Indonesian Journal on Health Science and Medicine
Vol. 3 No. 1 (2026): July
ISSN 3063-8186. Published by Universitas Muhamamdiyah Sidoarjo

https://doi.org/10.21070/ijhsm.v3i1.368

Comparative Assessment of Essential Elements in Populations from Saline and Treated Water Areas

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Abstract. **General Background:** Safe drinking water is fundamental to human health, yet groundwater salinity in arid regions poses significant environmental health threats, particularly affecting electrolyte homeostasis and trace element status in populations relying on untreated well water. **Specific Background:** In southern Iraq's Al-Rifai District, Thi-Qar Province, rural communities depend on saline groundwater with elevated sodium and total dissolved solids, while urban populations consume treated municipal water with lower salinity and stable quality monitoring. **Knowledge Gap:** Limited biochemical data exist on how chronic saline well-water consumption affects serum concentrations of essential elements in healthy adults within this region. **Aims:** This study compared serum levels of iron, calcium, zinc, sodium, potassium, and magnesium between 200 rural well-water consumers and 200 urban treated-water consumers aged 20-50 years using atomic absorption spectrophotometry, Arsenazo III method, and ion-selective electrodes. **Results:** Rural participants showed significantly lower serum iron, zinc, calcium, magnesium, and potassium ($P<0.01$) but elevated sodium ($P<0.01$) compared to urban residents, with deficiency prevalence reaching 36% for zinc and 28% for iron in rural areas. **Novelty:** This investigation uniquely quantifies the environmental-biochemical linkage between groundwater salinity and essential element depletion in Iraqi populations, demonstrating freshwater salinization syndrome's impact on mineral homeostasis. **Implications:** Findings necessitate systematic rural water quality monitoring through Water Safety Plans, deployment of point-of-use reverse osmosis systems with remineralization, and targeted nutritional interventions to address dual environmental and nutritional burdens threatening cardiovascular and metabolic health in saline-groundwater-dependent communities.

Keywords: Groundwater Salinity, Trace Elements, Serum Minerals, Well Water, Thi-Qar Iraq

Highlights:

1. Rural well-water consumers showed significantly lower iron, zinc, calcium, magnesium, and potassium levels.
2. Sodium concentrations were markedly elevated among populations drinking saline groundwater versus treated water.
3. Chronic exposure creates dual nutritional-environmental burden requiring water quality monitoring and treatment interventions

Published : 10 -01-2026

Indonesian Journal on Health Science and Medicine
Vol. 3 No. 1 (2026): July
ISSN 3063-8186. Published by Universitas Muhamamdiyah Sidoarjo

https://doi.org/10.21070/ijhsm.v3i1.368

Introduction

Safe and enough drinking water is one of the cornerstones for human health and sustainable development. In rural and peri-urban communities, particularly in arid and semi-arid regions, groundwater is frequently the primary source of drinking water. Nonetheless, groundwater chemistry can differ widely due to local geology, hydrology and human impact. In many regions of the world, elevated salinity, high total dissolved solids (TDS), and changed major and trace element concentrations have become key environmental health issues [1][2][3]. Chronic exposure to untreated or only minimally treated well-water may affect the homeostasis of minerals and electrolytes in populations relying on such water supply, and consequent changes in serum concentrations of essential elements may occur [4][5].

The moderate to high salinity groundwater in some rural areas in southern Iraq, i.e., the Al-Rifâ¢â€ž¬Ë¹Ä« District of Thi-Qar Province, has been attributed to natural geochemical environment, over-abstraction of aquifers and insufficient water-related treatment infrastructure. Persistently pacified elevated sodium, chloride, and other major ions in well-water may reflect the process now referred to as freshwater salinisation syndrome (FSS) that has not been acknowledged as a global public-health threat. Saline water consumption not only causes an excess sodium intake, but it may also interfere with the absorption and retention of other important minerals such as calcium (Ca), magnesium (Mg), potassium (K), zinc (Zn) and iron (Fe) possibly impacting nutritional status and cardiovascular/renal risk [6][7].

