

## Seasonal hydrochemical characterization and irrigation suitability of groundwater in selected towns of Awka south local government area, Nigeria

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ARTICLE INFO	ABSTRACT
<p><b>Keywords:</b> Groundwater, pH, total dissolved solids, total hardness, Water Quality Index, Sodium Adsorption Ratio, Permeability Index, Magnesium Hazard, Kelly's Ratio, and Nitrate Pollution Index</p> <p>Received: 28, Feb. 2026 Revised: 17, Mar. 2026 Accepted: 24, Mar. 2026</p> <p>©2026 Author(s): This is an open-access article distributed under the terms of the <a href="https://creativecommons.org/licenses/by/4.0/">Creative Commons Attribution 4.0 International</a></p> 	<p><i>Groundwater is a vital resource for domestic, agricultural, and industrial use, particularly in developing regions where access to safe surface water is limited. This study assessed the physicochemical characteristics and irrigation suitability of groundwater in selected towns (Awka, Nibo, Amawbia, and Nise) within Awka South Local Government Area, Anambra State, Nigeria. Groundwater samples were collected from boreholes during the dry (October–December 2024) and rainy (April–May 2025) seasons and analyzed using standard laboratory procedures. Key parameters evaluated included pH, total dissolved solids (TDS), total hardness (TH), major cations and anions, and heavy metals. To determine water suitability for irrigation, several indices were computed, including the Water Quality Index (WQI), Sodium Adsorption Ratio (SAR), Permeability Index (PI), Magnesium Hazard (MH), Kelly's Ratio (KR), and Nitrate Pollution Index (NPI). Results showed that groundwater in the study area is generally slightly acidic (pH 4.5–6.5) but within acceptable limits for most physicochemical parameters. WQI values for all samples were below 50, indicating good water quality and suitability for irrigation. SAR and KR values were low, suggesting minimal risk of soil structural degradation, while PI values indicated good permeability and favorable infiltration conditions. However, elevated NPI values (&gt;3), especially during the rainy season, suggest significant nitrate contamination risks requiring continuous monitoring. Total hardness values exceeded recommended thresholds, which may pose long-term soil and water quality challenges. Magnesium hazard was generally low, except in Nibo, where higher values may affect soil structure. Overall, the study concludes that groundwater in the area is largely suitable for irrigation, though concerns related to acidity, nitrate pollution, and hardness necessitate proper management and monitoring to ensure sustainable use.</i></p>

### INTRODUCTION

Groundwater quality in most developing countries, particularly in Africa, is extremely complicated due to a number of critical factors, including a poor water resources management system, a lack of accurate identification and prioritization of contamination sources, a lack of improved vulnerability and protection assessment of groundwater, and mismanagement of borehole and hand-dug well performance. Groundwater quality issues are more closely linked to the aforementioned factors in sub-Saharan Africa (Lapworth et al., 2017). Many African towns rely on groundwater resources for household, industrial, and agricultural use. Groundwater is a crucial supply of fresh

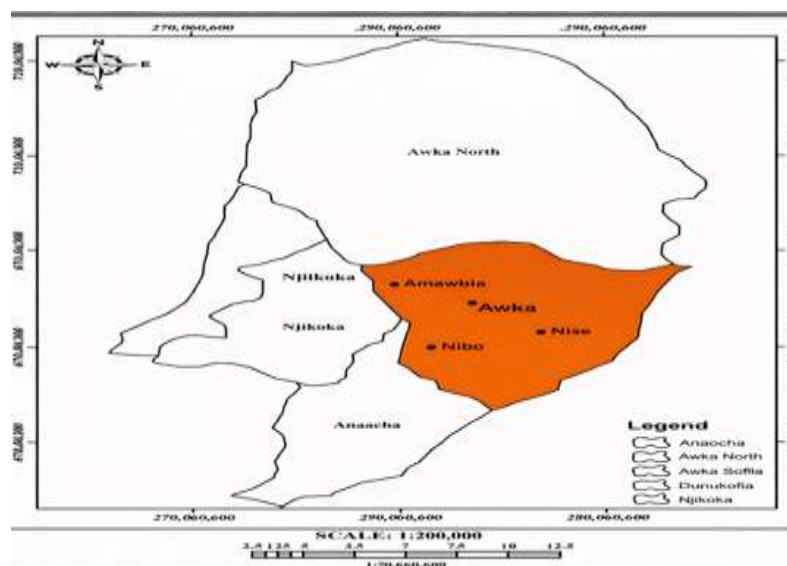
water for human life, and it is especially significant for drinking since it is less susceptible to surface pollution. The global problem of guaranteeing access to safe and high-quality drinking water is well recognized (Fayaji et al., 2019).

