



Article

Evaluation of some heavy metals resulting from oil well leaks in the Ain Zala field and its surrounding areas on soil and water

Sura Salim Hamid^{1*}, Alaa Taha Azeez², Nagham Salim Butrus³

¹ Department of Inorganic Chemistry, University of Mosul, Iraq.

² Department of Analytical Chemistry, University of Mosul, Iraq.

³ Department of Inorganic Chemistry, University of Mosul, Iraq.

*Email: corresponding_ surasalimhamid74@uomosul.edu.iq

Abstract

The ecology is being threatened by heavy metals, which are extremely hazardous compounds. Their prolonged persistent presence is what sets them apart. The purpose of this study was to measure the concentrations of Pb, Cd, Ni, Cr, V, and Fe in the soil and water surrounding underground petroleum leaks. Additionally, the physicochemical properties of the soil, water, and hydrocarbons were evaluated at six distinct locations (Kiara, Sheikh, Nimrod, Tal Afar, Zimara, Rabia). In Mosul, soil and water samples were taken on January 2, 2023, April 2, 2023, July 2, 2023, and October 2, 2023, at specific locations. The soil's heavy metal concentrations were as follows: The results showed that nickel was more abundant in the soil than other elements (Ni>Cu>Fe>Pb>Cr>Zn>Cd), while cadmium was least abundant. However, the amounts of heavy metals in the water were as follows, and the concentrations in the soil were below the WHO's allowed limits. >Cr>Fe >Pb >Cd>Cu, Ni>Zn All of the heavy metal concentrations were below the allowable

level for irrigation, and the mechanical analysis's findings demonstrated that the sand separator outperforms the other soil separators. According to the findings of the current investigation, oil leaks from wells have contaminated the soil and water in the Mosul Governorate near the Ain Zala fields with heavy metals.

Keywords: Soil contamination, Water, Heavy metals, Leaking Crude Oil Pipelines, and Mosul.

1. Introduction

Human exposure has resulted from the handling of metal trash generated during drilling because heterogeneous heavy metals are commonly found in the underlying formation layers. Exposure to heavy metals and their harmful effects have been connected to health issues in various places of the world [1]. Because hydrocarbon wells are in specific places and drilling activities have specific features, drilling crews frequently work on the rig and rest on platforms designed to give them enough housing in the surrounding environment until their shifts are completed [2].

Due to worries about food safety and the possible risks they represent to ecosystems and human health due to their mutagenic and carcinogenic qualities, the buildup of heavy metals in agricultural soils is a worldwide issue. [3]. Wastewater irrigation can oversaturate agricultural soils with heavy metals, leading to soil contamination and increased plant absorption of heavy metals. Furthermore, these metals have the potential to seep into environmental media, particularly shallow groundwater systems. [4].

Because of this, some heavy metals are categorized as species that harm living things, while others are essential for their development, growth, and well-being. The precise activity that occurred at the site is closely related to the type of metal pollution found in the contaminated soil [5]. The activities and disposal methods will determine the spectrum of contamination concentrations as well as the physical and chemical forms of contaminants. Because metals in soil might be solid, gaseous, or liquid, it may be more challenging to conduct research and interpret the results.

Because they are hazardous and do not biodegrade, heavy metals have drawn a lot of attention. Due to the usage of commercial agrochemicals on agricultural output, heavy metal contamination has dramatically increased over time in many towns and

agricultural districts. Nonetheless, all ecological components contain heavy metals from human activity. The increased anthropogenic intake of heavy metals has led to renewed attention on environmental poisons in recent years.

Human health may suffer if heavy metals are allowed to accumulate and spread over time in soil, surface water, and groundwater. [6]. despite the fact that they are not often considered harmful. The most common heavy metals in contaminated areas, in order of magnitude, are lead (Pb), chromium (Cr), arsenic (As), zinc (Zn), cadmium (Cd), copper (Cu), and mercury (Hg) [7]. There is strong evidence that several cancer types can arise because of extended exposure to low concentrations of carcinogenic heavy metals. Finding out how many of certain heavy metals were poisoning the land and water in the Ain Zala area because of oil wells was the goal of this investigation.

2. Materials And Methods

2.1. Description of the study area

The study area is 60 kilometers south of Mosul and is made up of agricultural lands close to the oil fields of the Qayyarah district, which is situated between two longitudes (43°20'55.87"E -43°6'2.66"E) east and two latitudes (35° 55'30.42"N - 35°34'36.56"N) north. These soils and lands are exposed to pollution due to the burning operations that those oil wells have been exposed to within the oil fields or from the presence of oil refineries and the smoke and ash they emit that contains metal and organic pollutants. The samples were taken on January 2, 2023, April 2, 2023, July 2, 2023, and October 2, 2023.

Table 1. Description of sampling location and pollution sources in Diyala.

Samples	Description
S1	Kiara
S2	Sheikh
S3	Nimrod
S4	Tal Afar
S5	zimara
S6	Rabia

2.2. Collection of Soil samples and Analysis heavy metals

Six different locations within the study area were used to gather soil samples, as shown in Table 1. Soil samples were taken from the top layer (0–15 cm) and placed in ziploc bags with clear labels before being brought to the lab for examination. The materials were crushed and filtered through a 2 mm mesh screen in the lab, allowed to air dry at room temperature, and then put into sterile plastic bags. After adding 10 milliliters of pure HNO₃, soil samples weighing one gram each were placed into digestion tubes. The ingredients were digested for eight hours at 96°C with intermittent stirring. Following complete digestion, the materials were placed in 100 mL volumetric flasks and filtered using Whatman No. 42 filter paper. Either distilled or deionized water was used to prepare the samples up to the 100 mL mark in the volumetric flask. Using an atomic absorption spectrophotometer (AAS), we determined the amounts of Pb, Ni, Cd, Cr, Fe, Zn, and Cu in the supernatant solutions [8]. Table 2 shows the permissible amount of heavy metal content in the soil.



