Assessment of Environmental Pollution by Certain Heavy Metals in the Soil of the Northern Refineries Company and Some Adjacent Soils

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Abstract

This study was conducted to assess soil contamination with heavy metals in the Baiji district of Salah al-Din Governorate. The study involved collecting 14 surface soil samples at a depth of 0 –20 cm from inside and outside the Baiji oil refinery and neighboring areas. Some chemical properties of the study soil, especially texture, as well as chemical properties, were determined, and the total content of heavy metals was measured using an atomic absorption spectrometer (AAS). Environmental pollution indices, including the pollution factor and enrichment factor, were also calculated to assess the severity of contamination. The most important findings can be summarized as follows Total nickel exceeded the permissible limit of 50 mg kg^{-1} at all sites, with concentrations of 166.96 – 92.20 mg kg^{-1} Total cadmium also recorded localized exceedances of the 3 mg/kg limit, with values reaching 5.16 mg/kg. In contrast, total concentrations of lead, copper, and cobalt remained within standard limits, indicating that nickel and cadmium are the primary pollutants associated with petroleum activities in the study area. Regarding the pollution factor index, the average values of heavy metals across all sites were as follows: lead, cadmium, nickel, cobalt, and copper had values of 1.5087, 4.7517, 3.9104, 0.8051, and 3.8887mg kg^{-1}, respectively. As for the enrichment factor index, the values of the elements in the same order were: 1.3757, 4.3435, 3.6607, 0.6909, and 3.5819, mg kg^{-1} respectively. The results regarding pollution criteria indicate that nickel and cadmium represent the elements with the highest cumulative risk.

Keywords: Environmental pollution, Baiji North soil refineries, assessment

Introduction

Soil is an essential natural resource for food production and maintaining ecological balance; however, it is subject to increasing pollution as a result of industrial and petroleum activities, particularly from crude oil and heavy metals. The Baiji district is one of the most affected areas in Iraq due to oil refining activities and the destruction it has suffered in recent years.

A study by [1] a significant increase in contaminant levels in the soil of the Baiji refinery, particularly emphasizing the need for remediation. The soil in the region is also a major environment for the accumulation of petroleum pollutants and heavy metals resulting from industrial processes and explosions, which negatively affects its fertility and threatens the health of living organisms. Heavy metals are among the most dangerous pollutants because they accumulate in the soil and move through the

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food chain. Previous studies by [2] have shown high concentrations of lead, cadmium, and chromium in the soil of Baiji, A study [16] confirmed the same findings, while a study by [14] examined the distribution of heavy metals in Beiji using GIS techniques, revealing high levels of contamination near the refinery and identifying hotspots requiring remediation. The study by [18] aimed to evaluate the use of treated industrial water from the Beiji refineries for agricultural irrigation. The results showed that most heavy metal concentrations were within permissible limits, though some elevated values required further treatment, and the study recommended the use of advanced filtration techniques to ensure safety. Given these deteriorating environmental conditions, there is a need to assess the extent of pollution and protect nearby water resources from contamination. Therefore, this study aimed to evaluate the level of heavy metal contamination (Pb, Ni, Cd, Co, Cu) in selected soils associated with the Beiji refinery.

Material and Methods

2-1 Study Area

The Beiji district is located in Salah al-Din Governorate in northern Iraq between (35°00′–35°20′ N) and (43°20′–43°40′ E). It is considered one of the most important industrial areas because it contains the Baiji refinery, with a capacity of approximately 290,000 barrels per day, making it an environmentally sensitive area prone to industrial pollution [3].

2-2 Sample Collection.

Fourteen (15) samples were collected from the locations indicated in the diagram, both inside and outside the refinery What is the distance between samples was one meter. The samples included five (5) samples from inside the Northern Refineries Company, five (5) soil samples from outside the company near the industrial wastewater drainage canal, and four (4) samples from adjacent lands. This was done to determine the accumulation and compare pollution levels between inside the company and the adjacent lands. Surface samples were collected at a depth of (0–20 cm) in plastic bags and transported directly to the laboratory for analysis.

2-3 Laboratory Analysis.