Researchers have expressed serious concerns about groundwater contamination caused by a variety of human activities, including storage tank leaks, chemical leaks, landfills, fertilizer and pesticide use, inadequate sanitation systems, and untreated waste and sewage discharge (Chamanehpour et al., 2020; Kalhor et al., 2019). Population expansion, as well as agricultural, industrial, residential, commercial, and urban activities, are all putting pressure on groundwater quantity and quality (Teng et al., 2019). According to Umobi et al. 2025, groundwater quality in awka agricultural zone is increasingly impacted by anthropogenic factors and climate change. Clean water should be affordable, available, and easily accessible at all times, with a focus on meeting at least the local standard for potable water quality. 60% of people in developing countries have access to average water supply, while approximately 35% have access to good sanitation facilities

## 2. METHODOLOGY

### 2.1 Study Area

The study was done in selected towns in Awka South Local government area (Awka, Nibo, Amawbia and Nise), Anambra State. Awka South is located in the Awka Agricultural zone within the derived savanna vegetative zone and experiences a tropical climate with two distinct seasons: the rainy season (March to April) and the dry season (October to November), the topography is hilly and in many parts flood erosion is a major problem. The soil is classified as deep porous ferralithic which is easy to till but subject to excessive leaching because it is formed from sandstone (Nweke and Winch, 1980).



Source: ArcGIS 10.8

**Figure. 2.1:** Map of Awka Agricultural Zone showing Awka, Amawbia, Nibo and Nise.

### 2.2 Methods of Groundwater Quality Assessment

#### 2.2.1 Mode of Sample Collection

A total of eight (8) water samples were collected, four (4) samples were collected during the wet/rainy season (April to May 2025) and four (4) samples (October to December 2024) during the dry season. The samples were collected in duplicate at every sample point (one batch of the samples were filtered and labelled A, these samples were used for cation analysis while the second batch of

the samples were not filtered, they were labelled B and were used for anion analysis). The water samples were collected with one liter plastic cans, the cans were washed thoroughly and rinsed properly before use. The samples were analyzed within the shortest time using the methods as recommended by APHA (1998). Some parameters including pH and turbidity were analyzed in the field to avoid deterioration, these parameters include; pH and EC, which were analyzed using a pH meter (Hanna model HI991300) and a conductivity meter (Model DDS-307) respectively

### 2.3 Water Analysis

The water samples were analyzed for the following parameters in the laboratory; temperature, pH, total dissolved solid, total hardness, calcium, magnesium, nitrate, electrical conductivity, chloride, bicarbonate, sulphate, sodium, potassium, iron and lead.

### 2.4 Drinking Water Quality Index (DWQI)

In this study, the drinking WQI (DWQI) was assessed based on seven analyzed groundwater parameters, namely  $\text{NO}_3^-$ , TDS,  $\text{SO}_4^{2-}$ ,  $\text{Na}^+$ ,  $\text{Cl}^-$ , TH, and pH.

$$RW_i = \frac{AW_i}{\sum_i^n AW_i} \quad (1)$$

$RW_i$  is the relative weight of each parameter

$AW_i$  defines the assigned weight of each parameter

$n$  is the total number of parameters.

### 2.5 Sodium Adsorption Ratio (SAR)

Sodium adsorption ratio were calculated using the following formula, *and all the ionic concentrations are in meq l<sup>-1</sup>*:

$$\text{SAR} = \frac{\text{Na}}{\sqrt{\frac{\text{Ca}^{2+} + \text{Mg}^{2+}}{2}}} \quad (2)$$

### 2.6 Permeability Index (PI)

Permeability index (PI) which were computed using eqn. 3, with all ions stated in meq/L:

$$\text{PI} = \frac{\text{Na}^+ + \sqrt{\text{HCO}_3^-}}{\text{Ca}^{2+} + \text{Mg}^{2+} + \text{Na}^+} \quad (3)$$

