Agriculture College – Wasit University

Dijlah Journal of
Agricultural Sciences

ISSN 2790 – 5985
eISSN 2790 – 5993

Dijlah J. Agric. Sci.، 5(1):52-63, 2026

Assessment of Groundwater Contamination by Heavy Metals (Cu, Pb, Cd, Cr, Co) in th Region of Wasit Governorate

Ban Firas Jalil Al-Saaeidi[1], Layth Saleem Salman Al-Shihmani[2], and Jamal Naser Abedalrahman[3]

[1,2,3] **Department of Soil and Water Resources, College of Agriculture, University of Wasit, Wasit, Iraq**

Corresponding author: ban@uowasit.edu.iq

Abstract:

A study was conducted to evaluate the groundwater quality and the extent of its contamination with heavy metals (Cu, Pb, Cd, Cr, Co) in the eastern part of Wasit Governorate within the areas of Badra and Zarbatia for 21 systematic wells, including 7 wells in Zarbatia lands and 14 wells in Badra lands. Groundwater samples from the wells were collected during four seasons starting from 15/8/2024 to 15/3/2025 for the study area, then placed in plastic bottles, and heavy metals (copper Cu, lead Pb, cadmium Cd, chromium Cr, cobalt Co) were measured using Atomic Absorption Spectrophotometer. The water quality was then evaluated according to the adopted standards to determine the risk of heavy metal contamination in the study area, during the four seasons, and according to Iraqi and international water quality standards and criteria.

The ranges of total concentrations of the five studied heavy metals (copper Cu, lead Pb, cadmium Cd, chromium Cr, cobalt Co) in well water were (0.093–0.486), (0.089–0.605), (0.09–0.175), (0.169–0.483), (0.091–0.147) mg L^{-1}, respectively. Natural factors such as rainfall, floods, and geological formations, in addition to human activities such as agriculture, mining, irrigation, fertilization, pest control, and human waste—whether industrial, military, or domestic—affected the supply of heavy metals to groundwater. The results showed that cadmium ion exceeded the limits of the World Health Organization, the United States Environmental Protection Agency, and Health Canada but remained within Iraqi standards. Chromium and lead exceeded all international and Iraqi standards, while cobalt ion was within Iraqi limits, and copper concentrations were below the internationally permitted limits but exceeded Iraqi standards .

Therefore, research and studies on heavy metals for these wells in Badra and Zarbatia should be given attention to assess the level of contamination and seek appropriate solutions.

Keywords: ***Groundwater, wells, heavy metals, lead, copper, cadmium, chromium, cobalt, pollution.***

Received:22/9/2025 **Accepted:19/10/2025** **Published:11/1/2026**

تقييم مدى تلوث المياه الجوفية بالعناصر الثقيلة (Cu ، Pb، Cd، Cr، Co) في منطقة شرق محافظة واسط

بان فراس جليل السعيدي **ليث سليم سلمان الشهماني** **جمال ناصر عبد الرحمن**

قسم التربة والموارد المائية، كلية الزراعة، جامعة واسط، واسط، العراق

المستخلص

اجريت دراسة لتقييم نوعية المياه الجوفية ومدى تلوثها بالعناصر الثقيلة (Cu، Pb، Cd، Cr، Co) في شرق محافظة واسط ضمن منطقتي (بدرة و زرباطية) ل21 بئر نظامي ، حيث شملت 7 ابار في أراضي منطقة زرباطية و14 بئر في أراضي بدرة ، جمعت عينات من المياه الجوفية للأبار خلال اربع مواسم ابتداء من تاريخ 15\8\2024 الى 15\3\2025 لمنطقة الدراسة ثم وضعت العينات في قناني بلاستيكية وتم قياس العناصر الثقيلة) النحاس Cu , الرصاص Pb , الكادميوم Cd , الكروم Cr , الكوبلت (Co بجهاز الامتصاص الذري . ثم جرى تقييم نوعية المياه وحسب المعايير المعتمدة لتحديد خطورة التلوث بالعناصر الثقيلة ضمن منطقة الدراسة وللمواسم الأربعة وبحسب المعايير والمحددات العراقية والعالمية لنوعيات المياه المتبعة.

