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Water Mineralization in the Tigris River Basin and Its Impact on Public Health: A Review

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Abstract

The Tigris River Basin is a major freshwater source for millions of people in Iraq and surrounding areas, but increasing mineralization and salinity threaten water quality and resource sustainability. This review examines the basin's hydrochemical characteristics, the factors contributing to mineralization, and their implications for public health. It considers dissolved inorganic constituents, including calcium, magnesium, sodium, chloride, sulfate, and bicarbonate, alongside total dissolved solids as an indicator of mineralization. The review identifies reduced river discharge, climate change, upstream dam construction, agricultural return flows, and untreated municipal and industrial effluents as contributors to deteriorating water quality. Although dissolved minerals are important for human health, excessive concentrations can compromise water quality and suitability for consumption. The discussion highlights potential cardiovascular, renal, and gastrointestinal health risks associated with elevated dissolved salts and heavy-metal contamination, with particular concern for vulnerable populations, including children and pregnant women. Poor water quality also places economic burdens on healthcare services and water treatment infrastructure. By connecting hydrochemical characteristics with environmental pressures and potential health consequences, this review provides an integrated account of mineralization in the Tigris River Basin. It emphasizes the interconnected implications of water quality deterioration for public health, treatment costs, and the sustainability of freshwater resources.

Keywords: Tigris River Basin; Water Mineralization; Salinity; Water Quality; Public Health

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Introduction

The Tigris is one of the most important rivers in the Middle East and is the lifeline of Iraq. Its source is in the south-east of Turkey, it crosses the borders of Syria, and it makes its way through Iraq from the north to the south, merging with the Euphrates River to form the Shatt al-Arab. Historically, the Tigris Basin has sustained agriculture, urban settlements, industrial activities and ecosystem services.

The quality of the water is a growing issue in the basin. The hydrochemical composition of the river has been changed by progressive deterioration due to population growth, rapid urbanisation, industrial development, agricultural activities and climate change [1-4]. The concentration of total dissolved solids (TDS), electrical conductivity (EC), sulfates, chlorides, and total hardness have been found to be increased in recent studies in several sectors of the Tigris River, especially in central and southern Iraq, where river discharge has significantly reduced [1-5]. These hydrochemical changes have been worrying issues due to the fact that the mineralization and salinity of river water tends to increase with the decrease of river flow and limited dilution capacity of the river for natural dilution.

Upstream dam construction, extended droughts, decreased annual precipitation, and higher demands for water also worsen water quality degradation. Further, untreated municipal wastewater, industrial effluents, and agricultural return flows contribute significant amounts of dissolved salts, nutrients, heavy metals, and other contaminants to the river, which can cause significant hydrochemical changes and water quality degradation [2–4]. New studies in the Tigris basin carried out in the last few years showed that significant amounts of heavy metals and mineralization are discharged into the river from the wastewater and water quality assessment based on various water quality indices revealed that several river segments in Baghdad are unsuitable for direct use for drinking purposes without additional treatment.

A number of hydrochemical parameters including total dissolved solids (TDS), electrical conductivity (EC), total hardness (TH), sulfate (SO_4^{2-}), chloride (Cl^-), calcium (Ca^{2+}) and magnesium (Mg^{2+}) have been employed as markers of mineralization processes and water quality. When guideline values are exceeded, these constituents can cause undesirable aesthetic changes to drinking water, scaling in water distribution systems and lowered suitability for irrigation, and may pose a health risk to sensitive populations [5,6].

The World Health Organization (WHO) suggests that physicochemical parameters be monitored continuously so as to ensure the safety of drinking water supplies, and in Iraq, the Drinking Water Standards provide maximum allowable levels for the main physicochemical parameters that should be considered to protect public health [5,7]. Therefore, a detailed assessment of the hydrochemical characteristic and mineralization processes in the Tigris river is crucial to detect source of pollution, assess spatial and temporal variations in the water quality and support sustainable water resources management. These evaluations also deliver scientific evidence for decision makers to formulate effective strategies to protect drinking water resources and reduce the effects of environmental and climatic change on Iraq's water security.