### 2.7 Magnesium Hazard (MH)

Magnesium Hazard was determined using the equation 4 (Raghunath, 1987).

$$\text{MH} = \frac{\text{Mg}^{2+}}{\text{Ca}^{2+} + \text{Mg}^{2+}} \times 100 \quad (4)$$

### 2.8 Kelly's Ratio (KR)

Kelly's ratio (KR) classified into two simple classes, namely suitable (<1) and unsuitable (>1) for irrigation purposes (Kelley, 1940; Kelley, 1963) was computed using the formular below.

$$\text{KR} = \frac{\text{Na}^+}{\text{Mg}^{2+} + \text{Ca}^{2+}} \quad (5)$$

## 2.9 Total Dissolved Solids (TDS)

Total dissolved solids (TDS) were calculated using Equation below:

$$TDS = \frac{A-B \times 10^3 \text{ mg/L}}{\text{Sample volume mL}} \quad (6)$$

Where A = weight of dish + solids (mg)

B = weight of dish before use (mg)

## 2.10 Nitrate Pollution Index (NPI)

Nitrate pollution Index (NPI) was calculated using Equation below:

$$NPI = \frac{C_m - C_s}{C_s} \quad (7)$$

## 2.11 Total Hardness

Total hardness was calculated using the below formula, *all the ionic concentrations are in meq l<sup>-1</sup>*:

$$TH = (Ca^{2+} + Mg^{2+}) \times 50 \quad (8)$$

## 3. RESULTS

### 3.1 Result of water analysis

The data from the field work and laboratory analysis of the various physicochemical parameters of the groundwater samples were obtained from four (4) different boreholes during dry season (October to December 2024) and during the rainy season (April to May 2025) in Awka, Amawbia, Nise and Nibo. The results of physicochemical data analysis are shown in Table 1.

**Table 1 Result of the Physicochemical properties of boreholes for the study area**

S/N	PARAMETERS	SEASON	AWKA	NIBO	AMAWBIA	NISE
1	Temperature (°C)	DS	29.6	27.2	29.3	27.5
		RS	23.7	22.9	22.4	22.6
2	Ph	DS	6.5	5.7	4.5	6.2
		RS	5.4	4.8	6.3	5.7
3	TDS (mg/L)	DS	263.31	157.4	225.1	284.8
		RS	35.37	266.83	158.2	228.2
4	Total Hardness (mg/L)	DS	85.4	48.1	69.7	85
		RS	87.7	48.6	64.82	70.1
5	Calcium (Ca <sup>2+</sup> )	DS	63.77	7.28	34.7	51.88
		RS	65.3	7.8	35.86	65.3
6	Magnesium (Mg <sup>2+</sup> ) (mg/L)	DS	21.67	12.55	18.05	16.44
		RS	21.93	21.67	12.55	18.05
7	Nitrate (NO <sub>3</sub> <sup>2-</sup> ) (mg/l)	DS	35.15	19.07	23.92	17.04
		RS	36.7	21.15	22.51	23.92
8	Electrical Conductivity (µS)	DS	407.6	246.7	351.8	438.5
		RS	408.22	247.01	353.14	439.7

9	<b>Chloride (Cl<sup>-</sup>) (mg/l)</b>	<b>DS</b>	11.5	30.31	44.73	17.5
10	<b>Bicarbonate HCO<sub>3</sub><sup>-</sup>(mg/l)</b>	<b>DS</b>	80.54	74.89	76.78	75.43
11	<b>Sulphate (SO<sub>4</sub><sup>2-</sup>) (mg/l)</b>	<b>DS</b>	18.74	32.18	14.82	11.76
12	<b>Sodium (Na<sup>2+</sup>) (mg/l)</b>	<b>DS</b>	6.18	6.28	6.88	1.92
13	<b>Potassium (K) (mg/l)</b>	<b>DS</b>	5.94	4.99	5.84	2.45
14	<b>Iron (Fe<sup>2+</sup>) (mg/l)</b>	<b>DS</b>	0.08	0.11	0.05	0.05
15	<b>Lead (pb)</b>	<b>DS</b>	0	0.002	0	0
		<b>RS</b>	0.001	0.003	0	0