بلغت مديات تراكيز العناصر الثقيلة الكلية للعناصر الخمسة المدروسة) النحاسCu ، الرصاصPb ، الكادميومCd ، الكروم Cr، الكوبلت (Co في مياه الابار (0.486-0.093)، (0.605-0.089)، (0.175-0.09)، (0.483-0.169)، (0.091-0.147) مليغرام لتر-1 على التوالي. اثرت العوامل الطبيعية كالأمطار والسيول والتكوينات الجيولوجية بالإضافة الى النشاطات البشرية كالزراعة والتعدين والري والتسميد والمكافحة والمخلفات البشرية سواء الصناعية او الحربية او المنزلية في امداد المياه الجوفية بالعناصر الثقيلة.. أظهرت نتائج أيون الكادميوم قد تجاوزت حدود منظمة الصحة العالمية ووكالة حماية البيئة الأمريكية والصحة الكندية وبقيت ضمن المحددات العراقية.. اما الكروم والرصاص قد تجاوزت جميع المواصفات الدولية والعراقية أما أيون الكوبلت كان ضمن الحدود العراقية ، اما تراكيز النحاس فقد انخفضت عن الحدود المسموح بها دولياً لكنها تجاوزت المواصفات العراقية. لذا يجب الاهتمام بالأبحاث والدراسات للمعادن الثقيلة لتلك الآبار في منطقتي بدرة وزرباطية لتقييم مستوى التلوث فيها والبحث عن الحلول المناسبة.

الكلمات المفتاحية: *المياه الجوفية، ابار، العناصر الثقيلة، الرصاص، النحاس، الكادميوم، الكروم، الكوبلت، تلوث*.

Introduction

The eastern region of Wasit Governorate is considered an important area for the utilization of water resources, especially groundwater, due to its exposure to intermittent flood seasons and long dry periods, in addition to the limited surface water and weak utilization of floodwaters. With the increasing effects of climate change, low rainfall in recent years, and the decline of the Tigris and Euphrates rivers' levels, the demand for groundwater has increased, leading to more well drilling to meet drinking and irrigation needs (Nassif and Jawad, 2013). The reliance on these resources has accelerated in arid and semi-arid areas due to water scarcity, population growth, and the expansion of agricultural activities, which has resulted in the overexploitation of groundwater, especially in border areas with Iran where surface water is absent.

Since groundwater represents a vital natural resource, its mismanagement and lack of protection from pollution sources lead to a decline in its quality and negative economic and environmental impacts (WHO, 2011). Water resources generally suffer from scarcity, depletion, and pollution in various forms, which necessitates reliance on water quality indicators to improve their quality (Talabi and Kayode, 2019). Groundwater is affected by multiple factors, including geographical location, well depth, and climatic changes, as its slow movement increases contact with rocks and raises dissolved substances concentrations (Al-Saadi, 2017). Salts and heavy metals may also infiltrate through groundwater or surface runoff and travel long distances before settling in aquifers (Hu et al., 2025).

The term heavy metals have no precise definition; generally, heavy metals include elements with a specific density greater than 6 g cm^{-3} and atomic numbers greater than 20, also called trace elements, because they occur at concentrations less than 100 mg kg^{-1}. There are 38 heavy metals, some of which are toxic under very specific conditions due to deposition and adsorption processes, including lead, cobalt, and cadmium. Lead and cadmium are elements that can be absorbed by plants and then enter the food chain (Zaikov *et al*., 2017).

Pollution by heavy metals is highly hazardous to health. The main sources of these elements are industrial, mining, domestic, and agricultural discharges (Obeid, 1988; Al-Gharawi, 1999). High concentrations of ions and toxic elements change water quality and may lead to its pollution, related to both natural and human sources such as weathering, mineral dissolution, volcanic activity, mining, burning coal, and wastewater discharge (Abdur et al., 2018). Researchers in recent decades have given increasing attention to heavy metal pollution in water due to the serious health and environmental risks when their levels exceed internationally permitted limits (Abdullah, 2013; Elhdad, 2019).

Human activities in general are among the most important causes of water quality deterioration, making it unsuitable for human use (Al-Abdali et al., 2020). Agricultural activities are considered one of the main indirect sources of groundwater pollution due to the random use of fertilizers, pesticides, and animal waste, which increase the concentrations of nitrogen, chloride, and other pollutants (Bob et al., 2016). Residential activities in landfill sites and waste disposal, along with chemical leaks, contribute to introducing many pollutants (Sahu and Kacholi, 2018). Mining and mineral extraction activities also have an effect (Al-Muhannawi, 2023).

