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A Review of Groundwater Quality in Iraq: A Critical Narrative Synthesis of Hydrogeochemical Controls, Contamination, and Water-Use Suitability

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Abstract

Increasing drought and irregularity of groundwater recharge, in conjunction with Iraq's increased dependence on the groundwater, led to increasing important quality assessment of these resources and its different uses; and also rising demand for surface water and the declining reliability. Available evidences relate to each of drinking water and other uses suitability, hydrogeological controls, pollution pressures, and spatial variation, all will be taken in the present review as a critical narrative review. Salinity and mineralization are among the most frequently reported factors, but their intensity varies considerably between groundwater reservoirs. Studies showed a clear spatial variation in groundwater quality across Iraqi aquifers, with existing regions with more suitable conditions and other suffer from greater restrictions related to salinity or local pollutants. The increase in nitrate concentrations in agricultural and wastewater-affected environments contributes to the documented non-cancer health concerns in the Bnslawa area of Erbil, based on 24 years of Dibdiba aquifer records, which demonstrate that degradation may progress over time rather than following a simple spatial gradient. Evidence relating to trace elements has become more substantial, although it remains localized. Studies in Saqlawiya have indicated excesses in lead and cadmium levels, while shallow, conflict-affected wells in Mosul have shown seasonal problems with heavy metals; other groundwater aquifers examined have shown acceptable levels of trace elements. Methodologically, modern Iraqi work increasingly combines water quality indicators, geographic information systems, multivariate statistics, stable isotopes, geo-statistics, entropy weighting, and other modern source-oriented approaches. Differences in sample design, scope of analysis, indicator construction, and reference standard selection continue to limit direct comparisons. Therefore, the literature as a whole does not support the existence of a single national quality category or a standardized treatment plan. The results indicate that groundwater management in Iraq must depend on specific assessment for each aquifer, long term monitoring programs, and linking water quality to hydrological conditions and use, rather than relying on a national unified classification.

Keywords:
Groundwater Quality, Hydro Geochemistry, Salinity, Trace Elements, Iraq, Water Quality Index, Narrative Review.

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1. Introduction

Water security in Iraq depends on both surface and groundwater due to the arid to semi-arid environment, which in turn leads to increasing pressure on the Tigris-Euphrates river system. Climate fluctuations, population growth, and agricultural demand have all made groundwater aquifers of great importance for local economic activity as well as for domestic supplies and irrigation (Al-Ansari, 2013; Alattar, 2024). The importance of groundwater has increased significantly since its initial use in emergencies. It is now routinely used in various human, agricultural, and industrial sectors, all of which depend on water quality and the reliability of groundwater systems.

Several factors influence the formation of the natural hydrochemical environment of groundwater in Iraq, including mineral dissolution, rock formation, ion exchange, evaporation, recharge, and hydraulic bonding. Therefore, it is impossible for a single process to explain the chemical composition of groundwater. Many direct and indirect human activities affect groundwater quality and alter the environment. These activities include irrigation, fertilizer use, wastewater discharge, urbanization, industrial activity, and over-extraction of resources. The impact of these activities varies from region to region. Rashdiya, Kirkuk, Wana, Tikrit, Wasit, Missan, Haditha, Erbil, Sharbazir, Al Jallam, Karbala, and southern Basrah all show substantial differences in hydrochemical facies, salinity, water-quality classifications, and locally inferred land-use effects.

Studies such as (Beg et al., 2021; Al-Gburi et al., 2023; Alaarajy et al., 2023; Ismail et al., 2023; Al-Sudani, 2024; Al-Gburi et al., 2024; Hamed et al., 2023; Al-Qurnawy et al., 2024) have confirmed and supported this disparity across the country.

Determining the suitability of groundwater for use after quality analysis depends not only on its chemical composition but also on its intended use. Water from a particular source may be unsuitable for drinking but suitable for certain industrial processes. Similarly, moderately saline groundwater from another source may be unsuitable for sensitive crops but suitable for other salt-tolerant crops, even when drainage and soil conditions are appropriate. This is not always the case, as the results of any study from a specific region should not be generalized to all of Iraq. For example, low-salinity groundwater is not considered suitable for drinking if high concentrations of nitrates, toxic trace elements, or microbiological contamination are present. Accordingly, the water-use suitability and hydrochemical state of the groundwater, must be clearly distinguished through the assessment.

This subject was taken from different angles through several studies, including a study of Hawez et al. (2021) which addressed the characteristics of groundwater in the Kurdistan Region, and the study of Hussein et al. (2025) that analyzed the concentrations of sulfate and chloride in Iraqi groundwater. Also, the study of Radhi et al. (2025) was tacked the quality of irrigation water in Salah al-Din governorate. An important picture about quality of groundwater in Iraq was presented by all these studies, but it still fragments. Many of these studies are focus on specific ions, specific areas, specific water uses, that will be limits the generate ability out of contexts that were performed on its. So, a question will be taking place, that is all available evidences are consistent and methodologically firmly established in order to Building a comprehensive national analysis that merge the hydrological process, nitrates salinity patterns, trace elements pollution, water quality for different uses, methodological constraints, and the strength of the inferences the studies reached? Also, it's important to clear distinguishing between the results which reflect limited local conditions and the conclusions which can be extend to wider range, because getting the reliable generalizations at the level of Iraq requires consistent and repeated evidence over different area and groundwater aquifers.

The review giants its important come from combing the available evidences and examine its critically to repeated hydrogeological pattern exploration, pressure and pollution sources, and the extent of groundwater suitability for different uses in Iraq. The review also seeks to clarify the strengths and weaknesses in the methods used that still founded which help to more clearly prioritizes for future research, identifying gaps, and water resources managements. The present review was adopted for its studies organizing on the subject matter instead of publication date arrangement. This method helps read the evidences in a more interconnected way, also facilities the identification of areas of agreement and disagreement among studies, highlighting regional differences, and determining the sides which have unclear or inconclusive evidences.

Despite increasing studies that which dealt the groundwater quality different regions of Iraq, current knowledge remains fragmented between specific aquifers and regions, with a clear difference in the indicators used, evaluation criteria, and methods on interpreting pollution sources (Beg et al., 2021; Al-Gburi et al., 2024). Most studies focus on the local assessment which depended on chemical measurements or water quality indices. While the linking between hydrological characteristics, geological formation, pollution sources, and different water uses need to be integrated at the national level (Alaarajy et al., 2023; Hamed et al., 2023; Alameer et al., 2026). Also, the difference in studies design, number of samples, time periods, and reference standard used for quality assessment making the direct comparison between different results is limited and it's difficult to reach a unified national classification of

groundwater quality (Al-Hily and Awadh, 2025; Mohsin et al., 2026).

Therefore, there is a needing to critical review that gathering available evidence and assess extent of possibility generation the local studies result at the level of Iraq, with tacking in the account the hydrological differences between aquifers and different regions. The present study aims to present a critical analysis of the quality of Iraqi groundwater through analyze the role of the hydrological and geochemical factors, identifying salinity and pollution patterns, assess water suitability for different uses like drinking, irrigation, and engineering and industrial uses (Al Maliki et al., 2024; Alameer et al., 2026). The scientific contribution of this review lie in moving beyond a mere compilation of previous studies towards a critical interpretation that clarifies the points of agreement between the evidence, and identifying the limits of water quality indices when using it to assess the complex groundwater systems, it proposes future priorities for monitoring and sustainable management of groundwater in Iraq (Al-Hily and Awadh, 2025; Naz et al., 2024).

Previous studies have addressed groundwater quality in Iraq form multiple angles (Beg et al., 2021; Al-Gburi et al., 2023; Al Maliki et al., 2024); some of the focused on evaluating the hydrochemical characteristics and water quality index[1] in specific regions, while other studies focused on identifying the salinity sources or evaluate impact of the agriculture and industrial activities on the groundwater quality (Alaarajy et al., 2023; Al-Gburi et al., 2024; Hamed et al., 2023). These studies have presented important information about the local condition for different aquifers, but most of them remained limited in terms of spatial zone or evaluation aim, and did not provide a comparative framework that linking the differences in hydrological unit, geochemical processes, pollution patterns, and end use water requirements at the Iraqi level.

The present review different from other studies in that it does not aim to evaluate a one location or single aquifer, rather it presenting a critical analysis of the available evidence at the Iraqi level, with analyze possibility of generalizing the results across different regions and identifying factors that control in spatial differences for groundwater quality. The review was also notable for incorporating evidence related to hydrogeology, hydrochemistry, non-organic pollutants, and suitability of water for drinking; irrigation; and engineering uses (Al-Hily and Awadh, 2025; Al-Kubaisi et al., 2025; Alameer et al., 2026). In addition to discuss limitation of analytical methods like water quality indices and statistical analyses when used to explain the complex groundwater systems (Naz et al., 2024; Mohsin et al., 2026).

[1] Water Quality Index (WQI)

2. Hydrogeological and environmental setting of Iraq

Iraq located east-north part of Arabian Peninsula, and extent within diverse geographic and climatic zones include mountainous regions in the north and northeast, transitional plain regions, and the vast alluvial plain in the center and south of the country, in addition to western desert. This geography and geology diversity lead to existence multi groundwater systems differ in the recharge sources, aquifers nature, flow direction, and drainage condition.

Iraqi's climate is characterized as arid to semi-arid, with a decrease the rainfall rates compare to high rates of evaporation, which has direct impact on the aquifer recharge and salinity development. Rainfall amount varies significantly between the northern mountainous regions, whereas recharge is more important, desert regions and southern plain where aridity and increased by evaporation prevail (Al-Ansari, 2013; Alattar, 2024).

Hydrogeologically, Iraq does not represent a unified groundwater system, rather consist of several regions and primary aquifers includes western desert, Al-Jazeera region, Low Folded Zone, and alluvial plain. These systems differ in term of nature of water bearing rocks, including fractured carbonate reservoir, clastic formations, and Quaternary deposits, in addition to evaporite formations that direct effect on water salinity and ionic composition (Jassim and Goff, 2006; Al-Jiburi and Al-Basrawi, 2009, 2011, 2012, 2014).