### 3.1.1 Seasonal Evaluation of Physicochemical Properties of the Groundwater Quality of the study areas

From the seasonal analysis (Table 1), it was discovered that temperatures were higher in the dry season (DS) (average 28.4°C) than in the rainy season (RS) (average 22.9°C), impacting chemical and biological processes (WHO, 2017). The pH varied from 4.5 to 6.5, which was continuously acidic in both seasons and fell below WHO, NSDWQ (6.5-8.5), and FAO (>6.5) recommendations, causing corrosion hazards and potentially affecting soil structure. Similar low pH levels were recorded in the Niger Delta and Anambra State (Egbueri, 2020; Nwankwoala and Umesi, 2015; Aghazadeh and Mogaddam, 2010), but Lagos and Abeokuta had alkaline pH levels (7.2-8.6) owing to carbonate buffering (Adepoju and Aladejana, 2021; Ogunyemi and Oladapo, 2016). TDS ranged from 35.37-266.83 mg/L for both seasons, within WHO/NSDWQ (500 mg/L) and FAO (<450 mg/L) guidelines.

However, ASO levels were increased, presumably impacting taste and irrigation (Ukpong and Udofia, 2011; Ibe and Egereonu, 2003). ASO had the greatest EC (360+ µS/cm) in both seasons, whereas irrigation was safe (<700 µS/cm) with modest RS increases owing to runoff (Okoro et al., 2021; FAO, 2016). The total hardness (48.1-87.7) for both seasons, met WHO (500 mg/L) and NSDWQ (150 mg/L) standards, making it appropriate for home and agricultural usage. Calcium (DS: 7.28 - 63.77 mg/L; RS: 7.8 to 65.3 mg/L) and magnesium (DS: 12.55 - 21.67 mg/L; RS: 12.55-21.93 mg/L) were within WHO (calcium: 200 mg/L, magnesium: 150 mg/L) and NSDWQ (magnesium: 100 mg/L) limits, beneficial for nutrition and soil conditioning.

The values for lead levels were below the detection limit (0.01 mg/L), indicating safe drinking and irrigation (WHO, 2017; NIS, 2015). Nitrate levels (17.04 - 36.7) were below WHO and NSDWQ limits of (50 mg/L). The electrical conductivity (EC) values of both seasons for irrigation matched FAO criteria (<3000 µS/cm), with EC (246.7 – 439.7 µS/cm) for both seasons, comparable with Usman et al. (2024) and Akakuru et al. (2021).

### 3.2 Water Quality Index

The Water Quality Index (WQI) is a numerical expression used to assess water quality. It takes into account several characteristics such as pH, TDS, and heavy metals. A WQI value less than 50 normally indicates good water quality. The Food and Agriculture Organization (FAO), World Health Organization (WHO), and Nigerian Standard for Drinking Water Quality (NSDWQ) all give drinking water quality recommendations that emphasize the significance of water safety and quality factors. Although the World Health Organization and NSDWQ Guidelines primarily focus on drinking water quality, their principles can be applied to assess irrigation water suitability. The FAO recommends considering WQI values when evaluating water quality for irrigation, even though their

specific guidelines may differ. WQI values below 50 are frequently considered suitable for irrigation, and the FAO's principles can be applied to assess irrigation water suitability (FAO, 2016).

**Table 2 Result of Water Quality Index**

	Awka	Nibo	Amawbia	Nise
DS	0.6172	20.4677	1.0848	0.5414
RS	1.3488	30.9875	0.9069	1.1727

However, the WQI of AS02, showed signs of high WQI value in the study area, the WQI values of the groundwater quality results are below 50 in both seasons (Table 2) suggesting that the water is suitable for irrigation, and with proper management, can promote healthy crop growth and development which is in agreement with works done by, Olisah and Onyekaozuru, (2023), Sanga *et al.*, (2023), Adeniyi *et al.* (2022), Hinge *et al.*, (2022), Akakuru *et al.*, (2021), Fijani *et al.*, (2017), and Amiri *et al.*, (2016).

### 3.3 Sodium Adsorption Rate (SAR)

The Sodium Adsorption Ratio (SAR) is an important statistic in evaluating water quality for irrigation since it evaluates sodium's ability to alter soil structure and crop development. Compared to research works by Aromolaran, (2023), Taiwo *et al.*, (2023), Zhou *et al.*, (2020), Sridharan and Senthil, (2017), Olaniyi and Adejoro, (2020), Nwachukwu and Okoro, (2019), and Adepetu and Adeyinka, (2018), it was discovered that the SAR values of this research fall below 10, indicating a low risk of soil structure degradation (Table 3), reduced water infiltration, and increased soil salinity and is generally suitable for irrigation, promoting healthy crop growth. This is also in agreement with FAO Guidelines in considering SAR values when evaluating water quality for irrigation which indicates that SAR values below 10 are generally considered suitable for irrigation.

