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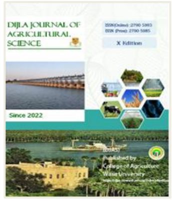

Research article

Impact of the Badra oil field on plant and water pollution in Wasit Governorate, Badra District

Asaad Hammadi Ghadhib and Mahdi Wasmey Seheib Alaidi

Department of Soil and Water Resources, College of Agriculture, Wasit University, Iraq

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ABSTRACT

To investigate the pollution status of heavy metals (vanadium, cadmium, lead, nickel, and arsenic), and to determine the impact of gases and volatile vapors from the Badra oil field in Badra District, Wasit Governorate, on plant and water pollution, and to measure the concentrations of these Metals in plants and water, and to compare these heavy metal concentrations with the international limits described by the (WHO, 2007) it was noted that heavy metals (vanadium, cadmium, lead, nickel, and arsenic) are considered pollutants of plants and water if their concentrations exceed (2, 0.2, 0.3, 10, and 1) mg/kg dry matter for plants and (0.05, 0.003, 0.01, 0.07, and 0.01) mg/L for water, respectively, three plant sites were selected at distances of (400, 800, and 1600) The source of pollution and water were measured from two locations (400 m and 800 m), in addition to a control sample at a distance of (3000 m). Soil and water samples were collected from the southeastern and northwestern sections of the field, in addition to the control sample. The results of the plant analysis showed a high average total concentration of heavy metals (vanadium, cadmium, lead, nickel, arsenic) at the studied locations in the southeastern part of the Badra oil field. At the first location (400 m), the concentrations were (14.69, 3.23, 15.51, 12.26, 4.55) and (11.14, 1.99, 13.31, 9.31, 3.53) mg/kg dry matter for the plants A. maurorum and Schanginia aegyptica, respectively, compared to the northwestern section at the same distance, with the first location (400 m) showing the highest concentration. As for the water samples, the analysis results showed elevated concentrations of heavy metals (vanadium, cadmium, lead, nickel, and arsenic) at the studied sites in the southeastern part of the Badra oil field. At the first site (400 m), the concentrations of these heavy metals in the water reached (0.092, 0.094, 0.093, 0.761, and 0.053) mg/L, respectively. In comparison, the northwestern part of the field, at the same distance, recorded lower values.

1. Introduction

Environmental pollution is one of the most prominent contemporary environmental issues, taking on serious dimensions at the environmental, economic, and social levels, particularly following the Industrial Revolution in Europe and the subsequent massive industrial expansion fueled by modern technological advancements. In recent years, industries have shifted towards complex production

*Corresponding author:
malaiedy@uowasit.edu.iq (Asaad Hammadi Ghadhib)

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patterns, accompanied by a significant increase in pollution rates. This has often led to the degradation of the biosphere and the disruption of the balance of ecosystems. While environmental pollution is not a new phenomenon, what distinguishes it today is its increasing severity and expanding scope, transforming it into a global problem that transcends political boundaries, thus prompting growing international attention. Addressing it requires international cooperation and concerted efforts, given that its effects exceed the capabilities of individual nations. Some studies have indicated that environmental risks now surpass the dangers of traditional conflicts and wars in their impact (Gharaybeh, 2010). Rapid population growth within cities, unplanned urban expansion, and increasing industrial and agricultural development have all contributed to exacerbating environmental pollution. This manifests as a negative impact on ecosystems and their functions through the introduction of solid, liquid, and gaseous pollutants, as well as other forms of energy such as noise, heat, and radiation, into the environment at rates exceeding its natural capacity for decomposition, mitigation, or recycling. This leads to the accumulation of these pollutants and an increase in their harmful effects (Curley, 2011) .

Environmental pollution with heavy metals is a specific type of pollution resulting from the accumulation of heavy metals such as lead (Pb), cadmium (Cd), mercury (Hg), nickel (Ni), and chromium (Cr) in various environmental components. Plant pollution with heavy metals constitutes one of the most prominent contemporary environmental problems, given the physiological and molecular disturbances these Metals cause in plants, in addition to their health risks through the food chain. Heavy metals are defined as Metals with high density and biological toxicity even at low concentrations, such as lead (Pb), cadmium (Cd), arsenic (As), mercury (Hg), nickel (Ni), and chromium (Cr). The danger of these Metals lies in their chemical stability. Their difficult biodegradability leads to their accumulation in the soil and transfer to plant tissues (Alloway, 2013). Water pollution with heavy Metals is one of the most dangerous forms of environmental pollution due to their high toxicity, bioaccumulation, and inability to biodegrade. The most common heavy Metals in aquatic environments include lead (Pb), cadmium (Cd), arsenic (As), mercury (Hg), chromium (Cr), nickel (Ni), copper (Cu), and zinc (Zn). The danger of these Metals lies in their ability to move through the food chain, leading to chronic health effects on humans and other living organisms (Alloway, 2013) .

