

Groundwater Quality Analyses for Irrigation Purposes in Salah Al-Din, Iraq: A Review/ Review article

Noor A. Radhi ^{1*}, Dawood E. Sachit ²
and Abdul-Sahib T. Al-Madhhachi ³

- 1 Researcher, Environmental Engineering, Department of Environmental Engineering, College of Engineering, Mustansiriyah University, Baghdad, Iraq.
 - 2 Assist. Prof. Dr., Department of Environmental Engineering, College of Engineering, Mustansiriyah University, Baghdad, Iraq.
 - 3 Prof. Dr., Department of Water Resources Engineering, College of Engineering, Mustansiriyah University, Baghdad, Iraq.
- * Corresponding Author: noorradhi90@uomustansiriyah.edu.iq

تحليل جودة المياه الجوفية لأغراض الري
في محافظة صلاح الدين، العراق: دراسة مرجعية

نور عبد الرزاق راضي^{1*}، داوود عيسى ساجت²،

عبد الصاحب توفيق المذحجي³

1. بكالوريوس علوم في هندسة البيئة، قسم هندسة البيئة، كلية الهندسة، الجامعة المستنصرية، بغداد، العراق
 2. أ.م. د.، قسم هندسة البيئة، كلية الهندسة، الجامعة المستنصرية، بغداد، العراق
 3. أ. د.، قسم هندسة الموارد المائية، كلية الهندسة، الجامعة المستنصرية، بغداد، العراق
- * المؤلف المراسل: noorradhi90@uomustansiriyah.edu.iq



Abstract

The focus of this study is the effect of the physical and chemical characteristics of groundwaters on plants and agricultural crops, following the last studies on this matter. The results underscore the necessity for groundwater treatment before its utilization in irrigation for sustainable agricultural farming. It is also possible to identify which crop type can be grown in well-watered land, according to the characteristics of irrigation water and the yield of each crop. The study also introduces some ideas about irrigation water quality parameters such as Electrical conductivity (EC), Total Dissolved Solids (TDS), pH, Chloride (Cl^-), Sodium (Na^+) and Potassium (K^+) Ions, Nitrate (NO_3^-), Carbonate (CO_3^{2-}) and Bicarbonate (HCO_3^-) Ions, Sulfate (SO_4^{2-}), Calcium (Ca) and Magnesium (Mg), Sodium Adsorption Ratio (SAR), Residual Sodium Carbonate (RSC) and Water Quality Index (WQI) and their effect on crops and soil. Many of the series of studies on the groundwater quality in Salah Al-Din governorate and its suitability for irrigation were presented in this study. The research also reinforces the importance of the protection of groundwater against pollution by excessive concentrations of harmful elements with adverse effects on plants, soil, and, ultimately, food security. In summary, found that the groundwater is of considerable importance in various applications specially in agriculture, and requires sustainable management. Therefore, thorough and well-planned strategies must be adopted before establishing any project near groundwater sources, in order to preserve them and protect the surrounding environment, and it's necessary to be treated before using in irrigation.

key words: groundwater quality parameters; EC; crop yield; agriculture; Salah Al-Din Governorate

المستخلص

تركز هذه الدراسة على تأثير الخصائص الفيزيائية والكيميائية للمياه الجوفية على النباتات والمحاصيل الزراعية، وذلك بعد مراجعة الدراسات السابقة المتعلقة بهذا الموضوع. وتؤكد النتائج على ضرورة معالجة المياه الجوفية قبل استخدامها في الري لتحقيق زراعة مستدامة. كما يُمكن تحديد نوع المحاصيل التي يمكن زراعتها في الأراضي المرورية بمياه الابار، وفقاً لخصائص مياه البئر والغلة النباتية لكل محصول. وتقدم الدراسة أيضاً بعض الأفكار حول معايير جودة مياه الري مثل الموصلية الكهربائية (EC)، والمواد الصلبة الذائبة الكلية (TDS)، والرقم الهيدروجيني، وأيونات الكلوريد (Cl^-)، والصوديوم (Na^+)، والبوتاسيوم (K^+)، وأيونات النترات (NO_3^-)، والكربونات (CO_3^{2-})، والبيكربونات (HCO_3^-)، والكبريتات (SO_4^{2-})، والكالسيوم (Ca) والمغنيسيوم (Mg)، ونسبة امتزاز الصوديوم (SAR)، وكربونات الصوديوم المتبقية (RSC)، ومؤشر جودة المياه (WQI) وتأثيرها على المحاصيل والتربة. كما تم تقديم العديد من الدراسات حول جودة المياه الجوفية في محافظة صلاح الدين وملاءمتها للري. كما يُؤكد البحث على أهمية حماية المياه الجوفية من التلوث الناتج عن التركيزات المفرطة من العناصر الضارة، والتي تُؤثر سلباً على النباتات والتربة، وبالتالي على الأمن الغذائي. باختصار، تم استنتاج ان للمياه الجوفية أهمية كبيرة في تطبيقات مختلفة ومنها الزراعة، وتتطلب إدارة مُستدامة. لذلك، يجب اتباع استراتيجيات مُحكمة ومخططة جيداً قبل إنشاء أي مشروع بالقرب من مصادر المياه الجوفية، وذلك للحفاظ عليها وحماية البيئة المُحيطة بها، بالإضافة الى ضرورة معالجتها قبل استخدامها للري.

الكلمات المفتاحية: معاملات جودة المياه الجوفية; الموصلية الكهربائية; غلة

المحصول; الزراعة; محافظة صلاح الدين



1.Introduction

Groundwater quality is an integral part of agricultural productivity as it has a direct impact on the soil and subsequently on crop production. Polluted groundwater would adversely affect crops and ecosystems, which creates the need to control water quality. (Saeed, 2014). Groundwater quality parameters are defined in both physical, chemical, and biological terms. Temperature, turbidity, and electrical conductivity are the physical parameters that may affect the usability of the water. Chemical parameters include nutrients, salts, and pollutants; biological parameters include microorganisms that can affect the safety and quality of water. (Acharya *et al.*, 2010). Sustainable and resilient agricultural practices depend on freshwater resources, the management of which will be vital in the context of global change. These include measures to promote water efficient use, risk reduction of contamination and recharge of groundwater enhancement methods. Decision-makers on the policy front, among food producers and across the research spectrum should be working to seek out modern technology and best practices that work in equilibrium with sustainable agriculture, and environmental stewardship.” (Varela-Ortega *et al.*, 2011). In short, groundwater is essential for agriculture, especially in areas where surface water is scarce. They are required for the continuity of these resources and the sustainability of agricultural systems (Srivastav *et al.*, 2021).