Iraqi groundwater is subject to multiple natural and human pressures, including changes of recharge rates, increased water withdrawal for agriculture purposes and domestic uses, impact of fertilizers, wastewater and industrial activities, which lead to a clear difference in water quality between regions and different aquifers (Al-Gburi et al., 2024; Al Maliki et al., 2024). The main hydrogeological and environmental characteristics controlling groundwater quality in Iraq, including geographic setting, climate, aquifer types, geological formations, and major natural and anthropogenic pressures, are summarized in Table 1.

3. Scope and approach of the narrative review

This article presents a critical narrative review, rather than systematic review. The evidence base is centered on studies that directly examined Iraqi aquifers and groundwater-dependent settings. The evidences base was expanded in the present review so that it is not limited to local groundwater quality evaluation studies, but it also includes studies which offers a hydrogeological and regional framework for Iraqi aquifers; studies related to hydrochemistry, salinity, nitrate, and trace elements; water suitability for drinking and irrigation; and sources of pollution. In addition to studies that use spatial,

Table 1. Main hydrogeological and environmental characteristics of Iraq relevant to groundwater quality assessment

Parameter	Description	Relevance to groundwater quality
Geographic location	Iraq is located in northeastern part of the Arabian Peninsula, approximately between latitudes 29-37° north and longitudes 38-49° east.	Controls regional climate and hydrogeological diversity, and therefore the variation in groundwater system.
Climate	Arid-semi arid climate, characterized by low rainfall rates and high evaporation rates.	It affects groundwater recharge rates, salinity development, water resource availability.
Major geomorphological regions	Mountain region, foothills, alluvial plain, western desert.	This led to variations in groundwater systems, recharge conditions, and water movement.
Major hydrogeological regions	Western desert, Al-Jazeera region, high folded zone, low folded zone, alluvial plain.	Control the characteristics of aquifer system and control hydrochemical composition of water
Types of main aquifers	Carbonate aquifers, clastic aquifers, Quaternary alluvial deposit aquifers.	Determine storage characteristic water movement paths, interaction processes between water and rocks.
Important geological formations	Important formations: Fatha, Injana, Mukdadiya, Bai Hassan, and Quaternary deposit	Control the mineral dissolution processes, develop the groundwater chemistry, especially sulfate, chloride, and salinity.
Influential natural factors	Evaporation, minerals dissolution, water-rock interaction, and recharge-drainage conditions.	Responsible for the nature variation in hydrochemical properties between aquifers and regions.
Major human pressures	Agriculture activity, fertilize use, waste water discharge, urban expansion, industrial activities, and overexploitation of groundwater.	Contribute the nitrate increasing, salinity, trace elements contamination in some regions.
Primary uses of groundwater	Drinking water, agriculture irrigation, domestic uses, and industrial uses.	Criteria required to assess water quality and its suitability for end use are defined.

statistical, and analogical methods to interpretation of change the groundwater quality. Priority was given to studies that provide information which can be directly links to aquifer or specified Iraqi region, this allows for comparison between evidences, and avoid generalize the local results at the national level. A targeted supplementary literature update, completed through 15 August 2026, was used to bring the review up to date and assess novelty. Searches drew on journal and publisher records, DOI-linked[1] article pages, and combinations of the terms Iraq, groundwater, quality, hydrochemistry, salinity, nitrate, heavy metals, drinking, irrigation, and WQI. Recent Iraq-focused studies and earlier review articles were retained when their bibliographic identity and study-level claims could be verified. Studies conducted outside Iraq are used only for conceptual or methodological context, not as evidence of Iraqi groundwater conditions.

The analysis of evidence in the present review was not limited to summarizing results of previous studies, but a critical comparison was conducted between the studies according to several key aspects including aquifer characteristics, geological conditions, pollutions indicators, sampling design, and assessing criteria. It has been focusing on identifying the recurring patterns between studies, as well as cases where results differ between regions with interpretate these differences depending on the local condition of aquifers, land uses, and methodological differences between studies. Also, the strength of the available evidence was also assessed and regions that need additional data were identified, such as long- term monitoring, tracking sources of pollution, and standardizing water quality assessment methodologies (Al Maliki et al., 2024; Al-Hily and Awadh, 2025; Mohsin et al., 2026).

The resulting evidence base is deliberately critical narrative synthesis and should not be interpreted as exhaustive. We did not apply a preregistered protocol, an exhaustive database search, duplicate screening, a PRISMA[2] flow diagram, or a formal risk-of-bias tool. Instead, we cross-checked bibliographic details and retained study-level claims against publisher or journal records and accessible article text. Claims that could not be traced to the cited source were either narrowed or removed. Interpretive weight was judged qualitatively. We considered sampling breadth, temporal replication, analyte coverage, transparency of water-quality benchmarks, the strength of source-attribution methods, and agreement between the reported data and the causal

[1] Digital Object Identifier (DOI)

[2] Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA)

interpretation. No numerical quality score was assigned. This approach was used to compare findings, expose contradictions, assess transferability, and distinguish recurring cross-study patterns from conclusions that remain local or weakly supported.

4. Regional hydrogeochemical controls and groundwater quality patterns

4.1. Lithostratigraphic and hydrogeological framework

Regional variation in groundwater chemistry in Iraq is not related to geographic location alone; rather, it directly reflects differences in the stratigraphic sequence, nature of the rocks, type of aquifer; structure and hydraulic conditions. Therefore, it must distinguish among the carbonate aquifers, clastic aquifers, evaporite formations, and Quaternary deposits when interpretation the salinity and ionic composition of groundwater (Jassim and Goff, 2006; Al-Jiburi and Al-Basrawi, 2012). This is clearly evident in the low folded zone, the Injana and Quaternary deposits represents the most important water- bearing unites, whereas Fatha Formations in the acts mainly as an important area hydrological control due to it evaporate layers west of the Tigris River, while Bai Hassan and Mukdadiya formations represent a primary aquifers over large parts east of Tigris rivers, beside the Injana and Quaternary deposits formations. The chemical and hydraulic characteristics of these aquifers are related with its stratigraphic, rocky, and structural nature, and its recharge and drainage condition (Al-Jiburi and Al-Basrawi, 2012).

The Fatha Formation is one of the most important units in explaining the high sulfate and mineralization levels in parts of Iraqi groundwater. Dating back to the Middle Miocene, the formation is characterized by periodic sequences of claystone, marl, limestone, gypsum, and anhydrite, with halite present in some sections. It therefore represents a potential geological source of calcium, sulfate, sodium, and chloride ions during water-rock interaction and dissolution (Al-Juboury and McCann, 2008). Field studies in Iraq have shown that this influence is not merely a stratigraphic assumption. In the Wana area northwest of Mosul, Ca–SO_4 was the dominant hydrochemical pattern, and analyses demonstrated that the dissolution of gypsum and carbonate rocks was a major factor controlling water chemistry, groundwater was influenced by Fatha formation as compared with groundwater associated with Quaternary deposits (Alaarajy et al., 2023).

The influence of the Fatha Formation is also evident in some aquifers that draw water from other formations. In the unconfined Injana aquifer in Ameriyah al-Fallujah, calcium was the major cation, while sulfate was the dominant anion. The study linked the elevated SO_4^{2-} levels to the presence of gypsum and anhydrite layers within the underlying Fatha Formation. The waters in the study showed high mineralization and a predominance of chloride-sulfate patterns, providing a direct example of the importance of the stratigraphic and hydraulic relationships between formations in interpreting water chemistry (Alnoory and Al-Kubaisi, 2022).

Geological control is not limited to evaporite formations. In the high-fold zone of northern and northeastern Iraq, there are two main groups of carbonate reservoirs: the first includes the Qamchuqa, Dokan, and Kometan reservoirs within the Bekhme karst group, and the second includes the Sinjar, Khurmala, and Avanah reservoirs within the Pila Spi fractured karst group. Groundwater in large parts of these reservoirs is characterized by relatively low salinity and a predominance of Ca (Mg)–HCO_3, while salinity and chemical composition change in the presence of the evaporite sequences of the Fatha Formation and its gypsum, anhydrite, and halite content (Jassim and Goff, 2006; Al-Basrawi and Al-Jiburi, 2014).

In the alluvial plain, Quaternary deposits form a complex reservoir system of clay, silt, sand, and gravel sequences. Fine-grained sediments generally act as low-permeability layers, while sand and gravel constitute the main water-bearing units. The rapid horizontal and vertical changes in these sediments, along with varying degrees of contact with surface water and adjacent formations, lead to significant differences in hydraulic and quality conditions. Salinity generally increases towards drainage areas, while water quality can improve locally near rivers and irrigation canals where they receive less saline water (Al-Jiburi and Al-Basrawi, 2011).

Thus, the spatial distribution of salinity, sulfates, bicarbonates, and chlorides in Iraqi groundwater cannot be explained in isolation from the aquifer-bearing geological formation, its relationship to adjacent formations, and the flow direction between recharge and drainage zones. Therefore, this stratigraphic and hydrogeological framework is used as a basis for interpreting the subsequent regional comparisons.

4.2. Hydrogeochemical controls and salinity evolution

Regional studies are not subject to a simple geographical rule. In southern Iraq, Al Maliki et al. (2024) linked mineralization to evaporation, the interaction of water with rocks, mineral dissolution/precipitation, and ion exchange. The chemical composition of the groundwater in Wana, northwest of Mosul, is formed differently, influenced by the dissolved and weathered gypsum and carbonates, while nitrates carry a lower agricultural signature (Alaarajy et al., 2023). The study by Ismail et al. (2023) demonstrated that Tikrit adds another layer of diversity, where evaporation and geochemical exchange exert a strong influence. The great value of these studies

lies not merely in their evidence of north-south gradients, but in their geological interpretation of aquifers and their recharge.

Even so, it is difficult to definitively differentiate between geological and human impacts based solely on measured concentrations, as this requires spatial evidence and the availability of source tracing methods.

Salinity is the recurring problem, but the literature does not point to one recurring cause. Elevated Electrical Conductivity[1] and Total Dissolved Solids[2], brackish-to-saline water, and salinity-related use restrictions appear across central, southern, and semi-arid settings. The pattern is evident in earlier and mid-period case studies (Awad et al., 2022; Alatar et al., 2023; Ismail et al., 2023; Al-Sudani, 2024; Al-Qurnawy et al., 2024; Al Maliki et al., 2024; Hussain et al., 2024). It remains visible in more recent work (Al-Kubaisi et al., 2025; Mohsin et al., 2026; Alameer et al., 2026). What changes from aquifer to aquifer is the mechanism. Studies variously implicate evaporation, mineral dissolution, water-rock interaction, saline or sabkha-related inputs, recharge conditions, and local agricultural or urban pressures. Repeated reports of salinity therefore describe a common outcome, not necessarily a common source. The source still has to be resolved at the site or aquifer scale.

