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Assessment of Sulfate and Chloride Concentrations in Groundwater and Their Impact on Public Health and the Environment in Iraq: A Review

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ABSTRACT

This study focuses on assessing the quality of groundwater wells in Iraq, analyzing the diffusion of high sulfate and chloride concentrations and their impacts on public health and the environment. The results highlight the necessary importance of these water sources in meeting the needs of rural areas, especially with increasing pressure on surface water resources. A comprehensive review of previous studies indicates frequent exceedances of these two ion concentrations above international standards World Health Organization (WHO) in several regions, calling for a more in-depth analysis of both natural (such as geochemical dissolution of sulfate-rich rocks) and human (such as unsustainable agricultural practices and sewage and industrial infiltration) sources of contamination. On the health front, the study highlights the clear link between the consumption of water contaminated with these ions and the spread of chronic diseases, such as kidney and gastrointestinal disorders, as well as their negative impacts on soil and infrastructure due to salt accumulation. The paper concludes with a call for strengthening water resource management policies and adopting innovative treatment solutions.

1. Introduction

1.1. Importance of Well Water in Rural Areas

Rural areas of Iraq depend on well water to fulfill both drinking and irrigation needs due to limited surface water availability and inadequate water treatment infrastructure. These wells provide a viable option for obtaining water because they tap into underground aquifers in regions facing fresh water shortages or pollution. Groundwater receives more protection against surface contamination compared to surface water but its quality and sustainability rely heavily on proper resource management[1].

Well water serves as a critical water source and plays a fundamental role in supporting both economic and social stability in communities. People in Iraqi villages with limited access to clean water sources use this water for everyday tasks like cooking and cleaning which affects their quality of life. The absence of proactive measures combined with neglect leads to pollutant accumulation which demands urgent sustainable resource management to prevent potential health and economic disasters. Research shows that infrastructure damage during conflicts [2] requires collaboration between stakeholders to improve water access and awareness of water conservation needs.

1.2. Overview of Water Quality Challenges

Iraq's well water quality has faced major challenges over the past few decades due to both natural factors and human activities. In rural

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areas, communities heavily rely on well water, which often fails to meet established safety standards. Contamination by heavy metals, nitrates, and pathogens poses significant health risks [1]. Additionally, post-conflict regions suffer from deteriorated infrastructure, worsening the existing issues. Urban populations, such as those in Mosul, increasingly depend on temporary wells that also raise concerns about drinking water safety [2].

Globally, water, food, and energy represent the three most pressing issues of our time. In response, domestic wastewater is increasingly treated not as waste, but as a valuable resource[3]. The reuse of treated wastewater has become a widely accepted solution to water scarcity, particularly for domestic uses such as landscape and crop irrigation. This approach not only conserves freshwater but also makes use of the nutrients present in wastewater, contributing to both water and energy sustainability[4].

Iraq faces climate change and the depletion of water resources. Warming temperatures and changing precipitation patterns result in drought and lead rural populations to resort to using unsafe water sources[5] . In addition, natural barriers have been reduced or are getting worse, so groundwater extraction leads to depletion and salinization, making them more vulnerable to pollution delivery, especially by natural predation[6].

The non-control of few agricultural practices causes excess leaching of fertilizers and pesticides into groundwater as well as overflow and expel of treated industrial effluents in nearby water bodies[7]. Similarly, turn off public health due to poor water quality is a reality visible, which makes the agricultural sector inefficient by harming irrigation sources[1]. It needs integrated solutions to mitigate infrastructure and response capability shortfalls, such as the need for increased water supply and storage facilities, monitoring systems for well water quality, and pollution control measures that safeguard human health without compromising ecological sustainability.

2. Assessment of Well Water Quality

2.1. Identification of Key Contaminants

Sulfates and chlorides are very much poor quality pollutants, as these two important pollutants influence the quality of well water very substantially in the country of Iraq. Their high concentrations are partially caused by natural factors like sulfate-bearing rock formations. On the other hand, human activities, like the uncontrolled release of industrial effluents and the seepage of fertilizer-rich irrigation water, intensify the situation[8]. Heavy industrial and the excessive use of chemicals during agriculture are also responsible for elevated levels of pollution, combined with high population density areas of cities.

Due to seawater intrusion of underground water along the lines of saline natural processes, the Gulf of Arabia, plus heavy human activities, the problem of high levels of chloride in well water in Iraq is quite complex. The most Index area for it was Mediterranean costal towns like Basra, where the salinity rate can range up to 7000 parts per million–14 times higher than those set by World Health Organisation(WHO) for safety Tests in the laboratory. The rising salinity not only causes a bad taste, but also endangers health and leads to chronic illness down the road.

