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Study of Groundwater Pollution Levels with Heavy Metals in Al-Zubair District

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Abstract

The study aims to assess the contamination of groundwater with some toxic heavy elements in the study area (Cr, Cu, Mn, Ni, Zn, Mo, Pb, As, Co, Fe). A total of (1200) samples were collected from 10 wells distributed in Al-Zubair district, with one sample per well per month from September 2022 to August 2023. The study found an increase in the levels of toxic heavy elements in groundwater beyond the allowable environmental limits, with the highest values recorded in the winter and spring seasons. The results of the statistical analysis showed significant differences with a probability of less than (0.05) between the selected seasons for the study. Strongly significant differences were found in some seasons, with the most prominent being the summer and winter seasons.

Keywords. *Groundwater, Heavy Elements, Water Pollution.*

Introduction

Groundwater is one of the important sources of water that fills the subsurface of the Earth and is present in the voids between sand, soil, and rocky fragments. These waters form aquifer layers, which are known as groundwater layers. These layers constitute a basin for water. Groundwater is considered a part of the natural water cycle on the Earth's surface. When it rains, this water seeps into the ground through soil and rocky fragments, percolating through porous rocks to reach a specific area where it accumulates (Sassi, 2021: 18).

Groundwater represents about 98% of the world's freshwater resources, distributed somewhat equitably among continents. Due to its underground nature, it is challenging to control its pollution. In recent times, after the industrial revolution, the pollution of groundwater has increased significantly due to the presence of heavy elements in both groundwater and surface water. These elements pose a high toxicity risk, and caution must be exercised.

Groundwater generally has better quality than surface water in many cases, and it is easier to access shallow groundwater. However, it is vulnerable to over-exploitation and pollution from various sources. Analyzing the mineral content of groundwater provides information about the interaction between the water and the rocks, including all the layers of groundwater and the processes that occur between them. This interaction enriches groundwater with minerals (Ahmed, 2017: 63).

Heavy metals are considered natural components of the Earth's crust. Some are biologically important and exist in very low concentrations. The main sources of heavy elements in soil are the natural chemical background of the Earth and pollution resulting from human activities. Toxic heavy elements are defined by having a high atomic weight and a specific density that exceeds that of water by five times or more (Sadeq & Abdul-Rahman, 2019: 29; Bretcan, et al., 2022: 2). They are toxic to forms of life and are not

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necessary for their preservation. The level of groundwater pollution tends to be higher compared to surface water due to the interaction of rocks with this water. It is also subjected to aeration and dissolution of minerals to a high extent. Additionally, local waste disposal sites, industrial activities, traffic movement, and the use of fertilizers and pesticides for agricultural purposes contribute to continuous groundwater pollution. These elements filter into groundwater, transfer to it, and eventually reach groundwater reservoirs, leading to its contamination (Ullah, et al., 2022: 2; Kana, 2022: 3; Salem & Alwalid, 2019: 156; Hasib &).

Study Problem

The study further addresses the question:

Are the groundwater sources in the Al-Zubair district free from heavy metal pollution and suitable for various uses?

Hypothesis

There is contamination in the groundwater of Al-Zubair district with heavy metals, which has rendered the groundwater unsuitable for various uses.

Aims of the Study

The study aims to achieve a set of points as follows:

1. Evaluate the suitability of groundwater samples from Al-Zubair district based on the obtained results.
2. Determine the potential pollution level of certain heavy elements in the sediments associated with groundwater.
3. Compare the laboratory analysis results of the study with the permissible environmental indicators.

Work Method

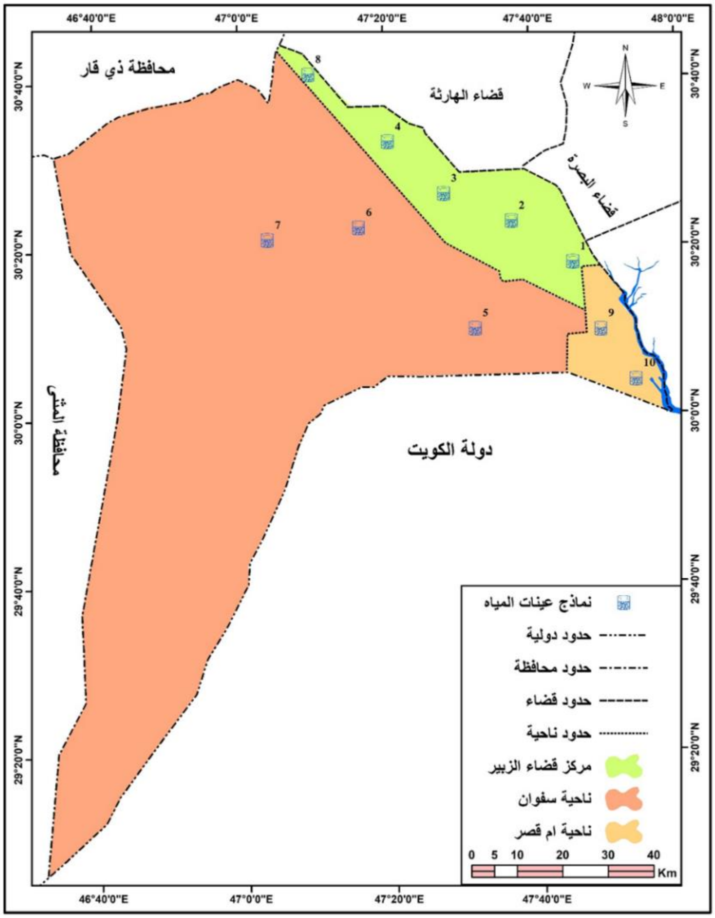
Ten wells were selected distributed in Al-Zubair district with depths ranging between (15-25) meters as shown in Table (1) and Map (1). A total of 1200 samples were collected for ten heavy elements (Iron Fe, Cobalt Co, Arsenic As, Lead Pb, Molybdenum Mo, Zinc Zn, Nickel Ni, Manganese Mn, Copper Cu, Chromium Cr), distributed over 12 months from September 2022 to August 2023 using 330 ml plastic bottles according to internationally recognized measurement methods. The data was distributed by season (Dry Season - Summer and Autumn) and (Wet Season - Spring and Winter). Sample collection took place from 8 AM to 12 PM, and information for each sample was recorded on its corresponding form and sent to the laboratory for analysis.

