Assessing the Water Quality of the Ground Water (Water Wells) Close to the Zakho District Oil and Gas Company

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Abstract

Groundwater is an essential freshwater resource, human activities, especially the mining of fossil fuels, can still contaminate it. This multidisciplinary study examines the quality of groundwater close to oil and gas production using hydro-geochemical and geographic analysis for five samples with multiply replicates. By combining the body of available literature, the research aims to understand the intricate relationships between these industrial activities and groundwater quality. The results show adherence to safety protocols and usually positive conformity with Iraqi regulatory norms. Neutral to slightly alkaline environments are indicated by pH readings that are continuously within permissible bounds. Additionally, there are no immediate worries about contamination or salinity because assessments of electrical conductivity, total dissolved solids, turbidity, and main ion concentrations all match regulatory criteria. Additionally, bacterial indications indicate low levels of contamination, which is consistent with safety regulations. Given the possible long-term effects on groundwater quality, the study emphasizes the significance of continuous monitoring and research, especially in light of variations in total hardness levels and trace metal concentrations. The results emphasize how important strict regulations and continuous evaluations are to protecting the environment and public health in areas with high oil and gas production. The principal results of this study can help policymakers gain a better understanding of the hydro-geochemical properties of groundwater concerning drinking water safety, thus aiding in the management of water resources to implement necessary measures.

Keywords: heavy metals, contamination, human health, ground water, oil and gas companies, drinking water wells.

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Introduction

Groundwater is a vital component of the planet's freshwater supplies and is required for the upkeep of ecosystems, agriculture, and human populations everywhere. But a lot of human endeavors, including those involved in the extraction and refinement of fossil fuels, have the potential to degrade groundwater quality. One of the biggest concerns here is the potential for groundwater pollution around oil and gas companies, many of which operate near densely inhabited areas and essential water sources [7].

Exploration and extraction of oil and natural gas are critical to modern industrial civilizations because they provide the energy resources needed to drive economic growth and support a variety of industries, including transportation and manufacturing. However, these operations may pose significant environmental risks, such as the release of hazardous compounds into the environment, which could affect groundwater quality [30].

The detrimental effects of oil and gas operations on groundwater quality have been shown in numerous studies. Numerous factors, including improper waste disposal procedures, storage tank leaks, unintentional spills, and the movement of pollutants through subterranean channels, can be blamed for these effects [3]. Hydrocarbons, heavy metals, and other chemicals used in the drilling and hydraulic fracturing (fracking) processes are common groundwater contaminants linked to oil and gas operations [5]. Concerns about possible groundwater contamination persist despite industry policies and regulations that attempt to reduce these risks, especially in areas with substantial oil and gas production. In order to protect the environment and public health, it is essential to assess the groundwater quality because these businesses are situated near water wells and other groundwater sources. With an emphasis on a particular case study area, this study offers a thorough examination of the groundwater quality surrounding the oil and gas industries [9].

Our goal is to analyze groundwater samples from wells near industrial sites in order to determine the type and extent of potential contamination, as well as the impact on the local population and ecosystem. By combining hydro-geochemical investigations, geospatial analysis, and regulatory concerns, this multidisciplinary initiative aims to shed light on the complex relationship between groundwater quality and oil and gas extraction. This introduction was created using key information from the sources [14] to provide background and context for the study. The aforementioned sources include a variety of scholarly works, industry reports, and research papers that all emphasize the importance of studying the impact of oil and gas activities on groundwater quality [17].

Literature Review: According to [10] the groundwater quality is an important component of Earth's freshwater resources because it supports ecosystems, agriculture, and human populations. However, there are serious concerns that the mining and processing of fossil fuels, particularly in the oil and gas industry, will pollute groundwater. This study examines previous research on the impact of oil and gas operations on groundwater quality, with a focus on common pollutants, pollution sources, environmental effects, regulatory responses, and research gaps.

Contaminant Sources and Pathways: Oil and gas operations contribute significantly to environmental pollution by releasing a variety of contaminants that can enter groundwater sources. The primary sources of such contamination are:

Unintentional spills: These incidents can occur during the extraction and transportation processes, causing direct environmental harm [2].