According to the approved standard specifications for the Iraqi mineral water in 2004, unsafe levels of sulfates were detected in water samples from several wells within Semel District, Dohuk Governorate. There were significant differences in the spatial distribution patterns of chloride and sulfate concentrations across the study area. These findings emphasize the importance of adopting effective preventive strategies through proactive community-based monitoring. Additionally, raising public awareness and implementing strict environmental policies are essential to mitigate future groundwater contamination risks.

These contaminants pose a direct threat to water quality and usability in various regions of Iraq. According to scientific studies, sulfates are linked to gastrointestinal disorders [9], while excess chloride alters the sensory characteristics of water, reducing its desirability [10]. Therefore, groundwater management efforts must focus on implementing strict monitoring strategies and raising community awareness of

the importance of primary treatment to ensure safe water for the population.

2.2. Regional Variations in Water Quality

There have been researches that show there is increasing cases of pollutants in water throughout different sites in the Northern Governorates area. In the region of the Governorate of Dohuk, you will notice the Semel district as the focal point of reference for Figures (1) and (2) [1],. These show that if you are to have Wells that are closer together with a similar geographical trend, there is potential for similar contaminates to be seen in the Wells as there are similar runoff and mismanagement factors.

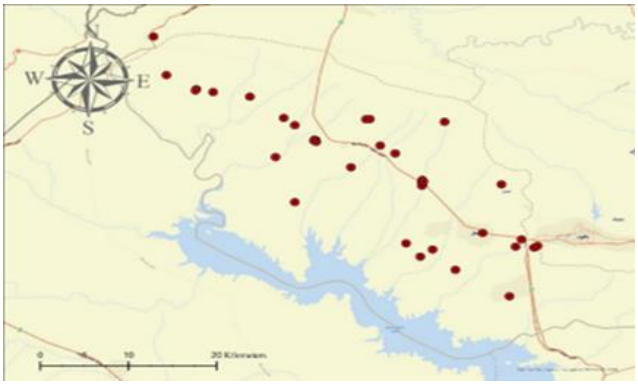

Figure 1: Geographic distribution of wells in Semel district [1].

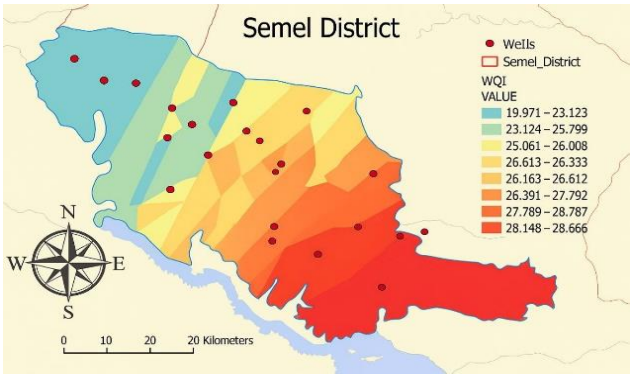

Figure 2: Spatial distribution of water quality levels[1].

Conversely, the Basra Governorate faces even more severe challenges due to saline intrusion from Gulf of Arabia and widespread pollution resulting from untreated wastewater disposal. Existing conventional treatment facilities are not equipped enough to remove a range of contaminants from the water supply, including notably heavy metals and organic materials.In this reality, local inhabitants turn to self-made cures. The result can be dangerous, such as using private desalination services for water and, if they so desire, buying brand name bottled water from abroad which will lead to an added health burden[11].

In addition, environmental pollution in Iraq was further aggravated by unregulated human activities, foremost among them the indiscriminate discharge of industrial waste water. As a result, water quality in Iraq suffered a catastrophic deterioration. Studies show that urban industrial areas are beset by the pollution of their water sources with toxic chemicals, a state of affairs in which residents' health is always at risk[7]. Further dereliction of environmental protection laws exacerbates the issue.

Geographical characteristics in Iraq have a major influence on the pattern and extent of pollution in water, as well as difficulties with securing safe drinking water. The north (e.g., Duhok) suffers pollution from intensive agricultural activities, while in the south the problem is focused on salinization or chemical spills by industries. Understanding these discrepancies provides a foundation for customized solutions to the environmental needs of each region.

3. Sources of Contamination

3.1. Natural Sources of Sulfate and Chloride

The sulfate and chloride high concentrations of Iraqi well water are attributable to the complexity interaction of unique geological features of the country along with different environmental factors. Iraq lies on sedimentary rock, which provides a background for the high salinity of groundwater through mineral dissolution[12]. Sources of sulfate ions that dissolve through weathering are mainly from gypsum and anhydrite minerals, and their high concentration in wells is the result of rainwater seeping to ground water[13] .

The formation of chloride ions takes a similar pathway, including the leaching of salt deposits or chemical exchange between groundwater and marine rock layers. [14] suggested that chloride concentrations are locally increased due to geological formations with soluble salts. In areas of high temperature,

evaporation is another element adding to these concentrations as the evaporation of fluids raises the acidity of the water by increasing the concentration of salts.

