Spatial Analysis of Groundwater Hydrochemistry and Suitability for Domestic Use in Ogun Waterside, Nigeria

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Abstract
Groundwater serves as the primary source of domestic water in Ogun Waterside; however, its quality is often compromised by both geological and anthropogenic influences. This study assessed the spatial distribution and statistical significance of selected water quality parameters in comparison with World Health Organization (WHO) standards. A total of 25 groundwater samples were collected across different lithological zones and analyzed for key physicochemical parameters, including pH, electrical conductivity (EC), total dissolved solids (TDS), major cations (Na^+, K^+, Mg^{2+}, Ca^{2+}), and anions (Cl^-, SO_4^{2-}, HCO_3^-, NO_3^-). The results were subjected to descriptive statistics, t-tests, and geospatial statistical analysis using the Kriging method to evaluate spatial variation in water quality across the study area. Descriptive statistics and t-tests revealed that several parameters—pH, EC, TDS, Na^+, K^+, Mg^{2+}, Ca^{2+}, Cl^-, SO_4^{2-}, HCO_3^-, and NO_3^- exhibited varying degrees of deviation from WHO recommended limits. Notably, K^+, Na^+, Mg^{2+}, Ca^{2+}, SO_4^{2-}, and NO_3^- differed significantly from WHO standards ($p < 0.05$), indicating potential environmental concerns. Spatial analysis based on the Average Mean Square Error (AMSE) showed that most parameters had low variability (AMSE ≈ 1.0), suggesting a relatively uniform distribution. However, nitrate displayed the highest AMSE (1.240), indicating substantial spatial variation likely due to anthropogenic inputs. These findings highlight the need for continuous groundwater monitoring and targeted management strategies, particularly in nitrate-prone areas. Furthermore, the results underscore the importance of investigating localized factors influencing parameter variability. Overall, the study provides a valuable baseline for environmental planning and water quality management in the Ogun Waterside region.

Keywords: *Hydrochemistry, spatial analysis, groundwater suitability, water pollution, Ogun Waterside.*

INTRODUCTION

The imperative for maintaining optimal water quality has increasingly become a focal point of concern both in Nigeria and internationally, as anthropogenic activities relentlessly continue to compromise the integrity of numerous aquatic ecosystems (Emenike et al., 2018; Iwar et al., 2021). Such activities, encompassing agricultural runoff, industrial effluents, inadequate waste management practices, and dredging operations, substantially exacerbate the degradation of aquatic environments (Harkness et al., 2017; Ukah et al., 2020; Varol, 2021). The pollution of groundwater, which serves as a vital source of potable water, has emerged as a significant environmental and public health hazard. As reported by the World Health Organization (WHO, 2017), the annual mortality associated with diseases attributable to unsafe water surpasses the total fatalities resulting from all forms of violence combined (Thomas, 2023). Recent projections indicate that more than 2 billion individuals worldwide continue to lack access to safely managed drinking water, with Sub-Saharan Africa, inclusive of Nigeria, being disproportionately impacted (WHO/UNICEF, 2023).

Groundwater contamination arises from both natural sources (e.g., geological leaching of minerals) and human activities (e.g., improper sanitation, agrochemical use, and industrial effluents) (Aithani et al., 2020; Thomas, 2021). Seasonal variations further influence contaminant levels, exacerbating the problem in certain periods (Badmus et al., 2020). Boopathiraj et al. (2022) highlights that waterborne diseases account for nearly 80% of illnesses in developing nations, with children under five being particularly vulnerable. Studies have shown that elevated levels of physicochemical parameters such as heavy metals, nitrates, and salinity in groundwater exceed WHO (2022) permissible limits, leading to severe health issues, including kidney damage, gastrointestinal diseases, and methemoglobinemia (Ahmadi et al., 2018; Wu et al., 2019). Despite these risks, groundwater is often perceived as inherently safe due to the misconception that natural filtration eliminates contaminants (Jiang et al., 2019). This false belief discourages necessary treatment and monitoring, leaving communities exposed to health hazards.

In Ogun Waterside, groundwater remains a primary water source, yet reports indicate contamination levels surpassing national and international safety standards. The area's high-water table and proximity to coastal zones contribute to salinity intrusion, rendering some wells unusable (Badmus et al., 2020). Residents rely heavily on shallow wells, many of which exhibit high salinity and suspected chemical pollutants, leading to increased cases of water-related illnesses. Despite these concerns, there is limited empirical data on groundwater quality in the region, and no comprehensive study has assessed the seasonal variability of contaminants or their health implications (Omo-Irabor et al., 2008).

Despite the critical reliance on groundwater in Ogun Waterside, there is insufficient research on the extent of contamination and its seasonal variations. The absence of recent, detailed studies on physicochemical parameters such as salinity, heavy metals, and nutrient levels leaves policymakers and public health officials without the necessary data to implement effective mitigation strategies. Furthermore, the community's reported complaints of salty-tasting water and rising health issues underscore the urgency of this investigation. This study seeks to evaluate the impacts of natural and anthropogenic activities on groundwater quality in Ogun Waterside, providing essential data to guide water safety interventions and public health awareness campaigns.

Over the years, the paradigm of geostatistical interpolation, along with spatial correlation and their respective applications, has been documented by a diverse spectrum of researchers on a global scale (Fallah et al. 2019). A multitude of scholars has employed geospatial statistical methodologies to investigate variations in groundwater quality (Gharbia et al. 2016; Johnson et al. 2018; Belkhiri et al. 2020). Geostatistics is a spatial statistical methodology that facilitates the assessment and representation of concentration distributions both spatially and temporally (Narany et al. 2014). It predicts estimated values predicated on the interrelationships among sample points and evaluates the uncertainty associated with these predictions. Kriging constitutes a linear interpolation technique that is utilized to generate probabilistic models of uncertainty pertaining to the values of specific attributes. Consequently, the integration of spatial information yields a robust mechanism for monitoring and management (Ali & Ahmad 2020).

