
SPATIAL VARIATION ASSESSMENT OF GROUNDWATER QUALITY IN IWO LOCAL GOVERNMENT AREA, OSUN STATE, NIGERIA.

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DOI: <https://doi.org/10.67203/sp.ICESID.2026>

ABSTRACT

Groundwater is the primary water source for over 60 % of Nigerians, but uncontrolled urban pollution infiltrates and contaminates the aquifer. Groundwater samples for the current study were collected from Iwo Local Government Area to investigate groundwater resources and generate spatial water-quality variation maps across seasons. The groundwater samples were chosen to represent the entire study area's built-up portion adequately. The physico-chemical parameters were measured during rainy and dry seasons. Parameters analysed were temperature, turbidity, pH, electrical conductivity, total suspended solids, total dissolved solids, total alkalinity, total hardness, chloride, sulphate, nitrate, phosphate, magnesium, total coliform, and calcium. The simple kriging interpolation method was used to generate groundwater quality maps for the selected groundwater quality parameters. The water quality data were linked to the sampling location (spatial) in ArcGIS, and maps were generated to show spatial distribution. Although most of the water quality parameters median range values of the various groundwater resources were satisfactory throughout the seasons, total hardness of 228.3 mg/l – 596.6 mg/l, calcium of 16 mg/l - 236.8 mg/l, sulphate of 219 mg/l – 354 mg/l, and phosphate of 0.30 mg/l – 3.42 mg/l were the groundwater quality parameters with spatial variations over the World Health Organisation standard values of 150 mg/l, 75 mg/l, 250 mg/l, and 0.05 mg/l respectively, for both rainy and dry seasons. It is suggested that all sources be monitored regularly and that treatments to improve total hardness be implemented.

Keywords: Geostatistical Analysis; Groundwater Quality Maps; Kriging Spatial Distribution; Iwo Local Government Area

1. INTRODUCTION

Increasing attempts for a better living level include reinstating a sufficient supply of drinkable water (United Nations Environment Programme, 2011). According to Abel and Adebayo (2017), water quality is defined as the physical, chemical, and microbiological attributes of water, which are evaluated by comparing concentrations of water quality measures to acceptable levels. Water of high quality has been defined as that supplied by waterworks and groundwater (Yan *et al.*, 2022; Kløve *et al.*, 2017).

However, the lack of high-quality surface water has increased groundwater consumption due to fast industrialisation and population growth (Ezechinyere and Stanislaus, 2023; Nas, 2009). Recently, many parts of the world, particularly Nigeria, have seen a decline in both the quantity and quality of groundwater sources (Adetona and Oladepo, 2021; Mahapatra *et al.*, 2012). These studies have used a water quality index to identify specific contaminated groundwater sources, without considering spatial kriging mapping for unsampled regions. Atobatele *et al.* (2026) have reported toxic heavy metal parameters in Iwo Local Government Area. While studies have reported microbial contamination in some of these groundwater sources in Nigeria (Izah *et al.*, 2022).

Some of the reported groundwater sources were close to contamination sources such as septic tanks and refuse dumpsites. Due to a lack of enough land space, septic tanks were mainly placed very close to groundwater sources. Insufficient sanitary landfills also caused refuse dumpsites to be commonly located near undeveloped land or foundations (Olayinka *et al.*, 2025). Abel and Adebayo (2017) stated that awkward and unsystematic waste discharged into the environment had increased the rate of sickness from groundwater.

Groundwater quality studies conducted in the Iwo Local Government Area demonstrated the need for regular groundwater quality assessments. Olutona *et al.* (2012) proposed that the physicochemical and microbiological analyses of groundwater in the Iwo Local Government Area be assessed regularly. The regular evaluation will aid in the early detection of any potential future degradation. Ogunbode and Ifabiyi (2014) also recommended that more research be done on the water quality in the Iwo Local Government Area. At the regional level, enough research has been done on the drinking and irrigation aspects of groundwater. On the other hand, little research has been done on groundwater quality assessment in the Iwo Local Government Area of Southwestern Nigeria. It is, therefore, essential to take representative samples according to the political wards in Iwo Local Government Area and evaluate the spatial distribution of groundwater quality from those sampled locations across the Iwo Local Government Area.

A more comprehensive diagnosis of the current state of contamination and close monitoring of its evolution is critical for preserving this resource. The fundamental goal of a monitoring programme is to collect and analyse a large number of groundwater samples in order to assess spatial changes (Ahmed, 2017). As a result, geographical monitoring of groundwater quality parameters is crucial, which is why this research was carried out. The present study aims to assess the spatial variations of groundwater quality parameters in Iwo Local Government Area, Osun State, Southwestern Nigeria. It's critical to understand the nature and chemistry of groundwater fluctuations because of natural and anthropogenic processes (Richardson *et al.*, 2024).

2. METHODOLOGY

2.1 Description of the Study Area

Iwo is one of the local government areas of Osun State, Nigeria. It is 245 km² in size. It is grouped according to local government clusters, namely: Isale Oba, Molete, Oke Adan, Gidigbo, and Oke Oba. These were subdivided further into the established 15 political wards. Rural, agricultural, and urban areas are all covered by the local government. Iwo town is formed by the urban region, located between Latitude 07°38' N to 07°40' N and Longitude 004°09' E to 004°11' E.

The Aiba water reservoir, which is located within a government forest reservation area in Iwo, is the town's principal source of drinkable water. Unfortunately, poor management and a rise in the area's population have resulted in an insufficient supply of drinkable water from the waterworks. The town's subsurface water sources were exploited as a result of this.

2.2 Climatic Setting

In the southern area of Nigeria, yearly rainfall ranges from 150 to 300 cm. Mean maximum ambient temperatures range from 33.84 °C in February to 28.8 °C in August, with mean minimum temperatures ranging from 25.18 °C in March to 23.0 °C in August.

2.3 Experimental Setup and Methods

Water samples were collected from 30 different locations and sources as detailed in Table 1. The population that relies on groundwater for drinking was the focus of the sampling. Groundwater sources were stratified and located at random using hand-held Global Positioning System (GPS) technology. In urban areas, most wells were lined; however, in rural regions, wells were unlined and operated by hand pumps. A hand-held GPS was used to record the location of each well.

The sampling was done twice, first during the rainy season (October) and again during the dry season (January). Samples were collected during these representative months of the two seasons, which were later periods of the two seasons, so that the samples could be a true representation of the seasons. There was a lot of rain during October and November, and the month of January was extremely cold. The samples were pulled from shallow wells with a plastic bucket and gathered from the taps of hand pump wells and boreholes.

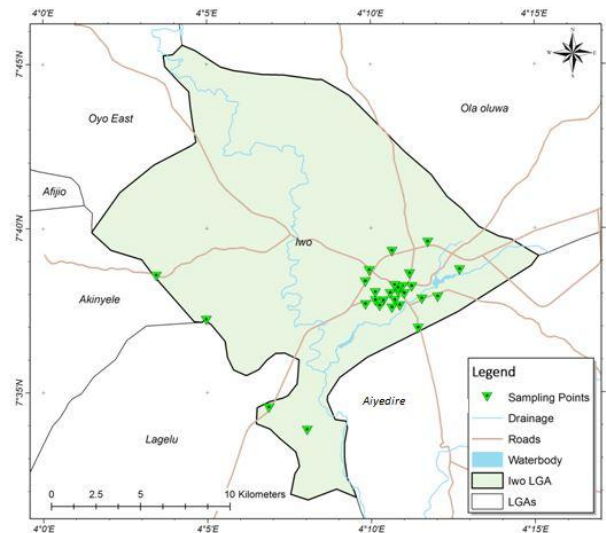


Figure 1: Study Area Map

Some experimental values were obtained on the spot, while others were obtained in the lab using three replicates and standard procedures. Before sampling, all glassware and sample bottles were cleansed with liquid detergents and rinsed with distilled water. To minimise confusion, the plastic bottles used for sampling were labelled according to political wards and then rinsed three times on-site with the groundwater being sampled. A two-litre water sample was obtained for physical and chemical characteristics, while a small, autoclaved glassware sample was collected for microbiological investigation. Before analysis, the samples were kept in the refrigerator for 5 hours (Jeje and Oladepo, 2014b). This was done to keep the physical, chemical, and microbiological qualities intact.

SPATIAL VARIATION ASSESSMENT OF GROUNDWATER QUALITY IN IWO LOCAL
GOVERNMENT AREA, OSUN STATE, NIGERIA.