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Storage tank leaks: Failures in containment systems can allow hazardous substances to escape into the surrounding environment [11].

Improper waste disposal methods: Inadequate waste management frequently results in toxic substances entering soil and water systems [27].

The movement of hydraulic fracturing fluids can endanger nearby groundwater supplies, especially if they contain hazardous chemicals [26].

These factors highlight the critical need for stringent regulatory measures and effective management practices to mitigate the risks associated with oil and gas operations to environmental health.

Common Groundwater Pollutants: Groundwater contaminants associated with oil and gas activities include hydrocarbons such as BTEX (benzene, toluene, ethylbenzene, and xylene) and volatile organic compounds (VOCs) [23]. According [25], heavy metals such as lead, arsenic, and cadmium can leak out of geological formations or into the environment as a result of industrial activities. Concerns about the chemicals used in hydraulic fracturing have also been expressed [19].

Environmental Impacts: By destroying aquatic ecosystems, disrupting habitats, and contaminating drinking water supplies, groundwater contamination from oil and gas operations can have a major negative impact on the environment, according to [6]. Long-lasting contaminated plumes that are difficult to clean up can be the result of contaminated migration [29].

Regulatory Framework: To monitor and reduce the risk of groundwater contamination from oil and gas operations, several regions have put laws and regulations into place [20]. Groundwater quality baseline evaluations and continuous monitoring are frequently mandated by regulations.

Research Gaps: Our knowledge of the threats that oil and gas operations pose to groundwater quality has advanced significantly, but there are still a number of unanswered questions. Among these are the need for improved assessment methods, long-term field research, and a better understanding of how pollutants travel and behave below the surface [28]. This review of the literature highlights how crucial it is to assess the quality of the groundwater near oil and gas operations. Our data collection and analysis procedures, the study's conclusions, and their implications for public health and environmental protection are all covered in detail in the sections that follow.

Materials and Methods

Study Location

To ensure that it represented a pertinent and potentially impacted region, the research area was chosen with consideration for its closeness to active oil and gas operations. The criteria that were chosen included geographic location, confirmed oil and gas operations, and sample accessibility.

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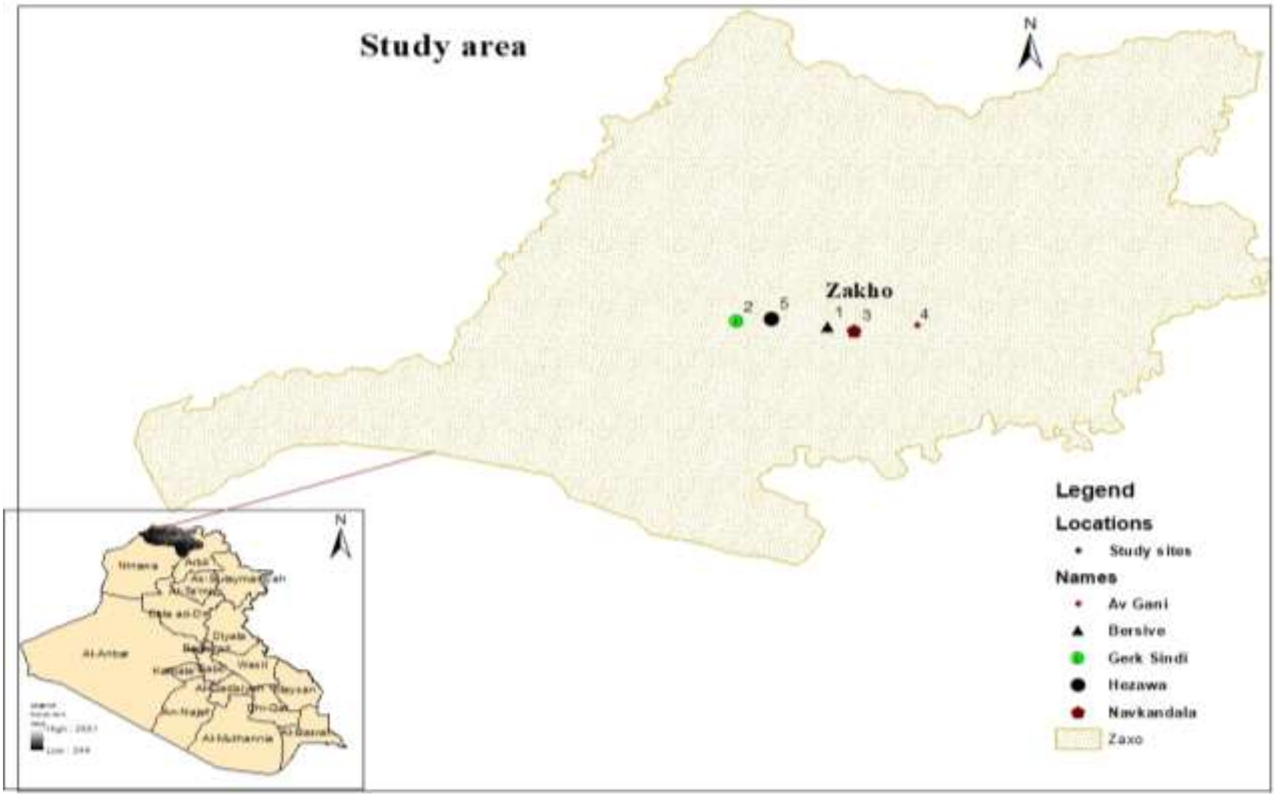

