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Assessment of Groundwater Quality and Suitability for Domestic and Irrigation use in Selected Parts of Oyo Town, Southwestern Nigeria

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ABSTRACT

This study assesses the groundwater quality in selected parts of Oyo Town, Southwestern Nigeria, to determine its suitability for domestic and irrigation purposes. Groundwater samples from 20 locations were analysed for physicochemical parameters, including pH, Electrical Conductivity (EC), Total Dissolved Solids (TDS), and major ion concentrations, following standard procedures by the American Public Health Association (APHA), using Atomic Absorption Spectrophotometry for cations and conventional titration for anions. The Water Quality Index (WQI) was calculated to evaluate drinking water suitability while irrigation indices such as Sodium Adsorption Ratio (SAR), Soluble Sodium Percentage (SSP), and Magnesium Adsorption Ratio (MAR) were assessed. The results revealed pH values between 5.38 and 7.99, EC ranging from 132 to 940µS/cm, and TDS between 117 and 607 mg/L, indicating low salinity levels across all samples. Most samples complied with WHO standards for drinking water, except for one (Loc18), categorized as unfit. Irrigation suitability analysis showed 85% of samples were excellent, while anomalies at specific locations (Loc10 and Loc6) indicated potential risks. These results indicate the impact of geogenic and anthropogenic factors on groundwater quality and highlight the importance of ongoing monitoring and sustainable management for effective resource utilization.

INTRODUCTION

Groundwater is an essential natural resource, serving as a primary source of water for drinking, irrigation, and industrial activities across the globe. Groundwater constitutes approximately 40% and 70% of the total global water resources used for irrigation and domestic purposes (Qiu 2010). Groundwater is particularly pronounced in arid and semi-arid regions where surface water resources are limited (Foster & Chilton, 2020). The increase in population pressure, industrialization, and agricultural activities have exacerbated the contamination of groundwater resources, particularly in developing countries (Tiwari *et al.*, 2023). The quality of groundwater, however, can be compromised by various natural and anthropogenic factors, leading to significant implications for both human health and agricultural productivity (Li *et al.*, 2022). This has necessitated comprehensive assessments of groundwater quality to ensure its safe use for both drinking and irrigation. Such evaluations help identify areas of concern and aid in formulating sustainable water management practices.

Traditionally, water quality assessment involves comparing specific parameters with established standards to evaluate the suitability of water for various uses. However, this practice does not give details a broad view concerning water conditions, since it evaluates the determined parameters individually (Tomas *et al.,* 2017). The Water Quality Index (WQI) is a comprehensive tool that amalgamates multiple water quality parameters into a single value, facilitating a holistic assessment of water suitability for various purposes like drinking, irrigation, or aquatic life. This index, as highlighted by El-Gamal (2017), streamlines the evaluation process by providing a quick and efficient means of determining the overall quality of water bodies, enabling informed decision-making in water resource management. Studies by Goher et al. (2014) and Salem et al. (2018) represent the widespread application of WQI in assessing water quality for different uses, showcasing its significance in environmental monitoring and planning.

The suitability of groundwater for drinking and irrigation purposes is largely determined by its physical and chemical properties. Parameters such as pH, electrical conductivity (EC), total dissolved solids (TDS), and the concentrations of major cations and anions are critical indicators of water quality (Ayers and Westcot, 2021). This study aims to assess the suitability of groundwater for domestic and irrigation use in the study area through an integrated analysis of physical parameters, cations, and anions with a focus on determining the water quality in some selected parts of Oyo. By comparing the results with recognized water quality standards, the study seeks to provide important insights into the current state of groundwater resources in the area and offer recommendations for their most favourable use.

Description of the study area

The study area which is located around Oyo township lies within the coordinates of N07° 47' 02" to N07˚ 62' 01" and E03° 52' 01" to E04° 00' 00" (figure 1). The study area is typically a tropical climate of relatively high temperatures with averagely high humidity and two maximal rainfall regimes which coincide with a period between March and October. The mean temperature is highest at the end of Harmattan (averaging 28°C), that is, from January to March, even during the rainfall months, average temperatures are between 24^0C and 25^0C while the annual range of temperature is about 6^0C. The study area is covered by the rain forest and derived savannah which is composed of large and tall deciduous crowned trees interspersed with thick shrub undergrowth. The study area is low-lying (low relief) and has a dendritic drainage which is controlled by the topography of the area.