Figure 1. The study area.

Table 2. The permissible amount of heavy metals in the soil (WHO, 2006).

Heavy metals	Permissible limit (mg kg ⁻¹) soil according to WHO, 2003
Pb%	50-300
Ni%	30-75
Cd%	1-3
Cr%	1-5
Fe%	50-100
Zn%	150-300
Cu%	50-140

2.3. Collection of water samples and Analysis

Water samples were gathered from six distinct sites within the study region (Kiara, Sheikh, Nimrod, Tal Afar, Zimara, and Rabia). After being cleaned with distilled water many times, they were stored in one-liter plastic bottles. Pb, Ni, Cd, Cr, Fe, Zn, and Cu concentrations in the supernatant solutions were determined by AAS. Table 3 lists the acceptable concentrations of heavy metals in irrigation water [9].

Table 3. Permissible limits for heavy metals in water for irrigation purposes.

Heavy metals	Permissible limit (µg mL ⁻¹) water according to WHO (The World Health Organization), 2003
Pb	5
Ni	0.2
Cd	0.01
Cr	0.1
Fe	2
Zn	5
Cu	3

2.4. Physicochemical parameters

In this investigation, samples of soil and water were analyzed, and the physicochemical parameters were examined. The pH was measured using an Eutech pH meter. Turbidity is measured with a turbidity meter, while electrical conduction (EC) is measured with a conductivity instrument. Total dissolved solids

(TDS) were measured by gravimetric method; calcium (Ca^{+2}) and magnesium (Mg^{+2}) were measured by titration method; the levels of chloride (Cl^{-1}) were evaluated by Mohr's method; and the levels of phosphate, nitrate, and sulfate were estimated by ion chromatography [10].

3. Laboratory analyzes soil and water samples

3.1. Particle Size Analysis

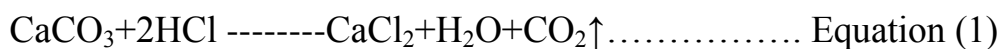
According to Gee and Bauder (1986), the hydrometer method was used to measure the quantities of clay, sand, and silt particles in the soil.

3.2. Determination of Organic materials in Soil and water

It was calculated using the Black-Walkley method, which involves titrating with ammonium ferrous sulphate 0.5 N and wet oxidizing potassium dichromate $\text{K}_2\text{Cr}_2\text{O}_7$ with concentrated sulfuric acid while an indicator (diphenylamine) is present [11].

3.3. Determination of carbonate in Soil

The Calcimeter Bernard was used to measure the amount of calcium carbonate that precipitated. This was done by treating a 1 g soil sample with hydrochloric acid (HCL) in a sealed reactor vessel. The basic technique for figuring out how much CaCO_3 (%) is present is the volumetric analysis of the carbon dioxide (CO_2) gas that is created when the acid solution (HCl-4N) reacts with the carbonate component of the soil sample [12]. An explanation of this procedure is given below:



3.4. Determine of Total Petroleum Hydrocarbons (TPH)

Water samples for Total Petroleum Hydrocarbon (TPH) were collected in 1Litre glass bottles and preserved with 2mL of 1:1 v/v tetraoxosulphate (vi) acid to $\text{pH} < 2$. All the water samples were then transported to the Microbiology Laboratory, where they were assayed within 24 hours of sampling. TPH was measured using the method specified by, APHA 2017, this method utilized the gas chromatography (GC) in addition to Flame Ionization Detector (FID) for TPH analysis in the oil extracts [13].

3.5. Soil contamination standards

The amount of heavy metal contamination and its presence in the soil were determined by using pollution assessment techniques, such as accumulation (Igeo) and pollution load indices.

$$\text{Geoaccumulation Index (Igeo)} = \text{Log}_2 \left(\frac{C_n}{1.5 \times B_n} \right) \dots\dots\dots \text{Equation (2)}$$

where B_n stands for the background concentration of heavy metals (control soil), C_n for the concentration of heavy metals in the soil under study, and 1.5 for the background correction factor. The level of heavy metal contamination in the soil around the research region was evaluated using equation (3).

The Geo-accumulation index (Igeo) is derived using the following criteria to determine the level of contamination: The Igeo values are as follows: 0–1 (unpolluted–moderately polluted), 1–2 (moderately polluted), 2–3 (moderately–strongly polluted), 3–4 (strongly polluted), > 5 (very polluted), and < 0 (unpolluted) [14].

$$\text{Geo accumulation Index (Igeo)} = \text{Log}_2 \left(\frac{C_n}{1.5 \times B_n} \right) \dots\dots\dots \text{Equation (3)}$$

3.5.1. Contamination factor (CF)

The current investigation also considered the study region's total pollution level caused by each heavy metal; the contamination factor (CF) was utilized in this study [15]. In equation (3), the ratio of the heavy metal concentration was measured to the values available in the background.

$$CF = \frac{(C \text{ metals})_{\text{samples}}}{(C \text{ metals})_{\text{background}}}$$

3.5.2. Enrichment Factor (EF)

One metric for evaluating the degree of soil pollution and figuring out how natural or man-made inputs affect the soil is the enrichment factor. Pb, Ni, Cd, Cr, Fe, Zn, and Cu are the main reference elements that are used to calculate the EF value. Because iron (Fe) is abundant in the soil of the study location, it was chosen as a

reference element for the current experiment. Iron is renowned for its ability to remain stable in soil and for not moving vertically. Moreover, from an anthropogenic perspective, its concentration doesn't change. [16]. Determine the EF values using the equation that follows:

$$F = \frac{(Cm/C Fe)_{samples}}{(Cm/C Fe)_{background}}$$

The soil sample's concentrations of the heavy element are indicated by (Cm), the comparison soil's concentration of the heavy element by (Cm Background), the comparison soil's concentration of iron by (CFe Background), and the soil sample's overall concentration of iron by (CFe). Table 4 shows the levels of EF interpretation.