Recent advancements in the application of geographic information systems (GIS) have significantly augmented their capacity for spatiotemporal data analysis, thereby enabling the delineation of distribution patterns of water quality variables (Bouteraa et al. 2019), as well as facilitating groundwater quality assessments through geostatistical methods (Nas & Berktay 2010; Selmane et al. 2022). In order to depict spatial variability, geostatistics employs Kriging, recognized as the optimal linear unbiased estimator for predicting absent data at unknown locations, which remains the most prevalent technique in environmental research, particularly within ecological and water quality studies. Recent advancements in GIS applications have further enhanced its capabilities for spatiotemporal data analysis, thereby establishing the geographic scope of groundwater quality parameters and facilitating groundwater quality evaluations through geostatistical approaches (Venkatramanan et al. 2016).

MATERIALS AND METHODS

Study Area

Ogun Waterside is located in the eastern Dahomey basin, bordered by Lagos, Ondo, and Ijebu East (figure 1). The region features extensive water coverage from Lagos to Ondo State (Odebiyi et. al., 2013). Accessibility is provided by limited motorable roads, feeder roads, and footpaths.

Geographically, it is defined by coordinates of longitude 46°E and 43.4°E, and latitudes 6.22°N and 6.36°N. Ogun Waterside experiences a tropical climate characterized by a wet season from March to October and a dry season from November to February (Ojelade et al., 202), and the annual rainfall averages 1300 mm, with monthly temperatures ranging from 23°C to 32°C (Amujo et al., 2022). The area was selected for study due to its intricate network of streams, rivers, and brackish waters. It is part of the Nigerian section of the Dahomey basin, which extends through Ghana, Togo, Benin, and into Nigeria's Niger Delta (Jones and Hockey 1964). The basin is bordered by Precambrian basement rocks to the north and the Atlantic Ocean to the south, known as the Bight of Benin (Falufosi & Osinowo, 2021).

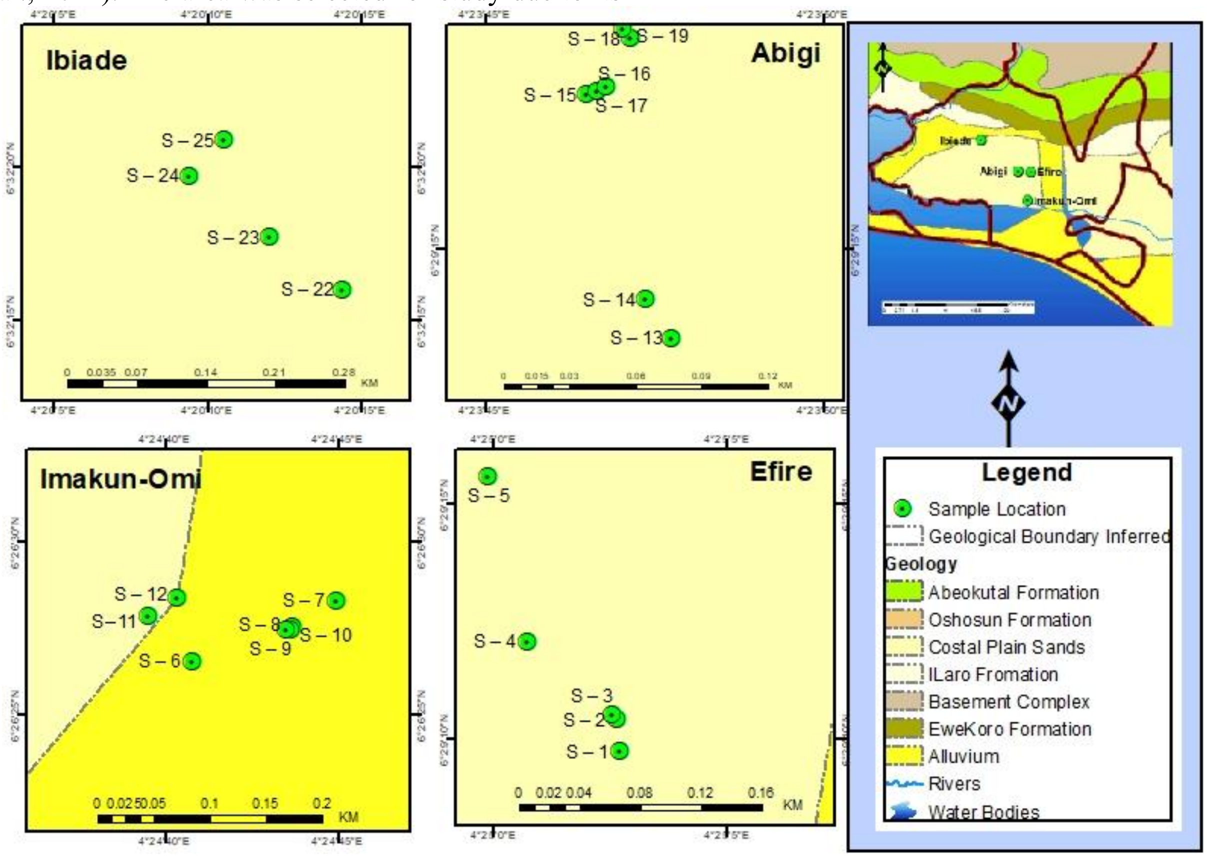

Figure 1: Sampling Points from the study area
Source: Field Survey, (2025)

Methodology

To evaluate groundwater contamination levels in Ogun Waterside, samples were collected from hand-dug wells located in both residential and agricultural areas. Water samples were obtained using high-quality, two-litre polypropylene bottles with narrow-mouth screw caps, which were pre-cleaned with dilute nitric acid and rinsed three times with demineralized water. Before sampling, each bottle was further rinsed with the water to be collected to minimize contamination. A total of 25 samples were collected from four villages, targeting different lithological zones. The samples were analysed for key physicochemical parameters including pH, electrical conductivity (EC), total dissolved solids (TDS), major cations (Na^+, K^+, Mg^{2+}, Ca^{2+}), and anions (Cl^-, SO_4^{2-}, HCO_3^-, NO_3^-).

Statistical significance was assessed using ANOVA and the Mann-Whitney U test. Additionally, the geospatial statistical technique, Kriging, was used to examine and map the spatial variation of hydrochemistry in ArcGIS, providing visual representation of contaminant distribution. Each sample was clearly labelled with relevant metadata; geo-location (coordinates), source (concentration level), and Label (sampling station tag), recorded in a field notebook to ensure traceability and avoid errors. Bottles were filled completely to exclude air bubbles, sealed tightly, and stored at 4°C until laboratory analysis. pH, EC, and TDS were also measured in-situ using portable instruments. Standard laboratory protocols aligned with WHO and NSDWQ guidelines were followed to assess the concentration of key anions and cations, including calcium, sodium, magnesium, iron, potassium, nitrate, sulphate, carbonate, chloride, and bicarbonate, to determine groundwater quality and contamination levels.

