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Irrigation water quality of Berqaber Reservoir and its implications for functional food safety

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ABSTRACT

Background: Irrigation water quality is a fundamental determinant of soil health, crop productivity, and the synthesis of health-promoting bioactive compounds in functional foods. This study evaluates the hydrochemical status of the Berqaber (Joghas) Reservoir and its inflowing rivers (Aghstev and Joghas) in the Tavush region of Armenia, a strategic water resource for regional agriculture, to assess their suitability for sustainable functional crop production.

Objective: This study aims to evaluate the hydrochemical status of the Berqaber Reservoir and its inflowing rivers (Aghstev and Joghas) in northern Armenia, assess their suitability for irrigation using established water quality indices, and examine the implications of irrigation water quality for the safety, nutritional content, and bioactive compound accumulation in functional crops.

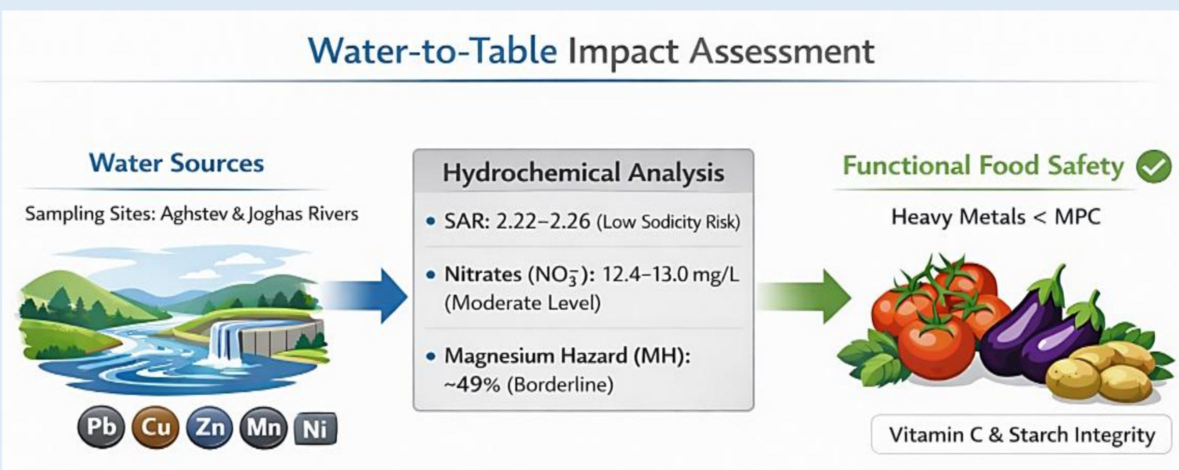
Methods: Water samples were collected in April and July 2024. Analyses included physicochemical parameters, such as pH, total dissolved solids (TDS), and major ions: calcium (Ca^{2+}), magnesium (Mg^{2+}), sodium (Na^{+}), bicarbonate (HCO_3^{-}), and chloride (Cl^{-}). Heavy metals analyzed included lead (Pb), copper (Cu), zinc (Zn), manganese (Mn), and nickel (Ni). Irrigation suitability indices were calculated: Sodium Adsorption Ratio (SAR), Magnesium Hazard (MH), and Stabler's coefficient (k). To validate irrigation safety, nitrate ion (NO_3^-) concentrations, heavy metal accumulation, and nutritional indicators (vitamin C and starch) were assessed in irrigated potatoes, tomatoes, and eggplants.

Results: The irrigation waters exhibited a slightly alkaline reaction (pH 7.4–7.5) with low salinity (TDS 480–570 mg/L). The ionic composition was dominated by Ca^{2+}, Mg^{2+}, Na^+, HCO_3^-, and Cl^-. SAR values (2.22–2.26) and Stabler's coefficients (≈10) classified the water as satisfactory for irrigation with low sodicity risk (United States Salinity Laboratory (USSL C2–S1 category). MH values (48.78–49.46%) approached the 50% threshold associated with potential soil structural sensitivity. NO_3^- concentrations (12.4–13.0 mg/L) exceeded the Armenian regulatory limit of 10 mg/L (Class 3, Moderate Quality), yet nitrate and heavy metal concentrations in edible crop tissues remained well below Maximum Permissible Concentrations (MPC), and nutritional parameters were unaffected.

Conclusion: The Berqaber Reservoir system provides irrigation water with low sodicity risk; however, borderline MH and elevated nitrate levels indicate moderate anthropogenic pressure. Despite this, nitrate and heavy metal concentrations in crops remain within permissible limits, ensuring their safety and functional quality. Effective institutional oversight and compliance with water quality regulations are essential to maintain long-term, sustainable, functional crop production.