Table 1: *Locations of Selected Hand Pump Boreholes, Boreholes, and Shallow Wells Within the Study Area*

S/N	Political ward	Location	Type of well	Depth (m)
1	Isale Oba Ward 01	Oke–Ola	Motorized Borehole	45
2	Isale Oba Ward 01	Palace road	Lined Well	4.57
3	Isale Oba Ward 02	Akinfenwa	Lined Well	4.86
4	Isale Oba Ward 02	Old barrack	Motorized Borehole	45
5	Isale Oba Ward 03	Hospital Gate	Lined Well	5.05
6	Isale Oba Ward 03	MOT junction	Motorized Borehole	45
7	Isale Oba Ward 04	Orikan Compd.	Lined Well	6.54
8	Isale Oba Ward 04	Oke odo	Lined Well	4.76
9	Molete Ward 05	Moseru Compd.	Lined Well	5.42
10	Molete Ward 05	Oja Oba	Lined Well	4.10
11	Molete Ward 06	Oriolowo	Motorized Borehole	50
12	Molete Ward 06	Gaa – Fulani	Hand Pump Well	-
13	Molete Ward 07	Molete ward 3	Lined well	8.92
14	Molete Ward 07	Saabo	Lined Well	5.46
15	Oke Adan Ward 08	Omosan Compd.	Unlined Well	3.45
16	Oke Adan Ward 08	Jagun Ilu Compd.	Unlined Well	4.12
17	Oke Adan Ward 09	Ponkuku compd.	Motorized Borehole	45
18	Oke Adan Ward 09	Lakata Compd.	Unlined well	3.78
19	Oke Adan Ward 10	KLM, Feesu	Motorized Borehole	45
20	Oke Adan Ward 10	Itesiwaju, Odoori	Motorized Borehole	50
21	Gidigbo Ward 11	Aipate	Lined Well	4.35
22	Gidigbo Ward 11	Owoeye Bus Stop	Motorized Borehole	45
23	Gidigbo Ward 12	Abanise	Motorized Borehole	45
24	Gidigbo Ward 12	Oke bode	Lined Well	4.56
25	Gidigbo Ward 13	Adeeke	Lined Well	5.25
26	Gidigbo Ward 13	Laito	Motorized Borehole	50
27	Oke Oba Ward 14	Agberire	Hand Pump Borehole	-
28	Oke Oba Ward 14	Alagbon	Hand Pump Borehole	-
29	Oke Oba Ward 15	Papa	Hand Pump Borehole	-
30	Oke Oba Ward 15	Mojibere Village	Unlined Well	8.36

Note: Hand pump boreholes were inaccessible for the measurement of depth.

The physical, chemical, and microbiological parameters such as temperature, turbidity, pH, electrical conductivity, total suspended solids, total dissolved solids, total alkalinity, total hardness, chloride, sulphate, nitrate, phosphate, magnesium, calcium, and total coliform were determined for the

collected water samples. All tests were conducted in line with research carried out by Olutona *et al.* (2012) and Ogunbode and Ifabiyi (2014).

With the help of a pH metre, a thermometer, and a platinum electrode conductivity metre, water samples were evaluated for hydrogen ion concentration (pH), temperature, and electrical conductivity (EC). A total dissolved solids meter was used to calculate the total dissolved solids (TDS). Titrimetric determination of chloride (Cl⁻) was performed using standard silver nitrate titration. The phosphate content (PO₄³⁻) of the water samples was evaluated using a colourimetric technique after digestion with concentrated sulphuric acid. The turbidimetric method with a spectrophotometer was used to determine the sulphate (SO₄²⁻). The standard Ethylene Diamine Tetra Acid (EDTA) titration method was used to determine the hardness (TH), which was buffered at pH 10. The amount of calcium (Ca) in water hardness was determined using the complexometric titration method, which involved titrating the water sample with a known concentration and volume of EDTA.

The difference between total and calcium hardness, reported as CaCO₃ equivalent, was used to calculate the presence of magnesium (Mg). Using phenolphthalein and mixed indicators, the total alkalinity (T. Al.) of the water samples was evaluated by titrating 100 mL of the samples with 0.2 N sulfuric acid solution. Total suspended solids (TSS) were determined using gravimetric measurement involving heating the sample in an oven, followed by cooling in a desiccator. An electronic turbidimeter with scattered-light detectors was used for turbidity (Turb.) measurement. Nitrate (NO₃⁻) was determined by the colourimeter method using a UV-VIS spectrophotometer. The membrane filtration method was used to get total coliform (TCC) in the water samples (microbiological analysis). The simple kriging method of interpolation was used to determine the groundwater quality of unsampled regions of Iwo Local Government Area.

2.4 Spatial Variation Assessment

The simple kriging method was used to generate groundwater quality maps for the selected groundwater quality parameters. The water quality data were linked to the sampling location (spatial) in ArcGIS, and maps showing spatial distribution were prepared to easily identify the variation in concentrations of the groundwater parameters at various study area locations. Spatial variation was evaluated using Simple Kriging (SK), which assumes a known stationary mean (μ) across the study area. Experimental semivariograms were computed to quantify spatial continuity using the isotropic semivariance equation:

$$\gamma(h) = \frac{1}{2N(h)} \sum_{i=1}^{N(h)} [Z(x_i) - Z(x_i+h)]^2 \quad (1)$$

where;

$\gamma(h)$ is the semivariance at lag distance h ,

$N(h)$ is the number of paired measurement points separated by distance h , and

$Z(x_i)$ and $Z(x_i + h)$ represent parameter values at spatial locations x_i and $x_i + h$.

The Simple Kriging estimator was defined as:

$$Z^*(x_0) = \mu + \sum_{i=1}^n \lambda_i [Z(x_i) - \mu] \quad (2)$$

Where;

$Z^*(x_0)$ is the estimated value at unsampled location x_0 ,

μ is the stationary sample mean,

n is the number of neighbouring observations, and

λ_i are the kriging weights derived from the covariance matrix.

Empirical semivariograms were fitted against theoretical models (Spherical, Exponential, and Gaussian) using non-linear least squares. The optimal model was selected based on minimizing the mean squared error. Geostatistical parameters nugget variance (C_0), structural variance (C), total sill ($C_0 + C$), and spatial range (a) were extracted. The spatial dependence ratio ($[C_0 / (C_0 + C)] \times 100$) was calculated to classify spatial autocorrelation as strong (<25%), moderate (25%–75%), or weak (>75%). Model performance and interpolation reliability were validated using Leave-One-Out Cross-Validation

(LOOCV). Interpolation accuracy was evaluated using Root Mean Square Error (RMSE), Mean Absolute Error (MAE), and the coefficient of determination (R^2). The ArcGIS software automatically executed all of these mathematical steps in the background while using the Simple Kriging interpolation. The environmental maps prepared from the water quality test results gave the groundwater quality characteristics of the Iwo Local Government Area.

3. RESULTS AND DISCUSSION

The deployment of geostatistical simple kriging interpolation in Iwo mirrors recent findings by studies in the Ibadan Metropolis, where Kriging and factor analysis were integrated to model groundwater variability (Thomas, 2023). Simple kriging was used consistently for all parameter maps.

3.1 pH

The five colours denoting the spatial variation of hydrogen ion concentration (pH) during the rainy and dry seasons were green, yellow, orange, brown, and grey, ranging between 5.5 and 6.5, 6.51 and 7.5, 7.51 and 8.5, 8.51 and 9.5, and 9.51 and 10.5, respectively, as shown in Figure 2a and b.