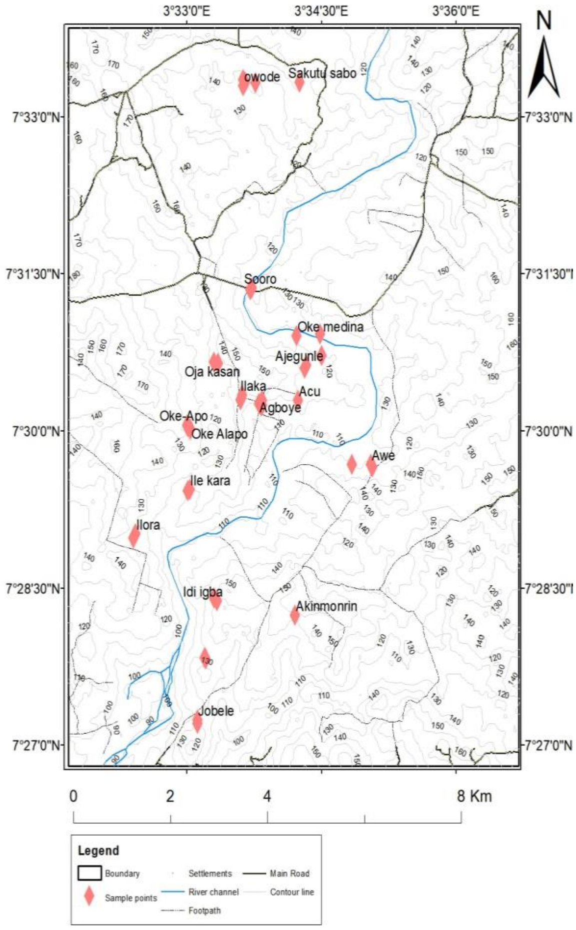

Figure 1: Description of the study area.

The study area is underlain by the rocks basement complex which primarily consists of the Migmatite-Gneiss-Quartzite complex as shown in Figure 2, low to medium-grade meta-sediments, and the Pan

African Granitoids which are syn-to post-tectonic intrusions (MacLeod *et al*., 1993). With these composite rocks, the study area has different minerals ranging from metallic and non-metallic, to industrial minerals to different grades of gemstones. The igneous and metamorphic rocks of the basement complex are crystalline and therefore have low porosity, and lack the hydraulic conductivity required for the groundwater flow (Todd and Mays, 2005). The overlying weathered rocks and sediments represent the aquifer units in the study area. The major source of water supply within the study area is through the hand-dug wells, a few boreholes and complimented by surface water. The hand-dug wells and surface water sources are vulnerable to anthropogenic activities, including the indiscriminate dumping of household solid waste and the use of pit latrines by the residents. These contribute to widespread pollution in the study area, particularly during heavy rain.