Novelty of the Study: This study is the first to integrate hydrochemical assessment of irrigation water with empirical validation of functional crop safety in the Tavush agroecosystem of northern Armenia. By linking irrigation water chemistry with crop nitrate accumulation, heavy metal transfer, and nutritional quality indicators, the research establishes a comprehensive "water-to-table" evaluation framework for sustainable functional food production in mountainous agricultural systems.

Keywords: irrigation water, water quality, heavy metals, sodium adsorption ratio, nitrates, magnesium hazard, Berqaber Reservoir, functional foods, water regulation



Graphical abstract: Overview of irrigation water quality, key hydrochemical indices, and crop safety outcomes supporting sustainable functional food production in the Berqaber reservoir system (Tavush region, Armenia).

INTRODUCTION

Water quality is a critical determinant of agricultural productivity, directly influencing crop growth, yield, and the synthesis of biologically active compounds that define functional foods. These compounds—including polyphenols, flavonoids, vitamins, and essential minerals—exhibit antioxidant, anti-inflammatory, and cardioprotective properties and significantly enhance the health-promoting value of agricultural products [1–3]. Functional food science integrates principles of nutrition, food technology, and health sciences to optimize the content, stability, and bioavailability of these compounds in crops.

Crop quality is further influenced by propagation methods, cultivation practices, and cultivar-specific responses. In vitro propagation has been shown to improve yield and fruit quality in strawberry cultivars [4], while targeted microfertilizer strategies enhance both productivity and nutritional value in potato crops under regional agroecological conditions [5].

Among cultivation factors, irrigation water chemistry plays a decisive role in nutrient availability, plant stress responses, and the metabolic pathways regulating bioactive compound synthesis [6]. Parameters such as salinity, SAR, magnesium content, nitrate concentration, and heavy metal presence affect not only productivity but also food safety. In particular, heavy metal contamination can impair seed germination and early plant development, reducing crop establishment and yield potential [7].

In anthropogenically impacted river systems of the Caucasus region, elevated ecological risks are particularly pronounced in semi-arid and mountainous environments, where limited water resources increase dependence on surface and groundwater for irrigation. In Armenia, similar hydrochemical concerns have been documented in the Ararat Valley and mountainous catchments [8].

Armenia's irregular precipitation distribution and increasing water scarcity make reservoirs and river systems essential for irrigation-based agriculture. The Berqaber (Joghas) Reservoir, supplied primarily by the Aghstev and Joghas rivers, plays a vital role in irrigating high-value crops in the Tavush region. However, agricultural runoff and untreated domestic wastewater pose growing threats to its hydrochemical stability and sanitary quality [9].

Elevated nitrate and trace metal concentrations in irrigation water raise particular concerns due to their influence on plant metabolism and potential accumulation in edible tissues, posing ecological and human health risks [10-11]. Although the Berqaber Reservoir is strategically important, comprehensive studies linking hydrochemical status, irrigation suitability, and functional crop production remain limited.

This approach aligns with the conceptual framework of functional food science, where environmental and agronomic conditions influence the accumulation of bioactive compounds that contribute to disease prevention and overall human health. Irrigation water quality can affect plant metabolic pathways responsible for the synthesis of antioxidants, vitamins, and other health-promoting phytochemicals, thereby linking agricultural resource management with nutritional outcomes and public health.

Therefore, this study aims to assess the hydrochemical and ecological status of the Berqaber Reservoir and its inflowing rivers, evaluate irrigation suitability using established water quality indices (SAR, MH, and Stabler's coefficient), and examine the implications for functional crop quality and bioactive compound accumulation in irrigated vegetables.

MATERIALS AND METHODS

Study area: The Berqaber (Joghas) Reservoir is an artificial reservoir located in Tavush Province, northern Armenia, on the middle course of the Joghas River at an elevation of approximately 650 m a.s.l. Commissioned in 1980, it has a surface area of 2.14 km², a maximum depth of about 60 m, and a total storage capacity of approximately 45 million m³ (active storage of approximately 43 million m³). The earthen dam is 1,275 m long and 64 m high. The reservoir historically supplied irrigation water to the Noyemberyan and Ijevan irrigation systems, serving nearly 10,000 ha of agricultural land in the border region [12].

Sampling and analysis: Water samples were collected in April and July 2024 from three sites: the Aghstev River, the Joghas River, and the Berqaber Reservoir to capture seasonal variability. Samples were collected in pre-cleaned polyethylene bottles, labeled in the field, and transported under cooled conditions. For heavy-metal analysis, samples were acidified to pH < 2 using ultrapure nitric acid.