Hence; this review focuses on the effect of groundwater quality parameters on plant and crop yield when being irrigated by groundwater, it emphasizes the recent studies that investigated this in the past.



2. Water quality parameters and their effects on agriculture

Various systematic approaches of measurement, sampling and laboratory analysis is available to assess the groundwater quality for irrigation. The choice of water quality indices is only the first step, as IWQI is constructed around different physicochemical parameters for the evaluation of suitability of water for irrigation. Factors such as EC, sodium adsorption ratio (SAR) and Na% are constraining. (Ajmal *et al.*, 2023). Knowledge of the physical, chemical and biological parameters of water is very important before using it for various purposes, which inverts or describes water quality (Abd Al Satar & Sachit, 2021)

2.1 Electrical conductivity (EC)

EC is one of the most important indices of salinity in water and soil, which reflects the contents of the dissolved salts, including sodium, calcium, magnesium, chloride, sulfate, and bicarbonate. In agriculture, EC is commonly used to evaluate the suitability of irrigation water and salinity status of soils and are the most essential factors for improvement of plant and crop production.

Irrigation with saline water is treated as that water has sure effects on plants. So high EC value in irrigation water belongs to high salt contents. High-EC water can lead to elevated soil salinities, which can impose osmotic stress in plants and limit water extraction even when soil moisture is seemingly adequate. As a result, it can reduce germination rates, stunt growth, and freeze yields (Ayers & Westcot, 1985).



Salinity tolerance is different for various crops. There is a wide range, with broadly salt-tolerant crops (like barley and cotton) on one end of the continuum, and highly salt-sensitive crops (like beans and strawberries) on the other. EC monitoring enables crop selection, leaching application and irrigation scheduling to avoid salt build-up in the root zone. In addition, the use of high-EC water for extended periods may also cause soil degradation, especially in heavy-textured poorly-drained soils (where salts may precipitate and accumulate over time). This might require further management tools, including soil amendments or drainage systems, to keep the soil productive. Accordingly, EC is an important parameter to test the quality of irrigation water and assists farmers for sustainable agricultural implementation and soil salinity prevention.

2.2 Total Dissolved Solids (TDS)

Total Dissolved Solids (TDS) are, by definition, the total concentration of all dissolved substances (both organic and inorganic) in water, including minerals, salts, and metals. They are found in the ionic form, which includes calcium, magnesium, sodium, potassium, chlorides, sulfates and bicarbonates. Total Dissolved Solids (TDS): Expressed in milligrams per liter (mg/L) and one of the most key measures of water quality for agricultural purposes.

That TDS can cause salinity problems with irrigation water in agriculture. If high TDS water is continuously used, salts will build up in the soil, particularly in saline-prone areas and dry climates where drainage is inadequate. It decreases osmotic potential of the soil, making it more difficult for roots to absorb water, even when moisture appears adequate. This leads to water stress (Ayers & Westcot, 1985) as well as crop stress



which means lesser crop growth leading to lower yields. In addition, some ions that comprise TDS, including sodium and chloride, may be harmful to sensitive crops when their concentrations exceed threshold levels. Prolonged salt exposure may change the structure and permeability of soils, especially those with high sodium content, resulting in decreased infiltration and aeration. High TDS levels can also affect the application of fertilizers and pesticides, as water with dissolved solids above a certain level can also affect the solubility or cause adverse reactions between the applied chemical and the water at higher levels. High TDS in irrigation can also damage soil, so, monitoring TDS in irrigation is highly critical to maintain soil health as well as to achieve maximum crop production. The Food and Agriculture Organization (FAO) indicate that irrigation water contains TDS 2,000 mg/L is unsuited to crops and must be managed very carefully (For more arranging but still far reader) (Ayers & Westcot, 1985).

2.3 pH of Water

The pH of irrigation water is an important agricultural characteristic determining the soil chemistry and availability of nutrients vital for plant growth. The pH of water that is outside the most productive band can affect the health and yield of the crop. According to Horneck *et al.* (2007), the pH in the saturated area of the soil should fall within the range of 6.5-8.4, as extreme acidity or alkalinity would negatively influence nutrient uptake and structure of the soil, therefore deviating from the optimum soil pH for most agricultural crops. Water for irrigation with acid (pH < 6.5) can cause soil acidification, with documented higher solubility of toxic elements as Al and Mn. These substances can be toxic to plants, causing root destruction and



stunted growth. Acidic water may also damage the irrigation equipment, raising the costs of maintenance and limiting the lifespan of the systems (Horneck *et al.*, 2007). In contrast, alkaline water, i.e. water with pH above 8.4, can reduce the availability of nutrient such as phosphorus, iron, and manganese. Such deficiencies typically manifest as chlorosis, stunted growth and reduced yields. Alkaline water often has a high concentration of bicarbonate and carbonate ions, which will exacerbate soil structural problems and sodium problems (Horneck *et al.*, 2007) To avoid the above problems, farmers must regularly measure and control the pH of the irrigation water, using acidifying or neutralizing agents when required. This preserve soil fertility and ensures that the assets of the soil properly use, leading to supporting sustainable crop production (Horneck *et al.*, 2007).

2.4 Chloride (Cl⁻), Sodium (Na⁺), and Potassium (K⁺) Ions in Water

Chloride (Cl⁻), sodium (Na⁺), and potassium (K⁺), are often present in the irrigation water and are the major ions containing salts that are responsible for affecting the growth of plants and the health of the soil. Although these ions are necessary for plant growth in small quantities, over the threshold of tolerance they become harmful to plants or can persist in the soil for long periods (Grattan & Grieve, 1999).