The World Health Organization (WHO,2022) indicated that the presence of heavy metals in water may result from natural sources such as the weathering of rocks and minerals containing these Metals. However, human activities represent the primary source of their concentrations exceeding environmentally permissible limits. Environmental pollution by heavy metals has received considerable attention from specialists, especially after observing the significant degradation of environmental resources such as soil, water, and air. This has led to an increase in environmental diseases, particularly among humans, due to the emissions from oil fields that cause significant environmental pollution. Based on the above, the importance of the current study in the Badra district is highlighted by its use of an integrated methodology combining chemical analysis of plants and water. The study aims to achieve the following objectives: to estimate the content of the most polluting heavy metals, such as lead, cadmium, nickel, vanadium, and arsenic, in the water and natural vegetation of the area surrounding the Badra oil field; and to identify the role of prevailing wind direction in the region in influencing water pollution. To investigate the pollution status of heavy metals (vanadium, cadmium, lead, nickel, and arsenic), and to determine the impact of gases and volatile vapors from the Badra oil field in Badra District, Wasit Governorate, on plant and water pollution.

2. Materials and Methods

2.1 Study Area

The study area, from which samples were collected, is located east of Wasit Governorate in the Badra district. The city of Badra is situated at coordinates 33.05° North and 46.07° East. The district is approximately 60 kilometers east of Kut, the governorate's capital. The district is characterized by industrial activity, with oil extraction being one of the most important industries in the region. The area contains approximately 22 oil wells and is surrounded by undeveloped land. The area has been divided into two parts: the southeastern and northwestern sections Table (1).

Table 1: locations of the sample sites in the study area

Southeast Sites	Coordinates	Northwest Sites	Coordinates	Northeast Sites	Coordinates
400 m	33° 01′ 50.04″ N 46° 01′ 15.89″ E	m 400	33° 02′ 41.46″ N, 46° 00′ 33.46″ E		
600 m	33° 01′ 38.62″ N, 46° 01′ 24.92″ E	m 600	33° 02′ 52.85″ N, 46° 00′ 24.44″ E	3000 m	33° 03′ 51.11″ N, 46° 01′ 45.68″ E
1600 m	33° 01′ 16.41″ N,46° 01′ 42.47″ E	m 1600	33° 03′ 15.08″ N, 46° 00′ 06.77″ E		

2.2 Field Work

Plant Samples

Plant samples (Alhagi maurorumand Schanginia aegyptica) were collected on September 18, 2025, from the southeastern and northwestern locations at three distances from the pollution source. These distances were 400, 800, and 1600 meters, respectively, for the southeastern and northwestern sections. A control sample was taken at a distance of 3000 meters, with three replicates for each distance and direction.

Water Samples

Water samples were collected on September 18, 2025, from the southeastern and northwestern locations of ponds and marshes within the study area, with three replicates for each location.

3.2 Laboratory Work

Soil Sample Analysis

Plant samples (vegetative parts) were collected from the dominant native plants in the area, namely Alhagi maurorumand Schanginia aegyptica, from different locations in the southeastern and northwestern parts of the Badra oil field, at distances of 400, 800, and 1600 m from the source of pollution, as well as a control site at a distance of 3000 m. The plant samples were washed with distilled water and oven-dried at 65°C for 48 hours until weight stabilized. They were then ground using an electric grinder, and 0.2 g of the plant sample was taken. The samples were digested using an acidic mixture ($HClO_4$:HNO_3) in a ratio of 1:4, according to the method described in (Jones, 2001). The heavy metal content of the plants was estimated using an atomic absorption spectrometer. 2-3-

2: Plant Sample Analysis Water samples were collected from ponds in the study area and from the locations mentioned for each direction, along with a sample from the control location. These samples were then placed in plastic bottles and refrigerated until the necessary laboratory analyses could be performed. The heavy metals (vanadium, cadmium, lead, nickel, and arsenic) were then estimated in the studied water samples according to the (APHA, 1998).

