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Using Heavy Metals Pollution Index (HPI) and Metal Index (MI) for Assessing quality of drinking water in Bardarash-Akre basin in Duhok governorate northern Iraq

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ABSTRACT

A total of forty-four groundwater samples were collected from several groundwater wells located at diverse depths and locations throughout the Kre-Bardarash basin in the Duhok governorate. The sample program began in May 2023 and includes the examination of several heavy elements, including but not limited to (As, Cd, Cu, Pb, Va, Ni, Zn, Bo, Cr, Co, Li, Mn, Se, and Ag)The essential goals of this research are to find that the samples have concentrations within the acceptable limits as prescribed in Iraqi drinking water standards. The average Heavy metal Pollution Index (HPI) concentration is 955, which is considerably less than the crucial index value of 100. The percentage of groundwater samples that exceeds the 100-index value is 5%, indicating that the water is completely unsuitable unfit for drinking, while 90 percent are rang from excellent to very poor quality according to HPI. The MI concentration was 0.16 with 88.6 % percent of groundwater samples were found to be very pure water class. The results show that the groundwater in the Akre-Bardarash basin of wells 1,2, and 3 is highly polluted in the northeast part, and wells 22 and 30 are also highly polluted in the south-east part. All of the wells mentioned above are unfit for human consumption. The impact of human activity and industrial activity on the study area has played an important role in the pollution of groundwater quality in the northeast and southwestern parts of the Akre-Bardarash Basin. According to the findings of the current study, it can be concluded that the water can be used safely for drinking without any negative effect on human health, except wells 1,2, and 3 in the northeast part and wells 22 and 30 in the southwest part.

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استخدام مؤشرات تلوث المعادن الثقيلة HPI و MI لتقيم جودة المياه الجوفية في حوض عقرة – بردرش في محافظة دهوك شمال العراق

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الملخص

تم أخذ اربعة واربعين نموذج من المياه الجوفية من آبار مختلفة و تقع على أعماق ومواقع مختلفة داخل حوض ئاكري بردرش الواقع في محافظة دهوك. بدأت أخذ العينات في مايو 2023 وتضمنت تحليل العديد من مكونات المعادن الثقيلة، بما في ذلك على سبيل المثال لا الحصر (As، Cd،Cu، Pb، Va، Ni، Zn، Bo، Cr، Co، Li، Mn، Se، and Ag). الأهداف الأساسية لهذا العمل البحثي هي إيجاد تراكيز للعينات ضمن الحدود المقبولة كما هو محدد في المواصفات القياسية لمياه الشرب العراقية. ويبلغ متوسط تركيز مؤشر التلوث بالمعادن الثقيلة 955، وهو أقل بكثير من قيمة المؤشر الحاسمة البالغة 100. وتبلغ نسبة عينات المياه الجوفية التي تزيد عن 100 قيمة 5%، مما يشير إلى أن المياه غير صالحة على الإطلاق وغير صالحة للشرب. في حين أن 90 بالمائة تتراوح بين الجودة الممتازة إلى الرديئة جدًا وفقًا لـ HPI. وكان تركيز MI 0.16 حيث وجد أن 88.6% من عينات المياه الجوفية هي من فئة المياه النقية جداً. أظهرت النتائج أن المياه الجوفية في حوض عقرة–بردرش للبئر 1،2،3 ملوثة جداً في الجزء الشمالي الشرقي والبئر 22 و30 أيضاً ملوثة جداً في الجزء الجنوبي الشرقي وجميع الآبار المذكورة أعلاه غير صالحة للاستهلاك البشري. لقد لعب تأثير النشاط البشري والنشاط الصناعي على منطقة الدراسة دوراً مهماً في التلوث في نوعية المياه الجوفية في الجزء الشمالي الشرقي والجنوبي الغربي من حوض عقرة بردرش. وبناء على نتائج الدراسة الحالية يمكن استنتاج أن المياه صالحة للشرب دون أي تأثير سلبي على صحة الإنسان باستثناء البئر 1،2 و3 في الجزء الشمالي الشرقي والبئرين 22 و30 في الجزء الجنوبي الغربي.

Introduction

Akre-Bardarash Basin which is located in the most fertile lands. The basin aquifers are unconfined aquifers that have seen drastic changes in their properties throughout the years, due to agricultural processes and other activities. Current research signifies the first of its kind within the Akre-Bardarash, addressing the pressing necessity to comprehend and control the issue of heavy metal pollution. The index plays a crucial role as a valuable instrument for evaluating the degree of contamination, its origins, and its potential repercussions on both the natural environment and human well-being[1]. Through the quantification of heavy metal pollutant levels in diverse environmental components like soil, water, and air, this investigation empowers local authorities and stakeholders to make well-informed choices and implement effective measures for mitigating these concerns[2]. Ultimately, the introduction of the Heavy Metal Pollution Index in Akre-Bardarash amplifies our capacity to protect the ecosystem and enhance the quality of life for local residents, while also setting a precedent for future environmental research and sustainable development initiatives[3]. Groundwater is seen as a crucial Desert location have little access to water, which is where the ground at various depths and variations from site to site [4]. Iraq's interest and demand for groundwater have grown dramatically in recent years, making it one of the world's most important natural water resources. In addition, groundwater is a crucial component for survival in parched regions[5]. Water quality is also linked to a number of geological and climatic factors, forming its own ecosystem governed by the laws of its environmental constituents[6](Al-Kubaisi and Al-Sumaidai.2022)

Since the beginning of time, people have understood how vital water is to both human survival and the survival of other living things. However, as agricultural and industrial activity has increased close to water sources, this water has become more vulnerable to pollution and a source of epidemics and diseases[2]. Heavy metal pollution in drinking waters is now one of the most serious environmental issues. When their levels in drinking water exceed the allowable limit, some of them can be harmful to human health [7].

One of the most important environmental problems nowadays is the presence of heavy metals in drinking water. Some of them may be detrimental to human health if the allowed limit is exceeded in drinking water [7]. Since recent years, using Heavy metal pollution index HPI and Metal index MI as pollution indices to assess groundwater quality for heavy metal detection has grown in popularity. These indices give information on the extent of pollution of groundwater resources[8]. Because they aggregate all of these elements' influences into a single figure, pollution indices are seen as a valuable tool for decision-makers, civil authorities, and environmental organizations in the management of water quality[9]. The primary objectives of the ongoing research are to assess the heavy metal content and heavy metal index pollution in groundwater samples from the Shamamik

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basin in order to determine their appropriateness for portable applications using the heavy metal pollution index (HPI). The present study seeks to investigate the origin and presence of heavy metals in groundwater, specifically those stemming from anthropogenic sources. This will be achieved through the application of the heavy metal pollution index and the metal index..

