Assessment of Heavy Metal Contamination of Groundwater in Rural Areas of Duhok City, Iraq

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ABSTRACT

This study investigates the quality of groundwater sources in the rural areas of Duhok City, Iraq, with a particular focus on heavy metal contamination, chemical composition, and properties of water. Water samples from 14 wells, serving as the main water source for the surrounding areas, were collected and analyzed. Water quality parameters including calcium (Ca^{2+}), magnesium (Mg^{2+}), chloride (Cl^{-}), potassium (K^{+}), and sulfate (SO_4^{2-}) values ranged from 24 to 105.6 mg/L, 6.832 to 50.752 mg/L, 18 to 34 mg/L, 1 to 7 mg/L, and 3.4 to 38 mg/L respectively. Common heavy metals like manganese (Mn), lead (Pb), copper (Cu), and cobalt (Co) exhibited varying concentrations. Most parameters meet the WHO standards, except for the elevated potassium in one sample, requiring attention. Additionally, 50% of the sampled wells showed elevated cadmium (Cd) levels. Possible sources of contamination include industrial activities, agricultural runoff, and geological factors, highlighting the importance of ongoing monitoring and targeted interventions to ensure access to clean and safe water.

Keywords-water quality; heavy metals; groundwater; pollution sources; public health

I. INTRODUCTION

Water is primarily sourced from two natural reservoirs: surface water, including freshwater lakes, rivers, and streams, and groundwater, such as boreholes and wells [1, 2]. Due to its polarity and hydrogen bonds, water possesses unique chemical properties, allowing it to dissolve, absorb, or suspend various compounds [3]. Consequently, in its natural state, water is not pure, as it accumulates contaminants from its surroundings, including those introduced by human and animal activities, and other biological processes [4]. Water degradation often arises from dissolved toxic heavy metals, rendering it unsuitable for human use [5]. Wastewater effluents notably impact water source quality. Moreover, industrial processes contribute significantly to heavy metal contamination in surface water sources [6, 7]. Surface water quality is influenced by natural biogeochemical processes and hydrological systems in river ecosystems in addition to human sources. [8]. The proliferation of urban landscapes, industrial development, and agricultural practices involving chemical fertilizers has led to a surge in toxic metallic contaminants in groundwater and surface water sources [9-11]. Industrial wastewater discharges, urban drainage networks, and stormwater runoff management systems contribute to heavy metal contamination in aquatic ecosystems [12]. The heavy metal contaminants significantly diminish water quality, posing a threat to public health [13]. Techniques such as Inductively Coupled Plasma Mass Spectrometry (ICP-MS) and Atomic Absorption Spectroscopy (AAS) are commonly employed to assess heavy metal contamination levels in water [14, 15]. The most common heavy metals humans are exposed to include aluminum, arsenic, cadmium, lead, and mercury. Each of these metals poses health risks upon exposure [16-24]. Understanding and mitigating the exposure to these heavy metals are critical for protecting the public health. Efforts are needed to address heavy metal contamination's threats to health and the environment [25-27].

The current study aims to assess the quality of water sources in the rural areas of the Mangesh subdistrict in Duhok City, Iraq, focusing on heavy metal contamination. This focus is particularly pertinent due to the prevalence of agricultural activities in these areas, which can contribute to the introduction of heavy metals into water sources. Additionally, the study aims to analyze the chemical composition and properties of water from these sources in order to mitigate potential risks to human health and the environment.

II. MATERIALS AND METHODS

A. *Field Sampling*

Water samples were collected from 14 wells situated in various villages surrounding Duhok, Iraq. These wells serve as the primary water sources for the respective villages, being the main sources for both drinking and agricultural use. It is worth noting that these areas are of significant importance in terms of agricultural food production and importation. Table I provides detailed information regarding the samples collected from each site, including sample identification, location, and corresponding codes. The sampling points can be seen in Figure 1.

