Journal of Geoscience and Environment Protection, 2026, 14(7), 427-439
https://www.scirp.org/journal/gep
ISSN Online: 2327-4344
ISSN Print: 2327-4336

Assessment of the Quality of Irrigation Water at Some Selected Parts of Atwima Nwabiagya North District

Vivian Isabella Seshie*, Solomon Owusu Ansah

Environmental and Safety Engineering Department, University of Mines and Technology, Tarkwa, Ghana
Email: *viseshie@umat.edu.gh, kingwood481@yahoo.com

How to cite this paper: Seshie, V. I., & Ansah, S. O. (2026). Assessment of the Quality of Irrigation Water at Some Selected Parts of Atwima Nwabiagya North District. *Journal of Geoscience and Environment Protection, 14,* 427-439.
https://doi.org/10.4236/gep.2026.147024

Received: June 23, 2026
Accepted: July 26, 2026
Published: July 29, 2026

Abstract

The quality of agricultural irrigation water is a critical determinant of crop productivity, soil physical health, and long-term agricultural sustainability. This study evaluated the hydrochemical suitability of water sources utilised for irrigation in selected agricultural zones within the Atwima Nwabiagya North District of Ghana. Seventeen irrigation water sources were sampled and systematically analysed for key physicochemical parameters and calculated agricultural suitability indices, including pH, electrical conductivity (EC), sodium adsorption ratio (SAR), sodium percentage (Na%), magnesium adsorption ratio (MAR), residual sodium carbonate (RSC), soluble sodium percentage (SSP), total hardness, total alkalinity, and concentrations of chloride, sulphate, boron (B), and iron (Fe). Based on calculated SAR (0.41 to 8.17) and RSC (0.11 to 0.55 meq/L) values, all evaluated water sources fell within safe limits, indicating low immediate risks of soil permeability issues. However, the calculated MAR ranged from 46% to 86%, with 16 out of the 17 analysed samples exceeding the critical 50% suitability threshold, signifying a widespread magnesium hazard capable of causing clay dispersion and soil compaction (borehole BH02 [46%] was the sole safe exception). This structural hazard is heavily compounded by highly elevated sodium percentages (Na% > 80% in 12 samples) and soluble sodium percentages (SSP > 80% in 14 samples except BH02 `68.76`, S03 `52.58`, and S12 `77.91`) across the majority of the sampling sites. Furthermore, while the slightly acidic pH (6.07 to 6.99), low EC (< 700 µS/cm), and moderate alkalinity levels were safe, boron concentrations (0.80 to 1.70 mg/L) consistently exceeded the agricultural safety threshold of 0.7 mg/L in 100% of the samples, presenting a severe toxicity risk for sensitive crops. Additionally, potentially hazardous iron concentrations exceeding 1.0 mg/L were recorded in several surface water sources, threatening micro-irrigation systems with physical clogging and inducing chemical phosphorus fixation in the receiving soils. The findings indi-

cate that while these water sources are safe from an osmotic salinity standpoint, their continuous use poses severe long-term risks of soil structural degradation and phytotoxicity. Regular hydrochemical monitoring and targeted soil management, such as gypsum amendments, are highly recommended to ensure sustainable agricultural production in the district.

Keywords

Irrigation Water Quality, Hydrochemistry, Magnesium Hazard (MAR), Soil Dispersion, Sodicity Hazard, Boron Toxicity

1. Introduction

Irrigation is the artificial application of water to land to support the growth of pastures, crops, and other vegetation. Irrigation is a process that involves human intervention to control soil moisture in the crop root zone while maintaining soil fertility. It can be instinctual or scientifically based. Because groundwater is suitable for various uses, poor irrigation water impacts crops and soil quality. Physical and chemical characteristics, highly influenced by geological formations and human activity, determine how groundwater quality varies in a given area (Sule et al., 2020). The potential for Ghana's economic and social change remains in the agriculture sector. Therefore, the sector must develop quickly to reach its full potential.

To ensure that the incomes of agricultural sector employees and Ghanaians are sustainable, there must be a significant increase in the productivity of all production components, especially food crops and livestock (Anon, 2017). Ghana's agriculture is primarily rain-fed, which contributes to the low productivity of the crop subsector. Increased access to irrigated agriculture is the goal of the Ministry of Food and agriculture's sub-programme. Farmers will be encouraged to participate in irrigation scheme management (operation and maintenance), irrigation infrastructure will be expanded and improved, irrigation service charges will be made easier to set and collect, water users' associations (WUAs) will be made more aware of the importance of irrigation, and the irrigation value chain will be strengthened (Anon, 2024).