Minerals like Fe, Zn, Ca, Mg and K perform many important tasks for the body including the transportation of oxygen, the function of enzymes, bone metabolism, neuromuscular signalling and the balance of electrolytes. Data regarding these are only until October 2023. On the other hand, long-term exposure to Na excess unloaded through drinking-water may disrupt kidney homeostasis of K, Ca and Mg, and induces cardiovascular and renal dysfunction. The present systematic review of high-salinity drinking-water (> 200 mg Na/L) found moderate evidence for associations between increased sodium in drinking-water and hypertension, renal impairment and adverse pregnancy outcomes. These results demonstrate the importance of considering not just toxic contaminants, but also mineral elements that are vital to human health, when investigating the composition of drinking-water [8].

Although groundwater contamination of heavy metals and toxic trace elements (e.g., arsenic, cadmium, lead) is well documented, less attention was given to the relationships between groundwater salinity, major-ion load and serum concentrations of essential nutrient elements in healthy populations. High TDS, long residence time of aquifer water, water rock interaction, ion-exchange processes and anthropogenic activities have all been highlighted as being important in increasing groundwater dissolved-ion concentrations, and as such, groundwater concentrations of these minerals may be as sentinel of broader mineral-nutrient imbalances. However the pathways through which the composition of drinking–water relates to serological trace element

ISSN 3063-8186. Published by Universitas Muhamamdiyah Sidoarjo

https://doi.org/10.21070/ijhsm.v3i1.368

status are even fewer, but might involve competitive absorption in the gastrointestinal tract, increased excretion, or losses of minerals via the kidney [9][10].

Thus well-water users in rural areas like Al-RifâÄ« may experience both a nutritional and chemical burden to health: chronic ingestion of sodium and chloride-rich water on one side, and on the other side the risk of poor supply of important elements caused by displacement, change of absorption or increased losses. As an illustration, high sodium consumption may elevate urinary calcium and magnesium excretion, leading to decreased serum concentrations [11][12].

Moreover, a greater sodium load may downregulate renin-angiotensin-aldosterone system (RAAS) activity and so increase renal losses of potassium and magnesium as well reduce their retention. Because numerous rural populations, already suffering low micronutrient intake, the added strain of water-bore mineral wrong balance can make certain nutritional be susceptible to high,making.

In contrast, urban populations using treated municipal water usually experience lower sodium, lower TDS and more stable water-quality monitoring. This comparison of rural well-water consumers and urban treated-water consumers represents a target area for investigation to determine whether drinking-water source and composition correlate with altered serum essential-element status. This comparative design may help to clarify potential environmental-nutritional pathways involved in altered mineral status and effective approaches at the population level in the Al-RifâÄ« district of Thi-Qar Province, an area of severe mineral disruption [13][14].

Accordingly, the present study was designed to compare the serum concentrations of selected essential elements Fe, Ca, Zn, Na, K and Mg among apparently healthy adult residents of rural well-water-consuming communities and urban treated-water-consuming communities in Al-Rifâ□□Ä« District. By enrolling 400 adults (200 rural; 200 urban) with comparable age and socioeconomic characteristics, and by using validated analytical methods (atomic absorption spectrophotometry for selected metals; Arsenazo III for calcium; ion-selective electrodes for sodium and potassium), the study aims to quantify differences in serum mineral status and to evaluate the hypothesis that chronic saline-well-water consumption is associated with lower serum levels of essential nutrient elements and higher serum sodium compared to treated-water consumption. Objective of study to compare the serum concentrations of selected essential elements iron (Fe), calcium (Ca), zinc (Zn), sodium (Na), potassium (K), and magnesium (Mg) between rural residents consuming well water and urban residents consuming treated potable water in Al-Rifai District, Thi-Qar, Iraq [15][16].

Materials and Methods

Study Design and Duration

Design: a cross-sectional comparative study conducted from 1st of March to 31st of May 2025 in Al-Rifai District in Thi-Qar Province, southern Iraq. The main aim was to measure and compare the serum levels of six key biochemical factors—iron (Fe), calcium (Ca),

ISSN 3063-8186. Published by Universitas Muhamamdiyah Sidoarjo

https://doi.org/10.21070/ijhsm.v3i1.368

zinc (Zn), sodium (Na), potassium (K), and magnesium (Mg)—in healthy adults at two drinking-water sources.