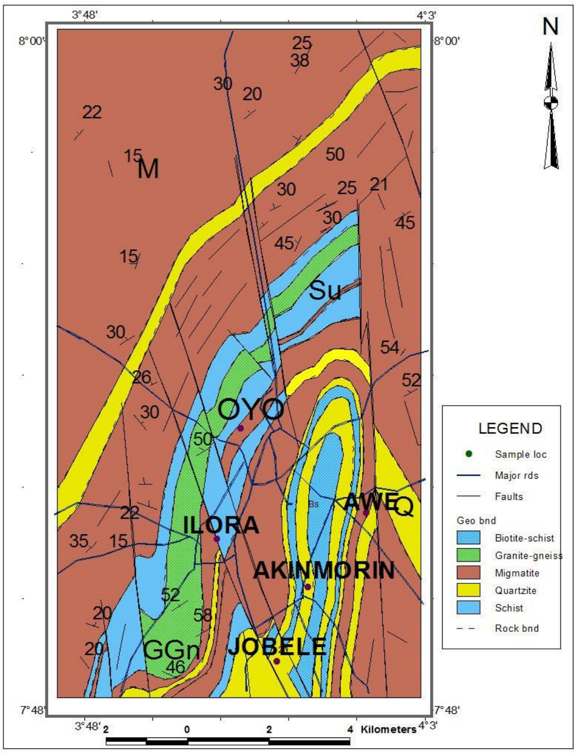

Figure 2: Geological map of the study area (after NGSA, 2006)

MATERIALS AND METHODS

The Water sampling and analysis

Groundwater samples from twenty (20) locations were collected from wells that were used for domestic purposes. Groundwater sampling locations are recorded with GPS (Global Positioning System) and are represented in Figure 1. Bore wells were pumped for five to ten minutes to eliminate the influence of stagnant water before collecting the groundwater samples, and groundwater samples were collected in 1-liter pre-cleaned polyethylene containers. After collection, all groundwater samples were labeled, sealed, transported to the laboratory and stored at a constant temperature of 4℃. The procedures for groundwater sample collection are accurately followed by the standard procedure of the American Public Health Association (APHA, 2012).

The geology, accessibility of the sampling points and spatial representation were used as a guide through the selection process for well selection. Water samples were collected in June at the peak of raining season. The pH, Total Dissolve Solid (TDS) and electrical conductivity (EC) were measured in situ immediately after collecting samples. The pH measurements were carried out by using pH/EC/TDS meter (Hanna HI9811-5) after calibration with pH 4.01 and 7.00 buffer solutions. Other water quality parameters such as total hardness (TH) as $CaCO_3$, bicarbonate (HCO_3^-), chloride (Cl^-), Sulphate (SO_4^{2-}), nitrate (NO_3^-), calcium (Ca^{2+}), magnesium (Mg^{2+}), potassium (K^+) and sodium (Na^+) were measured in the laboratory. The chemical analyses were performed in the ANALAB laboratory, in Ibadan, Nigeria, employing standard methods of Atomic Absorption Spectrophotometry for cations and convectional titration for anions.

Irrigation criteria

The sodium Absorption Ratio (SAR) was calculated based on Richards 1954 using Equation 1, Residual Sodium Bicarbonate (RSC) and Soluble Sodium Percentage (SSP) were calculated according to the relationships presented by Todd (1980) and Gupta (1987) using Equations 2 and 3. The permeability Index (PI) was calculated according to Doneen (1964) using Equation 4, while the Magnesium Adsorption Ratio (MAR) was calculated based on Raghunath 1987, Equation 5. The Kelly's Ratio (KR) (Kelly 1963) is represented in Equation 6. Ion concentrations are expressed in meq/L. Quality The result of the analysis was interpreted under the guidelines and standard specifications outlined by WHO (2017) for drinking water and irrigation quality.

$$SAR = \frac{Na^{+}}{\sqrt{[Ca^{2+}]+[Mg^{2+}]/2}} \quad (1)$$

$$RSC = (CO_3^{2-} + HCO_3^{-}) - (Ca^{2+} + Mg^{2+}) \quad (2)$$

$$SSP = \frac{(Na^{+} + K^{+})}{(Ca^{2+} + Mg^{2+} + Mg^{2+} + K^{+})} \times 100 \quad (3)$$

$$PI = \frac{Na^{+} + \sqrt{HCO_3^{-} \times 100}}{Ca^{2+} + Mg^{2+} + Na^{+}} \quad (4)$$

$$MAR = \frac{Mg^{2+} \times 100}{Ca^{2+} + Mg^{2+}} \quad (5)$$

$$KR = \frac{Na^{+}}{Ca^{2+} + Mg^{2+}} \quad (6)$$

Assessment of Water Quality Index (WQI)

Sener *et al.* (2017) and Singh et al. (2018) methods of calculating WQI was achieved following these four steps; (1) indicator selection, (2) indicator scoring, (3) assigning a relative weight of each indicator, and (4) aggregation of scores and weights in a single index. The scores of parameters (Si) were calculated as follows:

$$\mathbf{Si} = \frac{\text{Vactual} - \text{Videal}}{\text{Vstandard} - \text{Videal}} X\ 100$$

Where V_{actual} is the actual value of the parameter obtained by laboratory analysis, $V_{standard}$ is the standard value proposed by FAO guidelines, and V_{ideal} is the ideal value in pure water, which was considered 7 for pH and zero for other parameters.