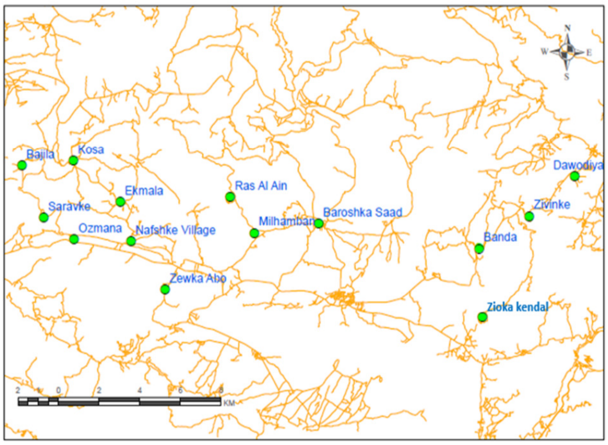

Fig. 1. The sampling points.

TABLE I. LOCATION CODES AND COORDINATES FOR SAMPLE COLLECTION

Location	Code	Longitude	Latitude
Nafshki Village	W1	42 58 763	37 03 626
Zioka Abou Village	W2	42 59 873	37 02 350
Ouzmana Village	W3	42 56 755	37 03 849
Sarafki Village	W4	42 55 724	37 04 106
Bagli Village	W5	42 54 989	37 04 672
Kosa Village	W6	42 56 545	37 05 .502
Ikmalah Village	W7	42 50 265	37 04 .193
Zioka Kendal Village	W8	42 46 686	36 46.984
Banda Village	W9	43 10 017	37 03 .620
Zafanki Village	W10	43 11813	37 04 .429
Dawudia Village	W11	43 13 333	37 05 .406
Broushka Saad Village	W12	43 04 650	37 04 .079
Ras Al Ain Village	W13	43 01 838	37 04 822
Malhabani Village	W14	43 02 612	37 03 392

The water samples were collected in glass bottles, that were utilized to prevent reactions with plastic materials or contamination. Before use, the sample bottles were washed with clean, deionized water. When taking a sample directly from the water source, the water was allowed to run through the tap for at least 1 min to flush out any debris or sediment from the pipes. Then, the sampler opened to lid and repeated this process one time, filling and emptying the sampler with water before finally filling it with the sample water and tightly closing the lid. Following these procedures, the sample was then transported to the laboratory for further analysis. These meticulous steps are essential to ensure the integrity of the water sample and thus ensure accurate analysis results.

B. *Methods*

The samples underwent filtration using Whatman 0.45 μm filters, followed by water sample digestion. The procedure involved transferring 100 ml of well water into a suitable container and adding 5 ml of concentrated HNO_3 [28]. The filtration system utilized a 0Z45 micro filter. Subsequently, the container was heated until evaporation reduced the volume to 5 ml, after which it was diluted in a 100 ml volumetric flask before atomic spectroscopy analysis with a Shimadzu AA-7000 [29]. Quality assurance measures and heavy metal analysis are crucial for accurate heavy metal analysis in water quality assessment. AAS and Inductively Coupled Plasma Optical Emission Spectrometry (ICP-OES) were utilized for precise single-element and multi-element analysis.

Flame atomic spectroscopy was employed for the analysis of Fe, Cu, Ni, Mn, and Zn, while graphite furnace was utilized for the analysis of CO, Cd, Al, Pb, and Cr. It is worth mentioning that this method was exclusively utilized for analyzing heavy metals, as no sample preparation was conducted for physicochemical analyses. Table II presents the comprehensive array of analytical methods, adhering to the standard protocols outlined by the WHO for water and wastewater examination, specifically focusing on the chemical composition and properties of water [31]. Table III details the heavy metal analysis results in the water samples using atomic spectroscopy. The procedures followed adhere to the standard protocols outlined by the WHO for water and wastewater examination, ensuring the reliability and accuracy of the results obtained [30].