Table 4. Levels of interpretation of the enrichment factor.

Enrichment Factor	Levels
$EF \leq 1$	No enrichment
$1 < EF \leq 3$	Little enrichment
$3 < EF \leq 5$	Moderate enrichment
$5 < EF \leq 10$	Moderately intense enrichment
$10 < EF \leq 25$	Extreme enrichment
$25 < EF \leq 50$	Very intense enrichment
$EF > 50$	Extremely extreme enrichment

4. Results and Discussion

4.1. Concentration of Heavy metals in Soil

There are concerns over the levels of heavy metals in the environment and the consequences that these metals have on human health. The concentrations of the seven heavy metals that were taken into consideration in this study are presented in Table 5, together with their distribution in each of the lithofacies that were obtained from the area under investigation.

Table 5. Levels of heavy metals (HMs) in soil samples

Sample	S1	S2	S3	S4	S5	S6
HMs (ppm)						
Pb	0.00145	0.00139	0.00139	0.00145	0.00125	0.00130
Ni	0.000624	0.000623	0.000623	0.000624	0.000622	0.000622
Cd	0.0000212	0.0000109	0.0000261	0.0000171	0.0000256	0.0000171
Cr	0.0000427	0.0000244	0.000280	0.000137	0.000239	0.000127
Fe	0.000234	0.000609	0.0000268	0.000788	0.000276	0.000499
Zn	0.0000652	0.0000414	0.0000506	0.0000573	0.0000355	0.0000447
Cu	0.000621	0.000206	0.000183	0.000899	0.000296	0.000288

The average concentrations of heavy metals for all soil samples that were analyzed range from 0.0000109 to 0.00145 ppm, as shown in Table 2. High concentrations of heavy metals in soil are mostly caused by the massive release of heavy metals into the soil during oil exploration and production using solvents containing heavy metals.

Lead levels in S1 and S4 were the highest in the current study at 0.00145 ppm, while S5 had the lowest value at 0.00125 ppm. All samples had significantly lower lead levels, regardless of how close they were to oil fields, according to the data. A hazardous metal that has been thoroughly studied in the literature, lead (Pb) can have a variety of biological effects based on the length of exposure.

The limited presence of clay, organic matter, and calcium carbonate in these sediments is responsible for their ability to adsorb and capture lead and other heavy metals, therefore stabilizing them. Conversely, it is observed Due to the high proportion of sand in these samples, clay soil has a greater capacity to retain heavy metals compared to sandy soil [17]. The findings imply that all samples contain low levels of lead, falling between 50 to 300 mg.kg-1 permissible range established by the FAO and WHO.

One of the components of soil is nickel (Ni), which occurs naturally in amounts of no more than 50 mg.kg-1. The nickel levels in the current study ranged from

0.000622 ppm in S5 and S6 to 0.000624 ppm in S1 and S4, respectively. The results show that all samples are regarded as having a low concentration of Ni and falling within the acceptable limits in the soil, which are 30-75 mg.kg⁻¹ as per the WHO and FAO. The amount of cadmium (Cd) in soil samples was found to be low in S2 (0.0000109 ppm) and high in S5 (0.0000256 ppm) in this investigation.

Chromium (Cr), the levels of Cr in the current study ranged from (0.000280) ppm in S3, to (0.0000244) ppm in S2, respectively. The low levels of chromium in the soil are due to the speed and direction of the wind, it is responsible for transporting pollutants and the chromium that they contain from the source of contamination to more distant places, where they are then deposited on the surface of the soil in those areas. When it comes to the distribution of heavy metals in the atmosphere, the weather conditions play a significant impact, particularly the issue of wind direction [18]. From the results it appears that the chromium concentrations were less than the permissible limit of 1-5 mg.kg⁻¹ according to the WHO and the FAO.

Zinc (Zn) and iron (Fe) are important for plants, as well as for humans and animals that ingest plant-derived products. The shortages of Zinc and Iron represent significant dietary challenges as they can lead to serious deterioration of animal and human health. Most of the essential nutrients for animals and humans are obtained from plants, which get them from the soil. Plant produce typically contains modest levels of zinc (Zn) and iron (Fe). The reflectance indicates a limited presence of zinc and iron in the soil. In present study, Iron (Fe) low levels (0.0000268) S3, and high levels (0.000788)ppm in S4, while Zinc (Zn) low levels in 0.0000355 in S4, high levels (0.0000652)ppm in S1,), the findings show that all samples had modest concentrations of iron and zinc within the acceptable limits in the soil, which, according to the WHO and FAO, range from 150 to 300 mg.kg⁻¹ for zinc and 50 to 100 mg.kg⁻¹ for iron.