Figure 1: Location map of the study area

Data Collection and Groundwater Sampling Design

In order to guarantee the collection of representative data, a methodical sampling approach was used. The selection of the water wells was based on how close they were to the oil and gas companies' drilling, production, and wastewater disposal facilities. To guarantee that wells within a given radius (say, one mile) of these facilities would be included, a minimum distance criterion was created. Using standard sampling procedures, groundwater samples were collected from a subset of the wells and placed in sterile, clean containers to avoid contamination as shown in fig (2).

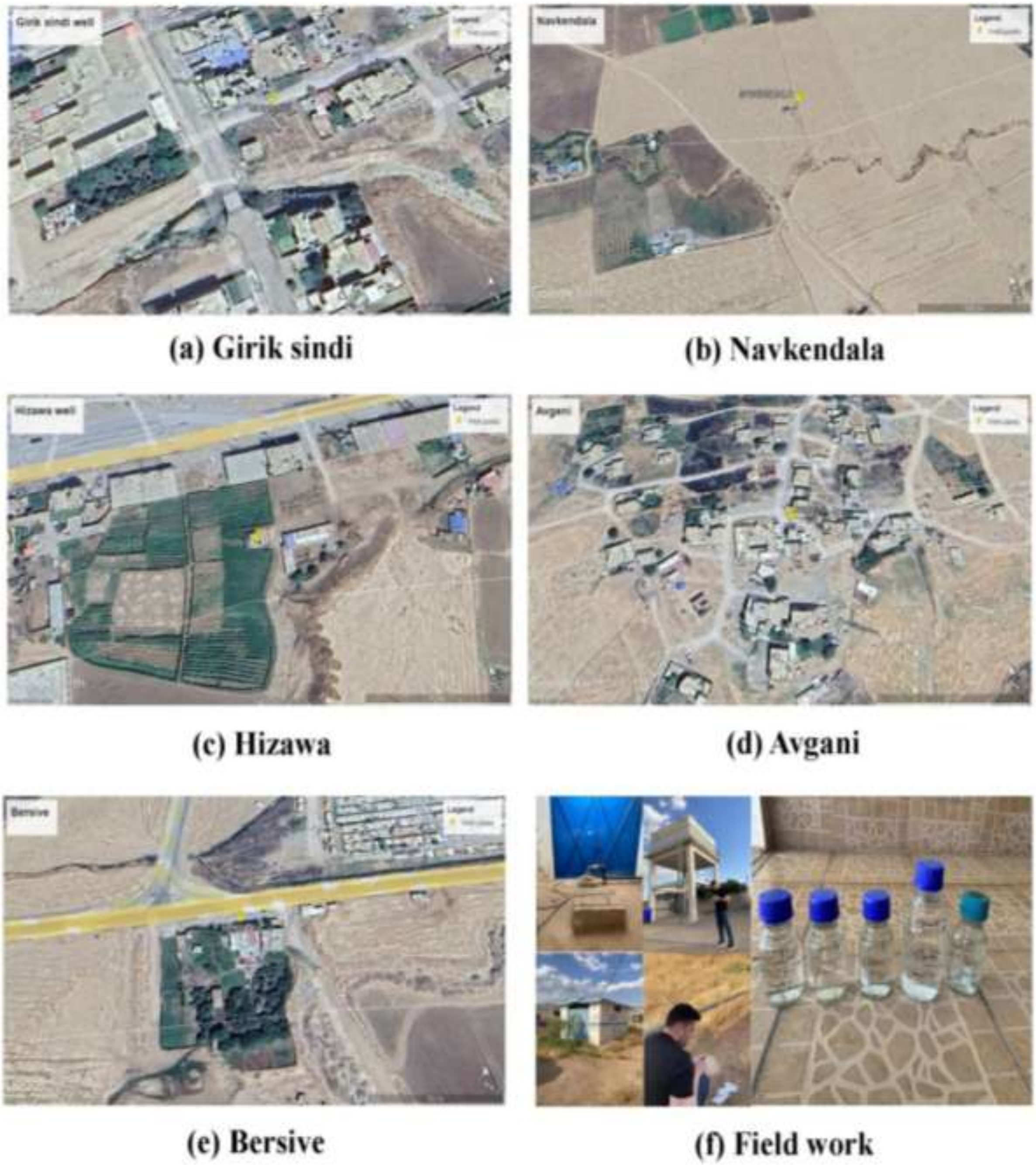

Figure 2: Data Collection and Field work.

Physicochemical and biological Parameters:

During the sampling process, to ascertain the concentration of particular contaminants, groundwater samples were subjected to laboratory analysis a number of physical and chemical characteristics, including temperature, electrical conductivity, pH, total Dissolved

Solids, TSS, Total Hardness, Turbidity NTU, Chloride (Cl^-), Calcium (Ca), Magnesium (Mg), Sodium (Na), Potassium (K), Bicarbonate HCO_3^{-2}, and Sulfate $(SO_4)^-$, were measured. Additionally, five heavy metals were analyzed (Fe, Mn, Cd, Pb, and Co). To set the scene for the groundwater's chemical analysis, these parameters were emphasized. while, the biological characteristics (MPN (cfu/ml), E-Coli and Organic compound) were measured.

Statistical Analysis