Table 1: Coordinates of Groundwater Sampling Sites and Well Depths in Al-Zubair District

Well's Number	Depth/ meters	Coordinates	
		°N	°E
1	19.9	3355320	765232
2	22.2	3364255	751731
3	17.0	3370211	736840
4	15.3	3381529	724530
5	20.9	3340628	743789
6	16.0	3362667	718176
7	17.6	3359887	698123
8	25.0	3396221	707057
9	19.8	3340628	771387
10	20.0	3329708	779130

Source: Fieldwork, 2023

Map 1: Locations of Groundwater Sampling in Al-Zubair District



*General Authority for Survey, Administrative Map of Basra Governorate, Baghdad, 2018.
**Field Study, 2023.

Methodology

The researcher followed a set of methodologies to achieve accuracy in this subject, including the descriptive-analytical method, the inductive method, and the statistical method, in order to obtain results for this study that are beneficial to society.

Study Limit

Geographical and Astronomical Limits

The district of Az Zubayr is located in the southwestern part of Basra Governorate, between latitude (29.10 - 30.50) degrees north, and longitude (46.40 - 48.20) degrees east. It is bordered by Abu Al-Khaseeb and Al-Faw districts to the east, Basra district to the northeast, Qurna and Al-Medina districts, and Thi Qar Governorate to the north. It is bordered by Kuwait to the south. Its estimated area is approximately 10,316 square kilometers, which represents about 54% of the total area of Basra

Governorate, which is 19,070 square kilometers. See Map (2).

Temporal Limits

The study period extended from September 2022 to August 2023.

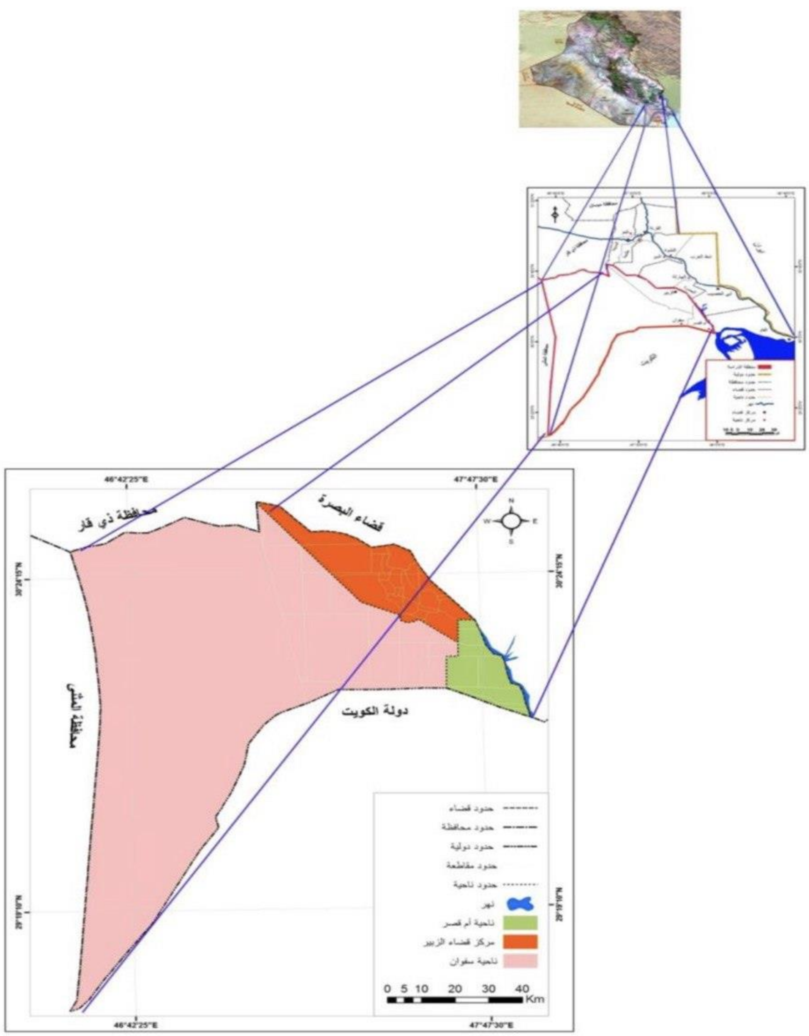
Objective Limits

The study focused on analyzing the aforementioned heavy elements in the groundwater of the study area.

Study Significance

This study is one of its kind and is considered important, as it aims to determine the quality and suitability of groundwater in the study area. It also seeks to identify the concentrations of heavy elements, which may render the water polluted and unsuitable for various uses. These heavy elements could potentially lead to the contamination of this water.

Map 2: Location of Al-Zubair District in Basra Governorate and Iraq.



*Source: General Authority for Survey, Administrative Map of Basra Governorate, Baghdad, 2018.

Results and Discussions

The heavy metals were classified into different categories based on their presence in the water, including essential heavy elements such as copper (Cu), zinc (Zn), and iron (Fe). There are also toxic metallic elements like lead (Pb), arsenic (As), and cobalt (Co). All of these elements have positive effects if they are within their natural proportions. However, if they exceed the permissible limit, they become toxic. This will be studied according to the four seasons as shown in Table (2).

Table 2: Environmental Limits for Some Heavy Metals in Soil / ppm

Metal	Environmental Limit/ ppm
Fe	1.05
Co	0.56
As	1.5
Pb	26.8
Mo	0.06
Zn	0.95
Ni	0.89
Mn	0.97
Cu	1.2
Cr	2.24

Source: World Health Organization, Regional Office for the Eastern Mediterranean, Regional Center for Environmental Health Activities, Amman, Jordan, 2003, p. 16.

The Dry Season (Summer)

According to the data provided in Table (3) and Figure (1), the following becomes evident.

