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Investigation the Level of Groundwater Pollution with Heavy Metals in Mazar-e-Sharif City

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ABSTRACT

The majority of drinking and consumable water sources for the residents of Mazar-e-Sharif city are supplied from underground water. Climate variations, depletion of underground water, pollution resulting from human activities, agriculture, industrial processes, and urban development have significantly impacted the quality of underground water in this region. In this research, the quality of groundwater in terms of contamination with heavy metals such as manganese, copper, aluminum, iron, cadmium, mercury, lead, and arsenic was investigated. Twenty-four random well samples were collected based on international sampling standards, and temperature and pH parameters were measured on-site. The concentration of heavy metals was measured using an atomic absorption spectrophotometer. Data analysis was performed using Excel and SPSS software, and GIS software was utilized for mapping the sampled points. Laboratory results indicated that the lead concentration in wells W6, W11, W20, and W22 was 0.014, 0.013, 0.02, and 0.012 milligrams per liter, respectively. The aluminum concentration in wells W5, W16, and W17 was 0.6, 0.5, and 0.4 milligrams per liter, respectively, and the cadmium concentration in well W3 was 0.005 milligrams per liter. The concentrations in these wells exceeded the recommended limits set by the World Health Organization (WHO). In the remaining wells, the concentrations of heavy metals were below the WHO limits. Descriptive statistics results showed that copper had the highest average concentration, and arsenic had the lowest concentration. Since underground water is the sole source of drinking and consumable water for the city's residents, it is recommended to conduct a systematic study of heavy metal concentrations in groundwater sources to reduce the adverse effects of contaminated water in certain wells.

Keywords- Groundwater, Heavy metals, Mazar-e-Sharif city, Water quality, World Health Organization (WHO).

I. INTRODUCTION

Groundwater is essential for the survival of living organisms, especially humans. Water used for human consumption from underground sources should not only be abundant but also safe and healthy [1]. This water source, obtained for drinking by humans from underground aquifers, is ideally free from pollutants that

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can cause diseases, in contrast to surface waters and other relatively contaminated water sources [2]. One major reason for the threat and contamination of groundwater is the unregulated use of natural resources and excessive waste production in developed countries. Various other factors, such as human activities, industrial wastewater contaminated with heavy metals, infiltration of saline water in coastal areas, regional topography, etc., significantly impact water quality [3]. Groundwater, due to prolonged contact with rocks and mutual interactions among them, becomes enriched with numerous ions, including rare elements and heavy metals.

Heavy metals are usually present in low concentrations in natural water. On the other hand, elements such as iron, zinc, copper, manganese, and cobalt are required in small amounts for metabolic activities in the body [4]. Therefore, the concentration of heavy metals in water, especially groundwater, is significant. It is evident that water pollution by heavy metals has become a global concern today due to its potential impact on the human food chain [5]. Research results indicate that heavy metals enter the body through the food chain and can be harmful to human health. Consumption of food contaminated with Pb, Cd, As, and other toxic elements can lead to a decrease in vitamin C, Fe, and other nutrients stored in the human body. The reduction in vitamin C, iron, and other nutrients results in a weakened immune system, impaired human performance, and associated disabilities [6]. The increase in the concentration of cationic metals such as nickel, cadmium, chromium, and lead in water accumulates in body tissues, reaching toxic levels that lead to diseases such as chronic anemia caused by cadmium and lung cancer caused by chromium [7]. Additionally, lead acts as a calcium substitute in the body, leading to the development of various cancerous tumors [8].

The toxicity and danger of heavy metals to animals and plants have been well established. Some metals such as zinc, copper, magnesium, and iron are essential for plants, and nickel is essential for animals. However, cadmium, chromium, and lead have no specific function in plants and animals. The increase in the concentration of heavy metals can have toxic effects and the potential for diseases on both plants and humans. Therefore, the concentration of heavy metals should not exceed the permissible limit [9]. The presence of heavy elements makes groundwater undesirable for irrigation and drinking. Therefore, conducting quality studies to determine the level of heavy elements in groundwater is a fundamental step for planning and managing water resources. For the survival of life, numerous studies by chemists and researchers worldwide have been conducted to assess the quality and investigate the concentration of elements, especially cationic metals, in groundwater sources.