**Table 3 Result of Sodium Adsorption Ratio**

	Awka	Nibo	Amawbia	Nise
DS	0.95	1.994	1.34	0.329
RS	0.949	1.654	1.409	0.321

### 3.4 Permeability Index (PI)

The Permeability Index (PI) is an important factor in determining water quality for irrigation applications. It assesses the possibility for water to permeate the soil and impact crop development. According to FAO irrigation guidelines (FAO, 2016), the PI values from this study are less than 25, indicating good soil infiltration (Table 4), lowering the risk of waterlogging and soil salinization. Crops are likely to benefit from good water infiltration, which promotes healthy root growth and development. Nibo borehole has high permeability index values (3.10 for dry season and 2.279 for rainy season), when compared to other boreholes.

**Table 4 Permeability Index Classification**

	Awka	Nibo	Amawbia	Nise
DS	0.947	3.109	1.403	1.101
RS	0.931	2.279	1.518	0.914

### 3.5 Magnesium Hazard (MH)

The Magnesium Hazard (MH) ratio evaluates the possible influence of magnesium on soil structure and crop growth when irrigation water is used. It is computed using the magnesium-to-calcium + magnesium ratio in the water. The Food and Agriculture Organization (FAO, 2016) suggests taking magnesium hazard into account when evaluating irrigation water quality, because

MH values more than 50 might signal possible soil structural difficulties (Table 5). However, the World Health Organization (WHO) provides drinking water quality guidelines but does not specifically address the magnesium hazard for irrigation purposes, whereas the Nigerian Standard for Drinking Water Quality (NSDWQ) establishes drinking water quality standards that can be used to evaluate irrigation water quality.

**Table 5 Maximum Hazard Classification**

	Awka	Nibo	Amawbia	Nise
DS	25.636	63.288	34.218	24.063
RS	25.14	65.287	36.351	21.524

Data gathered during the dry season (Table 5) revealed that all the boreholes with MH values <50 suggest a minimal risk of magnesium hazard, while 1 borehole (Nibo) with an MH value >50 may represent a risk to soil structure. Nibo borehole has a high magnesium hazard value. The rainy season results show that the with MH values <50 indicate a low risk, while 1 borehole (Nibo) with an MH value >50 may require closer monitoring as recommended by FAO magnesium hazard classification range and a few research works by Ojo and Tolulope, (2023), Getnet et al., (2022), and Suarez (2019) suggesting that high magnesium concentrations can affect soil structure and crop growth.

### 3.6 Kelly's Ratio (KR)

Kelly's Ratio (KR) is a parameter used to assess the suitability of water for irrigation purposes, as recommended by FAO Guidelines for Evaluating Water Quality for Irrigation. KR values are calculated based on the ratio of sodium to calcium plus magnesium in the water, with KR values greater than 1 (Table 6) indicating potential soil structure issues.

**Table 6 Result of Kelly's Ratio Classification**

	Awka	Nibo	Amawbia	Nise
DS	0.0723	0.317	0.13	0.028
RS	0.0715	0.283	0.123	0.025

During the dry season, boreholes Awka and Nise had very low KR values. All the boreholes tested had KR values <1, making them suitable for irrigation. During the rainy season (Table 6), all 4 boreholes in the study region have KR values <1, indicating their suitability for irrigation. Yusuf et al., (2024), Zhang et al., (2024), Abanyie et al., (2023), Kumar et al., (2020), Suarez (2019), Adejuwon et al., (2018), and Ogundele et al., (2020) evaluated groundwater quality for irrigation, emphasizing the impact of KR on soil structure and the importance of monitoring KR levels to prevent soil degradation.