High variability in rainfall further affects the high concentrations of anions in groundwater. Where rainfall is lacking (e.g. parts of Iraq), there is insufficient dilution and alkali earth sulfates and chlorides accumulate at high concentration. Chemical weathering of rocks alters the chemistry of water in a watershed by exchanging rock and mineral ions for those in infiltrating water[15].

The levels of sulfates and chlorides in Iraqi groundwater are highly dependent on the geological and hydrological properties of each region. E.g., because of salt leaching from soil or natural interactions affecting groundwater dynamics, agricultural parts register increased concentrations of those ions [14]. This indicates that, to ensure a proper water resource management, a deeper understanding of such natural phenomena is necessary.

3.2. Anthropogenic Activities Contributing to Contamination

An irrigation canal whose water is poisoned with industrial and agricultural effluents will sooner or later fail to serve any useful purpose. Leakage of agricultural fertilizers blends with industrial waste, and due to the poor treatment of city and industrial wastewater. A pesticide-and- fertilizer-infested runoff from agriculture is one of the leaders in these pollutants melting down into town water tables. Especially for those places where folks drink and are watered from rivers or wells, these pollutants mean long-term health damage.[16]

Toxic industrial waste being thoughtlessly dumped into the environment is the culprit behind the collapse in water quality throughout Iraq. As much as [17] estimates that 60% of Iraq's water systems have no purifying equipment at all. The result is that huge quantities of toxic substances, such as oil and heavy metals, find their way into rivers. The Shatt al-Arab River is one case in point of this man-made catastrophe. Oil residues from uncontrolled industrial activities lie on the surface.

Moreover, inadequate wastewater treatment practices worsen these problems. A large volume of municipal sewage enters rivers without proper purification. Public water treatment facilities often struggle with outdated infrastructure and limited resources, hampering their ability to remove contaminants. According to [18], traditional treatment systems frequently fail due to insufficient chlorine application, leaving organic materials like human waste in the water supply.

These anthropogenic factors collectively threaten the integrity of well water across Iraq, creating significant health risks for communities dependent on this essential resource for daily life and agriculture.

4. Health Impacts of Elevated Sulfate and Chloride Levels

4.1. Gastrointestinal Health Risks

Heightened sulfate and chloride concentrations in well water can lead to significant gastrointestinal health issues for those dependent on these sources. Consuming contaminated water introduces harmful pathogens and toxic substances, resulting in various enteric diseases. In Iraq, where well water quality is often compromised, inadequate management of wastewater and industrial pollutants exacerbates health threats[10]. Bacterial contaminants like E. coli and Campylobacter, from sewage leaks, pose particular risks by causing severe gastrointestinal distress such as diarrhea, vomiting, and abdominal pain.

In areas like Basra, where poisoned water supplies have trusted widespread health emergencies to play out—this situation is a critical one. In the summer of 2018 admissions to hospitals for such illnesses as gastroenteritis and gastroenteritis, which large numbers were blamed on water pollution, increased [18] Affected individuals suffered from symptoms ranging from mild discomfort all the way through to complex cases requiring hospitalization.

Drinking poor-quality well water over long periods increases the risk of chronic diseases as a result of frequent troubles with infections. Scientific evidence has shown that

sulfates may irritate the mucosa of your gastrointestinal tract [19]; meanwhile high chloride concentrations can worsen symptoms like severe thirst, nausea and heartburn by adding to dehydration caused by them. Therefore these two ions together pose a double danger to human health: not only will they bring on immediate effects but in due course their overabundant presence inside living bodies might help bring about still other diseases, or leave people dead.

To protect public health, the priority needs to be dealing with giving these poisons the treatment they deserve. Continuous monitoring strategies and highly focused health education programs can be distributed to a population which is then warned how dangerous pollution affects their water supply. In this way, their elimination will cut down on gastrointestinal diseases resulting from unclean water supplies.

4.2. Long-Term Health Consequences

When well water contains excessive sulfate, it may pose gastrointestinal health risks, especially for sensitive individuals. Clinical reviews have reported that ingestion of drinking water with sulfate levels above 500–700 mg/L can lead to osmotic diarrhea and intestinal discomfort, although symptoms typically resolve once levels normalize . These laxative effects are more pronounced in infants and visitors unaccustomed to such concentrations[20] .

As pollutants, and especially after being inhaled or having prolonged contact with them, these two substances produce yet one more threat. The bioaccumulation of sulfates and chlorides by the system can also lead over time to skin problems and harm vital organs.

In countries like Iraq, where environmental conditions and human activities are putting pressure on water quality from both sides the health effects of this pollution really have to be understood. Evidence from research is that the worsening of water quality risks transmitting water-borne diseases [10], involving everyone in comprehensive monitoring systems that deal immediately with pollution as well as its cumulative effects.

