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Analysis of Trace Metals in Groundwater from Mountain Springs

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Abstract

This study aimed to estimate the concentrations of several heavy metals, including cadmium (Cd), chromium (Cr), copper (Cu), iron (Fe), manganese (Mn), nickel (Ni), lead (Pb), and zinc (Zn), in fifteen springs around the Soran Independent Administration, Kurdistan Region of Iraq. Water samples were collected during two seasons (summer 2024 and winter 2025) and analyzed using inductively coupled plasma optical emission spectroscopy (ICP-OES). The results showed that most trace metals had higher concentrations in winter than in summer. The concentration ranges were: Cd (0.011–0.678 mg/L), Cr (0.300–0.548 mg/L), Cu (0.417–0.645 mg/L), Fe (0.022–0.199 mg/L), Mn (0.007–0.123 mg/L), Ni (0.002–0.047 mg/L), Pb (0.005–0.149 mg/L), and Zn (0.010–0.109 mg/L). Except for cadmium and chromium, which exceeded safe limits at all sites, the concentrations of most metals were generally below WHO guidelines for drinking water; however, lead at some sites also rendered the water unsuitable for drinking. According to the Heavy Metals Pollution Index (HPI), values above 100 in all studied springs (ranging from 405.94 to 16023.72 in summer and 811.12 to 1780.97 in winter) indicated contamination and unsuitability for human use. In contrast, based on the Metal Index (MI), most trace metals had values below 1, indicating no contamination. However, MI values for cadmium and chromium above 5 signified heavy pollution, and MI values for lead ranged from 0.5 to 22.2, varying from uncontaminated to heavily polluted. Based on these findings, this study recommends: (1) regular monitoring of Cd, Cr, and Pb concentrations; (2) implementation of pollution control measures, including regulated use of fertilizers and pesticides in surrounding agricultural areas; and (3) adoption of point-of-use water treatment systems for communities relying on these springs for drinking water.

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1. Introduction

Water is the most important and valuable natural resource upon which life on Earth depends. It plays a fundamental role in the development of various economic sectors, including agriculture, livestock, forestry, electricity generation, fish production, and other innovative activities [1, 2]. Nevertheless, the continuous growth of the human population increases the Water demand, and the sustainability of freshwater supplies is greatly threatened by widespread depletion of groundwater, pollution of surface water, and the impacts of climate change[3, 4]. Pollution of water with trace metals has numerous impacts on aquatic organisms, and the bioconcentration and bioaccumulation of these metals in the aquatic food chain put consumers, including humans, at risk [4]. The distribution and accumulation of metals in a water system are influenced by multiple factors, including sediment mineral composition and texture, adsorption processes, redox conditions, and physical transport.[5]. The term "heavy metals" colloquially refers to metallic elements with a high density. In biological contexts, this group includes both essential micronutrients (e.g., zinc, copper, iron) and non-essential elements, some of which can be toxic (e.g., lead, cadmium, mercury). Some heavy metals exhibit intense toxicity and harmful impacts [6]. Two main categories of metals are relevant to organisms. The first comprises essential elements, such as copper, iron, manganese, and zinc. These micronutrients, also known as trace elements, play vital roles in physiological and biochemical functions. While they are required for health, an excess of even these essential metals can become toxic. The second category includes non-essential elements, like cadmium, chromium, lead, and nickel, which are often environmental pollutants and are primarily toxic to organisms [7]. Trace metals enter the environment naturally or through geological processes, such as soil erosion, sediment movement, rock weathering, and volcanic activity. Pollution is also caused by acid rain, which carries heavy metals. Weathering and erosion of the Earth's crust release trace metals, which then enter the water system through surface runoff and groundwater flow. Household and industrial wastes, urban wastewater, fertilizers, and other factors are also attributable to human activities [8]. This study aims to evaluate the concentrations of selected trace metals in spring groundwater and to assess the level of contamination using different heavy-metal pollution indices.

2. Materials and Methods.

2.1. Description of the studied area

Soran is one of the largest and most important independent administrations in the Erbil Governorate, known for its natural water source and tourism potential, it consists of many districts and subdistrict like Haje-omaran, Choman, Qasre, Rwanduz and Khalifan, has an estimated population of around 200,000 to 250,000 People, who are located in northeastern Iraq at the coordinates line of 36.6539° N, 44.5421° E extended from latitude 36.6539° N and Longitude 44.5421° E. With Elevation a proximately 1,200 meters (3,937 feet) above sea level. It is characterized by its unique geology, water resources, climate, and soil conditions due to its location in the Zagros Mountains. The mountainous terrain results in numerous natural springs, which are a critical source of freshwater for local communities and livestock [9]. The distribution of sites across districts is as follows the site 1,2,3,4 and 5 belong to Choman District; however, the site 6,7,8, and 9 are shared between the Qasre and Rwanduz Districts. The Sreshma, Ble, and Malakan springs are located within the Khalifan and Malakan Districts, as shown in Figure 1 and Table 1.