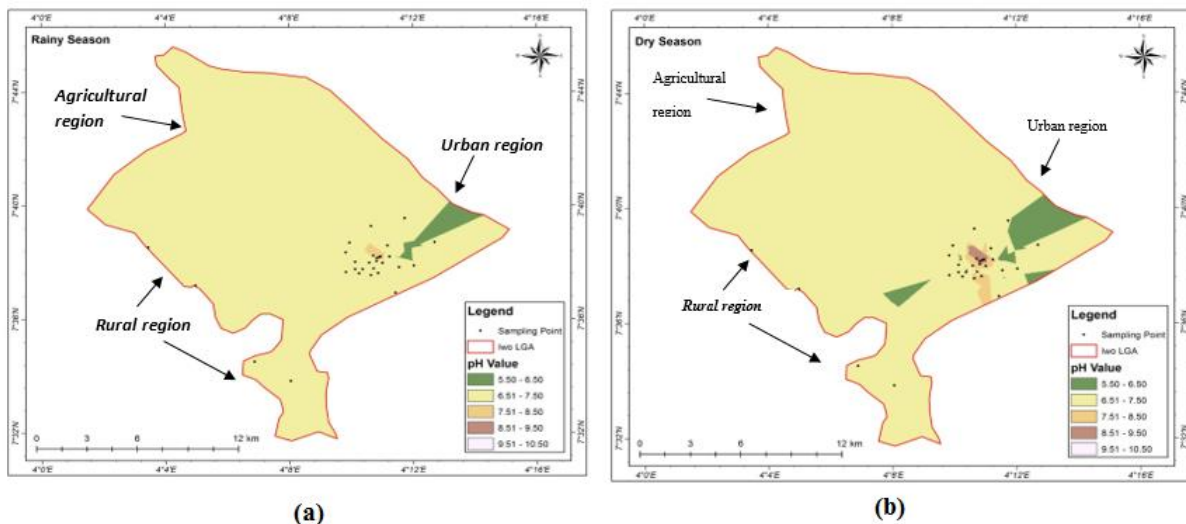


Figure 2: Spatial Variation of Hydrogen Ion Concentration (a) Rainy Season (b) Dry Season

The yellow and orange colours of the spatial variation correlated with the pH range standard values of 6.5 and 8.5. In Figure 2a, the yellow colour occurred mainly. This denoted that the groundwater pH of the study area was acceptable. However, some north-eastern parts of the study area were acidic, having a pH value less than 6.5. In Figure 2b, the yellow colour occurred around the rural and agricultural regions of the study area. These rural and agricultural regions included the last two political wards of Oke Oba Ward 14 and Oke Oba Ward 15. This denoted that the hydrogen ion concentrations of these regions' groundwater were acceptable. However, it increased from the rainy season to the dry season primarily due to extended water-rock interaction times during the dry season (Zhang *et al.*, 2023; Subba Rao, 2005).

3.2 Temperature

The five colours denoting the spatial variation of temperature during the rainy and dry seasons were green, yellow, orange, brown, and grey, ranging between 14.0 °C and 17.2 °C, 17.3 °C and 20.4 °C, 20.5 °C and 23.4 °C, 23.5 °C and 26.8 °C, and 26.9 °C and 30.5 °C, respectively, as shown in Figure 3 a and b.

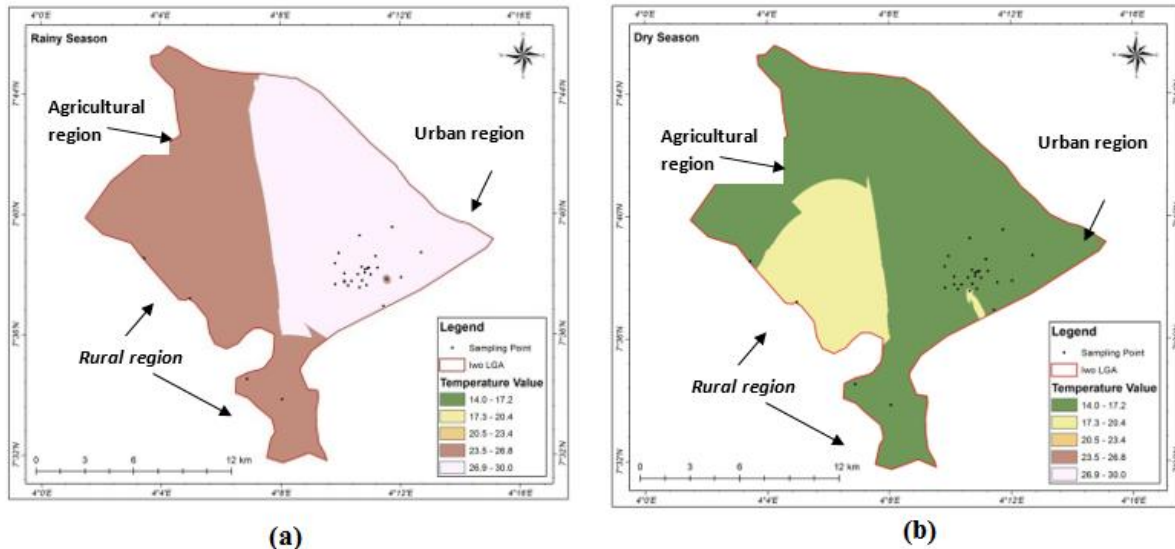


Figure 3: Spatial Variation of Temperature Concentration (a) Rainy Season (b) Dry Season

The green, yellow, and orange colours of the spatial variation correlated with the temperature standard value ($< 25\text{ }^{\circ}\text{C}$). In Figure 3a, the brown colour occurred mainly around the rural and agricultural region of the study area, which varied from $23.5\text{ }^{\circ}\text{C}$ and $26.8\text{ }^{\circ}\text{C}$. This denoted that the groundwater temperatures of these regions were still acceptable, which is slightly above $25\text{ }^{\circ}\text{C}$.

3.3 Electrical Conductivity

The five colours denoting the spatial variation of electrical conductivity during the rainy and dry seasons were green, yellow, orange, brown, and grey, ranging between $50\text{ }\mu\text{S/cm}$ and $410\text{ }\mu\text{S/cm}$, $411\text{ }\mu\text{S/cm}$ and $770\text{ }\mu\text{S/cm}$, $771\text{ }\mu\text{S/cm}$ and $1130\text{ }\mu\text{S/cm}$, $1131\text{ }\mu\text{S/cm}$ and $1490\text{ }\mu\text{S/cm}$, and $1491\text{ }\mu\text{S/cm}$ and $1850\text{ }\mu\text{S/cm}$, respectively, as shown in Figures 4a and b.

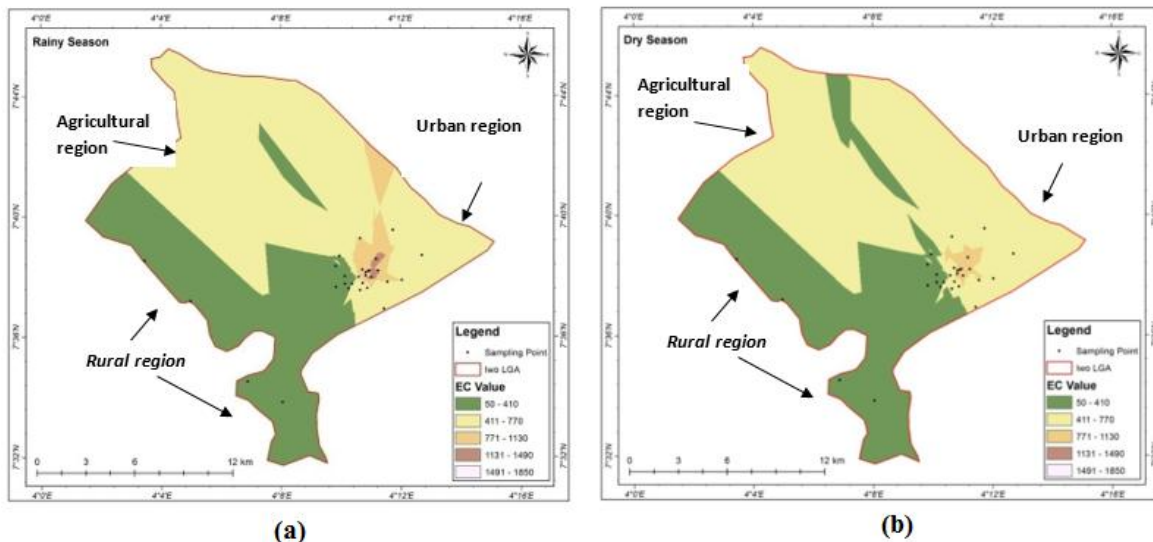


Figure 4: Spatial Variation of Electrical Conductivity Concentration (a) Rainy Season (b) Dry Season

The green, yellow, and orange colours of the spatial variation correlated with the standard value of electrical conductivity, which was less than $1000\text{ }\mu\text{S/cm}$. In Figure 4a, the green colour occurred mainly around the rural region and some parts of the agricultural and urban regions, which varied from $50\text{ }\mu\text{S/cm}$ and $410\text{ }\mu\text{S/cm}$. The other urban region displayed yellow and orange colours. These denoted that the groundwater electrical conductivity of these regions was acceptable, which were majorly below $1000\text{ }\mu\text{S/cm}$.

3.4 Total Dissolved Solids

The five colours denoting the spatial variation of total dissolved solids during the rainy and dry seasons were green, yellow, orange, brown, and grey, ranging between 30 mg/l and 228 mg/l, 229 mg/l and 426 mg/l, 427 mg/l and 624 mg/l, 625 mg/l and 822 mg/l, and 823 mg/l and 1020 mg/l, respectively as shown in Figure 5 a and b.