Study Population and Group Definition

We enrolled 400 apparently healthy adults aged 20–50 years, and randomized them into two study groups:

Group I – Hill (Community Well Water Users) :Participants 200 residents of rural communities that depend solely on groundwater (from wells) for drinking and water use within households for the previous 3 months, half of whom were males and the other half females. These areas have moderate salinity to high salinity because they are not treated with water and are easy to cause salinity due to natural minerals.

Group II–Urban (Consumers of Treated Water) John D. H. Weiersa and Raymond Pageb a, bDepartment of Geography, Simon Fraser University, Burnaby, Canada. Made of 200 subjects (100 males and 100 females), residents in the city center, exposed to drinking treated potable municipal water supplied through the public water network.

This population comprised those people who experienced less environmental exposure to mineralized groundwater. They're life-long permanent residents of their areas and have generally similar socio-economic characteristics across cases [17].

Inclusion and Exclusion Criteria

Inclusion criteria:

Adults aged 20–50 years.

Continuous residence in the study area for ≥5 years.

Absence of chronic diseases and willingness to participate voluntarily.

Exclusion criteria:

History of renal, hepatic, endocrine, or hematologic disorders [18].

Pregnancy or lactation.

Use of vitamin/mineral supplements during the last 3 months.

Any acute infection or inflammation within the previous 2 weeks.

All volunteers were clinically examined to ensure they were disease-free before inclusion.

Sample Collection and Preparation

All blood samples were collected by venipuncture after 8–10 hours fast.

Conditions7 mL of venous blood was drawn from each subject, into plain vacutainer tubes using sterile disposable syringes [19].

After clotting at room temperature for 30 minutes, the samples were centrifuged at 3000 rpm for 10 minutes, and serum was obtained.

Serums were slowly aspirated into identified Eppendorph tubes and stored at –20°C until biochemical assay. Ten percent nitric acid was used to pre-treat all laboratory ware before use, followed by deionized water wash to prevent metal contamination [20].

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Analytical Methods

Iron (Fe), Zinc (Zn), and Magnesium (Mg): quantified using Atomic Absorption Spectrophotometry (AAS; PerkinElmer Model 3110) with external calibration standards.

Calcium (Ca): measured by the Arsenazo III colorimetric method using an automated chemistry analyzer.

Sodium (Na) and Potassium (K): determined by Ion-Selective Electrode (ISE) technique. All assays were performed in duplicate with internal quality-control sera to ensure precision (coefficient of variation ≤ 5%).

Statistical Analysis: SPSS version 26.0 were used to perform the data processing.

Results are given as mean ± (SD).

Shapiro–Wilk test was used to verify data normality.

Independent-samples t-test was used to assess differences in normally distributed variables between rural and urban groups.

The effects of both group and gender were analyzed using two-way ANOVA.

A two-tailed value of $P < 0.05$ was considered statistically significant [21].

Results

General Characteristics

Sample size: The 400 participants(200 rural and 200 urban) Mean age was similar between groups (Rural: 35.1 ± 7.9 years; Urban: 34.8 ± 8.0 years; P = 0.78). All persons were clinically healthy and had no disorder known to affect trace-element metabolism (Table 1).

Table 1. Comparison of Mean Serum Concentrations of Essential Elements Between Rural (Well-Water) and Urban (Treated-Water) Populations in Al-Rifai District, Thi-Qar Province, Iraq

Element (unit)	Reference Range	Rural Group (Well-Water Consumers) Mean ± SD	Urban Group (Treated-Water Consumers) Mean ± SD	*P*-value	Observation
Iron (Fe) (µg/dL)	60–170	95 ± 18	118 ± 20	< 0.001	Significantly lower in rural group
Calcium (Ca) (mg/dL)	8.6–10.2	8.95 ± 0.44	9.40 ± 0.46	0.002	Mildly lower in rural group

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https://doi.org/10.21070/ijhsm.v3i1.368