The relative weight (R_{wi}) was calculated as follows:

$$\mathbf{R_{wi}} = {wi}/{\sum_{i=1}^{n} wi}$$

Where wi is the weight of each parameter and n is the number of parameters

$$\mathbf{wi = 1/VStandard}$$

Finally, WQI was calculated as follows: $\mathbf{WQI} = \sum \mathbf{Si}$

RESULTS AND DISCUSSION

Water quality

The descriptive statistics of groundwater quality parameters in selected parts of Oyo town, southwestern Nigeria are presented in Table 1. Also, for evaluating the groundwater quality, the Physicochemical parameters were compared with the World Health Organization (WHO) standard. The standard deviation (SD) values range from 0.0655 to 281.78, and this huge variance in the SD could be due to various hydrogeochemical reactions. The pH ranges between 5.38 and 7.99 with a mean of 6.67, which indicates Acidic to nearly Alkaline in nature. pH of the study area's groundwater is within the permissible limit of 6.5–8.5 (WHO, 2017) for drinking water in Table 1. EC is a measure of water's ability to conduct electricity, which depends on the concentration of dissolved ions. To understand the enrichment of salts in water, the EC can be classified as low enrichment of salts, if EC is < 1500μS/cm; medium enrichment of salts, if EC is between 1500 and 3000μS/cm; and high enrichment of salts, if EC is > 3000μS/cm, respectively (Rao et al., 2012). However, the EC of groundwater samples analysed was between 132 and 940μS/cm with an average of 535.46μS/cm (Table 1). According to the classification of EC, 100% of the groundwater samples come under the low enrichment of salts. Richard (1954) provided an interpretative relationship between the value of the EC and the degree of Suitability of irrigation water (Table 2). According to Richard (1954), all the water samples have low to moderately saline water and are therefore safe for irrigation purposes. The concentration of dissolved material in water is given by the weight of the material on evaporation of water to dryness up to a temperature of 180^0C. The values are expressed in mg/l. Major constituents of TDS include Bicarbonates (HCO_3^-), Sulphate (SO_4^{2-}) and Chlorides (Cl^-). Groundwater containing more than 1000 mg/l of TDS is commonly referred to as brackish water. In the study area, TDS in groundwater ranges from 117 to 607mg/L (Table 1) with a minimum concentration value from the bore well located at Elekara and a maximum value from the bore well located at Alapo. Table 1 shows the variation in the Total Dissolved Solid (TDS) values across all twenty water samples, with all measurements remaining below 1000mg/L recommended by WHO (2017).

Table 1: Statistics of physicochemical parameters

Parameters	Min	Maxi	Mean	SD	Coefficient Variation (CV)	WHO standard (2017)
pH	5.38	7.99	6.67	0.696	10.43%	6.5-8.5
TDS	117	607	315.96	136.51	43.20%	1000
EC	132	940	535.46	281.78	52.62%	1000
Total Alkalinity	0	249.69	92.272	63.795	69.13%	120mg/L
Ca^{2+}	4.61	59.78	27.74	12.915	46.56%	75mg/L
Mg^{2+}	3.821	18.12	11.127	4.899	44.03%	20mg/L
K^+	1.53	38.92	15.03	12.644	84.13%	55mg/L
Na^+	4.52	425.51	77.933	110.11	141.28%	200mg/L
Cl^-	19.88	762.24	130.45	161.34	123.68%	250mg/L
PO_4^-	0	0.202	0.063	0.0655	103.96%	0.1mg/L
HCO_3^-	0	237.51	75.66	56.33	74.45%	94.6mg/L
NO_3^-	0.051	10.81	4.29	3.411	79.51%	50mg/L
SO_4^-	4.49	17.21	9.140	3.752	41.05%	500mg/L