Materials and method

Study area

The Akre – Bardarash plain, which lies south-east of Duhok in northern Iraq, has been chosen as the research location for the current investigation. Latitudes 36° 39' 56.36 E 43° 52' 53.24 and longitudes N 36° 29' 23.42 E 43° 40' 24.27 define the region's boundaries. These plains are among the most productive in all of Iraq for farming for cultivating rice, potatoes, and tomatoes. Topographically, the region's landscape is generally flat or gently sloping, with just sporadic hills to break it up. The only mountains in the region are Maqlob Mountain in the west and Bakrman Mountain in the north. As a result, the area's height ranges from 171 to 1665 meters above sea level (Fig. 1).

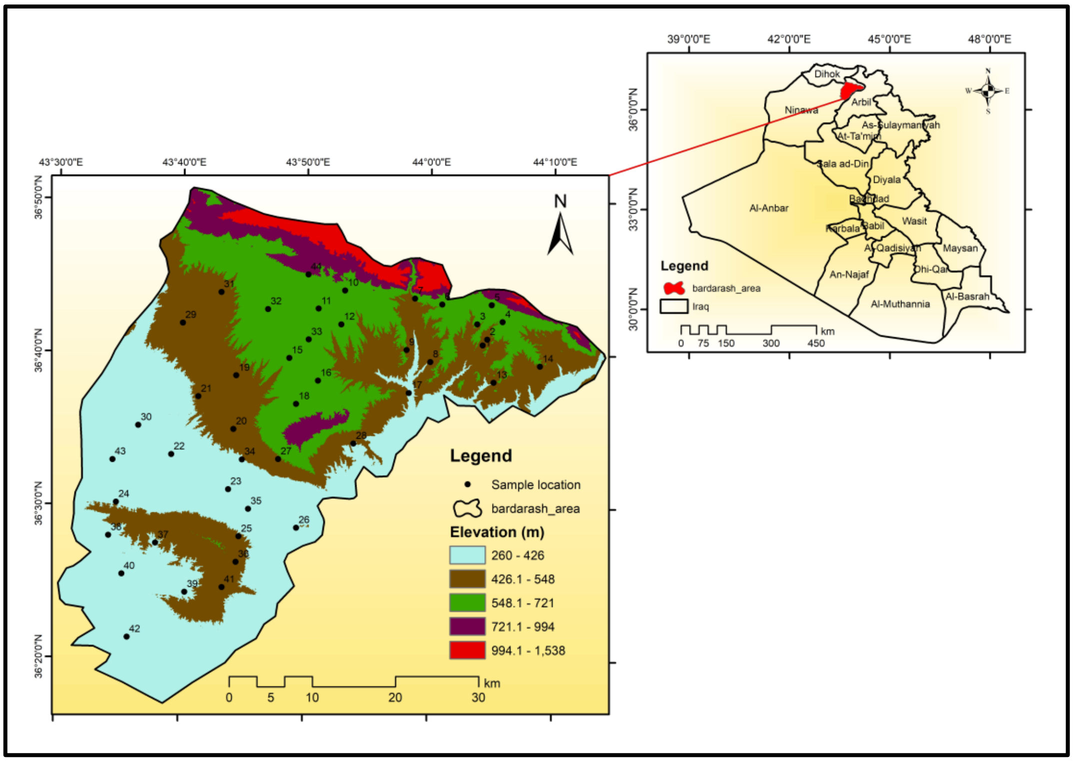

Fig. 1: Location map of Akre -Bardarash is located in the southeast of Duhok Governorate

Sampling

44 wells inside the Akre-Bardarash basin were chosen for the current investigation, and 44groundwater samples were collected for analysis and evaluation of the heavy metal concentrations table1. These groundwater wells have a depths range of 80 m to 350 m. Groundwater sampling was collected during 20 to 27 May 2023 Each sampling site's position was determined using a portable GPS. To ensure that drinkable water is present in every drinking water well , the sample locations were carefully chosen. Groundwater is frequently drank untreated in the research region. Prior to sampling, pumping was carried out for 10 to 15 minutes to guarantee the right sample was obtained. Throughout the collecting period, the weather was largely consistent. The water samples were filtered to eliminate impurities before being kept in high-density polyethylene (HDPE) containers that had already been treated with acid.

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Table1: The coordinates of sampling sites in the study area

wells	UTM- Easting	UTM Northing	altitude (m) above sea level)
1	416953.5	4059528	461.6
2	417498.4	4060231	498.7
3	416316.5	4062079	548.8
4	419363	4062336	549.5
5	418044.7	4064375	680
6	412101.1	4064469	557.3
7	408844.9	4065188	551.3
8	410661.5	4057518	459.1
9	407813	4058993	524.8
10	400420.6	4066180	637
11	397240.1	4063984	618.4
12	399961.9	4062080	590.5
13	418274.8	4055016	429.9
14	423839.2	4056950	496
15	393706.1	4058028	542.1
16	397154.2	4055287	662.9
17	408081.6	4053771	361
18	394528.6	4052478	605.9
19	387339.7	4055924	494
20	386986.2	4049442	447.6
21	382785.7	4053396	413
22	379519.5	4046408	376.3
23	386342	4042173	361
24	372868	4040663	382.5
25	387591.6	4036469	416.1
26	394532.1	4037508	382.8
27	392363.9	4045804	509.1
28	401411.5	4047674	395.8
29	380919.6	4062297	461
30	375547.7	4049939	364.4
31	385558.9	4066000	508.3
32	391173.1	4063929	607
33	396049.9	4060257	594.6
34	388003.4	4045759	404.9
35	388749.1	4039795	335.5
36	387247.1	4033378	456.5
37	377572.5	4035721	392.8
38	371939	4036657	374.7
39	381085.7	4029778	387.7
40	373510.6	4031980	348.2
41	385559.8	4030342	475.8
42	374153.5	4024349	316.1
43	372446.9	4045808	336.5
44	396017.7	4068105	699.8

Samples analysis

Groundwater samples were brought to the Erbil water directorate lab in cool-boxes and subjected to standards-compliant analysis by the American Public Health Association [10, 11]. A total of 14 heavy metals (As, Cd, Cu, Pb, Va, Ni, Zn, Bo, Cr, Co, Li, Mn, Se, and Ag) were examined in groundwater samples in general water directorate laboratories in Erbil. Table 2. All tested heavy metals were verified against the drinking water table's IRQ, 2011 norm[12].