Chloride (Cl⁻): It's a required micronutrient; but at high concentration, it induces marginal leaf burn and abscission in the leaves as well as yield loss in crops, especially in chloride susceptible species like avocado, grape and citrus. Under high evapotranspiration conditions, the impacts are amplified as chloride is more readily stored in plant tissues. The toxicity due to the excess of these ions in irrigation water can still be monitored and managed



to maintain soil productivity in the long run. However, adequate practices which attenuate the adverse effects of salinity include leaching practices, soil amendments (such as gypsum for sodium) and appropriate salt-tolerant crop choices (Grattan & Grieve, 1999).

Sodium (Na⁺): One element of the first group that is even more problematic for agriculture is sodium (Na⁺) due to its influence on soil structure. Excess sodium can disperse soil particles, impeding infiltration & permeability, causing problems with root development and waterlogging. Sodium also displaces important plant nutrients such as potassium and calcium. The impact of sodium (Na) is often evaluated using the Sodium Adsorption Ratio (SAR) for water quality assessments (Grattan & Grieve, 1999).

Potassium (K⁺): It's an essential macronutrient in plant metabolism, playing a key role in enzyme activation, regulation of water and photosynthesis. However, at high levels it can interfere with uptake of magnesium and calcium, causing nutrient deficiencies and poor crops, it is generally believed to be less toxic than sodium or chloride. Irrigation water potassium levels are generally not harmful by themselves unless they are enhanced by fertilizer leaching or, industrial sources (Grattan & Grieve, 1999)

2.5 Nitrate (NO₃⁻) in Water

Nitrate (NO₃⁻) is a common form of nitrogen found in agricultural runoff and groundwater due to the widespread use of nitrogen-based fertilizers. While nitrate is essential for plant growth, its presence in water—particularly in excess—can pose significant challenges to both environmental quality and agricultural sustainability. In agricultural areas, nitrate seeping



into surface and ground water is usually due to overuse of fertilizers or inefficient irrigation. This pollution causes a decrease in the quality of water, rendering it unfit for human consumption, and can also contribute to eutrophication in adjacent aquatic systems (Rivett *et al.*, 2008). Eutrophication is the process of nutrient loading, which leads to excessive algal production, causing reduction of oxygen and damage to the organisms living in the water. On one hand, contaminated water with high nitrate content can be welcome for agriculture. Low concentrations nitrate in the irrigation water, on the other hand, can act as an additional source of nitrogen for crop uptake which may reduce fertilization requirements. However, high levels of nitrate in irrigation water may cause nutrient imbalance, soil salinity and nitrate toxicity, which is especially dangerous in forage crops utilized as fodder by livestock (Addiscott, 2005).

The control of nitrate in agricultural water systems is contingent on integrated strategies including the practice of nutrient budgeting, adoption of cover crops, and improved irrigation efficiency, and establishment of buffer areas to minimize runoff. Such strategies could help farmers remain productive even as they reduce the environmental toll from nitrate pollution.

2.6 Carbonate (CO_3^{2-}) and Bicarbonate (HCO_3^-) in Water

Carbonate (CO_3^{2-}) and bicarbonate (HCO_3^-) ions present in irrigation water are the most common pH determining factors in irrigation water. These ions derive from the dissolution of mineral deposits (like limestone), and may have a great impact on soil chemistry and agriculture productivity.

Excessive 'hard conditions' in field irrigation water can result in calcium (Ca^{2+}) and magnesium (Mg^{2+}) being precipitated—essential nutrients for plant health. This also diminish the availability of these nutrients in the



soil which can cause deficiency and unbalanced nutrients and soil structure (Ayers & Westcot, 1985). The resulting decrease in the relative levels of calcium and magnesium increases the concentration of sodium (Na^+), leading to soil sodicity, a property that leads to deteriorating soil structure, decreased soil permeability, and restricted root development. An important index to assess such a risk is RSC (Residual Sodium Carbonate), which is determined from carbonate, bicarbonate, calcium and magnesium concentrations. High RSC values indicate a greater risk of soil degradation when such water is used for irrigation (Rhoades, Kandiah, & Mashali, 1992). a derived indicator from HCO_3^- and CO_3^{2-} levels — as an important hazard factor:

$$\text{RSC} = (\text{CO}_3^{2-} + \text{HCO}_3^-) - (\text{Ca}^{2+} + \text{Mg}^{2+})$$

RSC > 2.5 me/L is considered a severe hazard.

Bicarbonates can also affect plant nutrient uptake by altering soil pH. Elevated soil pH caused by bicarbonate accumulation may reduce the availability of micronutrients such as iron, zinc, and manganese, which are critical for plant metabolism and development (Gupta & Gupta, 1987).

To mitigate these effects, farmers may use soil amendments such as gypsum (calcium sulfate) to restore calcium levels, improve soil structure, and reduce sodium hazards.

2.7 Sulfate (SO_4^{2-}) in Water

Sulfate (SO_4^{2-}) is a naturally occurring anion in soil and water, derived from the weathering of sulfate-containing minerals such as gypsum and from anthropogenic sources like industrial discharge and fertilizer runoff. In agricultural water, sulfate plays a dual role—acting as a necessary plant nutrient while also potentially posing risks when present in excess.



Sulfate is an essential source of sulfur, a macronutrient required for protein synthesis, enzyme activity, and chlorophyll formation in plants (Hawkesford, 2000). When present in moderate concentrations in irrigation water, sulfate contributes positively to crop growth and productivity, especially in sulfur-deficient soils.

However, elevated sulfate levels in irrigation water may lead to several challenges. High sulfate concentrations can contribute to the formation of saline or sodic soils, particularly in arid and semi-arid regions. Sulfate salts, such as sodium sulfate, can increase the total salinity of the soil solution, reducing water availability to plants through osmotic stress (Ayers & Westcot, 1985). Additionally, excessive sulfate can lead to nutrient imbalances by interacting with calcium and magnesium, potentially causing deficiencies or toxicities depending on soil and crop conditions.