RESULTS AND DISCUSSION

Comparison between the Study Area Hydrochemistry and WHO Standard

The provided water quality parameters show considerable differences from the World Health Organization (WHO) guidelines (Table 1), with implications for both human health and environmental conditions.

First, the pH level of 6.84 is slightly acidic, falling below the recommended WHO guideline of 7.5. This suggests that the water may be too acidic for optimal aquatic life and could potentially cause discomfort for consumers if the water is used for drinking or irrigation according to Effiong et al., (2022). Makkar et al., (2020), further asserted that cidic water can also accelerate the corrosion of pipes and affect the taste of water (Schmidt & Huang, 2022). The Electrical Conductivity (EC) of 974.38 µS/cm is substantially higher than the WHO limit of 400 µS/cm, indicating a higher concentration of dissolved salts and minerals in the water. In the opinion of Chakraborty et al., (2021), elevated EC suggests possible pollution or an excessive number of dissolved ions, which can impact the taste and quality of the water. In addition, Gapparov & Isakova (2023), asserted that such high levels of EC are often linked with water salinity, which could harm aquatic life and soil health if used for irrigation. Similarly, the Total Dissolved Solids (TDS) value of 667.88 mg/L exceeds the recommended maximum of 500 mg/L. A higher TDS level means there is an increased presence of dissolved solids, which may negatively impact the water's taste and aesthetic quality. It could also pose health risks if consumed over time, especially in large quantities, due to the accumulation of potentially harmful substances according the Farjoudi & Alizadeh, (2021).

The observed potassium concentration of 61.52 mg/L is more than three times higher than the WHO guideline of 20 mg/L. Narasaki et al., (2022), concluded that potassium is essential for human health but in excessive amounts, it can lead to potential health problems, particularly for individuals with kidney issues. This elevated level could also indicate pollution or excess runoff from agricultural sources. On the other hand, the sodium concentration is 46.51 mg/L, which is well within the WHO guideline of 200 mg/L. This suggests that the water does not contain excessive sodium, making it relatively safe for consumption and suitable for irrigation purposes without causing salinity issues for plants.

Table 1: Comparing WHO Guideline and Observed concentration Levels

Parameter	WHO	Mean Observed
pH	7.5	6.84
EC	400	974.38
TDS	500	667.88
Potassium	20	61.52
Sodium	200	46.51
Magnesium	50	5.41
Calcium	100	4.98
Chloride	250	203.29
Sulphate	250	1.49
Carbonates	240	183.22
Nitrate	50	1.90

Source: Field Survey, (2025)

The magnesium concentration is 5.41 mg/L, far below the recommended 50 mg/L. Magnesium is an important mineral for both human health and plant growth, and its low levels in the water could indicate a deficiency (Ishfaq et al., 2022). The water might not provide enough magnesium for healthy aquatic ecosystems or for crops if used for irrigation (Qadir et al., 2018). Similarly, the calcium concentration is also much lower than the WHO guideline. At 4.98 mg/L, it falls far short of the 100 mg/L guideline. According to Kocak et al., (2011), calcium is essential for bone health in humans and helps regulate the hardness of water. Furthermore, Raskh (2020) and Baturin et al. (2022), stated that low levels of calcium in the water could reduce its quality and affect both human health and agricultural productivity.

The chloride concentration, measured at 203.29 mg/L, is below the WHO guideline of 250 mg/L, indicating that the water's chloride content is within acceptable limits. Chlorides are commonly associated with salinity, and this level suggests that the water does not pose significant risks due to high salinity, making it safe for consumption and use in irrigation (Roldan et al., 2020). The sulphate concentration, at 1.49 mg/L, is much lower than the WHO guideline of 250 mg/L. This indicates that the water has a very low level of sulphates, which according to Zak et al., (2021), is beneficial as high sulphate concentrations can lead to a bitter taste, laxative effects, and potential health risks when consumed in large amounts (Khan et al., 2020). In this case, the low level of sulphate is not a concern.

The carbonate level of 183.22 mg/L is within the WHO guideline of 240 mg/L, suggesting that the water's alkalinity is at an acceptable level. This is important for maintaining a balanced pH, as well as ensuring the water's suitability for both human use and plant growth. Lastly, the nitrate concentration of 1.90 mg/L is far below the WHO guideline of 50 mg/L, which is favourable. High nitrate levels are a concern, particularly for infants, as they can lead to serious health issues such as methemoglobinemia, commonly known as "blue baby syndrome" (Krolak & Raczuk, 2018). The observed low nitrate levels in this sample suggest the water is safe in this regard.

Furthermore, a chart (figure 2) was employed to examine the inherent differences between the observed values and the WHO standard. It can be observed that, on the overall, the observed EC, TDS, and Potassium concentration levels were higher than the permissible limit of the WHO, while the remaining parameters; pH, Sodium, Magnesium, Calcium, Chloride, Sulphate, Carbonates, and Nitrate were lower than the WHO limit with respect to concentration level.

