater pH in Abuja varies from 5.74 to 7.01, and in Delta, it ranges from 5.28 to 6.75, staying mostly within the WHO acceptable range for drinking water. Rainwater pH shows greater variability, with Abuja ranging from 4.71 to 6.06 and Delta from 4.66 to 5.48, occasionally falling below the ideal range, reflecting potential environmental pollution or natural atmospheric variations.

3.1.2 Biological oxygen demand

Both groundwater and rainwater BOD5 levels show significant variation across the 12-week period. Groundwater in Abuja shows a range from 15.22 mg/l to 17.01 mg/l, while rainwater ranges from 14.84 mg/l to 18.12 mg/l. Delta campus groundwater BOD5 fluctuates between 10.25 mg/l and 19.19 mg/l, and rainwater varies more significantly from 14.69 mg/l to 20.66 mg/l. The generally higher BOD5 values in rainwater indicate a higher presence of organic pollutants, possibly from atmospheric deposition.

3.1.3 Total dissolved oxygen

Groundwater TDS values in Abuja range from 120.29 mg/l to 197.11 mg/l, while rainwater values range from 128.51 mg/l to 214.39 mg/l. Delta campus groundwater TDS ranges from 116.89 mg/L to 221.06 mg/L, with rainwater showing higher variability from 124.25 mg/l to 265.12 mg/l. Rainwater tends to have higher TDS values, which may be due to atmospheric particles and dissolved gases.

3.1.4 Total hardness

Groundwater THS in Abuja ranges from 116.47 mg/l to 172.22 mg/l, while rainwater ranges from 328.52 mg/l to 414.32 mg/l. Delta campus groundwater THS ranges from 110.19 mg/l to 160.29 mg/l, with rainwater showing significantly higher values from 324.25 mg/L to 465.12 mg/l. The higher THS values in rainwater suggest a significant presence of dissolved minerals, likely from environmental deposition.

3.1.5 Iron (Fe) concentration

Groundwater iron concentrations in Abuja vary from 3.1361 to 4.9425 (10^{-2}) mg/l, while rainwater ranges from 3.3214 to 5.3937 (10^{-2}) mg/l. Delta campus shows groundwater iron levels between 4.0123 and 4.8043 (10^{-2}) mg/l, with rainwater values ranging from 4.0065 to 6.2157 (10^{-2}) mg/l. Elevated iron levels in rainwater could be attributed to atmospheric deposition from industrial emissions or natural sources.

3.1.6 Bacterial (E. coli + T. coli) concentration

Groundwater bacterial counts in Abuja range from 0.03 to 0.12 (10^2 cfu/ml), with rainwater varying from 0.002 to 0.019 (10^2 cfu/ml). Delta campus groundwater shows counts from 0.02 to 0.13 (10^2 cfu/ml), and rainwater ranges from 0.002 to 0.012 (10^2 cfu/ml).

3.1.7 Lead (Pb) concentration

Groundwater lead concentrations in Abuja range from 1.4458 to 2.1094 (10^{-2} mg/l), while rainwater ranges from 0.9218 to 1.9706 (10^{-2} mg/l). Delta campus groundwater lead levels range from 1.8369 to 3.2148 (10^{-2} mg/l), with rainwater varying from 1.0045 to 1.9928 (10^{-2} mg/l). Lead levels, while varying, indicate potential contamination sources in both rainwater The Water Quality Index (WQI) provides a composite measure of water quality by aggregating various water quality parameters into a single index value.

3.2 Water quality index values

The WQI values for the water samples range from 10.77 to 46.03. According to the benchmarks established, this range categorizes the water quality as ranging from excellent to good. This classification indicates that the water samples from both campuses generally meet the standard criteria for various water quality parameters, signifying a satisfactory level of water quality.