Additional regional studies confirm that the difference in salinity and ionic composition in groundwater not linked to a single pattern or a unified source, rather it affected by the overlap of geological and hydrogeological processes; and he human activities according to the nature of each reservoir. Studies in western Iraq shows that the hydrochemical properties differ among recovers due to differences in geological differences, mineral dissolution processes, recharge condition, and groundwater movement, which lead to a clear difference mineralization levels and water suitability between different reservoirs (Mukhlif et al., 2021; Al Maliki et al., 2024). Also, other studies which using the hydrochemical analyses and environmental isotopes in the middle regions of Iraq, shows that sources of salinity may be multiple and include dissolution of natural salts, the interaction between water and rocks, in addition to local human activities, so increasing of salinity or TDS values only not enough to determine the source of the deterioration without analyze the hydrogeological context of reservoir (Alhalbaasi et al., 2022; Al Maliki et al., 2024).

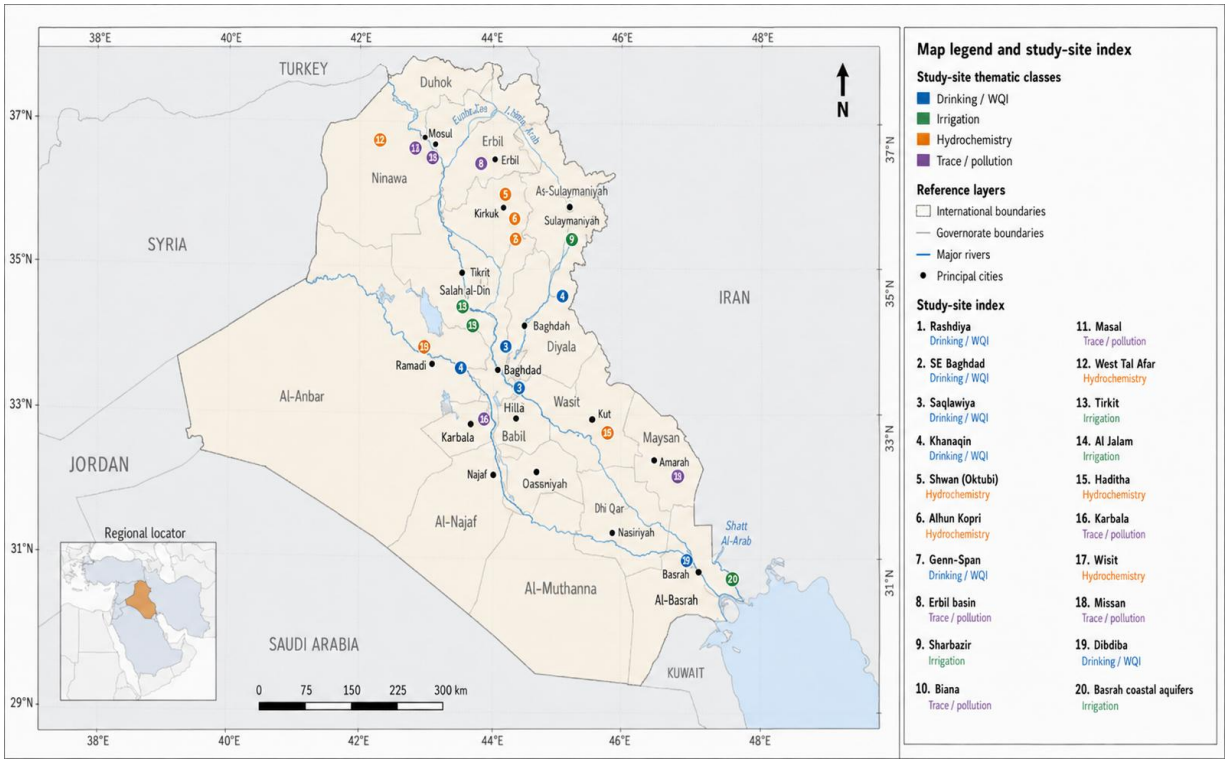
The following two studies brought two new sets of data that added dimensions that many previous snapshots lacked. In the study by Abdulameer and Al-Qurnawi (2025), 264 samples distributed over the period from 2000 to 2024 from the groundwater aquifer of the Dibdiba aquifer were examined, where they concluded that the WQI had deteriorated significantly over time, especially in the recent period, due to high concentrations of sulfates, chlorides, magnesium, sodium, and TDS. In Karbala, Alameer et al. (2026) present the hydrogeological characteristics of the groundwater in more details through the combination between each of major ion's analysis, stable isotopes, and radon-222. The results show a clear increase in concentration for each of calcium, magnesium, sulfates, and chlorides, beside a high nitrate concentration recording in some sites. Together, these two studies support the need for analytical separation between large-scale salinization and localized contaminant cross-linking, even when both occur within the same groundwater system.

This is where the chemistry of major ions comes in to help understand these differences, as hydrochemical evolution plays a role in the varying balance between calcium (Ca^{2+}), sodium (Na^{+}), magnesium (Mg^{2+}), potassium (K^{+}), sulfate (SO_4^{2-}), bicarbonate (HCO_3^{-}), chloride (Cl^{-}), and nitrate (NO_3^{-}) ions, as indicated by most Iraqi studies. The signatures of calcium, magnesium, and bicarbonate ions can result from the dissolution of carbonates, while the dissolution of evaporites and the mixing of saltwater can lead to elevated levels of sulfate, sodium, and chloride. Agricultural environments can add an additional factor, as salts can move between soil, irrigation water and groundwater under conditions of prolonged irrigation, excessive evaporation or inadequate drainage. Therefore, the reuse of this saline groundwater leads to increased osmotic stress and damage to soil structure, and gradually reduces the range of crops that remain economically viable.

Water quality may differ in two wells with similar values of sodium, sulfate, nitrate, trace elements, hardness, or precipitation potential, but they may differ in TDS. Therefore, TDS is a useful indicator of mineralization but cannot provide a complete diagnosis of groundwater quality. Therefore, a useful interpretation combines the total salinity signal with the ionic composition and then applies appropriate criteria for the intended use. Factors such as EC, sodium-related indicators, and the balance between major ions are particularly important in irrigation assessment. But the matter is different when evaluating drinking water, as chemical pollutants and toxic trace elements must also be taken into account, not just the taste. The locations of the reviewed study areas are shown in Fig. 1, and the confirmed contribution of representative studies focusing on Iraq is summarized in Table 2.

[1] Electrical Conductivity (EC)

[2] Total Dissolved Solids (TDS)



Note: The study area locations were roughly mapped from the reviewed literature.

Fig. 1. A map of Iraq showing the boundaries of the governorates, major rivers, key cities, and the geographical distribution of the representative groundwater study areas included in this study

Table 2. Representative Iraq-focused groundwater studies included in the expanded review

Verified contribution to this review	Study area / design	Study
Drinking WQI ranged from very poor to excellent; evaporation, rock-soil interaction, land use, and agricultural activity were identified as controls.	Rashdiya, central Iraq	Beg et al. (2021)
Show the differences of characteristics and hydrochemical types among reservoirs, water salinity was linked with to the washing and dissolution of minerals and mixing of water sources. Aso the difference of water suitability between reservoirs and according to different uses	Western Iraq; 64 groundwater samples from 7 regional reservoirs.	Mukhlif et al. (2021)
The water ranged within the semi-saline category, sodium was the predominate cation sulfate the predominate anion, WQI show a different between wells, while samples were suitable for agriculture uses according to standards	Abu-Jir, Al-Anbar; 15 groundwater samples	Al-Dulaimi and Al-Kubaisi (2022)
Hydrochemistry and environmental isotopes were merged to determine the salinity origin, and shows exiting more than one source for salinity including natural melting for salt compounds beside human activities like waste water and industrial water mixing.	Baghdad City; 15 samples during wet and dry seasons, 2021	Alhalbaasi et al. (2022)
Hydrochemistry results showed Ca dominance sulfate rich in groundwater; elevated SO4 anion was linked to each of gypsum and anhydrite in the underlying Fatha formation, demonstrating control on the chemistry of Injana aquifer.	Amirat AlFalluja, Injana unconfined aquifer; 15 well samples, during wet and dry seasons	Alnoory and Al-Kubaisi (2022)
Irrigation-focused hydrochemistry and multiple indices; pronounced EC/TDS and salinity hazards with mixed index classifications.	Greenbelt, northwestern Al-Najaf; 5 wells	Awad et al. (2022)

Cont. Table 2. Representative Iraq-focused groundwater studies included in the expanded review