To assess the practical impact of water quality on crops, major vegetables irrigated with these waters in the Ijevan region—potatoes, tomatoes, and eggplants—were analyzed for nitrate content, heavy metal accumulation, and nutritional parameters, including starch, vitamin C, and sugar content [5]. Each parameter was measured in triplicate.

Measured parameters:

- Physicochemical parameters: pH, electrical conductivity (EC), total dissolved solids (TDS), major cations (Ca^{2+}, Mg^{2+}, Na^+), and major anions (Cl^-, SO_4^{2-}, HCO_3^-, NO_3^-) [8-11, 13].
- Heavy metals: Pb, Cu, Zn, Mn, and Ni [7,14-15].
- Irrigation indices: sodium adsorption ratio (SAR), magnesium hazard (MH), and Stabler's coefficient (k) [16–18].

All analyses were performed according to Armenian national ecological standards [19] and international guidelines of the World Health Organization (WHO) [20]. Quality assurance included calibration with certified reference materials, blanks, and replicate measurements [19].

Calculation of irrigation water quality indices:

1. Sodium Adsorption Ratio (SAR) [17-21]: SAR predicts the potential for sodium accumulation in soils, affecting soil permeability and structure.

Formula:

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

Concentrations in meq/L.

2. Magnesium Hazard (MH) [18-21]: MH, also known as the Magnesium Adsorption Ratio (MAR), evaluates irrigation water suitability based on magnesium content. High magnesium may reduce soil structural stability.

Formula:

$$MH\ (\%) = (Mg^{2+} / (Ca^{2+} + Mg^{2+})) \times 100$$

Concentrations in meq/L; values expressed as %.

3. Stabler's Irrigation Coefficient (k) [16]: Stabler's coefficient is an empirical index based on sodium, chloride, and sulfate ions that indicates long-term irrigation suitability. Ionic concentrations are expressed in mg/L according to the original method.

Formulas:

- If $Na^+ > (Cl^- + SO_4^{2-})$: $k = 662 / (Na^+ - (Cl^- + SO_4^{2-}))$
- Chloride-dominated solution: $k = 288 / Cl^-$
- Sulfate-dominated solution: $k = 480\ SO_4^{2-}$

The interpretation of the calculated values for Stabler's irrigation coefficient is presented in Table 1.

Table 1. Interpretation scale for Stabler's irrigation coefficients

Coefficient (K)	Water Quality Category	Suitability for Crops
>18	Good	Excellent for all crops; maintains soil integrity
6–18	Satisfactory	Suitable for most crops; minimal risk of salinity
1.2–6	Poor/Marginal	Potential for soil degradation; may reduce yield
<1.2	Unsuitable	High risk of phytotoxicity and soil hardening

To ensure comparability across different irrigation indices, concentrations were converted from mass units (mg/L) to chemical equivalents (meq/L) using the factors listed in Table 2.

Table 2. Unit conversion factors (from mg/L to meq/L)

Ion	Valence	Equivalent Weight (mg/meq)
Na^{+}	1	22.99
Ca^{2+}	2	20.04
Mg^{2+}	2	12.15
Cl^{-}	1	35.45
SO_4^{2-}	2	48.03

Note: Equivalent weight was calculated as molecular weight divided by ionic charge. Ionic concentrations were converted from mg/L to meq/L using these factors.

Standards and guidelines: Water quality was evaluated against FAO Maximum Allowable Concentrations (MAC) for heavy metals [21] and Armenian national standards (RA Government Decision No. 75-N) [19]. The specific concentration thresholds used to determine the toxicological safety of the water are detailed in Table 3.

Table 3. FAO Maximum Allowable Concentrations (MAC) for heavy metals

Heavy Metal	FAO Maximum Allowable Limit (MAL) mg/L
Cu	0.20
Zn	2.0
Pb	5.0
Mn	0.20
Ni	0.20

Statistical analysis: The data were analyzed using analysis of variance (ANOVA) to identify statistically significant differences in water quality parameters and crop mineral content. Differences were considered significant at $p < 0.05$.

RESULTS AND DISCUSSION

Physicochemical suitability and MH: The waters of the Berqaber (Joghas) Reservoir and its inflowing rivers (Aghstev and Joghas) were slightly alkaline, with pH values ranging from 7.4 to 7.5, a condition favorable for nutrient availability and crop uptake. Total dissolved solids (TDS) ranged from 0.048% to 0.057%, indicating low salinity and confirming the suitability of these waters for irrigation purposes.