The spatial variations in green, yellow, and orange colours were within the permissible limit of total dissolved solids (500 mg/l). The green, yellow, and orange colours occurred mainly around the study area in both figures. This denoted that the total dissolved solids of the groundwater around these regions were acceptable, as they were mainly below 500 mg/l.

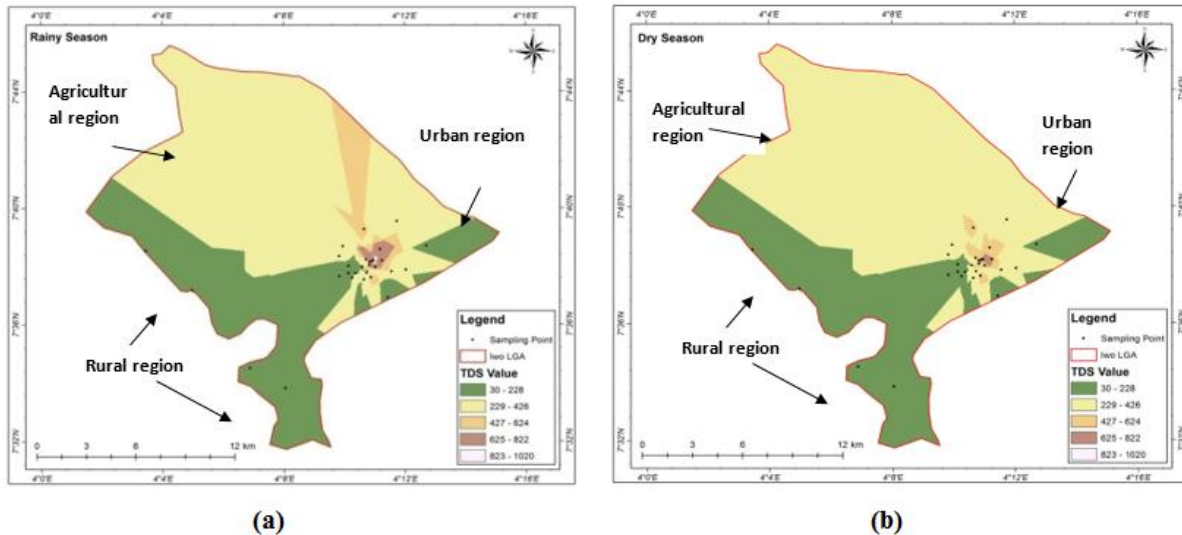


Figure 5: Spatial Variation of Total Dissolved Solids Concentration (a) Rainy Season (b) Dry Season

3.5 Total Suspended Solids

The five colours denoting the spatial variation of total suspended solids during the rainy and dry seasons were green, yellow, orange, brown, and grey, ranging between 50 mg/l and 130 mg/l, 131 mg/l and 210 mg/l, 211 mg/l and 290 mg/l, 291 mg/l and 370 mg/l, and 371 mg/l and 450 mg/l, respectively as shown in Figure 6 a and b.

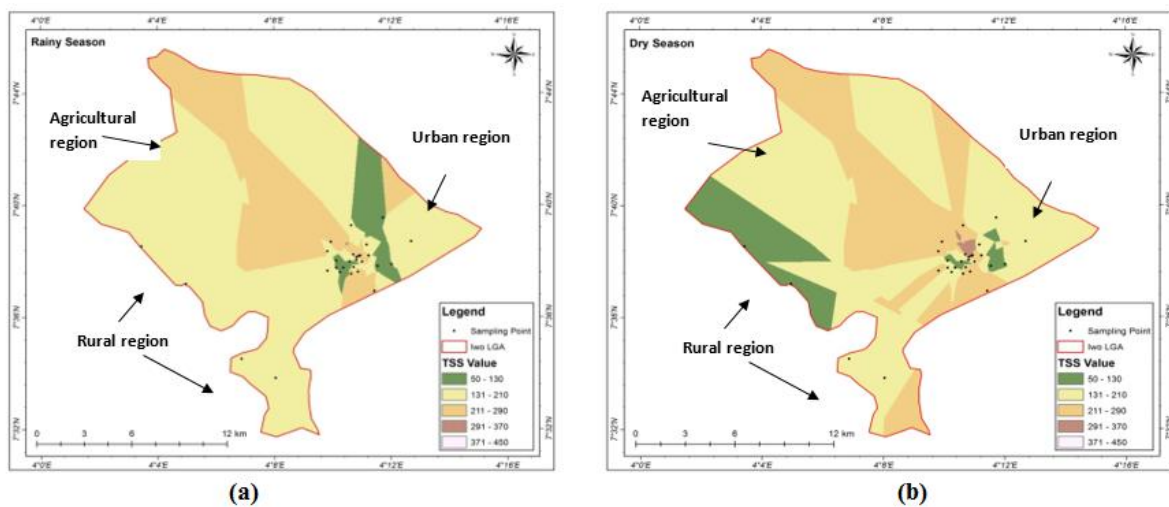


Figure 6: Spatial Variation of Total Suspended Solids Concentration (a) Rainy Season (b) Dry Season

The green and yellow colours occurred mainly around the rural region for the rainy and dry seasons. This denoted that the groundwater's total suspended solids around this region were acceptable, which was mainly below 250 mg/l.

3.6 Calcium

The five colours denoting the spatial variation of calcium during the rainy and dry seasons were green, yellow, orange, brown, and grey, ranging between 16.0 mg/l and 89.6 mg/l, 89.7 mg/l and 163.2 mg/l, 163.3 mg/l and 236.8 mg/l, 236.9 mg/l and 310.4 mg/l, and 310.5 mg/l and 384.0 mg/l, respectively, as shown in Figure 7 a and b.

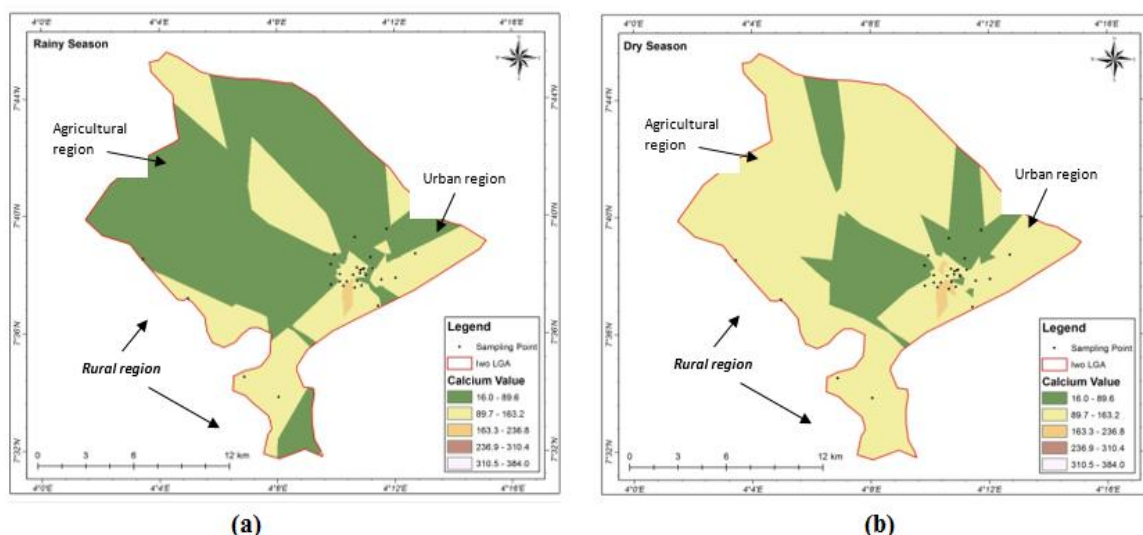


Figure 7: Spatial Variation of Calcium Concentration (a) Rainy Season (b) Dry Season

The green and yellow colours occurred mainly around the rural region for the rainy and dry seasons. This denoted that the groundwater calcium around this region was acceptable, which was mainly below 200 mg/l. The central part of the city displayed green, yellow, and orange colours, which indicated that its calcium ranged between 16 mg/l and 236.8 mg/l, which was unacceptably higher than 75 mg/l WHO standard.

3.7 Chloride

The five colours denoting the spatial variation of chloride during the rainy and dry seasons were green, yellow, orange, brown, and grey, ranging between 12.0 mg/l and 72.6 mg/l, 72.7 mg/l and 133.2 mg/l, 133.3 mg/l and 193.8 mg/l, 193.9 mg/l and 254.4 mg/l, and 254.5 mg/l and 375.6 mg/l, respectively as shown in Figure 8 a and b.