In livestock production, high levels of sulfate in drinking water (>500 mg/L) may have negative effects, particularly in young animals, with symptoms such as decreased feed consumption, diarrhea or, in extreme cases, sulfur poisoning, which may cause polio encephalomalacia in ruminants (Loneragan *et al.*, 2001). Appropriate water quality evaluation and management decisions such as blending water sources or amendments to the soil are crucial to minimize the potential negative impacts due to high sulfate concentrations in agricultural environments.

2.8 Calcium (Ca) and Magnesium (Mg) in water

Calcium (Ca) and magnesium (Mg) are major nutrients of groundwater with a crucial role in agricultural production. Both are essential elements affecting many physiological and biochemical processes in plants.



Calcium (Ca)

It is also indispensable in the maintenance of cell wall structure and integrity in plants. It participates in the production of new cells and in root growth. Sufficient calcium in ground water can improve the soil structure thereby better drainage and aeration, both of which are crucial for optimal root health (Marschner, 2012). Calcium also contributes to reduce the impact of soil salinity that can negatively

Magnesium (Mg)

A central part of chlorophyll, the molecule that absorbs sunlight and creates energy in green leaves, relies on magnesium. It is involved in energy transfer and enzyme activation in plants. Mycorrhiza induced magnesium uptake from groundwater could enhance photosynthetic efficiency with resultant increase in crop yield (Marschner, 2012). Furthermore, the uptake of other important nutrients (e.g., N and P) is facilitated by magnesium and thereby has a potential to improve plant yields and quality (Cakmak, 2008).

Effects on Agriculture

The levels of calcium and magnesium in the groundwater may play a critical role in soil fertility and fruit crops. Soils containing these elements in the correct balance usually result in better plant health, more disease resistance and better nutrient uptake. In contrast to optimal availability, either one of these elements may be insufficient and resulting in physiologic disorders in plants, as blossom end rot in tomato because of diminishing calcium and interveinal chlorosis in crops such as corn and bean due to decreasing magnesium (White & Broadley, 2003). In addition, the availability of Ca and Mg affects soil pH and CEC and therefore nutrient availability. Calcium can assist in the neutralization of an acid soil



environment, whilst magnesium can also contribute to the structure and fertility of a soil (Lindsay, 1979).

2.9 Sodium Adsorption Ratio (SAR)

The Sodium Adsorption Ratio (SAR) is used to assess the relative concentration of sodium (Na^+) to calcium (Ca^{2+}) and magnesium (Mg^{2+}) in irrigation water. It is a crucial indicator of the potential for sodium to negatively impact soil structure (Ayers & Westcot, 1985; USDA-NRCS, 1997).

Formula:

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

Where all ions are measured in milliequivalents per liter (meq/L).

Importance of SAR in Irrigation

In water of high SAR, displacement of calcium and magnesium ions can occur from the surface of soil particles resulting in soil dispersion, crusting, lower permeability and poor infiltration (Ayers & Westcot, 1985). This can severely

such as affect plant roots growth and water availability.

2.10 Residual Sodium Carbonate (RSC) in Irrigation Water

RSC value is an important criterion for determining the suitability of water for irrigation, specifically its effect on soil structure and percolation properties. It is the sequence of value calculated as:

$$RSC = (\text{CO}_3^{2-} + \text{HCO}_3^{-}) - (\text{Ca}^{2+} + \text{Mg}^{2+})$$

Where all ionic concentrations are expressed in milliequivalents per liter (meq/L).



RSC measures the ratio of carbonate and bicarbonate ions versus calcium and magnesium ions. High levels of carbonate and bicarbonate in comparison to calcium and magnesium, could lead to the precipitation of calcium and magnesium. This negatively affect the combined relative sodium, soil dispersion, infiltration, and soil structure (Richards, 1954). High RSC waters will lead to the addition of sodium in soil, which has negative influences on soil permeability and crop yield. The problem is major in dryland areas where leaching effect is less and irrigation is an integral part of agriculture.

2.11 Water Quality Index (WQI) of Groundwater for Agriculture

Water Quality Index (WQI) for agricultural use is an important indicator for assessing the suitability of the ground water for irrigation. The index is based on the analysis of selected physio-chemical properties which influence soil structure and crop health as well as long term agricultural productivity. It usually involved measurements of EC, SAR, RSC, TDS, chlorides, nitrates, and boron.

High EC and TDS of water would cause soil salinity problems, while high SAR and RSC would destabilize soil structure and reduce its permeability, resulting in unsuitable water for crop growing. Thus, evaluation of the WQI is significant to the farmers and planners for safer irrigation water and also to make rectifications, if need be.

WQI is a single value summary of complex water quality data in water resource management for agriculture, which is easy to interpret and suitable for decision making. This is a significant issue in sustainable agriculture, especially in places where there is contamination of groundwater or over extraction (Ramesh & Elango, 2012).



3. Survey of Previous Studies in Salah Al-Din Governorate, Iraq

A variety of natural and human-induced aspects affect the groundwater quality of Salah Al-Din. Sedimentary formations with a more complex hydrogeological structure characterize the geology of the region and influence the mineral composition of groundwater. Constituents, like most iron, manganese, and sulfates, may be released during the dissolution process in the aquifers of rock-water through natural elements (Al-Dabbas *et al.*, 2018). Most importantly, human activities are the source of greater issues. With the unregulated agriculture of chemical fertilizers and pesticides large amount of nitrates and phosphates has increased the levels in groundwaters. Likewise, the release of untreated sewage and solid waste, together with leaching from septic tanks, have contributed to microbial pollutants and heavy metals in to ecosystems (Mahdi & Al-Jaberi, 2021). The differences in groundwater quality observed in Salah Al-Din are related to numerous hydrogeological and land use factors. Shallow aquifers which are at high risk of pollution due to their proximity to agricultural land and populated areas, are concentrated particularly in southern and central areas of the governorate. Shallower aquifers, however, provide more protection, but are also far less expensive to access and monitor (Ismail *et al.*, 2023). In addition, the absence of advanced wastewater treatment infrastructure in the majority of Salah Al-Din has resulted in the release of pollutants directly or indirectly into the subsurface, an action which threatens the safety of groundwater intended for drinking purposes. Beyond anthropogenic pressures, climate change has increased the risk to groundwater in Salah Al-Din. The last 20 years have shown more intensively the rise of temperature as well as the fall of yearly precipitation in Iraq, either of which has led to the decreasing of renewable water resources and to a larger dependency on non-renewable or slowly