Concept of Mineralization

Mineralization is the natural and anthropogenic mechanism by which water becomes mineralized when it comes into contact with geology, soils and anthropogenic pollution sources. Minerals dissolve in the river water as it passes through various lithological units, thus adding dissolved ions to the water. Agricultural run-off, municipal wastes, industrial effluents, decreased river discharge, as well as natural weathering processes, can contribute greatly to the mineralization, as they lead to an increase in the amount of dissolved salts in the water, in the aquatic environment [8–11].

The prominent dissolved ions found in the Tigris River are calcium (Ca^{2+}), magnesium (Mg^{2+}), sodium (Na^{+}), potassium (K^{+}), chloride (Cl^{-}), sulfate (SO_4^{2-}), and bicarbonate (HCO_3^{-}). These ions are mainly from the dissolution of carbonate and gypsum and evaporite minerals and anthropogenic activities can significantly raise their concentration especially in the industrial and densely populated regions [8,9,12].The most common measurement of water mineralization is known as Total Dissolved Solids (TDS) and it is the concentration of all inorganic salts dissolved in the water plus a small percentage of dissolved organic material. TDS is strongly correlated with the electrical conductivity (EC) and both are important parameters to assess water quality. A high TDS usually indicates high concentration of salinity and mineralization which may impact the taste of drinking water, water system scaling problems, water system suitability for agricultural uses and overall water system quality [10,13].

The World Health Organization (WHO) suggests that levels of dissolved solids in drinking water should not exceed acceptable levels in order to ensure consumer acceptability and minimise operational issues within drinking water supply systems. Similarly, Iraqi drinking water standards set permissible limits for major ions including TDS in order to get good quality of drinking water. Thus, the measurement of mineralization based on TDS and major dissolved ions is a significant part of hydrochemical assessment and plays a vital role in the geochemical processes and in the identification of possible pollution sources in the Tigris River [13-15].

According to the World Health Organization (WHO):

TDS (mg/L)	Water Quality
<300	Excellent
300–600	Good
600–900	Fair
900–1200	Poor
>1200	Unacceptable

Several studies on the Tigris River reported TDS values exceeding recommended drinking-water limits in certain downstream locations[14].

Sources of Mineralization in the Tigris River Basin

The mineralisation of the Tigris River is due to natural geochemical processes interacting with anthropogenic activities. The relative importance of each source is variable in space and time, depending on the geological context, river discharge, land use, and climate. Human activities have increasingly affected the hydrochemical features of the river, especially in central and southern Iraq, where less water flow in the river has led to more accumulation of salts and other pollutants in the water [16, 17, 18, 19].

Geological Factors

The nature of the geology in the Tigris River Basin is a key factor in the natural mineralisation of the river water. The basin traverses wide-spread carbonate and evaporitic terrane rich in limestone, dolomite, gypsum and anhydrite. These rocks undergo chemical weathering and dissolution of major dissolved ions like calcium (Ca^{2+}), magnesium (Mg^{2+}), bicarbonate (HCO_3^-), sulfate (SO_4^{2-}) and to a lesser extent sodium (Na^+) and chloride (Cl^-) in the river system [16,20].Dissolution of carbonate minerals is the major source of water

hardness and alkalinity, while dissolution of the evaporite minerals, such as gypsum, is an important source of sulfate and total dissolved solids (TDS). Hence, the geology of the basin is the main natural source of mineralization of the Tigris River [20,21].

Reduced River Discharge

These factors have resulted in a significant reduction in river discharge in the Tigris over the past few decades, due to the building of dams upstream, the regulation of water resources by the two countries, the use of water for irrigation, droughts, water shortages, and climate change [17,22]. All of these have contributed to the natural dilution capacity of the river being significantly reduced and dissolved salts and other contaminants have built up.A strong negative correlation between river discharge and mineralization indicator (TDS and electrical conductivity – EC) has been shown in several studies. Concentrations of dissolved ions are significantly higher during low-flow conditions, especially in central and southern Iraq where evaporation rates are high and fresh water inflow into the water is low [16,17,22].