Data were gathered and statistically analyzed using the Gibbs and Pipper plots for basic descriptive and inferential statistics.

Quality Control

For the duration of the study, stringent quality control procedures were put in place to guarantee the precision and dependability of the data. This required using certified chemical analysis laboratories (University of Duhok, College of Agricultural Engineering Sciences – Agricultural Bearue), collecting samples in compliance with standard operating procedures, and including duplicate samples and blanks in order to test laboratory precision and identify any possible contamination.

Heavy Metal Pollution Index Calculation

The Heavy Metal Pollution Index (HPI) is a critical tool for assessing water quality by evaluating the concentration of heavy metals in water samples. To calculate the HPI, parameters such as iron (Fe), manganese (Mn), cadmium (Cd), lead (Pb), and copper (Cu) are typically considered. The HPI formula involves calculating a sub-index for each parameter based on its measured concentration, ideal value, and standard permissible value, and then combining these sub-indices to obtain the overall HPI value.

To calculate the HPI, we need the ideal and standard permissible values for each metal. Assuming these values are available, we can proceed with the calculation using the formula:

Qi = (Mi−IiSi−Ii) × 100 Qi = (Si−IiMi−Ii) ×100 …………1

Where:

Mi is the measured concentration of the ith parameter,

Ii is the ideal concentration of the ith parameter,

Si is the standard permissible concentration of the ith parameter.