Verified contribution to this review	Study area / design	Study
Spatial and temporal analysis showed inconsistent quality, with clear quality decline in 2017. Also, GIS and geostatistical techniques were used the reveal the spatial WQI variation and link the decline with impact of untreated domestic and industrial wastewater	Erbil City; 61 well, wet and dry season, 2015-2017	Ababakr et al. (2023)
Gypsum/carbonate dissolution and weathering dominated chemistry; PCA indicated an agricultural effect on nitrate.	Wana, northwest of Mosul; 18 wells, two seasons	Alaarajy et al. (2023)
Evaporation was the primary hydrochemical control; sampled groundwater was reported generally unsuitable for drinking and irrigation.	Al Jallam Desert, Salah Al-Din; 9 samples	Alatar et al. (2023)
Hydrogeochemical processes and drinking WQI; most groundwater samples were poor to very poor for drinking.	Shwan sub-basin, Kirkuk; 32 groundwater samples plus one river sample, two seasons	Al-Gburi et al. (2023)
The study showed changes between the two recharge periods; most samples were having a resh and moderate salinity water and suitable for drinking purposes according to the used criteria except one ell with high nitrate; also, these samples generally were suitable for irrigation with some restricts limited number of samples.	Erbil, Pirmam; 62 groundwater sample during two recharge periods of October 2021 and may 2022	Esmael and Seeyan (2023)
Major, minor, and trace-element assessment; wastewater pathways were linked to groundwater pollution.	Erbil central sub-basin; 27 groundwater + 3 wastewater samples, two seasons	Hamed et al. (2023)
Evaporation-dominated hydrochemistry; medium-to-bad drinking classification and strong irrigation-salinity constraints.	Tikrit, Salah Al-Din; 27 shallow wells	Ismail et al. (2023)
Reported all sampled wells suitable for drinking and irrigation under the adopted criteria and suitable for most evaluated industrial uses.	Sharbazir, Sulaymaniyah; 11 wells, two seasons	Muhammed and Mail (2023)
Hydrochemical facies, brackish/high-salt character, and calculation of drinking/irrigation quality indices.	Southern Haditha; 18 samples	Al-Dulaimi and Al-Shamma'a (2023)
Groundwater-level dynamics and monitoring limitations; used here as hydrologic/monitoring context, not as groundwater-chemistry evidence.	Iraq; 517 observation wells plus GRACE[1] and ancillary data	Alattar (2024)
Major-ion source apportionment, agricultural nitrate signal, petroleum-brine influence in selected wells, and spatially variable drinking WQI.	Missan Governorate; 44 groundwater samples	Al-Gburi et al. (2024)
Major ions plus stable isotopes; evaporation and geochemical processes-controlled salinity; most samples unsuitable for drinking, while a substantial proportion met irrigation criteria with salinity management.	Southern Iraq; wells and springs	Al Maliki et al. (2024)
Drinking and irrigation assessment with GIS; strong TDS/salinity limitations and marked spatial variability.	South of Basrah; 12 groundwater samples	Al-Qurnawy et al. (2024)
Brackish-to-saline groundwater with spatial salinity decrease associated with surface-water recharge in parts of the study area.	Wasit Governorate; 40 inventoried wells	Al-Sudani (2024)
Groundwater-quality and multivariate assessment; supports the synthesis of high mineralization and hydrochemical variability in Karbala.	Karbala region; 50 wells	Hussain et al. (2024)
Nitrate exceeded the cited WHO limit in about 25.9% of samples; source indicators implicated fertilizer and septic/wastewater inputs; health-risk assessment showed greater risk for infants and children.	Erbil-Bnaslawa; 27 wells, wet and dry seasons	Tawfeeq et al. (2024)

[1] Gravity Recovery and Climate Experiment (GRACE)

Cont. Table 2. Representative Iraq-focused groundwater studies included in the expanded review

Study	Study area / design	Verified contribution to this review
Abdulameer and Al-Qurnawi (2025)	Dibdiba aquifer, Zubair-Safwan; 264 samples spanning 2000-2024	Long-term WQI assessment documented progressive deterioration and strong spatial heterogeneity, with recent-period degradation linked mainly to sulfate, chloride, Mg, Na, and TDS.
Abdullah and Awadh (2025)	Al-Qarma, west of Baghdad; 20 shallows well, 2024	Shows the most samples were violated the water drinking standard for TDS, EC, hardness, Cl, So_4, while irrigation suitability varied because of salinity. Also, the hydrochemical diagrams showed dominance Na-CL and Ca-Mg-So_4; and influences of gypsum and halite melting; evaporation; and aquiculture activity.
Akbar and Al-Shamma'a (2025)	Altun Kopri Basin, Northeastern Iraq; hydrochemistry evaluation, WQI and HPI[1]	The study showed that the water was poorly mineralized, and WQI classified good to excellent, also trace elements indices pointed to a suitable level according to chemical criteria used, with recommendation to perform a biological evaluation before the final decision about drinking suitability.
Al-Hily and Awadh (2025)	Southeastern Baghdad; 15 shallow wells	Only 3 wells met all cited WHO criteria although most WQI scores were excellent-to-good; irrigation indices indicated low sodium hazard. Demonstrates that composite WQI can mask parameter-specific exceedances.
Al-Kubaisi et al. (2025)	Saqlawiya, Anbar	Multiple hydro-geoenvironmental indicators classified groundwater as unsuitable for drinking and moderately-to-severely restricted for irrigation; Cd and Pb were the trace-element exceptions to otherwise acceptable reported levels.
Alameer et al. (2026)	Karbala; 17 groundwater/associated-water samples	Integrated major ions, stable isotopes, ^{222}Rn, and suitability assessment; documented strong mineralization and sulfate-chloride-rich hydrochemistry with localized nitrate enrichment.
Al-Gburi and Alkhafaji (2026)	Erbil, Goma-Span watershed, 47 well to measure the water level and 34 sample for hydrochemistry analysis	The study showed a general suitability for drinking and irrigation a according to indicators used, with a primary role for geological factors and a secondary agriculture impact. Also, WQI, PIG[2], and HPI showed a good level, despite recording high values for TDS, hardness, and bicarbonates in some wells.
Altahaan and Dobslaw (2026)	Mosul; 8 shallow/deep wells across four campaigns in 2022-2023	Localized post-conflict evidence of seasonal and annual variability in Cd, Pb, Cr, Ni, and Zn; shallow conflict-zone wells were more vulnerable than deeper wells.
Khadim et al. (2026)	Khanaqin, Diyala; 24 boreholes	DWQI[3] classified 84% as good/excellent and irrigation indices classified 79.42% as highly suitable, while spatial analysis still indicated localized population-related pressure.
Mohsin et al. (2026)	West Tal Afar; 21 groundwater samples	EWQI classified 85.7% of wells as extremely poor for drinking; irrigation was mostly unsuitable to severely restricted; PCA separated evaporite-related salinity from agricultural/nitrate influence.

[1] Heavy Metal Pollution Index (HPI)
[2] Pollution Index of Groundwater (PIG)
[3] Drinking Water Quality Index (DWQI)

5. Anthropogenic contamination and emerging pollution risks

5.1. Agricultural inputs and nitrate

The chemical composition of groundwater is influenced by human factors to varying degrees from place to place, with results indicating that nitrate and potassium levels are affected by fertilizer inputs (Alaarajy et al., 2023). Parts of Maysan showed a similar pattern associated with agriculture fertilizers use (Al-Gburi et al., 2024).

The interpretation of nitrate sources in groundwater is cannot based on concentration data alone, rather, it

needs integration the chemical data with land use, hydrogeological characteristics, and statistical analyses. Studies showed that increasing nitrate may be related to agriculture activity and using fertilizers, but determining the final source require distinguishing between agriculture effects, sewage leak, and possible natural resources (Alaarajy et al., 2023; Al-Gburi et al., 2024). It could be getting more convincing interpretation about the nitrate sources when the concentration data is read along with land use patterns and statistical results. Alaarajy et al. (2023) noted in this context that the Principal Component Analysis[1] in the Wana area unveil a clear link between agricultural activity and the high concentrations for nitrate ion.

A study by Al-Gburi et al. (2024) in Maysan Governorate demonstrated a correlation between potassium (K^+) and nitrate (NO_3^-) levels and agricultural fertilizer inputs. It also revealed a decline in groundwater quality linked to elevated nitrate concentrations in a group of wells within the Ali Al-Gharbi agricultural area. Similarly, Tawfeeq et al. (2024) highlighted the health implications of this problem in the Bnaslawa area of Erbil, where approximately 25.9% of samples exceeded the permissible nitrate concentration limits according to World Health Organization[2] guidelines during both growing seasons. Health risk assessments showed that infants and children are more susceptible to non-cancer health risks than adults, while ion ratios indicated groundwater may be affected by leaks from agricultural fertilizers and septic tanks. PCA was also used in the West Tal Afar region to distinguish between human influences and geological factors, and the results showed that rising nitrate concentrations, in conjunction with increasing salinity, represents one of the main factors contributing to the deterioration of the suitability of groundwater for drinking purposes (Mohsin et al., 2026).

Despite important of these indices to identify the nitrate sources, the statistical relation between nitrate and land uses does not always proving direct transmission path of the pollutants. Therefore, enhancing the interpretation of the nitrate sources in Iraq require integrate the chemical analyses with stable isotopes, time monitoring, groundwater movement data, and pollutants transmission samples to achieve a more accurate identification of pollution sources and their transmission routes (Mohsin et al., 2026).

The reliability level of identifying sources nitrates is different according to methodology different that each study takes. The studies value are shows when it exceeds just concentration measurement to interpretation nitrate sources, also factors that controls Its existence and distribution. Each of multivariate analyses, land use relations, and diagnostic ionic ratios can be give a useful indicator about a possible nitrate source but still indirect evidence that cannot reach to unsurely level which is offers by the direct source tracking methods. This interpretation can be strong by using nitrate isotopes, repeated monitoring, trend data of groundwater flow, and also pollutant transport modeling. The combination for these tools helping in determining the pollution sources and travel routes with high precision, also can give a more reliable quantitative assessment. From here, the importance of discrimination between three level of Reasoning which it detecting the presence of nitrates and to prove its statistical correlation with potential sources then reach to more precise definition of source mechanism and pathway of nitrate transfer to groundwater. The future studies about the nitrate pollution in Iraq should be links the chemical evidence with potential exposure pathways instead of just concentration comparison with standard limits. also, it's important to more clearly discriminations among the different nitrate sources, especially waste water seepage, agricultural inputs, and other human activities that can influence on groundwater quality.

5.2. Trace elements and industrial-urban pressures: evidence and limitations

Wells near oil production areas there also carried major ionic patterns associated with brine solutions from oil fields (Al-Gburi et al., 2024). In Erbil, Hamed et al. (2023) examined major, minor, and trace elements in a study of wastewater-related groundwater pollution.

The trace elements studies in groundwater have shown growing interest but with limited and unbalanced spatial covering in Iraq. For example, group of trace elements have been studied in Erbil by Hamed et al. (2023), but studies like this stay distributed in limited areas and did not providing a comprehensive geographic picture over country level. The trace elements assessments study was conducted in Al-Saqlawiya by Al-Kubaisi et al. (2025), the results exhibit the concentrations for each of nickel, copper, cobalt, and zinc stay within adopted guidelines, but lead and cadmium represented most worrying elements because their concentrations exceeded those guidelines.