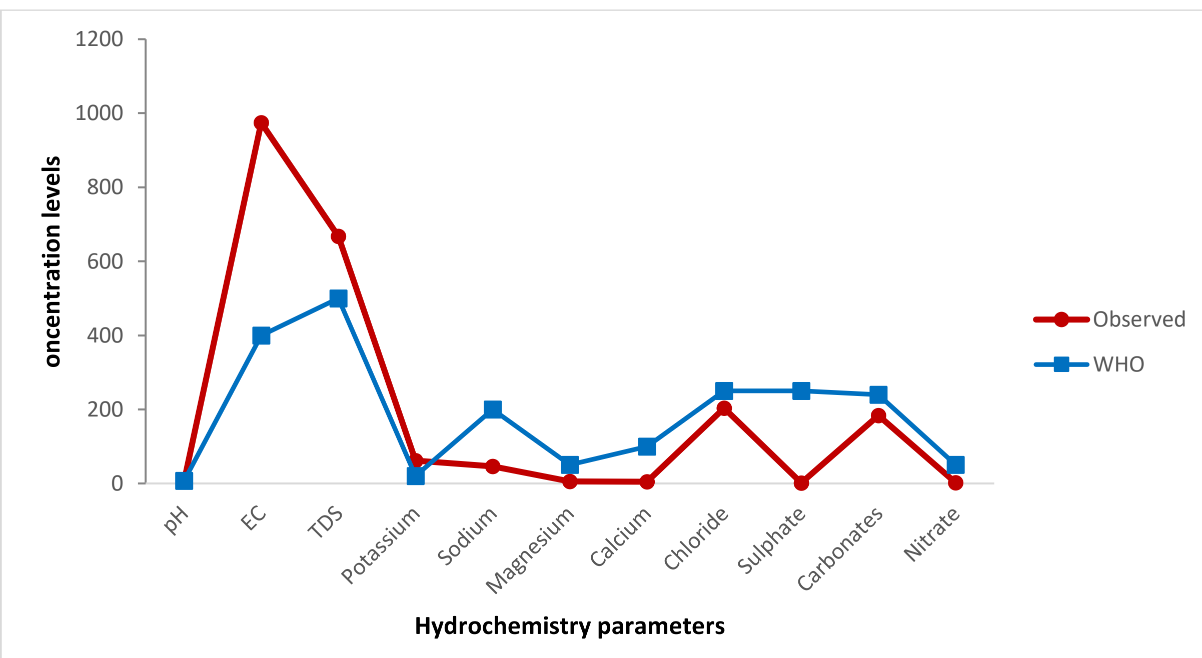

Figure 2: Observed Hydrochemistry Levels and WHO limits
Source: Field Survey, (2025)

Comparison between Observed Concentration levels and WHO standard

The results of the t-test provide a comparison of the means between two groups for each parameter. The t-test for pH yields a t-value of -6.793 and a p-value of 0.000, which is less than the conventional significance level of 0.05. This indicates that there is a statistically significant difference in the pH levels between the two groups. The mean difference of -0.66080 suggests that the first group has a lower pH than the second. The 95% confidence interval for the mean difference ranges from -0.86158 to -0.46002, which does not include zero, further supporting the conclusion that the difference is significant. For Electrical Conductivity (EC), the t-value is 1.306, and the p-value is 0.204, which is greater than 0.05. This indicates that the difference in EC between the two groups is not statistically significant. Despite the mean difference of 574.38040, the confidence interval ranging from -333.25931 to 1482.02011 includes zero, suggesting that the difference could be due to random variation.

The t-test result for Total Dissolved Solids (TDS) shows a t-value of 0.421 and a p-value of 0.678, which is well above the 0.05 threshold for statistical significance. This indicates that there is no significant difference in TDS between the two groups. The mean difference of 167.88400 and the confidence interval ranging from -655.71744 to 991.48544 includes zero, further confirming that the difference is not statistically significant. For Potassium, the t-value is 2.254, with a p-value of 0.034, which is less than 0.05, indicating a statistically significant difference between the groups. The mean difference of 41.51960 shows that the first group has significantly higher levels of potassium compared to the second group. The confidence interval for the mean difference ranges from 3.50999 to 79.52921, which does not include zero, reinforcing the significance of the difference in potassium levels between the groups.

In the case of Sodium, the t-value is -26.087, and the p-value is 0.000, indicating a highly significant difference between the two groups. The mean difference of -153.49040 suggests that the first group has significantly lower sodium levels. The confidence interval for this difference ranges from -165.63382 to -141.34698, which does not include zero, confirming that the difference in sodium levels is statistically significant. Magnesium also shows a statistically significant difference between the two groups, with a t-value of -76.102 and a p-value of 0.000. The mean difference of -44.58720 suggests that the first group has lower magnesium levels. The confidence interval for the mean difference ranges from -45.79641 to -43.37799, and since it does not include zero, the result is highly significant, indicating a clear difference in magnesium levels between the two groups.

The t-test for Calcium yields a t-value of -83.713 and a p-value of 0.000, showing a highly significant difference between the groups. The mean difference of -95.01960 suggests that the first group has lower calcium levels compared to the second group. The confidence interval for the mean difference ranges from -97.36224 to -92.67696, which does not include zero, confirming that the difference in calcium levels is statistically significant. For Chloride, the t-value is -0.378 with a p-value of 0.709, indicating that there is no significant difference between the chloride levels of the two groups. The mean difference of -46.70920 and the confidence interval ranging from -302.01443 to 208.59603 includes zero, suggesting that the difference in chloride levels is not statistically meaningful.

The t-value for Sulphate is -570.534, and the p-value is 0.000, indicating a highly significant difference between the two groups. The mean difference of -248.50800 shows that the first group has lower sulphate levels. The confidence interval for this difference ranges from -249.40697 to -247.60903, which does not include zero, confirming that the difference in sulphate levels is statistically significant. For Carbonates, the t-value is -1.113, with a p-value of 0.277, which is above the 0.05 significance level. This means that the difference in carbonate levels between the two groups is not statistically significant. The mean difference of -56.77680 and the confidence interval ranging from -162.05043 to 48.49683, which includes zero, further suggest that there is no significant difference between the groups in terms of carbonates.

Finally, the t-test for Nitrate yields a t-value of -38.513 and a p-value of 0.000, indicating a statistically significant difference between the two groups. The mean difference of -48.09800 suggests that the first group has significantly lower nitrate levels. The confidence interval for the mean difference ranges from -50.67552 to -45.52048, and since it does not include zero, the result confirms that the difference in nitrate levels is statistically

significant. In conclusion, the t-test results show statistically significant differences in pH, potassium, sodium, magnesium, calcium, sulphate, and nitrate between the two groups, as evidenced by their p-values being less than 0.05.
These parameters show clear differences between the groups, with confidence intervals that do not include zero. In contrast, parameters such as EC, TDS, chloride, and carbonates do not exhibit significant differences, as their p-values are greater than 0.05, and their confidence intervals include zero. This suggests that while some parameters are crucial for distinguishing between the groups, others do not show meaningful differences.