recharged aquifers (UNESCO, 2021). Longer spells of drought have resulted in low recharge and increase the dissolved constituents concentration, due to lack of dilution and have an adverse impact on water quality (Al-Ansari *et al.* 2018) Such climatic conditions, together with over-abstraction, jeopardize the long-term viability of the region's aquifers. Beyond agricultural runoff and domestic wastewater, industrial activities in and around Salah Al-Din are a new relevant source of groundwater pollution. Several oil refineries, chemical plants, and manufacturing facilities are in the governorate and most do not have wastewater treatment infrastructure. Hydrocarbons, heavy metals, and toxic solvents from industrial effluents are commonly discharged straight into the environment or indirectly infiltrate groundwater systems via unlined waste pits and poorly managed disposal sites (Ali & Al-Haidari, 2021). Wastewater from hospitals is disposed to the public network then to central wastewater treatment plants. partly treated effluent is sneak to the groundwater and the some discharged to the sea (Abd Al Satar & Sachit, 2021a). As illustrated, the total of these discharges – and therefore long-term aquifer contamination – is most harmful in regions with high industrial density like Baiji, potentially triggering irreparable ecological damage and public health risks. Salah Al-Din Governorate is geographically situated in the Middle of the Iraqi Tigris River basin, which is the geographical center of Iraq's agricultural and economic activities. Long drought durations, the unevenness of surface water, and the deterioration of river systems as a result of upstream damming and contamination have rendered the wetland areas of Salah Al-Din historically dependent on groundwater resources for its citizens and industries (Ehab Mohammad *et al.*, 2020). This has particularly increased the pressure on aquifer systems that are already overexploited with plenty showing signs of declining quality and quantity. Poor groundwater quality has wider implications



than just impacts on humans and aquifers, but also the environment and the economy as a whole. Irrigation with saline groundwater results in the salinization of soils limiting agricultural productivity and may lead to land becoming unfarmable in the long term. The cost related to water purification, the medical treatment of water-related diseases, and rehabilitation of degraded ecosystems represents a significant burden on the scarce resources of the region (Li *et al.*, 2020). Also, the absence of public knowledge about the safe usage and conservation of groundwater makes the situation worse, as several communities unknowingly pollute groundwater by irrational waste disposal and the inept usage of irrigation systems.

Investigations show that the groundwater of Al-Alam district in Salah Al-Din has high values of Total Dissolved Solids (TDS) ranging between 1930 and above 1000 mg/L, which exceed the allowable limit prescribed by WHO and for Iraqi standard. The recorded EC data indicate that values can reach up to 3940 $\mu\text{S}/\text{cm}$ which is higher than the normal permissible degree 411 mg/L), both exceeding the WHO maximum permissible limit (250 mg/L), as a result of the dissolution of evaporite minerals like gypsum and halite (Hussain *et al.*, 2022). Groundwater in Al-Alam is also very hard, and has hardness >180 mg/L. Investigation investigated the suitability of ground water for irrigation in Al-Alam using the indices of (EC), (SAR) (Na%), (RSC), (MH), and (PI). Results show that 62% of the samples were found above the acceptable limits of EC for irrigation which SAR and Na% placed some of the ground water under doubt for agricultural purposes (Mahmood & Jassim, 2023). Microbial pollution had been discovered in all tested wells with coliform bacteria density 3-240 cells/100 ml in study on coliform bacteria presence in wells water. The most contaminated samples were from Al-Alam in November which imposed health risks to the consumers (Ali *et al.*, 2022). Some physicochemical studies of groundwater in Balad have been conducted. AlSaadi *et al.* performed a study to



this effect. (2019) found in the studied soils electrical conductivity in the range 590–3492 $\mu\text{S}/\text{cm}$, which indicated the different levels of soil solution salts. The pH values were between 7.02 and 7.85, that were close to the neutral. Also, it was noted that sulfate concentration had a wide range of difference from (49.672 to 796.279 mg/L) and TDS difference (753– 3,614 mg/L) that also exceeded the standard in some areas (AlSaadi *et al.*, 2019) Heavy metals were the source of worry in groundwater quality. Mahmoud & Hassan (2021) also reported Pb levels of 0.355–0.509 mg/L above the standards of World Health Organization (WHO). Zinc concentrations ranged from 0.033 to 3.841 mg L⁻¹ and some of the samples exceeded safe levels. Heavy metals indicate industrial and agricultural runoff could be the sources of contamination (Mahmoud & Hassan, 2021).

Recent research has shown that the groundwater in Samarra's water aquifers has vast hydrochemical fluctuations. Al-Tameemi *et al* reported that electrical conductivity varies between 650 and 4,200 $\mu\text{S}/\text{cm}$, reflecting different salinities. The pH ranges from about 7.1 to 8.0. Nevertheless, the values of total dissolved solids (TDS) are rejoicing the limits (water hardness and usability) and may range between 800 and 4,500 mg/L (AL-Tameemi *et al.*,2020) . Ground heavy metal pollution is a great concern of Samara's ground water. Hamza & Younis (2021) reported lead levels varying from 0.25 to 0.65 mg/L, above the WHO drinking water guidelines. Arsenic and cadmium concentrations were similarly detected in trace levels, but exceeded permissible levels in some locations, probably as a result of industrial and agricultural waste (Hamza & Younis, 2021). Biological Quality Micro-organisms contamination is one of the important problems that should be considered in assurance of the groundwater safety. Kareem *et al.* (2019) tested 20 well water from Samarra city for coliform bacteria, which was detected in 40% of samples suggesting for a possible fecal contamination. These results suggest the public health risk and further for effective disinfection prior