TABLE II. METHODS FOR CHEMICAL COMPOSITION AND OTHER WATER PROPERTIES ACQUISITION

Parameter	Symbol	Method	Limit
Ph	pH	pH meter	6.5-8.5
Turbidity	Turb	Turbidimetric	<5
Electrical Conductivity	EC	Conductivity	0-5000
Total Dissolved Solids	TDS	Conductivity	<1000
Nitrate	NO_3^-	UV Sp. metric	<50
Total Alkalinity	T.Al	H_2So_4 T.metric	125-200
Total Hardness	TH	EDTA	100-500
Magnesium	Mg^{+2}	Titration	30-150
Chloride	Cl^-	Silver nitrate	<250
Sodium	Na^+	Flame p.metric	<200
Potassium	K^+	Flame p.metric	2-3
Sulfate	SO^4	Turbidimetric	<250
Calcium	Ca^{+2}	EDTA	<200

Note: The unit of all parameters, except pH, is mg/L

TABLE III. HEAVY METAL LIMITS

Element	**Symbol**	**Limit (ppm)**
Iron	Fe	0.3
Copper	Cu	1
Manganese	Mn	0.1
Zinc	Zn	3
Cobalt	Co	0.005
Nickel	Ni	0.1
Lead	Pb	0.05
Cadmium	Cd	0.005
Chromium VI	Cr^{+6}	0.05

III. RESULTS AND DISCUSSION

A. Assessment of Water Quality

The analysis results are presented in Table IV, which displays the chemical composition and properties of the water samples. These results provide valuable insights into the quality and characteristics of the water samples, aiding in assessing their suitability for various purposes.

The turbidity levels in the water samples ranged from 0.1 to 4.7 NTU, falling within the recommended safe limit of less than 5 NTU set by the WHO for drinking water. pH values ranged from 6.5 to 8.14, meeting the WHO guideline of 6.5 to 8.5. EC values ranged from 527 to 787 µS/cm, indicating the presence in the water of dissolved ions within permissible limits. TDS values ranged from 337.28 to 503.68 mg/L, remaining below the WHO's recommended guideline of 1000 mg/L for drinking water. Nitrate levels of 56.39 mg/L exceed the WHO guideline of 50 mg/L for drinking water in the W12 sample. Elevated nitrate concentrations indicate potential contamination, likely from agricultural activities or other anthropogenic sources. The T.Al concentrations ranged from 240 to 368 mg/L, with all samples, except from sample 6, exceeding the recommended range of 125-200 mg/L according to WHO guidelines for safe drinking water. These variations underscore the importance of further investigation to ensure compliance with safety standards and address potential health risks posed by elevated alkalinity levels [32].

The dataset encompasses various water quality parameters including TH, Ca^{+2}, Mg^{+2}, Cl^{-}, Na^{+}, K^{+}, and SO^{-4}. TH values ranged from 172 to 412 mg/L, remaining within the recommended range of 100-500 mg/L. Ca^{+2} concentrations fell between 24 to 105.6 mg/L, adhering to the acceptable range of 75-200 mg/L. Mg^{+2} levels varied from 6.832 to 50.752 mg/L, meeting the specified range of 30-150 mg/L. Cl^{-} concentrations fell between 18 to 34 mg/L, remaining below the threshold of 250 mg/L. Na^{+} concentrations ranged from 4.8 to 107 mg/L, staying below the 200 mg/L limit. K^{+} levels ranged from 1 to 7 mg/L, except for sample 8 with a notably higher value of 24 mg/L, which warrants further investigation. Sulfate concentrations ranged from 3.4 to 38 mg/L, remaining below the specified limit of 250 mg/L. Overall, while most parameters are within the acceptable limits, the elevated K^{+} level in sample 8 necessitates attention and potential remediation measures.