Copper (Cu), Soil copper accumulation resulting from human activities, including mining, industry, agriculture, and waste disposal. Although Cu is necessary, high quantities can cause phytotoxicity and hinder the action of soil organisms, resulting in a decrease in soil functioning. The current study's Cu levels ranged from 0.000183 ppm in S3 to 0.000899 ppm in S4, respectively. Based on the findings, all the samples are believed to have low copper concentrations and to fall within the FAO and WHO-established acceptable range of 50–140 mg.kg⁻¹ in soil. Based on

the findings, we deduced that the soil's heavy metal concentrations were as follows: The results showed that nickel was more abundant in the soil than other elements (Ni>Cu>Fe>Pb>Cr>Zn>Cd), while cadmium was least abundant. Nonetheless, the levels of heavy metals in the soil were below the WHO-permitted thresholds.

4.2. Concentration of Heavy metals in Water

Groundwater is vulnerable to contamination by leaching waste, untreated sewage, and industrial emissions that seep into the ground and reach water-bearing rock formations, or oil storage sites may pose a risk to groundwater if they sleep or spill and are not Use adequate measures at the spill site as these materials often seep into the soil, increasing the possibility of groundwater contamination[19]. The concentrations of Pb, Ni, Cd, Cr, Fe, Zn, and Cu that were employed in this investigation varied from 0.008 to 0.0168, 2.537 to 1.552, 0.00644-0.0125, 0.0101 to 0.0993, 0.0092 to 0.0197, 0.0203 to 0.0905, and 0.001-0.00259. In comparison to other heavy metals, nickel had the greatest value across all research regions (S1–S7), whereas copper had the lowest levels throughout such locations. The findings lead us to the conclusion that the water's heavy metal concentrations were as follows: The concentrations of all heavy metals were below the allowable limit for irrigation purposes (Ni>Zn >Cr>Fe >Pb >Cd>Cu).

Table 6. Concentration of heavy metals (HMs) in water samples.

Samples	S1	S2	S3	S4	S5	S6
HMs(ppm)						
Pb	0.0132	0.0160	0.0168	0.0160	0.0157	0.00804
Ni	1.554	1.556	1.552	1.554	2.537	1.552
Cd	0.00891	0.0125	0.00644	0.00973	0.00840	0.00716
Cr	0.0993	0.0709	0.0101	0.0980	0.0778	0.0881
Fe	0.0156	0.0176	0.0140	0.0197	0.00920	0.0125
Zn	0.0580	0.0905	0.0203	0.0332	0.0810	0.00469
Cu	0.00124	0.00144	0.00205	0.00100	0.00259	0.00224

*Levels of calcium (CaCO₃) and organic matter in soil and water samples.

Calcium carbonate (CaCO₃) is the most common carbonate mineral. It is the dominant form in soil, especially dry and semi-arid soils. One of the most significant variables influencing the physical, chemical, and biological characteristics of soil is the quantity and distribution of carbonates [20]. Carbonates, for instance, significantly affect stability, adsorption-desorption, and pH of soil. Due to their reactivity and alkaline character, carbonate minerals raise soil pH. The pH of soil that contains carbonates ranges from 7.1 to 8.5 [21, 22]. It also works to form the limestone horizon, which prevents the movement of water. From the results it is also noted that the calcium levels in S1, S4, S5, and S6 are much lower than those in S2 and S3. This is most likely because gypsum, which predominates in the solid section of the soil, is present in S2 and S3. The S2 and S3 soils are categorized as extremely calcareous, while the S1, S4, S5, and S6 soils are categorized as medium limestone.

Table 7. Levels of calcium (CaCO₃) and organic matter in soil and water samples.

Soil Samples	%CaCO ₃	%Organic materials (Soil samples)	%Soil moisture	%Organic materials (water samples)
S1	24	1.93	3.8	0.13
S2	30	1.58	5.86	0.12
S3	30.5	2.96	6.49	0.12
S4	27.5	2.75	8.84	0.11
S5	22	2.10	7.38	0.096
S6	21.5	2.69	5.08	0.093

The percentage of organic materials in the soil ranged from 1.58% to 2.96 percent, according to Table (7)'s results, whereas the percentage of organic materials in the water ranged from 0.093% to 0.13 percent. According to the study, there is a

discernible variation in the amount of organic matter in the soils in the areas under investigation. Overall, the dry climate causes a decrease in the amounts of organic matter in all soils. This decrease is explained by the areas' exposure to high temperatures and little rainfall, as well as the lack of organic matter and nutrients from outside sources. While an oversupply of organic matter can affect soil pH by lowering it, insufficient amounts of organic matter might worsen soil erosion processes.

4.3. Mechanical analysis of soil

According to the comprehensive categorization chart textures (US, 1976 and taxonomy keys to soil taxonomy, 1986 in Clement and Frances, 1998), the following is the conclusion that may be drawn. There is a distinction that may be made between soil samples that are divided into three categories:

- Class clay loam soil: for sample S2, S3, and S5 soil.
- Class of loam Soil for sample S1 and S4 soil.
- Class sandy loam soil: for sample S6 soil.

Table 8. Results of mechanical analysis of soil separations in the study area.

			Soil moisture %
S1	Sand	34.05	Loam
	Clay	25.95	
	Silt	40	
S2	Sand	44.05	Clay loam
	Clay	35.95	
	Silt	20	
S3	Sand	41.55	Clay loam
	Clay	28.45	
	Silt	30	
S4	Sand	29.05	Silty loam
	Clay	18.45	
	Silt	52.5	
S5	Sand	36.55	Clay loam
	Clay	30.95	
	Silt	32.5	

S6	Sand	61.55	Sandy loam
	Clay	10.95	
	Silt	27.5	

Soils at sites A, B, C, and D consist of loamy sand, sand, loam, and clay loam, respectively. Variability in soil composition significantly influences the concentration of pollutants obtained from the polluted soil. Further investigation revealed that the effectiveness of remediation was contingent upon the soil type, with significantly greater efficacy shown in sand compared to clay soil. This disparity can be elucidated by the less compact arrangement of soil particles in sandy soil and the greater adhesiveness and malleability of clay cement. A clay soil is a type of malleable soil mostly composed of hydrous silicate of aluminum. Microscopically, clay consists of minute particles [23].