Research conducted by Geravand and colleagues (2017) on the effects of heavy metals on the groundwater quality near landfill sites indicates a significant difference in the concentration of heavy metals (chromium, iron, manganese, lead, zinc, and magnesium) in wells near landfill sites compared to wells located away from landfill sites. The average concentration of lead, magnesium, and iron exceeds the drinking water standard [10]. Results from the study by Kaur and her colleagues (2017) investigating the concentration of heavy metals and pesticides in agricultural soil and groundwater in the Mansa region show that the concentrations of Ni, Hg, Se, and Cd in both soil and groundwater samples are significantly higher. The concentration of Sr is also higher in both soil and groundwater [11]. The study of heavy metal concentrations in groundwater and soils in the Thane region was conducted by Bhagure (2011). Their findings indicate that the concentrations of arsenic, nickel, silver, and cadmium exceed WHO standards [12]. Eziz and colleagues (2023) studied the groundwater of the BLB region in northwestern China to examine the concentrations of elements Cr, Cu, Ni, manganese, and zinc. In this study, the average concentrations of cadmium, chromium, copper, manganese, nickel, and zinc in BLB groundwater are below the Chinese groundwater quality standard. However, the maximum concentrations of manganese, cadmium, and nickel in groundwater exceed this standard [13].

This research focuses on investigating the contamination levels of groundwater in the city of Mazar-e-Sharif with heavy metals. Due to various human activities such as small-scale industrial facilities, agriculture, urban and domestic wastewater, and construction, the potential for the release of heavy metals into the groundwater exists. As the primary source of drinking and domestic water for the residents of this city is groundwater, there has been no prior research on assessing the concentrations of heavy metals in this area. Given the importance of the issue, conducting such studies is essential to determine the concentrations of heavy metals in the groundwater of Mazar-e-Sharif.

II. MATERIALS AND METHODS

2.1. Study Area Overview

Mazar-e-Sharif, the capital of Balkh province, is one of the four major cities in Afghanistan, covering an area of 66.13 square kilometers. It is situated at the lowest elevation in Afghanistan, with an altitude of 357 meters above sea level (Figure 1). This city holds a unique geographical position, bordered to the south by Charqint, to the north by Hairatan, to the east by Khulm, and to the west by Balkh. The climate of the region is characterized by hot and dry summers (with a maximum temperature of up to 45 °C) and very cold winters. In the south of the city, the Labors Mountains receive rainfall during the winter season, which contributes to water runoff reaching Mazar-e-Sharif. The presence of the Labors mountain range in the south of the city means that rainwater from

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the mountain slopes may carry heavy metals into the city's water sources. Approximately 20 kilometers west of the city, there is a fertilizer and electricity factory with a production capacity of 110 tons of fertilizer per 24 hours. The wastewater from this factory may contribute to the pollution of underground water. Additionally, small-scale factories have been established in this city. The existence of these factories and municipal wastewater may potentially lead to contamination of underground water with heavy metals.

2.2. Data Collection

Prior to sampling from the study wells, initial information about the wells, household sewage channels, and human activities in the vicinity or around water sources was gathered from individuals residing near these water sources. This data was collected to obtain a better understanding of the sampling area, including information about human activities that could potentially lead to the accumulation of heavy metals and possible waterborne diseases resulting from the consumption of water contaminated with heavy metals. The data collected through this method played a crucial role in enhancing the credibility of our results in the findings section of the research.

2.3. Sampling

For the purpose of sampling from the wells in Mazar-e-Sharif city after collecting preliminary information about underground water sources, initial steps were taken to gather and study scientific and practical resources in this field. In this research, topographic maps, water resource maps, and geological maps were utilized to understand the extent of water resources presence, the direction of groundwater flow, and to gain a better understanding of the region's geography. This was done to determine the sampling areas based on the direction of water flow and the distribution of water sources.

In order to determine the concentration of heavy metals, sampling was conducted from 24 deep wells located at various points across the city. Following international guidelines to prevent and minimize errors in laboratory work, the water source tap was run for 2 to 3 minutes, and then two samples of equal volume were collected from each deep well. The samples from the 24 wells were collected in 500-milliliter polyethylene containers. Prior to sampling, the polyethylene containers were washed three times, first with nitric acid and then with distilled water [16, 15, 12, 14]. The collected samples for the analysis of heavy metal concentrations were labeled with the date, time, and sampling location, and they were stored in polyethylene containers. Sampling and analysis were conducted at different times. The coordinates of the water sources' locations (Table 2) and the locations of the deep wells on the map (Figure 1) were plotted using GIS (Geographic Information System) software.