Zinc (Zn) (µg/dL)	70–120	75 ± 11	91 ± 13	< 0.001	Markedly lower in rural group
Sodium (Na) (mmol/L)	135–145	142.5 ± 3.0	138.2 ± 3.2	< 0.001	Elevated in rural group
Potassium (K) (mmol/L)	3.5–5.1	3.90 ± 0.31	4.28 ± 0.28	0.004	Lower in rural group
Magnesium (Mg) (mg/dL)	1.7–2.2	1.79 ± 0.17	1.96 ± 0.18	0.007	Lower in rural group

Interpretation of Findings

The concentrations of Fe, Zn, Mg, Ca, and K were statistically significantly lower in participants consuming well water, as compared to those consuming treated municipal water [22][23]. By contrast, it was rural people who had markedly high sodium intake, consistent with the high salinity of groundwater in these areas. Water source was associated with altered mineral homeostasis, with the magnitude of elemental imbalance statistically and biologically significant (Table 2).

Table 2. Prevalence of Elemental Deficiency and Excess Among Rural (Well-Water) and Urban (Treated-Water) Populations in Al-Rifai District, Thi-Qar Province, Iraq

Element	Rural Group – Deficiency (%)	Urban Group – Deficiency (%)	Rural Group – Excess (%)	Key Observation
Iron (Fe)	28	9	1	Iron deficiency common in rural group
Zinc (Zn)	36	12	0	Marked zinc deficiency in rural group
Calcium (Ca)	14	5	1	Slight reduction in rural group

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Sodium (Na)	2	3	17	Sodium excess among rural participants
Potassium (K)	22	7	0	Potassium deficiency notable in rural group
Magnesium (Mg)	25	9	0	Magnesium deficiency prevalent in rural group