TABLE IV. CHEMICAL COMPOSITION AND PROPERTIES OF THE WATER SAMPLES

Sample	**Turb**	**pH**	**EC**	**TDS**	**NO^{-3}**	**T.Al**	**TH**	**Ca^{+2}**	**Mg^{+2}**	**Cl^{-}**	**Na^{+}**	**K^{+}**	**SO^{4}**
W1	0.4	7.2	640.4	409.856	8.0626	368	360	94.4	30.256	18	7.3	1	3.4
W2	0.2	7.51	527	337.28	6.6007	282	308	51.2	43.92	20	25.5	2	10
W3	0.4	7.01	668.6	427.904	13.7773	344	376	105.6	27.328	20	5.5	1	4
W4	2.1	7.19	644.5	412.48	7.2652	344	348	73.6	40.016	18	12	2	4
W5	2	7.32	621.1	397.504	5.8033	326	352	72	41.968	16	10	2	4
W6	0.4	7.86	555.2	355.328	0.0886	240	172	24	27.328	24	70	2	38
W7	0.2	7.24	649.4	415.616	18.606	322	368	88	36.112	16	9.2	1	14
W8	2.2	7.48	731.8	468.352	35.2628	368	408	83.2	48.8	24	14	7	14
W9	0.2	8.14	528	337.92	0.0886	264	80	20.8	6.832	22	107	1	15
W10	0.7	7.43	624	399.36	31.9403	296	324	88	25.376	24	18.3	1	15
W11	0.1	7.36	614	392.96	23.7005	312	352	91.2	30.256	18	4.8	2	4
W12	4.7	7.45	722	462.08	56.3939	308	376	67.2	50.752	32	12	1	10
W13	1.7	7.42	686	439.04	46.958	290	360	80	39.04	28	12.5	3	14
W14	0.3	7.38	606	387.84	11.518	328	352	80	37.088	18	9	2	22

B. Analysis of Heavy Metal Concentrations

The concentrations of various heavy metals in the water samples are summarized in Table V. The findings provide insights into the heavy metal contamination levels in the water sources under investigation. The concentrations of heavy metals in the water samples are within the acceptable ranges according to WHO standards. Fe levels range from 0.0055 ppm to 0.1459 ppm, Cu levels were from 0.0062614 ppm to 0.0140881 ppm, Mn from 0.00073213 ppm to 0.01892564 ppm, and Zn from 0.00750 ppm to 3.8929 ppm. All values fall within the permissible limits except for sample W5, where the zinc concentration exceeds the recommended threshold. The high Zn concentration in sample W5 could stem from industrial discharge, agricultural runoff, or natural geological sources, common factors contributing to elevated zinc levels in water bodies. The concentrations of Co, Ni, and Pb in the water samples were all found to be within the acceptable limits. Cobalt concentrations ranged from 0.00006552 ppm to 0.00029432 ppm, nickel concentrations varied from 0.0010813 ppm to 0.0302767 ppm, and lead concentrations ranged from 0.0004666 ppm to 0.0060625 ppm, all well below the recommended limits.

The exceedance of the recommended Cd limit in approximately 50% of the samples, particularly from W1 to W7, underscores a noteworthy concern regarding water quality. Such instances of elevated Cd levels may pose health risks to consumers if left unaddressed. The high Cd levels in the samples could stem from various sources like industrial runoff, agricultural practices, and natural processes [33, 34]. Identifying these sources is critical for implementing effective mitigation strategies to safeguard water quality and public health. Identifying the specific sources would need further investigation.

Cr levels were undetectable (Nill) across all samples, indicating minimal chromium in the tested water. This suggests that chromium contamination is not a significant concern based on the analysis conducted. The Al concentrations in the samples ranged from 0.0085 ppm to 0.1569 ppm, well within the permissible limit of 0.2 ppm, indicating that aluminum levels in the tested water samples are below the regulatory threshold. The comprehensive analysis of the water samples revealed varying values of heavy metal concentrations and physicochemical properties. While the majority of the parameters remained within the acceptable limits set by regulatory standards, some deviations were observed. Notably, zinc levels in sample W5 exceeded the permissible range, warranting further investigation into potential sources of contamination. Additionally, the absence of detectable chromium levels across all samples indicates minimal chromium contamination. Overall, these findings underscore the importance of regular monitoring and management practices to ensure safe drinking water quality.