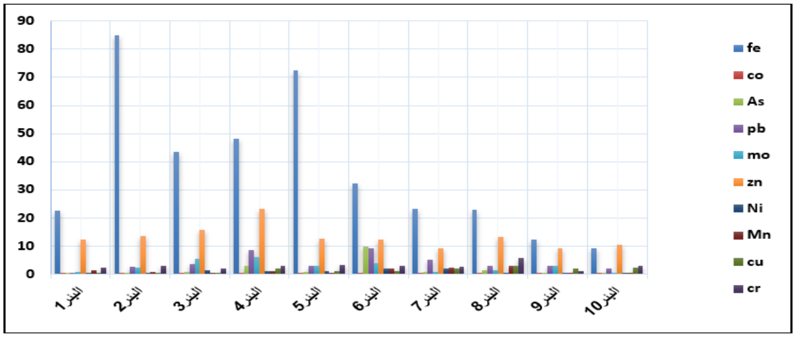
Table 3: Seasonal Concentrations and Significant Differences of Heavy Elements (ppm) in Groundwater for Al-Zubair District (Summer - Dry Season)

Metal Location	Fe	Co	As	Pb	Mo	Zn	Ni	Mn	Cu	Cr
Well 1	22.5	0.3	0.1	0.5	0.9	12.3	0.1	1.5	0.5	2.2
Well 2	85.1	0.1	0.1	2.7	2.3	13.5	0.5	0.9	0.5	2.9
Well 3	43.5	0.1	0.9	3.5	5.3	15.7	1.5	0.3	0.5	2.1
Well 4	48.2	0.2	2.9	8.5	6.1	23.2	1.1	1.2	1.9	2.9
Well 5	72.5	0.2	0.7	3.1	2.9	12.7	1.2	0.2	1.1	3.2
Well 6	32.3	0.5	9.8	9.3	3.8	12.3	1.9	2.1	1.1	3.1
Well 7	23.1	0.2	0.8	5.2	0.7	9.2	1.9	2.3	2.1	2.7
Well 8	22.9	0.4	1.3	3.1	1.3	13.3	0.5	2.9	2.8	5.9
Well 9	12.3	0.1	0.5	3.1	2.8	9.1	0.1	0.3	1.9	1.2
Well 10	9.3	0.3	0.1	2.1	0.5	10.5	0.5	0.4	2.3	2.9
Limit	1.05	0.56	1.5	26.8	0.06	0.95	0.89	0.97	1.2	2.24
Autumn	[†]0.009	0.969	0.125	0.141	0.352	0	0.753	0.254	0.086	0.004
Winter	0	0	0.699	0	0.004	0	0.017	0	0	0
Spring	0	0	0.865	0.001	0.014	0	0.033	0.005	0	0

[†] The numbers in these fields indicate the value of the statistical relationship and the significant differences between the concentrations of heavy elements according to the seasons.

Source: Laboratory Analysis Results, College of Science, Department of Environment, 2022-2023.

Fig. 1: Seasonal concentrations of heavy elements in groundwater for Al-Zubair district (Dry season - Summer) (ppm).



Source: Table 3 data.

Iron Fe

Iron is naturally found in the form of hematite, a black iron oxide, and it is discharged into water when extracted from its ore. It is an essential element for the diet of most living organisms. However, in this study, the concentrations of iron exceeded the permissible environmental limits significantly, reaching 1.05 ppm. Well number 3 recorded the highest value at 85.1 ppm, followed by well number 5 with a value of 72.5 ppm. The third highest concentration was in well number 4 at 48.2 ppm. The remaining well values ranged between 9.3 and 43.5 ppm. By applying the statistical significance (Isd), it was found that there were significant differences between the summer and winter seasons, with a p-value of 0.000. Similarly, there were significant differences between the summer and spring seasons, with a p-value of 0.000, indicating a very strong relationship. As for the summer and autumn seasons, the difference between them was 0.009.

Cobalt Co

When the concentration of cobalt exceeds the permissible environmental limit of 0.56 ppm, it becomes toxic. This toxicity can lead to a disruption in heart muscle function due to a hindrance in oxygen delivery, resulting in the cessation of vital physiological and chemical functions in the human body, affecting the ribonucleic acid (RNA). In the study area, the cobalt concentration did not exceed the permissible environmental limit. The value in well 1 was 0.3 ppm, while in wells 2 and 3 it was 0.1 ppm. The remaining well values ranged between 0.2 and 0.5 ppm. By applying statistical significance, it was found that there were significant differences between the summer and winter seasons, with a p-value of 0.000. Similarly, there were significant differences between the summer and spring seasons, with a p-value of 0.000, indicating a very strong relationship. As for the summer and autumn seasons, it was statistically evident that there was no significant difference between them, with a calculated p-value of 0.969.

Arsenic As

It is a naturally occurring element that is odorless and is available in the environment in an inorganic form. It seeps into groundwater through porous rocks and increases with industrial activities. If arsenic exceeds the permissible environmental limit of 1.5 ppm, it becomes toxic and harms the circulatory system and nervous system of humans. It may also lead to cancer. In the study area, some wells exceeded the permissible limit, while others did not. Well 6 recorded the highest concentration, reaching 9.8 ppm, followed by well 4 with a value of 2.9 ppm. The concentration of (As) in the remaining wells ranged between 0.5 and 0.9 ppm. Statistically, there were no significant differences between the summer and spring seasons, with a p-value of 0.865. Similarly, there were no significant differences between the autumn and summer seasons, with a p-value of 0.125. Additionally, there were no significant differences between the summer and winter seasons, with a p-value of 0.699.

Lead Pb

Lead is considered one of the most important heavy metals due to its high toxicity and widespread occurrence. In urban areas, lead levels are often elevated, primarily due to emissions from transportation, accounting for over 60%. This is the main cause of lead contamination in cities. Lead toxicity increases if it exceeds the permissible environmental limit of 26.8 ppm. In the study area, it was observed that none of the samples exceeded the permissible limit. The value from well sample 6 was 9.3 ppm, from well sample 4 it was 8.5 ppm, and from well sample 7 it was 5.2 ppm. The remaining values ranged between 0.5 and 3.1 ppm. Statistically, there were significant differences between the summer and spring seasons with a p-value of 0.014, and between the summer and winter seasons with a p-value of 0.000. However, no significant differences were found between the autumn and summer seasons, with a p-value of 0.141.

Molybdenum Mo

It is a chemical element naturally present in the environment. It leaches from the soil into groundwater when it is in the form of ions. However, its toxicity increases when the pH exceeds 6.5. In the study area, the molybdenum concentration exceeded the permissible environmental limit of 0.06 ppm. The highest values were found in samples collected from well 4, with a concentration of 6.1 ppm, followed by well 3 with a concentration of 5.3 ppm. Well 6 ranked third with a concentration of 3.8 ppm. The remaining well values ranged between 0.5 and 2.3 ppm. To indicate statistical significance, it was found that there is a significant difference between the summer and winter seasons with a p-value of 0.004. There is also a significant difference between the summer and spring seasons with a p-value of 0.014. However, no significant difference was observed between the summer and autumn seasons, with a p-value of 0.352.