3.3 Analysis of variance for water quality index of rain and groundwater

Using Analysis of Variance (ANOVA) to evaluate the significance of variations in the Water Quality Index (WQI) among different water samples collected from various campuses of the University of Port Harcourt. The ANOVA results for groundwater samples from the Abuja and Delta campuses show no significant difference in water quality between the two locations. The F-statistic (0.04926) is lower than the critical F-value (4.30095), indicating non-significance. The high p-value (0.8264) further supports this, suggesting uniformity in groundwater quality across both campuses. Similar to groundwater, the ANOVA results for rainwater samples also indicate no significant difference in water quality between the Abuja and Delta campuses. The F-statistic (0.11535) is below the critical F-value, and the p-value (0.73735) is higher than the significance level, confirming uniformity in rainwater quality across the campuses.

The ANOVA results for the Abuja campus reveal a significant difference in water quality between groundwater and rainwater samples. The high F-statistic (18.5404) compared to the critical F-value indicates substantial variation. The low p-value (0.00029) further supports this, signifying statistically significant differences in water quality parameters between groundwater and rainwater at the Abuja campus. The ANOVA results for the Delta campus also demonstrate a significant difference in water quality between groundwater and rainwater samples. The F-statistic (8.66069) exceeds the critical F-value, indicating notable variations. The low p-value (0.00752) reinforces this, highlighting statistically significant differences in water quality parameters between groundwater and rainwater at the Delta campus.

3.4 Regression analysis of water quality index of rain and groundwater

The regression analysis was conducted to establish a meaningful relationship between groundwater and rainwater quality using the Water Quality Index (WQI) parameter. Various regression models were explored, including linear regression, logarithmic model, exponential model, and polynomial regression, to identify the most suitable model capturing the dynamics between these two water sources at the University of Port Harcourt.

3.4.1 Different regression models for Abuja Campus

The regression analysis for the Abuja campus revealed that all models, including linear, logarithmic, exponential, and polynomial regression, were statistically significant in representing the relationship between groundwater and rainwater WQI. Notably, the polynomial regression model stood out with a high determination coefficient (R^2) value of 91.38%, indicating a strong association between groundwater and rainwater qualities at the Abuja campus. This suggests that the developed regression models successfully explain a significant portion of the variability in water quality between these two sources.