Table 2: IRQ With the Iraqi standard of potable water

Class	Property/characteristics	HPI
1	Very pure	<0.3
2	pure	0. 3-1
3	Slightly Affected	1-2
4	Moderatel Affected	2-4
5	Strongly Affected	4-6
6	Seriously Affected	>6

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Heavy metal pollution index (HPI) and Metal index (MI) Estimation

According to Hafez and Zakhem (2015)[13] and Sheykhi and Moore (2012) [14], the heavy metal pollution index (HPI) is a indicator of rankings and a practical method for determining the amount of heavy metals in water. This served as an illustration of how metals interact to impact the general quality of water. [15] Reza et al. Researchers have utilized the HPI index to study surface water extensively. [16-18] all presented research on HPI in groundwater.

$$HPI = \frac{\sum_{i=1}^{n} QiWi}{\sum_{i=1}^{n} Wi} \quad \ldots\ldots\ldots.1$$

Where Wi and Qi represent the unit weightage and sub-index of I parameter, furthermore. As shown in the equation1, n is the total number of parameters to be considered.

The Qi (sub-index) is calculated by,

$$Qi = \sum_{i=1}^{n} \frac{Mi - Ii}{Si - Ii} * 100 \quad \ldots\ldots.2$$

Where Mi and Li depict the monitored and ideal values of the I parameter, respectively, Si represents the standard value of the I "the parameter in parts per million (ppm): as shown in equation (2) and table 3.

Table3: Calculation of HPI on sample 3

		Si	Li	mg/L	Wi	Qi	Wi Qi
1	Cd	0.003		2.66	333.3333	88666.67	29555556
2	Co	0.002		0.0020	500	100	50000
3	Cu	1	1.5	0.003	1	0.3	0.3
4	Pb	0.01		0.891	100	8910	891000
5	Li	0.001		0.001	1000	100	100000
6	Zn	3		0.0055	0.333333	0.183333	0.061111
7	Va	0.001		0.01	1000	1000	1000000
8	Cr	0.05		0.0981	20	196.2	3924
9	Ba	1.3		0.06	0.769231	4.615385	3.550296
					2955.436		31600483
						HPI	0.10268

Metal index (MI) is essentially described by [19] It is defined as the ratio of each element's concentration in the solution to the maximum allowable concentration for each element.

$$MI = \sum_{i=1}^{n} \frac{Ci}{(MAC)i} \quad \ldots\ldots3$$

Where MI is index of metal, Ci is the concentration of elements in a given solution. MAC is the maximum permissible concentration for each element, and subscript i represents the i of samples, as shown in equation (3) table4and subscript i represents the i of samples, as shown in equation (3) table 4.

Table 4: Calculation of MI on sample 3

Metal	Mi (n=10)	Si	Ii	Wi	Qi	Wi*Qi	MI
Co	0.3961	50	0.85	0.02	0.9235	0.01847	
Cd	0.0527	5	0.201	0.2	3.0902	0.618045	
Zn	0.0481	3000	0.104	0.00033	0.0019	6.15E-07	
Fe	0.0925	300	0.122	0.00333	0.0098	3.28E-05	
Ni	0.1961	20	0.208	0.05	0.0601	0.003006	
Cr	2.6321	50	4.174	0.02	3.3647	0.067294	
Pb	0.421	10	0.55	0.1	1.3651	0.136508	
Li	0.1296	5	0.284	0.2	3.274	0.654792	
							0.000413

Result and Discussion

Heavy metal concentrations

Heavy metals and metalloids have been shown to have negative effects in several studies, especially when their concentrations are over permissible limits [20] . Table 5 and Figure 2 provide more details on the findings of the analysis of heavy metals in the examined well water. The concentration of heavy

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metals in the environment fluctuates depending on the geological formation of the wells as well as manmade activity including industries, pesticides, agricultural fertilizers, fossil fuels, land development activities, and soil erosion brought on by precipitation[21]. The concentrations of heavy metals in water samples are put in the next descending arrangement:
Ag>Co>Va>Li>As>Cr>Ni>B>Pb>Cu>Se>Cd>Zn> Mn. Heavy metals of Ag, Co, Va, Li, As, and Ni are still below detectable limits but in some wells are detected but in lower limits. The concentrations of heavy metals in the current study as mentioned above higher than permissible levels recommended by IRQ guidelines for drinking purposes[22] .Heavy metals of Boron (B)ranges from 0.0149-0.6329 mg / lead (Pb) ranges from 0.0077-0.8956mg / cupper (Cu) ranges from 0.0091-0.8956, Selenium (Se) ranges from0.01-1.2mg/cadmium(Cd) ranges from 0.0304-2.69 mg/zinc (Zn) ranges from 0.088-4.465mg/l, and Manganese(Mn) ranges from0.00118-3.1mg/l. The highest concentration of heavy metals was recorded in well 1,2 by direct effect of oil and gas industry activity in this area, while in wells 23,30 were due to excessive use of fertilizer by farmers. During long time more 70 years ago especially this region are shallow groundwater table less than 30 m and high aquifer transmissivity [23]. The statistical analysis including the maximum value, minimum value, and average were tabulated for respective Heavy metals (Table 2). Arsenic, cadmium, boron, selenium, silver, all groundwater samples are safe and can be used for drinking purpose according to their heavy metal content.Excess Nickle and Manganese in some well's concentrations are due to their presence in earth's crust [24]. The combined impact of industrial pollutants and agricultural fertilizers increase level of heavy metal pollution in groundwater, particularly in the north east and southwest portion of Akre - Bardarash Basin. Even if each and every heavy metal characteristic has been examined and mapped independently, the analysis of the cumulative effects of heavy metals is absolutely crucial Fig 2.