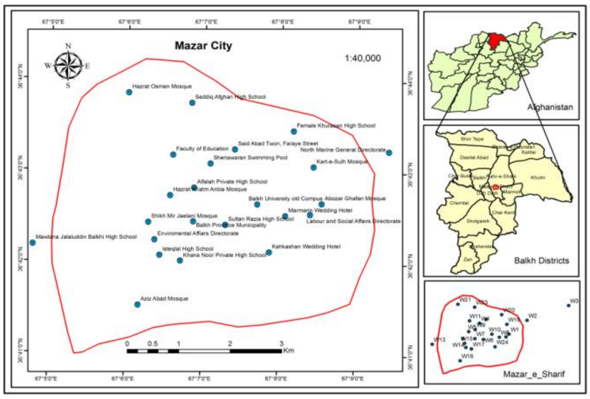

Figure 1: The specific locations of the sampled wells in the studied area, Mazar-i-Sharif city.

Table 1: Length and width of the city, sampled areas, and well codes.

Wells Code	Location	LAT	LONG
W1	Abozar Ghafari Mosque	36.710961	67.142549
W2	North Marine General Directorate	36.720609	67.157036
W3	Balkh University new Compus	36.73128	67.190908
W4	Shenawaran Swimming Pool	36.718045	67.118227
W5	Hazrat Khatm Anbia Mosque	36.712141	67.10956
W6	Sultan Razia High School	36.706917	67.121686
W7	Balkh Province Municipality	36.707431	67.114669
W8	Marmarin Wedding Hotel	36.708661	67.134691
W9	Alfalah Private High School	36.713595	67.114753
W10	Balkh University old Compus	36.710735	67.128541
W11	Faculty of Education	36.719551	67.110042
W12	Shikh Mir Jaelani Mosque	36.707219	67.104887
W13	Mawlana Jalaluddin Balkhi High School	36.702988	67.079857
W14	Isteqlal High School	36.701225	67.107454
W15	Enviromental Affiars Directorate	36.704042	67.106328
W16	Aziz Abad Mosque	36.692077	67.102938

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W17	Khana Noor Private High School	36.700252	67.111978
W18	Labour and Social Affairs Directorate	36.708967	67.140087
W19	Kart-e-Sulh Mosque	36.717664	67.140655
W20	Female Khurasan High School	36.72416	67.136212
W21	Hazrat Osman Mosque	36.73075	67.10021
W22	Said Abad Twon, Faraye Street	36.720694	67.123487
W23	Seddiq Afghan High School	36.729045	67.113962
W24	Kahkashan Wedding Hotel	36.702021	67.131307

The collected samples for determining the concentration of heavy metals (iron, copper, arsenic, lead, cadmium, aluminum, silver, and manganese) were transferred to the laboratory. To stabilize the samples, each polyethylene bottle containing a sample was fixed with 2 milliliters of nitric acid until its pH reached below 2. The determination of heavy metal concentrations was performed using the Atomic Absorption Spectrophotometry method. The instrument used for this analysis is a model (DR 2700) manufactured by the company (HACH). Statistical analysis of the sample parameters was carried out using Excel and SPSS software.

2.4. Statistical Analysis of the Research

For statistical analyses in this research, SPSS software version 26 was employed. Descriptive statistics were utilized to analyze the variables, as shown in Table 2, indicating that copper has the highest mean, while arsenic has the lowest mean (Figure 2).

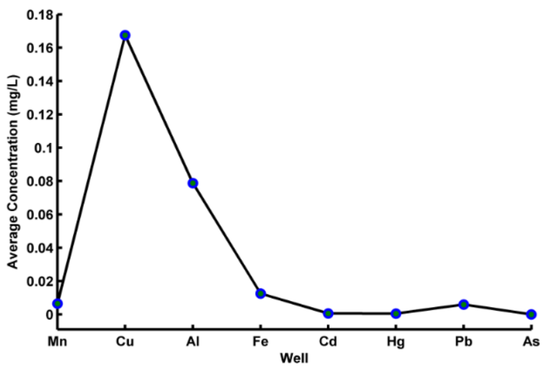

Figure 2: Graph of the average concentration of heavy metals in the water of the studied wells.