Agricultural Return Flows

In Iraq, agriculture is the most important consumer of freshwater and one of the major anthropogenic sources of mineralization of the river water. Dissolved salts, fertilizers, nitrates (NO_3^-), phosphates (PO_4^{3-}), pesticides and other agrochemicals can be carried back into the river from cultivated areas via irrigation return flows [18,23].Under arid and semi-arid climatic conditions, continuous irrigation induces salinization of soil and salts are gradually accumulated and mobilized to surface waters. These processes lead to higher TDS, electrical conductivity, nutrients, and salinity levels, especially when discharge through the river is low [18,22,23].

Municipal and Industrial Wastewater

Rapid population growth and urbanisation combined with the lack of adequate wastewater treatment facilities have significantly contributed to the load of pollutants entering the Tigris River. The principal anthropogenic sources of dissolved and suspended contaminants are municipal wastewater, industrial effluents, hospital discharges and improper disposal of solid wastes [17,19].These discharges lead to higher levels of dissolved solids, nutrients, organic material, heavy metals and other potentially hazardous elements, thus degrading the quality of the water and making abstraction more hazardous. Unprocessed wastewater has been found to be a major source of high levels of TDS, electrical conductivity,

nutrients and trace metals in the river downstream of Baghdad in recent studies. The results clearly show that the water quality is significantly degraded in southern Baghdad and extends downstream to central and southern Iraq, where the pollution loads and decreased river flow due to the cumulative effects cause further deterioration of water quality as a result of mineralization [18,19].

Overall, the current hydrochemical characteristics of the Tigris River are controlled by the combined effects of natural geological weathering and increasing anthropogenic pressures. These sources in relation to each other are crucial to determine the pollution hotspots, assessing the temporal variation in water quality and developing sustainable water quality management strategies for the protection of Iraq's freshwater resources [16–23].

Hydrochemical Characteristics of the Tigris River

Natural geological processes, climatic factors and anthropogenic activities have a combined effect on the hydrochemical properties of the Tigris river. In recent decades, however, spatial and seasonal changes in river chemistry have become more apparent because of decreased discharge of river water, population growth, agricultural expansion, and discharges of wastewater [24–27].Recently, the electro-chemical analysis of the river has revealed the progressive enhancement of electrical conductivity (EC), total dissolved solids (TDS), total hardness (TH), sulfate (SO_4^{2-}), chloride (Cl^-) and sodium (Na^+) concentrations in several reaches of this river, in southern Iraq especially after Baghdad. The river flow generally decreases, the evaporation increases and the capacity for dilution is reduced during the dry season, which accompanies these increases.Mineralization of a river is one of the best indicators of electrical conductivity and total dissolved solids that are based on the total concentration of dissolved ionic species. A lot of research has been conducted and it has been proved that both EC and TDS follow a positive trend when the mineral content of the Tigris River increases [24,25]. Similarly, the amount of calcium and magnesium, the dissolved minerals, which are derived from carbonate and evaporite rocks in the basin, mostly regulate the total hardness of the water.

A number of investigations have reported that the concentrations of EC, TDS, sulfate and chloride exceeded the recommended limits by World Health Organization (WHO) and Iraqi Drinking Water Standards in several monitoring stations especially in low

river discharge periods [25,28,29]. Seasonal degradation is most pronounced in summer when river flow is greatly reduced, and evaporation rates are high.

One of the most popular methods used is the Water Quality Index (WQI) to assess the overall quality of river water for drinking. Pollution intensity and hydrochemical conditions in the area have led to classification of certain sections of river Tigris as good, poor and unsuitable for direct human consumption in recent studies. Municipal effluents, industrial effluents, and agricultural return flows have a combined effect on increasing mineralization and pollutant levels, the worst of which is generally observed downstream from the main urban centers [26,27].Therefore, hydrochemical characterization is an important tool in evaluating the geochemical evolution of river water, determining the source of pollution, and water resources management to protect water quality for drinking purposes in Iraq.