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Table 5: Heavy metal concentration and Statistical parameters of analyzed groundwater samples

	As	Cd	Cu	Pb	Va	Ni	Zn	Boron	Cr	Co	Li	Mn	Se	Ag
	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L
1	0.0421	0.624	0.9721	0.8066	<0.0010	0.0738	0.19	<0.00020	0.036	<0.0020	<0.0010	0.522	1.02	<0.0100
2	0.0679	2.69	0.5351	0.8956	<0.0010	0.3918	1.666	<0.00020	0.0987	<0.0020	<0.0010	2.3	0.87	0.0114
3	0.0181	<0.00040	0.0111	0.0096	0.0493	0.0097	0.0961	0.6329	0.003	<0.0020	0.0071	<0.00050	0.0177	<0.0010
4	0.0648	<0.00040	0.0101	0.0106	<0.0010	0.0048	0.0898	<0.00020	<0.0010	<0.0020	<0.0010	<0.00050	<0.0100	<0.0010
5	0.0219	<0.00040	0.0105	0.0117	0.0032	0.0048	0.0895	<0.00020	<0.0010	<0.0020	<0.0010	<0.00050	<0.0100	<0.0010
6	0.0438	<0.00040	0.5971	0.012	0.0031	0.0048	2.926	<0.00020	<0.0010	<0.0020	<0.0010	<0.00050	<0.0100	<0.0010
7	0.0117	<0.00040	0.0119	0.0096	0.0095	0.0061	1.686	0.0907	<0.0010	<0.0020	0.0122	<0.00050	<0.0100	<0.0010
8	0.0793	<0.00040	0.0113	0.0096	0.012	0.0096	0.272	0.0249	<0.0010	<0.0020	0.0107	<0.00050	<0.0100	<0.0010
9	0.0648	0.0455	0.9361	0.4356	<0.0010	0.0858	3.646	<0.00020	0.5206	<0.0010	<0.0010	1.35	1.11	<0.0100
10	0.0647	0.0578	0.9991	0.2616	0.012	0.0448	4.465	0.0249	<0.0010	<0.0020	<0.0010	0.0012	<0.0100	<0.0010
11	0.0066	0.0304	0.0091	0.0096	0.0014	0.0048	0.088	0.0149	0.0016	0.002	0.001	<0.00050	0.01	0.001
12	0.0068	<0.00040	0.0096	0.0103	0.0052	0.0051	0.189	0.1034	0.0021	<0.0020	0.0142	<0.00050	<0.0100	<0.0010
13	0.007	<0.00040	0.0101	0.0077	0.0042	0.0055	0.0901	<0.00020	0.0022	<0.0020	0.0153	<0.00050	<0.0100	<0.0010
14	0.0058	<0.00040	0.0112	0.0097	0.0083	0.3918	0.393	0.0941	0.0032	<0.0020	0.013	<0.00050	<0.0100	<0.0010
15	0.0068	<0.00040	0.0131	0.0106	0.0027	0.0063	0.36	0.1469	<0.0010	<0.0020	0.019	<0.00050	<0.0100	<0.0010
16	0.0087	<0.00040	0.0131	0.0077	0.0031	0.0096	0.414	0.1529	0.0022	<0.0020	0.0176	<0.00050	<0.0100	<0.0010
17	0.0117	<0.00040	0.0123	0.0097	0.0047	0.008	0.0909	0.1109	0.0054	<0.0020	0.0113	<0.00050	<0.0100	<0.0010
18	0.0073	<0.00040	0.0149	0.0096	0.0064	0.0114	0.19	0.1149	0.0029	<0.0020	0.0119	<0.00050	<0.0100	<0.0010
19	0.0058	<0.00040	0.0143	0.0095	0.0088	0.0112	0.249	0.0963	0.0039	<0.0020	0.0093	<0.00050	<0.0100	<0.0010
20	0.0127	<0.00040	0.0631	0.0086	0.0047	0.0056	0.0933	0.1849	0.0017	<0.0020	0.0182	<0.00050	<0.0100	<0.0010
21	0.008	0.0304	0.0107	0.0102	0.0014	0.0048	0.088	0.0149	0.0016	0.002	0.001	<0.00050	0.01	0.001
22	0.061	2.08	0.5231	0.7756	<0.0010	0.3657	1.27	<0.00020	0.0887	<0.0020	<0.0010	3.1	1.2	0.0114
23	0.053	<0.00040	0.0101	0.011	0.0103	0.0066	0.0944	0.0313	0.0031	<0.0020	0.004	<0.00050	<0.0100	<0.0010
24	0.0131	<0.00040	0.0098	0.0566	0.007	0.0069	0.0893	0.0322	0.0041	<0.0020	0.0067	<0.00050	<0.0100	<0.0010
25	0.0273	<0.00040	0.0119	0.0096	0.0115	0.0062	0.31	0.1319	0.0045	<0.0020	0.017	<0.00050	<0.0100	<0.0010
26	0.0128	<0.00040	0.0129	0.0096	0.0139	0.0069	0.1294	0.1079	0.0042	<0.0020	0.0052	<0.00050	<0.0100	<0.0010
27	0.0084	<0.00040	0.0128	0.0093	0.0096	0.0056	0.1477	0.0974	0.0094	<0.0020	0.0102	<0.00050	<0.0100	<0.0010
28	0.019	0.0304	0.0091	0.0087	0.0014	0.0048	2.956	0.0149	0.0016	0.002	0.001	<0.00050	0.01	0.001
29	0.0082	<0.00040	0.0095	0.0095	<0.0010	0.0048	0.544	0.0286	0.0023	<0.0020	0.0035	<0.00050	<0.0100	<0.0010
30	0.0481	0.664	0.9854	0.8466	<0.0010	0.0768	0.18	<0.00020	0.038	<0.0020	<0.0010	0.532	0.026	<0.0100
31	0.0077	<0.00040	0.0131	0.0077	0.0031	0.0096	0.414	0.1529	0.0022	<0.0020	0.0176	<0.00050	<0.0100	<0.0010