Zinc Zn

Zinc is considered one of the most widely used metals after iron, aluminum, and copper, and it is utilized in various industries. Zinc is distributed in the aquifer-bearing soil in five forms: soluble in water, exchangeable, associated with carbonates, associated with iron and manganese oxides, associated with primary minerals, and associated with organic matter. In the study area, zinc concentrations exceeded the permissible environmental limit of 0.59 ppm. The highest value was found in samples collected from well 4, with a concentration of 23.2 ppm, followed by well 3 with a concentration of 15.7 ppm. Well 2 ranked third with a concentration of 13.5 ppm. The remaining well values ranged between 9.1 and 12.7 ppm. To indicate statistical significance, it was found that there is a highly significant difference between the summer season and the other seasons with a p-value of 0.000.

Nickel Ni

Nickel is naturally present in the form of small particles, and its concentration in water is very low, on the order of parts per billion, making it difficult to measure without highly sensitive instruments. The average concentration of nickel in drinkable water is less than 2 parts per trillion (ppt). However, you may be exposed to higher levels if you live near major industrial areas. In the study area, some wells exceeded the permissible limit for nickel, which is 0.89 ppm. Wells 6 and 7 had the highest concentrations, with values of 1.9 ppm, followed by well 3 with a value of 1.5 ppm. Well 5 ranked third with a value of 1.2 ppm. The remaining well values ranged from 0.1 to 1.1 ppm. To indicate statistical significance and significance, it was found that there is a significance between the summer and spring seasons with a p-value of 0.033, and between the summer and winter seasons with a p-value of 0.017. However, no statistical significance was observed between the summer and autumn seasons, with a p-value of 0.753.

Manganese Mn

Manganese ore consists of manganese dioxide in the form of vein fillings in rocks. It is one of the common toxic heavy elements that increase with industrial emissions and human activities. In the study area, some wells exceeded the permissible limit for manganese, which is 0.97 ppm. Well 8 recorded the highest value at 2.9 ppm, followed by well 7 with a value of 2.3 ppm, and well 6 came third with a value of 2.1 ppm. The remaining well values ranged from 0.2 to 1.5 ppm. After applying statistical equations, it was found that there is a significant difference between the summer and spring seasons with a p-value of 0.005, and between the summer and winter seasons with a p-value of 0.000. However, there was no significant difference between the summer and autumn seasons, with a p-value of 0.254.

Copper Cu

Copper is a common heavy metal found in the environment and is widely distributed through industry. It enters groundwater due to industrial waste containing copper and agricultural pesticides, becoming harmful if it exceeds the permissible limit, which is 1.2 ppm. In some wells in the study area, the samples exceeded the permissible limit, while in others, they did not. Well 8 recorded the highest value, with a copper concentration of 2.8 ppm, followed by well 10 with a value of 2.3 ppm. Well 7 came third with a value of 2.1 ppm. The remaining well concentrations ranged from 0.5 to 1.1 ppm. After applying the LSD test, it was found that there is a significant difference between the summer and winter seasons with a p-value of 0.000, and between the summer and spring seasons with a p-value of 0.000. However, there was no significant difference between the summer and autumn seasons, with a p-value of 0.086.

Chromium Cr

Chromium is a naturally occurring element found in the environment in solid, liquid, or gaseous form. It enters groundwater after being emitted as a result of industrial processes and remains suspended in water to a large extent. It becomes harmful if it exceeds the permissible limit, which is 2.24 ppm. The samples collected in the study area showed values that exceeded the permissible limit, while others did not. Well 8 had the highest values, with a chromium concentration of 5.9 ppm, followed by well 5 with a value of 3.2 ppm. Well 6 came third with a value of 3.1 ppm. To indicate statistical significance, it was found that there is a significant difference between the summer and autumn seasons with a p-value of 0.004, between the summer and winter seasons with a p-value of 0.000, and between the summer and spring seasons with a p-value of 0.000.

The Dry Season (Autumn)

According to the data provided in Table (4) and Figure (2), the following becomes evident

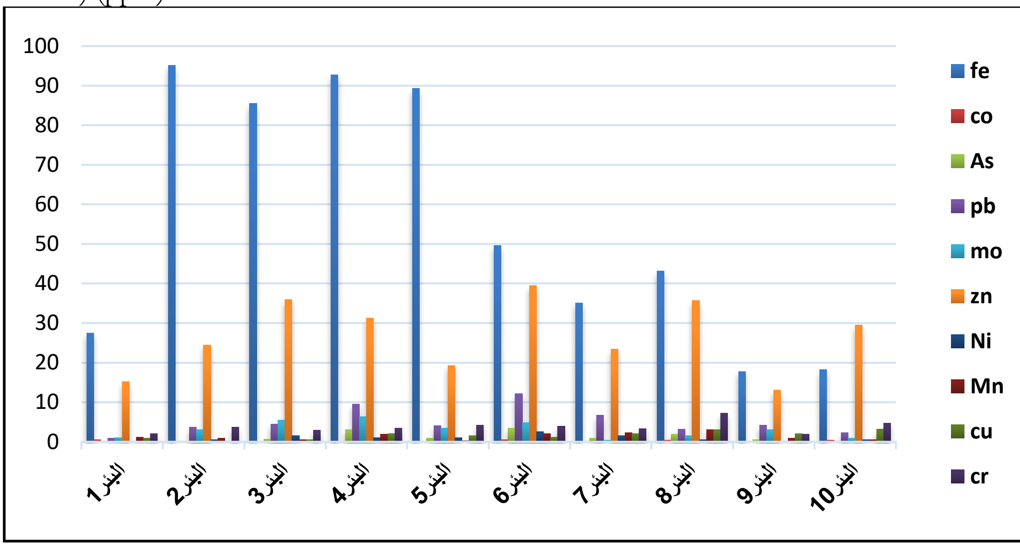
Table 4: Seasonal and annual concentrations, as well as significant differences of heavy elements in groundwater in Al-Zubair district (Autumn - Dry season) (ppm).