2.4 Statistical Analysis

The Statistical Analysis System (SAS) software (2018) was used to analyze the data to study the effect of different factors (location, dimensions, and plant type) on the studied characteristics (concentrations of heavy metals in water and plants). A completely randomized design (CRD) factorial experiment was used, and significant differences between means were compared using the Least Significant Difference (LSD) method, as described by (Al-Rawi, 1981).

3. Results and Discussion

3.1 Total Vanadium (V) Concentration in Plants

The results of the study, shown in Table (2), indicate a clear variation in the concentrations of vanadium (V) in the vegetative parts of Alhagi maurorum and Schanginia aegyptica plants, depending on the distance from the pollution source, the direction, and the plant type. This variation reflects the impact of industrial activities, particularly the Badra oil field, on raising the levels of heavy metals in the surrounding environment due to gaseous emissions and industrial dust. The highest concentrations were recorded at the first location (400 m), reaching (14.69) mg V/kg dry matter in the firefly and (11.14) mg V/kg dry matter in the camelthorn. The values then gradually decreased with increasing distance, reaching their lowest levels in the control sample (3000 m), which amounted to 0.25 and 0.13 mg/kg dry matter for both plants.

Table 2. Total vanadium concentration in the vegetative parts of Alhagi maurorum and Schanginia aegyptica (mg/kg dry matter)

Sites	Distance from pollution source (m)	*Schanginia aegyptiaca*	*A. maurorum*	Average
Southeast	400	14.69	11.14	12.915
	800	9.37	7.1567	8.265
	1600	5.37	3.52	4.445
Control	3000	0.25	0.13	0.19
	Average	7.42	5.48	
	LSD 0.05	Distance	Plant	Pant* distance
		0.96 *	0.68*	1.27 *
Northwest	400	11.17	7.19	9.18
	800	6.25	4.48	5.36
	1600	3.46	1.55	2.51
Control	3000	0.25	0.13	0.19
	Average	5.28	3.33	
	LSD 0.05	Distance	Plant	Pant* distance
		0.86 *	0.61 *	1.22*
Global Limitation (WHO/FAO, 2007)		0.1-2 mg/kg dry matter		

In the northwest direction, the results showed relatively lower concentrations, with the highest values at the first location 400 m 11.17 mg V/ kg dry matter and 7.19 mg V/ kg dry matter of Alhagi maurorum. This indicates the influence of the prevailing wind direction in the area, which aids in the transport and deposition of pollutants. Wind plays a key role in the distribution of fine particles emitted from the oil field, which contain Metals such as vanadium, leading to their accumulation in one direction rather than another. The results of the current study are consistent with those of (Reimann, C., & de Caritat, P. ,2021).The results also showed that accumulated Schanginia aegyptica vanadium more than Alhagi maurorum at all locations, with an overall average of (7.42 mg V/ kg dry matter of Schanginia aegyptica and 5.48 mg V/ kg dry matter of Alhagi maurorum in the southeast direction, and (5.28 and 3.33) in the southeast direction. mg/kg dry matter) in the northwest direction, and this is attributed to physiological differences between the two plants, such as absorption efficiency, the nature of the root system, and the ability to transport and store Metals within plant tissues. Recent studies have shown that plant responses to heavy metals vary considerably among species, making some species more capable of accumulating them and thus useful as bioindicators of pollution (Ali et al., 2023) .

Statistical analysis revealed significant differences in the effects of distance and plant type, as well as the interaction between them, as evidenced by the LSD values at a probability level of 0.05. This indicates that the effect of distance on vanadium concentrations depends on the plant type. This interaction reflects the complex behavior of heavy metals in ecosystems, where physical, chemical, and biological factors intertwine to determine their distribution and transport patterns. Comparing the results with the global limits for vanadium concentration in plants (0.1–2 mg V/ kgdry matter, according to(WHO/FAO, 2007) reveals that most of the recorded values, especially in locations near and intermediate to the pollution source, clearly exceed these limits. This indicates high levels of pollution, attributed to the direct deposition of vanadium on vegetative parts from the atmosphere, in addition to its absorption from contaminated soil.

Total Cadmium (Cd) Concentration in Plants

The results indicate a clear spatial and directional variation in the concentrations of cadmium (Cd) in the vegetative parts of the plants Alhagi maurorum and Schanginia aegyptica in the Badra oil field area (Table 3). This reflects the direct impact of oil activities on increasing the levels of heavy metals in the surrounding plant environment. Cadmium is a toxic element often associated with industrial activities, oil extraction, and fuel combustion. It enters the environment through gaseous emissions, fine particulate deposition, or soil leaching (Tchounwou, 2022).