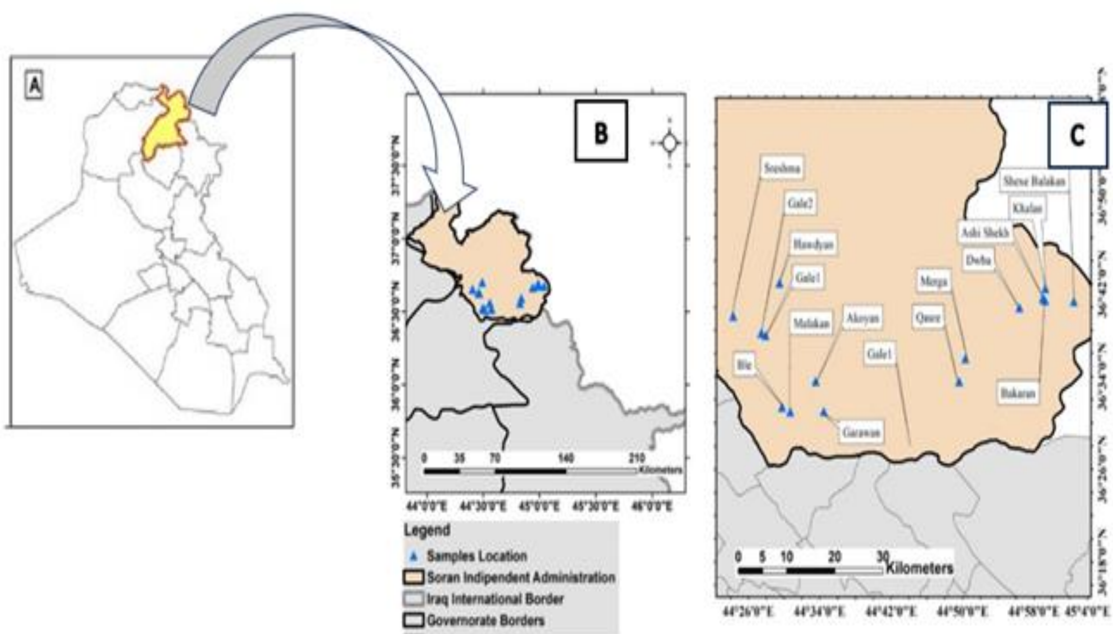

Figure. 1. Shown. A- Map of Iraq B- Map of Soran independent administration C- study sites from Haje Omran to Malakan

Table 1. The kind and site of the area studied within the Soran independent administration

Site	Location	X_Area	Y_Area	Height
1	Shekhe Balakan	45.040824	36.675352	1779m
2	Khalan	44.987777	36.693740	1685m
3	Bakaran	44.987344	36.676259	1610m
4	Ashe Shekh	44.987344	36.676259	1521m
5	Dwba	44.939418	36.665834	1253m
6	Merga	44.838565	36.592635	1198m
7	Qasre	44.826916	36.559788	1085m
8	Garawan	44.558500	36.565038	755m
9	Akoyan	44.573720	36.516546	1078m
10	Hawdyan	44.491611	36.701395	568m
11	Gale 1	44.465511	36.626497	522m
12	Gale 2	44.457355	36.629091	742m
13	Sreshma	44.405018	36.653759	852m
14	Ble	44.496157	36.523108	952m
15	Malakan	44.511539	36.516173	1012m

2.2. Collection of samples

2.2.1. Sampling Strategy

To ensure representativeness of the hydrogeological variability of the Soran region, fifteen springs were selected based on the following criteria: (1) geographic distribution across all districts (Choman, Qasre, Rwanduz, Khalifan, and Malakan), (2) elevation range from 522 m to 1779 m to capture different hydrogeological settings, and (3) accessibility for sampling during both seasons. The selected springs provide critical freshwater sources for local communities and livestock.

2.2.2. Sample Collection and Preservation

Water samples were collected from fifteen springs over two seasons: summer (August 2024) and winter (January 2025). During each season, samples were collected once from each spring, with three replicate samples taken per site per sampling event, resulting in a total of 45 samples per season (15 sites × 3 replicates). The water samples were collected in polypropylene containers that were pre-washed with deionized water to prevent contamination. Samples were immediately placed in a portable icebox at 4°C and transported to the laboratory within 6 hours of collection. Upon arrival at the laboratory, samples were filtered using a Whatman 0.45 µm filter paper. Nitric acid (HNO_3) was added to achieve a pH of less than 2.0 to reduce sedimentation and adsorption on the container walls [3].

2.3. Sample Analysis

The samples taken were analyzed to determine the values of heavy metals, including Cd, Cr, Cu, Fe, Mn, Ni, and Zn, utilizing inductively coupled plasma optical emission spectroscopy (ICP-OES), according to the standard method for the examination of water and wastewater[10].