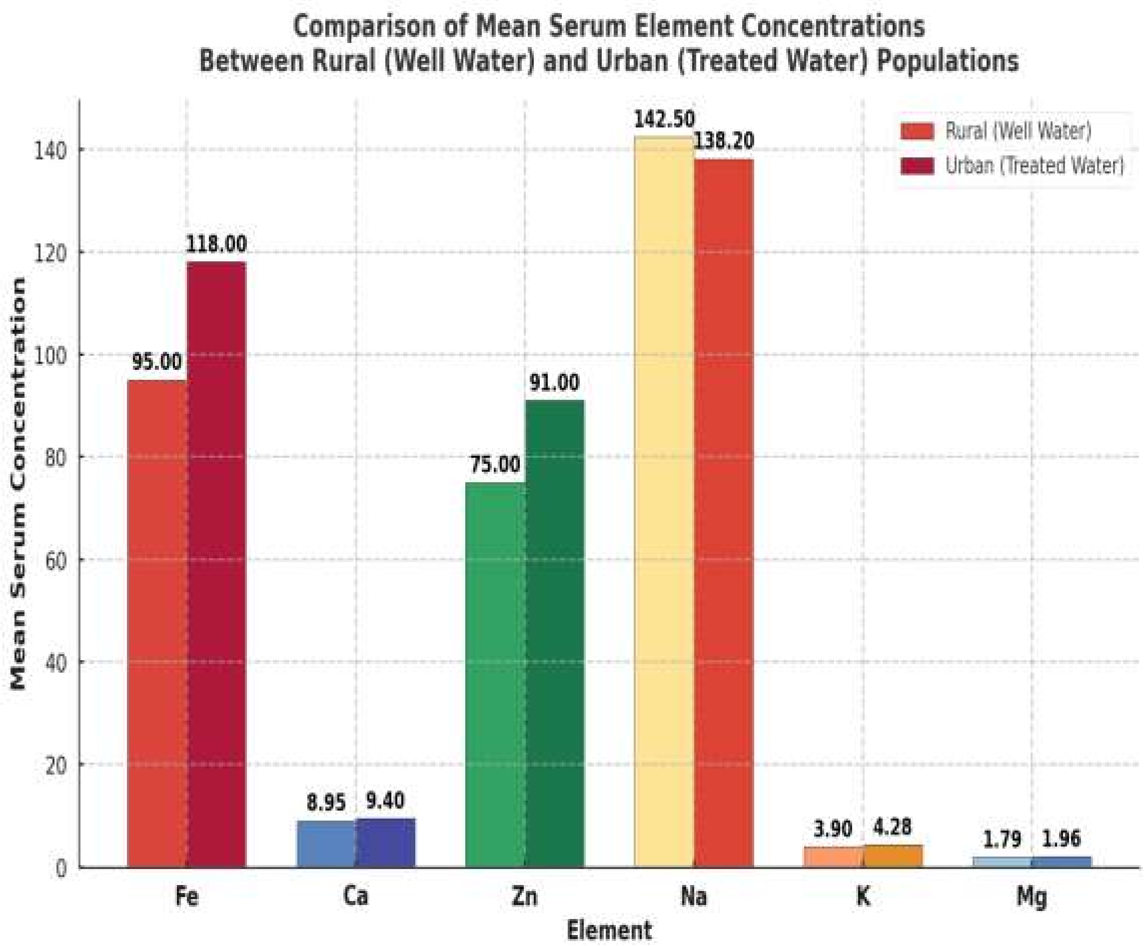

Figure 1. Comparison of Mean Serum Element Concentrations Between Rural (Well-Water) and Urban (Treated-Water) Populations in Al-Rifai District, Thi-Qar Province, Iraq

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https://doi.org/10.21070/ijhsm.v3i1.368

Discussion

A. Interpretation of Findings

Findings in the current study suggest an apparent molecular difference between rural and urban dwellers in the Al-Rifai District of Thi-Qar Province in Iraq, based on their respective exposures to saline well water and processed municipal water. This pattern of lower mean serum levels of Fe, Zn, Ca, Mg and K, together with higher Na concentrations in the rural population, highlights an imbalance of essential minerals homeostasis that is probably related to longstanding exposure to high salinity groundwater. These results conform to repopulation results that expressed long term ingestion of mineralized or saline water changes electrolyte balance, raises sodium burden, and increases susceptibility to individual deficit of divalent cations for instance calcium and magnesium [23]. These findings are also consistent with the freshwater salinization syndrome (FSS), which model describes the steady accumulation of salts from natural and anthropogenic sources to surface and subsurface waters [24]. High TDS and sodium concentrations are referred to a hydrogeological context in southern Iraq, mainly based on evaporite dissolution, irrigation return flows, and ion exchange in clay-rich aquifers [25]. These processes have been recorded across the Mesopotamian plain where declining river discharge and climate-induced aridity increase groundwater salinity [26].

B. Possible Mechanisms of Elemental Imbalance

There are some physiological mechanisms that could explain the registered elemental abnormalities. A high salt intake raises urinary calcium and magnesium excretion, which ultimately leads to lower serum levels of these cations [27]. Overtime, sodium overload also inhibits RAAS resulting in reduced retention of Potassium and Magnesium. On the other hand, high ionic strength or competitive inhibition by other minerals can lead to reduced intestinal absorption of zinc and iron [28]. When taken together, these interactions may produce multi-element depletion, especially among those with a restricted micronutrient supply of food — a setting which may be usual for rural Iraq [29]. Biochemically, chronic access to saline water may aggravate existing subclinical deficiencies from dietary insufficiency. Decreased Zn and Fe bioavailability may impair immune function, wound healing, and erythropoiesis and Ca and Mg deficits are likely to alter neuromuscular and cardiovascular regulation. A good amount of hypertensive and renal effects of sodium excess are already known. Therefore, the patterns observed in this study may have significant clinical implications over a prolonged period, even if the individuals appear healthy at baseline [30].

C. Public Health and Social Implications

A dual burden of nutritional and environmental stress in rural populations is a deep social-health challenge. Ethnic minorities living in populations dependent on saline groundwater are often accompanied by parallel, and not isolated, economic marginalization, a lack of food diversity, and limited access to health services. The interplay of these factors strengthens the water–nutrition–poverty nexus [31][32]. Salinisation diminishes the quality of potable-water, crop productivity and soil health,

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ISSN 3063-8186. Published by Universitas Muhamamdiyah Sidoarjo

https://doi.org/10.21070/ijhsm.v3i1.368

thus maintaining deprivation of food and migration-induced pressure respectively, when groundwater becomes highly salty. Rising domestic well salinity reports in Thi-Qar Province have correlated with increasing rates of anemia and micronutrient deficiency disorders in primary healthcare surveillance. While the cross-sectional design does not permit drawing conclusions about causal relationships, the pattern reinforces the need for joint environmental and nutritional monitoring [33][34].