Also, there was a seasonal variation in concentrations for each of cadmium, lead, chromium, nickel, and zinc belongs to shallow wells than deep wells in the Mosul conflict zone. According to this, the groundwater temporal and spatial pollution variation have been showed for these elements. Beside that there was a violation of standards for cadmium levels have been noted over most study area wells, and several minerals also violate its drinking standards in a number of shallow wells. However, this pattern cannot be found in all areas including Altun Kopri area, where the study of Akbar and Al-Shamma'a (2025) shows excellent to good

[1] Principal Component Analysis (PCA)
[2] World Health Organization (WHO)

groundwater quality using WQI and Heavy Metal Pollution Index. Currently available evidence does not refer to wide heavy metals contamination in the groundwater at a national level, however; limited spatial and temporal coverage prevent reaching a comprehensive final conclusion.

Current evidence refers to that trace element contamination in Iraqi groundwater appears to be linked to specific locations and local conditions, rather than a nationwide phenomenon. Interpretation of these elements depending on the aquifer nature, wells depth, potential sources of pollution, and industrial or surrounding urban activities, which confirms needing to standard monitoring programs consisting the same elements group and a unified analyses methods across different regions (Hamed et al., 2023; Al-Kubaisi et al., 2025; Altahaan and Dobslaw, 2026).

There is a disparity spatial and temporal coverage to studies relating to trace elements in Iraq despite its availability in only a few areas, it is therefore unbalanced. This making a clear gap in understanding how trace element pollution is distributed and its variations between different regions and over time. Studies that differ in measured items and diverse analysis approaches used, it makes it difficult to making direct and reliable comparisons between their results. So, in order to understand the deep aquifers behavior which, have different storage and geochemical characteristics, and distinguish from the most vulnerable shallow aquifers especially in area with conflict-affected and industrial activities, more standardized monitoring programs are needed. This includes adopted a standing group of trace elements and a quality monitoring consistent preforms, in which allows results comparison with more assurance for different sites and over time.

5.3. Microbiological contamination: an underdeveloped evidence base

It is difficult to evaluate the microbiological safety of groundwater regardless of the surrounding sanitation conditions, especially in shallow aquifers which the more waste water seepage in it, and area which have a waste water infrastructure weak or a limited. However, Iraqi studies that were reviewed shows microbiological indicators with less frequently investigated and less regularity as comparison with salinity and hydrochemical variables indicators which are measured routinely. So, the accessibility to a reliable national picture about extent of the spread of pathogens in groundwater is limited by this gap. Therefore, its useful future studies to combining the microbiological indicators with chemical analyses within a uniform assessing framework, especially in rural and semi-urban areas where the population relies heavily on untreated groundwater.

The limitation in microbiological data represents one of important gaps in assessing groundwater quality in Iraq, as most available studies focuses on the chemical indicators like salinity, major ions, and trace elements, while information related to microbial risks are limited, therefore, future studies must integrate the microbiological analyses with chemical and hydrogeological indices to obtain a more comprehensive assessment of groundwater safety, especially for shallow aquifers and areas with limited sanitation services.

6. Groundwater suitability for different uses

6.1. Drinking and domestic use

After identifying the natural and human factors affecting groundwater quality, assessing the suitability of water for drinking requires integrate the chemical composition with approved health standards and not relying only on single index. Iraqi studies clarify existing a clear spatial variation for suitability of groundwater for drinking, whereas results between aquifers and regions differ according to hydrogeological characteristics, salinity levels, concentrations of nitrates and trace elements, and the criteria used in evaluations (Al-Gburi et al., 2023; Al-Hily and Awadh, 2025; Mohsin et al., 2026).

The studies of (Al-Gburi et al., 2023; Ismail et al., 2023; Muhammed and Mail, 2023) indicated absent obvious uniform pattern which can generalization over country, and there is a clear drinking groundwater quality spatial contrast. This variety did not reduce by the studies published in 2025–2026, in fact, she confirmed the obvious groundwater quality spatial differences continuity Between the regions of Iraq. Whereas in Shwan area, the well groundwater was classified as poor and very poor, while in Tikrit within moderate to poor, but in Sharbazir area have a relatively good quality. In another area, Altun Kopri, the groundwater classified within acceptable level according to Index of Heavy Metal Pollution, and showed excellent to good quality using the index of water quality (Akbar and Al-Shamma'a, 2025).

Studies from central and western Iraq provide a further examples spatial variation of the groundwater suitability. For instance, in Abu Jir area of Anbar, 15 samples showed that the water is generally belong to semi-saline water category, with demonstrate sodium within cations and sulfates within anions, also WQI shows a difference among wells since most of them within acceptable classifiers according index used, while several wells were unsuitable, also. Also, the samples were classified as suitable for agriculture purposes according to study criteria (Al-Dulaimi and Al-Kubaisi, 2022).

In the Karma district, west of Baghdad, analysis results of 20 shallow well showed that most samples exceed the drinking water standards with regard to dissolved solids, EC, hardness, chloride, and sulfates.

While the suitability of irrigation ranged between good and unsuitable because of high risk of salinity despite relatively low risk of sodium. Also, hydrochemical diagrams shows demonstrate two patterns of Ca-Mg-So_4 and Na-Cl, and the study linked this composition with the processes of gypsum and halite; evaporation; and interaction between rocks and water, in addition to agriculture impact (Abdullah and Awadh, 2025). These findings support the need to avoid generalization the classification of single region to the entire western or central Iraq, because the water suitability may be differ clearly between reservoirs and locations even within the same geographic region.

In the Goma-Span area, Al-Gburi and Alkhafaji (2026) reported that the groundwater that was studied had excellent to good ratings for the WQI and low values for the pollution index.

In contrast, the groundwater in the Saqlawiya area was classified as unfit for drinking (Al-Kubaisi et al., 2025), highlighting the heterogeneity of groundwater quality across different regions of Iraq. The entropy-weighted WQI results for the West Tal Afar region showed that approximately 85.7% of wells fall into the "extremely poor" category (Mohsin et al., 2026). In the Khanaqin region, the situation was different, with a more favorable pattern observed, where 84% of wells were classified as "good" or "excellent" according to the drinking WQI (Khadim et al., 2026).

A study of the Goma-Span basin also showed water quality ranging from "excellent" to "good" (Al-Gburi and Alkhafaji, 2026), reflecting the continued clear spatial variation in groundwater quality across Iraq. Adopting a unified national standard for assessing groundwater potability would help reduce the variability between different study results. However, in addition to studies that consider the specific hydrogeological and environmental conditions of each region, the available evidence suggests that an interpretation based on the characteristics of each aquifer remains the most suitable approach for obtaining more accurate and applicable assessments.

The southeast Baghdad study showed meeting the WHO criteria for just 3 of 15 wells, while the other was exceeded these criteria for some indicators especially the total dissolve solids, sodium and sulfates. So, the groundwater seems to be acceptable according to a composite index while some components exceed its standards, so the judging the suitability of water different according to the indicator or standard used. This result confirms important the not being satisfied with the WQI overall assessment, rather, reading it alongside the individual values of the basic standards. Reducing the palatability and increased likelihood of deposit and scale formation in groundwater relate to high each of total dissolve solids and hardness. While exceeding standards for nitrates or toxic trace elements require a more details assessment of possible risks. The benefit of WQI come from introduce a simple general picture about water state over many variables, but although, it cannot be enough unless variable test individually and insuring stay within standards, it is also necessary preform an independent assessment of health risks. So, when a groundwater suitability assessment, it must be clarifying the foundations and criteria upon which the classification is based, with an explicitly specify the approved standard reference and statement of the percentage of samples that exceeded the permissible limits for each variable. This in turn making the evaluation results are more transparent and accurate, and reduces the likelihood of misinterpretation of general classifications.

Different studies use different criteria to evaluate the groundwater quality, some of them use WHO standard, while other adopted the national standards or water quality indicators that were developed for specific purposes. This discrepancy limits the possibility preforming a direct reliable comparison among classifies resulting different studies. In order to enhance the clarity and comparability of the results, studies must accurately define the approved reference framework with a statement of its issuance, the approved limit values for each standard, and the limits of analytical disclosure, in addition to determining the percentage of samples that exceed the permissible limits. Documenting these details is essential to ensure the consistency of the evaluation process and to enhance the reliability of spatial comparisons between studies; their absence may weaken the accuracy of the comparison and increase the likelihood of misinterpreting spatial differences.

The reliability of drinking water suitability evaluation, in addition to different in the adopted criteria and indices, is affected by uncertainty linking to laboratory measurement and decision-making method about matching the results to the permissible limits. In this context, Bagheban et al. (2025) study explained that applying the decision-making rules based to uncertainty for measurement may affects the judgment of conformity for drinking water quality indicators, like nitrate; turbidity; and pH. The importance of this result is highlighted by groundwater quality when concentrations of some pollutants close to standard limits, the depending on the measurement value only, without taking into account the uncertainty and verifying the quality on the analysis, may resulting inaccurate classification of water suitability. Therefore, enhancing reliability of Iraqi studies requires documentation the analysis methods; limits of disclosure; and uncertainty of measuring, in addition to identifying the criteria used in the classification.

6.2. Suitability for agricultural irrigation

The requirements of water quality which used for irrigation differ from the water drinking requirements,

agriculture suitability depends on interaction of water quality with soil properties, crop yield type, irrigation system, and drainage conditions. Therefore, the classification of groundwater for irrigation cannot interpreted as regard to only salinity or one index, but must integrate sodium indices and salinity with local agriculture condition (Awad et al., 2022; Khondoker et al., 2023).

The irrigation literature is no more uniform than the drinking-water evidence. Strong salinity constraints were reported in the Greenbelt, Al Jallam, Tikrit, and southern Basrah (Awad et al., 2022; Alatar et al., 2023; Ismail et al., 2023; Al-Qurnawy et al., 2024).

Sharbazir and a substantial fraction of the southern-Iraq samples assessed by Al Maliki et al. (2024) were more favorable under the criteria applied (Muhammed and Mail, 2023). Recent studies preserve the same spread. All 15 southeastern-Baghdad samples had low sodium hazard and acceptable irrigation indices despite drinking-water exceedances (Al-Hily and Awadh, 2025). Saqlawiya ranged from moderately to severely restricted for irrigation (Al-Kubaisi et al., 2025), while West Tal Afar was mostly unsuitable to severely restricted (Mohsin et al., 2026).