People living in areas that are unaware of such risks take in polluted water from wells, because they do not have a sense as to the importance of monitoring water quality [18]. It is this that aggravates health problems, leads to increased financial pressures on health care systems and worsens the overall quality of life in an area.

To solve these challenges, field studies need to be conducted to assess health risks related to sulfates and chlorides and give accurate data to properly design health programs that effectively reduce pollution of the water in Iraqi villages dependent on wells for their drinking.

5. Environmental Implications of Contaminated Well Water

5.1. Effects on Local Ecosystems

[21] In Iraq, well water contamination significantly threatens human health and the surrounding ecosystems. Pollutants like sulfates and chlorides jeopardize aquatic environments, leading to shifts in species dynamics where vulnerable organisms may vanish, allowing more resilient species to thrive. This imbalance undermines biodiversity and ecological resilience. Research indicates that pollutants from domestic waste, agricultural runoff, and industrial discharges introduce excessive nutrients into water bodies, promoting harmful algal blooms [21]. These blooms degrade water quality and diminish oxygen levels, creating lifeless zones detrimental to aquatic life.

The problem is exacerbated by the interaction between groundwater and surface water. Pollutants leaking from wells into nearby rivers or lakes contribute to widespread pollution extending beyond the local scale [22]. Furthermore, increased salinity in water damages its suitability for aquatic life and undermines the functioning of necessary hydrological systems.

Agriculture has a severe crisis of water quality. With high salinity in irrigation water, crops will not grow well and this can also affect animal health: livestock depend on close-by drinking water that may be polluted [23]. Farmers who use contaminated wells end up with slow growth in crops due to an accumulation of toxic substances in soil, which reduces crop quality. Harmful effects extend to

diminishing fish catch, imperiling the livelihood of coastal communities.

These environment crises cannot be solved without understanding the connection between human behavior and ecosystems. Good governance practices are indispensable for human health and to restore injured ecosystems[18].

5.2. Impact on Agriculture and Livestock

The state of well water in Iraq plays a crucial role in agricultural and livestock health, primarily influenced by contamination from diverse sources. Heightened concentrations of pollutants, including sulfates and chlorides, can adversely affect the vitality of crops and animals alike. For instance, high salinity resulting from saline intrusion, especially in areas like Basra, has dramatically disrupted farming practices. Consequently, farmers are compelled to use saline river water for irrigation, which can lead to decreased crop yields and deteriorating soil quality. Prolonged exposure of soils to saline conditions may also trigger desertification and a reduction in arable land, thereby threatening agricultural productivity، as noted in [18].

Livestock face similar risks due to compromised water quality. Animals that drink contaminated water may suffer from health complications ranging from digestive issues to lasting organ damage, posing a threat to herd viability[10]. Additionally, the dependence on groundwater for drinking supplies exposes livestock to further contaminants that can hinder growth rates and reproductive success.

The entire agricultural ecosystem becomes unbalanced when crops fail or livestock suffers as a result of tainted water sources. This predicament is worsened by insufficient wastewater treatment facilities that allow harmful substances from agricultural runoff and domestic waste to seep into the groundwater system as discussed in[17]. The situation is exacerbated by climatic changes; rising temperatures and unpredictable rainfall patterns due to climate change place additional pressure on already strained water resources[24].

In rural communities where alternative freshwater options are limited, securing safe well water is paramount for the sustainability of both crop cultivation and livestock rearing. Therefore, it is imperative to implement measures not only for immediate remediation but also for the long-term management of water resources—one that prioritizes public health alongside agricultural sustainability.

6. Recommendations for Improving Water Quality Management in Iraq

6.1. Enhancing Monitoring Programs for Well Water Quality

The use of Geographic Information Systems (GIS) can significantly improve water quality evaluations through spatial analysis of groundwater regions and can significantly help with making decisions in the field. Regular assessments using standardized metrics like the Water Quality Index (WQI) provide clear indicators for stakeholders. The WQI offers a comprehensive evaluation of water bodies by integrating multiple parameters, helping identify pollution patterns and fostering effective communication with policymakers and the public [1].

It is necessary to form a multi-disciplinary monitoring team so that various efforts can be unified across different regions, as emphasized in[18], and seek a system that effectively complies environmental regulations and implements clear chronic solutions Canberra. The team will monitor field changes, integrate community voices into decision-making centres and design solutions on the basis of recent data outputs.

Targeted investments in personnel training for advanced sampling techniques and rapid response to pollution incidents can boost the capacity of local institutions. Furthermore, organized educational seminars are helpful in raising community awareness of the dangers of poor quality water and ways to catch polluters early.

Collaboration among government agencies, Non-Governmental Organizations (NGOs) and academic institutions is crucial for sharing knowledge and distributing resources, so that Iraq's vital groundwater resources can be protected through pinpoint interventions.

Institute a monitoring system for WQI record, a comprehensive list of the different indicators that will have to be tested to see if they are in line with regional or global standards.