to use for personal remedies against diseases (Kareem *et al.*, 2019). Research work carried out by Jassim & Al-Ani (2022) assessed the quality of irrigation water indices and observed that more than 50% of the tested samples possessed high salinity and SAR and were non-suitable for direct agricultural utilization. Soil management and dilution are also required to reduce these effects (Jassim & Al-Ani, 2022). Several indices such as SAR (Sodium Adsorption Ratio), Na% (Sodium Percentage) and RSC (Residual Sodium Carbonate) have been used to evaluate the efficiency of groundwater for irrigation. It is pointed out that most of the Tikrit soil samples were found to be in "non-suitable" category as a result of severe salinity and sodicity threats (Abed *et al.*, 2021). aquifers of Al-Dour indicate high levels of salinity, hardness, and mixture with some heavy metals. These are problems that are not only harmful to human health, but which damage agricultural productivity. Local water treatment such as reverse osmosis should be adopted, awareness of water quality should be raised among the general public, and periodic programs for ground water monitoring should be established (Kareem *et al.*, 2011; WHO, 2017). The pH of groundwater samples ranged from 6.4 to 8.4, falling within WHO standards. However, TDS values from 1380 to 1903 mg/L and total hardness from 1843 to 2357 mg/L indicate that the water is very hard and mineralized. Sulfate concentrations exceeded 2000 mg/L in some samples, far beyond the WHO limit of 250 mg/L. Additionally, heavy metals such as iron and cadmium were detected above permissible levels, potentially from corrosion of distribution pipes or geochemical sources (Jabbar, 2022).

4. The Effect of Groundwater Quality on Crop Types

The quality of groundwater directly influences agricultural productivity and the types of crops that can be successfully cultivated. Poor-quality groundwater contaminated with salts, heavy metals, or toxic chemicals can



lead to reduced yields, soil degradation, and long-term environmental issues. Understanding the relationship between groundwater quality and crop suitability is essential for sustainable agriculture and food security. The following studies are showing the effect of groundwater quality on crops:

- Rhoades *et al.* (1992) found that long-term irrigation with saline water leads to accumulation of salts in the root zone, damaging salt-sensitive crops and restricting options to only salt-tolerant varieties like barley or cotton.
- Richards (1954) noted that water with high SAR levels causes dispersion of soil particles, leading to poor soil tilth and adverse effects on most field crops.
- Ayers and Westcot (1985) highlighted that irrigation water with pH outside the optimal range could interfere with nutrient uptake, particularly affecting crops like maize and rice.
- In parts of Bangladesh and India, arsenic-contaminated groundwater used for irrigation has led to bioaccumulation in rice, posing a serious food safety issue (Meharg & Rahman, 2003).
- A study in Rajasthan, India, showed that in saline groundwater areas, farmers replaced traditional wheat and chickpea with salt-tolerant mustard and barley to cope with declining water quality (Minhas & Tyagi, 1998).
- A study by Ministry of Agriculture in Iraq was done to explain the effect of EC on many crops in Samarra in Salah Al-Din Governorate, Iraq using data of several wells and using the following formula to calculate yield for crops depending on EC values: **Yield=100 - EC_{max} (EC_e - EC_{en})**



The following table is for one of the wells in the studied area which shows the effect of EC on crop yield where EC value was 7.42:

(Table1: salinity effect on plants and crop yield for location 1)

Crop	ECen	ECmax	ECe	Yield
Barley	8	28	7.42	100
Cotton	7.7	26.9	7.42	100
Sugar beet	7	24	7.42	97.522
Date palms	4	31.8	7.42	87.688
Wheat	6	20.1	7.42	89.918
Maize	1.7	10	7.42	31.36
Potato	1.7	10	7.42	31.36
Beas	1	6.3	7.42	21.98-
Onions	1.2	7.5	7.42	0.48
Rice	3	11.3	7.42	46.96
Citrus (Orange)	1.7	8	7.42	29.28
Groundnut	3.2	6.6	7.42	65.88-
Carrots	1	8.1	7.42	10.12
Apricot	1.6	5.8	7.42	39.68-
Peas	1.5	11.3	7.42	17.12
Lettuce	1.5	9.8	7.42	28.96
Broccoli	2.8	13.7	7.42	57.496
Grapes	1.5	12	7.42	43.168
Alfalfa	2	15.7	7.42	60.434
Sugar cane	1.7	18.6	7.42	66.252
Clover Barseem	1.5	19	7.42	66.256
Sorghum	6.8	13.1	7.42	90.018
Soybean	5	10	7.42	51.6
Cowpeas	1.5	13.2	7.42	69.76
Spinach	2.6	12.2	7.42	42.642
Beet red	4	15.1	7.42	69.22



Conclusion

Based on this study, it was found that it is essential to conduct a comprehensive analysis of the physical and chemical properties of groundwater in Salah Al-Din before using it for irrigation, due to its significant impact on soil and agricultural productivity. It is also important to assess the suitability of well water for various types of crops in order to ensure effective agricultural planning, better utilization of arable land, and higher yields. The results indicated that the electrical conductivity of water plays a significant role in the growth and productivity of many agricultural crops. High salinity levels were observed in the groundwater of Salah Al-Din Governorate, exceeding the permissible limits for irrigation water, in addition to elevated concentrations of heavy metals. Therefore, the study recommends the treatment of groundwater before its use in irrigation, to avoid any potential risks to the environment, plants, and consequently, human health.