Table 3. Total Cadmium Concentration in the Vegetative Parts of Alhagi maurorum and Schanginia aegyptica (mg Cd/kg dry matter).

Sites	Distance from pollution source (m)	*Schanginia aegyptiaca*	*A. maurorum*	Average
Southeast	400	3.23	1.99	2.61
	800	0.95	0.84	0.89
	1600	0.76	0.63	0.69
Control	3000	0.19	0.13	0.16
	Average	1.28	0.89	
	LSD 0.05	Distance	Plant	Pant* distance
		0.42*	0.30*	0.60*
Northwest	400	2.18	1.14	1.66
	800	0.89	0.66	0.77
	1600	0.49	0.42	0.46

Control	3000	0.19	0.13	0.16
	Average	0.94	0.59	
	LSD 0.05	Distance	Plant	Pant* distance
		0.38*	0.27*	0.54*
Global Limitation (WHO/FAO, 2007)			0.2 mg/kg dry matter	

The results showed that the highest cadmium concentrations were recorded at locations close to the pollution source (400 m), reaching 3.23 mg Cd.kg-1 dry matter in the firefly and 1.99 mg Cd.kg-1 dry matter in the camelthorn plant in the southeast direction. These values gradually decreased with increasing distance, reaching their lowest levels at the comparison site (3000 m). This gradient indicates a clear inverse relationship between cadmium concentration and distance from the pollution source, a common pattern in environments affected by oil activities. Pollutants tend to concentrate near extraction or burning sites and then decrease due to dispersion, precipitation, and adsorption processes in the soil. The results also showed a clear directional variation, with concentrations being higher in the southeast direction compared to the northwest at all distances .

This difference is attributed to the influence of climatic factors, particularly the prevailing wind direction in the region, which contributes to transporting pollutants from the oil field site to neighboring areas, leading to their accumulation in the southeast direction. It is more specific than others. Recent studies confirm that the transport of heavy metals in oil-bearing environments is significantly affected by atmospheric factors such as wind speed and direction, in addition to surface characteristics (Rinklebe et al., 2021). The results showed that the fireweed Schanginia aegyptica had a superior cadmium accumulation rate compared to Alhagi maurorum at all sites, recording a higher average in both directions. This is attributed to physiological differences between the two plants, as plant species differ in their ability to absorb heavy Metals from the soil and transport them to their vegetative parts, depending on root type, absorption efficiency, and intracellular accumulation mechanisms .

Recent studies have indicated that some wild plants possess a high capacity for cadmium accumulation, making them effective bioindicators of environmental pollution. Statistical analysis revealed significant differences in the effects of distance and plant type, as well as the interaction between them, indicating that cadmium distribution in plants does not depend on a single factor, but rather results from a complex interaction between several environmental and biotic factors. This overlap reflects the fact that the effect of distance from the pollution source varies depending on the plant species. Comparing the results with the global limits for cadmium concentration in plants (0.2 mg Cd/kg dry matter, according to (WHO/FAO, 2007) reveals that most of the recorded values, especially in locations near and to the extent of the Badra oil field, significantly exceed this limit. This indicates a high level of environmental pollution that could lead to the transfer of cadmium through the food chain, posing a risk to human and animal health due to the toxicity of this element and its ability to bioaccumulate within living organisms.

Total Lead (Pb) Concentration in Plants

There is a significant increase in lead concentrations for the plants Alhagi maurorum and Schanginia aegyptica at distances close to the pollution source, reaching 15.51 mg Pb/kg dry matter in Schanginia aegyptica and 13.31 mg Pb/kg dry matter in Alhagi maurorum The concentration of lead in the vegetative parts of camelthorn (at 400 m) at the southeastern site decreased gradually with distance, reaching 0.20 and 0.08 mg Pb.kg-1 dry matter for camelthorn and camelthorn respectively at 3000 m.

This gradient is attributed to the fact that lead is deposited densely near its source and then decreases due to atmospheric dispersal and precipitation (Table 4). The results of the current study are consistent with those of Singh et al. (2021), which found that the concentration of heavy metals in plants decreases with distance from the pollution source. Furthermore, the lower values at the comparison site confirm that the high concentrations are due to pollution and not to the natural soil background .