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	As	Cd	Cu	Pb	Va	Ni	Zn	Boron	Cr	Co	Li	Mn	Se	Ag
	μg/L	μg/L	μg/L	μg/L	μg/L	μg/L	μg/L	μg/L	μg/L	μg/L	μg/L	μg/L	μg/L	μg/L
32	0.0113	<0.00040	0.0123	0.0097	0.0047	0.008	0.0909	0.1109	0.0054	<0.0020	0.0113	<0.00050	<0.0100	<0.0010
33	0.0063	<0.00040	0.0149	0.0096	0.0064	0.0114	0.19	0.1149	0.0029	<0.0020	0.0119	<0.00050	<0.0100	<0.0010
34	0.006	<0.00040	0.0143	0.0095	0.0088	0.0112	0.249	0.0963	0.0039	<0.0020	0.0093	<0.00050	<0.0100	<0.0010
35	0.0117	<0.00040	0.0631	0.0086	0.0047	0.0056	0.0933	0.1849	0.0017	<0.0020	0.0182	<0.00050	<0.0100	<0.0010
36	0.0083	0.0304	0.0107	0.0102	0.0014	0.0048	0.088	0.0149	0.0016	0.002	0.001	<0.00050	0.01	0.001
37	0.019	<0.00040	0.0132	0.01	0.0098	0.0238	0.088	0.0386	0.006	<0.0020	0.0092	<0.00050	<0.0100	<0.0010
38	0.051	<0.00040	0.0101	0.011	0.0103	0.0066	0.0944	0.0313	0.0031	<0.0020	0.004	<0.00050	<0.0100	<0.0010
39	0.0135	<0.00040	0.0098	0.0566	0.007	0.0069	0.0893	0.0322	0.0041	<0.0020	0.0067	<0.00050	<0.0100	<0.0010
40	0.0283	<0.00040	0.0119	0.0096	0.0115	0.0062	0.31	0.1319	0.0045	<0.0020	0.017	<0.00050	<0.0100	<0.0010
41	0.0129	<0.00040	0.0129	0.0096	0.0139	0.0069	0.1294	0.1079	0.0042	<0.0020	0.0052	<0.00050	<0.0100	<0.0010
42	0.0087	<0.00040	0.0128	0.0093	0.0096	0.0056	0.1477	0.0974	0.0094	<0.0020	0.0102	<0.00050	<0.0100	<0.0010
43	0.018	0.0304	0.0091	0.0087	0.0014	0.0048	2.956	0.0149	0.0016	0.002	0.001	<0.00050	0.01	0.001
44	0.0092	<0.00040	0.0095	0.0095	<0.0010	0.0048	0.544	0.0286	0.0023	<0.0020	0.0035	<0.00050	<0.0100	<0.0010
min	0.0058	0.0304	0.0091	0.0077	0.0014	0.0048	0.088	0.0149	0.0016	0.002	0.001	0.0012	0.01	0.001
max	0.0793	2.69	0.9991	0.8956	0.0493	0.3918	4.465	0.6329	0.5206	0.002	0.019	3.1	1.2	0.0114
A.V	0.0234	0.5739	0.1381	0.1019	0.0079	0.0386	0.6495	0.0974	0.0242	0.002	0.0096	1.3009	0.3903	0.004

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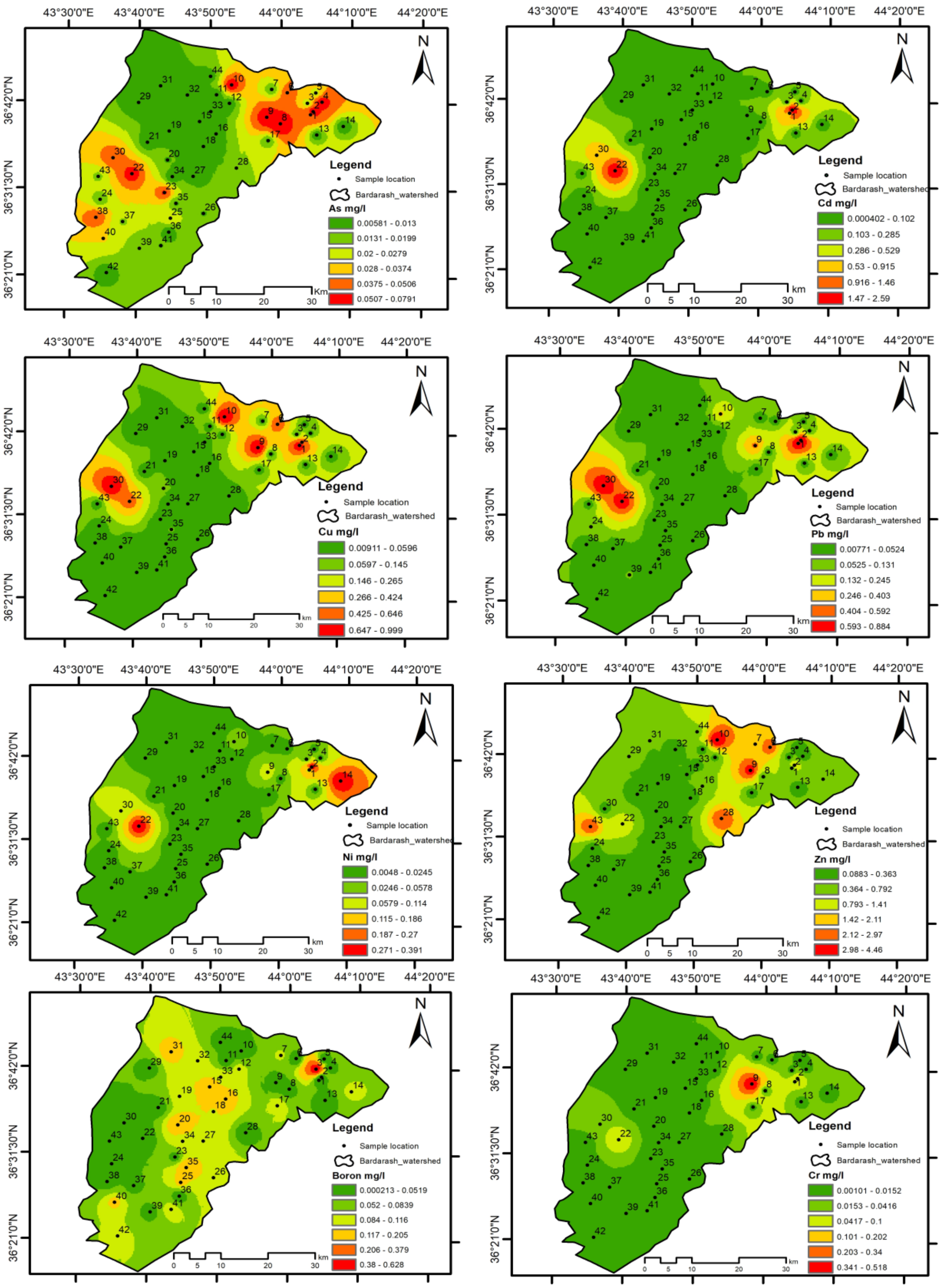