As shown in Table 4, the hydrochemical profile is characterized by Ca–Mg dominance with moderate HCO_3^- content. The calculated MH ranged from 48.78% to 49.46%. Although these values remain below the critical threshold of 50%, their proximity to this limit indicates a borderline condition. Prolonged irrigation with such water, particularly in the absence of calcium-enriching soil amendments, may promote soil dispersion and reduce permeability, potentially compromising soil structure over time [21].

Table 4. Hydrochemical composition and ionic balance of water samples (May–July 2024)

Parameter	Unit	Aghstev River	Joghas River	Berqaber Reservoir
pH	–	7.4 ± 0.1	7.5 ± 0.1	7.4 ± 0.1
TDS	%	0.048–0.057	0.052–0.056	0.050–0.057
Ca^{2+}	mg/L (meq/L)	76.0 (3.80)	75.6 (3.78)	75.0 (3.75)
Mg^{2+}	mg/L (meq/L)	44.0 (3.62)	45.0 (3.70)	44.5 (3.66)
Na^{+}	mg/L (meq/L)	112.4 (4.89)	110.8 (4.82)	111.5 (4.85)
HCO_3^-	mg/L (meq/L)	390.0 (6.39)	398.0 (6.52)	399.0 (6.54)
Cl^-	mg/L (meq/L)	203.5 (5.74)	204.1 (5.76)	203.8 (5.75)
NO_3^-	mg/L (meq/L)	12.4 (0.20)	13.0 (0.21)	12.7 (0.20)
SAR	–	2.26	2.22	2.25
MH	%	48.78	49.46	49.39

Note: Values are expressed as mg/L (meq/L) and represent the mean of three replicates. Conversion to milliequivalents was performed using standard atomic weight factors. LSD ($p < 0.05$) was applied for all parameters; differences among sites were not significant ($p > 0.05$) for pH, TDS, Ca, Mg, and Na, whereas nitrate (NO_3^-) showed slight but significant variation.

Similar hydrochemical characterization studies conducted for other Armenian catchments, such as the Voghji River basin, have also reported dominant Ca–Mg facies and general suitability for irrigation under moderate salinity conditions, highlighting regional consistency in irrigation water quality patterns within Armenia's diverse hydroecological settings [22]. The relative distribution of Ca^{2+} and magnesium ions across all sampling sites is illustrated in Figure 1. The Mg/Ca ratio highlights the near-threshold magnesium dominance, suggesting the need for continuous monitoring to prevent long-term soil structural degradation.

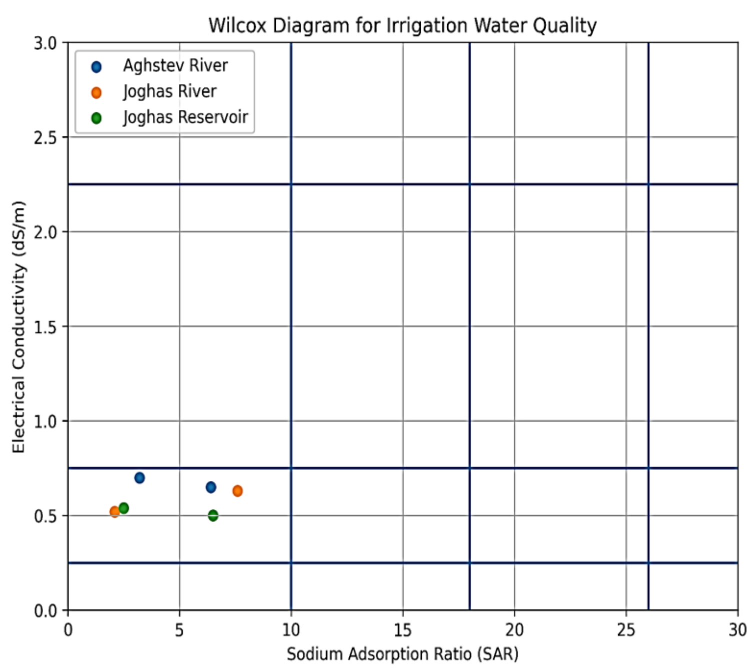


Figure 1. Comparison of Ca^{2+} and Mg^{2+} concentrations in the Aghstev River, Joghas River, and Berqaber Reservoir. Concentrations are expressed in meq/L. The Mg/Ca ratio highlights potential impacts on soil structure and stability, with values near the 50% threshold indicating the need for careful, ongoing monitoring.