Dependable access to usable water is necessary for irrigation-based agriculture. Water quality issues have frequently been ignored because of the abundance of high-quality water supplies. Water availability and water quality for irrigation issues are developing in many ways. As a result of the excessive use of all high-quality resources, new irrigation projects and ongoing projects seeking more or replacement supplies are forced to rely on subpar, unwanted sources. To avoid problems when using these low-quality water supplies, adequate planning must ensure that water quality is utilised to its fullest. The study evaluates irrigation water quality in parts of the Atwima Nwabiagya North District.

2. Materials, Methods Used

2.1. Sampling and Analysis

Water samples were collected from 17 sources using water sampling bottles. These sources include rivers, streams, and boreholes, with most being streams. Water sampling was conducted once during the coinciding harvest and rainy seasons (May). Multiple samples were collected from 17 irrigation sources which were rivers serving the district's major farms to ensure broad representation. The locations of water samples were recorded with a handheld GPS. While sampling sites were distributed randomly across the district, selection was specifically guided by and focused on the dominant water sources utilised for agricultural irrigation in the region. The samples were sealed, stored in the ice chest at low temperatures, and transported to the Environmental and Safety Engineering laboratory at the University of Mines and Technology, Tarkwa, Ghana, for analysis. Figure 1 below shows the locations of the sampling points and their corresponding GPS locations.

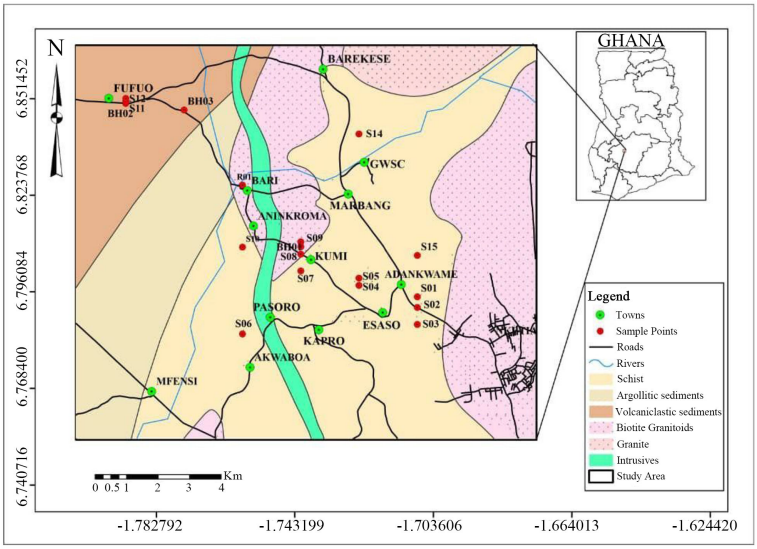

Figure 1. Sample location.

2.2. Analysis of Samples

Physicochemical parameters—including pH, electrical conductivity (EC), total dissolved solids (TDS), and salinity—were measured using a multi-parameter meter calibrated with standard buffer solutions (pH 4.01, 7.00, and 10.01), ensuring deionised water rinses between successive measurements. Total hardness (TH), total alkalinity (TA), and boron (B) concentrations were determined photometrically.

For major cation analysis (Na^+, Mg^{2+}, Ca^{2+} and K^+), 100 mL sample aliquots were digested with 5 mL of concentrated nitric acid (HCO_3^-) and heated for 2.5 hours. Concentrations of Na^+, K^+, and Ca^{2+} were subsequently quantified using a flame photometer. Major anions (Cl^-, SO_4^{2-}, CO_3^{2-} and HCO_3^-) were systematically analysed using standard hydrochemical protocols.

Quality Assurance and Quality Control (QA/QC)

To ensure analytical precision and accuracy, rigorous QA/QC protocols were integrated into the laboratory workflow. Every analytical batch included procedural blanks to monitor for reagent-grade contamination, with all blank values falling below the method detection limits. Instrument precision was verified through replicate analyses of randomly selected samples, ensuring a relative percent difference (RPD) of <5%. Analytical accuracy was further validated using certified reference materials (CRMs) to determine the percentage recovery of each heavy metal, with acceptable recovery rates maintained within the 80% - 120% range. Additionally, mid-range calibration standards were re-analyzed every ten samples to check for instrumental baseline drift, ensuring that all reported concentrations met established threshold requirements for scientific reproducibility.