The wide surface area and chemical and mechanical stability of the clay component, which is primarily composed of clay minerals, give it a high absorption capacity and a strong ability to absorb mineral elements. In contrast, sandy soils have a smaller absorption volume and capacity, but clay soils have a higher capacity to absorb contaminants.

Larger holes cause it to absorb heavy metals poorly, which causes them to migrate into surface and groundwater. As demonstrated by the mechanical analysis results, the percentage of classified soil (sand, clay, and silt) varied. The percentage of sand ranged from 29.05 to 61.55 gm kg⁻¹, the percentage of clay ranged from 10.95 to 35.95 gm kg⁻¹, and the percentage of silt ranged from 20 to 52.5 gm kg⁻¹. It is evident from these results that the sand separator outperforms the other soil separators.

4.4. Physicochemical analysis

The physicochemical parameters measured in this study are displayed in Table 9. That pH can affect the solubility and mobility of heavy metals in soil. The ability of soil to stabilize heavy metals increases with an increase of pH, in this study the examination of soil samples indicated that the pH levels at various sites ranged from (6.6 to 8.1). The pH level of soil can reveal whether heavy metals or chemicals are present. It is evident that the study area's soil had a neutral to slightly

basic degree of reactivity. Iraq's soil is calcareous, and the presence of carbonates has a significant impact on the degree of soil reactivity. Therefore, the high degree of soil reactivity can be attributed to the climate and parent material rich in calcium carbonate. A carbonate soil's pH is more than 7.

Table 9. Physiochemical Parameters of soil samples.

Physiochemical Parameters of soils samples									
Samples	pH	EC ($\mu\text{c}/\text{cm}$)	SO_4^{-2}	NO_3^-	PO_4^{-3}	Ca^{+2}	Mg^{+2}	Na^{+1}	K^{+1}
S1	7.4	6.30	0.066	48.50	41.1	0.032	0.017	43	588
S2	7.9	2.00	0.045	25.05	12	0.0072	0.026	27	280
S3	8.1	2.40	0.05	3.30	13.89	0.010	0.027	25	520
S4	7.8	4.20	0.062	03.57	6.78	0.026	0.029	31	692
S5	7.8	3.20	0.044	06.60	9.63	0.0052	0.029	29	336
S6	6.6	15.10	0.057	84.76	24.48	0.034	0.031	25	176

The electrical conductivity (EC) values in the current investigation ranged from 2.00 to 15.10 $\mu\text{c}/\text{cm}$, per Shrivastava and Kumar (2015) [24]. These findings unequivocally demonstrate that most of the soils had normal salinity (less than 4 $\mu\text{c}/\text{cm}$), with S6 and S1 having higher EC values above 4 $\mu\text{c}/\text{cm}$. These soils are consequently categorized as saline soils for a variety of reasons, chief among them being the weathering of salt rocks, little rainfall, high surface evaporation, and pollution from petroleum waste [25], which accounts for its rise in these two areas. Regarding anions: Regarding anions, we observe that primary nitrites, with values ranging from 6.6 to 84.76 ppm, predominate at all locations, followed by phosphates, with levels ranging from 6.78 to 41.1 ppm.

As against the dominance of PO_4^{-3} to S1 with concentration 41.1 ppm, and sulfates are third with levels 0.045-0.066 ppm. For soluble cations: Regarding the contents of soluble cations ($\text{Ca}^{=2}$, $\text{Mg}^{=2}$, Na^+ , and K^+), we note that there is a predominance of K^+ in the soil of all studied areas, ranging from (176 to 588) ppm, with a very large difference from the rest of the cations, followed by Na, Mg, and then Ca at the lowest levels.

Potassium (K^+) values in the soil of the study area ranged between (176-588) ppm. There is a variation in potassium values for some sites, and it is generally observed

that potassium values rise due to the dry climate conditions and the increase in chemical weathering processes that release potassium and make it available to plants, by converting potassium from an unavailable mineral form to available forms that plants can benefit from. From her. In addition, feldspar and mica are resistant to weathering, as they release large amounts of available potassium. This explains the high potassium values in the soil of the study area.

Sodium (Na⁺) is the only essential cation that is not considered essential for plant growth. In the current study, Na⁺ levels were high at a rate of S1 and the reason for the high sodium level in some locations, especially in sample S1, which recorded the highest value, followed by S5, is due to high temperatures and the use of contamination salty water, which contains a high percentage of sodium salts, over time leads to salinity in both the surface and subsurface layers due to the high sodium content in those soils, in addition to natural weathering. For rocks or parent material that are considered one of the main sources of sodic soils. Compared to calcium and magnesium, which recorded the lowest levels in the soil (0.0052-0.035) ppm and (0.017- 0.031) ppm respectively, in the current study the reason for this is that calcium and magnesium are essential plant nutrients that are easily absorbed by the plant.

Table 10. Physicochemical parameters of water samples.