2.4. Heavy Metal Contamination Indices

Heavy metal contamination indices are an assessment tool that provides the combined impact of every heavy metal on overall water quality. The accumulation and distribution of heavy metals in aquatic systems are governed by a complex interplay of geochemical factors, including sediment properties, adsorption processes, redox conditions, and physical transport. In this context, metals are critically classified as either essential trace elements (e.g., Cu, Fe, Zn), which are vital for biological functions but toxic at high concentrations, or non-essential elements (e.g., Pb, Cd, Hg), which are primarily toxic environmental pollutants. These metals can enter water bodies through natural processes like the weathering and erosion of the Earth's crust. Therefore, this study aimed to quantify the heavy metal concentrations in selected springs within the Sorn Independent Administration and assess their suitability for drinking water using established contamination indices. For the index calculations, weighting factors (W_i) were assigned to each metal based on its recommended standard value (S_i), following the methodology of [11].

For estimating the HPI index, the following steps were included:

1. Estimating the weight unit for all factors.
2. Determining the sub-index value.
3. Total of sub-index.

The weight of every factor can be estimated by utilizing Equation (1):

$W_i = K / S_i$ ……….(1)

For the calculation, sub-indices (Q_i) were derived for each metal. Here, **V_i** represents the measured concentration of the *i* variable (metal) in the water sample, and **S_i** represents its corresponding standard permissible limit or guideline value. The sub-index Q_i for each metal was then computed as the ratio of its measured concentration to its standard value.

$Q_i = 100\, V_i/S_i$ ……….(2)

Where Wi is the weight of the unit, Si is the permissible level mentioned in the standard for every factor.
The Heavy Metal Pollution Index (HPI) is calculated as follows:

$$\text{HPI} = \frac{\sum_{i=1}^{n} Q_i W_i}{\sum_{i=1}^{n} W_i}$$ ……….(3)

where:
Q_i is the sub-index of the i-th heavy metal,
W_i is the assigned unit weight of the i-th metal, reflecting its relative influence on water quality,
S_i is the permissible concentration level for metal i as per the World Health Organization (WHO) drinking water guidelines, and
n is the total number of heavy metals considered.
The sub-index Q_i is defined as:

$$Q_i = \frac{C_i}{S_i} \times 100$$

where C_i is the measured concentration of metal i in the water sample. The critical threshold for the HPI is 100, indicating the maximum acceptable pollution level [11]

2.5. Single factor pollution index method

The single-factor pollution index (SFPI) method evaluates contamination by comparing measured pollutant concentrations with established environmental quality standards [12]. Advantages include easy operation and simplicity of application; however, it is just used to reflect the pollution degree of each element of heavy metal in the studied area. In addition, it cannot reflect all contamination values resulting from the combination of different contamination factors[12]. See equation (4) for the calculation.

$$P_i = \frac{Ci}{S_i}$$ ……….(4)

The symbol "Pi" refers to the single-factor indices of heavy metal i; the symbol "Ci" refers to the calorific value of heavy metal i in water sources, and the symbol "Si" represents the standard concentration used to evaluate heavy metals in groundwater and surface water. The single-factor pollution index classification criteria are explained in Table 2.

Table 2. Single factor pollution index

Indice	Range	Contamination Degree
single factor index	$Pi \leq 1$	Uncontaminated
	$1 < Pi \leq 2$	Light pollution
	$2 < Pi \leq 3$	Moderately polluted
	$Pi > 3$	Heavy pollution

2.6. Statistical Analysis

Descriptive statistics, including mean and standard deviation (SD), were calculated for all trace metal concentrations across the 15 sampling sites for each season (summer 2024 and winter 2025). Normality of the data was assessed using the Shapiro-Wilk test. To evaluate seasonal differences, a paired t-test was conducted to compare summer and winter concentrations for each metal, with a significance level set at $p < 0.05$. All statistical analyses were performed using IBM SPSS Statistics (version 26.0) and Microsoft Excel (version 2019).