2.3. Sodium Adsorption Ratio

The Sodium Adsorption Ratio (SAR) assesses the potential for sodium to participate in soil cation-exchange reactions relative to calcium and magnesium. Expressed in milliequivalents per litre (meq/L) as defined in Equation (1), higher SAR values indicate elevated risk of soil sodication and reduced irrigation suitability. Waters with an SAR exceeding 13 are classified as sodic; however, an SAR between 1 and 3, paired with an EC < 700 μS/cm, indicates a negligible risk of impairment of soil infiltration rate (Fianko & Korankye, 2020).

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

where concentrations are in Meq/L.

2.4. Magnesium Ratio

The Magnesium Adsorption Ratio (MAR) evaluates the proportion of magnesium relative to total divalent cations, as high magnesium adsorption degrades soil structural properties. Soil physical degradation typically occurs when the MAR exceeds 50% (Equation (2)) (He et al., 2013).

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

where concentrations are in Meq/L.

2.5. Sodium Percentage (Na%)

Assessing the sodium percentage (Na%) is critical because elevated sodium levels induce structural sodicity hazards and impair soil permeability, as calculated via Equation (3) (He et al., 2013).

$$Na\% = (Na^{+1} \times 100)/(Ca^{2+} + Mg^{2+} + Na^{+1} + K^{+1}) \quad (3)$$

where concentrations are in Meq/L.

2.6. Soluble Sodium Percentage

The Soluble Sodium Percentage (SSP), calculated via Equation (4), is a critical index for evaluating sodicity hazards, as highly elevated SSP values can impair seed

germination and cause stunted vegetative growth.

$$SSP = (Na^+ + K^+) \times 100/(Ca^{2+} + Mg^{2+} + Na^+ + K^+) \quad (4)$$

where all concentrations are expressed in Meq/L.

2.7. Bicarbonate Hazard

The bicarbonate hazard is usually expressed as Residual Sodium Carbonate (RSC). RSC is always evaluated using Equation (5) below.

$$RSC = (HCO_3^- + CO_3^{2-}) - \left(Ca^{2+} + Mg^{2+}\right) \quad (5)$$

where all concentrations are expressed in Meq/L.

Elevated bicarbonate concentrations promote the precipitation of calcium and magnesium as carbonate minerals, raising the relative proportion of sodium and exacerbating sodicity hazards. This geochemical process is quantified via the Residual Sodium Carbonate (RSC) index; under the Eaton (1950) classification framework, irrigation water is considered safe at an RSC < 1.25 meq/L, marginally suitable requiring targeted management between 1.25 and 2.5 meq/L, and entirely unsuitable at values exceeding 2.5 meq/L.

2.8. Total Dissolved Salts

Irrigation water salinity originates from the geogenic weathering and dissolution of soil minerals such as calcite and gypsum (Richards, 1954). As irrigation water evaporates or is transpired, these dissolved salts accumulate in the root zone (Ayers & Westcot, 1985), elevating soil osmotic pressure and restricting plant water uptake to induce growth-stunting physiological moisture stress (Anon, 2019).

Under the Wilcox (1955) classification framework, irrigation suitability is categorized based on Total Dissolved Solids (TDS) concentrations: values below 450 mg/L are classified as "excellent", 450 to 750 mg/L as "good", 750 to 2000 mg/L as "permissible", and concentrations exceeding 2000 mg/L as "unsuitable" for agricultural use. In this study, all monitored sampling locations fell within the highly safe, "excellent" range (Wilcox, 1955), confirming their suitability for sustainable agricultural irrigation based on TDS levels.

3. Results and Discussion

3.1. Total Hardness and Total Alkalinity

Total Hardness (TH) reflects the concentration of divalent metallic cations, primarily Ca^{2+} and Mg^{2+}. While excessively high TH leads to mineral scale formation in irrigation piping and localised crop damage (Abusam & Al-Anzi, 2011), extremely low hardness is also structurally problematic. In this study, all monitored samples fell within the "soft water" classification (**Table 1**).

Standard frameworks classify total hardness (as $CaCO_3$) into soft (0 - 60 mg/L), moderately hard (61 - 120 mg/L), hard (121 - 180 mg/L), and very hard (>180 mg/L) regimes (Wilcox, 1955; Tiri et al., 2020; **Table 1**). Agronomically, continu-

ous irrigation with soft water triggers clay dispersion, structural collapse, and impaired infiltration due to a deficiency of divalent Ca^{2+} and Mg^{2+}.

Conversely, total alkalinity—the acid-neutralizing capacity driven by H_2CO_3, HCO_3^-, and CO_3^{2-}—remained withinafe limits for most samples, except BH02, S02 and S03, which fell below recommended thresholds (Abusam & Al-Anzi, 2011). Highly alkaline water exhibits strong buffering capacities that resist pH reduction (Richards, 1954), potentially locking soil pH in alkaline ranges and reducing the bioavailability of essential iron, manganese, and phosphorus.