### 3.7 Nitrate Pollution Index (NPI)

The results of the groundwater quality assessment of the study area as compared to the FAO guidelines for groundwater quality index showed that during the dry season (Table 8) 2 boreholes (Nibo and Nise) with NPI values are within 2-3 (Table 7) and will require monitoring, while 2 boreholes (Awka and Amawbia) with NPI values >3 pose a significant risk. During the rainy season (Figure 7 and Table 8), all the boreholes have NPI values greater than 3 and pose a significant risk. Asomaku (2023), Pandit and Kateja (2023), and Zhang et al. (2012) argued for increased emphasis on the importance of monitoring NPI levels to prevent environmental degradation, highlighting the impact of nitrate pollution on soil and water health.

**Table 7 Nitrate Pollution Index (NPI) Classification**

	Awka	Nibo	Amawbia	Nise
DS	4.515	2.907	3.392	2.704
RS	4.67	3.115	3.251	3.392

### 3.8 Total Hardness (TH)

The total hardness classification of water is critical for determining its appropriateness for irrigation applications in order to maintain optimal water quality and avoid potential soil and water concerns. Wali et al., (2020), Swistock, (2017), Dhanasekarapandian et al., (2016), and Aminiyan et al., (2016) research works support the importance of monitoring water hardness to prevent potential soil and water quality issues, and our literature review revealed that the TH results they obtained were similar to the results obtained from the study area.

**Table 8 Total Hardness (TH) Classification**

	Awka	Nibo	Amawbia	Nise
DS	4272	991.5	2637.5	3416
RS	4361.5	1123.5	2817	4160

According to the findings of this study (Table 8), all the boreholes had values greater than 300 mg/L for both seasons, posing significant risks to soil and water quality. High total hardness levels can cause scaling, reduction in soil permeability, and impact soil structure and fertility. As a result, the Food and Agriculture Organization's water quality index categorization recommends taking water hardness into account when assessing irrigation appropriateness.

### 3.9 Total Dissolved Solids

The TDS classification of water is critical for determining its suitability for irrigation, with previous research by Zhang et al., (2024), Asomaku, (2023), Pandit and Kateja (2023), Alam and Singh, (2022), Singh et al., (2022), and Kumar and Krishna, (2021) supporting the importance of monitoring TDS levels to avoid potential soil and water quality issues.

**Table 9: Total Dissolved Solids (TDS)**

	Awka	Nibo	Amawbia	Nise
DS	266.31	157.4	225.1	284.8
RS	35.37	266.83	158.2	228.2

According to the data from the study area's groundwater quality test, the dry season (DS) values (Table 9) ranged from 157.4 mg/L to 284.8 mg/L, and the rainy season (RS) values (Table 9) ranged from 35.37 mg/L to 266.83 mg/L, which is less than the FAO's recommended water quality index of 450 mg/L for irrigation purposes. The Food and Agriculture Organization suggests taking TDS levels into account when determining irrigation water appropriateness. High TDS levels (>450 mg/L) may cause soil salinity and lower agricultural production.

## CONCLUSION

The groundwater quality in the study areas were assessed using major irrigation appropriateness indicators derived from FAO, WHO, and NSDWQ standards. The following parameters were examined: Water Quality Index (WQI), Sodium Adsorption Ratio (SAR), Permeability Index (PI), Magnesium Hazard (MH), Kelly's Ratio (KR), Nitrate Pollution Index (NPI), Total Hardness (TH), and Total Dissolved Solids (TDS). All the boreholes had WQI values of less than 50, indicating that they were suitable for irrigation. SAR, and KR data generally indicated a minimal risk of soil deterioration. The PI values recorded in this study are than 25, indicating good

soil infiltration, lowering the risk of waterlogging and salinization. The magnesium hazard was generally modest, except in Nibo, where concentrations surpassed the threshold (>50), indicating possible concerns. During the rainy season, all the boreholes have NPI values, greater than 3 suggesting nitrate contamination danger, necessitating monitoring, but, during the dry season, only 2 boreholes (Awka and Amawbia) with NP values greater than 3, pose a significant risk. Total hardness exceeded 300 mg/L, for all the seasons in this study, indicating potential soil and water quality issues. However, TDS levels remained below the FAO's 450 mg/L standard, indicating a low danger of salinization. Several metrics fell outside of the standards in the study areas. The pH in the study area was somewhat acidic (4.5-6.5), indicating probable corrosion, consistent with regional studies. Heavy metal concentrations (such as lead, cadmium, and iron) were minimal, indicating that residential usage was safe in most locations. For irrigation, increased electrical conductivity suggested salinity hazards, necessitating careful control.

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