Fig. 2: Spatial distribution of heavy metal concentration in Akre-Bardarash basin

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Table 5: Heavy metal concentration and Statistical parameters of analyzed groundwater samples

	As	Cd	Cu	Pb	Va	Ni	Zn	Boron	Cr	Co	Li	Mn	Se	Ag
	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L
1	0.0421	0.624	0.9721	0.8066	<0.0010	0.0738	0.19	<0.00020	0.036	<0.0020	<0.0010	0.522	1.02	<0.0100
2	0.0679	2.69	0.5351	0.8956	<0.0010	0.3918	1.666	<0.00020	0.0987	<0.0020	<0.0010	2.3	0.87	0.0114
3	0.0181	<0.00040	0.0111	0.0096	0.0493	0.0097	0.0961	0.6329	0.003	<0.0020	0.0071	<0.00050	0.0177	<0.0010
4	0.0648	<0.00040	0.0101	0.0106	<0.0010	0.0048	0.0898	<0.00020	<0.0010	<0.0020	<0.0010	<0.00050	<0.0100	<0.0010
5	0.0219	<0.00040	0.0105	0.0117	0.0032	0.0048	0.0895	<0.00020	<0.0010	<0.0020	<0.0010	<0.00050	<0.0100	<0.0010
6	0.0438	<0.00040	0.5971	0.012	0.0031	0.0048	2.926	<0.00020	<0.0010	<0.0020	<0.0010	<0.00050	<0.0100	<0.0010
7	0.0117	<0.00040	0.0119	0.0096	0.0095	0.0061	1.686	0.0907	<0.0010	<0.0020	0.0122	<0.00050	<0.0100	<0.0010
8	0.0793	<0.00040	0.0113	0.0096	0.012	0.0096	0.272	0.0249	<0.0010	<0.0020	0.0107	<0.00050	<0.0100	<0.0010
9	0.0648	0.0455	0.9361	0.4356	<0.0010	0.0858	3.646	<0.00020	0.5206	<0.0010	<0.0010	1.35	1.11	<0.0100
10	0.0647	0.0578	0.9991	0.2616	0.012	0.0448	4.465	0.0249	<0.0010	<0.0020	<0.0010	0.0012	<0.0100	<0.0010
11	0.0066	0.0304	0.0091	0.0096	0.0014	0.0048	0.088	0.0149	0.0016	0.002	0.001	<0.00050	0.01	0.001
12	0.0068	<0.00040	0.0096	0.0103	0.0052	0.0051	0.189	0.1034	0.0021	<0.0020	0.0142	<0.00050	<0.0100	<0.0010
13	0.007	<0.00040	0.0101	0.0077	0.0042	0.0055	0.0901	<0.00020	0.0022	<0.0020	0.0153	<0.00050	<0.0100	<0.0010
14	0.0058	<0.00040	0.0112	0.0097	0.0083	0.3918	0.393	0.0941	0.0032	<0.0020	0.013	<0.00050	<0.0100	<0.0010
15	0.0068	<0.00040	0.0131	0.0106	0.0027	0.0063	0.36	0.1469	<0.0010	<0.0020	0.019	<0.00050	<0.0100	<0.0010
16	0.0087	<0.00040	0.0131	0.0077	0.0031	0.0096	0.414	0.1529	0.0022	<0.0020	0.0176	<0.00050	<0.0100	<0.0010
17	0.0117	<0.00040	0.0123	0.0097	0.0047	0.008	0.0909	0.1109	0.0054	<0.0020	0.0113	<0.00050	<0.0100	<0.0010
18	0.0073	<0.00040	0.0149	0.0096	0.0064	0.0114	0.19	0.1149	0.0029	<0.0020	0.0119	<0.00050	<0.0100	<0.0010
19	0.0058	<0.00040	0.0143	0.0095	0.0088	0.0112	0.249	0.0963	0.0039	<0.0020	0.0093	<0.00050	<0.0100	<0.0010
20	0.0127	<0.00040	0.0631	0.0086	0.0047	0.0056	0.0933	0.1849	0.0017	<0.0020	0.0182	<0.00050	<0.0100	<0.0010
21	0.008	0.0304	0.0107	0.0102	0.0014	0.0048	0.088	0.0149	0.0016	0.002	0.001	<0.00050	0.01	0.001
22	0.061	2.08	0.5231	0.7756	<0.0010	0.3657	1.27	<0.00020	0.0887	<0.0020	<0.0010	3.1	1.2	0.0114
23	0.053	<0.00040	0.0101	0.011	0.0103	0.0066	0.0944	0.0313	0.0031	<0.0020	0.004	<0.00050	<0.0100	<0.0010
24	0.0131	<0.00040	0.0098	0.0566	0.007	0.0069	0.0893	0.0322	0.0041	<0.0020	0.0067	<0.00050	<0.0100	<0.0010
25	0.0273	<0.00040	0.0119	0.0096	0.0115	0.0062	0.31	0.1319	0.0045	<0.0020	0.017	<0.00050	<0.0100	<0.0010
26	0.0128	<0.00040	0.0129	0.0096	0.0139	0.0069	0.1294	0.1079	0.0042	<0.0020	0.0052	<0.00050	<0.0100	<0.0010
27	0.0084	<0.00040	0.0128	0.0093	0.0096	0.0056	0.1477	0.0974	0.0094	<0.0020	0.0102	<0.00050	<0.0100	<0.0010
28	0.019	0.0304	0.0091	0.0087	0.0014	0.0048	2.956	0.0149	0.0016	0.002	0.001	<0.00050	0.01	0.001
29	0.0082	<0.00040	0.0095	0.0095	<0.0010	0.0048	0.544	0.0286	0.0023	<0.0020	0.0035	<0.00050	<0.0100	<0.0010
30	0.0481	0.664	0.9854	0.8466	<0.0010	0.0768	0.18	<0.00020	0.038	<0.0020	<0.0010	0.532	0.026	<0.0100
31	0.0077	<0.00040	0.0131	0.0077	0.0031	0.0096	0.414	0.1529	0.0022	<0.0020	0.0176	<0.00050	<0.0100	<0.0010