SAR and irrigation suitability: The SAR ranged from 2.22 to 2.26, placing all water samples in the C2–S1 category according to the Wilcox classification [21], indicating moderate salinity and low sodium hazard. The Stabler coefficient (k ≈ 10.14) further confirms satisfactory water quality, with minimal risk of long-term alkalinity buildup [16]. However, while SAR and salinity levels are favorable, the overall ecological status of the water system is influenced by nutrient loading. Specifically, the elevated nitrate concentrations (12.4–13.0 mg/L) place these waters in Class 3 (Moderate Quality) according to Armenian national regulatory standards (RA Government Decision No. 75-N) [19], highlighting moderate anthropogenic impact. Statistical analysis (ANOVA) indicated that SAR and K values were consistent across all sites ($p > 0.05$), reflecting a uniform hydrochemical profile throughout the reservoir system. Figure 2 illustrates the relationship between SAR and EC across all sampling sites.

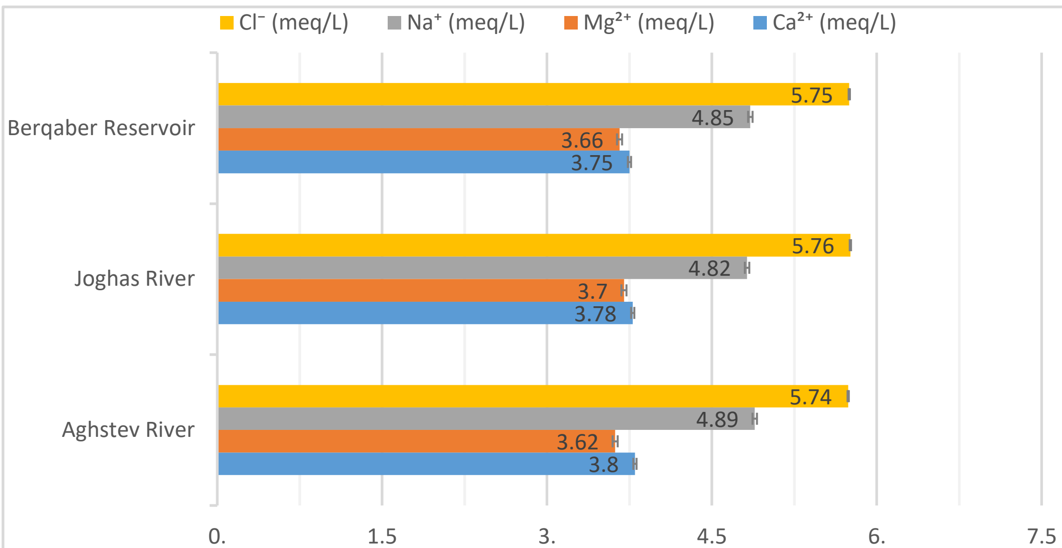


Figure 2. Distribution of major cations (Ca^{2+}, Mg^{2+}, Na^{+}) and anions (Cl^{-}) at the Aghstev River, Joghas River, and Berqaber Reservoir sampling sites. Concentrations are expressed in meq/L. Values represent the mean of three replicates collected during the 2024 sampling period.

Nitrate concentrations and regulatory compliance: Nitrate concentrations (NO_3^-) in the irrigation water ranged from 12.4 to 13.0 mg/L. According to RA Government Decision No. 75-N [19], these values correspond to Class 3 (Moderate Quality), reflecting moderate anthropogenic pressure from agricultural runoff within the Joghas basin. Elevated nitrate levels may influence the synthesis of bioactive antioxidants in functional crops, emphasizing the importance of monitoring and management strategies to maintain crop quality [10, 23]. Changes in nitrogen availability may regulate plant metabolic pathways associated with phenolic compound synthesis, antioxidant enzyme activity, and vitamin accumulation, thereby influencing the functional and nutritional properties of crops.

In the broader context of increasing global water stress and agricultural intensification, these nutrient-loading trends underscore the need for sustainable irrigation management strategies [24].