Metal Location	Fe	Co	As	Pb	Mo	Zn	Ni	Mn	Cu	Cr
Well 1	27.5	0.5	0.2	0.9	1.1	15.2	0.2	1.2	0.9	2.1
Well 2	95.1	0.1	0.2	3.7	3.1	24.5	0.5	0.9	0.2	3.7
Well 3	85.5	0.2	0.7	4.5	5.5	35.9	1.5	0.5	0.5	2.9
Well 4	92.7	0.1	3.1	9.5	6.4	31.3	1.1	1.9	2.1	3.5
Well 5	89.3	0.1	0.9	4.1	3.5	19.3	1.1	0.3	1.5	4.2
Well 6	49.6	0.5	3.5	12.2	4.9	39.5	2.5	2.1	1.2	3.9
Well 7	35.1	0.1	0.9	6.7	0.4	23.4	1.5	2.3	2.1	3.3
Well 8	43.1	0.4	1.9	3.2	1.5	35.7	0.5	3.1	3.1	7.2
Well 9	17.8	0.1	0.5	4.2	3.1	13.1	0.2	0.9	2.1	1.9
Well 10	18.3	0.4	0.2	2.3	0.9	29.5	0.6	0.5	3.2	4.7
Limit	1.05	0.56	1.5	26.8	0.06	0.95	0.89	0.97	1.2	2.24
Winter	0	0	0.055	0	0.046	0.594	0.037	0.007	0	0

Spring	0	0	0.173	0.065	0.125	0.143	0.068	0.097	0.001	0.002
Summer	0.009	0.969	0.125	0.141	0.352	0	0.753	0.254	0.086	0.004

Source: Laboratory Analysis Results, College of Science, Department of Environment, 2022-2023.

Fig. 2: Seasonal concentrations of heavy elements in groundwater in Al-Zubair district (Autumn - Dry season) (ppm).



Source: Table 4 data

Iron Fe

Iron exceeds the environmentally allowed limit in the wells of the study area, which is (1.05) ppm. Significantly, well 2 recorded the highest concentrations at (95.1) ppm, followed by well 4 with a value of (92.7) ppm, and well 5 came in third with a value of (89.3) ppm. The rest of the values ranged between (17.8-85.5) ppm. By applying the statistical significance (lsd), it is found that there is a very strong relationship between autumn, winter, and spring with a value of (0.000), and there is a strong relationship between autumn and summer with a value of (0.009).

Cobalt Co

Cobalt concentrations in the selected samples exceeded the environmentally allowed limit. Well (1 and 6) recorded a value of (0.5) ppm, while the rest of the samples ranged between (0.1-0.4) ppm. To demonstrate the statistical differences, there is a significant difference between autumn and winter, and between autumn and spring, with a value of (0.000). However, no significant difference was found between autumn and summer, as the correlation value was (0.969).

Arsenic As

Some samples in the study area exceeded the environmentally allowed limit for arsenic, which is (1.5) ppm, while others did not exceed it. The highest value was recorded for well 6, reaching (3.5) ppm, followed by well 4 with a value of (3.1) ppm, and thirdly, well 8 with a concentration of (1.9) ppm. The remaining well values ranged between (0.2-0.7) ppm. For the purpose of demonstrating statistical differences, no clear significant differences were found between autumn and winter, autumn and spring, or between autumn and summer. The correlation values were (0.055, 0.173, 0.125) respectively.

Lead Pb

None of the well samples exceeded the environmentally allowed limit, which is (26.8) ppm. The highest values were recorded in well (6) with a value of (12.2) ppm, followed by well (4) with a value of (9.5) ppm, and well (7) came in third with a lead concentration of (6.7) ppm. The rest of the values ranged between (0.9-4.5) ppm. Statistically, there is a very strong relationship between autumn and winter with a value of (0.00). No statistical significance was found between autumn and spring, and summer. Their statistical values were (0.056, 0.141) respectively.

Molybdenum Mo

Samples from the study area exceeded the environmentally allowed limit, which is (0.06). Well 4 recorded the highest value at (6.4) ppm, followed by well 3 with a value of (5.5) ppm, and well 6 came in third with a value of (4.9) ppm. The values for the rest of the wells ranged between (0.4-3.5) ppm. To demonstrate the statistical differences, a relationship was found between autumn and winter with a value of (0.046). No statistical significance was found between autumn and spring, and summer. The relationships between them were (0.125 and 0.352) respectively.

Zinc Zn

Zinc samples in the study area exceeded the environmentally allowed limit, which is (0.95) ppm. Well 6 came first with a value of (39.5) ppm, followed by well 3 with a value of (35.9) ppm, and well 8 came in third with a value of (35.7) ppm. The values for the rest of the wells ranged between (13.1-29.5) ppm. To demonstrate the statistical differences, a significant difference was found between autumn and summer with a value of (0.000), and there was no significant difference between autumn and winter, and autumn and spring. The values were statistically (0.594 and 0.143) respectively.

Nickel Ni

Some well water samples in the study area exceeded the environmentally allowed limit, which is (0.89) ppm. In five wells, the values were as follows: well 6 recorded a value of (2.5) ppm, followed by wells 7 and 3 with a value of (1.5) ppm. The concentrations of the remaining samples ranged between (0.2-1.1) ppm. To demonstrate the statistical differences, a relationship was found between autumn and winter with a value of (0.037). No statistically significant relationship was found between autumn and spring, nor between autumn and summer. The relationship values were (0.068 and 0.753) respectively.

Manganese Mn

Five wells exceeded the environmentally allowed limit for manganese, which is (0.97) ppm. Well 8 recorded the highest value at (3.1) ppm, followed by well 7 with a value of (2.3) ppm, and well 6 came in third with a value of (2.1) ppm. The values for manganese in the rest of the samples from the study area ranged between (0.3-1.9) ppm. To demonstrate the statistical differences, a strong statistical relationship was found between autumn and winter with a value of (0.007). However, no relationship was found between autumn and both spring and summer. The statistical values were (0.097, 0.254) respectively.

Copper Cu

After reviewing the laboratory results, it was found that 6 wells exceeded the environmentally allowed limit for copper, which is (1.2) ppm. Well 10 came first with a value of (3.2) ppm, followed by well 8 with a value of (3.1) ppm. Well 4, well 7, and well 9 came in third with a value of (2.1) ppm. The values for the remaining wells ranged between (0.2-1.5) ppm. To demonstrate the statistical differences, significant differences were found between autumn and winter with a value of (0.000), and between autumn and spring with a value of (0.001). There was no statistically significant difference between autumn and summer, as the relationship value was (0.085).