Public Health Implications of Mineralized Water

The chemical composition of drinking water is closely associated with human health. Although essential minerals such as calcium and magnesium are beneficial at moderate concentrations, excessive mineralization may adversely affect water quality and increase health risks, particularly among vulnerable populations including children, older adults, pregnant women, and individuals with chronic diseases [28,30].

Cardiovascular Diseases

High levels of sodium in drinking water can lead to high blood pressure, water retention, and greater cardiovascular risks, especially in people with high blood pressure, chronic kidney disease, and heart failure [30]. Excessive intake of drinking water with high concentration of both salt and sodium has also been linked to higher cardiovascular morbidity in susceptible populations.

Kidney Disorders

Mineralized water makes the kidney have to work harder to filter. High levels of calcium, magnesium, sulfate and other dissolved minerals can lead to kidney stones, kidney damage and imbalances in electrolytes, particularly if combined with low fluid intake [28,31]. People who already have kidney disease are more susceptible to these harmful effects.

Gastrointestinal Effects

Sulfate can have a laxative effect, leading to diarrhea, gastrointestinal irritation, abdominal discomfort, and dehydration, if there is a high concentration of sulfate. Infants and young children are particularly vulnerable due to their increased sensitivity to electrolyte disturbances and dehydration [28].

Heavy Metal Exposure

Mineralization processes can also improve the mobility and transportation of trace metals such as lead (Pb), cadmium (Cd), chromium (Cr), nickel (Ni) and arsenic (As) that are toxic and are derived from industrial activities, wastewater discharges and contaminated sediments [25,27]. Exposure to these contaminants over prolonged periods of time have been linked to neurological disorders, developmental abnormalities, nephrotoxicity, hepatotoxicity, reproductive disorders, and an increased risk of several types of cancer [30,32].

Indirect Public Health Effects

The degradation of rivers water quality also has indirect effects on public health. A poor water source makes the treatment of drinking water more complicated and costly, decreases the amount of safe freshwater available, may affect food security by irrigating with saline water, and leads to higher household expenses on drinking water and health care services [29,33]. In addition, inadequate and/or substandard treatment systems can allow surface water to be contaminated and spread waterborne disease.The overall health effects of mineralised water are dependent on the concentration and composition of the dissolved constituents, length of exposure, susceptibility of the individual, and effectiveness of the water treatment processes. Hence, monitoring of hydrochemical parameters should be carried out continuously and proper drinking water standards should be strictly followed to reduce health risk and sustain water resources in the Tigris River Basin in the long term.

Vulnerable Populations

Mineralized drinking water has not the same effects on everyone. Adverse effects are more severe in specific age groups, depending on physiological conditions, nutrition status and underlying diseases in addition to available safe drinking water. Therefore, several

population groups are seen as being at special risk due to the health impacts of water quality problems [34–36].

Children

Infants and young children are especially vulnerable due to their greater water consumption per kg of body weight and immature systems. Sulfate may cause diarrhea and depletion of body water, and salinity may cause electrolyte imbalance. Chronic exposure to contaminated drinking water can also negatively impact growth, cognition and nutrition [34,35].

Pregnant Women

Pregnant women are also a high-risk group, because there is an elevated requirement for water during pregnancy and physiological alterations in water and electrolyte balance. Where the water is highly mineralized, especially in high sodium levels, it can lead to hypertension, edema and complications in pregnancy in susceptible people [35].

Older Adults

It is more likely to occur in older adults due to decreased renal function and in the presence of greater chronic diseases like hypertension, diabetes mellitus, cardiovascular disease, and chronic kidney disease. Too many dissolved salts can exacerbate these situations and lead to dehydration and electrolyte imbalance [34,36].

Patients with Chronic Diseases

Chronic kidney disease, heart failure, liver disease, and hypertension patients must be mindful of minerals and electrolytes intake. Diseases may become more severe and clinical management may be more difficult when water contains high levels of dissolved minerals, such as sodium [35,37].

Low-Income Communities

The poor are affected disproportionately since they have limited access to drinking water that is treated to a standard acceptable for good health, and may be receiving drinking water from untreated surface water. The financial capacity also limits their capacity to afford purchase of bottled water or water treatment systems at home, which further exacerbates health inequalities over the longer term and exposure to contaminated water [38].As a whole, safeguarding vulnerable populations should be seen as a public health priority in the national water management strategies.