The fact that the toxic metal copper has the highest mean is a cause for concern if it exceeds the permissible limits set by international standards.

III. RESULTS

For the purpose of analyzing the concentration of heavy metals, two samples were taken from each of the 24 deep wells located in various areas of the city. The results of this research include an examination of the trend of changes in the measured parameters in well water samples using statistical methods and a comparison of the results with WHO standards. The analysis results of groundwater samples in the studied areas, after analyzing the concentration levels of heavy metals (manganese, iron, copper, zinc, cadmium, lead, arsenic, and aluminum), are presented in Table 3.

IV. DISCUSSION AND FINDINGS

The levels of heavy metal concentrations in the studied water sources, considering the conducted analyses, and the trend of changes induced in the concentrations of the studied heavy metals in the wells are analyzed and explained as follows.

Manganese (Mn):

Manganese is typically naturally present in the environment and may enter water sources due to agricultural activities. The human body requires manganese, and its deficiency can lead to skeletal abnormalities and reproductive issues. However, excessive intake of this element can result in neurological and psychiatric disorders [19]. The analysis results, as depicted in the diagram in Figure 3, indicate that manganese concentrations in all water sources are significantly lower compared to the World Health Organization (WHO) standards. In terms of manganese metal, the groundwater studied in this research is not considered a threat to human health and living organisms.

Copper (Cu):

The concentration of copper in all analyzed samples is lower than the World Health Organization (WHO) recommended standards.

Table 2: Descriptive statistics of variables.

Variable	Mg	Cu	Al	Fe	Cd	Hg	Pb	As
N	24	24	24	24	24	24	24	24
Mean	0.0 065	0.1 675	0.0 788	0.0 125	0.0 007	0.0 006	0.0 059	0.0 001
Std. Deviation	0.0 052	0.1 496	0.1 660	0.0 177	0.0 012	0.0 007	0.0 052	0.0 000
Maximum	0.0 230	0.8 000	0.6 000	0.0 600	0.0 050	0.0 020	0.0 200	0.0 001
Minimum	0.0 010	0.0 500	0.0 001	0.0 001	0.0 001	0.0 001	0.0 001	0.0 001
Range	0.0 220	0.7 500	0.5 999	0.0 599	0.0 049	0.0 019	0.0 199	0.0 000
Variance	0.0 000	0.0 220	0.0 280	0.0 000	0.0 000	0.0 000	0.0 000	0.0 000
Asymp. Sig. (2-tailed)	.20 0	0.0 01	0.0 001	0.0 001	0.0 001	0.0 001	0.0 30	0.0 001

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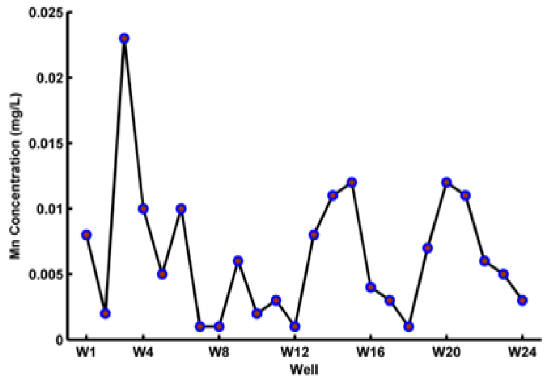

Figure 3. Graph of Mn changes in aquatic resources

As shown in Figure 4, well number 11, located in the Sheikh Mir Gilani Mosque area, has the lowest copper concentration among the studied wells. Copper is an essential nutrient for humans and animals. Its deficiency can lead to diseases such as osteoporosis in infants and children, anemia, a decrease in white blood cell count, and connective tissue disorders affecting skeletal health.

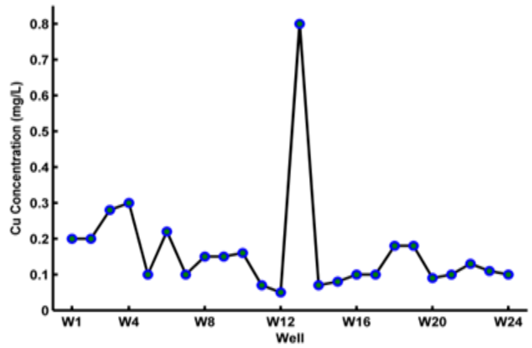

Figure 4. Graph of Cu changes in aquatic resources

When the copper concentration in the human body exceeds the recommended standard, it can lead to toxicity and problems such as stomach pain, hematemesis, melanosis, jaundice, loss of appetite, and gastroenteropathy associated with erosion [23].