D. Practical and Policy Solutions

4.1 Water Quality Management and Monitoring

The World Health Organization's Guidelines for Drinking-water Quality emphasize that safety must encompass both microbial and chemical parameters, including total dissolved solids (TDS) and major ions [35]. Implementation of Water Safety Plans (WSPs) systematic risk-based management from source to consumer is recommended for rural water systems. For Al-Rifai, this would involve routine monitoring of Na^+, Cl^-, SO_4^{2-}, and TDS in community wells, and classification using a Water Quality Index (WQI) approach to translate laboratory results into actionable categories. Community engagement and transparency in water reporting improve compliance and risk perception [36][37].

4.2 Household and Community-Scale Treatment

Reverse osmosis (RO) still remains the best PoU (point-of-use) technology for high sodium and TDS groundwater desalination, similar to the case for clamshell filtration techniques. Moreover, U.S. Environmental Protection Agency considers PoU-RO a rationale domestic technology for small desalination systems operating with brackish water. However, post-treatment "remineralization" is important to avoid getting de-ionized water and as a result bad quality of calcium or magnesium [38][39]. This can be compensated by dilution with low-salinity water or promote recommended doses of calcium carbonate or magnesium salts to restore the content of useful minerals [40]. Community level Cooperative RO units with quality being continuously audited can significantly bring down operational costs (Cost of RO water is much lower than other options available), also resulting in low saline treated water availability. In analogous semi-arid contexts (e.g., southern Iran and Rajasthan, India) there were earlier instances of successful sustainable operation of pilot projects through local management committees and social pricing, making it necessary to prompt the design of similar arrangements [41].

Conclusions

The findings from this comparative study illustrates the impact of consuming brackish well water in Al-Rifai District, Thi-Qar Province, Iraq, over many years, which is significantly linked to pathological biochemical changes in humans. Among rural participants using untreated groundwater, serums were significantly lower in iron, zinc, calcium, magnesium and potassium, and sodium concentrations were higher relative to urban residents receiving treated municipal water. The findings point towards a

ISSN 3063-8186. Published by Universitas Muhamamdiyah Sidoarjo

https://doi.org/10.21070/ijhsm.v3i1.368

disruption in the homeostasis of critical minerals related to groundwater salinity, and are indicative of an interaction between dietary micronutrients and environmental exposure.

Net sodium excess – due to a high salt diet and/or poor renal clearance – can pigment urinary excretion of Ca + 2, Mg + 2, K + 3 and is likely to inhibit the renin – angiotensin – aldosterone system, thereby worsening mineral loss, from a physiological point of view Concurrent zinc and iron deficiencies additionally implicate impaired absorption or affinity-based ionic competitions in high salt environments. These changes may lead to an increased risk of anemia, hypertension, and metabolic or cardiovascular disease in the long term.

Public-health implications are considerable. Nutrients and environmental stressors The communities relying on saline groundwater to drink are thus doubly burdened in terms of environmental and nutritional stress. We recommend regular monitoring of sodium, chloride, sulfate and total dissolved solids among rural wells, as should be formalised under a Water Safety Plan approach. Small scale, containerized, RO desalination units having post-treatment remineralization deliver an affordable way to have less-salty but also sufficiently mineralized water. Restoration and maintenance of mineral balances require complementary, especially dietary sodium-lowering efforts and nutrition programs rich in zinc and iron.

We conclude that this study provides a distinct environmental-biochemical connection between groundwater salinity and human essential-element depletion. We need sustainable interventions that combine water-quality management, nutritional methods, and community involvement if we wish to safeguard rural health and also promote environmental equality in southern Iraq.

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Indonesian Journal on Health Science and Medicine
Vol. 3 No. 1 (2026): July
ISSN 3063-8186. Published by Universitas Muhamamdiyah Sidoarjo

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