3. Results and discussion

Heavy metals analysis of the spring water is seen in Tables 3 and 4.The values of copper, iron, manganese, nickel and zinc changed between (0.417 to 0.645mg/L), (0.022 to 0.199mg/L), (0.007 to 0.123mg/L) and (0.010 to 0.109mg/L) in a row, The concentrations of copper, iron, nickel, and zinc at all studied sites, in both seasons, were below their respective World Health Organization (WHO) drinking water guideline values (see Table 3 and 4 for comparison). Therefore, for these four metals, the measured water quality does not pose a health risk from these specific contaminants [13]. The concentrations of cadmium, chromium, and lead varied between (0.011to 0.678mg/L), (0.300 to 0.548 mg/L), (0.005 to 0.149mg/L) in a row, which was much more than the WHO[13]. Seasonal variation analysis revealed that most trace metals exhibited higher concentrations in winter (January 2025) compared to summer (August 2024). To determine whether these differences were statistically significant, a paired t-test was performed. The results (Table 5) showed statistically significant differences ($p < 0.05$) between summer and winter concentrations for Cd, Cr, Cu, Fe, Pb, and Ni, with winter concentrations being significantly higher. This seasonal pattern can be explained by increased surface runoff during the winter rainy season, which transports metals from agricultural soils, weathered bedrock, and anthropogenic sources into the spring water systems. In contrast, Mn and Zn showed no significant seasonal differences ($p > 0.05$), indicating that these metals originate primarily from natural geogenic sources rather than seasonal anthropogenic activities. These findings confirm that seasonal variation plays a critical role in the contamination levels of most trace metals in the studied springs. These seasonal variations may be attributed to increased surface runoff during the winter rainy season, which facilitates the transport of metals from agricultural soils, weathered bedrock, and anthropogenic sources into spring water systems. Manganese and zinc showed no significant seasonal differences ($p > 0.05$), suggesting relatively stable background concentrations from geogenic sources. The spatial distribution of this contamination reveals two probable sources. First, chromium levels were consistently elevated across all sites and seasons, suggesting a predominant geogenic origin from the natural weathering of chromium-rich minerals within the bedrock of the Zagros Mountains. Conversely, cadmium and lead exhibited more variable concentrations. Notably, the highest levels were recorded at sites [e.g., Sites 6, 8, 12] located near agricultural zones or roads, indicating potential localized anthropogenic influence through mechanisms such as infiltration from fertilizer use, pesticide application, or particulate deposition. While springs are fed by groundwater and are generally buffered from direct surface pollution, the region's fractured karst aquifers may facilitate the rapid transport of surface contaminants in specific localities. This distinction between widespread geological contribution and site-specific human activity is critical for targeted remediation and water resource management in the Soran area.[14]. Pb and Cr are the most harmful and widespread chemical components in nature that cause serious damage to humans if the natural limits recommended before for human health are exceeded. These elements are released into the atmosphere through industrial processes and the open burning of waste materials [15]. The wide use of fertilizers, paints, and emissions from factories within the study's spring can be a source of Cd [16]. Several pollutants can be added and cause an increase in the values of trace metals inside Erbil province, such as the oil industry, burning fuel in various types of cars, and the intensity of high traffic[17]. For evaluating the heavy metal pollution index (HPI) of spring water in the investigation area, we selected eight elements (Cd, Cr, Cu, Fe, Pb, Mn, Ni, and Zn). Table 7 shows the results of calculating the heavy metal pollution index. This is over 100, the critical contamination index for all sites studied through the study period. This means that all sites under study were contaminated with heavy metals, and their levels were higher than the safe limit recommended by the World Health Organization[13]. Pollutants emitted in industry include gases from oil refineries and coal burning, trace components in lime materials, dust from grinding, organic wastes in raw materials, toxic components and organic contaminants, and organic waste emissions from raw materials[18, 19]. The single-factor pollution index was less than 1 for Cu, Fe, Mn, Ni, and Zn in all sites for As, Ba, Ni, and Zn that were considered uncontaminated, while for Pb ranged between uncontaminated to heavy polluted, and for Cd and Cr, it recorded values more than 3, which were considered heavily polluted, as shown in Tables 7 and 8. Environmental pollution with heavy metals is an international problem because these elements are non-biodegradable and most of them have negative impacts on humans and other organisms when their levels exceed these levels. These heavy metals are usually accumulated through events such as volcanoes, hurricanes, and rock erosion, or through human intervention, such as the utilization of pesticides or waste disposal, and activities in agriculture and industry that cause increased levels of risk pollutants[20]. Nevertheless, the concentrations of cadmium and chromium are higher than the levels recommended by the World Health Organization. This is due to the geology of the area, human activities, and the soil characteristics of the study wells. This means that the amounts of cadmium and chromium in each well are constantly increasing. Cadmium can enter water systems through groundwater flow, releasing chemicals from the materials that contain it. Farmers utilize pesticides to protect their crops and increase yields. Chromium appears to be particularly prevalent because it was formerly utilized in pesticides. Chromium can enter the water systems of water during runoff from neighboring farms, leading to elevated chromium levels in the water[21]. Concentrations of lead in the study area were found to be higher than the allowable limit for drinking water use. This increase is attributed to the agricultural lands surrounding the study area, where various lead-containing materials are used in crop production. This leads to the accumulation of lead in the soil and seepage into streams during the rainy season [22] 23]

Table 3: - Spatial difference of Heavy Metals as mg/L in the studied area during August 2024