Name sample	pH	T.D.S ppm	Turbidity	Ca ²⁺ ppm	Mg ²⁺ ppm	Na ppm	K ppm
S1	8.9	208	3.19	70	44	6	5
S2	7.7	407	0.00	100	66.4	23	3
S3	8.3	600	1.08	130	72	28	4
S4	7.5	861	0.83	200	86	32	6
S5	8.8	402	0.00	70	66.7	24	3
S6	7.2	747	0.30	150	87	45	10

The examination of water samples indicated that the pH levels at various sites ranged from 7.2 to 8.8. The pH level of water can indicate the presence of chemical or heavy metal contamination [26]. This variation can be related to changes in the levels of inorganic and organic contaminants. The pH values of sites (8.9) S1 and (8.8) S5 were higher than the permissible limits (6.5-8.5) set by the WHO in 2011

[27]. Certainly, the soil in the studied area exhibited a neutral to rather basic level of reactivity. The significant level of soil reaction can be attributed to the climatic circumstances and the calcium carbonate-rich source material during soil formation. The content of carbonates significantly influences the extent of soil reactivity, since carbonated soil is distinguished by a high pH level. Exceeding 7. Elevated pH levels in the water definitively indicate contamination and render it unsuitable for drinking.

Total dissolved solids (TDS) in the water samples ranged from 208 mg/L (S1) to 861 mg/L (S4). The results in the study are within the permitted levels set by the World Health Organization in 2011. Turbidity refers to the state of suspended solids in water, encompassing various substances such as waste materials, sewage, and plankton [28]. In this study, the highest value of 3.19 NTU was recorded at S1, while the lowest value of 0.0 NTU was recorded at S2 and S5. All the readings did not exceed the acceptable limit the WHO set. The elevated turbidity levels noted in the current analysis may be attributed to the presence of sediments and sewage loads originating from the adjacent regions [29]. The elevated turbidity levels render the water unfit for consumption, bathing, and the optimal survival of aquatic organisms; the results obtained in this study agree with other study reported by Roy et al [30].

The amount of calcium (Ca) and magnesium (Mg) in the water is used to measure its hardness [31]. The World Health Organization (WHO) stated in 2011 that water should not include more than 500 mg/L of calcium (Ca) or magnesium (Mg). The Ca and Mg concentrations were found to be below the suggested levels. Additionally, Kaur et al. (2021) [32] reported that the calcium and magnesium levels in their investigation fell within permissible bounds.

4.5. Evaluate TPH concentrations of soil samples

Total petroleum hydrocarbon (TPH) concentrations in the soils under study ranged from 0.5 to 93.59 mg.kg⁻¹, according to the data in Table (11) and Figure (2). We also observe that there is a significant and distinct spatial variation in TPH concentrations in the soils within the research area. The highest concentrations appeared in the soil of sample S5 adjacent to the oil fields in the samples close to the oil wells and S4, which are under the influence of liquid waste released by those oil wells, where the concentration of TPH in these two locations reached

(93.59 and 47.49) mg.kg⁻¹, respectively. The accidental spills that occur near these oil wells cause organic pollution to those sites because of transportation operations and poor storage, as the origin of the high concentration of TPH in the soil is heavy petroleum compounds or heavy oil resulting from oil exploration activities, ruptured pipelines, and refinery waste, as indicated in Figure 2 below. This is strong evidence of groundwater contamination by hydrocarbon leaks in the studied areas. The high levels observed in these two locations in the study area are comparable to those found by Al-Halfy et al., (2021) in the soils inside the Rumaila oil field, which amounted to (500, 530, 47490, 590, 93750) mg.kg⁻¹ of Total content of petroleum hydrocarbons in the five different sites [33]. It falls within the range of 110 to 194058 mg.kg⁻¹ of TPH found by Pinedo et al. (2013) in sixty-two soil samples throughout the Netherlands [34]. Much higher levels of TPH in the range of 43,500 to 83,800 mg.kg⁻¹ have been reported in soils contaminated with crude oil in Indonesia [35].

Table 11. Evaluate TPH concentrations of soil samples using (GC-FID) analysis.

Sample No.	Weight (gm)	TPH (mg/g)
S1	80.12	12.77
S2	80.08	0.53
S3	80	0.5
S4	80.05	47.49
S5	80.11	93.59
S6	80.14	0.59

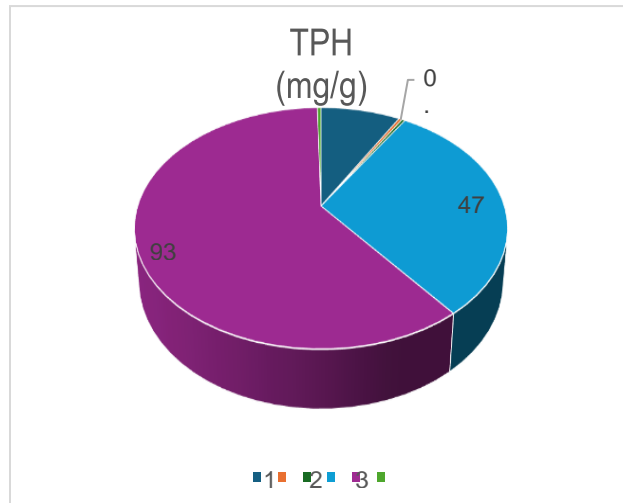


Figure (2). Total hydrocarbon concentrations in the study area.

Table 12. Contamination factors for soil.