Chromium Cr

Upon studying the results, it was found that seven wells exceeded the environmentally allowed limit for chromium, which is (2.24) ppm. Well 8 had the highest value of chromium at (7.2) ppm, followed by well 10 with a value of (4.7) ppm, and well 5 came in third with a value of (4.2) ppm. The remaining concentrations ranged between (1.9-3.9) ppm. To demonstrate the statistical differences, a very strong relationship was found between autumn and winter with a value of (0.000), and a strong relationship was also found between autumn and both summer and spring (0.002, 0.004) respectively.

The Wet Season (Spring)

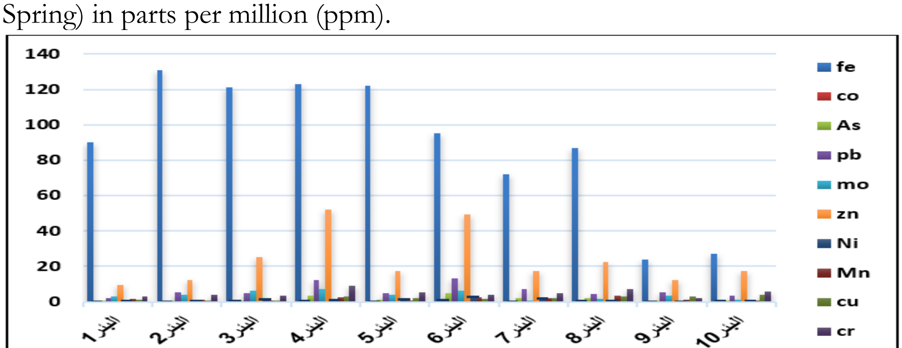
When analyzing Table (5) and Figure (3), it is evident that in some wells, some elements have exceeded the environmentally allowable limit, as follows:

Table 5: Seasonal concentrations and statistical differences of heavy elements in groundwater for Al-Zubair district (Wet season - Spring).

Metal Location	Fe	Co	As	Pb	Mo	Zn	Ni	Mn	Cu	Cr
Well 1	90	0.4	0.9	2.3	3.1	9.3	0.7	1.5	1.1	3.1
Well 2	131	0.1	0.3	5.2	4.1	12.3	0.8	1.1	0.8	4.1
Well 3	121	0.8	0.6	5.1	6.1	25.2	1.5	0.7	0.7	3.3
Well 4	123	0.5	3.4	12.3	7.3	52.2	1.1	2.5	3.1	9.1
Well 5	122	0.1	1.2	4.9	4.1	17.5	1.5	0.7	2.2	5.5
Well 6	95.1	1.1	4.9	13.1	6.5	49.6	2.9	2.4	1.8	4.1
Well 7	72.1	0.2	2.1	7.3	0.8	17.3	1.9	2.2	2.3	4.9
Well 8	87	0.7	2.1	4.3	1.7	22.3	0.9	3.5	3.1	7.2
Well 9	24	0.3	0.7	5.4	3.5	12.1	0.3	1.3	2.9	2.2
Well 10	27	0.7	0.5	3.5	1.1	17.5	0.7	0.9	4.1	5.9
Limit	1.05	0.56	1.5	26.8	0.06	0.95	0.89	0.97	1.2	2.24
Autumn	0	0	0.173	0.065	0.125	0.046	0.068	0.097	0.001	0.002
Winter	0.002	0.306	0.578	0.028	0.641	0.143	0.795	0.284	0.502	0.101
Summer	0	0	0.865	0.001	0.014	0	0.033	0.005	0	0

Source: Laboratory Analysis Results, College of Science, Department of Environment, 2022-2023.

Fig. 3: Seasonal concentrations of heavy elements in groundwater for Al-Zubair district (Wet season - Spring) in parts per million (ppm).



Source: Table 5 data

Iron Fe

Iron concentrations in the wells of the study area exceeded the permissible environmental limit of (1.05) ppm. Notably, well 2 recorded the highest concentration at (131) ppm, followed by well 4 at (123) ppm, and well 5 at (122) ppm. The rest of the well samples ranged between (24-121) ppm. To determine the significance, LSD was applied, revealing a very strong relationship between the spring and autumn seasons, as well as between spring and summer, with values reaching (0.000). There was also a strong relationship between spring and winter, with a value of (0.002).

Cobalt Co

Laboratory analysis of the study samples shows that only one well exceeded the permissible limit, while the rest of the wells did not exceed the permissible environmental limit. Well 6 was the one that exceeded the limit, with a value of (1.1), while the values for the other wells ranged between (0.1-0.8) ppm. By applying LSD, significant differences were found between the spring and autumn, and between spring and summer, with values reaching (0.000). However, no significant difference was found between spring and winter, with a relationship value of (0.306).

Arsenic As

The results indicate that in four wells, the permissible environmental limit was exceeded. The highest values were recorded in well 6 at (4.9) ppm, followed by well 4 at (3.4) ppm, and wells 7 and 8 at (2.1) ppm. In the remaining well samples, the limit was not exceeded, with values ranging between (0.3-1.2) ppm. To determine the significance, LSD was applied, revealing no significant relationship between spring and the other seasons (autumn, winter, summer), with relationship values of (0.173, 0.578, 0.865) respectively.

Lead Pb

Upon analyzing the samples, it was found that none of the wells exceeded the permissible environmental limit, which is (26.8) ppm. The highest value was recorded in well 6 at (13.1) ppm, followed by well 4 at (12.3) ppm. The third-highest value for lead was recorded in well 7 at (7.3) ppm. The remaining values ranged between (2.3-5.4) ppm. To determine the significance, LSD was applied, revealing a significant relationship with a strong statistical correlation between spring and winter, as well as between spring and summer, with values reaching (0.028, 0.001) respectively. However, no significant relationship was found between spring and autumn, with a relationship value of (0.065).

Molybdenum Mo

Upon analyzing the results, it was found that in all study samples, the permissible environmental limit was exceeded, which is (0.06) ppm. The highest values were for well 4 at (7.3) ppm, followed by well 6 at (6.5) ppm, and well 3 at (6.1) ppm. The remaining values ranged between (0.8-4.1) ppm. To determine the significance, LSD was applied, revealing significant differences between spring and summer, with a value of (0.014). No significant relationship was recorded between spring and the other seasons (autumn, winter), with relationship values of (0.125, 0.641) respectively.