Table 2: Difference between WHO and Observed levels

Parameters	t-test for Equality of Means						
	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
						Lower	Upper
pH	-6.793	24	.000	-.66080 -.66080	.09728	-.86158	-.46002
EC	1.306	24	.204	574.38040 574.38040	439.76954	-333.25931	1482.02011
TDS	.421	24	.678	167.88400 167.88400	399.05132	-655.71744	991.48544
Potassium	2.254	24	.034	41.51960 41.51960	18.41641	3.50999	79.52921
Sodium	-26.087	24	.000	-153.49040 -153.49040	5.88373	-165.63382	-141.34698
Magnesium	-76.102	24	.000	-44.58720 -44.58720	.58589	-45.79641	-43.37799
Calcium	-83.713	24	.000	-95.01960 -95.01960	1.13506	-97.36224	-92.67696
Chloride	-.378	24	.709	-46.70920 -46.70920	123.70047	-302.01443	208.59603
Sulphate	-570.534	24	.000	-248.50800 -248.50800	.43557	-249.40697	-247.60903
Carbonates	-1.113	24	.277	-56.77680 -56.77680	51.00717	-162.05043	48.49683
Nitrate	-38.513	24	.000	-48.09800 -48.09800	1.24886	-50.67552	-45.52048

Source: Field Survey, (2025)

From the t-test results, several inferences can be made based on the significant and non-significant differences observed across various parameters. These inferences help to understand the characteristics of the two groups being compared and suggest possible factors influencing the observed differences.
The significant difference in pH levels (p-value = 0.000) indicates that the two groups exhibit distinct pH characteristics. The mean difference of -0.66080 suggests that the first group has a lower pH than the second group. This could have implications for the chemical composition of the samples, as pH influences many biological and chemical processes. The lower pH in the first group may suggest more acidic conditions, which could affect the solubility of minerals and the overall health of aquatic ecosystems if these groups represent water samples.
The lack of a significant difference in EC (p-value = 0.204) suggests that the ionic strength or the presence of dissolved salts is similar between the two groups. EC is often used to assess water quality,

as higher values typically indicate higher concentrations of dissolved ions. The non-significant difference suggests that the conductivity of the two groups is comparable, meaning the levels of salts or minerals do not vary greatly between them. The TDS results, with a p-value of 0.678, show no significant difference between the groups, indicating that the total amount of dissolved solids, which reflects the overall mineral content, is similar in both groups. This suggests that neither group has significantly higher or lower concentrations of dissolved substances, which can include salts, minerals, and organic matter.

The significant difference in potassium levels (p-value = 0.034) suggests that the first group has notably higher potassium concentrations. Potassium is essential for many biological functions, and higher levels in the first group might indicate a specific environmental factor, such as agricultural runoff or higher soil potassium levels, which could be influencing the concentration in water or samples from the first group. The significant difference in sodium levels (p-value = 0.000), with the first group having lower sodium concentrations, could indicate differences in the sources of water or other environmental conditions between the two groups. Low sodium levels might suggest more freshwater conditions, while higher sodium concentrations could be associated with saline or brackish environments. The significant difference in magnesium levels (p-value = 0.000) implies that the first group has lower magnesium concentrations. Magnesium is a key element in water chemistry, affecting water hardness and biological processes. The lower magnesium levels in the first group could indicate softer water, which may have implications for aquatic life and ecosystem health.

The significant difference in calcium levels (p-value = 0.000), with the first group having lower levels, suggests variations in water hardness between the groups. Calcium is another important component of water hardness, and the difference may reflect differences in the geology of the areas from which the groups are derived, with the first group potentially coming from regions with lower calcium concentrations. Conversely, the lack of a significant difference in chloride levels (p-value = 0.709) indicates that the concentration of chloride ions is similar in both groups. Chloride is commonly used as a marker for salinity, and the lack of significant difference suggests that the salinity levels between the two groups are comparable.

The highly significant difference in sulphate levels (p-value = 0.000) suggests that the first group has lower sulphate concentrations. Sulphate levels can be influenced by both natural sources (such as the weathering of minerals) and anthropogenic activities (such as industrial discharges). The lower sulphate levels in the first group might suggest less pollution or different water chemistry compared to the second group. Also, the lack of a significant difference in carbonates (p-value = 0.277) suggests that carbonate levels, which are related to water buffering capacity, are similar across the two groups. This implies that the groups do not differ substantially in terms of their ability to buffer pH changes, which can have implications for the stability of aquatic ecosystems. Finally, the significant difference in nitrate levels (p-value = 0.000), with the first group having lower nitrate concentrations, suggests that the first group may be exposed to fewer anthropogenic inputs, such as agricultural runoff or wastewater contamination, which often contribute to high nitrate levels. Lower nitrate levels in the first group might also indicate better water quality, especially in regions where excess nutrients can lead to eutrophication and environmental degradation.

Overall, the inferences suggest that some key parameters, such as pH, potassium, sodium, magnesium, calcium, sulphate, and nitrate, exhibit distinct differences between the two groups. These differences may be influenced by environmental factors such as water source, land use, pollution levels, or natural geological variations. In contrast, parameters like EC, TDS, chloride, and carbonates show no significant differences, indicating that these factors are more consistent across the groups. The results suggest that the two groups may differ in terms of water quality and environmental conditions, particularly in relation to specific ions like potassium, sodium, magnesium, and sulphate.

Spatial Analysis of Water Quality Parameters

In order to examine the spatial variation of the water quality parameters under consideration, the geo-statistical technique Kriging was employed to examine these parameters over space utilising the obtained coordinates. The result Average Mean Square Error (AMSE) of the Kriging statistical technique was first presented in a table, then a plot showing the observed values against the predicted values was also obtained, finally spatial prediction maps were generated to depict the spatial variation of the parameters.

The Average Mean Square Error (AMSE) values presented in the table 3, offer valuable insights into the spatial distribution and consistency of various parameters within the study area. Parameters such as pH, Electrical Conductivity (EC), Total Dissolved Solids (TDS), sulphate, and carbonates have relatively low AMSE values, ranging from 0.929 to 0.994. These values suggest that the concentrations of these substances are fairly stable across the region, with minimal spatial variation. The low AMSE values indicate that the observed levels are closely aligned with the expected or predicted values, meaning these parameters are relatively predictable and show consistent behaviour across different spatial locations. For example, pH, EC, and TDS all display similar patterns of uniform distribution, suggesting that factors influencing these parameters are relatively constant across the study area.