Table 4: Total lead concentration in the vegetative parts of Alhagi maurorum and Schanginia aegyptica in the study area (mg Pb/kg dry matter).

Sites	Distance from pollution source (m)	*Schanginia aegyptiaca*	*A. maurorum*	Average
Southeast	400	15.51	13.31	14.41
	800	10.39	9.38	9.89
	1600	7.57	6.23	6.90
Control	3000	0.20	0.08	0.14
Average		8.42	7.25	
LSD 0.05		Distance 0.68*	Plant 0.48*	Pant* distance 0.97*
Northwest	400	10.54	8.44	9.49
	800	8.31	6.11	7.21
	1600	5.47	4.3667	4.92
Control	3000	0.20	0.08	0.14
Average		6.13	4.75	
LSD 0.05		Distance 1.11*	Plant 0.78*	Pant* distance 1.57*
Global Limitation (WHO/FAO, 2007)		0.3 mg/kg dry matter		

The results in Table (4) show a spatial difference between the two sites. The southeastern site recorded a higher average concentration of 8.42 mg Pb/kg dry matter for Schanginia aegyptica and 7.25 mg Pb/kg dry matter for Alhagi maurorum compared to the northwestern site (6.13 and 4.75 mg Pb/kg dry matter for Schanginia aegyptica and Alhagi maurorum, respectively). This can be explained by the influence of the prevailing wind direction in the area.Recent studies have shown that the distribution of heavy metals is affected by local environmental factors such as wind movement and soil type, leading to clear spatial variation in concentrations (Li et al., 2020). As for the plants, the highest concentrations were recorded in Schanginia aegyptica (10.54 mg Pb/kg dry matter) compared to Alhagi maurorum (8.44 mg Pb/kg dry matter) at the first site (400 m) in the northwestern part. Studies indicate that plants differ in their ability to absorb these substances. Heavy metal absorption and transport depend on root characteristics and internal transport mechanisms. Some species have higher accumulation efficiency. Lead may enter through the roots or be deposited directly on the leaves from contaminated dust, increasing its concentration in the vegetative parts (Dubey and Sharma, 2021). The results also show that all values (except at the comparison site) exceeded the internationally accepted limit (0.3 mg Pb/kg dry matter, as defined by the (WHO/FAO, 2007), indicating severe contamination.

Total Nickel (Ni) Concentration in Plants

The results show high nickel concentrations in the vegetative parts of Schanginia aegyptica and Alhagi maurorum, respectively Alhagi maurorum plants at distances close to the pollution source. At the southeastern site, the concentration reached 12.26 mg Ni/kg dry matter in the firefly and 9 .31 mg Ni/kg dry matter in the camelthorn and A. Alhagi maurorum, respectively. Ni/kg dry matter in the Alhagi maurorum plant was highest at the first site (400 m), then gradually decreased with increasing distance, reaching 0.96 and 0.78 mg Ni/kg dry matter at 3000 m. This decrease is attributed to the spatial gradient in heavy element deposition, where they accumulate near the source and decrease with distance due to dispersion and precipitation. This pattern is common in polluted environments. This behavior also reflects the nature of nickel as an element transported by dust and fine particles and deposited in soils near the source. The results of the current study are consistent with those of (Chen and Wu ,2021). The results also showed significant differences between the two sites, with the southeastern part recording the highest value at 6.51 mg Ni/kg dry matter for the Schanginia aegyptica while the northwestern part recorded an average of 5.50 mg Ni/kg dry matter for the Schanginia aegyptica This can be explained by the prevailing wind direction in the area .

Table 5. Total nickel concentration in the vegetative parts of plants in the study area (mg Ni/kg dry matter)

Sites	Distance from pollution source (m)	*Schanginia aegyptiaca*	*A. maurorum*	Average
	400	12.26	9.31	10.78
Southeast	800	8.56	4.32	6.44
	1600	4.27	3.34	3.80
Control	3000	0.96	0.78	0.87
Average		6.51	4.44	
LSD 0.05		Distance 1.07*	Plant 0.75*	Pant* distance 1.51*
	400	11.54	8.11	9.82
Northwest	800	6.18	4.27	5.22
	1600	3.32	1.85	2.59
Control	3000	0.96	0.78	0.87
Average		5.50	3.75	
LSD 0.05		Distance 1.06*	Plant 0.75*	Pant* distance 1.51*
Global Limitation (WHO/FAO, 2007)		1-10 mg/kg dry matter		