Table 1. Hydrochemical characterisation and irrigation quality assessment indices.

SAMPLE ID	pH	Ec (µs/cm)	TDS	TA (mg/L)	TH (mg/L)	Salinity	Boron (mg/L)	SAR	MAR	Na%	SSP
BH01	6.84	243	150	140	<2.00	0.14	1.3	6.2	63	84.85	87.74
BH02	6.99	407	254	270	<2.00	0.24	0.8	4.13	46	68.4	68.76
BH03	6.07	119.6	74.1	67	<2.00	0.07	1.7	8.17	67	94	94.36
R01	6.67	124	78.1	69	<2.00	0.07	1.3	6.15	72	86.14	90.88
S01	6.49	120.2	76.7	43	8	0.07	1.1	3.97	86	79.72	82.08
S02	6.54	79.4	49.5	26	<2.00	0.05	1.5	5.42	56	90.9	92.42
S03	6.42	61.5	38.5	29	<2.00	0.04	0.8	0.41	58	44.84	52.58
S04	6.5	107.8	67.3	47	12	0.07	1.3	6.11	71	89.39	90.96
S05	6.32	100.6	61.6	40	<2.00	0.06	1.1	6.04	62	90.22	92.29
S06	6.4	99.6	62.3	43	<2.00	0.06	0.8	4.87	60	87.48	90.17
S07	6.53	101.9	62.4	44	<2.00	0.06	0.9	4.89	54	87.27	89.43
S08	6.56	97.5	60.8	41	<2.00	0.06	1.5	5.54	63	89.65	91.55
S09	6.61	151.1	95.7	67	<2.00	0.09	0.9	7.11	81	89.42	90.94
S10	6.55	107.7	65.9	50	<2.00	0.07	1.2	6.29	63	91.05	92.84
S11	6.65	180.3	113	74	3	0.11	1.3	6.01	80	85.15	86.88
S12	6.42	96.5	60.7	45	6	0.06	1.6	2.92	73	76.94	77.91
S14	6.8	157	98.1	62	<2.00	0.09	1.2	4.17	61	78.62	82.87

Total Dissolved Salts

Total Dissolved Solids (TDS), originating from geogenic weathering and anthropogenic runoff, accumulate in the root zone during evapotranspiration. This raises soil osmotic potential and restricts moisture absorption, inducing "physiological drought", stunted vegetative growth, and reduced crop yields (Abusam & Al-Anzi, 2011). Within the study area, these geochemical pathways are heavily influenced by surrounding land-use activities, notably active quarry mining operations and the integration of livestock farming within the crop cultivation zones. Quarry mines accelerate geogenic weathering by mechanically fracturing bedrock and exposing fresh mineral surfaces to precipitation, thereby facilitating the dissolution and leaching of inorganic salts into nearby agricultural water and soil

systems. Concurrently, the co-practised animal farming introduces a significant anthropogenic footprint; surface runoff and leaching from manure and livestock waste enrich the local hydrological system with highly soluble ions (such as nitrates, chlorides, sodium, and potassium), thereby compounding the regional TDS accumulation. Under the Wilcox (1955) classification framework, irrigation water is categorised as excellent (<450 mg/L), good (450 - 750 mg/L), permissible (750 - 2000 mg/L), and unsuitable (>2000 mg/L). In the present study, all analysed locations exhibited TDS concentrations well within the excellent threshold (<450 mg/L), representing negligible osmotic and salinity risks for local agricultural activities.

3.2. Electrical Conductivity (EC)

Electrical conductivity (EC) is the primary indicator for assessing irrigation salinity hazards. Elevated EC increases soil osmotic pressure, inducing "physiological drought" that restricts moisture absorption and forces plants to expend metabolic energy to overcome osmotic barriers, leading to cellular dehydration and stunted development (Abusam & Al-Anzi, 2011). According to the US Salinity Laboratory, EC values below 250 µS/cm represent low-salinity hazards, while values exceeding 750 µS/cm pose high-salinity hazards. In this study, all analysed water sources except sample BH02 exhibited low-to-medium salinity hazards, indicating high agricultural suitability with no immediate threat of root-zone salinisation.