Soil Contamination Factors (Igeo), (EF), (CF)			
Sample soil	Igeo	CF	EF
<u>Zn²⁺</u>	4.82	0.162	0.059
<u>Pb²⁺</u>	3.98	1.14	0.42
<u>Cd²⁺</u>	-3.17	0.88	0.32
<u>Cu</u>	7.39	3.89	1.49
<u>Ni²⁺</u>	5.23	1.96	0.715
<u>Fe²⁺</u>	15.52	3.02	1.00

Table (12) presents the estimated geo-accumulation index for the six heavy metals for which background concentration values are known. The heavy metals' geo-accumulation index showed a wide range of contamination levels, from moderately-strongly polluted too severely polluted. The pollution of Zn recorded (4.82) which means strongly-extremely polluted. The Igeo value of Pb recorded (3.98); for Cd it recorded (-3.17); for Cu, it recorded (7.39); for Ni, it was recorded (5.23), and Fe recorded (15.52). Computed Igeo values indicate that Fe, Cu, and Ni will have more significant impacts compared to Cd, Pb, and Zn. The elevated degree of iron in this area could be attributed to the upward movement of submerged sediment deposits at shallow depths. Insufficient implementation of preventive measures before drilling hydrocarbon wells will result in contamination of the soils in the environment by subsurface soil samples obtained during drilling operations. Determined the contamination factor. Figure 9 displays the calculated

results for each of the lithofacies that are being studied. Four major categories can be used to classify estimated contamination factors: low contamination factors are represented by $CF < 1$, moderate contamination factors are represented by $1 \leq CF < 3$, considerable contamination factors are represented by $3 \leq CF < 6$, and very high contamination factors are represented by $CF \geq 6$. When compared to the baseline examination carried out in the same location, the Cu and Fe contamination factors are much higher, measuring 3.89 and 3.02, respectively.

The heavy metal contamination of the lithofacies declined as follows: Cu > Fe > Ni > Pb > Cd > Zn. The calculated coefficient of freedom (CF) indicates that the field environment will be moderately contaminated with Pb, Cd, and Zn, and severely contaminated with Cu, Fe, and Ni. As shown in Table 12, the enrichment factor was determined by measuring the concentrations of heavy metals in six soil sections near the oil fields in the research area.

According to the results, the average EF values for heavy metal pollution increase in the following order, with EF values varying depending on the kind of soil in the study area: Zn > Cd > Pb > Ni > Fe > Cu. The heavy metals zinc, cadmium, lead, nickel, and iron are in the no concern zone since their enrichment factor values were less than or equal to 1 ($EF < 1$), while only copper is in the mild enrichment range ($1 > EF \leq 3$), as shown in Table (12). If the EF value is more than one, the heavy elements are often primarily derived from natural sources when the EF value is near or less than one.

5. Conclusion

The current study results indicated contamination of the soil and water of the areas adjacent to the Ain Zala fields in Mosul Governorate with heavy metals due to oil leaks from wells. Conducting more studies to find solutions and ways to prevent these metals that affect environmental components is preferable.

References

- [1] Vasiliu B-C, Trufanda S-A, Teodorescu C, Teslaru S, Sioustis I-A, Luchian I, et al. CORRELATIONS BETWEEN SALIVARY CORTISOL LEVELS AND PERIODONTAL DISEASE. REVIEW. Romanian Journal of Medical and Dental Education. 2021;10(2).

- [2] Ghorbani MR, Ghanavati N, Babaenejad T, Nazarpour A, Payandeh K. Assessment of the potential ecological and human health risks of heavy metals in Ahvaz oil field, Iran. PLoS One. 2020;15(11):e0242703.
- [3] Hosseini K, Taghavi L, Ghasemi S, Dehghani Ghanatghestani M. Health risk assessment of total petroleum hydrocarbons and heavy metals in groundwater and soils in petrochemical pipelines. International Journal of Environmental Science and Technology. 2023;20(2):1411-20.
- [4] Jahandari A, Abbasnejad B. Environmental pollution status and health risk assessment of selective heavy metal (oid) s in Iran's agricultural soils: A review. Journal of Geochemical Exploration. 2023:107330.
- [5] Mahvi A, Eslami F, Baghani A, Khanjani N, Yaghmaeian K, Mansoorian H. Heavy metal pollution status in soil for different land activities by contamination indices and ecological risk assessment. International Journal of Environmental Science and Technology. 2022;19(8):7599-616.
- [6] Boateng TK, Opoku F, Acquah SO, Akoto O. Pollution evaluation, sources and risk assessment of heavy metals in hand-dug wells from Ejisu-Juaben Municipality, Ghana. Environmental systems research. 2015;4:1-12.
- [7] Rastmanesh F, Shalhaf F, Moradi R, Prinzhofer A. Health risk assessment of heavy metals in Ahvaz oilfield using environmental indicators. International Journal of Environmental Science and Technology. 2020;17(12):4669-78.
- [8] Kinuthia GK, Ngure V, Beti D, Lugalia R, Wangila A, Kamau L. Levels of heavy metals in wastewater and soil samples from open drainage channels in Nairobi, Kenya: community health implication. Scientific reports. 2020;10(1):8434.
- [9] Akhtar N, Syakir M, Rai S, Saini R, Pant N, Anees M, et al. Multivariate investigation of heavy metals in the groundwater for irrigation and drinking in Garautha Tehsil, Jhansi District, India. Analytical Letters. 2020;53(5):774-94.
- [10] Kaur H, Katyal P, Chandel S. Assessment of water quality using different physicochemical and biological parameters: a case study of Buddha nallah, Punjab, India. Environment Conservation Journal. 2022;23(3):145-59.
- [11] Täumer K, Stoffregen H, Wessolek G. Determination of repellency distribution using soil organic matter and water content. Geoderma. 2005;125(1-2):107-15.