This should also include compliance with NEQS, as provision of an essential aid to meeting Phase III requirements for those who need it is needed more than ever "(Table 1 provides a clear landmark for stakeholders Within the table is a translation of standards from 1994 NEQS and WHO1971 guidelines.)

Table 1: NEQS and WHO standard for drinking water parameters[7].

Sr. No.	Parameters	NEQS	WHO Guideline
1	Color	<15 TCU	15 TCU
2	Turbidity	<5 NTU	<5 NTU
3	pH	6.5–8.5	6.5–8.5
4	TDS	<1000	1000 mg/L
5	Nitrates	<50 mg/L	50 mg/L
6	Fluorides	<1.5 mg/L	1.5 mg/L
7	Residual Chlorine	0.2–0.5 mg/L	0.2 mg/L
8	Total Hardness	<500 mg/L	500 mg/L
9	Arsenic	<0.05 mg/L	0.01 mg/L
10	*E.coli*	0 CFU/100 mL	0 CFU/100 mL

6.2. Implementing Better Wastewater Treatment Solutions

In order to improve both drinking water quality and protect public health, in Iraq it is crucial that they put into practice effective solutions for wastewater treatment. Many treatment facilities are in a state of disrepair or are unable to cope with the demand. This causes a good deal of fresh water to be polluted. To meet these challenges requires an equally broad-based strategy and it includes clearly defined laws about reuse of the water afterall not every drop should go down drain or to farm. What is needed for this environmental emergency has already been foreseen by [10]: a National Water Master Plan comprehensive enough to promote sustainable practices across municipal, agricultural, and industrial sectors is required.

Enhancing the capacity and efficiency of existing wastewater treatment plants (WWTPs) is also essential. Many plants lack the technical expertise and trained personnel needed for effective operation, making operator training programs vital [10]. Research should focus on innovative techniques to improve water safety during reuse.

Mitigating point-source pollution from domestic and industrial sources is another key factor in advancing wastewater treatment. Stricter regulations on effluent standards will ensure that only treated water meets health guidelines before entering waterways. Implementing advanced technologies, such as activated carbon filters, can improve the aesthetic quality of treated water while reducing contaminants [10].

Decentralized treatment systems offer immediate benefits for rural areas where large-scale WWTPs are not feasible. Small-scale solutions like constructed wetlands can treat domestic wastewater locally while promoting community engagement in resource management[25].

Raising public awareness about the risks associated with untreated sewage and the importance of proper sanitation will support more effective wastewater management initiatives throughout Iraq[18] . These coordinated efforts are vital for restoring well water quality and enhancing resilience against future environmental challenges.

7. Community Awareness and Education Initiatives

7.1. Importance of Public Awareness Campaigns

Public awareness initiatives play a crucial role in addressing water quality issues in Iraq, particularly regarding well water safety and sustainability. These programs educate communities about the risks of contaminated water, which can lead to serious health problems, including gastrointestinal disorders. The 2018 health crisis in Basra highlighted the lack of awareness among individuals about how to protect themselves from polluted sources, as authorities failed to provide timely information on preventive measures [18] .

Support from the community and resilient communications programs are important for promoting knowledge of safe drinking water and linking local respondents with their administrative level behind which you hid the truth water-treatment plant at the end of block quotestart_highlight blockquote end_highlight Typically, initiatives like publishing brochures and sending messages on safe drinking practices will help raise the consciousness of the publicHowever, the challenge lies in integrating these efforts, especially for groups whose effective communication is limited, as was the case in 2018 [18] Experts maintain that promoting responsible agricultural practices among farmers is of central importance in efforts to reduce pollution of the groundwater by man.

For instance, awareness campaigns need to be mounted along with rules on the use of chemical fertilizers and pesticides putting into operation consumption-saving methods in order to avoid removing ground water recharge areas[26] Modern technologies such as geographic information systems (GIS) can be used to identify areas with low environmental resilience and alert communities to the potential that their water supply might be poisoned, as one work documents [7]Awareness-raising activities will remain the mainstay of programs for improving well water quality in Iraq and creating a culture of water conservation.

7.2. Training Programs for Farmers and Industrial Operators

Educational initiatives are essential for both farmers and industrial operators, so as to improve well water quality threatened by pollution in Iraq. These programs should educate stakeholders about sustainable agricultural practices that save water and cut down on chemical pollution. For example, the cultivation of crops requiring less water can reduce reliance on local resources.[27] Advanced irrigation techniques such as drip irrigation can increase water efficiency and crop productivity.

A fundamental goal of training programs for farmers and industrial operators in Iraq is to protect the ground-water resources. These programs should advocate sustainable farming methods: alternatives might include selecting less water-needy crops for fields; in a study reviewed elsewhere this was underscored by findings[27] .In addition, modern irrigation systems like drip irrigation help to improve water management and harvests.