Zinc Zn

Upon examining the laboratory results, it was found that all samples collected from the wells exceeded the permissible environmental limit for zinc. Well 4 recorded the highest value at (52.2) ppm, followed by well 6 at (49.9) ppm, and well 3 at (25.2) ppm. The remaining values ranged between (9.3-22.3) ppm. To determine the significance, LSD was applied, revealing extremely strong significant differences between spring and summer, with a value of (0.000). There was also a strong significant relationship between spring and autumn, with a value of (0.046). No significant difference was found between spring and winter, with a statistical value of (0.143).

Nickel Ni

In the study area, five wells exceeded the permissible environmental limit, which is (2.9) ppm. The highest value was in well 6 at (2.9) ppm, followed by well 7 at (1.9) ppm. Well 3 and 5 tied for third place with a value of (1.5) ppm. The remaining well values ranged between (0.3-1.1) ppm. To determine the significance, LSD was applied, revealing significant differences between spring and summer, with a relationship value of (0.033). No statistically significant relationship was proven between spring and autumn, as well as winter. The respective relationship values were (0.068, 0.795).

Manganese Mn

Manganese exceeded the permissible environmental limit in this season in seven wells from the study samples. The highest values were recorded in well 8 at (3.5) ppm, followed by well 4 at (2.5) ppm. Well 6 came in third with a value of (2.4) ppm. The remaining values ranged between (0.7-2.2) ppm. To determine the significance, LSD was applied, revealing extremely strong significant differences between spring and summer, with a value of (0.000). There was also a strong significant difference between spring and autumn, with a value of (0.001). No relationship was found between spring and winter, with a relationship value of (0.502).

Copper Cu

Upon studying the sample results, it was found that the permissible limit was exceeded in five locations. The highest values were recorded in well 10 with a copper value of (4.1) ppm, followed by well 4 and well 8 with a value of (3.1) ppm. Well 9 came in third with a value of (2.9) ppm. The remaining sample values ranged between (0.7-2.3) ppm. To indicate the significance, LSD was applied, revealing significant differences between spring and summer, with a value of (0.000). There was also a significant difference between spring and autumn, with a value of (0.097). No significant difference was found between spring and winter, with a value of (0.502).

Chromium Cr

Upon studying the laboratory results of the wells in the study area, it was found that they exceeded the permissible limit environmentally, except for well 9, which had a value of (2.2) ppm. As for the other wells, the highest value was in well 4 at (9.1) ppm, followed by well 8 at (7.2) ppm. Well 10 came in third with a value of (5.9) ppm. The remaining values ranged between (2.2-5.5) ppm. To indicate the significance, it was revealed that there are strong significant differences between spring and autumn, with a value of (0.002), and between spring and summer, indicating extremely strong statistical significance at (0.000). There is no significant difference between spring and winter, as the relationship value is (0.101).

The Wet Season (Winter)

From Table (6) and Figure (4), we find that in some wells, the allowable limits for the elements were exceeded, while in others, they were not exceeded. This can be summarized as follows:

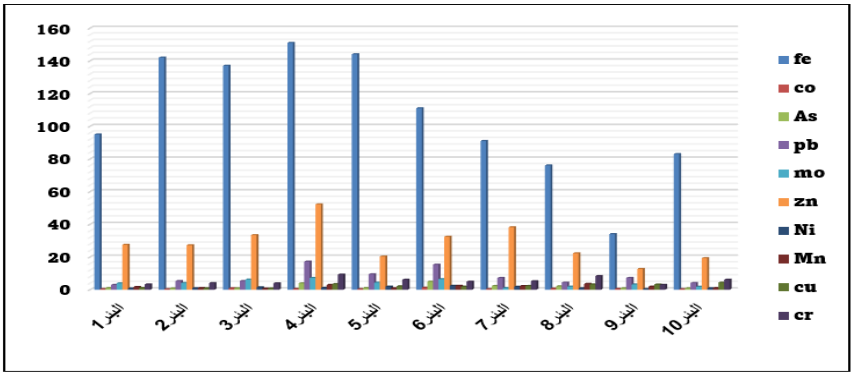
Table 6: Seasonal Concentrations and Significance Differences of Heavy Metals in Groundwater for Al-Zubair District (Wet Season - Winter).

Metal Location	Fe	Co	As	Pb	Mo	Zn	Ni	Mn	Cu	Cr
Well 1	95	0.4	1.1	2.9	3.9	27.5	0.8	1.7	1.1	3.2
Well 2	142	0.3	0.8	5.3	4.1	27.2	0.9	1.1	0.9	4
Well 3	137	0.9	0.9	5.3	6.2	33.4	1.5	0.7	0.8	3.9
Well 4	151	0.5	3.9	17.2	7.2	52.2	1.2	2.9	3.4	9.2
Well 5	144	0.4	1.1	9.4	4.3	20.3	1.9	0.9	2.1	6.1
Well 6	111	1.3	4.9	15.3	6.5	32.4	2.4	2.4	1.9	4.9
Well 7	91	0.4	2.3	7.2	1.1	38.2	1.8	2.2	2.3	5.2
Well 8	76	0.7	2.1	4.3	1.9	22.3	0.9	3.5	3.2	8.3
Well 9	34	0.5	0.9	7.2	3.2	12.7	0.4	1.9	3.1	2.9
Well 10	83	0.3	0.9	4.1	1.8	19.3	0.9	1.1	4.3	6.1
Limit	1.05	0.56	1.5	26.8	0.06	0.95	0.89	0.97	1.2	2.24

Autumn	0	0	0.055	0	0.046	0.594	0.037	0.007	0	0
Spring	0.002	0.306	0.578	0.028	0.641	0.143	0.795	0.284	0.502	0.101
Summer	0	0	0.699	0	0.004	0	0.017	0	0	0

Source: Laboratory Analysis Results, College of Science, Department of Environment, 2022-2023.

Fig. 4: Seasonal Concentrations of Heavy Metals in Groundwater for Al-Zubair District (Wet Season – Winter



Source: Table 6 data

Iron Fe

Iron levels in the wells of the study area exceeded the environmentally permissible limit of (1.05) ppm. Remarkably, the highest values were recorded in Well 4, reaching (151) ppm, followed by Well 5 with (144) ppm, and Well 2 with (142) ppm. The remaining values ranged between (34 - 142) ppm. To demonstrate the statistical differences, the LSD test was applied, revealing significant differences. There is a very strong relationship between the winter season and both autumn and summer seasons with a significance level of (0.000). Additionally, a strong relationship was observed between the winter and spring seasons with a significance level of (0.002).