Elements / Sites	Cd	Cr	Cu	Fe	Pb	Mn	Ni	Zn
Standard values (WHO)	0.003	0.05	2	0.3	0.01	0.3	0.07	5
1	0.017	0.548	0.426	0.199	0.025	0.100	0.031	0.053
2	0.059	0.511	0.417	0.186	0.067	0.009	0.027	0.030
3	0.011	0.494	0.429	0.167	0.050	0.110	0.026	0.010
4	0.111	0.470	0.456	0.175	0.039	0.009	0.021	0.069
5	0.208	0.471	0.443	0.152	0.007	0.115	0.016	0.071
6	0.356	0.475	0.460	0.146	0.006	0.009	0.013	0.065
7	0.522	0.432	0.462	0.153	0.013	0.007	0.014	0.065
8	0.678	0.407	0.453	0.124	0.061	0.009	0.008	0.058
9	0.088	0.403	0.458	0.150	0.110	0.100	0.002	0.060
10	0.076	0.418	0.485	0.105	0.149	0.118	0.004	0.054
11	0.075	0.390	0.473	0.085	0.143	0.117	0.010	0.056
12	0.069	0.413	0.498	0.093	0.119	0.112	0.022	0.062
13	0.063	0.370	0.490	0.100	0.102	0.009	0.040	0.068
14	0.057	0.363	0.516	0.077	0.083	0.118	0.047	0.079
15	0.055	0.386	0.511	0.096	0.068	0.111	0.040	0.083

Table 4: - Spatial difference of Heavy Metals as mg/L in the studied area during Winter-2025.

Elements / Sites	Cd	Cr	Cu	Fe	Pb	Mn	Ni	Zn
Standard values	0.003	0.05	2	0.3	0.01	0.3	0.07	5
1	0.047	0.341	0.528	0.053	0.055	0.111	0.036	0.078
2	0.045	0.362	0.568	0.045	0.038	0.009	0.035	0.103
3	0.042	0.318	0.554	0.034	0.039	0.009	0.032	0.087
4	0.040	0.345	0.548	0.058	0.034	0.123	0.023	0.094
5	0.037	0.347	0.559	0.039	0.027	0.111	0.021	0.099
6	0.034	0.348	0.631	0.042	0.017	0.009	0.019	0.033
7	0.033	0.330	0.607	0.030	0.005	0.009	0.012	0.088
8	0.034	0.334	0.614	0.029	0.014	0.100	0.011	0.067
9	0.034	0.319	0.624	0.044	0.021	0.121	0.010	0.048
10	0.032	0.330	0.607	0.056	0.032	0.118	0.008	0.096
11	0.038	0.331	0.619	0.109	0.038	0.116	0.007	0.109
12	0.043	0.315	0.645	0.092	0.043	0.111	0.003	0.028
13	0.047	0.325	0.624	0.048	0.047	0.009	0.005	0.022
14	0.055	0.314	0.621	0.031	0.055	0.112	0.005	0.020
15	0.069	0.300	0.629	0.022	0.069	0.118	0.012	0.057

Table 5. Descriptive statistics of trace metal concentrations (mg/L) across all study sites.

Metal	Summer 2024 (Mean ± SD)	Winter 2025 (Mean ± SD)	p-value	WHO Guideline
Cadmium (Cd)	0.182 ± 0.198	0.043 ± 0.011	< 0.05	0.003
Chromium (Cr)	0.442 ± 0.058	0.331 ± 0.018	< 0.05	0.05
Copper (Cu)	0.466 ± 0.032	0.598 ± 0.036	< 0.05	2.0
Iron (Fe)	0.134 ± 0.038	0.050 ± 0.024	< 0.05	0.3
Lead (Pb)	0.071 ± 0.049	0.036 ± 0.018	< 0.05	0.01
Manganese (Mn)	0.079 ± 0.052	0.099 ± 0.054	> 0.05	0.3
Nickel (Ni)	0.024 ± 0.018	0.015 ± 0.016	< 0.05	0.07
Zinc (Zn)	0.058 ± 0.020	0.064 ± 0.032	> 0.05	5.0

Note: SD = Standard Deviation; p-value from paired t-test comparing summer and winter concentrations; $p < 0.05$ considered statistically significant.

Table 6: Heavy Metals Pollution Indices in the studied location through the studied period

Sites	Name of Spring	Value of HPI index (10-8-2024)	Value of HPI index (10-1-2025)	Status
1	Shekhe Balakan	504.85	1245.89	Polluted
2	Khalan	1577.79	1165.02	Polluted
3	Bakaran	405.94	1093.09	Polluted
4	Ashe Shekh	2720.88	1038.35	Polluted
5	Dwba	4921.34	952.84	Polluted
6	Merga	8381.52	861.62	Polluted
7	Qasre	1227.45	811.12	Polluted
8	Garawan	16023.72	858.80	Polluted
9	Akoyan	2324.76	867.22	Polluted
10	Hawdyan	2126.73	846.56	Polluted
11	Gale 1	2089.23	976.35	Polluted
12	Gale 2	1903.16	1161.44	Polluted
13	Sreshma	1721.97	1291.62	Polluted
14	Ble	1541.14	1780.97	Polluted
15	Malakan	1464.04	1716.44	Polluted