Moreover, educating people on hygienic waste disposal methods is an important frontier in rural areas, where cesspools are still widely used as a means for dumping wastewater and thus endangering groundwater supplies. Therefore, training schemes need to be designed that teach farmers how to create self-sustaining water services. Then there could also be workshops where communities learn how to check water quality, address potential sources for contamination of groundwater and the like.

Partnerships with community organizations provide quality Bush schools that take local needs into account by customizing programs and involving parents in the learning process [18]. Community participation in these projects is an underlying theme necessary for gaining acceptance of new technologies and the sustainable practices that these programs always advocate.

Industrial operators also need training on how to exercise good stewardship of the environment by meeting environmental standards in such areas as industrial waste treatment. A comprehensive program of public enlightenment will enable both farmers and industrialists to understand their responsibility for keeping ground water safe [28].

Regular appraisals of these training projects are essential if they are to be fine-tuned according to changing needs or the quality of water levels [1]. The exchange of views between

participants fosters continuous improvement among those who are committed to sound management of the country's water resources.

8. Policy Recommendations for Sustainable Management Practices in Iraq's Water Resources

8.1. Strengthening Regulations on Agricultural Practices

Enhancing regulations around agricultural practices is crucial for mitigating contamination of well water quality in Iraq. The existing legal framework includes the Water Resources Conservation Law No. 2 of 2001, which mandates wastewater management and prohibits waste discharge into public waters without consent from the Environment Protection and Improvement Directorate (EPID). However, enforcement has often been inadequate, allowing agricultural runoff containing pesticides and fertilizers to enter waterways unregulated[18] .

A comprehensive initiative to enhance environmental compliance is urgently needed. To achieve this goal, all mechanizms for monitoring agricultural practices should be strengthened. It may be done by regular inspection tours ensuring that those sites comply with environmental requirements[29]. Also, training workshops can teach farmers ways cut back on excessive use of agricultural chemicals, which in turn keeps air and water almost pollution-free. Nor should the relevant authorities tolerate any environmental crimes committing polluters but with stringent and fair laws conduct strict supervision of their activities to ensure water remains unpolluted[18].

Community awareness programs could emphasize the hows of agricultural pollution on human health and the ecosystem. By raising consciousness of sustainable agricultural techniques, the amount of collective effort and acceptance increases. Savings on water resources mean this can eventually even guarantee sustainability for the agricultural circle in future times [30].

In addition, better cooperation between government departments for agriculture and the environment can help design comprehensive policies to fight groundwater pollution. Such a participatory approach allows this environmental management pattern to take account of how land use affects water quality, thus improving itself. Essentially, strengthening the law on agriculture fills a gap that must be plugged if sustainable development is to be achieved and Iraq's water resources are not to suffer further depredation.

8.2. Promoting Integrated Water Resource Management

Fostering integrated water resource management (IWRM) in Iraq is crucial for addressing increasing water scarcity and contamination. IWRM emphasizes a holistic approach that connects water resources with social, economic, and environmental factors[31]. Successful implementation requires stakeholders to collaborate on a national water policy that aligns efforts across agriculture, industry, and urban planning.

A gentle balance of the old, Qanats used for groundwater replenishment with the modern, desalination plants, can be a game-changer in the water availability spectrum. The process of treating wastewater and using it for irrigation of crops helps save fresh water and reduce pollution.

Adequate infrastructure development is integral to effective sustainable water resource management. Increasing water reuse and mitigating health risks of pollution can be achieved through the upgrading of wastewater treatment plants [10] In addition, awareness of responsible practices promotes community involvement with the conservation of water. Preventive types of measures to stop pollutants from entering into wells need training courses for farmers and industrial workers.

To this end, aid from international organizations is vital to supply the resources necessary to improve IWRM in Iraq. This needs collaboration between the governments, civil society and the private sector to create regulatory frameworks which support sustainable development and to incentivise conservation[32].

Furthermore, regional cooperation on the management of shared transboundary water resources could reduce tensions over transnational rivers, such as the Tigris and

Euphrates. However, these challenges must be met with smart solutions that are compatible with Iraq's geography and the socioeconomic realities on the ground.

9. Conclusion

Iraq needs a comprehensive strategy that tackles its water resources problems head on. Because it is vital for people to drink, well water in Iraq must be examined for quality. And reliable measurement is key to accurately defining the amount of pollution present. In particular, high levels of sulfates, chlorides, and other pollutants pose a great risk to public health and the wider environment. Nowhere is this more true than in water-poor rural areas, whose people depend almost exclusively on well water for their day-to-day needs. Comprehensive measures must be taken to prevent any further deterioration of water resources. Besides strengthening regulations and enforcement efforts for pollution control in both industrial discharges and agricultural practices, priority work should now focus on improving infrastructure so that everyone has access to safe drinking water. Educational programs must be established which raise people's consciousness about pollution sources and enjoin farmers to practice sustainable living with a view toward maintaining a healthy environment and cutting health risks. To sum up, water resources in Iraq need three-fold cooperation involving research, policy and people. It should set sights on intermediate-long term solutions meeting the needs of coming generations, and in the long-run enhanced resistance to climate change.