3.3. Magnesium Adsorption Ratio

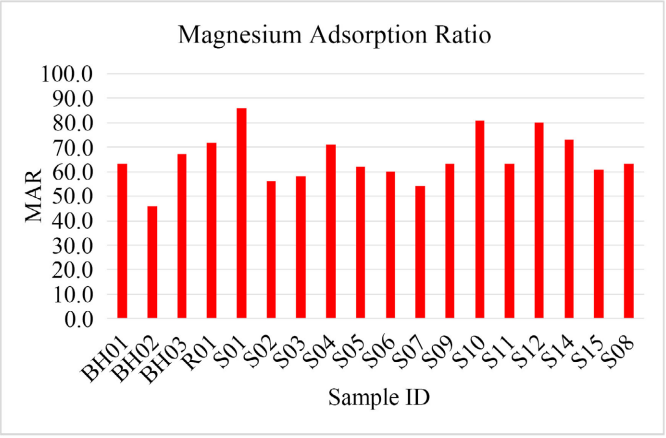

Figure 2. Magnesium adsorption ratio.

The Magnesium Adsorption Ratio (MAR) assesses structural soil risks, as excess Mg^{2+} relative to Ca^{2+} induces sodium-like clay dispersion and deflocculation due to the larger hydrated ionic radius and weaker binding affinity of Mg^{2+} to clay complexes (Paliwal, 1972). Under the Paliwal (1972) framework, values exceeding 50% are categorized as unsuitable/hazardous, whereas those below 50% are considered suitable. In this study, the majority of analysed samples were unsafe

(MAR > 50%), with sample BH02 recording a suitable peak of 46%, indicating no immediate magnesium hazard to regional soil structures (**Figure 2**).

3.4. Sodium Percent (Na%)

The sodium percentage (Na%) assesses agricultural sodicity by calculating the ratio of monovalent Na^+ and K^+ to total cations (Richards, 1954; Chemura et al., 2014; Shahid, Zaman, & Heng, 2018). Excessive sodium displaces divalent Ca^{2+} and Mg^{2+} on clay complexes, triggering clay dispersion, colloid swelling, and macroporosity collapse (Hillel, 2000; Qadir & Schubert, 2002).

The Wilcox (1955) framework classifies irrigation suitability based on Na% limits: excellent (<20%), good (20% - 40%), permissible (40% - 60%), doubtful (60% - 80%), and unsuitable (>80%). Hydrochemical analysis showed that the majority of study samples were unsuitable (Na% > 80%), with only S01, S12, S14, and BH02 classified as doubtful (Richards, 1954) and S03 as permissible (Chemura et al., 2014). This severe sodium footprint threatens long-term soil alkalization and compaction, necessitating calcium-rich soil amendments (Wilcox, 1955; **Figure 3**).

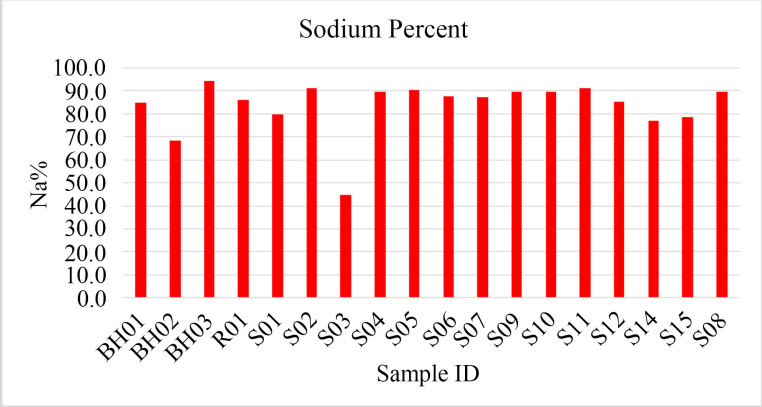

Figure 3. Sodium percentage distribution.

3.5. Sodium Adsorption Ratio (SAR)

Compared to the sodium percentage, the Sodium Adsorption Ratio (SAR) is a more reliable predictor of soil permeability hazards because it accounts for the flocculating and mitigating effects of divalent Ca^{2+} and Mg^{2+} on clay dispersion (Richards, 1954). This mathematical relationship is defined in Equation (6), with all ionic concentrations expressed in milliequivalents per litre (meq/L).

$$SAR = [Na^+]/\sqrt{(0.5 \times ([Ca^{2+}] + [Mg^{2+}]))} \quad (6)$$

Applying high-SAR water increases the soil's exchangeable sodium percentage (ESP), causing clay lattice swelling, soil aggregate breakdown, and surface physical sealing, which severely restricts water infiltration and induces crop water stress and poor root aeration (Hillel, 2000; Qadir & Schubert, 2002). Under standard classifications, water with an SAR < 10 is classified as "Excellent" (low hazard), while values exceeding 26 are unsuitable.