Due to the increasing reliance on groundwater in the eastern areas of Wasit Governorate, evaluating the quality of these waters has become necessary to determine their suitability for different uses. The issue of assessing groundwater quality has not received sufficient attention previously, despite the potential for contamination and high concentrations of some harmful heavy metals with negative impacts on the environment and human health. Accordingly, this study aims to evaluate the groundwater quality in the eastern part of Wasit Governorate to determine the extent of its pollution and its content of harmful heavy metals.

Materials and Methods

Study Area

The study area is located in Iraq within Wasit Governorate, specifically in Badra District and part of Zurbatiyah Subdistrict. Zurbatiyah lies to the northeast of Badra and represents the international border separating Iraq from neighboring Iran. The study area covers approximately 6,500 km², currently witnessing important phases of construction, development, and investments in the agricultural, industrial, and tourism sectors. Geographically, the area is located between longitudes (E 45°20′–46°46′) and latitudes (N 33°–33°30′), as shown in Figure (1).

Fieldwork and Water Sample Collection

Multiple field visits were conducted to explore the study area, examine its geographical and agricultural nature, determine its extent, and identify the wells. Twenty-one wells within the study area were selected randomly for determining some chemical and physical characteristics and evaluating the suitability of groundwater for various uses. Their locations were recorded using a GPS device. Samples were collected from the wells after operating the installed pumps and placed in 1.5-liter plastic bottles after ensuring their cleanliness.

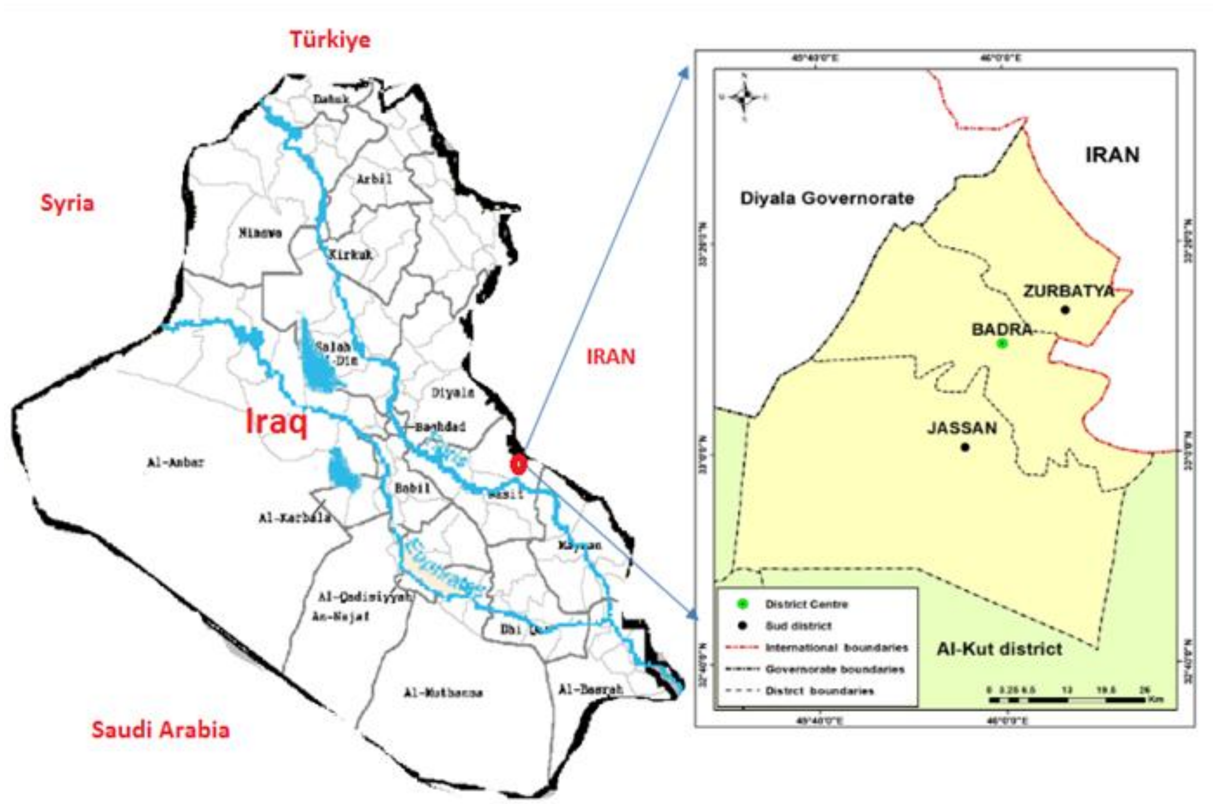

Figure 1: The study area is located in Iraq within Wasit Governorate, Badra.