According to Robinove *et al.*, 1958 these water samples are classified as non-saline and therefore excellent for irrigation purpose (Table 3). Alkalinity caused by the presence of CO_3^{2-}, HCO_3^- and OH^- of Ca^{2+}, Mg^{2+}, K^+ and Na^+. $CaCO_3^-$ is the most usual constituent that causes alkalinity. Alkalinity is expressed in mg/L and the limit for drinking water is 120mg/L. Total alkalinity in the study area ranges between 0mg/L and 249.69mg/L (Table 1). Minimum value of 0mg/L was observed at Oke medina, ACU, Ajegunle while a maximum value of 249.69mg/L was observed at Sabo area.

Table 2: Suitability of irrigation water based on the EC Values (Richard, 1954)

S/N	Electrical conductivity	Water Type	Suitability for irrigation
1	<250	Low saline water	Entirely safe
2	250-750	Moderately saline	Safe under most conditions
3	750-2250	Medium to High saline	Safe only with permeable soil and leaching
4	2250-4000	High salinity	Unfair for irrigation
5	4000-6000	Very high salinity	Unfair for irrigation
6	>6000	Excessive Salinity	Unfair for irrigation

Co-efficient of variation (CV %)

Naturally, the difference in the coefficient of variation (CV %) values displays the distribution of chemical variables in the groundwater. In this study, the highest CV is Na^+ (141.28%), followed by Cl^- (123.68%), PO_4^-(103.96%), K^{2+} (84.13%), NO_3^- (79.51%), HCO_3^- (74.45%), TA (69.13%), EC (52.62%), Ca^{2+}(47.56%), Mg^{2+} (44.03%), TDS (43.20%), SO_4^{2-} (41.05%), pH (10.43%). This observation indicates that Na^+, Cl^-, PO_4^{2-}, K^{2+} and NO_3^- could be the principal key factors that typically control the groundwater chemistry in the study area.

Table 3: TDS values for irrigation use (Robinove *et al.,* 1958)

Classification	Total Dissolve Solids(mg/L)
Non-saline	<1000
Slightly Saline	1000-3000
Moderately Saline	3000-10,000
Very Saline	>10,000

Water Quality Index (WQI)

Table 4 shows the findings of the calculated WQI, which shows an indicator of water quality in the study area. The groundwater values fell between excellent to unfit for drinking based on NSF standards in Table 5, ranging from 3.49 to 103.94. 75% satisfactory water quality, 20% has poor water quality and 5% of the water sample has extremely bad water quality which is just one sample (Loc18). This indicates that both geogenic and anthropogenic processes have a greater effect on the study area's groundwater quality.

Sustainability for Irrigation

1. **Sodium adsorption ratio (SAR)**

The value obtained for the Sodium Adsorption Ratio (SAR) based on the present study is less than 10, except for Loc7 and Loc10 where the values are higher than 10. Based on the rating indices presented in Table 6, water samples from Loc1-6, 8, 9, and 11-20 are described as "Excellent" for irrigation purposes. The SAR obtained for Loc7 (Soro) and Loc 10 (Ilaka) are 12.961 and 11.234, respectively which are described as "Good" for irrigation. Based on the SAR result obtained for the study area, the groundwater values are within the recommended maximum permissible limit of 26 and therefore excellent for irrigation purposes.