Under the Chemura et al. (2014) frameworks, irrigation water is classified by SAR into excellent (<10, low hazard), good (10 - 18, medium hazard), fair (19 - 26, high hazard), and poor/unsuitable (>26, very high hazard). Despite elevated sodium percentages (Na%) in this study, all calculated SAR values remained within the safe "Excellent" to "Good" ranges (SAR < 18), demonstrating that divalent cations successfully mitigate immediate soil sodicity risks (**Figure 4**).

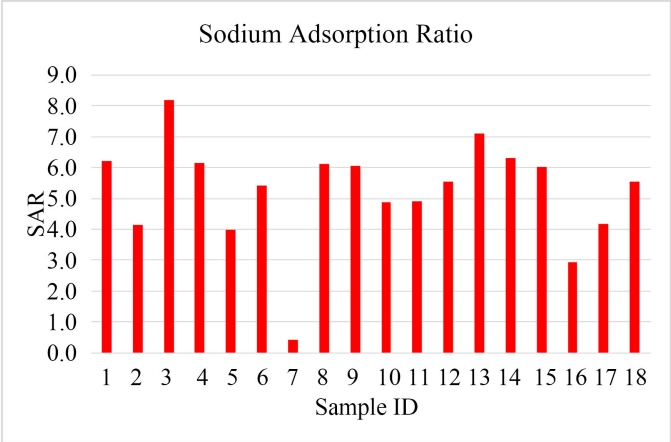

Figure 4. Sodium adsorption ratio.

3.6. Soluble Sodium Percentage (SSP)

Distinct from SAR, the Soluble Sodium Percentage (SSP) evaluates irrigation sodicity hazards by calculating the ratio of soluble monovalent Na^+ and K^+ to total cations, expressed in meq/L in Equation (7).

$$SSP = ([Na^+] + [K^+]/[Ca^{2+}] + [Mg^{2+}] + [Na^+] + [K^+]) \times 100 \quad (7)$$

An SSP > 50% promotes exchangeable sodium accumulation, clay dispersion, and pore blockage, severely degrading soil permeability and inducing root-zone waterlogging and stunted crop growth (Ayers & Westcot, 1985). All analyzed samples exceeded this critical threshold, making them unsuitable for continuous irrigation without amendments. This elevated sodium footprint stems from both geogenic silicate weathering and anthropogenic contributions (e.g., fertilizer leaching, greywater runoff). Standard agricultural classifications (Wilcox, 1955) define suitability based on SSP: excellent (<20%), good (20% - 40%), permissible (41% - 60%), doubtful (61% - 80%), and unsuitable (>80%).

3.7. Specific Hydrochemical Parameters and Crop Suitability

3.7.1. Potential Hydrogen (pH) and Overall Salinity HazardSource Apportionment

Irrigation water pH controls soil chemical equilibrium and nutrient bioavailability. While alkaline water (pH > 8.5) promotes calcium carbonate ($CaCO_3$) precipitation and physical blockages in micro-irrigation systems (Ayers & Westcot, 1985), sub-optimal acidic water (pH < 6.5) was observed in samples BH03, S01, S03, S05, S06 and S12. Continuous acidic irrigation enhances the solubility of toxic

trivalent aluminum (Al^{3+}) and divalent manganese (Mn^{2+}), causing phytotoxicity and stunted root elongation, while accelerating basic cation leaching (Ca^{2+}, Mg^{2+}, K^{+}) and fixing orthophosphates into insoluble complexes.

Conversely, overall salinity poses no immediate osmotic hazards. Elevated salinity disrupts root moisture uptake by lowering soil osmotic potential, inducing physiological drought, leaf necrosis, and yield loss (Ayers & Westcot, 1985). All analyzed water samples remained safely below the FAO "No Restriction" threshold (EC < 0.7 dS/m; TDS < 450 mg/L), indicating negligible osmotic risks.

3.7.2. Specific Ion Hazards: Boron (B) and Chloride (Cl^{-})

Boron (B) possesses an exceptionally narrow safety margin; deficiency halts meristematic growth, while excess accumulates in leaf margins, causing chlorosis, photosynthesis disruption, and necrosis (Ayers & Westcot, 1985). In this study, 100% of the samples exceeded the FAO safety threshold of 0.7 mg/L (ranging from 0.80 to 1.70 mg/L), indicating a widespread boron toxicity risk. This elevated footprint is attribute to geogenic weathering of borosilicates, exacerbated by anthropogenic fertilizers and detergent-laden greywater.

Table 2. Hydrochemical analytical results of monitored water samples.