Sampling was conducted on four occasions across different seasons of the year as following schedule:

- First sampling: August 15, 2024
- Second sampling: November 15, 2024
- Third sampling: January 15, 2025
- Fourth sampling: March 15, 2025 (final sampling period)

Table 1. Names and coordinates of wells within the study area

Well Code	Registered Well Name	Location	X (Longitude)	Y (Latitude)
A1	Hazem Abbas Majid	Badra	45.946734	33.108695
A2	Sami Sharad	Badra	45.960295	33.112428
A3	Imad Salman Barfi	Badra	45.948708	33.110728
A4	Ali Hashim	Badra	45.951841	33.194530
A5	Ali Alwan Abd Al-Sahib (1)	Badra	45.57569	33.831900
A6	Ali Alwan Abd Al-Sahib (2)	Badra	45.57632	33.803080
A7	Ali Alwan Abd Al-Sahib (3)	Badra	45.57366	33.805030
A8	Khudair Mani	Badra	45.97956	33.125160

A9	Qasim Abd Al-Wahid Buri	Badra	45.92660	33.109100
A10	Abd Al-Hussein Farhan	Badra	45.97514	33.128380
A11	Hassan Lafta Asad	Badra	45.98268	33.124080
A12	Lakin Ansar	Badra	45.96340	33.112320
A13	Abd Al-Razzaq Abd Al-Raouf	Badra	45.95288	33.115950
A14	Basel Abd Al-Razzaq	Badra	45.95445	33.114950
A15	Iyad Ahmed Faraj	Zurbatiya	45.98208	33.150260
A16	Abd Al-Sahib Abd Al-Karim (1)	Zurbatiya	—	—
A17	Jasim Mohammed Jasim	Zurbatiya	46.055739	33.145387
A18	Abd Al-Sahib Abd Al-Karim (2)	Zurbatiya	46.078010	33.139294
A19	Wahab Karim	Zurbatiya	45.92660	33.109100
A20	Al-Walida	Zurbatiya	46.564889	33.148528
A21	Hussein Hadi	Zurbatiya	46.059357	33.148120

Measurement of Dissolved Heavy Metals in Groundwater

After collecting groundwater samples on the specified dates, the concentrations of heavy metals (lead, copper, cadmium, chromium, cobalt) in the studied wells were measured using a Flame Atomic Absorption Spectrophotometer (FAAS), according to APHA (2017). Statistical Analysis System (SAS, 2018) was used to analyze the data to study the effect of season, location (Zurbatiyah and Badra), and their interaction on the studied properties according to a Randomized Complete Block Design (RCBD). Differences between means were compared using the Least Significant Difference (LSD) test.

Water, especially well water, is classified according to its suitability for agricultural and domestic purposes by measuring the concentration of heavy metals and comparing them with critical limits of international standards such as the World Health Organization (WHO), the United States Environmental Protection Agency (USEPA), Health Canada, and Iraqi standards (IQS), to determine the conformity of groundwater characteristics with global and local criteria for human consumption.

Results and Discussion

Heavy Metals in Groundwater

1. Lead (Pb) Concentration

Lead (Pb) occurs in nature combined with sulfur in the mineral galena (PbS). One of the most important sources of lead pollution is gasoline engine exhaust, accounting for about 80% of total lead in the air (Sherene, 2010).

The results of lead concentrations in Table (2) indicate significant differences in lead values between locations and in the interaction between lead and seasons at a probability level of 0.05. However, no significant differences were observed between seasons. The mean lead values (Table 2) showed a significant increase in Zurbatiyah, reaching 0.386 mg L^{-1} compared to Badra, which reached 0.267 mg L^{-1}. This may be attributed to several reasons, including differences in geological nature, as some types of rocks, such as sedimentary rocks containing heavy minerals with natural lead content, may release lead into groundwater through geochemical processes. In addition, differences in pollution sources are important, as most war residues were in Zurbatiyah, affecting lead levels, since military barracks existed in the area during the 1980s and battles occurred during the eight-year Iran-Iraq war. Residues carrying lead may have infiltrated groundwater (Al-Mahnawi, 2023).