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	As	Cd	Cu	Pb	Va	Ni	Zn	Boron	Cr	Co	Li	Mn	Se	Ag
	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L
32	0.0113	<0.00040	0.0123	0.0097	0.0047	0.008	0.0909	0.1109	0.0054	<0.0020	0.0113	<0.00050	<0.0100	<0.0010
33	0.0063	<0.00040	0.0149	0.0096	0.0064	0.0114	0.19	0.1149	0.0029	<0.0020	0.0119	<0.00050	<0.0100	<0.0010
34	0.006	<0.00040	0.0143	0.0095	0.0088	0.0112	0.249	0.0963	0.0039	<0.0020	0.0093	<0.00050	<0.0100	<0.0010
35	0.0117	<0.00040	0.0631	0.0086	0.0047	0.0056	0.0933	0.1849	0.0017	<0.0020	0.0182	<0.00050	<0.0100	<0.0010
36	0.0083	0.0304	0.0107	0.0102	0.0014	0.0048	0.088	0.0149	0.0016	0.002	0.001	<0.00050	0.01	0.001
37	0.019	<0.00040	0.0132	0.01	0.0098	0.0238	0.088	0.0386	0.006	<0.0020	0.0092	<0.00050	<0.0100	<0.0010
38	0.051	<0.00040	0.0101	0.011	0.0103	0.0066	0.0944	0.0313	0.0031	<0.0020	0.004	<0.00050	<0.0100	<0.0010
39	0.0135	<0.00040	0.0098	0.0566	0.007	0.0069	0.0893	0.0322	0.0041	<0.0020	0.0067	<0.00050	<0.0100	<0.0010
40	0.0283	<0.00040	0.0119	0.0096	0.0115	0.0062	0.31	0.1319	0.0045	<0.0020	0.017	<0.00050	<0.0100	<0.0010
41	0.0129	<0.00040	0.0129	0.0096	0.0139	0.0069	0.1294	0.1079	0.0042	<0.0020	0.0052	<0.00050	<0.0100	<0.0010
42	0.0087	<0.00040	0.0128	0.0093	0.0096	0.0056	0.1477	0.0974	0.0094	<0.0020	0.0102	<0.00050	<0.0100	<0.0010
43	0.018	0.0304	0.0091	0.0087	0.0014	0.0048	2.956	0.0149	0.0016	0.002	0.001	<0.00050	0.01	0.001
44	0.0092	<0.00040	0.0095	0.0095	<0.0010	0.0048	0.544	0.0286	0.0023	<0.0020	0.0035	<0.00050	<0.0100	<0.0010
min	0.0058	0.0304	0.0091	0.0077	0.0014	0.0048	0.088	0.0149	0.0016	0.002	0.001	0.0012	0.01	0.001
max	0.0793	2.69	0.9991	0.8956	0.0493	0.3918	4.465	0.6329	0.5206	0.002	0.019	3.1	1.2	0.0114
A.V	0.0234	0.5739	0.1381	0.1019	0.0079	0.0386	0.6495	0.0974	0.0242	0.002	0.0096	1.3009	0.3903	0.004

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Heavy metal pollution index (HPI) &Metal pollution (MI)

As it integrates numerous factors to provide a single value that can be compared with other values, the heavy metal pollution index is a useful tool for characterizing surface water contamination[25], [26].This study's main objective is to assess the Heavy Metal Pollution Index (HPI) and Metal Index (MI), two important heavy metal pollution indicators to determine water suitability for human consumption. The HPI and MI estimations in the Akre-Bardarash basin (sample 2) are shown in Table 3. Table 6 shows the MI and HPI values in the research area's chosen wells, whereas Fig 3 and 4 shows the variance in MI and HPI.

Table 6: Metal pollution index& Heavy Metal pollution index results for Akre-Bardarash basin

No.	HPI	MI	No.	HPI	MI
1	291.001	0.57813	23	51.3387	0.0994
2	107.12	0.4797	24	49.0527	0.0991
3	193.831	0.10268	25	99.8296	0.099
4	10.6702	0.0986	26	67.7655	0.0989
5	16.5745	0.09794	27	69.521	0.0983
6	16.1913	0.09952	28	10.6691	0.0986
7	76.707	0.09892	29	19.2847	0.153
8	79.5414	0.10023	30	184.001	0.5872
9	62.1276	0.66283	31	71.8771	0.0979
10	65.6111	0.68638	32	55.8901	0.098
11	15.0217	0.09741	33	64.6796	0.0983
12	68.1254	0.09786	34	62.9263	0.0985
13	68.2733	0.0977	35	80.311	0.0979
14	74.1936	0.11754	36	10.6691	0.0975
15	76.7046	0.09773	37	66.4069	0.0995
16	71.8771	0.09794	38	51.3387	0.0994
17	55.8901	0.09801	39	49.0527	0.0991
18	64.6796	0.09829	40	99.8296	0.099
19	62.9263	0.09851	41	67.7655	0.0989
20	80.311	0.09791	42	69.521	0.0983
21	10.6691	0.09745	43	10.6691	0.0986
22	103.015	0.46783	44	19.2847	0.153
			Min	10.6691	0.0974
			Max	291.001	0.6864
			Meam	68.2442	0.1667

When the HPI result is more than 100 (HPI > 100), the water is considered to be contaminated; when it is lower than 100 (HPI 100), it is not. Table 4 shows the current HPI value for all wells, which is 97.66 (HPI 100), indicating that no pollution was found but was still considered to be at critical levels of contamination [27]. According to table 5 [28], the categorization of HPI water samples is as follows: 22.72% of samples are excellent, 4.54% are good, 45.45% are bad, 15.90% are very poor, and 11.36% are unsuitable. The water samples 1to 44 (except sample 1,2,3.22,30) are vary from excellent to very poor, while sample1,2,3,22, an30 are unsuitable Fig4. Excessive HPI values in the sample1,2, and 3 by direct effect of oil and gas production activity such as well drilling EPF (Early production facility), EWT (Extended well test) , and excessive use of fertilizer by farmer around wells 22 and30. The increased HPI value is due to higher levels of total cadmium, copper, lead, nickel, zinc, and vanadium in groundwater samples.