The green, yellow, orange, and brown colours of the spatial variation were within the permissible limit of chloride (250 mg/l). In Figure 8a, the green and yellow colours occurred mainly around the rural region and some parts of the urban area. This denoted that the chloride concentrations of the groundwater around these regions were acceptable, as they were below 250 mg/l. Two northern parts of the city displayed grey colours encircled by brown and orange colours. The grey colour ranged between 254.5 mg/l 375.6 mg/l, which was unacceptable.

In Figure 8b, the green, yellow, orange and brown colours occurred mainly around the study area for the dry season. The significant green colour in the agricultural and rural regions denoted that the chloride concentration of the groundwater in the study area was mainly acceptable. A groundwater source in the north-eastern part displayed a grey colour, which is encircled by brown and orange colours. This indicated that its chloride concentration ranged between 254.5 mg/l and 375.6 mg/l, which was unacceptable.

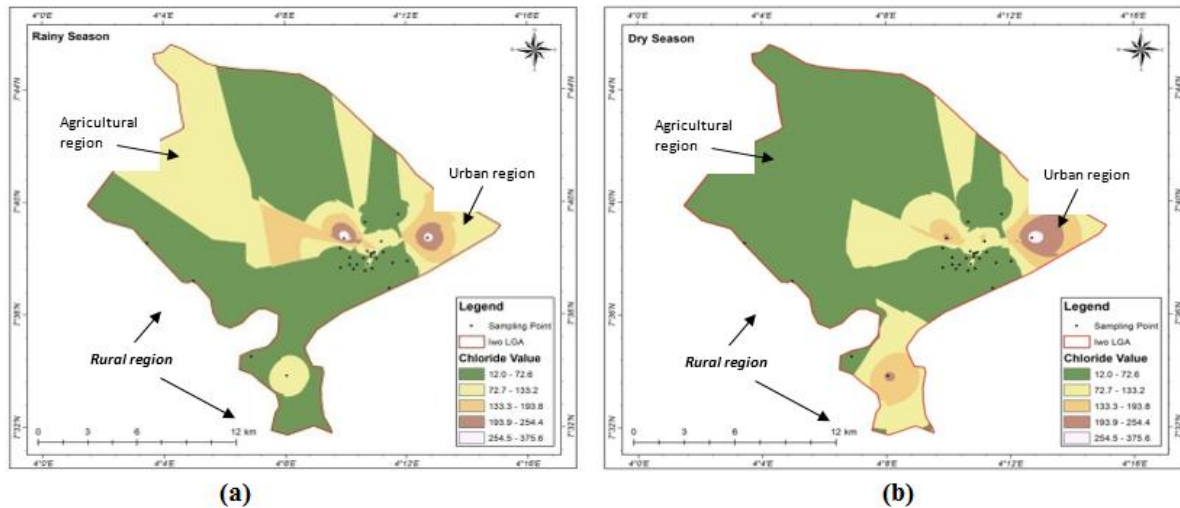


Figure 8: Spatial Variation of Chloride Concentration (a) Rainy Season (b) Dry Season

3.8 Magnesium

The five colours denoting the spatial variation of magnesium during the rainy and dry seasons were green, yellow, orange, brown, and grey, ranging between 0.40 mg/l and 1.54 mg/l, 1.55 mg/l and 2.68 mg/l, 2.69 mg/l and 3.82 mg/l, 3.83 mg/l and 4.96 mg/l, and 4.97 mg/l and 6.10 mg/l, respectively as shown in Figure 9 a and b.

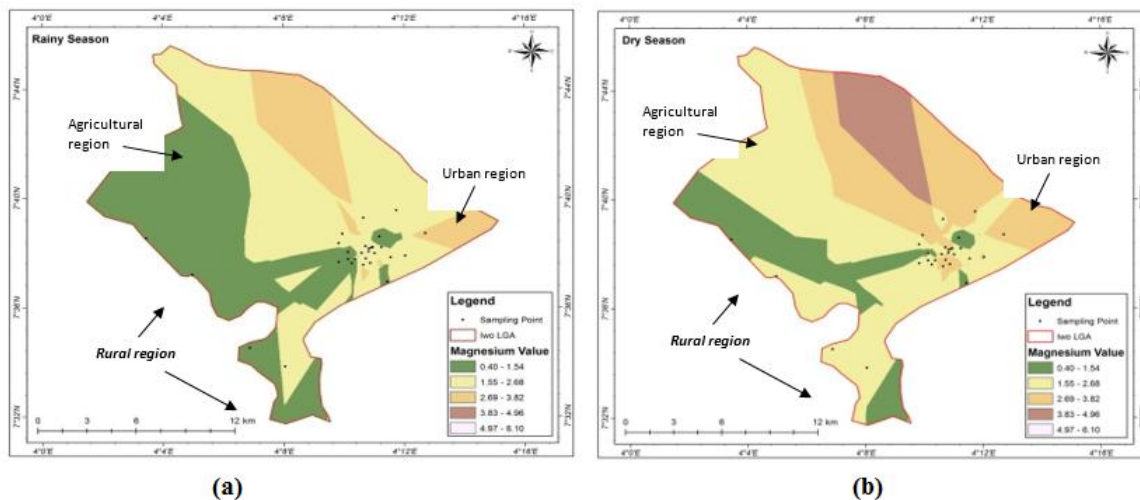


Figure 9: Spatial Variation of Magnesium Concentration (a) Rainy Season (b) Dry Season

The green, yellow, orange, brown, and grey colours of the spatial variation were within the permissible limit of magnesium (50 mg/l). In Figure 9a, the green colour occurred mainly in the rural and agricultural regions of the study area. This denoted that the magnesium concentration of the groundwater around this region was lower than in other regions. The other parts of the study area, including the urban region, displayed little green and orange colours and mostly yellow. These colours ranged between 0.4 mg/l and 3.82 mg/l, which were acceptable.

In Figure 9b, the green and yellow colours occurred mainly in the southern region of the study area. This denoted that the magnesium concentration of the groundwater around this region was lower than in agricultural and urban regions. The other parts of the study area displayed little green and mainly yellow, orange, and brown colours. These colours, which occurred in the study area, ranged between 0.4 mg/l and 4.96 mg/l, which were acceptable.

3.9 Nitrate

The five colours denoting the spatial variation of nitrate concentration during the rainy and dry seasons were green, yellow, orange, brown, and grey, ranging between 12.0 mg/l and 28.6 mg/l, 28.7

mg/l and 45.2 mg/l, 45.3 mg/l and 61.8 mg/l, 61.9 mg/l and 78.4 mg/l, and 78.5 mg/l and 95.0 mg/l, respectively as shown in Figure 10 a and b.

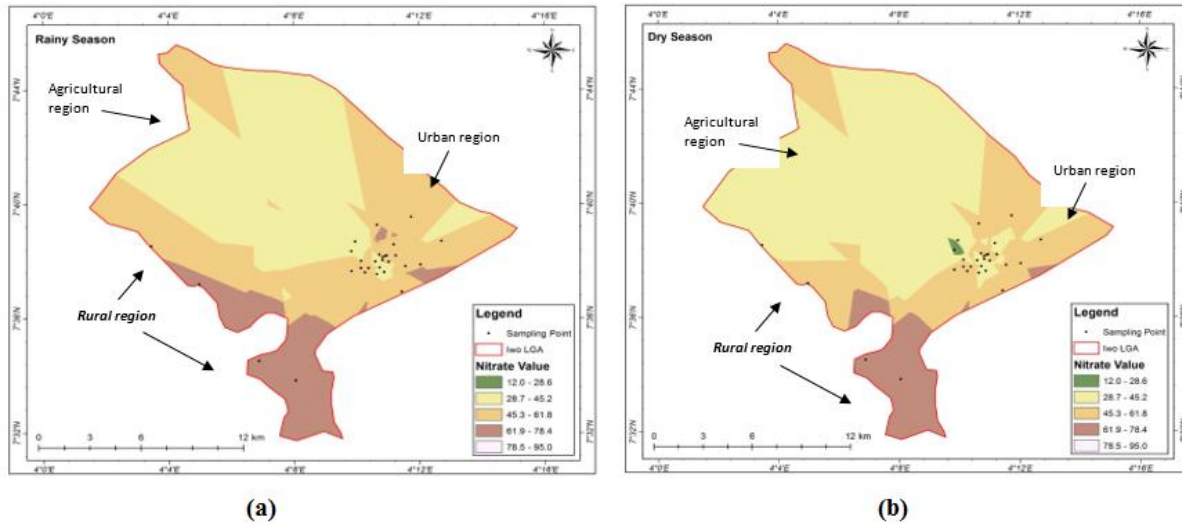


Figure 10: Spatial Variation of Nitrate Concentration (a) Rainy Season (b) Dry Season

The green and yellow colours of the spatial variation were within the permissible limit of nitrate (50 mg/l). The brown and orange colours occurred mainly in the southern region of the study area, including some parts of the city. This denoted that the nitrate concentration of the groundwater around this region was largely unacceptable because it was more than 50 mg/l. The other parts of the study area displayed a yellow colour that occurred in the north-western region. This indicated that nitrate concentration ranged between 28.7 mg/l and 45.2 mg/l, which was acceptable.