Table 7: - Assessment results of the Metal index during August 2024

Sites \ Elements	Cd	Cr	Cu	Fe	Pb	Mn	Ni	Zn
1	5.760	10.800	0.213	0.663	2.500	0.033	0.442	0.010
2	19.800	10.220	0.208	0.620	6.700	0.333	0.385	0.006
3	3.666	9.88	0.214	0.556	5.000	0.332	0.371	0.002
4	37.00	9.40	0.228	0.583	3.95	0.377	0.300	0.013
5	69.33	9.42	0.221	0.506	0.700	0.383	0.228	0.014
6	118.66	9.50	0.230	0.486	0.600	0.030	0.185	0.013
7	174.00	8.78	0.231	0.51	1.300	0.023	0.200	0.013
8	226.00	8.14	0.229	0.413	6.100	0.030	0.114	0.011
9	29.33	8.06	0.229	0.500	11.00	0.333	0.028	0.012
10	25.33	8.20	0.242	0.350	14.90	0.390	0.057	0.010
11	25.00	7.80	0.236	0.283	14.30	0.396	0.142	0.011
12	23.033	8.26	0.249	0.310	11.90	0.373	0.314	0.012
13	21.00	7.40	0.245	0.333	10.20	0.03	0.614	0.013
14	19.00	7.26	0.258	0.256	8.30	0.393	0.671	0.015
15	18.333	7.62	0.255	0.320	6.80	0.37	0.571	0.016

Table 8: - Assessment results of the Metal index during January 2025

Sites \ Elements	Cd	Cr	Cu	Fe	Pb	Mn	Ni	Zn
1	15.666	6.82	0.264	0.176	5.50	0.37	0.514	0.015
2	15.00	7.40	0.290	0.150	3.80	0.03	0.500	0.020
3	14.00	6.36	0.279	0.113	3.90	0.03	0.457	0.017
4	13.330	6.90	0.274	0.193	3.43	0.41	0.328	0.018
5	12.333	6.94	0.279	0.130	2.70	0.37	0.300	0.019
6	11.333	6.96	0.315	0.140	1.70	0.03	0.271	0.006
7	11.000	6.60	0.303	0.100	0.50	0.33	0.171	0.017
8	11.333	7.88	0.307	0.096	1.40	0.403	0.157	0.013
9	11.333	6.38	0.312	0.146	2.10	0.403	0.142	0.009
10	10.666	6.60	0.303	0.186	3.30	0.393	0.114	0.019
11	12.666	6.62	0.309	0.363	2.79	0.386	0.100	0.021
12	14.333	6.30	0.307	0.306	6.10	0.370	0.042	0.005
13	15.666	6.50	0.312	0.160	7.80	0.030	0.071	0.004
14	18.333	6.28	0.310	0.106	22.20	0.373	0.071	0.004
15	23.00	6.00	0.314	0.743	3.60	0.396	0.171	0.011

4. Conclusions

Depending on the analysis of water samples, heavy metals such as Copper, Iron, Manganese, Nickel, and Zinc are generally found to be within the permitted limits, except for the higher levels of cadmium, chromium, and lead noted in all sites. According to the Heavy Metals Pollution Index, all studied springs are considered polluted by heavy metals. While all examined springs were deemed to be heavily to moderately polluted by Cadmium, Chromium, and Lead, and considered uncontaminated by the remaining heavy metals under this study, according to the Single Factor Pollution Index.
Based on the findings of this study, continuous monitoring of groundwater quality in the Soran region is recommended to prevent potential health risks associated with heavy metal contamination. Chronic exposure to elevated levels of cadmium, chromium, and lead through drinking water may pose serious health threats, including kidney damage, carcinogenic effects, and neurological disorders. Therefore, regular water quality assessment, pollution control measures, and public awareness campaigns are essential to protect local communities that rely on these springs for drinking water.

5-Acknowledgments

We would sincerely like to thank the Soran University- Soran independent administration, and Salahaddin University, Erbil. Kurdistan Region, Iraq, for supporting this research.

6. Declarations

6.1 Ethics approval and consent to participate

This study did not involve any human participants, human data, or animal subjects, as it was based solely on water sample analysis.

6.2 Availability of Data and Materials

Data will be provided upon receiving a valid request.

6.3 Conflicts of interest

There is no conflict of interest

6.4 Funding:

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References

[1] H. A. Ameen, "Spring water quality assessment using water quality index in villages of Barwari Bala, Duhok, Kurdistan Region, Iraq," " *Appl. Water Sci.,* vol. 9, no. 8, pp. 176-188, 2019, DOI: 10.1007/s13201-019-1080-z

[2] J. Toma and M. Othman, "Determination of the trace metals in Bottled Water That Available in Erbil City, Iraq, *J. Environ. Stud.*,vol. 6, no. 1, pp. 31-37, 2011.