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References

[1] B. Tahir and I. Kareem, "Assessment of Groundwater Quality in the Semel District of Duhok City, Iraq: Implications for Agriculture and Aquaculture," *Egypt. J. Aquat. Biol. Fish.*, vol. 28, no. 5, pp. 685–699, 2024.

[2] J. Schillinger, G. Özerol, and M. Heldeweg, "A social-ecological systems perspective on the impacts of armed conflict on water resources management: Case studies from the Middle East," *Geoforum*, vol. 133, pp. 101–116, 2022.

[3] A. D. Benetti, "Water reuse: issues, technologies, and applications," 2008, Accessed: Jun. 03, 2025. [Online]. Available: https://www.sidalc.net/search/Record/oai:scielo:S1413-41522008000300001/Description

[4] Zaidun Naji Abudi, "Using sawdust to treat synthetic municipal wastewater and its consequent transformation into biogas," *J. Ecol. Eng.*, vol. 19, no. 5, pp. 10–18, 2018.

[5] N. I. Eltaif, M. A. Gharaibeh, and A. M. Fadhil Al-Quraishi, "Impact of climate change on Iraq: severe water scarcity and desertification," Springer, 2024. Accessed: Apr. 09, 2025. [Online]. Available: https://link.springer.com/chapter/10.1007/698_2024_1100

[6] A. Chabuk *et al.*, "Creating the Distribution Map of Groundwater for Drinking Uses Using Physio-Chemical Variables; Case Study: Al-Hilla City, Iraq," *Water. Air. Soil Pollut.*, vol. 233, no. 6, p. 218, Jun. 2022, doi: 10.1007/s11270-022-05660-3.

[7] R. Nawaz *et al.*, "Water Quality Index and human health risk assessment of drinking water in selected urban areas of a Mega City," *Toxics*, vol. 11, no. 7, p. 577, 2023.

[8] F. K. Ahmed, F. A. Kubba, and Sadiq S. Muhsun, "MATHEMATICAL ANALYSIS OF 2-D STEADY SEEPAGE FLOW AND THE BEHAVIOR OF CONTAMINATES TRANSPORTATION THROUGH HOMOGENEOUS EARTH DAM USING COMSOL SOFTWARE," *J. Eng. Sustain. Dev.*, vol. 24, no. 5, pp. 19–27, 2020.

[9] I. A. Al-Khatib, M. Al-Jabari, and M. Al-Oqaili, "Assessment of Bacteriological Quality and Physiochemical Parameters of Domestic Water Sources in Jenin Governorate: A Case Study," *J. Environ. Public Health*, vol. 2023, pp. 1–10, Jul. 2023, doi: 10.1155/2023/8000728.

[10] E. C. Todd, "Waterborne diseases and wastewater treatment in Iraq," *J. Food Prot.*, vol. 87, no. 1, p. 100204, 2024.

[11] A. S. A. Chalabi and Department of Environmental and Pollution Eng., Southern Technical University, Al Basra Iraq, "Evaluation of the Efficiency and Quality of the Water of the Al-Hartha Water Treatment Plant in Basra City," *Curr. World Environ.*, vol. 15, no. 1, pp. 75–86, Apr. 2020, doi: 10.12944/CWE.15.1.11.

[12] O. N. Al-Sheikh and A. M. AL-Shamma'a, "Hydrochemical of Groundwater for Al Dammam unconfined Aquifer within Al-Salman Basin, Al-Muthana Governorate, South West Iraq," *Iraqi J. Sci.*, pp. 1336–1349, Jun. 2019, doi: 10.24996/ijs.2019.60.6.17.

[13] A. K. Ibrahim, S. H. Ahmed, A. Y. Radeef, and M. M. Hazzaa, "Statistical analysis of groundwater quality parameters in selected sites at Kirkuk

governorate/Iraq," in *IOP Conference Series: Materials Science and Engineering*, IOP Publishing, 2021, p. 012028. Accessed: Apr. 09, 2025. [Online]. Available: https://iopscience.iop.org/article/10.1088/1757-899X/1058/1/012028/meta

[14] A. M. A. Taha, S. M. Shratooh, and A. H. Jasim, "Limnological properties of euphrates river in Al-anbar province, Iraq," *Health Educ. Health Promot.*, vol. 11, no. 3, pp. 499–505, 2023.

[15] G. A. Mostafa, A. S. Alhusain, M. F. El-Tohamy, and H. AlRabiah, "Evaluation of some anions in groundwater in Riyadh, Saudi Arabia, and human health risk assessment of nitrate and fluoride," *Sci. Rep.*, vol. 14, no. 1, p. 24752, 2024.