Aluminum (Al):

Aluminum is the third most abundant element in the Earth's crust, and during extraction, it can find its way into surface water, groundwater, and the environment. Research on the toxicity of elements indicates that aluminum can pose a significant threat to humans, animals, and plants, and it may be the source of many diseases [26]. The results of the analysis in (Figure 5) indicate that the concentration of aluminum in wells W5, W16, and W17 is 0.6 mg/L, 0.5 mg/L, and 0.4 mg/L, respectively. While the World Health Organization's standard guideline for this metal is 0.2 milligrams per liter. Therefore, except for the three mentioned wells, the aluminum concentration in all wells is below the recommended limit set by the World Health Organization.

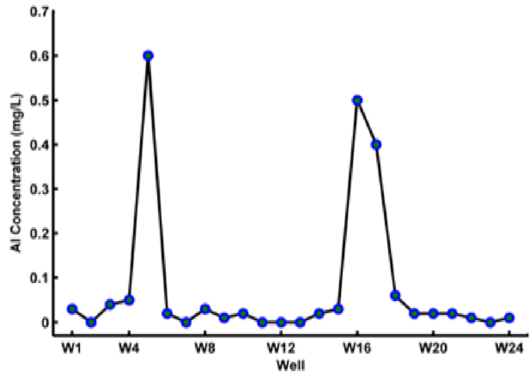

Figure 5. Graph of Al changes in aquatic resources

Iron (Fe):

Iron is an essential element for proper body function and health [20]. As depicted in (Figure 6), the iron concentration in this research varies from 0.01 to 0.06 milligrams per liter. In none of the studied wells, the iron concentration exceeds the World Health Organization (WHO) guidelines. Iron is a vital mineral in human nutrition. Although there is no specific guideline for iron in drinking water yet, as the concentration of iron in levels found in drinking water does not have a significant impact on health, exceeding the acceptable limit of iron can alter the taste of water and affect its acceptability [21].

Cadmium (Cd):

As shown in Figure 7, the highest cadmium concentration is attributed to well number 4 in the Public Administration block, reaching 0.005 mg/L. The World Health Organization's standard limit for this metal is 0.003 mg/L. Therefore, except for the aforementioned well, the cadmium concentration in all wells is below the recommended limit set by the World Health Organization. Research conducted on the cadmium metal indicates that even at low concentrations, this metal in drinking water is toxic to both humans and living organisms. Particularly, certain specific cadmium compounds are highly poisonous to humans. One of the significant pathways for cadmium transfer to humans is through the consumption of plants, as cadmium is readily absorbed by plants [24]. An increase in the concentration of the cadmium element in the body may lead to diseases such as renal, hepatic, and skeletal disorders [25, 17].

Table 3: Results of heavy metal concentration analysis in the water samples of the studied wells.

Wells Code	pH	Mn	Cu	Al	Fe	Cd	Hg	Pb	As
W1	6.8	0.008	0.200	0.030	0.000	0.000	0.000	0.001	BDL
W2	7.7	0.002	0.200	0.000	0.000	0.000	0.001	0.005	BDL
W3	7.5	0.023	0.280	0.040	0.050	0.005	0.002	0.004	BDL