Implications for Sustainable Development in Iraq

The progressive mineralization of the Tigris River has various implications that not only affect water quality, but also the achievement of several Sustainable Development Goals (SDGs), specifically SDG 3 (Good Health and Well-being), SDG 6 (Clean Water and Sanitation), SDG 2 (Zero Hunger) and SDG 13 (Climate Action) [39].

Public Health

Poor water quality leads to a rise in waterborne diseases and to chronic health conditions due to high mineral levels in the water, which places additional strain on health systems. Preventing disease and enhancing community health outcomes is thus important for water safety [34,39].

Water Security

The saline and mineralization conditions will lead to potable water scarcity and require the use of advanced water treatment technologies. The increasing deterioration of river water quality poses a risk for Iraq's long-term water security, especially in the light of population growth and climate change [39,40].

Agricultural Productivity

In Iraq the largest water use is by agriculture. Saline water irrigation leads to salinization of soil, lowers soil permeability, lowers crop yield and compromises food security in the long-term. These effects were especially noticeable in southern and central Iraq, where water resources are heavily relied on for irrigation from the Tigris River [40,41].

Economic Development

The adverse impacts of poor water quality are significant economically because of the heightened use of drinking water treatment systems, wastewater treatment systems, health and hygiene services, rehabilitation of water infrastructure, and loss of agricultural productivity. Such economic costs can significantly limit community and national development capacity and increase the fragility of local communities [39,41].

Policy Recommendations

Coordination of scientific, technical and institutional actions are needed to manage the mineralization river in Tigris and these actions need to be taken to mitigate the pollution sources as well as to sustain its water resources in the long term.

Short-Term Measures

The immediate interventions should be aimed at public health risk reduction by:

- Ongoing monitoring at strategic monitoring stations of TDS, EC, major ions and heavy metals.
- Expansion and modernization of DWTFs to increase the efficiency of removal of dissolved contaminants.
- Awareness campaigns on safe drinking water and household water treatment.
- Response plans for times of extreme drought or high salinity

Medium-Term Measures

To achieve a reduction in pollutant inputs and better water quality management through medium term strategies, do the following:

- Improving municipal and industrial waste water treatment facilities.
- Inspecting environmental laws related to the discharge of industrial effluents.
- Encouraging the adoption of efficient irrigation technologies in order to reduce the agricultural return flows.
- Developing a national hydrochemical monitoring network that is integrated into Geographic Information Systems (GIS), remote sensing and real-time monitoring systems.
- Improving interactions between the environmental, health, and agriculture/water resource sectors.

Long-Term Measures

Long-term sustainability requires comprehensive basin-scale management through:

- Implementation of Integrated Water Resources Management (IWRM) principles throughout the Tigris Basin.
- Strengthening transboundary water cooperation among Iraq, Türkiye, and Syria to improve water allocation and environmental protection.
- Developing climate change adaptation strategies that enhance drought resilience and improve water-use efficiency.
- Promoting sustainable groundwater management to reduce pressure on surface water resources.

- Restoring wetlands and riparian ecosystems to improve natural water purification and biodiversity conservation.
- Expanding scientific research on hydrochemical evolution, emerging contaminants, and public health risks to support evidence-based policy development.

Successful implementation of these recommendations will improve drinking water quality, reduce public health risks, strengthen water security, and contribute to achieving sustainable development in Iraq [41,42].

Conclusion

The Tigris River Basin has been undergoing chronic mineralization due to a reduction of river discharge, climate change, agricultural return flows, and growing anthropogenic pollution. The high levels of dissolved minerals and salts are causing a significant public health issue and water quality problems. High mineralization rates are linked to cardiovascular diseases, kidney diseases, gastrointestinal diseases and a general socioeconomic burden. Addressing this issue requires a need for integrated water resources management, wastewater treatment, continuous monitoring of hydrochemical parameters and regional cooperation to protect the public health and sustainability of Iraq's most precious freshwater resource.

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