Table 2. Lead (Pb) values (mg L^{-1}) in groundwater wells of the study area

Season	Zurbatiya	Badra	Mean
Summer	0.384	0.265	0.325
Autumn	0.386	0.264	0.325
Winter	0.387	0.261	0.324
Spring	0.387	0.278	0.333
Mean	0.386	0.267	—

LSD values:
Location = 0.052*, Season = 0.069 (ns), Interaction = 0.103*, *Significant at $P \leq 0.05$.

2. Copper (Cu) Concentration

Copper deposition in water generally depends on the presence of other elements in the aquatic environment and its properties, such as oxygen content, water temperature, total hardness, and type of other dissolved salts (Al-Haik, 2017).

The results of copper concentrations in Table (3) show significant differences in copper values between the two locations and the interaction between copper and seasons at a probability level of 0.05, while no significant differences were found between seasons. The mean values of copper ion in Table (3) show significant differences between the two locations, with Zurbatiyah recording 0.326 mg L^{-1} compared to Badra, which recorded 0.264 mg L^{-1}. Spatial differences between study sites are evident. The lower copper concentrations may be due to small amounts of copper precipitated at the bottom (Al-Mashhadani, 2019; Al-Mahnawi, 2023). Copper-bearing minerals in the Earth's crust are limited and have low solubility. Copper ionic forms may adsorb onto clay minerals or combine with compounds like copper sulfide due to variations in sulfur content between the two locations. Additionally, copper may be affected by the alkaline conditions of water (Awad, 2024).

Table 3. Mean copper (Cu) concentrations (mg L^{-1}) in groundwater wells of the study area

Season	Zurbatiya	Badra	Mean

Summer	0.338	0.273	0.306
Autumn	0.315	0.259	0.287
Winter	0.322	0.256	0.289
Spring	0.328	0.266	0.297
Mean	0.326	0.264	—

LSD values:
Location = 0.039*, Season = 0.052 (ns), Interaction = 0.078* *Significant at $P \leq 0.05$.

The higher copper levels in Zurbatiyah may be due to higher copper content in geological formations containing copper minerals such as basalt or igneous and metamorphic rocks with copper sulfides. Variations in pH also affect solubility, as copper dissolves more in lower pH water than in alkaline water. Oxidizing conditions may increase the solubility of some copper forms in water. Mining and metal extraction may lead to copper leaching into groundwater. Additionally, war residues or the use of chemical fertilizers and pesticides to increase agricultural productivity contribute to copper pollution. Hydrogeological conditions may also affect the movement and accumulation of copper in groundwater (Sadiq, 2020).

3. Cadmium (Cd) Concentration

Cadmium occurs in nature in its metallic state (Cd) and is rarely found as cations (Cd^{2+}), which are dominant in most natural sediments. Cadmium minerals are generally insoluble in water, but it can enter the environment through natural processes such as weathering, volcanic eruptions, and forest fires, while its salts can dissolve easily (Southerland, 2016). Cadmium may also originate from human activities such as mining, agriculture, industrial waste discharge, coal ash, fossil fuels, and sewage processes (Rini & Charles, 2018).

The results for cadmium values in Table (4) indicate significant differences between seasons and their interaction at a 0.05 probability level, while no significant differences were observed between locations. The mean cadmium ion values in Table (4) show no significant differences between locations, with only slight, non-significant variations, suggesting no substantial difference in the number of cadmium-containing pollutants in nature between the sites. Agricultural and human uses of cadmium-containing fertilizers and pollutants also show no variation between locations or in groundwater (Abbas, 2018).

Table 4. Mean cadmium (Cd) concentrations (mg L^{-1}) in groundwater wells of the study area

Season	Zurbatiya	Badra	Mean
Summer	0.137	0.131	0.134
Autumn	0.114	0.120	0.117
Winter	0.132	0.124	0.128
Spring	0.261	0.130	0.196
Mean	0.161	0.126	—

LSD values:
Location = 0.039 (ns), Season = 0.052*, Interaction = 0.079* *Significant at P ≤ 0.05.