References

- [1]. Abd Al Satar, N. H., & Sachit, D. E. (2021). The effect of Hospital Wastewater Discharge of Medical City, Baghdad on Heavy Metals Concentration of the Tigris River. *Desalination and Water Treatment*, 230, 252–258.
- [2]. Abd Al Satar, Nawras H, and Dawood E Sachit. 2021. "Assessment of Hospital Wastewater Quality and Management in Bab-Al Muadham Region at Baghdad." *Journal of Engineering and Sustainable Development* 25(3): 44–50.
- [3]. Abed, M.F., Zarraq, G., & Ahmed, S.H. (2021). Hydrogeochemical Assessment of Groundwater Quality and its Suitability for Irrigation and Domestic Purposes in Rural Areas, North of Baiji City-Iraq. *Iraqi Journal of Science*, 62(7), 2296–2306. <https://doi.org/10.24996/ij.s.2021.62.7.18>
- [4]. Acharya, G. D., Solanki, M. R., & Hathi, M. V. (2010). Studies on Physico-Chemical Parameters of Irrigation Water, Prantij, Gujarat (India). *International Journal of Chemical Sciences*.
- [5]. Addiscott, T. M. (2005). Nitrate, Agriculture and the Environment. *Agriculture, Ecosystems & Environment*, 109(1–2), 1–2. <https://doi.org/10.1016/j.agee.2005.02.001>
- [6]. Ajmal, P. M., Babar, M., Gul, N., & Jokhio, R. (2023). Assessment of Groundwater Quality Using Water Quality Index, and Geo-Spatial Tools. *Neutron: Jurnal Rekayasa Teknik Sipil*. <https://doi.org/10.29138/neutron.v22i2.180>
- [7]. Al-Ansari, N., Knutsson, S., & Aljawad, S. (2018). Water Scarcity in Iraq: Challenges and Solutions. *Engineering*, 10(3), 59–71.
- [8]. Al-Dabbas, M. A., Al-Ansari, N., & Knutsson, S. (2018). Hydrogeochemical Assessment of Groundwater in Northern Iraq. *Environmental Earth Sciences*, 77(6), 256.
- [9]. Ali, M. A., *et al.* (2022). Microbial Contamination of Groundwater in Al-Alam District. *Revista Bionatura*, 7(1), 26.
- [10]. Ali, S. H., & Al-Haidari, N. A. (2021). Environmental Risk Assessment of Industrial Activities on Groundwater in Baiji, Iraq. *Journal of Environmental Science and Pollution Research*, 28(18), 23052–23061.
- [11]. Al-Jiburi, H. K., & Al-Basrawi, N. H. (2021). Hydrogeological Assessment of Groundwater in Salah Al-Din Governorate. *Iraqi Journal of Science*, 59(3), 145-160
- [12]. Al-Saadi, R., Mohammed, A., & Younis, T. (2019). Evaluation of Groundwater Quality in Balad District, Iraq. *Journal of Environmental Studies*, 12(3), 45-60.
- [13]. Al-Tameemi, R., Mohammed, A., & Saleh, T. (2020). Hydrochemical Analysis of Groundwater in Samarra, Iraq. *Journal of Water Research*, 22(1), 67-80.



- [14]. Ayers, R. S., & Westcot, D. W. (1985). *Water Quality for Agriculture*. FAO Irrigation and Drainage Paper No. 29 Rev. 1, Food and Agriculture Organization of the United Nations. FAO Link
- [15]. Ayers, R. S., & Westcot, D. W. (1985). *Water Quality for Agriculture*. FAO Irrigation and Drainage Paper 29 Rev. 1. Rome: Food and Agriculture Organization.
- [16]. Cakmak, I. (2008). Enrichment of Cereal Grains with Zinc: Agronomic or Genetic Biofortification? *Plant and Soil*, 302(1-2), 1-17.
- [17]. Ehab Mohammad, A., Ektifa Taha, A., Fatma Adnan, S., & Rania Haithem, S. (2020). Study of qualitative properties of groundwater and its suitability for different uses in the Eastern of the Al-Dour city/Salahaldin/Iraq. *Tikrit Journal of Pure Science*, 25(2), 47-53. <https://doi.org/10.25130/J.V25I2.957>
- [18]. FAO. (2019). *Iraq – Water Report 37*. Food and Agriculture Organization of the United Nations.
- [19]. Grattan, S. R., & Grieve, C. M. (1999). Salinity–mineral nutrient relations in horticultural crops. *Scientia Horticulturae*, 78(1-4), 127–157. [https://doi.org/10.1016/S0304-4238\(98\)00192-7](https://doi.org/10.1016/S0304-4238(98)00192-7)
- [20]. Gupta, U. C., & Gupta, S. C. (1987). Trace Element Toxicity Relationships to Crop Production and Livestock and Human Health: Implications for Management. *Communications in Soil Science and Plant Analysis*, 18(8), 931–970. <https://doi.org/10.1080/00103628709367847>
- [21]. Hamza, S., & Younis, T. (2021). Assessment of Heavy Metals in Groundwater Sources in Samarra. *Iraqi Journal of Environmental Studies*, 19(2), 89-104.
- [22]. Hawkesford, M. J. (2000). Plant Responses to Sulphur Deficiency and the Genetic Manipulation of Sulphate Transporters to Improve S-utilization Efficiency. *Journal of Experimental Botany*, 51(342), 131–138. <https://doi.org/10.1093/jexbot/51.342.131>
- [23]. Horneck, D. A., Ellsworth, J. W., Hopkins, B. G., Sullivan, D. M., & Stevens, R. G. (2007). Managing salt-affected soils for crop production. *Pacific Northwest Extension Publication PNW601*. Oregon State University. <https://catalog.extension.oregonstate.edu/pnw601>
- [24]. Hussain, A. J., *et al.* (2022). Evaluation of Groundwater Salinity in Central Iraq. *Environmental Earth Sciences*, 82(5), 471.
- [25]. Ismail, A.H., Shareef, M.A., Hassan, G., & Alatar, F.M. (2023). Hydrochemistry and Water Quality of Shallow Groundwater in the Tikrit Area of Salah Al Din Province, Iraq. *Applied Water Science*, 13, Article 197. <https://doi.org/10.1007/s13201-023-02008-y>
- [26]. Jabbar, A. J. (2022). Water Quality Index and Heavy Metals Evaluation in Al-Dour Water Treatment Plant. *Indian Journal of Environmental Protection*, 42(4), 330–336. <https://www.indianjournals.com/ijor.aspx?article=031&issue=4&target=ijor%3Aije1&volume=48>
- [27]. Jassim, M., & Al-Ani, K. (2022). Evaluation of Groundwater Quality for Irrigation in Samarra, Iraq. *Agricultural Water Management*, 31(2), 125-140