The overall HPI is then calculated by summing the weighted sub-indices for each parameter. Interpretation Without specific ideal and permissible values, we cannot calculate exact HPI values. However, based on the high concentrations of metals like cadmium and lead, it is likely that the HPI values for these locations would exceed the critical threshold of 100, indicating significant pollution. This suggests that the water quality in these areas may not be suitable for drinking or other uses without proper treatment. The exact HPI values cannot be calculated without additional data, the high concentrations of certain heavy metals suggest that these water sources may be significantly polluted, necessitating further investigation and remediation efforts.

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Results

Each site's pH values fall within 6.5 and 8.5, which is within Iraq's typical range and indicates neutral to slightly alkaline conditions and showing that dissolved ions in the water are within permissible limits. No pH value is outside of the granted range, as demonstrated in Table 1. The electrical conductivity ratings of all the places are within the ranges of the Iraqi standard (0 to 0.75), which is connected to minimal salinity and authorized use, the pH and electrical conductivity were in the ranges this may be due to the absence of coal or iron sulfide minerals, our results are identical with [8]. Because the total dissolved solids (TDS) concentrations are consistently below the Iraqi limit of 1000 mg/L, the groundwater contains relatively few dissolved solids and salts. A Gibbs plot is a graphical tool for comprehending the major processes that control the hydrochemistry of water bodies, such as groundwater.

It entails comparing the ratio of specific ions to Total Dissolved Solids (TDS) to determine whether atmospheric precipitation, rock-water interaction, or evaporation have the greatest impact on water chemistry, or may be due to the small influence of sanitary conditions, chemical fertilizers, irrigation return flow, and industrial discharges as represented by (Sughosh Madhav, 2018) and [8]. Given data from multiple locations (Gerik Sindi, Hezawa, Bersive, Navkandala, and Av Gani), we can analyze the Gibbs plot ratios:

The cation ratio is Na/(Na + Ca). This ratio ranges from 0.149 to 0.173, indicating that sodium contributes far less than calcium. This indicates that rock-water interaction may have a greater impact on water chemistry than evaporation. The anion ratio $Cl/(Cl+HCO_3)$ $Cl+HCO_3$): The values range from 4.96 to 5.3, which are significantly high. However, these values appear to have been calculated incorrectly based on the information provided. Since it shows the percentage of chloride to the total of bicarbonate and chloride, this ratio should normally be less than one. The ratios will be significantly lower if we perform accurate calculations using the given meq/L values. For instance, $Cl/(Cl+HCO_3) = 0.7/ (0.7+4.14) \approx 0.144$ in Gerik Sindi.

Bicarbonate dominance, which suggests rock-water interaction, is indicated by this updated computation. The fact that (HCO_3) bicarbonate predominates over chloride suggests that in these regions, groundwater chemistry is most influenced by rock-water interaction. This conclusion is further supported by the cation ratios, which demonstrate a notable contribution from calcium, which is typical in systems that are dominated by rocks. The high TDS readings (varying from 350 to 368 mg/L) may imply some evaporation influence, although this is not the dominant cause, according to the Gibbs plot analysis [22].

The plot demonstrated that rock weathering was a significant contributor to key ions in the water table (1) (Fig. 3). The influence of rock-water contact on groundwater is likely amplified by persistent climatic conditions and surface contaminants, particularly from overuse of fertilizers, irrigation runoff, industrial effluents, and household waste.

The primary ion composition provides inform ation about the hydrogeological and hydro-chemical characteristics of the groundwater system. By categorizing the groundwater into hydro-chemical types, the fundamentals of hydro-geochemistry in the study area can be understood. The Schoeller classification, which is based on the presence of seven major ions in groundwater, was used to classify and define the groundwater in the study area [4]. Figure (4), Table (2). illustrates that Ca^{2+} is the dominant cation and HCO_3 − is the primary anion in the study area's groundwater composition.