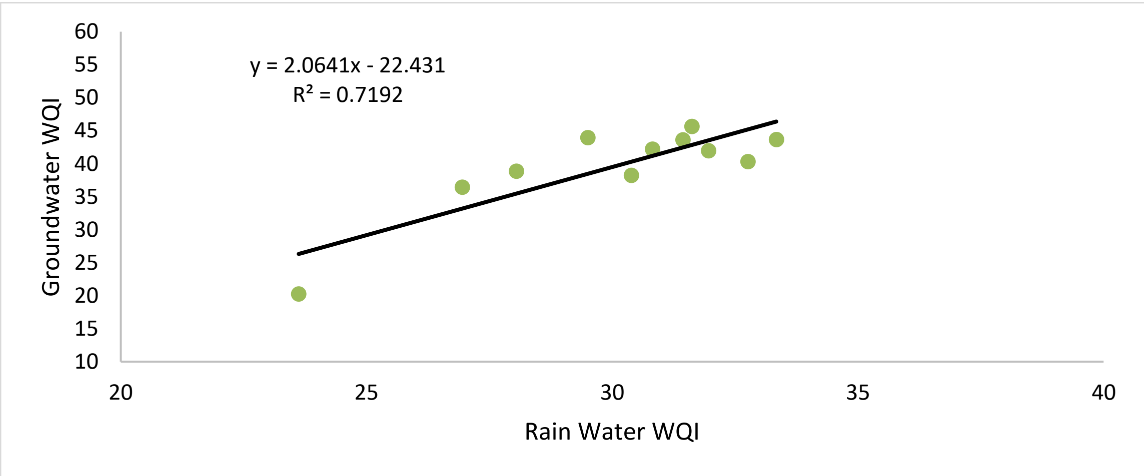

Fig. 17: Linear regression model for Abuja

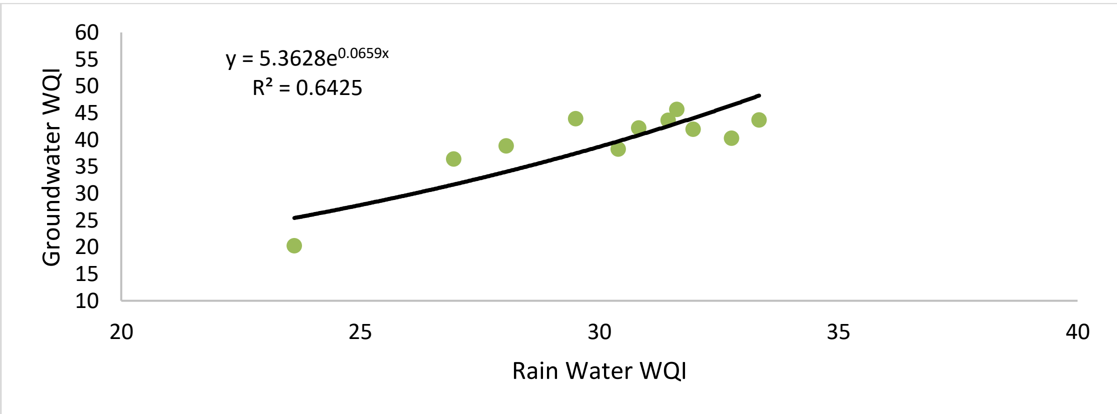

Fig. 18: Exponential regression model for Abuja

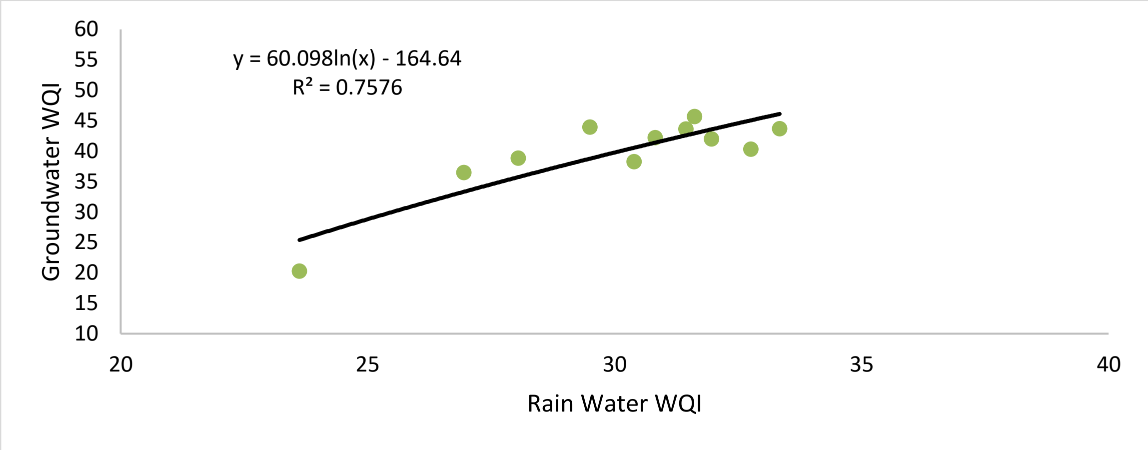

Fig. 19: Logarithm regression model for Abuja

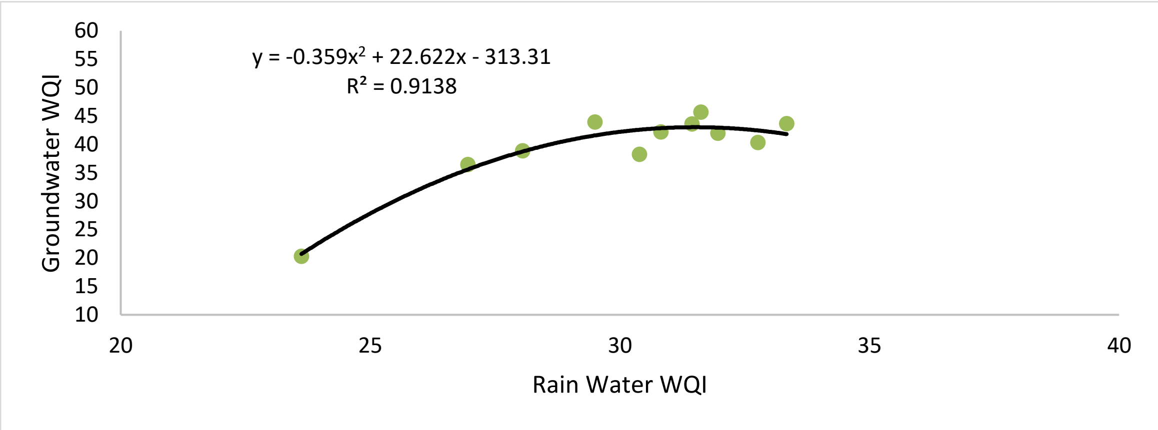

Fig. 20: Polynomial regression model for Abuja

3.4.2 Different regression models for Delta Campus

Similar to the Abuja campus, the regression analysis for the Delta campus demonstrated that all regression models significantly represented the relationship between groundwater and rainwater WQI. The determination coefficients (R^2) for each model were highly satisfactory, with the polynomial regression model exhibiting an impressive R^2 value of 86.53%. This indicates a robust and meaningful association between groundwater and rainwater qualities at the Delta campus. Overall, the regression models successfully captured and explained a significant proportion of the variability in water quality between these two sources at the Delta campus.