Regarding plant differences, Alhagi maurorum accumulated nickel more than Schanginia aegyptica at all sites. The first site (400 m) in the northwestern part recorded 11.54 mg Ni/kg dry matter (NDM) compared to 8.11 mg Ni/kg dry matter for the camelthorn. This is attributed to differences in the physiological characteristics of the two species. Some plants have a higher capacity to absorb and transport heavy metals to their aerial parts due to the efficiency of their transport systems. The results of the current study are consistent with those of (Ahmad et al, 2022). Furthermore, the exceeding of some values of the internationally permissible upper limit (10 mg Ni/kg dry matter) (WHO/FAO, 2007) indicates significant pollution in the sites near the Badra oil field.

Total Arsenic (As) Concentration in the Plant

The results in Table (6) show a clear variation in arsenic concentrations in the vegetative parts of plants Schanginia aegyptica and, Alhagi maurorum exhibited varying concentrations relative to the pollution source. The highest values were recorded at the closest point (400 m) in the southeastern location, reaching 4.55 mg As/kg dry matter in Schanginia aegyptica and 3.53 mg As/kg dry matter in Alhagi maurorum. These values then gradually decreased with distance, reaching 0.66 and 0.35 mg As/kg-1 dry matter in the control sample (3000 m). This pattern indicates that arsenic distribution is spatially correlated with the intensity of deposition near the emission source, a behavior documented in environments affected by industrial and agricultural activities (WHO, 2007). This decline in concentrations can be explained by the fact that arsenic is often transported via dust and suspended particles, then deposited in nearby soil, where it is subsequently absorbed by roots .

Its relative stability in the soil contributes to its accumulation near the source over extended periods. The results of the current study, in conjunction with those of Smedley et al. (2017), indicate that arsenic is one of the most toxic and stable Metals in terrestrial environments, making it susceptible to bioaccumulation in plants. The results showed a difference between the two sites, with values in the southeastern site being higher than those in the northwestern site (4.55 and 3.53 mg As/kg dry matter for the plants Schanginia aegyptica and , Alhagi maurorum in the southeastern part), while they were (2.83 and 2.29 mg As/kg dry matter for the plants Alhagi maurorum in the northwestern part). This difference is attributed to the prevailing wind direction in the region, which transports pollutants in one direction rather than another. The results of the current study are consistent with those of (Rahman ,2021). The clear superiority of Schanginia aegyptica over Alhagi maurorum in arsenic accumulation reflects a difference in the physiological capacity of the two species. Schanginia aegyptica is more efficient at absorbing and transporting arsenic. Arsenic is transported to the aerial parts of camelthorn, while camelthorn tends to reduce its translocation or storage in the roots. Studies in plant physiology have confirmed that plants differ considerably in their mechanisms for dealing with arsenic, with some species possessing higher tolerance and accumulation capacities (Zhao et al., 2020).

Table 6. Total arsenic concentration in the vegetative parts of plants in the study area (mg As/kg dry matter)

Sites	Distance from pollution source (m)	*Schanginia aegyptiaca*	*A. maurorum*	Average
Southeast	00	4.55	3.53	4.04
	800	2.88	2.41	2.65
	1600	1.74	0.99	1.36
Control	3000	0.66	0.35	0.50
Average		2.46	1.82	
LSD 0.05		Distance 0.70*	Plant 0.49*	Pant* distance 0.99*
Northwest	400	2.83	2.29	2.56
	800	2.09	1.22	1.65
	1600	0.85	0.66	0.76
Control	3000	0.51	0.35	0.43
Average		1.57	1.13	
LSD 0.05		Distance 0.25*	Plant 0.17*	Pant* distance 0.35*

Global Limitation (WHO/FAO, 2007)	0.01-1 mg/kg dry matter

Comparing the results with the global limits issued by the World Health Organization (WHO) and the Food and Agriculture Organization (FAO), which range from 0.01 to 1 mg As/kg dry matter (according to WHO/FAO reports, 2007), it becomes clear that many of the values recorded at sites near the Badra oil field and in the southeastern part significantly exceeded the upper limit, indicating high levels of arsenic pollution.