Sample ID	SO_4^{2-} (ppm)	Cl^{-} (ppm)	CO_3^{2-} (ppm)	HCO_3^{2-} (ppm)	Na (ppm)	K (ppm)	Ca (ppm)	Mg (ppm)	Fe (ppm)
BH01	<5.00	<0.50	0	57	25	3.7	3	3.06	0.53
BH02	45	4.3	0	75	35	0.8	19.4	9.84	<0.01
BH03	13	5	0	25	18	0.3	0.8	0.97	<0.01
R01	<5.00	5.9	0	44	18	4.3	1.2	1.85	8.33
S01	49	3.2	0	43	16	2	1.1	4.21	1.19
S02	11	1.3	0	24	11	0.8	0.9	0.69	0.22
S03	10	2	0	27	0.8	0.6	0.8	0.66	5.2
S04	9	3.3	0	17	17	1.3	1.1	1.66	2.17
S05	<5.00	2.1	0	18	14	1.4	1	1.01	1.77
S06	11	3.4	0	21	12	1.6	1.2	1.1	4.64
S07	<5.00	<0.50	0	19	13	1.4	1.6	1.16	2.19
S08	<5.00	3.3	0	15	13	1.2	1	1.05	1.3
S09	5	3.2	0	37	23	1.7	1	2.54	7.62
S10	<5.00	3.3	0	17	14	1.2	0.9	0.94	1.82
S11	12	6.3	0	54	25	2.2	1.7	4.18	9.75
S12	11	3.2	0	45	11	0.6	1.9	3.12	9.27
S14	<5.00	2.1	0	55	17	4	3.2	3.06	0.74

Conversely, chloride (Cl^{-}) poses no agricultural threat. Although excess chloride can accumulate in foliar tissues via transpiration to cause leaf necrosis (Ayers & Westcot, 1985), concentrations across all monitored sites were exceptionally

low (<0.50 to 6.30 mg/L), remaining orders of magnitude below conservative FAO thresholds of 142 mg/L (surface) and 106 mg/L (sprinkler). The comprehensive hydrochemical concentrations of these major anions and cations across the monitored locations are compiled in Table 2.

3.7.3. Operational and Agronomic Hazards: Iron (Fe) and Residual Sodium Carbonate (RSC) Source Apportionment

Dissolved iron (Fe) concentrations exceeded the FAO safety threshold of 1.0 mg/L in the majority of samples (Ayers & Westcot, 1985), with severe elevations in S11 (9.75 mg/L), S12 (9.27 mg/L), R01 (8.33 mg/L), and S09 (7.62 mg/L); only BH01, BH02, BH03, S02, and S14 were safe. Operationally, dissolved Fe^{2+} undergoes aeration-induced oxidation to precipitate as insoluble ferric hydroxide ($Fe(OH)_3$) slime, which promotes bacterially mediated emitter clogging. Agronomically, excess soluble iron under acidic conditions binds with phosphate anions to form insoluble complexes, locking out essential phosphorus and molybdenum.

Lastly, bicarbonate-induced hazards, assessed via the Residual Sodium Carbonate (RSC) index, were negligible. All samples fell safely within the acceptable limit of <1.5 meq/L, indicating zero risk of bicarbonate-induced soil or crop degradation.

4. Conclusions

This study executed a comprehensive hydrochemical evaluation of surface and groundwater sources to determine their suitability for sustainable agricultural irrigation. From a basic salinity and sodicity perspective, standard parameters—specifically Electrical Conductivity (EC < 250 µS/cm), Total Dissolved Solids (TDS < 450 mg/L), and Sodium Adsorption Ratio (SAR < 10)—indicate that all monitored sources present low-salinity hazards, falling within the "Excellent" (S1/C1) category with negligible risks of immediate osmotic crop stress.

However, a deeper physical-chemical and agronomic assessment reveals critical, long-term degradation pathways.

The water sources pose a severe cumulative risk of soil structural collapse. The Magnesium Adsorption Ratio (MAR) exceeded the critical 50% suitability threshold in 16 out of 17 samples (reaching a peak of 86% in sample S01), with borehole BH02 (46%) as the sole safe exception. This magnesium dominance is heavily exacerbated by elevated Sodium Percentages (Na% > 80%) and Soluble Sodium Percentages (SSP > 80%) at most sites. Because the water is concurrently characterised by extremely low Total Hardness (TH < 2.0 mg/L as $CaCO_3$), continuous irrigation with these calcium-deficient, sodium- and magnesium-rich waters will inevitably trigger clay dispersion, colloid swelling, pore blockage, and a severe loss of soil hydraulic conductivity.