On the other hand, parameters such as potassium, sodium, magnesium, chloride, and calcium show slightly higher AMSE values, ranging from 1.008 to 1.089. These values indicate a moderate level of spatial variation, meaning that while these parameters generally follow a predictable trend, there are localized differences in their concentrations. For example, sodium and potassium levels may vary more in certain areas, possibly due to different environmental influences or natural variations in the local water chemistry. The slightly elevated AMSE values suggest that there is some degree of error in predicting the exact concentrations of these elements at specific locations, though the variation is still relatively minimal compared to more erratic parameters.

The most notable exception is nitrate, which exhibits the highest AMSE value of 1.240. This large value indicates that nitrate concentrations are highly variable across the study area. The high AMSE suggests that nitrate levels fluctuate significantly between locations, making them less predictable than other parameters. Such variation could be due to localized environmental factors, such as agricultural runoff, wastewater discharge, or varying land use practices that influence nitrate concentrations differently across the region. The higher spatial variation in nitrate levels could point to areas where human activities or natural processes are contributing to significant differences in nitrate contamination.

In conclusion, the AMSE values suggest that most of the parameters in the study exhibit relatively stable and predictable spatial distributions, with minimal errors or deviations from expected values. However, parameters like potassium, sodium, magnesium, chloride, and calcium show slight variation, indicating that there are some localized differences in their concentrations. Nitrate, with the highest AMSE value, stands out as the most erratic parameter, reflecting considerable spatial variability that could be attributed to environmental or anthropogenic factors. This analysis highlights the importance of considering spatial variation when interpreting the data, as some parameters are more consistently distributed than others across the study area.

Table 3: Spatial Distribution Statistics

Parameter	AMSE
pH	0.945
EC	0.940
TDS	0.929
Potassium	1.012
Sodium	1.021
Magnesium	1.027
Calcium	1.089
Chloride	1.031
Sulphate	0.994
Carbonates	1.008
Nitrate	1.240

Source: Field Survey, (2025)

The kriging analysis (figure 3), revealed that low levels of pH are clustered toward northwest of the study area (sample points 16, 20, and 23) stretching towards the centre region of the study area while higher values of pH was discovered to be clustered towards the south eastern region of the study area (sample points 8, 9, and 12). A prediction/spatial variation kriging analysis (figure 4) was generated to show the variation of E.C across the study area. The coordinates of the sample points were used to aid in the depiction of the parameter over space. The kriging analysis revealed that low levels of E.C are clustered toward northwest of the study area stretching towards the centre region of the study area while higher values of E.C was discovered at two sample points; point 7 and 14. The observed TDS values as obtained from laboratory analysis ranged between 142 to 1,720 g/mol. The spatial variation of TDS was depicted with aid of a prediction/spatial variation kriging analysis (figure 5) which was generated to show the variation of TDS across the study area. The coordinates of the sample points were used to aid in the depiction of the parameter over space. The kriging analysis revealed that lower levels of TDS are clustered toward southeast of the study area stretching from the centre region of the study area while higher values of TDS was discovered at three sample points; point 20, 21, and 23, which are dispersed in pattern.

The kriging analysis revealed (figure 6) that higher concentration levels of Potassium (K^+) are clustered toward east of the study area while lower concentration values of Potassium (K^+) was observed towards the southeast section of the study area. Mid-range values were observed to be dispersed across the study area. The kriging analysis revealed that higher concentration levels of Sodium (Na^+) (figure 7) are clustered toward east of the study area while lower concentration values of Sodium (Na^+) was observed towards the southeast section of the study area. Mid-range values were observed to be dispersed across the study area. The kriging analysis revealed that higher concentration levels of Magnesium (Mg^{2+}) (figure 8) are clustered toward east of the study area while lower concentration values of Magnesium (Mg^{2+}) was observed towards the southeast section of the study area. Mid-range values were observed to be dispersed across the study area. The kriging analysis revealed that higher concentration levels of Calcium (Ca^{2+}) (figure 9), was recorded at only Sample station 1 (SS-1) towards the southeast of the study area while lower concentration values of Calcium (Ca^{2+}) was dispersed across the study area. Mid-range values were observed to be sparsely located across the study area.

The kriging analysis revealed that higher concentration levels of Chloride (Cl^-) (figure 10), was recorded at only Sample stations 23 and 25 (SS-23 and SS-25) towards the northwest, and at sample station 9 (SS-9) at the southeast end of the study area, while lower concentration values of Chloride (Cl^-) was dispersed across the study area spreading from the east section downwards towards the southwest of the study area. Mid-range values were observed to be dispersed across the study area. The kriging analysis revealed that higher concentration levels of Sulphate (SO_4^{2-}) (figure 11), was recorded at only Sample stations 12 (SS-12) towards the southeast end of the study area, while lower concentration values of Sulphate (SO_4^{2-}) was clustered around the northwest section of the study area at Sample stations 22 and 23 (SS-22 and SS-23). Mid-range values were observed to be dispersed across the study area. The kriging analysis revealed that higher concentration levels of Carbonate (HCO_3^-) (figure 12), was recorded at Sample station 11 (SS-11) in the southeast and Sample station 23 (SS-23) in the northwest end of the study area, while Mid-range concentration and lower concentration values of Carbonate (HCO_3^-) was dispersed across the study area.

The kriging analysis revealed that higher concentration levels of Nitrates (NO_3^-) (figure 13), was recorded at Sample station 19 (SS-19) towards the northeast and Sample station 20 (SS-20), and 18 (SS-18) towards the mid-region of the study area, while lower concentration values of Nitrates (NO_3^-) was clustered in the northwest of the study area. Mid-range concentration values are dispersed across the study area.