TABLE V. HEAVY METAL CONCENTRATIONS (PPM) IN WATER SAMPLES

Sample	**Fe**	**Cu**	**Mn**	**Zn**	**Co**	**Ni**	**Pb**	**Cd**	**Cr^{+6}**	**Al**
W1	0.0358	0.0140881	0.00130536	0.2557	0.00010195	0.0216262	0.001591	**0.0151018**	Nill	0.01252338
W2	0.0303	0.0093921	0.01602040	Nill	0.00012383	0.0108131	0.0008864	**0.0127173**	Nill	0.13468737
W3	Nill	0.0125228	0.00049669	0.0133	0.00007523	0.0194636	0.0009485	**0.0135121**	Nill	0.00854646
W4	0.0482	0.0125228	0.00231204	0.9949	0.00011653	0.017301	0.0014042	**0.0143069**	Nill	0.15692614
W5	0.1459	0.0133054	0.01892564	**3.8929**	0.00029432	0.0151383	0.0060625	**0.0151018**	Nill	0.01573351
W6	0.0138	0.0133054	0.00233867	0.0447	0.00012383	0.0108131	0.0004666	**0.0151018**	Nill	0.01478667
W7	0.0055	0.0133054	0.00143432	0.1218	0.00009952	0.017301	0.0009691	**0.016294**	Nill	0.01589943
W8	0.1156	0.0062614	0.00441942	1.767	0.00006794	0.0259514	0.0034726	0.0031793	Nill	0.09423245
W9	Nill	Nill	0.00044926	0.1298	0.00025042	0.0227075	0.0007486	0.0027819	Nill	0.00898900
W10	Nill	Nill	0.00049253	Nill	0.00005823	0.0302767	0.0008244	0.0019871	Nill	0.00912885
W11	Nill	Nill	0.00083946	Nill	0.00016274	Nill	0.0008451	0.0015897	Nill	0.04289411
W12	0.0716	Nill	0.00801186	Nill	0.00010924	0.0021626	0.0008864	0.0023845	Nill	0.13360824
W13	0.0358	Nill	0.00326548	1.1467	0.00008737	0.0086505	0.0052296	0.0027819	Nill	0.08578475
W14	0.044	0.0039134	0.00073213	0.00750	0.00006552	0.0010813	0.00216	0.0019871	Nill	0.01384208

IV. CONCLUSION

This study delved into the quality of groundwater sources in rural Duhok City, Iraq, with a specific emphasis on heavy metal contamination. By analyzing water samples from 14 wells, insights into the chemical composition and properties of water, alongside heavy metal concentrations, were unveiled. The findings highlight the presence of elevated cadmium levels in a substantial portion of the sampled wells, with one source exceeding the permissible limits. The study underscores the urgent need for ongoing monitoring and targeted interventions to address potential contamination sources and ensure the provision of safe drinking water to local communities. Furthermore, the study's significance lies in its approach to assessing water quality for both human consumption and agricultural use, addressing critical aspects of community livelihood and sustenance. This dual focus underscores the study's relevance in meeting the diverse needs of rural communities dependent on groundwater resources. Additionally, the study emphasizes the crucial role of proactive measures in mitigating health risks from heavy metal exposure, ensuring the well-being of rural communities. While valuable, acknowledging limitations is important, and future research should focus on identifying contamination sources and assessing long-term health impacts.

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DECLARATION OF INTEREST

The authors declare that they have no competing financial interests or personal relationships that could have influenced the work reported in this study.

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