2. **Soluble Sodium Percentage (SSP)**

The range of values obtained for the Soluble Sodium Percentage (SSP) parameter provides an estimate of the sodium ions that are present in the water sample, which indicates the probable hazard that could result from the accumulation of sodium ions. SSP is often used in the determination of the suitability of water for irrigation purposes. A high percentage of sodium in water for irrigation purposes can potentially stunt plant growth and reduce soil permeability (Joshi *et al.,* 2009). Based on the study, the values obtained for SSP range between 19.348% - 82.709%. Based on Todd 1980 (Table 7), only Loc2 has a value that is below 20 with a value of 19.348% which can be described as "Excellent" for irrigation purposes, while Loc10 has a higher value of 82.709% which is higher than the recommended permissible limits of 80% and therefore is rated as "Unsuitable" for irrigation. Also, other locations have values ranging from "Good to Fair" for irrigation, while Loc10 has a higher value of 82.709% which is higher than the recommended permissible limits of 80% and therefore is rated as "Unsuitable" for irrigation. Also, other locations have values ranging from "Good to Fair" for irrigation.

Table 4: Water quality index from the sampling point

S/N	Sampling ID	WQI	Remark
LOC1	Awe	15.23	Excellent
LOC2	OkeAlawe	13.23	Excellent
LOC3	Akinmorin	71.78	Poor
LOC4	lsaleAkinmorin	3.49	Excellent
LOC5	Elekara	12.86	Excellent
LOC6	Sabo	37.66	Good
LOC7	Soro	31.41	Good
LOC8	Oke Medina	41.73	Good
LOC9	Ilora	51.31	Poor
LOC10	Ilaka	57.88	Poor
LOC11	Oja Akesan	45.73	Good
LOC12	Agboye	70.06	Poor
LOC13	Akunlemu	40.0	Good
LOC14	Idi-igba	34.02	Good
LOC15	Ajegunle	46.05	Good
LOC16	Alapo	22.66	Excellent
LOC17	Ori awo	44.62	Good
LOC18	Oke- Alapo	103.94	Unfit for drinking
LOC19	Jobele	41.71	Good
LOC20	Sakutu	45.96	Good

Table 5: Water quality standard according to NSF

Water Quality	Rank
0-25	Excellent
26-50	Good
51-75	Poor
76-100	Very poor
Above 100	Unfit for drinking

3. Magnesium Adsorption Ratio (MAR)

Magnesium content of water is considered as one of the most important qualitative criteria in determining the quality of water for irrigation. Joshi *et al*, (2009) stated that Ca^+ and Mg^+ maintain a state of equilibrium in most water, but increasing the amount of magnesium in water will increase the salinity of the water and therefore decline the crop yield. The range values obtained for the Magnesium Ration (MAR) within the study area is between 22.33 and 79.28% The value obtained in this study area shows that 85% of the values obtained are less than 50% and so according to Paliwail (1972) MAR values, the result indicates that the water samples are considered "suitable" with no hazardous effect to the soil. Water samples obtained from Loc6, Loc14 and Loc15 have high values of 79.28%, 52.61% and 53.22% respectively and therefore are classified to be "Unsuitable" for irrigation.

4. The permeability Index (PI)

The permeability Index value obtained in this study ranges between 0.271% and 19.374%. Soil permeability is affected by the continuous use of irrigated water with high values of sodium bicarbonate and total dissolved solids. Based on the classification of Doneen (1964), the results obtained in this study indicate that, the water is suitable for irrigation purposes. Also, the range value for Kelly Ration obtained in this study is 0.144 and 4.651%.

5. Kelly Ration (KR)

The KR value of eighteen locations is significantly lower than the one obtained in Loc7 and Loc9 respectively. Based on Kelly (1946) classification, the result shows that only two out of the twenty locations have water that are unsuitable for irrigation because they are higher than the permissible limit recommended.

6. Residual sodium Bicarbonate (RSBC)

Also, the suitability of water for irrigation purpose is influenced by the concentration of bicarbonate and carbonate within the soil, for the reason that water samples with high RSBC value have a tendency to have relatively high pH, which makes the land irrigated by such water to become infertile because of the deposition of sodium carbonate (Eaton, 1950). Based on this study, the highest value obtained for the RSBC for the water samples in the study area is 1.121meq/L. According to the classification on Table 4, these water samples are indicated to be "suitable" for irrigation. The result obtained for TDS, EC, SA, RSBC, and PI shows that the values obtained for all the water samples are within the acceptable limits of the regulatory standards for irrigation purposes.