The results showing in table (4) show significant seasonal differences for cadmium during the study period, with the highest mean recorded in spring at 0.196 mg L^{-1} and the lowest in autumn at 0.117 mg L^{-1}. This may be due to heavy rainfall during spring, which increases surface water flow into groundwater, potentially carrying cadmium from various sources such as agricultural activities and industrial discharge. Groundwater levels may also rise due to natural recharge, causing dissolution of heavy minerals from rocks or soil into groundwater. Increased human activity during the spring agricultural season, including fertilizer and pesticide use, may also raise the likelihood of cadmium leaching into groundwater. Additionally, higher rainfall and floods in spring may wash fertilizers, pesticides, and heavy metal residues from surface soil into groundwater layers (Chowdhury et al., 2025).

Regarding the interaction between locations and seasons, significant differences were observed. The highest cadmium levels were recorded in both sites during summer at 0.131 mg L^{-1} and in Zurbatiyah during spring at 0.126 mg L^{-1}. Cadmium in Badra during summer exceeded the overall mean by 3.9%, while in Zurbatiyah during spring, cadmium concentration exceeded the overall mean by 62.11%.

4. Chromium (Cr) Concentration

Chromium (Cr) contamination in groundwater and soil has become a major environmental concern worldwide. In nature, chromium exists mainly in two oxidation states: Cr (VI) and Cr (III). Among these, Cr (VI) is characterized by high mobility, solubility in aqueous solutions, and resistance to natural biodegradation, making it a particularly hazardous pollutant (Hu et al., 2025).

The results of chromium concentrations in Table (5) indicate significant differences between locations and in the interaction between chromium and seasons at a probability level of 0.05, while no significant differences were found between seasons.

Table 5. Mean chromium (Cr) concentrations (mg L^{-1}) in groundwater wells of the study area

Season	Zurbatiya	Badra	Mean
Summer	0.358	0.329	0.344
Autumn	0.342	0.308	0.325
Winter	0.351	0.307	0.329
Spring	0.361	0.317	0.339
Mean	0.353	0.315	—

LSD values:
Location = 0.029*, Season = 0.040 (ns), Interaction = 0.048*, *Significant at P ≤ 0.05

Table (5) results show the highest mean chromium value in Zurbatiyah at 0.353 mg L^{-1}, while in Badra it was 0.315 mg L^{-1}. This may be due to several reasons, including that Zurbatiyah may contain rocks or minerals with naturally higher chromium concentrations, or due to the use of fertilizers and pesticides containing chromium, which increase its levels. Hydrogeological conditions such as groundwater flow rate, porosity, and soil chemical composition also influence the movement and distribution of chromium in groundwater (Rini & Charles, 2018).

5. Cobalt (Co) Concentration

Cobalt exists in groundwater in several forms, including dissolved ions, colloidal particles, and organic complexes. However, dissolved cobalt ions are the most common and can interact with organic matter to form complexes, increasing their mobility in groundwater (Havlin, 2014).

The results of cobalt values in Table (6) show significant differences between locations, seasons, and their interaction at a 0.05 probability level. The mean cobalt values in Table (6) indicate a significant increase in Zurbatiyah at 0.124 mg L^{-1} compared to Badra at 0.113 mg L^{-1}. This may be attributed to several factors, including differences in geological formations and cobalt sources between the locations. Some rocks or minerals rich in cobalt, such as basalt and metallic rocks, may be more abundant in one location, leading to leaching into groundwater. Differences in the intensity of industrial, agricultural, and mining activities between locations can affect the amount of cobalt released. Chemical conditions such as pH, the presence of organic matter, and redox conditions in groundwater also influence cobalt behavior and mobility (Al-Dhifan & Al-Rais, 2018).

Table 6. Mean cobalt (Co) concentrations (mg L^{-1}) in groundwater wells of the study area

Season	Zurbatiya	Badra	Mean
Summer	0.123	0.111	0.117
Autumn	0.121	0.106	0.114
Winter	0.122	0.112	0.117
Spring	0.128	0.124	0.126
Mean	0.124	0.113	—

LSD values:
Location = 0.0074*, Season = 0.009*, Interaction = 0.015*, *Significant at $P \leq 0.05$

The current study results indicate significant seasonal differences, as shown in Table (6). The highest mean cobalt concentration was recorded in spring at 0.126 mg L^{-1}, while the lowest was in autumn at 0.114 mg L^{-1}. This may be due to increased rainfall in spring, which enhances water flow through soil and rocks, increasing cobalt dissolution. Spring also coincides with higher agricultural activity, including irrigation, fertilization, pest control, and rising temperatures, which together enhance cobalt mobilization during this season.