[3] J. J. Toma and F. H. Aziz, "Heavy metals compositions in springs and streams from Shaqlawa district, Erbil Province, Kurdistan region of Iraq," *Zanco J. Pure Appl. Sci., v*ol. 34, no. 4, pp. 45-52, 2022,DOI: 10.25130/tjps.v29i2.1592

[4] T. Taha, "Clay mineralogy and heavy metal geochemistry of the Tigris River sediments in selected area of northern Iraq," *Tikrit J. Pure Sci.,* vol. 28, pp. 107-116, Oct. 2023,. DOI: 10.25130/tjps.v28i5.1081

[5] Q. Li, Z. Han, Y. Tian, H. Xiao, and M. Yang, "Risk assessment of heavy metal in farmlands and crops near Pb–Zn mine Tailing Ponds in Niujiaotang, China," *Toxics,* vol. 11, no. 2, pp. 106-124, 2023, DOI: 10.3390/toxics11020106

[6] S. A. Al-Asadi, W. S. Al-Qurnawi, A. B. Al Hawash, H. B. Ghalib, and N.-H. A. Alkhlifa, "Water quality and impacting factors on heavy metals levels in Shatt Al-Arab River, Basra, Iraq," *AAppl. Water Sci.,* vol. 10, no. 5, pp. 1-15, 2020. DOI:10.1007/s13201-020-01196-1

[7] Z. Salih, J. Toma, A. Aziz, T. Hassan, and F. Aziz, "Evaluation of Rainwater Quality in Some Polluted Locations within Erbil Province," *Pol. J. Environ. Stud.,*vol. 33, no. 2, pp. 1839-1848, 2024. DOI:10.15244/pjoes/173997

[8] V. M. Wagh, D. B. Panaskar, S. V. Mukate, S. K. Gaikwad, A. A. Muley, and A. M. Varade, "Health risk assessment of heavy metal contamination in groundwater of Kadava River Basin, Nashik, India," *Model. Earth Syst. Environ.,*vol. 4, pp. 969-980, 2018. DOI: 10.1007/s40808-018-0496-z

[9] J. J. Toma and F. H. Aziz, "New records of algae in Shaqlawa district, Erbil, Kurdistan region of Iraq," *Al-Nahrain J. Sci.,*vol. 24, no. 3, pp. 55-62, 2021. DOI:10.21123/bsj.2023.7657

[10]W. C. Lipps, E. B. Braun-Howland, and T. E. Baxter, *Standard methods for the examination of water and wastewater*. American public health association, 2023. 10.2105/SMWW.2882.086

[11]A. Mughal *et al.*, "Risk analysis of heavy metals and groundwater quality indices in residential areas: a case study in the Rajanpur District, Pakistan," *Water,* vol. 14, no. 21, pp. 139-157, 2022. DOI: 10.3390/w14213551

[12]H. Xie, X. Yang, J. Xu, and D. Zhong, "Heavy metals pollution and potential ecological health risk assessment in the Yangtze River reaches," *J. Environ. Chem. Eng.,*vol. 11, no. 2, pp. 109489-109514, 2023. DOI: 10.1016/j.heliyon.2024.e30739

[13]W. H. Organization, *Guidelines for drinking-water quality: incorporating the first and second addenda*. World Health Organization, 2022.

[14]H. S. Ghalib and M. M. Ramal, "Spatial and temporal water quality evaluation of heavy metals of Habbaniyah Lake, Iraq," *Int. J. Des. Nat. Ecodynamics,* vol. 16, no. 4, pp. 467-475, 2021. DOI: https://doi.org/10.18280/ijsdp.160715

[15] S. H. Muhyadeen and R. A. Ramadhan, "Outdoor Air Contaminants-Heavy Metals and Associated Health Risks in Duhok-Iraq," *Sci. J. Univ. Zakho,* vol. 11, no. 1, pp. 78-83, 2023. DOI: 10.25271/sjuoz.2023.11.1.1043

[16] A. Kannah and H. Shihab, "A Study of Some Physical and Chemical Properties of the water of the Tigris River within the city of Mosul, Iraq," *J. Educ. Sci.,*, vol. 34 pp. 2021-1458, 08/11 2022. DOI: 10.33899/jes.v34i4.49251

[17]K. Khwedim, M. T. Ahmed, and M. A. Najemalden, "Survey of some heavy metals and radioactivity in the dust in a selected area in Kirkuk Governorate-Northern Iraq," *Iraqi J. Sci.*, pp. 3817-3824, 2022.