CONCLUSION

The assessment of groundwater quality in selected parts of Oyo Town reveals variability across locations for both drinking and irrigation suitability.

Table 6: Values for parameter indices

Location	SAR	SSP (%)	MAR (%)	PI %	KR meq/L	RSBC meq/L
LOC1	0.347106	24.42548	41.42937	0.27087	0.222399	-0.71336
LOC2	0.238058	19.34757	23.06871	8.466648	0.144186	0.614834
LOC3	0.587957	26.18288	35.86561	6.694382	0.298908	1.121281
LOC4	0.799577	36.16128	35.91244	6.897401	0.460666	0.897628
LOC5	0.637833	34.59248	36.78865	8.186578	0.47498	0.614834
LOC6	1.050721	44.98082	79.28915	5.787483	0.704952	0.668179
LOC7	12.96142	79.73567	27.15634	19.37436	4.540391	0.924218
LOC8	0.663949	31.32999	22.33413	2.687091	0.316449	-1.37679
LOC9	1.871588	48.59125	41.4278	3.471498	0.801965	-1.19583
LOC10	11.23402	82.70931	37.72908	14.43156	4.650978	0.212827
LOC11	0.693426	33.41644	36.57383	0.970435	0.247744	-2.48446
LOC12	1.511046	50.29196	43.03764	4.586575	0.718595	0.038099
LOC13	1.73888	51.94475	42.46494	4.277947	0.244743	-0.3281
LOC14	1.412209	38.18298	52.60758	4.038539	0.60339	-0.20018
LOC15	1.509798	39.59615	53.22846	4.48287	0.637813	0.219923
LOC16	2.428996	55.6685	43.35851	2.997826	0.98405	-1.72554
LOC17	2.464084	55.79272	43.12687	4.450023	0.994511	-0.20018
LOC18	2.431029	55.89248	43.99129	4.617609	0.998588	-0.69495
LOC19	0.647934	32.02232	38.85211	6.244633	0.400657	0.298246
LOC20	0.673364	33.24117	38.33692	6.606138	0.430579	0.377075

Table 7: Summary of irrigation indices calculated for groundwater of the area

Parameters	Range	Irrigation Class
SAR (Ayers and Westcot, 1985)	<10 10-18 18-26 >26	Excellent Good Fair Poor
SSP (Todd, 1980)	<20 20-40 40-80 >80	Excellent Good Fair Unsuitable
MAR (Paliwal,1972)	<50 >50	Suitable Unsuitable
RSBC (Nassem et al., 2010)	<2.5 >2.5	Suitable Unsuitable
PI (Doneen,1964)	<60 >60	Suitable Unsuitable
KR (Kelly,1946)	<1 1-2 >2	Suitable Marginal Unsuitable

The pH values, ranging from 5.38 to 7.99, indicate slightly acidic to nearly alkaline water, with all samples meeting the WHO standard (6.5–8.5) for drinking water. Electrical Conductivity (EC) values range between 132µS/cm and 940µS/cm, classifying the groundwater as having low salinity, which is suitable for irrigation under most conditions. Total Dissolved Solids (TDS) values ranges from 117mg/L to 607 mg/L, classifying all samples as non-saline, confirming suitability for irrigation purposes. Sodium Adsorption Ratio (SAR) values, with most samples below 10 except at Loc7 (12.96) and Loc10 (11.23), confirm that the majority of water is excellent for irrigation, with only minor exceptions rated as good. The Water Quality Index (WQI) classifies 75% of the groundwater samples as excellent, 20% as poor, and one groundwater sample (Loc18) as unfit for drinking due to high contamination levels. The permeability index and

Kelly's Ratio values confirm overall irrigation suitability across most locations, except for Loc7 and Loc9.

This result shows the influence of both natural and human-induced factors on water quality. Locations with anomalies, such as Loc10 and Loc18, require attention and management to address the water quality issues. Regular monitoring, remediation strategies, and sustainable water resource management practices are recommended to safeguard groundwater resources and ensure their long-term usability in Oyo Town.

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