- [12] Canakci H, Sidik W, Kilic IH. Effect of bacterial calcium carbonate precipitation on compressibility and shear strength of organic soil. *Soils and Foundations*. 2015;55(5):1211-21.
- [13] Tudararo-Aherobo L, Odeniyi K. Assessment of Hydrocarbon and Microbial Contamination of Groundwater Facilities Located Around Selected Petroleum Product Tank Farms in Delta State.
- [14] Okoro EE, Okolie AG, Sanni SE, Omeje M. Toxicology of heavy metals to subsurface lithofacies and drillers during drilling of hydrocarbon wells. *Scientific reports*. 2020;10(1):6152.
- [15] Tian K, Huang B, Xing Z, Hu W. Geochemical baseline establishment and ecological risk evaluation of heavy metals in greenhouse soils from Dongtai, China. *Ecological indicators*. 2017;72:510-20.
- [16] Abdullah MIC, Sah ASRM, Haris H. Geoaccumulation index and enrichment factor of arsenic in surface sediment of Bukit Merah Reservoir, Malaysia. *Tropical Life Sciences Research*. 2020;31(3):109.
- [17] Piķula D, Stępień W. Effect of the degree of soil contamination with heavy metals on their mobility in the soil profile in a microplot experiment. *Agronomy*. 2021;11(5):878.
- [18] Shahid M, Shamsad S, Rafiq M, Khalid S, Bibi I, Niazi NK, et al. Chromium speciation, bioavailability, uptake, toxicity and detoxification in soil-plant system: A review. *Chemosphere*. 2017;178:513-33.
- [19] Ochiba NK. Assessment Of Levels Of Selected Heavy Metals In Borehole Water In Ongata Rongai, Kajiado County, Kenya: University Of Nairobi; 2020.
- [20] Miftah A, Tirkolaei HK, Bilsel H, editors. Bio-precipitation of CaCO₃ for soil improvement: A Review. IOP Conference Series: Materials Science and Engineering; 2020: IOP Publishing.
- [21] Niaz A, Ranjha A, Rahmatullah AH, Waqas M. Boron status of soils as affected by different soil characteristics–pH, CaCO₃, organic matter and clay contents. *Pakistan Journal of Agricultural Sciences*. 2007;44(3):428-35.
- [22] Umer MI, Rajab SM, Ismail HK, editors. Effect of CaCO₃ form on soil inherent quality properties of calcareous soils. *Materials Science Forum*; 2020: Trans Tech Publ.
- [23] Abdel-Moghny T, Mohamed RS, El-Sayed E, Mohammed Aly S, Snousy MG. Effect of Soil Texture on Remediation of Hydrocarbons □ Contaminated

- Soil at El-Minia District, Upper Egypt. International Scholarly Research Notices. 2012;2012(1):406598.
- [24] Shrivastava P, Kumar R. Soil salinity: A serious environmental issue and plant growth promoting bacteria as one of the tools for its alleviation. Saudi journal of biological sciences. 2015;22(2):123-31.
- [25] Hussain B, Ashraf MN, Abbas A, Li J, Farooq M. Cadmium stress in paddy fields: effects of soil conditions and remediation strategies. Science of The Total Environment. 2021;754:142188.
- [26] Liu Y, Sakthivel T, Hu F, Tian Y, Wu D, Ang EH, et al. Enhancing the d/p band center proximity with amorphous-crystalline interface coupling for boosted pH-robust water electrolysis. Advanced Energy Materials. 2023;13(11):2203797.
- [27] World Health Organization. Safe Drinking-Water from Desalination: Guidance on Risk Assessment and Risk Management Procedures to Ensure the Safety of Desalinated Drinking-Water. 1 Mar. 2011, <https://www.who.int/publications/i/item/WHO-HSE-WSH-11.03>. Accessed 2 Apr. 2025.
- [28] Xu M, Zhou W, Zhu Z, Peng C, Peng Y. Study on the preparation of polysilicate ferric flocculant and its treatment of high turbidity tailings water. Journal of Water Process Engineering. 2021;44:102457.
- [29] Gupta N, Pandey P, Hussain J. Effect of physicochemical and biological parameters on the quality of river water of Narmada, Madhya Pradesh, India. Water Science. 2017;31(1):11-23.
- [30] Roy M, Shamim F, Chatterjee S. Evaluation of physicochemical and Biological parameters on the water quality of ShilabatiRiver, West Bengal, India. Water Science. 2021;35(1):71-81.
- [31] Egbueri JC. A multi-model study for understanding the contamination mechanisms, toxicity and health risks of hardness, sulfate, and nitrate in natural water resources. Environmental Science and Pollution Research. 2023;30(22):61626-58.
- [32] Kaur J, Kaur V, Pakade YB, Katnoria JK. A study on water quality monitoring of Buddha Nullah, Ludhiana, Punjab (India). Environmental Geochemistry and Health. 2021;43:2699-722.

- [33] Al-Halfy AA, Qurnawi W, Al-Hawash AB. Evaluation of Oil Spills in Sandy Soil of Rumaila Oil Field Area in Basra, Southern Iraq. Marsh Buofetin. 2021;16(1):47-66.
- [34] Pinedo J, Ibáñez R, Lijzen J, Irabien A. Assessment of soil pollution based on total petroleum hydrocarbons and individual oil substances. Journal of environmental management. 2013;130:72-9.
- [35] Sari GL, Trihadiningrum Y. Bioremediation of petroleum hydrocarbons in crude oil contaminated soil from wonocolo public oilfields using aerobic composting with yard waste and rumen residue amendments. Journal of Sustainable Development of Energy, Water and Environment Systems. 2019;7(3):482-92.