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Table 7: Groundwater quality classification based on pollution indices HPI & MI

Index methods	Range /Class	Quality /Character	Number of samples	% of samples in each class
HPI	<25	Excellent	10	22.72
	26 to 50	Good	2	4.54
	51 to 75	Poor	20	45.45
	76 to100	Very poor	7	15.90
	>100	Unsuitable	5	11.36
Index methods	**Range/Class**	**Quality/Character**	**Number of samples**	**%of samples in each class**
MI	<0. 1	Very pure (Class I)	33	79
	0. 1 to 0.3	Pure (Class II)	7	15.90
	0.3 to 2	Slightly affected (Class III)	4	9.09
	2 to 4	Moderately affected (Class IV)		
	4 to 6	Strongly affected (Class V)		
	> 6	Seriously affected (Class VI)		

The MI values have been calculated for each and every sampling well location by substituting the analysis results in the above-mentioned equation (2) to calculate Qi which have been substituted in the equation (1) to calculate metal index (MI). The results along with the geographic coordinates have been interpolated using ArcGIS to obtain the spatial distribution of whole basin. Heavy metal pollution index values mapped according to their result as shown in table4 and Fig5. The MI values above 0. 3 is considered as threat for the ground water and below MI value considered pure water [17].

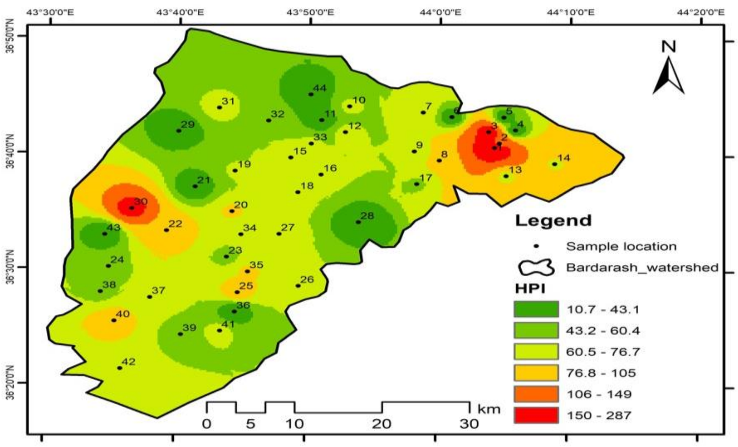

Fig. 3: Spatial distribution map of HPI in Akre -Bardarash basin

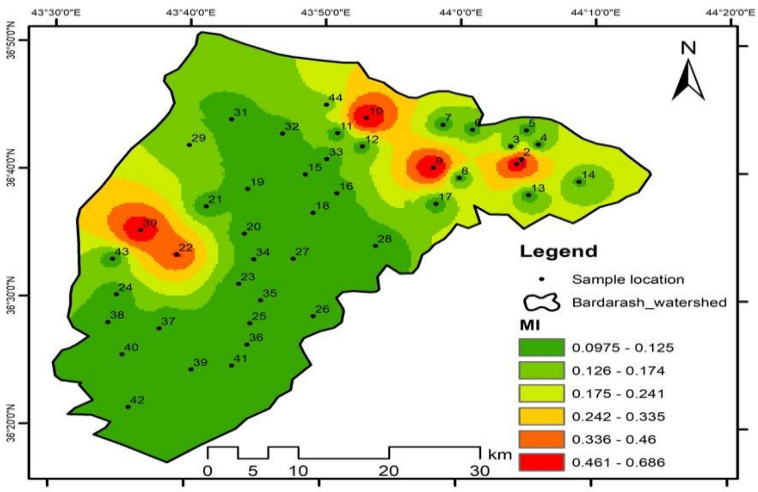

Fig. 4: Spatial distribution map of MI in Akre -Bardarash basin

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Mean value of metal index concentration was discovered to be 0.16 with 88.6 % of samples are classified very pure (class I), which are suitable for drinking use, with the remaining 11.36 percent of samples classified pure (class II) table4. Table 5 demonstrates the distribution of groundwater quality in Akre-Bardarash basin based on Metal index concentration. Figure 5 depicts the groundwater quality distribution of MI in study area. From the MI spatial distribution maps figure5, it is clear the main hazardous zones have been found in the village Gojar and jonala(sample1,2, and3)northeast part and village Dostak and Qaranaz village (sample22 and 30) south west part of study area. The less hazardous threat zones (MI from <0.1) have been found in middle part of study area.

Conclusion

Assessing the levels of heavy metal content in groundwater throughout the Akre-Bardarash basin was the main goal of the current study. The Heavy Metal Pollution Index (HPI) and Metal Index (MI) indices have emerged as the most significant and successful ways for assessing the concentration of heavy metals as well as the influence of human activity on this concentration. Considering the research being done currently, the main findings are as follows: The mean value of HPI was 97.66. Extreme HPI values were discovered in approximately 10% of the samples. The average MI concentration was 0.16, with 88.6% percent of groundwater samples classified as very pure. The conclusion highlights the impact of the oil and gas production industry’s activities and the area's inadequate management of influent. The cause of groundwater contamination, which results in severely low water quality that is dangerous to drink, appears to be a high concentration of heavy metals. Before being released into the natural environment, heavy crude oil and wastewater from the oil and gas industry should be treated individually. The heavy metal pollution index model, which is used here as a technique for evaluating all pollution level of groundwater in terms of heavy metals, is more beneficial and promising than metal index, which is use to assess heavy metals in a given groundwater sample. Findings suggest that the best method for evaluating groundwater quality is HPI. The HPI model could be applied to other suspect areas in the future. Except wells 1.2, and 3in the north east part and well 22,30 in the south west part of the basin are polluted by heavy metals. This research indicate that the water can be used for drinking purpose and safe water for human consumption with no negative effects on human health in most wells except wells numbe1,2,3,22, and30. According to the results of analyzing heavy metal concentration in groundwater of Akre-Bardarash basin, found less than guideline limit recommended by Iraqi drinking water standard except in site 1,2,3,22 and30 for pb,Cd,and As depending on single constituent heavy metals .Heavy metal pollution index (HPI) values have showed that the groundwater of Akre-Bardarash basin are free from heavy metal pollution and can be used for human consumption.

Recommendation

Akre-Bardarash groundwater wells should be continuously monitored, especially in the northwest and southwest part.

Acknowledgments

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