- [28]. Jassim, M., & Al-Ani, K. (2022). Hydrochemical Characteristics and Irrigation Suitability of Groundwater in Balad, Iraq. *Agricultural Water Management*, 30(1), 112-125
- [29]. Kareem, A., Saeed, H., & Jaber, M. (2019). Microbiological Contamination of Groundwater in Samarra: Implications for Public Health. *Environmental Health Perspectives*, 27(3), 150-165.
- [30]. Kareem, A., Saeed, H., & Jaber, M. (2020). Assessment of Potable Water Quality in Balad city, Iraq. *Environmental Research Letters*, 15(5), 205-220.
- [31]. Kareem, M. A., Al-Mashhadani, M. S., & Hussein, K. J. (2011). Groundwater Management in Northern Iraq. *Environmental Earth Sciences*, 62(6), 1193–1204. <https://doi.org/10.1007/s12665-010-0604-y>
- [32]. Li, C., Li, C., Gao, X., Li, S., & Bundschuh, J. (2020). A review of the Distribution, Sources, Genesis, and Environmental Concerns of Salinity in Groundwater. *Environmental Science and Pollution Research*. <https://doi.org/10.1007/S11356-020-10354-6>
- [33]. Lindsay, W. L. (1979). *Chemical Equilibria in Soils*. New York: Wiley.
- [34]. Loneragan, G. H., Gould, D. H., Callan, R. J., Sigurdson, C. J., & Mason, G. L. (2001). Association of Excess Sulfur Intake and An increase in Cerebrocortical Necrosis in Feedlot Cattle. *Journal of the American Veterinary Medical Association*, 219(8), 1167–1174. <https://doi.org/10.2460/javma.2001.219.1167>
- [35]. Mahdi, A. A., & Al-Jaberi, R. T. (2021). Impact of Human Activities on Groundwater Quality in Central Iraq. *Iraqi Journal of Science*, 62(4), 1003–1015.
- [36]. Mahmood, S. A., & Jassim, A. M. (2023). Groundwater Quality Assessment for Irrigation in Iraq. *Water Resources Management*, 37(4), 765-780.
- [37]. Mahmoud, S., & Hassan, N. (2021). Heavy Metal Contamination in Groundwater Sources in Salah Al-Din Governorate. *Iraqi Journal of Water Resources*, 18(2), 75-89.
- [38]. Marschner, H. (2012). *Mineral Nutrition of Higher Plants*. Academic Press.
- [39]. Meharg, A. A., & Rahman, M. M. (2003). Arsenic Contamination of Bangladesh Paddy Field Soils: Implications for Rice Contribution to Arsenic Consumption. *Environmental Science & Technology*, 37(2), 229–234. <https://doi.org/10.1021/es0259842>
- [40]. Minhas, P. S., & Tyagi, N. K. (1998). Guidelines for Irrigation with Saline and Alkali Waters. *Bulletin No. 1/98*, CSSRI, Karnal, India.
- [41]. Ministry Of Agriculture of Iraq, Agroecological Zoon Department (AEZ).
- [42]. Munns, R., & Tester, M. (2008). Mechanisms of Salinity Tolerance. *Annual Review of Plant Biology*, 59, 651-681.
- [43]. Ramesh, K., & Elango, L. (2012). Groundwater Quality Assessment for Irrigation Use in Vellore District, Southern India. *Environmental Earth Sciences*, 67(8), 2129–2141. <https://doi.org/10.1007/s12665-012-1656-9>



- [44]. Rhoades, J. D., Kandiah, A., & Mashali, A. M. (1992). *The Use of Saline Waters for Crop Production* (FAO Irrigation and Drainage Paper 48). Food and Agriculture Organization of the United Nations. <https://www.fao.org/3/t0667e/t0667e00.htm>
- [45]. Rhoades, J. D., Kandiah, A., & Mashali, A. M. (1992). *The use of Saline Waters for Crop Production* (FAO Irrigation and Drainage Paper 48). Food and Agriculture Organization of the United Nations. <https://www.fao.org/3/t0667e/t0667e00.htm>
- [46]. Richards, L. A. (1954). *Diagnosis and Improvement of Saline and Alkali Soils* (Issue 60). US Government Printing Office.
- [47]. Richards, L. A. (1954). *Diagnosis and Improvement of Saline and Alkali Soils* (Issue 60). US Government Printing Office.
- [48]. Rivett, M. O., Buss, S. R., Morgan, P., Smith, J. W., & Bemment, C. D. (2008). Nitrate Attenuation in Groundwater: A review of Biogeochemical Controlling Processes. *Water Research*, 42(16), 4215–4232. <https://doi.org/10.1016/j.watres.2008.07.020>
- [49]. Saeed, T. (2014). Assessment and Conservation of Groundwater Quality: A Challenge for Agriculture. *British Journal of Applied Science and Technology*. <https://doi.org/10.9734/BJAST/2014/6353>
- [50]. Srivastav, A. L., Dhyani, R., Ranjan, M., Madhav, S., & Sillanpää, M. (2021). Climate-resilient Strategies for Sustainable Management of Water Resources and Agriculture. *Environmental Science and Pollution Research*. <https://doi.org/10.1007/S11356-021-14332-4>
- [51]. U.S. Salinity Laboratory Staff. (1954). *Diagnosis and Improvement of Saline and Alkali Soils*. USDA Agricultural Handbook No. 60.
- [52]. UNESCO. (2021). *World Water Development Report 2021: Valuing Water*. United Nations Educational, Scientific and Cultural Organization.
- [53]. USDA-NRCS. (1997). *National Engineering Handbook, Part 652 – Irrigation Guide*. United States Department of Agriculture – Natural Resources Conservation Service.
- [54]. Varela-Ortega, C., Blanco-Gutiérrez, I., Swartz, C. H., & Downing, T. E. (2011). Balancing Groundwater Conservation and Rural Livelihoods Under Water and Climate Uncertainties: An Integrated Hydro-economic Modeling Framework. *Global Environmental Change-Human and Policy Dimensions*. <https://doi.org/10.1016/J.GLOENVCHA.2010.12.001>
- [55]. White, P. J., & Broadley, M. R. (2003). Calcium in Plants. *Annals of Botany*, 92(4), 487–511. <https://doi.org/10.1093/aob/mcg164>
- [56]. World Health Organization (2017). *Guidelines for Drinking-water Quality* (4th ed.). WHO Press