[18]B. Mahdi, K. Yousif, and L. S. Dosky, "Characterization of airborne particles collected in Duhok city (in Iraq), by using various techniques," *IOP Conf. Ser.: Mater. Sci. Eng.*, vol. 454, no. 1, pp. 012073-012098 2018 DOI: 10.25271/sjuoz.2023.11.1.1043

[19]J. J. Toma, "Trace metal composition in Ainkawa groundwater Erbil. Kurdistan of Iraq," *Zanco J. Pure Appl. Sci.,*vol. 20, no. 2, pp. 65-74, 2008.

[20]A. M. Kannah and F. Shihab, "Heavy metals levels in the water of the Tigris River in the City of Mosul, Iraq," *Egypt. J. Aquat. Biol. Fish.,* vol. 26, no. 6, pp. 1007-1020, 2022.

[21]M. F. Abed, G. A. Zarraq, and S. H. Ahmed, "Assessment of groundwater pollution using aqueous geo-environmental indices, Baiji Province, Salah Al-Din, Iraq," *Iraqi Geol. J., ,* vol. 1, no. 2, pp. 94-104, 2022. DOI: 10.25130/tjes.30.1.3

[22]A. A. Al-Kinani and A. J. Al-Azawi, "Study of the effect of agricultural and domestic pollutants on the water quality of the Diyala River in Iraq," *Int. J. Health Sci.,* no. II, pp. 9092-9098, 2022. DOI: 10.53730/ijhs.v6nS2.7374

[23]S. Jalal, "Exploring the Distribution of Microplastics and Heavy Metals in Agricultural Soils and the Evaluation of Risk Indices in Erbil City," *J. Educ. Sci.,*vol. 34, p. 4, 10/01 2025. DOI: 10.33899/jes.v34i4.49251

تحليل العناصر النزرة في المياه الجوفية بالينابيع الجبلية

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المستخلص

هدفت هذه الدراسة إلى تقدير تركيزات عدد من المعادن الثقيلة، بما في ذلك الكادميوم(Cd) ، والكروم(Cr) ، والنحاس(Cu) ، والحديد(Fe) ، والمنغنيز (Mn)، والنيكل(Ni) ، والرصاص(Pb) ، والزنك(Zn) ، في خمسة عشر ينبوعًا حول إدارة سوران المستقلة، إقليم كوردستان العراق. تم جمع عينات المياه خلال موسمين (صيف 2024 وشتاء 2025) وتحليلها باستخدام مطياف الانبعاث البصري للبلازما المقترنة حثياً .(ICP-OES) أظهرت النتائج أن معظم العناصر النزرة كانت ذات تركيزات أعلى في الشتاء مقارنة بالصيف. تراوحت تراكيز العناصر كالتالي: الكادميوم (0.011–0.678 ملغ/لتر)، الكروم (0.300–0.548 ملغ/لتر)، النحاس (0.417–0.645 ملغ/لتر)، الحديد (0.022–0.199 ملغ/لتر)، المنغنيز (0.007–0.123 ملغ/لتر)، النيكل (0.002–0.047 ملغ/لتر)، الرصاص (0.005–0.149 ملغ/لتر)، والزنك (0.010–0.109 ملغ/لتر).

وباستثناء الكادميوم والكروم اللذين تجاوزا الحدود الآمنة في جميع المواقع، كانت تراكيز معظم المعادن بشكل عام أقل من إرشادات منظمة الصحة العالمية لمياه الشرب؛ ومع ذلك، فإن الرصاص في بعض المواقع جعل المياه أيضًا غير صالحة للشرب. وفقًا لمؤشر تلوث المعادن الثقيلة(HPI) ، أشارت القيم التي تجاوزت 100 في جميع الينابيع المدروسة (التي تراوحت بين 405.94 و 16023.72 في الصيف و 811.12 و 1780.97 في الشتاء) إلى وجود تلوث وعدم صلاحية للاستخدام البشري. وفي المقابل، ووفقًا لمؤشر المعادن(MI) ، كانت قيم معظم العناصر النزرة أقل من 1، مما يشير إلى عدم وجود تلوث. ومع ذلك، فإن قيم مؤشر المعادن (MI)للكادميوم والكروم التي تجاوزت 5 تشير إلى تلوث شديد، في حين تراوحت قيم المؤشر للرصاص بين 0.5 و 22.2، متدرجة بين غير ملوث إلى شديد التلوث.

بناءً على هذه النتائج، توصي هذه الدراسة بـ: (1) المراقبة المنتظمة لتركيزات الكادميوم والكروم والرصاص في هذه الينابيع؛ (2) تنفيذ تدابير للسيطرة على التلوث، بما في ذلك تنظيم استخدام الأسمدة والمبيدات الحشرية في المناطق الزراعية المحيطة؛ و (3) اعتماد أنظمة معالجة المياه عند نقطة الاستخدام للمجتمعات التي تعتمد على هذه الينابيع لمياه الشرب.