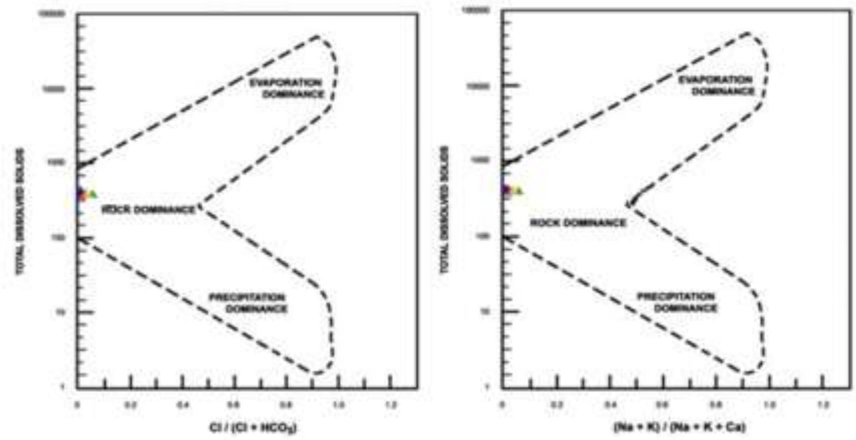

Figure 3: Mechanistic Analysis of Ground Water Composition Variations by Gibb's Diagram.

To better understand the hydro-geochemical processes, a Piper trigram was constructed for this study, leveraging its resistance to human intervention. Figure 4 shows the Piper trigram, which highlights the primary ion components in the study area. In terms of cations, the vast majority of the samples were located in the lower left delta-type region's B and C regions. This indicated that there was no dominant type in Gerik Sindi, Hezawa, Bersiva, and AvGani, and a mixture of Magnisum-type for Nav Kandala. Bicarbonate-type water is prevalent in (Gerik Sindi, Hezawa, Bersiva, and Nav Kandala), as evidenced by the majority of the samples clustering in the E region of the delta-type area towards the lower left (Figure 4).

Nonetheless, the bulk of the samples were located in the lower left (AvGani) B region of the delta-type region, suggesting a preponderance of bicarbonate-type water. For (AvGani), this indicated a mix-type mixture; therefore, carbonate hardness surpasses 50%-type in (Gerik Sindi, Hezawa, Bersiva, and Nav Kandala) and the identical job were done [22].

The TSS range is not very wide between locations. As Table 1 illustrates, it is challenging to ascertain the environmental significance of these values because there are no established standards. The Iraqi turbidity threshold of 10 NTU is significantly exceeded, signifying clean water with suspended organic and inorganic particles such sediments or microscopic organisms. All of the major ions' concentrations, chloride, calcium, magnesium, sodium, potassium, carbonate, CO_3^{-2}, and sulfate, usually lie within the Iraqi criteria, which indicates that they are all generally within allowable bounds. The overall hardness levels vary by region. Iraqi criteria are not defined, but by contrasting them with general international norms, these values can be further understood the same work done by [18].

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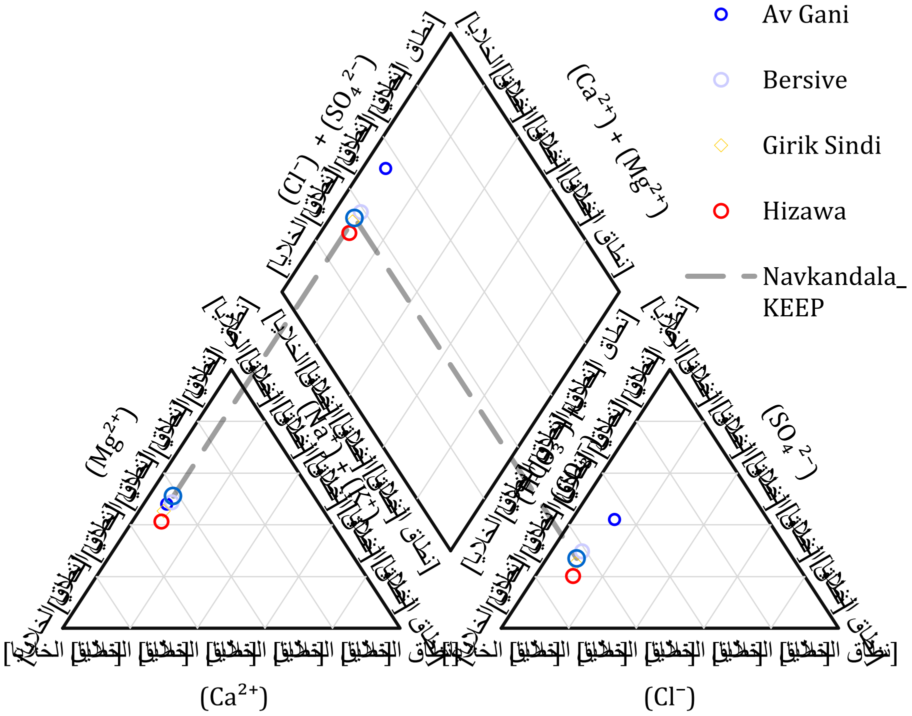