The significant difference observed between the two seasons was the decrease in the nitrate concentration of the study area from the rainy to the dry season. This reduction can be a result of a decline in the rate of dissolution of nitrate ions from fertilisers, wastes, septic tanks, and pit latrines into the groundwater, aided by rainfall during the rainy season (Aleku *et al.*, 2024).

3.10 Phosphate

The five colours denoting the spatial variation of phosphate concentration during the rainy and dry seasons were green, yellow, orange, brown, and grey, ranging between 0.30 mg/l and 1.08 mg/l, 1.09 mg/l and 1.86 mg/l, 1.87 mg/l and 2.64 mg/l, 2.65 mg/l and 3.42 mg/l, and 3.43 mg/l and 4.20 mg/l, respectively as shown in Figure 11 a and b.

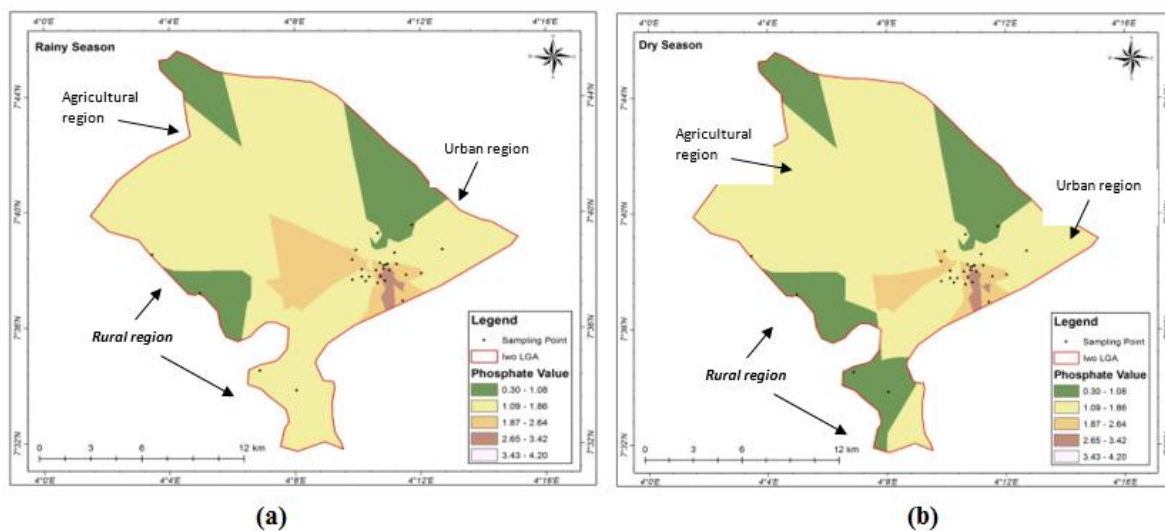


Figure 11: Spatial Variation of Phosphate Concentration (a) Rainy Season (b) Dry Season

All the colours of the spatial variation were above the permissible limit of phosphate (0.05 mg/l). The green and yellow colours occurred mainly in the rural region of the study area. This indicated that the phosphate concentration of the groundwater around this region was lower than that of the urban region. The other parts of the study area, like the agricultural region displayed green, yellow, orange, and brown colours. The phosphate concentrations of the study area ranged between 0.30 mg/l and 3.42 mg/l, which were unacceptable. This can be attributed to microbial cycling in the groundwater (Li *et al.*, 2024).

3.11 Sulphate

The five colours denoting the spatial variation of sulphate concentration during the rainy and dry seasons were green, yellow, orange, brown, and grey, ranging between 150 mg/l and 218 mg/l, 219 mg/l and 286 mg/l, 287 mg/l and 354 mg/l, 355 mg/l and 422 mg/l, and 423 mg/l and 490 mg/l, respectively as shown in Figure 12 a and b.

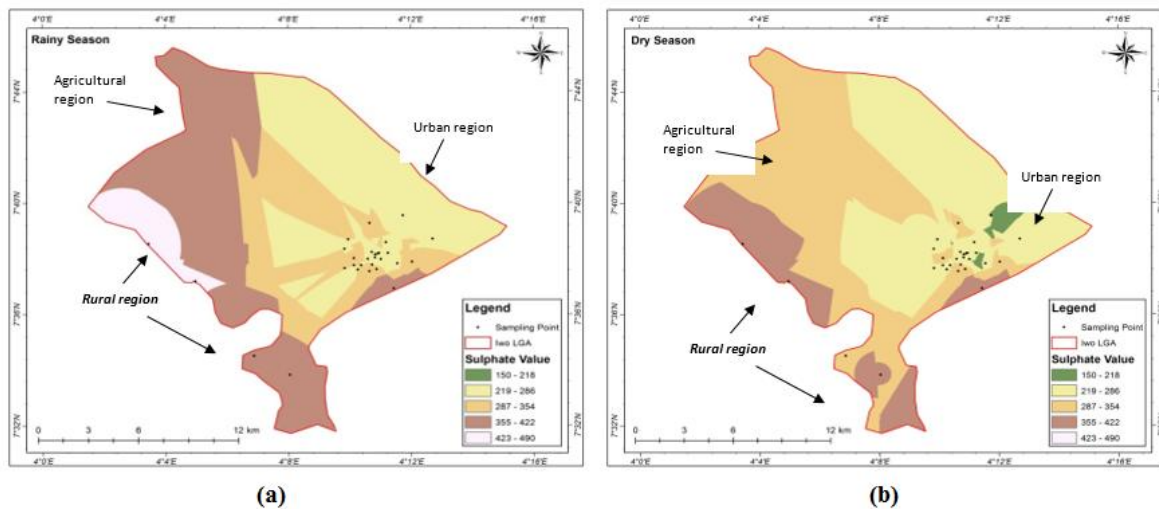


Figure 12: Spatial Variation of Sulphate Concentration (a) Rainy Season (b) Dry Season

The green colour of the spatial variation was below the permissible limit of sulphate (250 mg/l). The brown and grey colours occurred mainly in the rural and agricultural regions of the study area. This denoted that the sulphate concentration of the groundwater around these regions were higher than that of the urban region. The other parts of the study area displayed yellow, orange and green (Figure 12b) colours. This denoted that the spatial variations of sulphate concentrations in the urban region for rainy and dry seasons ranged between 219 mg/l and 354 mg/l, which were largely unacceptable.

The significant difference observed between the two seasons was the decrease in the sulphate concentration of the study area from the rainy to the dry season. This reduction can be a result of the decline in the rate of dissolution of sulphate from rocks and other sulphate sources of contamination into the groundwater, aided by rainfall during the rainy season (Mattos *et al.*, 2018).

3.12 Total Coliform

The five colours denoting the spatial variation of total coliform concentration during the rainy and dry seasons were green, yellow, orange, brown and grey ranging between 0 cfu/ml $\times 10^{-4}$ and 09 cfu/ml $\times 10^{-4}$, 10 cfu/ml $\times 10^{-4}$ and 19 cfu/ml $\times 10^{-4}$, 20 cfu/ml $\times 10^{-4}$ and 79 cfu/ml $\times 10^{-4}$, 80 cfu/ml $\times 10^{-4}$ and 99 cfu/ml $\times 10^{-4}$, and 100 cfu/ml $\times 10^{-4}$ and 120 cfu/ml $\times 10^{-4}$, respectively as shown in Figure 13 a and b.

The green colour of the spatial variation was below the permissible limit of total coliform (10 cfu/ml $\times 10^{-4}$). The green colour encircled the urban region of the study area. This denoted that the total coliform of the groundwater around this region was within the acceptable limit. The central part of the urban region displayed yellow, orange, and brown colours. This denoted that the total coliform of this region ranged between 10 cfu/ml $\times 10^{-4}$ and 99 cfu/ml $\times 10^{-4}$, which was unacceptable.