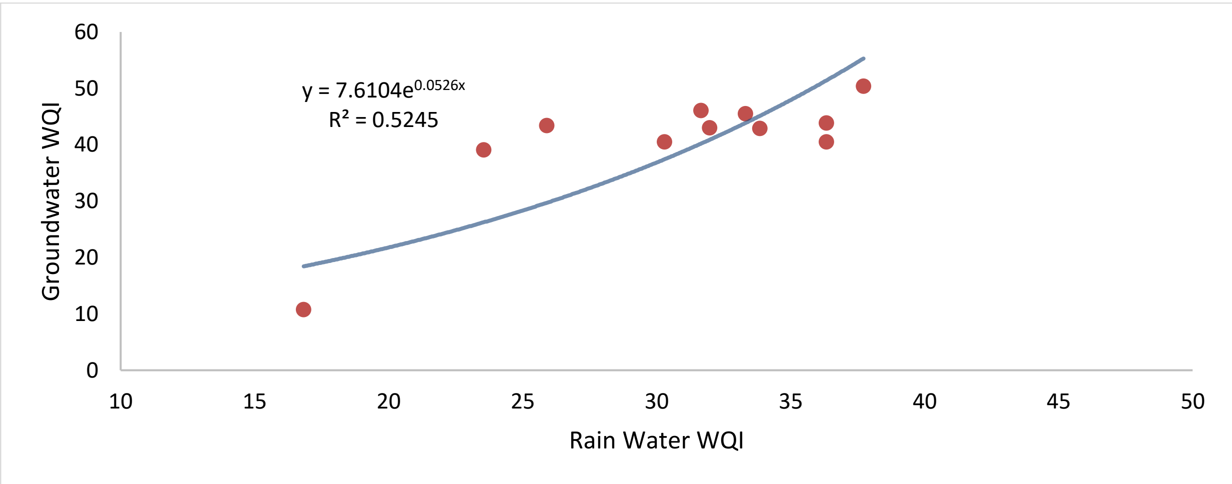

Fig. 21: Exponential regression model for Delta Campus

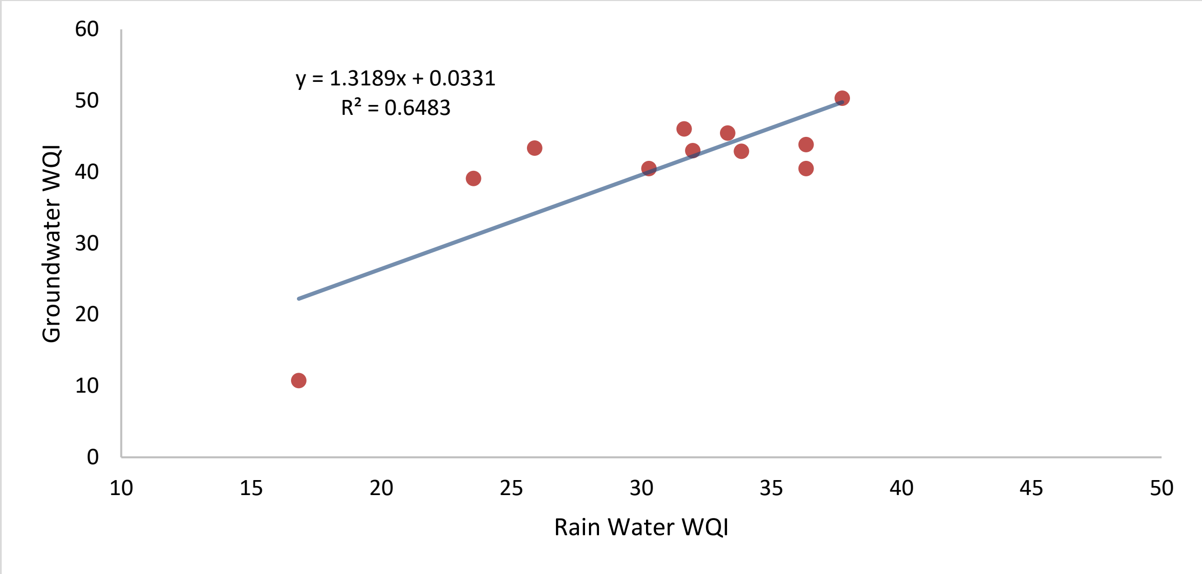

Fig. 22: Linear regression model for Delta Campus

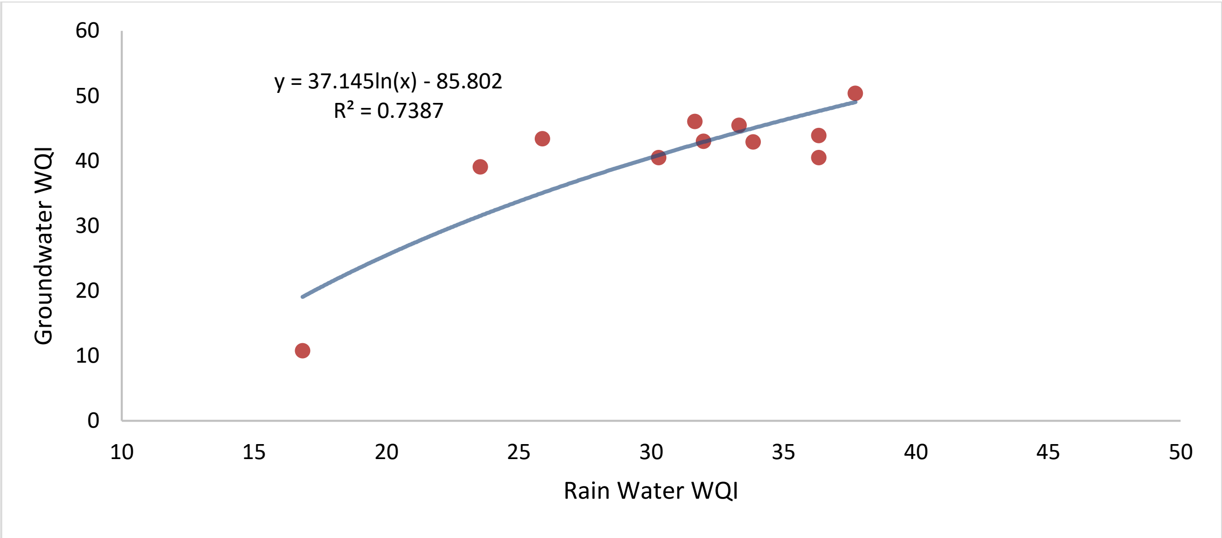

Fig. 23: Logarithmic regression model for Delta Campus

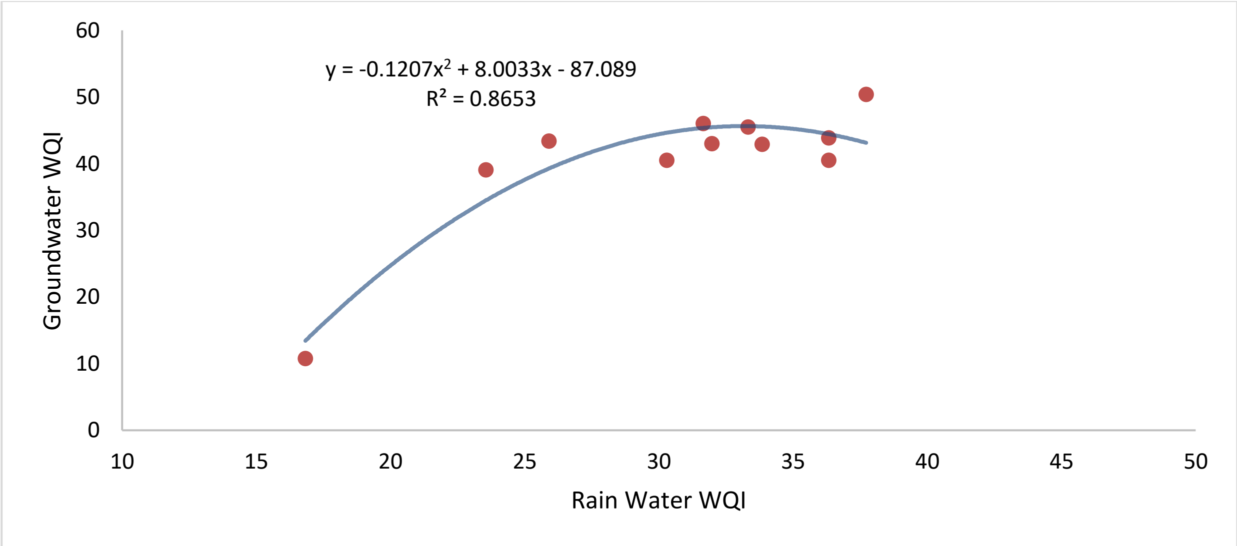

Fig. 24: Polynomial regression model for Delta Campus

4. Conclusion

A comparative analysis of rainwater and groundwater qualities within the University of Port Harcourt, focusing on the Abuja and Delta campuses over a twelve-week period was carried out. Key water quality parameters, including pH, BOD, TDS, THS, bacterial concentration, and metal content (Fe and Pb), were measured, and the Water Quality Index (WQI) was calculated to assess overall water quality. The results showed that both groundwater and rainwater consistently fell within the "excellent" to "good" categories of water quality, according to WHO and Nigerian standards. The WQI values ranged from 10.77 to 46.03. Groundwater remained more stable but showed notable hardness and metal contamination, with lead concentrations ranging from 1.44×10^{-2} mg/l to 3.21×10^{-2} mg/l. Rainwater displayed higher variability in parameters like total dissolved solids (TDS) and total hardness (THS), with THS values for rainwater ranging from 324.25 mg/L to 465.12 mg/l and TDS values reaching a maximum of 265.12 mg/l. ANOVA analysis revealed significant differences between groundwater and rainwater quality at both campuses. At the Abuja campus, a high F-statistic of 18.5404 indicated substantial variation in water quality between the two sources. Similarly, at the Delta campus, an F-statistic of 8.66069 confirmed statistically significant differences between groundwater and rainwater. Groundwater pH values ranged from 5.28 to 7.01, while rainwater exhibited slightly more acidic values, ranging from 4.66 to 6.06, reflecting atmospheric influences. Biological oxygen demand (BOD_5) for groundwater fluctuated between 10.25 mg/l and 19.19 mg/l, while rainwater showed slightly higher variability, with values between 14.69 mg/l and 20.66 mg/l. Regression analysis showed a strong relationship between the Groundwater Quality Index (GWQI) and Rainwater Quality Index (RWQI). The polynomial regression model for the Abuja campus had an R^2 value of 91.38%, while the Delta campus had an R^2 value of 86.53%, indicating that the models successfully explained the variability in water quality between the two sources.

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