Figure 4: Groundwater types and faces plotted on Piper diagram

Table 1: Physio-chemical Characteristics Value in Groundwater samples.

Parameters	Sample Locations					Iraq Standard
	Gerik Sindi	Hezawa	Bersive	Nav kandala	Av Gani	
pH	7.12	7.04	7.01	7.13	7.22	6.5-8.5
Ec, dS.m-1	0.564	0.558	0.582	0.547	0.575	0–0.75
Total Dissolved Solids mg/L	360.96	357.12	355.02	350.08	368	1000
TSS mg/L	16.7	18.04	18.07	17.75	16.92	….
Total Hardness mg/L	298.49	268.73	343.12	309.74	343.17	500
Turbidity NTU.	0.3	0.3	0.4	0.3	0.3	10

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Table 2: Concentrations of Chemicals parameters in Groundwater samples.

Parameters	Sample Locations					Iraq Standard
	Gerik Sindi	Hezawa	Bersive	Nav kandala	Av Gani	
	meq/L					
Chloride (Cl^-)	0. 7	0.81	0.72	0.69	0.71	350
Calcium (Ca)	3.8	3.6	4.1	3.59	4.2	150
Magnesium (Mg)	2.2	1.8	2.8	2.64	2.7	100
Sodium (Na)	0.67	0.71	0.86	0.69	0.73	200
Potassium (K)	0.02	0.02	0.04	0.02	0.04	12
Bicarbonate HCO_3=	4.14	4.2	3.96	4.2	4.3	30-600
Sulfate $(SO_4)^-$	2.45	1.96	3.14	2.84	3.17	250

Coliforms, a group of ubiquitous bacteria, can be found in soil and water, as well as within the digestive systems of humans and animals. The majority of common coliforms are not harmful and play a vital role in the digestive system. Fecal coliform bacteria are found specifically in the feces and intestines of warm-blooded animals. According to Table 3 bacterial indicators (MPN and E-Coli), which suggest little to no bacterial pollution, Iraq's groundwater meets the standards for acceptable water quality. This is return to the advanced cleaning systems such as disinfection, filtration, and chlorination are commonly used to eliminate or reduce the presence of coliform bacteria, advanced technologies, including ultraviolet (UV) disinfection and membrane filtration, are also employed for enhanced treatment efficacy [13].

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Table 3: Biological Characteristics Value in Groundwater samples

Parameters	Sample Locations					Iraq Standard
	Gerik Sindi	Hezawa	Bersive	Nav kandala	Av Gani	
Bacteriological: MPN, cfu/ml	0	0	1*10-1	0	0	1-10
E-Coli	Nil	Nil	Nil	Nil	Nil	….
Organic compound	….	….	….	….	….	….