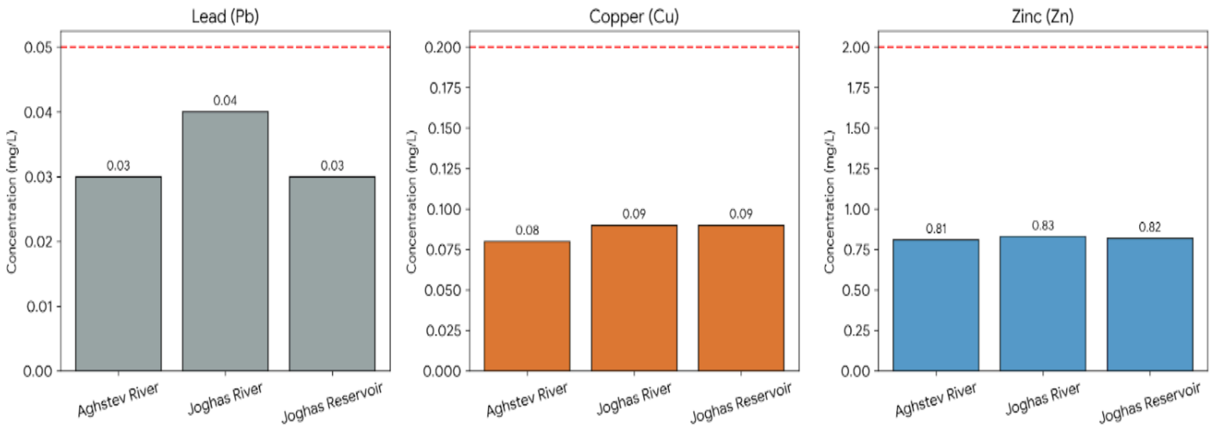


Figure 3. Nitrate (NO_3^-) concentrations in Aghstev River, Joghas River, and Berqaber Reservoir relative to the Armenian regulatory limit of 10 mg/L. Values above the threshold indicate potential risks for crop safety and groundwater contamination.

Heavy metal safety: All measured heavy metals—including Pb, Cu, Zn, Mn, and Ni—remained below the FAO Maximum Allowable Concentrations (MAC) [21-25], indicating no immediate toxicological risk for functional crop irrigation. This finding contrasts with the significantly higher concentrations of toxic elements reported in soil and water resources near industrial and mining zones in the Armenian Highlands [26], suggesting that the Berqaber reservoir system currently remains relatively isolated from heavy industrial pollution. However, prolonged irrigation and ongoing anthropogenic pressures could lead to gradual accumulation over time; therefore, continuous monitoring is recommended [27]. Figure 4 presents a safety zone radar chart illustrating heavy metal concentrations across all sites.

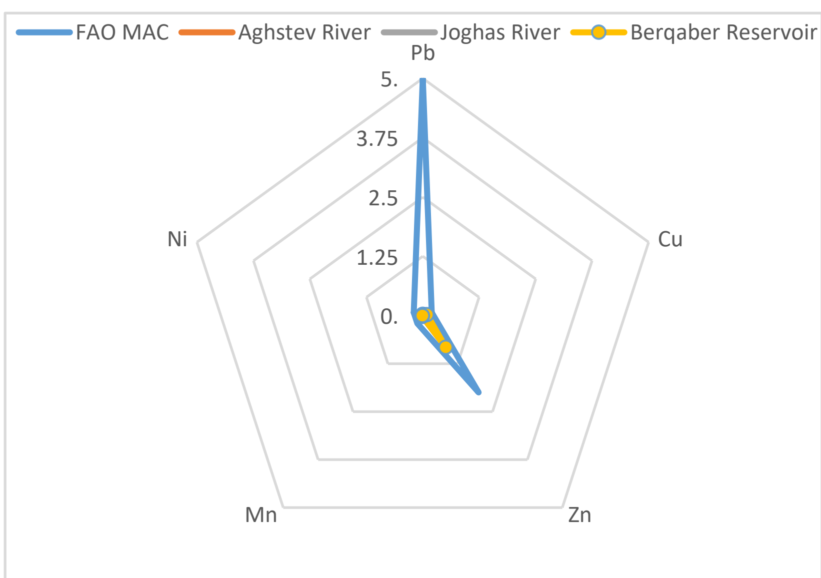


Figure 4. Heavy Metal Safety Zone Radar Chart showing Pb, Cu, Zn, Mn, and Ni concentrations in the Aghstev River, Joghas River, and Berqaber Reservoir. All concentrations are below the FAO Maximum Allowable Concentrations (MAC), indicating safe irrigation conditions for functional crop production.

Validation through crop quality analysis: The safety of the irrigation water was evaluated by analyzing potatoes, tomatoes, and eggplants cultivated in the Ijevan region. Although nitrate concentrations in the irrigation water corresponded to Class 3 (Moderate Quality) [19], nitrate levels in edible tissues remained within the MPC established by regional regulations [28].

Measured nitrate concentrations were:

- Potatoes: 140–155 mg/kg (MPC: 250 mg/kg)
- Tomatoes: 90–115 mg/kg (MPC: 200 mg/kg)
- Eggplants: 65–75 mg/kg (MPC: 210 mg/kg)

Heavy metals—including Pb, Cu, Zn, Mn, Ni, and arsenic (As)—were detected only in trace amounts or were below detection limits in all analyzed crops, indicating no transfer from irrigation water under current conditions [29-30]. These observations are consistent with studies suggesting that the extent of heavy metal accumulation in plants and soil is highly dependent on the source water quality and the duration of irrigation exposure [31].