Heavy Metal Concentrations in Water

The results in Table (7) show significant differences in the concentrations of heavy metals (vanadium, cadmium, lead, nickel, arsenic, cobalt, and chromium) in the water near the Badra oil field. The results indicate that the highest pollution levels are concentrated in nearby areas, particularly in the southeastern part of the oil field (400 m), then gradually decrease at (800 m), reaching their lowest levels at the comparison site (3000 m) and in the northwestern part of the Badra oil field.

Table 7. Concentration of heavy metals in the studied water samples (mg/L)

Sites	Distance	V	Cd	Pb	Ni	As
Southeast	400	0.092	0.094	0.093	0.761	0.053
	800	0.071	0.053	0.061	0.503	0.044
Control	3000	0.043	0.002	0.006	0.060	0.005
LSD 0.05		0.015*	0.0033*	0.0123*	0.021*	0.0029*
Northwest	400	0.084	0.004	0.062	0.371	0.032
	800	0.076	0.003	0.044	0.088	0.018
Control	3000	0.043	0.002	0.006	0.060	0.005
LSD 0.05		0.0103*	0.002*	0.0113*	0.065 *	0.0035*
(WHO ,2011)		0.05 Mg/L	0.003	0.01	0.07	0.01

The results of the statistical analysis in Table (7) showed a significant increase in the concentration of vanadium in the polluted water samples, especially in the southeast direction at the first location (400 m), where the highest value was recorded at (0.092 mg. L-1) compared to the lowest value recorded in the comparison sample at a distance of (3000 m) at (0.043 Mg/L), while the highest concentration in the northwest direction was (0.084 Mg/L). When comparing these values with the limits allowed by the World Health Organization (WHO, 2011) (0.05 Mg/L), it appears that the concentrations of vanadium in the locations near the Badra oil field exceeded the allowed limit, indicating the presence of clear industrial pollution in the waters of the area surrounding the oil field .

The results of the study showed a spatial variation in vanadium concentrations between the two study directions, as the southeast direction recorded higher values compared to the northwest direction. This can be explained by the influence of the prevailing wind direction in the region (northwest), which works to transport emissions and vapors containing heavy Metals towards the southeast, leading to an increase in the accumulation of these Metals in the waters near the oil field. The results in Table (7) show a significant increase in cadmium concentration in the southeast direction (0.094 Mg/L) exceeding the internationally permissible limit according to the World Health Organization (WHO, 2011) (0.003 Mg/L). This increase is attributed to the presence of cadmium as an impurity component in crude oil, in addition to its emissions from incomplete combustion of associated gases. Furthermore, water produced from oil fields may contain high concentrations of cadmium. In contrast, very low concentrations were recorded in the northwest direction, indicating the influence of prevailing winds in the region. Lead recorded its highest value in the southeast direction (0.093 Mg/L at 400 m), exceeding the internationally permissible limit for the element (0.01 Mg/L with a gradual decrease in the northwest direction.

The presence of lead in oil environments is linked to heavy fuel combustion processes, emissions resulting from industrial burning, and crude oil spills and waste. The operational environment is also affected, as lead is characterized by its association with suspended particles, which facilitates its migration and deposition in water. Nickel recorded its highest value at 0.761 mg/L at the first site (400 m) in the southeast direction, which is significantly higher than the permissible limit (0.07 mg/L), reflecting severe contamination. Nickel is a characteristic element of heavy crude oil, as it is a component of its geochemical structure. Flaring and gaseous emissions in oil fields contribute significantly to increasing its concentrations. The arsenic concentration reached 0.053 mg/L in the southeast direction at the first site (400 m), exceeding the permissible limit (0.01 mg/L), with a clear decrease in the northwest direction. Arsenic is associated with crude oil and production water, where it occurs as a natural impurity, and it can also be released during separation and treatment processes.

Conclusions

The study concludes that higher concentrations of heavy metals in areas near oilfield facilities, particularly in the southeast, compared to more distant locations. This distribution indicates the transfer of pollutants from the soil and airborne particles resulting from oil activities into surface water and shallow groundwater. These results also confirm the direct impact of oilfield operations on water quality, necessitating continuous monitoring of heavy metal concentrations to mitigate associated environmental and health risks. Botanical analysis of the plants over Alhagi maurorum showed a difference in their ability to accumulate heavy metals. recorded higher concentrations compared to Alhagi maurorum, indicating differences in physiological characteristics and absorption capacity between plant species. This variation reinforces the importance of using plants as bioindicators to assess pollution levels in oilfield environments, as the concentrations of Metals in their tissues reflect their degree of exposure to pollutants.

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