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W4	7.1	0.010	0.300	0.050	0.010	0.000	0.000	0.002	BDL
W5	7.4	0.005	0.100	0.600	0.010	0.000	0.001	0.000	BDL
W6	7.1	0.010	0.220	0.020	0.010	0.000	0.000	0.014	BDL
W7	7.1	0.001	0.100	0.000	0.000	0.000	0.001	0.004	BDL
W8	7.1	0.001	0.150	0.030	0.000	0.000	0.000	0.002	BDL
W9	6.7	0.006	0.150	0.010	0.030	0.002	0.002	0.003	BDL
W10	7.5	0.002	0.160	0.020	0.010	0.000	0.000	0.001	BDL
W11	7.0	0.003	0.070	0.000	0.000	0.000	0.000	0.013	BDL
W12	7.3	0.001	0.050	0.000	0.000	0.000	0.000	0.009	BDL
W13	7.2	0.008	0.800	0.000	0.000	0.000	0.000	0.004	BDL
W14	7.0	0.011	0.070	0.020	0.000	0.000	0.000	0.002	BDL
W15	7.0	0.012	0.080	0.030	0.000	0.000	0.000	0.000	BDL
W16	7.2	0.004	0.100	0.500	0.010	0.000	0.001	0.006	BDL
W17	7.2	0.003	0.100	0.400	0.010	0.000	0.001	0.008	BDL
W18	7.3	0.001	0.180	0.060	0.000	0.000	0.000	0.003	BDL
W19	7.3	0.007	0.180	0.020	0.000	0.000	0.000	0.001	BDL
W20	7.0	0.012	0.090	0.020	0.060	0.003	0.000	0.020	BDL
W21	7.2	0.011	0.100	0.020	0.050	0.002	0.000	0.009	BDL
W22	7.3	0.006	0.130	0.010	0.020	0.001	0.002	0.012	BDL
W23	7.0	0.005	0.110	0.000	0.010	0.000	0.001	0.009	BDL
W24	6.9	0.003	0.100	0.010	0.020	0.001	0.000	0.010	BDL
WHO		0.400	2.000	0.200	0.300	0.003	0.001	0.010	0.010

Mercury (Hg):

As shown in Figure 8, the concentration of mercury in wells W3, W9, and W22 is higher than the World Health Organization (WHO) standards.

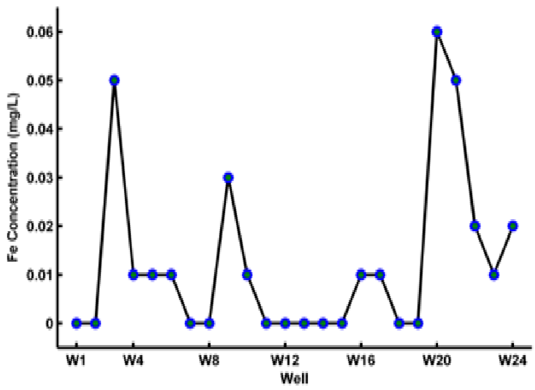

Figure 6. Graph of Fe changes in aquatic resources

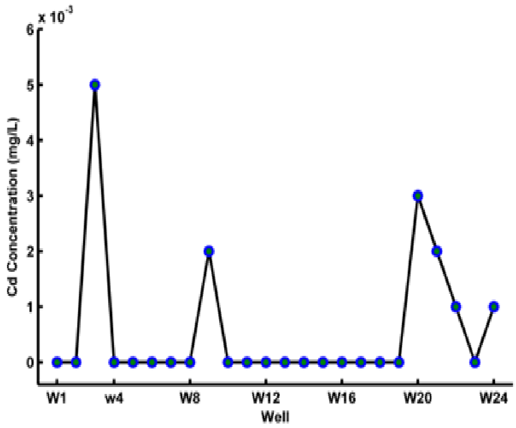

Figure 7. Graph of Cd changes in aquatic resources

In wells W2, W5, W7, W16, W17, and W23, the concentration of mercury is equal to the WHO standards, while in the remaining wells studied, the concentration of mercury is reported to be lower than the WHO standards. The presence of mercury in water sources, even in low concentrations, can pose a threat to the health of a wide range of organisms, including humans [17]. Mercury is widely found in aquatic sources such as lakes, *rivers*, and oceans. It is absorbed by microorganisms and transformed into methyl mercury within these microorganisms, leading to significant disruptions in the life of organisms. The primary reason for the transfer of mercury into the human body is the consumption of fish contaminated with methyl mercury [18].