Nutritional quality indicators remained stable:

- Starch content in potatoes: 15.8–18.4%
- Vitamin C levels in tomatoes and eggplants remained within normal physiological ranges.

These results confirm that moderate nitrate pressure in irrigation water did not compromise the nutritional and functional quality of the produce [29-30].

The discrepancy between elevated nitrate levels in irrigation water and compliant crop concentrations highlight the soil–plant buffering effect. Soil microbial nitrate immobilization, rhizosphere processes, and crop enzymatic nitrate assimilation likely limit nitrate transfer to edible tissues [13-14,32]. Vegetables grown under controlled irrigation often maintain nitrate levels within safe limits despite elevated nitrate levels in source water [10]. These findings underscore the importance of precision nutrient management for maintaining sustainable functional crop production [33].

Key hydrochemical indicators and risk assessment: To provide an integrated overview of irrigation water safety and potential risks to functional crop production, key hydrochemical indicators were evaluated against regulatory limits and agronomic thresholds. Parameters, including nitrate concentrations, MH, SAR, and heavy metal levels, were assessed to identify current environmental pressures and potential long-term risks. Nitrate concentrations exceeded local ecological norms, highlighting moderate anthropogenic influence from agricultural runoff.

The MH values were close to the 50% threshold, indicating a borderline condition that could affect soil structure if not carefully managed. In contrast, SAR and heavy metals remained within acceptable limits, suggesting low risk for sodium-induced soil degradation and negligible toxicological impact on crops. Table 5 summarizes the actual values, regulatory benchmarks, and associated risk levels for these key indicators, providing a concise risk assessment framework for sustainable irrigation management in the Berqaber basin.

Table 5. Key hydrochemical indicators and associated risk levels for irrigation water in the Berqaber (Joghas) Reservoir system (2024).

Indicator	Actual Value (2024)	Regulatory Limit / Threshold	Status	Risk Level
NO_3^-	12.4–13.0 mg/L	10 mg/L (RA Norm)	Class 3 (Moderate)	Moderate
MH	48.78–49.46%	50%	Borderline	Moderate (Requires monitoring)
SAR	2.22–2.26	<10	Within Norm	Low (Safe)
Heavy Metals	< MAC	FAO Standards	Within Norm	Very Low

Note: Nitrate concentrations exceed local ecological norms by 24–30%, representing the primary environmental pressure. MH is near the 50% threshold, suggesting potential soil structural risk over long-term irrigation. SAR and heavy metals are within safe limits. Targeted nitrogen management and monitoring are recommended for sustainable functional crop production.

Overall, the hydrochemical profile indicates irrigation suitability under current conditions; however, nitrate loading and borderline magnesium hazard warrant adaptive nutrient and soil management strategies to prevent long-term degradation.

Recommendations and Strategic Solutions

To protect the functional value of crops and ensure the long-term ecological sustainability of the Joghas basin, a targeted management strategy is recommended. Nitrogen fertilizer application should be strictly regulated through science-based norms, including optimized timing, dosage, and application techniques. In addition, sensor-based nutrient monitoring is recommended to minimize nitrate leaching and reduce biogenic element inflow into the reservoir. The combined use of organic amendments, such as compost or biochar, together with calcium-rich soil conditioners, is also recommended to stabilize the calcium-to-magnesium balance and help maintain soil structure, permeability, and long-term productivity. At the institutional level, oversight of water-use rights must be reinforced in accordance with the RA Water Code, and Water User Companies (WUCs) should operate as active regulatory bodies rather than merely administrative entities. In parallel, wastewater treatment infrastructure for agricultural, municipal, and industrial effluents must be upgraded to improve basin-wide water quality. Finally, continuous monitoring programs should be established to track nitrate dynamics and heavy metal accumulation in soils under long-term irrigation, while periodic soil health assessments remain essential to maintain the “clean” status required for functional and export-oriented crop production.

Scientific Innovation and Practical Implications

This study provides novel insights into the interplay between irrigation water hydrochemistry and the functional quality of crops in the Tavush region. The findings explicitly align with the Functional Food Center’s (FFC) 17-Step Model [33]. Specifically, the research contributes to Steps 1 (Basic Research) and 2 (Identification and Examination of Bioactive Compounds) by establishing how environmental factors determine the integrity of raw material. Furthermore, it supports Step 8 (Standardization and Cultivation Practices) by emphasizing the need for optimized irrigation standards that enhance bioactive compound accumulation.