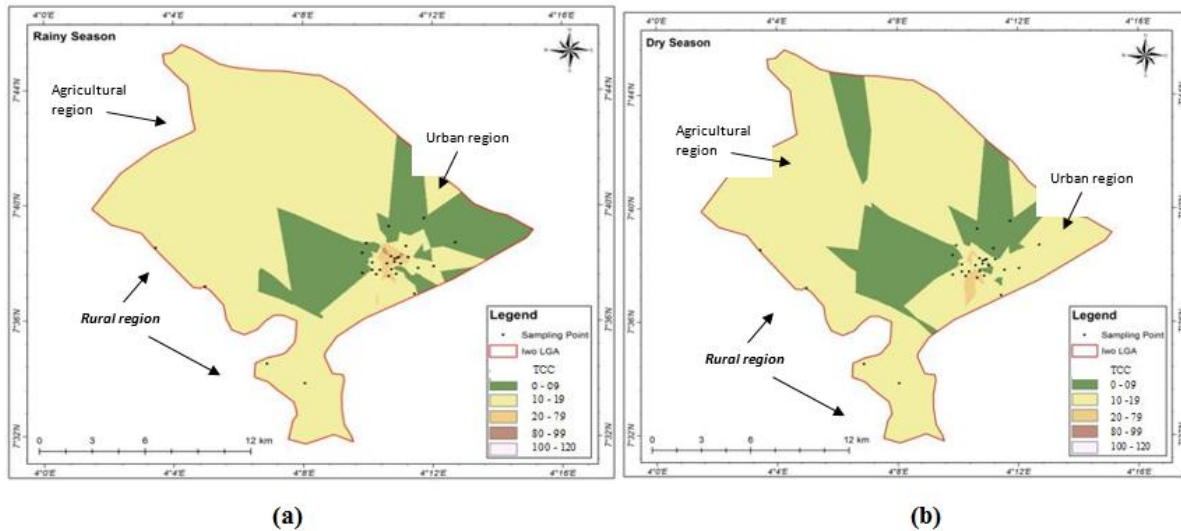


Figure 13: Spatial Variation of Total Coliform Concentration (a) Rainy Season (b) Dry Season

3.13 Total Alkalinity

The five colours denoting the spatial variation of total alkalinity during the rainy and dry seasons were green, yellow, orange, brown, and grey, ranging between 15 mg/l and 86 mg/l, 87 mg/l and 157 mg/l, 158 mg/l and 228 mg/l, 229 mg/l and 299 mg/l, and 300 mg/l and 370 mg/l, respectively, as shown in Figure 14 a and b.

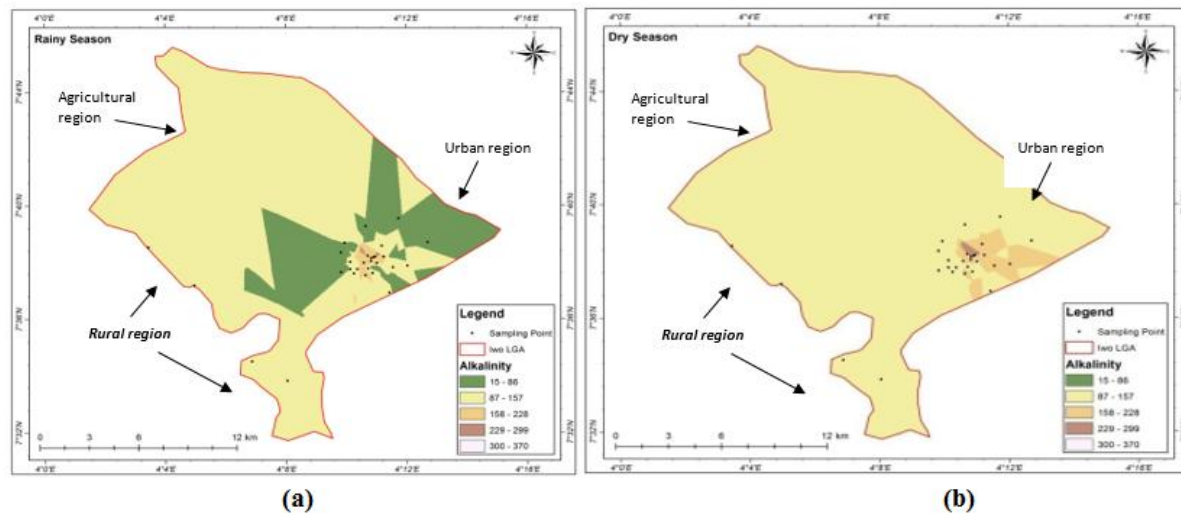


Figure 14: Spatial Variation of Total Alkalinity Concentration (a) Rainy Season (b) Dry Season

The green, yellow, and orange colours of the spatial variation were within the permissible limit of total alkalinity (200 mg/l). The brown and orange colours occurred in the central part of the urban region. This denoted that the total alkalinity of the groundwater around this region was slightly above 200 mg/l, which was somewhat unacceptable. The other rural and agricultural regions displayed green and yellow colours, ranging between 15 mg/l and 157 mg/l, which were acceptable.

3.14 Total Hardness

The five colours denoting the spatial variation of total hardness during the rainy and dry seasons were green, yellow, orange, brown, and grey, ranging between 44.0 mg/l and 228.2 mg/l, 228.3 mg/l and 412.4 mg/l, 412.5 mg/l and 596.6 mg/l, 596.7 mg/l and 780.8 mg/l, and 780.9 mg/l and 965.0 mg/l, respectively as shown in Figure 15 a and b.

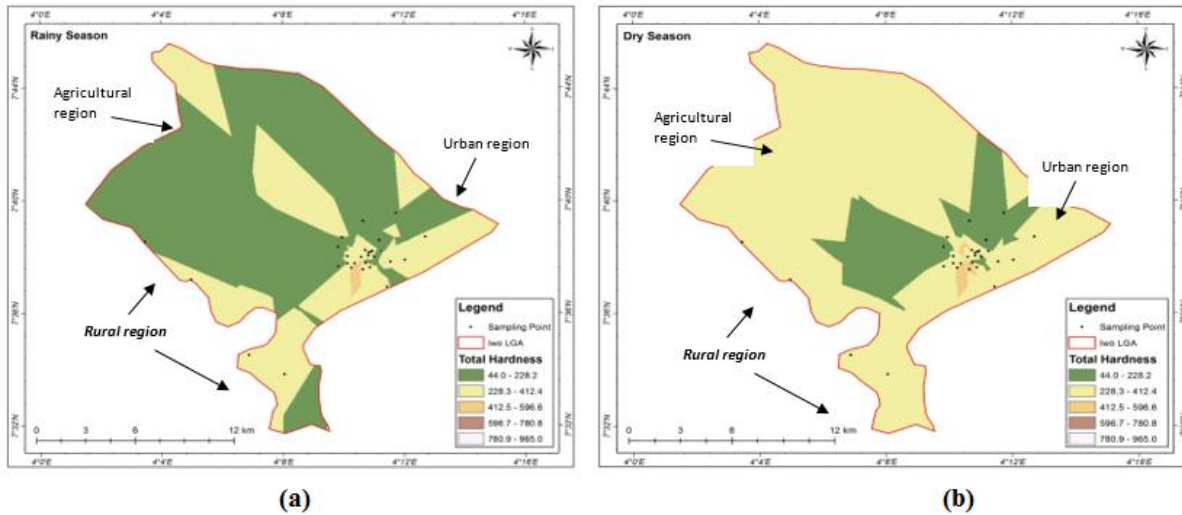


Figure 15: *Spatial Variation of Total Hardness Concentration (a) Rainy Season (b) Dry Season*

In Figure 15a, the green colour of the spatial variation was within the permissible limit of total hardness (150 mg/l). The green colour occurred mainly in the agricultural region. This denoted that the total hardness of the groundwater around this region was slightly acceptable, which was close to 150 mg/l. The southern part of the study area displayed a yellow colour and a little orange colour. This denoted that the southern region ranged mainly between 228.3 mg/l and 596.6 mg/l, which was unacceptable.

In Figure 15 b, the green colour of the spatial variation during the dry season was within the permissible limit of total hardness (150 mg/l). The yellow colour occurred mainly in the rural region, and this denoted that the total hardness of the groundwater around this region was unacceptable and substantially exceeded the WHO standard limit across significant portions of the study area, particularly during the dry season. This prediction from the interpolation could be indicative of localised carbonate/sulphate rock dissolution and weathering processes as reported in previous studies (Mattos *et al.*, 2018). The urban part of the study area displayed green, yellow, and orange colours. The green colour locations denote that total hardness was within 150 mg/l, which was acceptable.