Groundwater Pollution by Heavy Metals

Table (7) shows that cadmium ion (Cd^{2+}) values exceed the permissible limits according to WHO (2011), USEPA (2007), and Health Canada (2013), but remain within Iraqi standards (IQS, 2009). No international standards were found for cobalt ions, although cobalt is toxic at high concentrations; its levels did not exceed Iraqi limits.

Table 7. Classification of groundwater based on heavy metal concentrations according to international and local standards

Heavy Metal	WHO (2011)	USEPA (2007)	Health Canada (2013)	IQS (2009)	Present Study
Cadmium (Cd)	0.03	0.005	0.005	1	0.059–0.175
Cobalt (Co)	—	—	—	0.5	0.09–0.203
Chromium (Cr)	0.05	0.10	0.005	0.05	0.169–0.512
Copper (Cu)	2.0	1.3	1.0	0.03	0.093–0.491
Lead (Pb)	0.01	0.015	0.01	0.01	0.089–0.605

Chromium (Cr) values exceed all international and Iraqi drinking water standards and are therefore unsuitable for consumption. Copper (Cu) values do not exceed international limits and are suitable for drinking after treatment, but exceed Iraqi standards. Lead (Pb) values exceed all international and local standards, making the water unsafe for drinking.

The presence of these pollutants in groundwater in the study area may result from fertilizer leaching containing heavy metals, certain pesticides, industrial or war-related waste infiltrating groundwater, and natural geological formations that release metals into groundwater.

References

- **Al-Jubouri, H. T. (2013)**. *Groundwater Systems in the Euphrates Basin between Hit and Haditha.* Master's Thesis, College of Education–Ibn Rushd, University of Baghdad.
- **Al-Mhanawi, N. J. S. (2023).** *Study of Some Heavy Metals in Well Water and Soil Using Al-Aqool Plant as a Bioindicator of Pollution.* Master's Thesis, College of Science, University of Al-Qadisiyah.
- **Al-Khatib, S. A. (2012).** *Water Pollution.* Egyptian Library for Printing, Publishing, and Distribution, Alexandria University, Faculty of Agriculture.
- **Hmeil, A. S., Jabril, K., & Al-Warfali, H. (2016).** *Study of Heavy Metal Concentrations in Watermelon Fruit.* College of Science, University of Sabha, p. 8.
- **Ubaid, F. A. (1988).** *Methods of Analytical Chemistry.* Dar Al-Kitab Press, University of Mosul.
- **Al-Haik, N. (2017).** *Introduction to Water Chemistry (Pollution–Treatment–Analysis).* Higher Institute for Applied Science and Technology, Syrian Arab Republic, p. 122.
- **Al-Mashhadani, M. H. S. (2019).** *Environmental Reality of Khoser River Water and Some Treatment Techniques.* PhD Thesis, College of Education for Pure Sciences, University of Mosul.