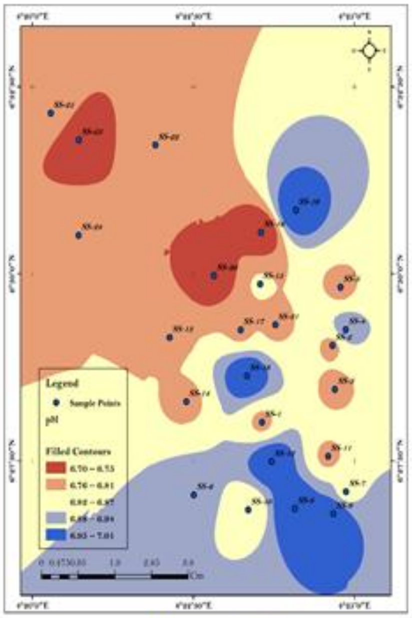

Figure 3. pH

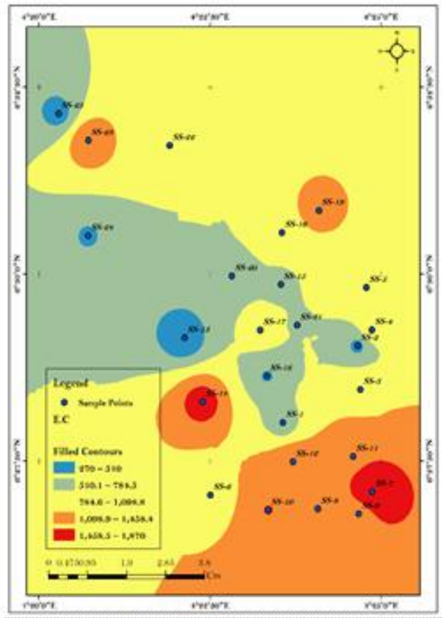

Figure 4. E.C

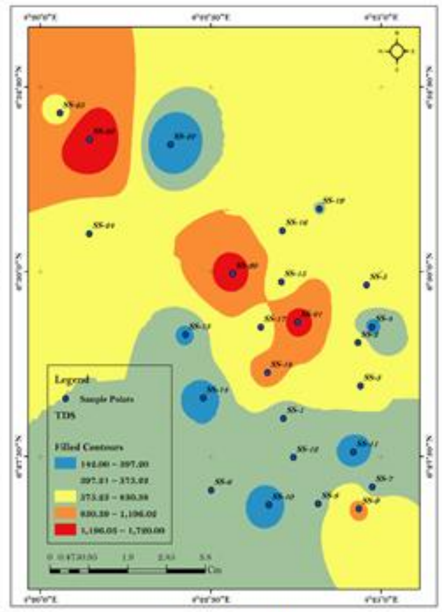

Figure 5. TDS

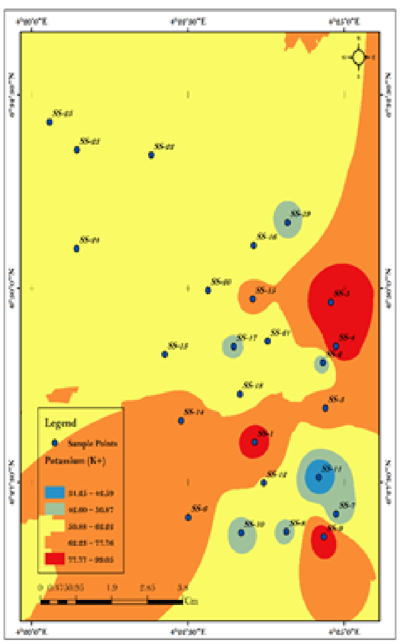

Figure 6. Potassium

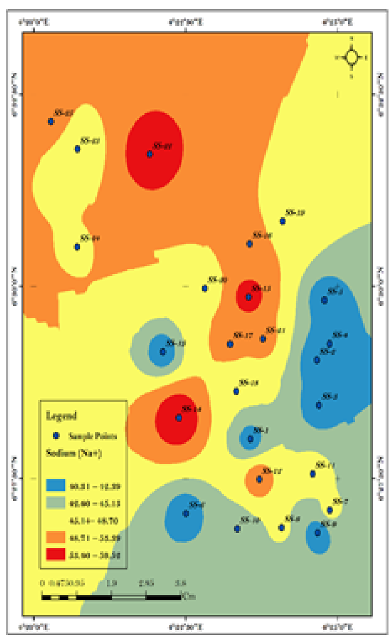

Figure 7. Sodium

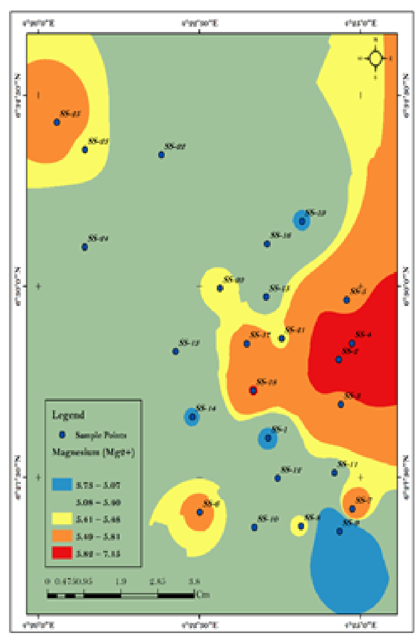

Figure 8. Magnesium

Source: Field Survey, (2025)