Khanaqin was much more favorable: Khadim et al. (2026) classified 79.42% of wells as highly suitable using multiple irrigation indices. Favorable classifications were also reported for Goma-Span (Al-Gburi and Alkhafaji, 2026). The practical outcome is at the local, not the national, level; therefore, irrigation decisions must be made at the site and crop level.

These classifications represent only part of the agricultural issue. Water unsuitable for irrigating a salt-sensitive crop may still be usable for a more salt-tolerant crop, provided that drainage, leaching, and soil management are adequate. Conversely, the repeated use of marginal-quality groundwater without effective drainage can accelerate secondary salinization. Larger studies on salinity and irrigation underscore this point, showing that water quality categories are more useful when interpreted in conjunction with crop tolerance, irrigation technique, soil texture, and drainage, rather than as a universal threshold (Khondoker et al., 2023).

Studies often fail to follow up on the relationship between water chemistry and field response. Groundwater suitability evaluation in most Iraqi studies preforms based on sample sites chemical properties without taking into account important agricultural factors, like soil salinity, crop productivity, trace element uptake, as well as the long-term cumulative effects of repeated irrigation.

This limits the comprehensiveness of assessing water suitability for irrigation, as water properties are not linked to soil and crop conditions and the effects of continuous use. So, future studies must link the chemical classifications with actual agriculture results through long field studies. This approach would provide a more reliable basis for managerial decision-making, compared to relying on a single indicator or a limited, immediate assessment.

6.3. Engineering and industrial applications

The Iraqi groundwater suitability assessment studies for industrial purposes still limited. One of the studies evaluated the well water for some industrial activities except the paper industry Muhammed and Mail (2023), while other studies were limited to the industrial suitability indirect evaluations without preforming a specialized assessment for this purpose.

However, recent studies, such as Alameer et al. (2026) and Mohsin et al. (2026), have pointed to potential problems associated with high concentrations of TDS, water hardness, sulfates, and chlorides, and the resulting scaling, sedimentation and corrosion risk; and increased need for water pretreatment before use in some industrial applications.

These concerns are further supported by the high levels of mineralization recorded in Karbala and western Tal Afar. However, these studies did not provide a detailed assessment of the water's suitability for specific industrial processes.

Therefore, it is preferable to evaluate water suitability for industrial uses in light of the specific requirements of each industry or production process, rather than relying primarily on drinking water or irrigation standards.

Water requirements for engineering and industrial uses differ from the drinking or irrigation water requirements, the suitability depends on the nature of the industrial process itself and the properties of water affect corrosion, sedimentation, or operational efficiency. Therefore, depending on drinking-water or irrigation standards alone may not accurately reflect suitability of water for different industrial processes, this necessitates the development of specific assessments linked to the requirements of each industrial sector (Muhammed and Mail, 2023; Alameer et al., 2026).

This issue reveals a clear gap in current research, which can be addressed by moving beyond the application of drinking water or irrigation standards to industrial assessments, and focusing instead on qualitative standards related to the efficiency of industrial processes and the requirements of each use. Key criteria include hardness, alkalinity, silica, chloride, and sulfate content, along with indicators of water sedimentation and corrosion and scaling risk, and trace element concentrations.

Therefore, future water management studies, recommendations, and strategies should be tailored to the specific requirements of each industrial sector, as the water quality standards for oil operations may differ significantly from those required in other industries.

7. Analytical approaches and evidence limitations

7.1. Analytical and spatial tool used in Iraqi groundwater studies

Recent Iraqi groundwater studies are no longer limited to traditional hydrochemical surveys; instead, they increasingly apply integrated analytical approaches. More integrated approaches were adopted, employing a variety of analytical tools. These approaches include water quality indicators, rock formation analysis, and various statistics, Geographic Information Systems[1], isotopic analysis and statistical analysis, in addition to health risk assessment models and time data analysis. An example of this approach is the study of Tawfeeq et al. (2024) in the Bnslawa area of Erbil, which integrate an improved WQI, GIS, Diagnostic Ionic Ratios, and Assessment of Nitrate-Associated Health Risks. In another study by Abdulameer and Al-Qurnawi (2025), the change in the WQI over time was assessed using a 24-year dataset of groundwater from the Dibdibah aquifer.

In the study by Al-Hily and Awadh (2025), the composite WQI was compared with individual drinking water standards and irrigation indices. Also, in the study by Mohsin et al. (2026), the entropy-weighted WQI, the individual WQI, PCA and GIS were combined. Alameer et al. (2026) used stable isotopes and ^{222}Rn to evaluate hydrochemical properties and water usage in Karbala. The trend of change is clear, with an increasing proportion of published studies now seeking to provide a more comprehensive explanation by employing descriptive chemistry, which remains important.

These studies reflect transfer of Iraqi groundwater assessment from traditional chemical analyses towards using more integrated tools combine chemical indices, spatial analyses, statistical methods, and source tracking techniques. These tools offer greater ability to interpretate the spatial variation and identify influencing factors, however, the value of these results depends primarily on the quality of sampling design, number of wells, spatial distribution and accuracy of input data. Therefore, the development of analytical methods does not compensate for the lack of basic data or weak temporal and spatial coverage (Tawfeeq et al., 2024; Ababakr et al., 2023; Alameer et al., 2026).

Other studies from Kurdistan Iraq conform that groundwater quality does not remain fixed in space or time, even within the same zone of Erbil. In the Erbil-Pirmam area, 62 samples were analyzed during two different recharge periods in October 2021 and May 2022. The study showed that most of groundwater samples were fresh or moderately saline and suitable for drinking within approved standards, except one well that record a high nitrate concentration. Also, water was generally suitable for irrigation with some limited restricts for a small number of samples (Esmael and Seeyan, 2023).

A spatial and temporal analysis of 61 wells in Erbil during the period of 2015-2017 and both wet and dry seasons showed that the WQI changes over time and location. The study recorded a decline in water quality in 2017 compared to previous years. GIS techniques of Inverse Distance Weighting[2] and Kriging were used to represent the spatial variation; the study linked the part of decline in quality is due to the impact of untreated domestic and industrial wastewater (Ababakr et al., 2023). Studies in the Kurdistan Region demonstrate that groundwater quality assessment cannot rely on a single study or time period, even within the same geographic area. The Erbil–Pirmam study showed seasonal variations in hydrochemical properties, while the Erbil spatial and temporal study revealed that water quality varies depending on location and time period. This underscores the importance of integrating hydrochemical analysis with spatial tools such as GIS when interpreting spatial and temporal variations in groundwater quality (Esmael and Seeyan, 2023; Ababakr et al., 2023).

Another useful methodological model was proposed by Naz et al. (2024) in Pakistan, each of water quality and geostatistical analysis indices were combing in order to evaluate a wide range groundwater data. However, this study was not used as evidence of the groundwater condition in Iraq; it was cited only to illustrate the integration of the spatial and chemical indices for future groundwater assessment.

One of important methodological sides of developing a monitoring program of groundwater quality enhancing the trace element detection techniques, especially elements that represents a health risk when existing with low concentrations. In this context, Ghorbani and Mohammadi Isaabad (2024) develops a method for colorimetric detection of inorganic arsenic in water using BF2-Curcumin-based detector and silica nanosheets, with studied the pH and interchanging ions effects on the detection efficiency. This study explains possibility development a field-testing tool to support water quality monitoring programs, but uses for groundwater quality requires verifying the suitability of limits of disclosure; measurements accuracy; and effects of chemical composition of the samples, in addition to confirming the results by the adopted laboratory analyses. These applications represent a systematic approach may be needful in the future for Iraqi monitoring programs, it is not considered evidence of arsenic contamination in Iraqi groundwater.

[1] Geographic Information Systems (GIS)

[2] Inverse Distance Weighting (IDW)

7.2. Limitations of current assessment approaches

Neither PCA nor clustering analysis alone can identify the source of contamination or explain variability and clustering in pollutant concentrations. Therefore, methodological diversity is only useful when the boundaries of each method remain clearly defined. GIS is a useful tool for understanding spatial variation in groundwater quality. However, the accuracy of the patterns it reveals for understanding spatial variation in groundwater quality is directly related to the number of samples, their distribution, and the design of the field survey. Each of WQI and Entropy-Weighted Water Quality Index[1] provide a brief and easy-to-explain assessment for general state of groundwater, but the criteria choice affects each of results of the two indicators, the relative weights assigned to the variables, and the reference limits adopted in constructing the index. The importance of this distinction by the results of the study by Al-Hily and Awadh (2025) in southeast Baghdad are shown, where a general WQI showed satisfactory classification although failure to meet some individual drinking-water criteria. So, Clarity and transparency of the application methodology represent a basing to make reliable comparisons between studies, rather than focusing on the complexity or novelty of the methodology, which contributes to a sound interpretation of the results and an accurate understanding of the differences between them.

Despite the important of the water quality indices and statistical methods to simplifying complex data, the results interpretation must not depend on these tools individually. So, using a complex index like WQI may led to concealing violation of some important individual variables, also the statistical methods may not always prove the source of pollution without existing supported evidence like isotopes or groundwater movement data. Therefore, the most reliable rating requires integrate chemical indices and source tracking methods (Al-Hily and Awadh, 2025; Naz et al., 2024; Mohsin et al., 2026).

8. Critical synthesis: what can and cannot be generalized?

Most studies point to two main patterns which can be considered frequent at the regional level; first, there is a clear discrepancy in groundwater quality across Iraqi aquifers, with salinity and mineralization being the most common problems; second, the chemical composition nature of groundwater resulting from the natural and human processes, not a single factor. There are several processes which contribute to shaping the natural hydrochemical properties of groundwater, these are Processes of metal dissolution, water's reaction with rocks, and evaporation. on the other side, several varying changes may occur to these characteristics due to various human activities, including sewage leaks, agricultural runoff, oil activities, and the effects of conflict zones. All these indicators confirm the need to consider the nature of the use when assessing groundwater quality. Each of drinking, irrigation, engineering and industrial uses, have different standards and classifications and cannot mixing especially for drinking purposes. Although the composite indices importance in providing a comprehensive assessment of the water situation, but the actual assessment of risks or their suitability for the intended use requires referring to the individual values of the standards and determining the extent to which they exceed permissible limits.