- **Al-Saadi, H. A. (2017).** *Aquatic Environment.* Al-Yazouri Scientific Publishing, Amman, Jordan, p. 33.
- **Sadiq, A. J. F. (2020).** *Analytical Study of Well Water Pollution in Some Villages Around Kirkuk Governorate.* Master's Thesis, College of Science, University of Kirkuk.
- **Al-Dhifan, T. A. R., & Al-Rais, S. A. (2018).** *Guide to Interpreting Soil and Water Analysis Results.* Comprehensive Agricultural Library for Irrigation and Water – Agricultural Books.
- **Al-Gharawi, M. A. H. (1999).** *Measurement of Radioactivity in Imported Cereals and Legumes.* Master's Thesis, University of Baghdad.
- **Al-Abdali, B., Al-Ghaib, M. D., & Al-Zarbi, A. H. (2020).** *Evaluation of Groundwater Quality in Birsis, Green Mountain – Libya.* Libyan Journal of Environmental Science and Technology.
- **Abbas, A. K., & Al-Jubouri, H. H. R. (2018).** *Assessment of Lead, Nickel, and Cadmium Pollution from Industrial Waste in Euphrates Chemical and Cement Plants in Agricultural Soil of Babil Governorate.* Advanced Soil Science Journal, Vol. 18, No. 1, pp. 70–78.
- **Tuma, W. A. (2024).** *Impact of Emissions from Brick Factories in Al-Kut City on Physicochemical Properties and Pollution of Soil, Water, and Plants with Some Heavy Metals.* Master's Thesis, College of Agriculture, University of Wasit.
- **Abdullah, E. J. (2013).** *Evolution of Surface Water Quality Indices for Heavy Metals of Diyala River – Iraq*, 3(8), pp. 63–70.
- **Abdur, R., Dong-Xing, G., Abida, F., Sardar, K., Salman, Z., Shah, J., Seema, A. K., Muhammad, S. K., & Raees, K. (2018).** *Fluoride Prevalence in Groundwater Around a Fluorite Mining Area in the Floodplain of the River Swat, Pakistan.* Science of the Total Environment, 635, 203.
- **APHA (American Public Health Association). (2017).** *Standard Methods for the Examination of Water and Wastewater,* 23rd Edition, A.P.H.A., 1015 Fifteen Street, N.W., Washington DC, USA.
- **Bob, M., Rahman, N. A., Elamin, A., & Taher, S. (2016).** *Assessment of Groundwater Suitability for Irrigation in Madinah City, Saudi Arabia.* Arabian Journal of Geoscience, 9(38), 1–11.
- **Charles, C., & Rini, D. S. (2018).** *Cadmium Contamination and the Role of Bioaccumulator Plant as a Remediation Agent.* International Conference on Science and Applied Science (ICSAS).
- **Chowdhury, A. N., *et al*. (2025).** *Heavy Metal (Pb, Cd, and Cr) Contamination and Human Health Risk Assessment of Groundwater in Kuakata, Southern Coastal Region of Bangladesh.* Geosystems and Geoenvironment, 4(1), 100325.
- **Elhdad, A. M. A. (2019).** *Assessment of Surface Water Quality, Raw versus Treated, for Different Uses at Dakahlia Governorate, Egypt.* Egyptian Journal of Chemistry, pp. 1517–1529.

- **Havlin, J. L. (2014).** *Soil Fertility and Nutrient Management.* In Encyclopedia of Natural Resources: Land, pp. 460–469.
- **Health Canada. (2013).** *Minister Ambrose Addresses the 146th Canadian Medical Association Meeting – Working Together for Real Outcomes.* Retrieved February 1, 2014, from http://news.gc.ca/web/article-en.do?nid=765229.
- **Hu, D., *et al.* (2025).** *ZVI and Ball Milling Co-Modified Biochar for Chromium (Cr(VI)) Removal from Groundwater: Performance Optimization and Mechanisms.* Colloids and Surfaces A: Physicochemical and Engineering Aspects, 714, 136574.
- **IQS (2009).** *Standards of Water Quality (Iraqi Guideline).*
- **Jawad, M. A., & Nassif, D. M. (2013).** *Study of the Chemical and Physical Properties of Some Groundwater Wells and the Extent of Their Pollution in Samarra City.* Diyala Journal for Pure Sciences, 11(4), 15–23.
- **Kacholi, D. S., & Sahu, M. (2018).** *Levels and Health Risk Assessment of Heavy Metals in Soil, Water, and Vegetables of Dar es Salaam, Tanzania.* Journal of Chemistry, Article ID 1402674, 9 pages.
- **Sherene, T. (2010)**. *Mobility and Transport of Heavy Metals in Polluted Soil Environment.* Biological Forum - An International Journal, 2(2), 112–121.
- **Southerland, E. (2016).** *U.S. EPA, Aquatic Life Ambient Water Quality Criteria.* Office of Water, Office of Science and Technology.
- **Talabi, A. O., & Kayode, T. J. (2019).** *Groundwater Pollution and Remediation.* Journal of Water Resource and Protection, 1161–119.
- **USEPA (2007).** *National Recommended Water Quality Criteria.* Office of Water, Office of Science and Technology (4304T).
- **WHO (2011).** *Guidelines for Drinking Water Quality.* Geneva, Switzerland. Master Tree Grower Program, Melbourne, Australia.
- **Zaikov, G. E., Weisfeld, L. I., Lisitsyn, E. M., & Bekuzarova, S. A. (2017).** *Heavy Metals and Other Pollutants in the Environment.* Apple Academic Press, Inc.