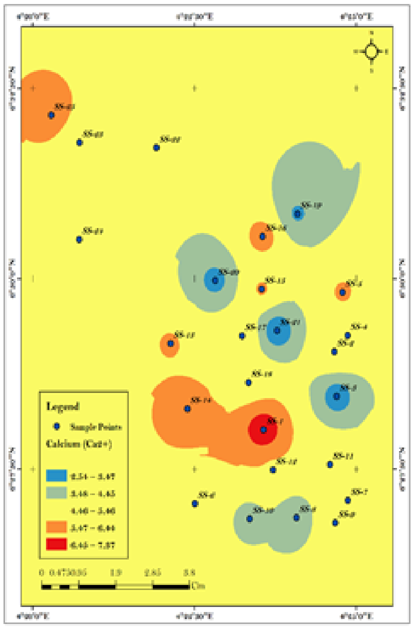

Figure 9. Calcium

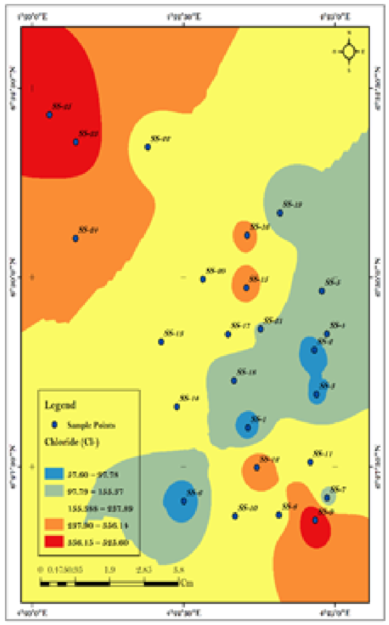

Figure 10. Chloride

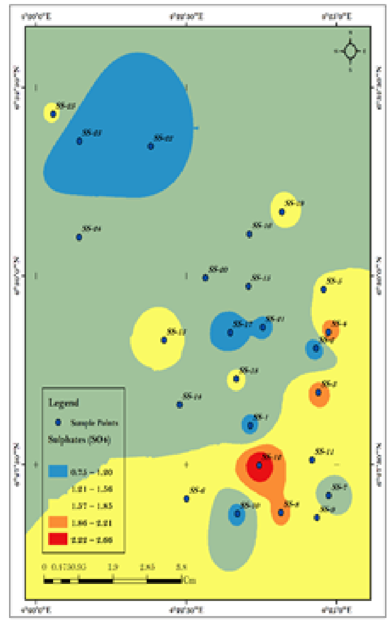

Figure 11. Sulphates

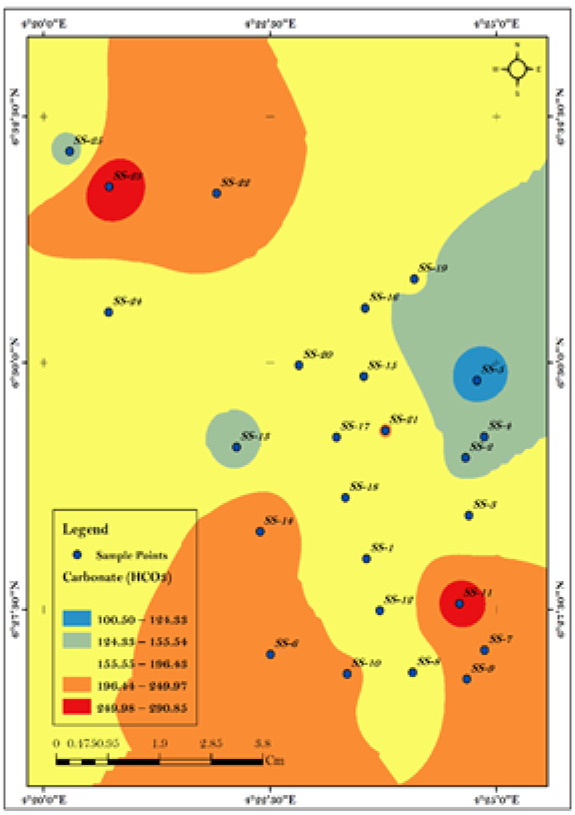

Figure 12. Carbonates

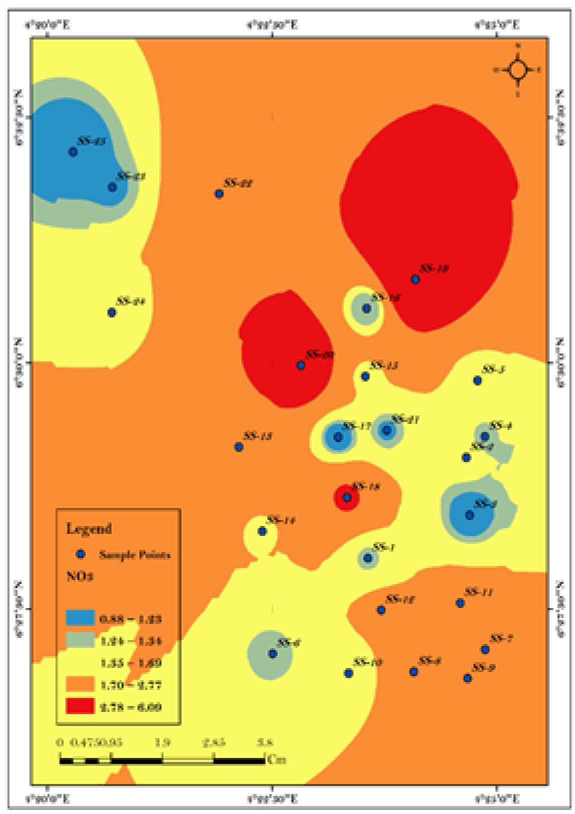

Figure 13. Nitrates

Source: Field Survey, (2025)

CONCLUSION AND RECOMMENDATIONS

In conclusion, the spatial distribution statistics using Average Mean Square Error (AMSE) values indicates that most of the parameters exhibit relatively stable and predictable distributions across the study area. Parameters such as pH, Electrical

Conductivity (EC), Total Dissolved Solids (TDS), sulphate, and carbonates demonstrate low AMSE values, suggesting minimal spatial variation and consistent concentrations throughout the region. These parameters are generally influenced by stable environmental factors, making their spatial distribution predictable. In contrast, parameters like potassium, sodium, magnesium, chloride, and calcium show slight variation, with moderate AMSE values, pointing to some localized differences in concentrations. The most significant finding is the high spatial variability in nitrate concentrations, as reflected by its highest AMSE value. This suggests that nitrate levels are more influenced by localized factors such as agricultural runoff, wastewater discharge, and differing land-use practices, leading to significant spatial differences in concentrations.

Based on these findings, several recommendations can be made. It is crucial to monitor and manage nitrate concentrations carefully, as their high spatial variability may indicate areas where pollution or nutrient runoff is more pronounced. Implementing targeted strategies for managing agricultural runoff, wastewater discharge, and land-use practices could help mitigate nitrate contamination in areas with high variability. Additionally, while most of the parameters show consistent distributions, continued monitoring of elements like sodium, potassium, and calcium is recommended to identify any emerging trends or localized sources of variation. Furthermore, the stable performance of parameters such as pH, EC, and TDS suggests that these may serve as reliable indicators for assessing overall water quality across the region. Future research should focus on understanding the specific environmental or anthropogenic factors contributing to the observed spatial variability, particularly in relation to nitrate, to enhance environmental management practices and improve water quality across the study area.

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