The study identified a critical Boron (B) crisis, with 100% of the analysed samples exceeding the safety threshold of 0.7 mg/L (0.8 to 1.7 mg/L), presenting severe phytotoxicity risks for sensitive crops. This is compounded by severe Iron (Fe) pollution in several surface and river samples—notably S11 (9.75 mg/L) and S12

(9.27 mg/L)—which exceeds the 1.0 mg/L limit, presenting a dual risk of clogging micro-irrigation emitters with ferric slime and chemically locking up essential orthophosphate and molybdenum. Furthermore, localised sub-optimal pH levels (pH < 6.5, notably in borehole BH03 [6.07]) will accelerate the leaching of basic nutrients while increasing heavy metal bioavailability.

Consequently, while suitable from an osmotic salinity standpoint, these water sources present long-term structural and chemical threats to the receiving soil-crop system, necessitating the use of calcium-rich soil amendments (such as gypsum) and targeted filtration systems to ensure sustainable agricultural production.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

Abusam, A., & Al-Anzi, B. (2011). Comparison between the Irrigation Qualities of Conventional Tertiary and UF+RO Advanced Treated Wastewaters. *Agricultural Sciences, 2,* 526-532. https://doi.org/10.4236/as.2011.24068

Anon (2017). *Agricultural Sector Progress Report, 2016*. Ministry of Food and Agriculture.

Anon (2019). *Boron Tolerance of Crops: USDA ARS*. https://www.ars.usda.gov/pacific-west-area/riverside-ca/agricultural-water-efficiency-and-salinity-research-unit/docs/databases/boron-tolerance-of-crops/

Anon (2024). *Atwima Nwabiagya. Ministry of Food and Agriculture (2022)*. https://www.mofep.gov.gh/sites/default/files/pbb-estimates/2021/2021-PBB-MOFA.pdf

Ayers, R. S., & Westcot, D. W. (1985). *Water Quality for Agriculture. Irrigation and Drainage Paper No. 29*. Food and Agriculture Organization of the United Nations.

Chemura, A., Kutywayo, D., Chagwesha, T. M., & Chidoko, P. (2014). An Assessment of Irrigation Water Quality and Selected Soil Parameters at Mutema Irrigation Scheme, Zimbabwe. *Journal of Water Resource and Protection, 6,* 132-140. https://doi.org/10.4236/jwarp.2014.62018

Eaton, F. M. (1950). Significance of Carbonates in Irrigation Waters. *Soil Science, 69,* 123-134. https://doi.org/10.1097/00010694-195002000-00004

Fianko, J. R., & Korankye, M. B. (2020). Quality Characteristics of Water Used for Irrigation in Urban and Peri-Urban Agriculture in Greater Accra Region of Ghana: Health and Environmental Risk. *West African Journal of Applied Ecology, 28,* 131-143.

He, Y., DeSutter, T. M., & Clay, D. E. (2013). Dispersion of Pure Clay Minerals as Influenced by Calcium/Magnesium Ratios, Sodium Adsorption Ratio, and Electrical Conductivity. *Soil Science Society of America Journal, 77,* 2014-2019. https://doi.org/10.2136/sssaj2013.05.0206n

Hillel, D. (2000). *Salinity Management for Sustainable Irrigation: Integrating Science and Environmental Considerations*. The World Bank. https://doi.org/10.1596/0-8213-4773-x

Paliwal, K. V. (1972). *Irrigation with Saline Water* (p. 198). ICARI Monograph No. 2, New Delhi.

Qadir, M., & Schubert, S. (2002). Degradation Processes and Nutrient Constraints in Sodic Soils. *Land Degradation & Development, 13,* 275-294. https://doi.org/10.1002/ldr.504

Richards, L. A. (1954). Diagnosis and Improvement of Saline and Alkali Soils. *Soil Science, 78,* 154. https://doi.org/10.1097/00010694-195408000-00012

Shahid, S. A., Zaman, M., & Heng, L. (2018). *Guideline for Salinity Assessment, Mitigation and Adaptation Using Nuclear and Related Techniques*. Springer, 113-131.

Sule, S., Abashiya, M., & Musa, I. (2020). Analysis of Water Quality of Small-Scale Irrigation Scheme in Kwadon, Yamaltu-Deba LGA of Gombe State, Nigeria. *EQA—International Journal of Environmental Quality, 41,* 33-39.

Tiri, A., Belkhiri, L., Asma, M., & Mouni, L. (2020). Suitability and Assessment of Surface Water for Irrigation Purpose. In *Water Chemistry* (p. 250). Intech Open. https://doi.org/10.5772/intechopen.86651

Wilcox, L. V. (1955). *Classification and Use of Irrigation Waters* (p. 969). US Department of Agriculture.