A comparison of Iraqi studies reveals recurring patterns that may be considered regionally significant, such as the prevalence of salinity and mineralization problems and their correlation with evaporation, mineral dissolution, and the nature of the aquifer formations. However, the interpretation of these patterns must remain linked to the characteristics of each aquifer, as variations in stratigraphy, well depth, recharge conditions, and land use lead to significant differences in the mechanisms of water quality development across regions. Therefore, similar findings across several sites do not necessarily imply a unified cause at the national level (Al-Jiburi and Al-Basrawi, 2011, 2012; Al Maliki et al., 2024).

The geographical factors used in each study-namely, well depth, groundwater recharge rate, rock composition, and land use-represent analytical parameters that work together to influence the result; therefore, they cannot be considered in isolation. Recent studies conducted in 2025 and 2026 provided data indicating existing a clear spatial variation for groundwater quality, instate of a unified national pattern for water quality in Iraq. Recent studies showed a clear spatial variation for groundwater quality instead of unified national pattern.

Modern studies showed existing a clear spatial contrast in groundwater quality instead of unified national pattern. Some regions like Altun kopri and Khanaqin, showed a more suitable condition according to indices used in these studies, while regions like Saqlawiya and West Tal Afar showed greater restrictions on use. These differences reflect the properties of local aquifers, recharge condition, evaluation methods used, and do not represent a fixed national ranking of groundwater quality (Akbar and Al-Shamma'a, 2025; Khadim et al., 2026; Al-Kubaisi et al., 2025; Mohsin et al., 2026). However, similar results cannot be expected in other areas of Iraq due to local variations in the hydrogeological and hydrochemical characteristics of the groundwater. Southeast Baghdad provides a further example of this complexity, as the overall WQI classification does not always reflect the degree to which

[1] Entropy-Weighted Water Quality Index (EWQI)

all individual criteria adhere to acceptable limits. Therefore, the results of these studies remain more indicative of the reservoirs and areas that were examined, and should not be generalized to the rest of the aquifer systems in Iraq.

The available database on groundwater quality in Iraq remains limited in terms of diversity, with most studies focusing on a repetitive set of traditional variables, such as major ions, salinity, EC, TDS, and nitrates. Although recent studies in Saqlawiya and Mosul have shown increased interest in trace elements in recent years, the variation in measured elements and analytical methods still limits the possibility of national-level comparability. In contrast, published data remain far less available with regard to microbiological indicators, petroleum-associated organic compounds, pesticides, and emerging pollutants, as well as studies addressing repeated or long-term exposure.

Conversely, some findings cannot be generalized beyond the original study, particularly those related to local hazards such as trace elements, pollution from industrial activities, the effects of conflict, or specific nitrate sources. The generalizability of these findings depends on the number of samples, the time coverage, the source tracing method, and the homogeneity of data across studies. So, national-level groundwater quality assessments should be based on pooling evidence while respecting the specific characteristics of each hydrogeological system (Hamed et al., 2023; Al-Kubaisi et al., 2025; Altahaan and Dobslaw, 2026).

This deficiency can affect the overall national picture simply by giving greater weight to variables with larger datasets. Table 3 summarizes the strength and limitations of the evidence; Fig. 2 illustrates how the main controls, signals, and effects of use are conceptually related.

9. Research gaps and future priorities

9.1. Long-term monitoring and temporal data gaps

Time remains the most significant missing dimension in the Iraqi groundwater evidence base. A 24-year record of the Dibdiba aquifer was provided by Abdulameer and Al-Qurnawi (2025), but only two years of seasonal observations from Mosul were added in Altahaan and Dobslaw (2026). The limitations of time series data represent one of the biggest obstacles to understanding develop the groundwater quality in Iraq, most studies provide an image of the water condition during a specific period without ability to identify long-term trends. Therefore, establish a continuous monitoring network of selected wells represents a key step to distinguish between natural climate related changes and recharge and changes resulting from human activities (Abdulameer and Al-Qurnawi, 2025; Altahaan and Dobslaw, 2026). Most assessments still rely on short-term spatial surveys that show where conditions have changed, but do not provide sufficient information about their persistence. Therefore, to separate long-term geochemical behavior from incidental contamination and to track changes associated with drought, water extraction, irrigation, urbanization, and land-use change.

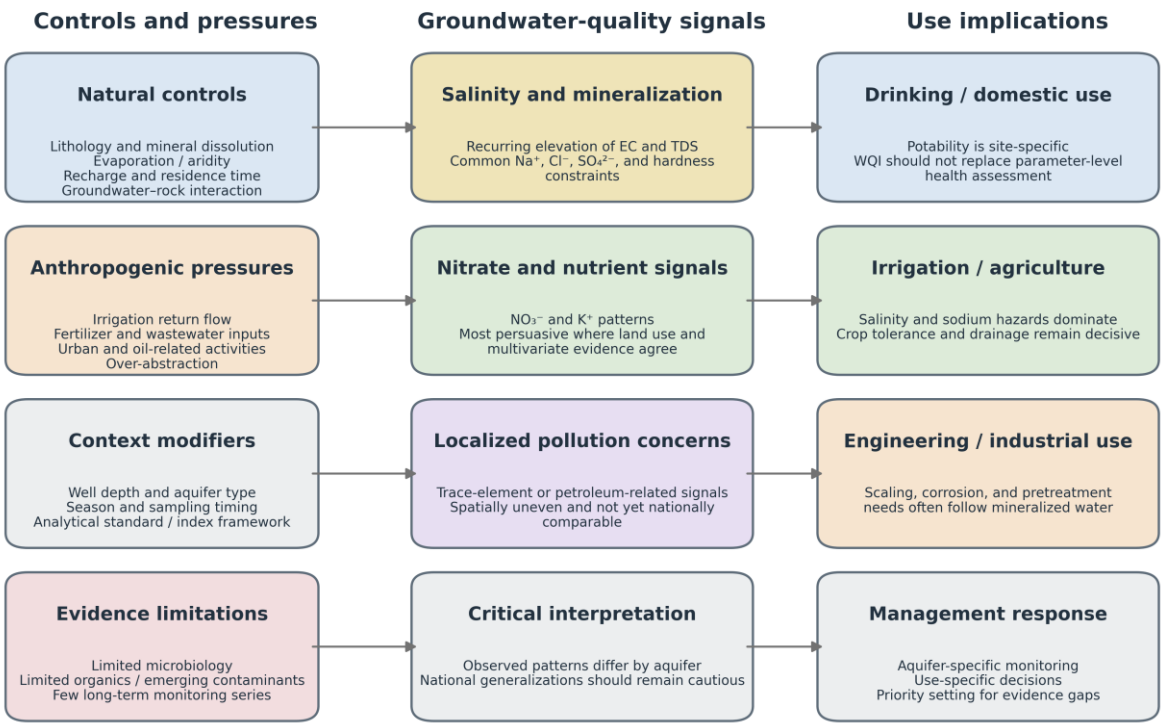
The important of the long-term monitoring for groundwater increasing when the changes in the water quality linking to the hydrological and climate changes that affect the aquifer. Doctorsafaei et al. (2026) have been develop a complex index to evaluate the groundwater drought for the Zayandeh Rud River Basin in Iran, based on the integrating a constant and dynamic indicators including aquifer properties; water level; rainfall recharge; and environmental conditions using geographic information system, the study based to data series extended from 2000 to 2020. Despite that the index is basically aims to evaluate the groundwater droughting, rather than a direct indicator of its chemical composition, so; it explains the importance of dealing with the aquifer as a system that changes spatially and temporally. For Iraqi state, this trend can be leveraged through linking between the records of the groundwater levels; recharge; and climate changes on the one hand, and the changes in the salinity; EC; and major ions from other hand, with the aim of promoting an understanding of water quality evolution and distinguishing between natural and human influences.

9.2. Surface – groundwater interaction and conceptual models

Groundwater is often studied in isolation from its associated surface water systems, in many parts of Iraq, canals, rivers, drainage networks, and aquifers are hydraulically or operationally interconnected. Studying each component separately makes it difficult to explain recharge, seepage, backflow, and saltwater intrusion. Understanding these processes is possible through the provision of a more realistic hydrogeological context resulting from integrated conceptual models of surface and groundwater (Al-Jiburi and Al-Basrawi, 2011; Alattar, 2024).

9.3. Source identification and pollution tracing

The relationship between statistical correlations and agricultural or industrial land use may be helpful, but it does not prove causation, as detecting groundwater signals is often easier than pinpointing their exact origin. Therefore, identifying the source of pollution presents a different challenge. For stronger inferences, it is advisable to combine these correlations with geochemical indicators, pollutant fingerprints, stable isotopes, groundwater levels, well construction information, or transport models. This is particularly useful for salinity, nitrates, petroleum-related inputs, and trace elements, where multiple potential sources may coexist (Al Maliki et al., 2024; Naz et al., 2024).



Note. The authors developed this conceptual framework based on the Iraq-focused literature compiled in this review.

Fig. 2. A conceptual framework that integrates key natural controls, human pressures, recurring groundwater quality indicators, and the main impacts of uses mentioned in the literature focusing on Iraq

Table 3. The evidence strength, limitations, and future priorities identified in iraq-focused groundwater studies

Theme	Evidence position	What is reasonably supported	Primary limitation
Salinity / mineralization	Strong, recurrent	Frequent EC/TDS and sulfate-chloride constraints across multiple aquifer settings; both geogenic and management-related mechanisms occur.	Sources differ by aquifer; salinity should not be assigned one national cause.
Nitrate	Moderate, localized	Agricultural and sanitation-related influences are supported in several studies; health-risk implications are documented in Erbil-Bnaslawa.	Few studies use isotopic source apportionment or long-term transport analysis.
Trace elements	Emerging, localized	Pb/Cd problems are reported in Saqlawiya and multi-metal seasonal problems in shallow post-conflict Mosul wells; other areas show favorable indices.	Uneven analyte panels, site coverage, temporal replication, and QA/QC[1] reporting.