[16] A. J. Al-Yasiri, "Iraq's post-2003 environmental pollution: Issues and solutions," *Akkad J. Contemp. Econ. Stud.*, vol. 1, no. 1, pp. 1–16, 2021.

[17] T. R. Zolnikov, "The Maladies of Water and War: Addressing Poor Water Quality in Iraq," *Am. J. Public Health*, vol. 103, no. 6, pp. 980–987, Jun. 2013, doi: 10.2105/AJPH.2012.301118.

[18] M. Skelton, "Competing over the Tigris: The politics of water governance in Iraq," *Inst. Reg. Int. Stud.*, 2022, Accessed: Apr. 09, 2025. [Online]. Available: https://auis.edu.krd/iris/sites/default/files/IRIS_Competing%20over%20the%20Tigris-11.11.2022_0_2.pdf

[19] T. Hyarat, M. Al Kuisi, and G. Saffarini, "Assessment of groundwater quality using water quality index (WQI) and multivariate statistical analysis in Amman-Zarqa area/Jordan," *Water Pract. Technol.*, vol. 17, no. 8, pp. 1582–1602, 2022.

[20] W. D. Heizer *et al.*, "Intestinal effects of sulfate in drinking water on normal human subjects," *Dig. Dis. Sci.*, vol. 42, no. 5, pp. 1055–1061, May 1997, doi: 10.1023/a:1018801522760.

[21] J. Alcamo, "Water quality and its interlinkages with the Sustainable Development Goals," *Curr. Opin. Environ. Sustain.*, vol. 36, pp. 126–140, 2019, doi: 10.1016/j.cosust.2018.11.005.

[22] S. K. Pramada and S. Venugopal, "Interaction Between Groundwater and Surface Water and Its Effect on Groundwater Quality," in *Environmental Processes and Management*, vol. 91, R. M. Singh, P. Shukla, and P. Singh, Eds., in Water Science and Technology Library, vol. 91. , Cham: Springer International Publishing, 2020, pp. 381–395. doi: 10.1007/978-3-030-38152-3_20.

[23] G. E. Ikpi, T. N. Nganje, A. Edet, C. I. Adamu, and G. A. Eyong, "Investigation of hydrochemical characteristic, water quality and associated health risks of metals and metalloids in water resources in the vicinity of Akamkpa quarry district, southeastern, Nigeria," *Geochem. Trans.*, vol. 25, no. 1, p. 7, 2024.

[24] H. I. Z. Al-Sudani and L. A. Fadhil, "Hydrochemical Evaluation of Unconfined Aquifer In Wasit Governorate-East of Iraq," 2024, Accessed: Apr. 19, 2025. [Online]. Available: https://www.ijresonline.com/assets/year/volume-11-issue-5/IJRES-V11I5P121.pdf

[25] T. Karches, "Reduction of Environmental Pollution Applying Decentralised Wastewater Treatment Systems in Small Communities 1," *Acad. Appl. Res. Mil. Public Manag. Sci.*, vol. 18, no. 2, pp. 57–63, 2019.

[26] H. A. K. Al-Jaf, "Water Quality Index Application to Evaluate the Ground Water Quality in Kalar City-Kurdistan Region-Iraq," *IOP Conf. Ser. Earth Environ. Sci.*, vol. 1120, no. 1, 2022, doi: 10.1088/1755-1315/1120/1/012002.

[27] S. R. K. Al-Taei, "Examination of Several physiochemical characteristics of underground water collected from various wells situated south Baghdad-IRAQ," *J. Biol.*, 2015.

[28] M. C. Tomei, "Best available techniques as a sustainability tool for industrial water management and treatment," *Sustain. Ind. Water Use Perspect. Incent. Tools*, p. 343, 2021.

[29] B. Chugg, B. Anderson, S. Eicher, S. Lee, and D. E. Ho, "Enhancing environmental enforcement with near real-time monitoring: Likelihood-based detection of structural expansion of intensive livestock farms," *Int. J. Appl. Earth Obs. Geoinformation*, vol. 103, p. 102463, 2021.

[30] C. Qing, S. Guo, X. Deng, and D. Xu, "Farmers' awareness of environmental protection and rural residential environment improvement: a case study of Sichuan province, China," *Environ. Dev. Sustain.*, vol. 24, no. 9, pp. 11301–11319, Sep. 2022, doi: 10.1007/s10668-021-01909-9.

[31] W. Verstraete, P. Van de Caveye, and V. Diamantis, "Maximum use of resources present in domestic 'used water,'" *Bioresour. Technol.*, vol. 100, no. 23, pp. 5537–5545, Dec. 2009, doi: 10.1016/j.biortech.2009.05.047.

[32] UNICEF, "Running Dry: water scarcity threatens lives and development in Iraq," *Línea E. U. UNESCO*, vol. 29, 2021.