Cobalt Co

Upon examining the sample results, it was found that none of the samples exceeded the environmentally permissible limit for this element, which is (0.56) ppm, except for one well, Well 6, with a value of (1.3) ppm. The rest of the well samples ranged between (0.3 - 0.9) ppm. To indicate the statistical differences, a clear relationship was observed in the statistical correlation between the winter season and both autumn and summer seasons with a very strong correlation of (0.000). There was no significant correlation between the winter and spring seasons, with a correlation value of (0.306).

Arsenic As

From the laboratory analysis results, it was found that arsenic exceeded the environmental limit of (1.5) ppm in four study locations. Well 6 recorded the highest value at (4.9) ppm, followed by Well 4 with an arsenic value of (3.9) ppm, and Well 7 with a value of (2.3) ppm. The remaining values ranged between (0.8 - 2.1) ppm. To indicate the statistical differences, it was observed that there was no significant difference between the winter and autumn seasons, the winter and spring seasons, and the winter and summer seasons. The recorded statistical values were (0.055, 0.578, 0.699) respectively.

Lead Pb

Upon examining the samples and laboratory results, it was found that none of the wells exceeded the environmentally permissible limit, which is (26.8) ppm. The highest value was recorded in Well 4 at

(17.2) ppm, followed by Well 6 at (15.3) ppm, and then Well 5 at (9.4) ppm. The remaining lead values ranged between (2.9 - 7.2) ppm. For the purpose of indicating the significant differences (using LSD), a very strong statistical relationship was found between the winter season and both autumn and summer seasons, with a significance level of (0.000). There was also a statistical relationship between the winter and spring seasons, with a significance level of (0.028).

Molybdenum Mo

Upon examining the results of the analyzed samples, it was found that in all wells, molybdenum levels exceeded the environmentally permissible limit, which is (0.06) ppm. Well 4 had the highest value at (7.2) ppm, followed by Well 6 at (6.5) ppm, and then Well 3 at (6.2) ppm. The remaining values ranged between (1.1 - 4.3) ppm. To indicate the significant differences, it was evident that there is a significant relationship between the winter season and both autumn and summer seasons, with significance levels of (0.046) and (0.004) respectively. There was no significant correlation between the winter and spring seasons, with a significance level of (0.641).

Zinc Zn

Upon analyzing the sample results, it was found that zinc levels exceeded the environmentally permissible limit, which is (0.95), in all wells. The highest values were recorded in Well 4 at (52.2) ppm, followed by Well 7 at (38.2) ppm, and then Well 3 at (33.4) ppm. The remaining well values ranged between (12.7 - 27.5) ppm. To indicate the significant differences, it was evident that there is a very strong statistical relationship between the winter and summer seasons, with a significance level of (0.000). However, there was no statistically significant difference between the winter and spring seasons, and between the winter and autumn seasons, with correlation values of (0.143, 0.594) respectively.

Nickel Ni

From the study of laboratory results, it is evident that nickel has exceeded the environmentally permissible limit, which is (0.89) ppm. The highest value was recorded in Well 6 at (2.4) ppm, followed by Well 5 at (1.9) ppm, and then Well 7 at (1.8) ppm. The remaining well values ranged between (0.4 - 1.5) ppm. To indicate the significant differences (using LSD), a statistically significant relationship was found between the winter and autumn seasons, with a significance level of (0.037). There was no statistical relationship between the winter season and both spring and summer seasons, with correlation values of (0.795) and (0.017) respectively.

Manganese Mn

Manganese has exceeded the environmentally permissible limit, which is (0.97), in most of the study's samples. The highest values were recorded in Well 8 at (3.5) ppm, followed by Well 4 at (2.9) ppm, and then Well 6 at (2.4) ppm. The remaining values ranged between (0.7 - 2.2) ppm. To indicate the significant differences, it was evident that there is a statistically significant relationship between the winter season and both autumn and summer seasons, with significance levels of (0.007) and (0.000) respectively. There was no statistically significant difference between the winter and spring seasons, with a correlation value of (0.284).

Copper Cu

Upon reviewing the analysis results, it was found that seven wells exceeded the environmentally permissible limit for copper, which is (1.2) ppm. The highest value was recorded in Well 10 at (4.3) ppm, followed by Well 4 at (3.4) ppm, and then Well 8 at (3.2) ppm. The remaining well values ranged between (0.8 - 3.1) ppm. To indicate the significant differences, it was evident that there is a very strong statistical relationship between the winter and summer seasons, and between the winter and autumn seasons, with significance levels of (0.000). There was no statistically significant difference between the winter and spring seasons, with a correlation value of (0.502).

Chromium Cr

Upon analyzing the sample results, it is evident that chromium has exceeded the environmentally permissible limit, which is (2.24) ppm, in nine of the wells. Well 4 recorded the highest value at (9.2) ppm, followed by Well 8 at (8.3) ppm. Wells 5 and 10 came in third with a value of (6.1) ppm. The remaining values ranged between (2.9 - 5.2) ppm. To indicate the significant differences, it was evident that there is an extremely high statistical significance between winter and summer, as well as between winter and autumn, with significance values of (0.000). There was no difference between winter and spring, with a correlation value of (0.101).

Results

The study has yielded the following results:

1. Pollution levels of iron, lead, chromium, and zinc are higher compared to the other elements in the study area.
2. Pollution levels are elevated in Wells 6, 4, 7, and 3 compared to the other wells in the study area, possibly due to their proximity to the oil pipelines. Leakage in the oil pipelines may be a cause of the increased concentrations of heavy elements in these wells.
3. There is no completely pure well (100%).
4. Pollution levels in the wells are higher in winter and spring (wet season) compared to summer and autumn (dry season).
5. Iron pollution levels have increased throughout the study period in all examined samples.
6. There are highly statistically significant differences observed in most of the studied elements and study seasons, with the majority having a significance level of (0.000).

Recommendations

1. The need for continuous monitoring of water quality.
2. The necessity for relevant authorities to focus on monitoring pollutant quantities and determining their concentrations.
3. Attempting to reduce the volume of seepage into the soil as it causes significant pollution.
4. Raising awareness among residents about the dangers of toxic elements.
5. Installing filters for well water before human consumption.
6. Implementing strict laws prohibiting the disposal of chemicals in the soil.
7. Burying industrial waste that may leak heavy elements away from groundwater sources.
8. Utilizing modern methods for treating groundwater, such as chemical treatment.

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