[1] Quality Assurance/Quality Control (QA/QC)

Cont. Table 3. The evidence strength, limitations, and future priorities identified in iraq-focused groundwater studies

Theme	Evidence position	What is reasonably supported	Primary limitation
Microbiological quality	Weak / underrepresented	Potential vulnerability is plausible for shallow domestic wells and wastewater-affected settings.	Insufficient comparable Iraq-focused datasets in the reviewed evidence base.
Drinking suitability	Strong but index-sensitive	Large spatial contrast is consistently demonstrated; no single national potability class is defensible.	Different standards and WQI constructions can produce non-equivalent classifications.
Irrigation suitability	Strong but context-dependent	Salinity and sodium hazards vary greatly; both restricted and favorable aquifers are documented.	Chemical indices are rarely linked to long-term soil salinity, crop response, or drainage performance.
Engineering / industrial use	Limited	High mineralization has clear scaling/corrosion relevance; a few studies assess industrial categories directly.	Most studies do not use process-specific engineering criteria.

9.4. Data standardization and national groundwater database

Comparability is a more practical constraint, but it affects almost all analyses. A national baseline dataset might include field parameters, EC, TDS, major cations and anions, nitrates, some trace elements, and microbiological indicators. Additional hazards could include pesticides, oil-related pollutants, or other emerging concerns. Equally important are accompanying metadata. Information such as sampling date, aquifer unit, well depth, analytical method, detection limit, quality assurance/quality control procedures, accurate reference version, and the percentage of samples exceeding each threshold should be available in all studies. WQI studies also need to adhere to standards so that a positive composite result does not mask a critical factor. Therefore, for a meta-analysis or a truly systematic review in the future to be more feasible, standardization is essential.

9.5. Linking water quality with environmental and human responses

Many published studies are limited to chemical classification, without moving on to a deeper analysis that goes beyond this level. The next question to be raised regarding agriculture is what effect this has on soil salinity, crop response, and pollutant uptake. More evidence is needed on treatment effectiveness and exposure in studies related to domestic use. Industrial studies should consider the chemistry, sedimentation, corrosion, and water requirements of each process. Fig. 3 summarizes the major research gaps and future priorities identified in this review. Governance research has unanswered questions regarding pollution control measures, monitoring networks, and stakeholder coordination.

10. Management implications

The evidence argues against managing Iraqi groundwater under a single management criterion. At the aquifer scale, monitoring should establish the hydrochemical baseline and separate persistent geogenic mineralization from superimposed contamination. Wells used for drinking, irrigation, or industry require different decisions. Drinking-water assessment should consider parameter-specific health criteria alongside any composite WQI. Irrigation decisions need crop tolerance, soil condition, drainage, and water chemistry to be considered together. For engineering and industrial use, pretreatment and corrosion or scaling control should reflect the actual feed-water chemistry rather than a generic groundwater label.

Available evidence indicate that interactive management of groundwater in Iraq should be based on aquifer system boundaries rather than administration boundaries, because of the differences in geological formations, recharge conditions and flow direction led to clear differences in groundwater quality across regions. Therefore, monitoring programs must be design according to hydrogeological properties for each aquifer, with identifying the primary variables including salinity, major ions, nitrate, trace elements, and microbiological indicators when needed (Al-Jiburi and Al-Basrawi, 2011, 2012; Al Maliki et al., 2024).

Prevention is the necessary complement to monitoring. Once contamination reaches an aquifer, treatment is usually more difficult than controlling the source. Among the top priorities for mitigating

Theme	Current evidence strength	Spatial coverage	Future research priority	Interpretive note
Salinity / mineralization	Strong	Multi-province	Moderate	Recurring constraint, but source mix remains aquifer-specific.
Major-ion hydrochemistry	Strong	Multi-province	Moderate	Commonly reported and comparatively mature.
Drinking suitability / WQI	Good	Multi-province	Moderate	Useful, but index construction affects interpretation.
Irrigation suitability	Good	Multi-province	Moderate	Needs stronger links to crop and soil outcomes.
Nitrate and land-use linkage	Good	Local	High	Source attribution remains weaker than exceedance reporting.
Temporal monitoring	Moderate	Sparse	Very high	Only a few multi-year datasets are currently available.
Trace elements	Moderate	Local	Very high	Localized evidence; weak national comparability.
Microbiological indicators	Weak	Sparse	Very high	Under-represented despite public-health relevance.
Organic / emerging contaminants	Weak	Sparse	Very high	Major national gap in the present literature base.
Industrial process suitability	Weak	Sparse	High	Mostly inferred; process-specific datasets remain scarce.

Qualitative ratings developed by the authors from the critical synthesis of the Iraq-focused literature reviewed in this study.

Note. Ratings are interpretive categories assigned by the authors from the critical synthesis of the reviewed Iraq-focused literature and do not represent formal meta-analytic effect estimates.

Fig. 3. Evidence gaps and future research priorities identified from Iraq-focused groundwater studies

groundwater degradation are wastewater management, along with regulating industrial and irrigation discharges, protecting water resources, and improving fertilizer use management. GIS can help identify areas requiring more intensive monitoring or intervention, provided it is based on sufficient field data and is regularly updated to reflect changes in groundwater status and land use patterns. Also, reducing the deuteriation of groundwater require moving from focusing on the processing after pollution occurrence to controlling sources before arrival to aquifer. This consist enhance the waste water management, regulating the use of fertilizers, monitor the industrial activities, linking water quality data with spatial information to choosing region that needs for monitoring or larger intervention. However, the effectiveness of these tools depending on providing sufficient and continuously updated field data (Ababakr et al., 2023; Tawfeeq et al., 2024).

Although several forms of collaboration exist among universities, water authorities, environmental agencies, agricultural institutions, and local communities in collecting or using groundwater data for different purposes, weak institutional coordination continues to pose a significant practical challenge. This fragmentation negatively impacts and limits the possibility of data sharing, the standardization of monitoring methods, and the integration of findings within a comprehensive national groundwater management framework. The value of evidence increases when these datasets are linked. Alattar (2024) focused on groundwater levels and dynamics rather than its chemical composition, but this study highlights this point. Monitoring well data and satellite data can complement each other; however, inconsistent time-series monitoring limits the possible conclusions. To support better decision-making at the regional and national levels, as well as to reduce duplication of efforts and improve spatial and temporal coverage, a common framework for groundwater quantity and quality is recommended.

Development a national framework for groundwater management requires standardizing data collection methods, evaluation criteria, mechanisms for sharing information between different institutions, with maintaining the privacy of each hydrogeological system. This does not mean creating a unified classification for all aquifers, rather, develop a unified approach for data collection and analyses allows for accurate comparison while taking into account the natural differences between aquifers (Alattar, 2024; Al-Jiburi and Al-Basrawi, 2015).

11. Conclusion

Salinity and mineralization are among the most stable factors affecting the quality of vitally important Iraqi groundwater, resulting in significant variations in its quality, as demonstrated by published studies. The present review showed that groundwater quality in Iraq

affected by intersection group of natural and human factors, changes in water quality cannot be explained by only one factor. Also, salinity development and mineralization liking directly to nature of geological formations, aquifer properties, recharge conditions and groundwater movement. Therefore, water quality explanation must be depending on the hydrogeological framework for each aquifer instead of adopting a unified national classification for all regions (Al-Jiburi and Al-Basrawi, 2011, 2012; Al Maliki et al., 2024).

Elevated nitrate levels have also been observed in many agricultural areas and areas affected by wastewater. Recent studies in Saqlawiya (2025) and Mosul (2026) have documented localized trace-element contamination in shallow, vulnerable wells constructed after the conflict in Mosul with multiple metals. These cases are particularly significant because they are specific and do not indicate widespread heavy metal contamination throughout Iraq. Also, available evidence indicated that effects of human activities, like agriculture; waste water and industrial activities, often appear locally and are related to the conditions of the region or aquifer, so it cannot be considered an indicator of existing a widespread pollution for all Iraqi groundwater. Therefore, identify the region most vulnerable to deterioration require targeted monitoring based on aquifer properties and local pressure resources (Tawfeeq et al., 2024; Al-Kubaisi et al., 2025; Altahaan and Dobslaw, 2026).

Groundwater quality changes from one region to another affecting by natural geochemical processes and human-induced pressures which vary according to each of aquifer location, well depth, recharge rate, and surrounding land use patterns. Some studies showed more suitable condition to regions like Altun Kopri, Khanaqin, and Goma-Span, while other regions like Al-Saqlawiya and West Tal Afar showed greater restrictions on some uses. These differences reflect the aquifers properties and the criteria used in assessment, rather than a fixed national ranking of water quality. In addition, it is not necessarily possible to meet all individual variables of drinking water standards when a composite index applied to get a general groundwater classification, this is what the results of a study in southeast Baghdad showed. So, it must be using the true chemical properties values for each site to groundwater quality assessment for different purposes like drinking, irrigation, or engineering uses, and taking into account the nature of the aquifer and the surrounding local conditions. Also, it is important to choose indicators suitable for assessment nature and its intended purpose, also transparency necessary in explain how each classification derived.

The present review confirms that composite indicators of water quality provide useful evidence for quick comparison between locations, but they cannot replace the assessment of individual variables or explain the hydrogeological context. Some of general classification may conceals significant violations for some elements which have healthy or operational importance, so the more reliable rating requires integrate the composite indices with chemical analyses, temporal data, and source tracking methods (Al-Hily and Awadh, 2025; Mohsin et al., 2026).

The studies comparison can be enhanced through build complete evidence for different time periods and groundwater levels. This is therefore requiring adopting more consistent practices for analyses and reporting, and also providing long-term monitoring records. In addition, the contamination sources identification still requires more powerful evidence and needing for increased systematic attention to interactions between surface and groundwater. The groundwater quality monitoring must just don't care to variables which traditionally subject to periodic measurements, but need a scope expanding to include more comprehensive monitoring of microbiological and organic pollutants which have a potential negative effect on groundwater quality. Also, recommending develop a specific evaluation and classification framework for each aquifer, which according to principles of a unified national system for groundwater quality classification with tacking in accounting the local hydrogeological properties and relying more accurately on scientific evidence and available data.

The scholarly contribution of present review lies in providing a critical synthesis of the published evidence about groundwater quality in Iraq, through integrating hydrogeological and hydrochemical information; pollution sources; suitability of water for different uses within single framework. The results show that sustainable management of groundwater requires a long-time monitoring program, standardizing data collection and analysis methodologies and developing a special assessment for each aquifer, taking into account the local properties and final using of water.

This approach in turn provides more reliability scientific basis for general health protection, supporting agricultural productivity and infrastructure protection in addition to promoting sustainable management to groundwater and continuous grantee for a long time.

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