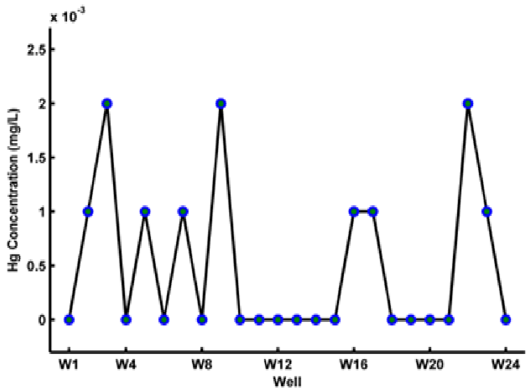

Figure 8. Graph of Hg changes in aquatic resources

Lead (Pb):

Research conducted on groundwater has described lead as a highly toxic metal. Excessive use of this element leads to widespread environmental pollution and health issues [26]. The concentration of lead in wells, specifically W6, W11, W20, and W22 under study,

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exceeds the recommendations of the World Health Organization. Figure 9 indicates that well number 20, located in the Lesa Nasvan Khersan area, has the highest lead concentration at 0.02 mg/L. The main sources that contaminate groundwater with lead include the combustion of fossil fuels, lead-based paints, gasoline, cosmetics, soldering, and industrial soil pollution [27, 18]. When the concentration of this element in water sources exceeds the permissible limit, it can cause damage to the kidneys, impact the nervous system, and lead to mental impairment [28].

Arsenic (As):

Arsenic, a colorless and tasteless element, exists naturally in the environment. It can be released through volcanic activities, weathering of rocks, forest ash residues, and human activities. Some fertilizers and pesticides can also liberate significant amounts of arsenic into the environment [29]. Water sources can be contaminated with arsenic through household waste, municipal waste, and improper disposal of industrial wastewater [30]. Elevated levels of arsenic in the human body can lead to severe vomiting, disruption of blood circulation, damage to the nervous system, and even death [22]. In all studied wells (Figure 10), the concentration of arsenic was below detectable limits (BDL).

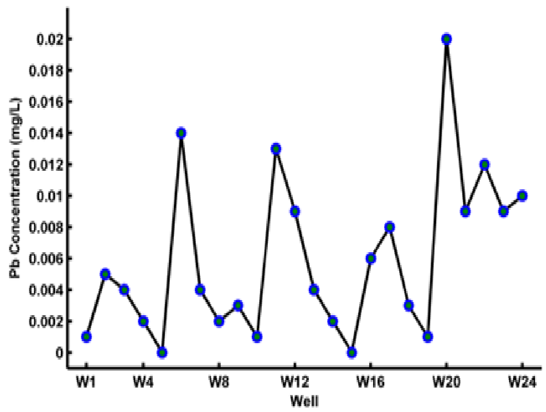

Figure 9. Graph of Pb changes in aquatic resources

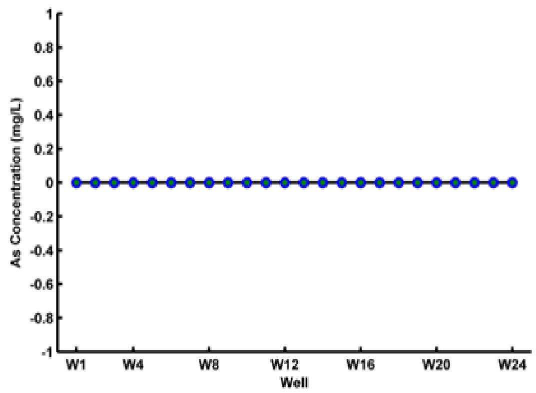

Figure 10. Graph of as changes in aquatic resources

V. CONCLUSION

The contamination of groundwater with heavy metals has become a global concern. Therefore, the concentrations of heavy metals (manganese, copper, aluminum, iron, cadmium, mercury, lead, and arsenic) in the groundwater of Mazar-e-Sharif city were investigated. The results of these studies indicated that the concentration of aluminum in three wells, lead in four wells, cadmium in one well, and mercury in three wells exceeded the recommended standards of the World Health Organization. However, the concentration of heavy metals in the remaining wells was below the guidelines of the World Health Organization (2011). Only arsenic among the investigated heavy metals was below the detectable limit. The dissolution of mineral rocks, the use of pesticides containing heavy elements in agricultural lands, small-scale industrial effluents, and domestic wastewater contribute to the spread of these metals in the soil. As a result, heavy metals enter groundwater through rain and surface water. It is therefore recommended that domestic and municipal wastewater be collected in a designated area, and a method for removing heavy metals from the composition of these wastewaters be considered. In addition, regular monitoring of drinking water for heavy metals by responsible authorities is crucial to prevent their entry into the human food chain. This preventive approach helps control and reduce potential health risks associated with heavy metal pollution.

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