Heavy metals can leach into drinking water from household plumbing and service lines, mining operations, petroleum refineries, electronics manufacturers, municipal waste disposal, cement plants, and natural mineral deposits. The trace elements concentrations in Iraq generally follow Iraqi regulations, although there are a few sites where the metal concentrations are either near or over the acceptable norms. Further investigation may be required to assess any environmental impacts. In Addition, the groundwater quality near oil and gas operations in the defined regions often satisfies Iraqi criteria. In-depth investigation and monitoring may be necessary to assess the long-term impacts on the environment and public health [15].

Table 4 : Trace Metals (Fe, Mn, Cd, Pb, Cu) Values

Parameters	Symb.	Unit	Sample Locations					Iraq Standard
			Gerik Sindi	Hezawa	Bersive	Nav kandala	Av Gani	
Iron	Fe	meq/L	0.9	0.87	0.93	0.89	0.85	0.3
Manganese	Mn		0.52	0.64	0.59	0.51	0.55	0.1
Cadimoum	Cd		0.0001	0.0000	0.0000	0.0002	0.0000	0.003
Lead	Pb		0.0021	0.0001	0.000	0.0013	0.0010	0.01
Copper	Cu		0.2	0.00	0.18	0.19	0.3	1.0

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HPI index Based on the data from the sample stations at Gerik Sindi, Hezawa, Bersiva, Nav Kandala, and Av Gani, we can observe the following: Iron (Fe): Concentrations are relatively low and consistent across all locations, around 0.4 mg/l. Manganese (Mn):

Concentrations are high and consistent across all locations, with values averaging 10.4 mg/L. Cadmium (Cd) concentrations are also high and consistent, at approximately 150 mg/L. Lead (Pb): Concentrations are significant; equals (0) zero mg/L. Copper (Cu): Concentrations are high and consistent, averaging around 7.1 mg/L [1]

The contamination results from the characteristics of the soil and the compositions of the underlying rocks. Weathering and leaching of soluble salts from the soil and the underlying rocks can impact the region's water resources, the variances in these locations are most likely due to differences in the heavy metals concentrations assessment schemes used by HPI index [15].

Table 5: Statistical average by HPI value of ground water samples.

Parameters	Symb.	Unit	Sample Locations					HIP Average Standard
			Gerik Sindi	Hezawa	Bersive	Nav kandala	Av Gani	
Iron	Fe	meq/L	0.4	0.4	0.3	0.4	0.4	0.4
Manganese	Mn		10.4	10.3	10.4	10.4	10.4	10.4
Cadmium	Cd		150	150	150	150	150	150
Lead	Pb		0.0	0.0	0.0	0.0	0.0	0.0
Copper	Cu		7.1	7.1	7.1	7.1	7.1	7.1

Discussion

The findings indicate that, while some areas have acceptable water quality parameters suitable for specific uses such as irrigation due to low TDS levels and appropriate ion balances, others face challenges due to high salinity or contamination.

Advanced treatment methods may be required to improve water quality that falls short of standards.

Continuous monitoring is required to assess the long-term environmental impacts of industrial activities and agricultural runoff on groundwater resources.

Overall, these studies highlight the importance of understanding local hydro geochemical processes when assessing water resources across the KRG.

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Conclusions

The comprehensive analysis of groundwater quality near oil and gas operations reveals that the water consistently meets Iraqi regulatory standards, pH readings ranged from neutral to slightly alkaline, indicating chemical stability. Electrical conductivity, total dissolved solids, turbidity, and major ion concentrations all affirm the absence of pollution or salinity concerns, while bacterial markers indicate low contamination levels that are below safe microbiological limits.

Although total hardness levels vary and trace metal concentrations are generally within acceptable limits, certain areas warrant further investigation because some measurements lack defined regulatory thresholds.

These findings highlight the important necessity for continual study and monitoring to ensure groundwater quality in the face of industrial activities.

The findings also highlight the necessity of tight regulatory frameworks, long-term pollution control plans, and proper waste disposal procedures in effectively managing groundwater resources while protecting public health and the environment.

In addition, it is necessary to continuously assess and monitor the quality of groundwater in order to track changes over time and determine the effectiveness of management strategies. In summary, this study highlights the necessity of sustained evaluation efforts to ensure groundwater remains a safe and sustainable resource for current and future generations.

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