As highlighted in recent literature within the Armenian agroecological context, mineral inputs and institutional oversight are closely linked to functional value [34-35]. This study demonstrates that hydrochemical suitability alone is insufficient; an integrative approach encompassing structured validation from environmental inputs to health outcomes is required [36]. By linking the RA Water Code and WUC oversight to the 17-Step Model, the research bridges agricultural resource management with functional food science.

Ultimately, integrating legal and institutional measures, including transparent water-use licensing and effective operation of WUCs, is essential to ensure equitable water distribution, maintain soil health, and safeguard the nutritional and functional value of crops in semi-arid agroecosystems.

Impact statement: Building on these insights, this study demonstrates a direct relationship between irrigation water hydrochemistry and the biochemical quality of functional crops. By identifying nitrate exceedances and a borderline magnesium hazard, it provides a science-based framework for integrated management of water, soil, and nutrients**,** supporting sustainable agricultural production while protecting the nutritional and therapeutic value of crops in semi-arid agroecosystems.

CONCLUSION

Based on the 2024 hydrochemical assessment of the Berqaber (Joghas) Reservoir and its inflowing rivers, irrigation waters can be classified within the C2–S1 category, indicating moderate salinity and low sodium hazard. The calculated Stabler coefficient (approximately 10.14) further confirms that the waters are generally suitable for irrigation and do not pose an immediate risk of sodicity under current conditions. At the same time, the MH values (48.78–49.46%) remain below the critical threshold of 50%; however, their proximity to this limit indicates a borderline condition. Without appropriate soil management practices, such as the application of calcium-rich amendments, prolonged irrigation may increase the risk of soil dispersion and reduced permeability (hydraulic conductivity). The primary hydrochemical concern is the elevated nitrate concentration, ranging from 12.4 to 13.0 mg/L, which exceeds the Armenian regulatory limit of 10 mg/L. This level represents the main environmental pressure on the system and may negatively influence the synthesis of health-promoting bioactive compounds in functional crops. Nevertheless, empirical analysis of potatoes, tomatoes, and eggplants grown under irrigation from this water source confirms product safety. Nitrate and heavy metal concentrations (Pb, Cu, Zn, Mn, Ni, and As) in edible plant tissues remained well below the established Maximum Permissible Concentrations, demonstrating that, despite hydrochemical deviations in the irrigation water, the harvested crops retain their functional and nutritional integrity. In addition, the persistence of nitrate-related environmental pressures underscores the necessity of a robust regulatory framework for irrigation water management. While the RA Water Code and the statutes governing WUCs establish the formal foundation for water governance, effective implementation and institutional coordination remain critical to achieving sustainable water quality outcomes. WUCs play a pivotal role in operational monitoring and distribution management; however, localized nutrient accumulation in downstream areas suggests cumulative agricultural inputs, thereby highlighting the need for strengthened monitoring and adaptive management strategies. Overall, these findings demonstrate that hydrochemical suitability, though essential, must be complemented by the consistent enforcement of water quality standards and coordinated oversight among responsible institutions, while enhanced interagency collaboration and monitoring mechanisms will further support environmental resilience, sustainable resource utilization, and the long-term integrity of functional food systems.

List of Abbreviations: ANAU, Armenian National Agrarian University; ANOVA, Analysis of Variance; As; Arsenic; Ca^{2+}, Calcium ion; Cl^{-}, Chloride ion; Cu, Copper; HCO_3^{-}, Bicarbonate ion; *k* / Stabler's coefficient, Empirical irrigation water suitability index; MAC, Maximum Allowable Concentration; Mn, Manganese; MH, Magnesium Hazard; Mg^{2+}, Magnesium ion; Na^{+}, Sodium ion; Ni, Nickel; NO_3^{-}, Nitrate ion; Pb, Lead; RA, Republic of Armenia; SAR, Sodium Adsorption Ratio; S1, Low sodium hazard; SO_4^{2-}, Sulfate ion; TDS, Total Dissolved Solids; USSL, United States Salinity Laboratory classification; WUC, Water User Company; Zn, Zinc; MPC, Maximum Permissible Concentration; EC, Electrical Conductivity.

Authors' Contributions: MG contributed to conceptualization, methodology, validation, resources, data curation, original draft preparation, and manuscript review and editing. GM contributed to methodology, data curation, and manuscript review and editing. AM contributed to methodology, data curation, and manuscript review and editing. HS contributed to methodology, data curation, and manuscript review and editing. IH contributed to methodology, data curation, resources, original draft preparation, and manuscript review and editing. VA, KT, MH, AV, and Mhov contributed to resources, manuscript review, and editing. AT contributed to resources, data curation, and manuscript review and editing. AH contributed to conceptualization, methodology, validation, resources, data curation, original draft preparation, and manuscript review and editing. All authors have read and approved the final manuscript.

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