3.15 Turbidity

The five colours denoting the spatial variation of turbidity during the rainy and dry seasons were green, yellow, orange, brown and grey, ranging between 1.0 NTU and 2.6 NTU, 2.7 NTU and 4.2 NTU, 4.3 NTU and 5.8 NTU, 5.9 NTU and 7.4 NTU, and 7.5 NTU and 9.0 NTU, respectively, as shown in Figure 16 a and b.

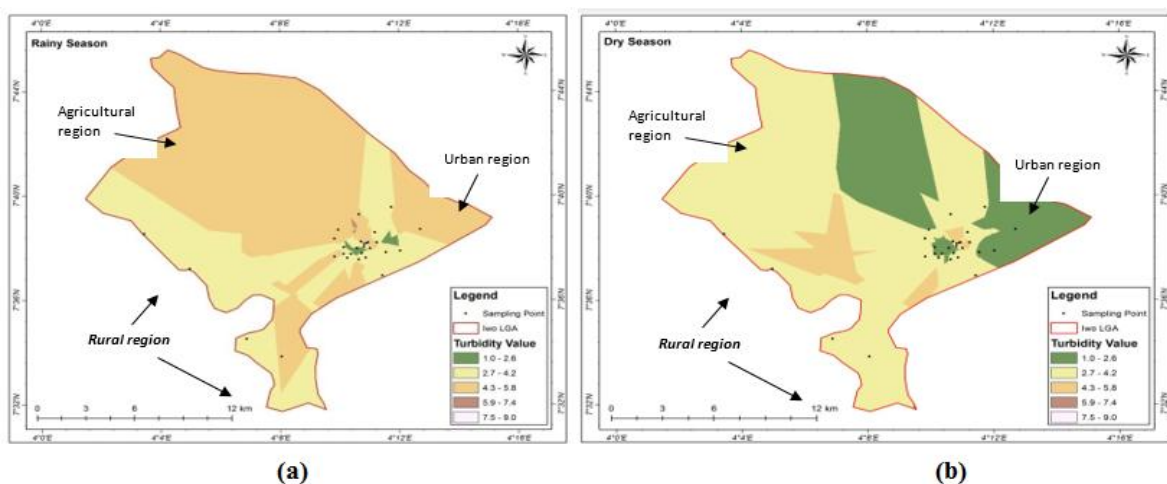


Figure 16: *Spatial Variation of Turbidity Concentration (a) Rainy Season (b) Dry Season*

The green and yellow colours of the spatial variation were within the permissible turbidity limit (5 NTU). The yellow colour occurred mainly in the rural region, which denoted that the groundwater turbidity around this region was acceptable which was below 5 NTU. The urban region of the study area displayed mainly green, yellow, and orange colours with a bit of brown colour. This brown colour indicated that some parts of the urban and agricultural regions ranged between 5.9 NTU and 7.4 NTU, which was unacceptable. The significant difference observed in the agricultural and urban regions between the two seasons was the decrease in the turbidity of groundwater from the rainy to the dry season.

Table 2 shows the descriptive statistics for each groundwater parameter recorded for Iwo Local Government Area during the rainy season, while Table 3 shows the descriptive statistics for each groundwater parameter recorded for Iwo Local Government Area during the dry season. It was observed that during the rainy season, the mean values of temperature (27.48 °C), nitrate (52.16 mg/l), and total coliform count (22.67 cfu/ml $\times 10^{-4}$) were greater than WHO values of 25 °C, 50 mg/l, and 10 cfu/ml $\times 10^{-4}$ respectively. During the dry season, the mean values of temperature (16.20 °C), nitrate (48.29 mg/l), and total coliform count (6.63 cfu/ml $\times 10^{-4}$) were less than WHO values of 25 °C, 50 mg/l, and 10 cfu/ml $\times 10^{-4}$ respectively. In addition, total hardness, calcium, phosphate, and sulphate had consistent mean values greater than WHO standard values for both rainy and dry seasons. Other parameters like pH, electrical conductivity, total dissolved solids, total alkalinity, total suspended solids, turbidity, magnesium, and chloride had mean values for both rainy and dry seasons less than the WHO standard.

Table 2: Groundwater Parameters Mean Against WHO Values for Rainy Season

SN	Parameter	WHO	Minimum	Maximum	Mean	Standard Error	Standard Dev.	Coefficient of Variation (%)
1	pH (-)	6.5 – 8.5	5.6	8.5	7.07	±0.114	±0.625	8.84
2	Temp (°C)	25	23.4	29.8	27.48	±0.261	±1.429	5.20
3	EC (µS/cm)	1000	86	1843	568.60	±94.059	±515.180	90.61
4	TDS (mg/l)	500	53	1013	330.57	±54.352	±297.701	90.06
5	T. Al. (mg/l)	200	15	370	120.57	±15.927	±87.234	72.35
6	TSS (mg/l)	250	50	450	180.00	±22.565	±123.596	68.66
7	Turb. (NTU)	5	1	9	3.90	±0.379	±2.074	53.17
8	TH (mg/l)	150	44	796	252.93	±32.553	±178.298	70.49
9	Ca (mg/l)	75	16	317	98.27	±13.057	±71.518	72.78
10	Mg (mg/l)	50	0.73	5.4	1.91	±0.225	±1.230	64.51
11	Cl (mg/l)	250	13.99	313.9	67.13	±13.681	±74.936	111.63
12	NO ₃ ⁻ (mg/l)	50	14.19	94.33	52.16	±4.162	±22.796	43.70
13	SO ₄ ²⁻ (mg/l)	250	155.2	488.31	305.12	±17.511	±95.910	31.43
14	PO ₄ ³⁻ (mg/l)	0.05	0.35	4.184	1.76	±0.178	±0.972	55.17
15	TCC(cfu/ml)x 10 ⁻⁴	10	0	78	22.67	±4.555	±24.951	110.08

SPATIAL VARIATION ASSESSMENT OF GROUNDWATER QUALITY IN IWO LOCAL
GOVERNMENT AREA, OSUN STATE, NIGERIA.

Table 3: *Groundwater Parameters Mean Against WHO Values for Dry Season*

SN	Parameter	WHO	Minimum	Maximum	Mean	Standard Error	Standard Dev.	Coefficient of Variation (%)
1	pH (-)	6.5 – 8.5	5.5	10.5	7.16	±0.210	±1.148	16.03
2	Temp (°C)	25	14	24.1	16.20	±0.471	±2.578	15.91
3	EC (µS/cm)	1000	51	1615	504.97	±80.224	±439.403	87.02
4	TDS (mg/l)	500	33	888	308.30	±49.234	±269.666	87.47
5	T. Al. (mg/l)	200	52	363	141.43	±13.442	±73.626	52.06
6	TSS (mg/l)	250	50	450	190.00	±24.377	±133.520	70.27
7	Turb. (NTU)	5	1	8	3.03	±0.373	±2.042	67.33
8	TH (mg/l)	150	55	964	299.63	±37.694	±206.458	68.90
9	Ca (mg/l)	75	20	384	115.83	±14.970	±81.996	70.79
10	Mg (mg/l)	50	0.49	6.08	2.32	±0.281	±1.540	66.43
11	Cl (mg/l)	250	12.5	290.41	68.44	±13.324	±72.981	106.63
12	NO ₃ ⁻ (mg/l)	50	12.77	83.39	48.29	±3.739	±20.481	42.41
13	SO ₄ ²⁻ (mg/l)	250	150.54	483.43	285.70	±17.540	±96.068	33.63
14	PO ₄ ³⁻ (mg/l)	0.05	0.597	4.1	1.71	±0.174	±0.954	55.95
15	TCC(cfu/ml)x 10 ⁻⁴	10	0	20	6.63	±1.221	±6.688	100.82

4. CONCLUSION

The groundwater sources from Iwo Local Government Area show that the measured parameters exhibited seasonal variation, with concentrations being primarily higher during the rainy season than during the dry season. However, the groundwater quality maps for total hardness, pH, and calcium show higher spatial variation of concentrations in the dry season than in the rainy season. This assessment provided information on groundwater features in the Iwo Local Government Area in Osun State of Nigeria. The kriging interpolation method was used to predict the value of a parameter at an unmeasured location over a spatial region, resulting in the generation of spatial distribution maps. The groundwater quality variation maps generated from water quality test results revealed groundwater quality characteristics in the Iwo Local Government Area. The different processes responsible for the acquisition of groundwater chemistry studied, according to spatial variation assessment studies, are the residence time of the water in contact with the rock, the infiltration of substances related to anthropogenic activities (agricultural fertilisers, household and industrial waste), and the intensity of rainfall. It is recommended that the identified locations be subjected to water treatment techniques to reduce total hardness.

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