3-3-1: Chemical and Physical Properties of the Study Soil

The samples were air-dried at room temperature, then root residues, plant debris, and gravel were removed; they were gently ground and sieved using a sieve with a mesh size of 2 mm. Chemical and physical analyses were conducted, and the results are shown in Table 1. Soil fractions were estimated using the Hydrometer method according to[12] and Electrical conductivity (EC) and pH of the soil extract (1:1) were measured according to [21].The organic matter content was estimated using the method of[15], while the cation exchange capacity (CEC) was estimated using the sodium saturation method according to[20].The gypsum content was estimated using the acetone precipitation method according to[21], and calcium carbonate according to [10].

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Table 1. Some physicochemical properties of the study soil

Soil Texture Class	Soil particle size gm kg^{-1} Clay	Silt	Sand	EC ds m^{-1}	pH	$CaCO_3$ g kg^{-1}	$CaSO_4.2H_2O$ kg^{-1}	Organic matter g kg^{-1}	CEC cmol kg^{-1}	Sample
L	124.10	448.60	427.30	1.69	7.60	203	60.01	41.23	20.88	S11
SL	106.40	293.80	600.01	1.82	7.57	260	82.13	32.16	22.19	S12
SL	176.80	240.02	583.30	1.98	7.30	281	102	37.10	24.06	S13
SL	181.00	364.08	364.07	2.74	7.25	292	90.1	10.07	15.77	S14
L	151.00	402.00	448.00	2.77	7.22	197	37.4	8.04	13.81	S15
L	220.66	418.59	360.75	3.35	7.02	172	28.3	7.34	11.72	S21
SCL	240.05	272.10	488.08	3.17	7.11	181	22.4	11.22	10.84	S22
CL	280.02	386.04	396.00	3.22	7.12	162	61.02	10.03	10.61	S23
L	151.00	300.02	450.03	3.12	7.10	105	75.3	9.41	12.13	S24
CL	281.00	325.00	397.00	3.24	7.11	271	62.14	6.71	12.41	S25
CL	335.44	342.05	225.22	4.48	6.98	202	113.7	5.31	16.43	S31
CL	334.30	341.33	228.49	4.32	6.92	112	121.8	6.42	17.24	S32
SL	100.30	751.00	148.00	5.16	6.65	121	150.2	21.10	19.13	S33
CL	281.05	387.00	396.00	4.63	6.75	261	161.4	19.03	18.43	S34

2-4 Calculation of Environmental Pollution Indices.

2-4-1 Contamination Factor (CF) According to [13], the contamination factor is defined as the ratio of the concentration of the element of interest in the soil under study to its concentration in the reference soil unaffected by human activities. It can be calculated using the following equation:

CF = Cm sample / Cm background Where:

- **Cm (sample)**: The concentration of the element in the soil under study, in units of mg/kg or ppm.
- **(Background concentration)**: The concentration of the same element in natural soil, representing background values prior to contamination.

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Table 2. Classification of Contamination Factor (CF) values according to [13]

Level of Contamination	Contamination Factor (CF)
Low contamination	Cf<1
Moderate contamination	1 ≤ Cf<3
Considerable contamination	3 ≤ Cf<6
Very high contamination	Cf>6

2-4-2 Enrichment Factor (EF)

According to [17], the enrichment factor (EF) is used to assess the extent of accumulation of a specific element in the soil compared to a stable reference element, such as iron, and is calculated using the following equation:

$$EF = (Cm\_(sample)/CFe^{(++)}\_(sample)) / (Cm/CFe^{++}\_(background))$$

Where: Cm sample): the concentration of the element under study in the soil.

CFe_ (sample): concentration of iron in the soil.

Cm_(background): concentration of the same element in the reference soil.

CFe_(background): concentration of iron in the reference soil.

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Table 3. Classification of Enrichment Factors (EF) according to [17]

Enrichment Level	Enrichment Factor
Minor or Minimal Enrichment	EF<2
Moderate Enrichment	2 ≤ EF<5
Moderately Severe Enrichment	5 ≤ EF<10
Severe Enrichment	10 ≤ EF<25
Very Severe Enrichment	25 ≤ EF<50
Extremely Severe Enrichment	EF>50

Results and Discussion

3-1 Assessment of Total Concentrations of Heavy Metals in Soils of the Study Area

The results of total heavy metal concentrations in the study area's soil, shown in Table 4, revealed a clear variation in pollution levels when compared to the standard limits adopted by the World Health [24] and shown in Table 5. Nickel (Ni) recorded the highest pollution levels, as its concentrations at all study sites exceeded the maximum permissible limit for soil of 50 mg kg^{-1}, with values ranging from 92.2 to 166.96 mg/kg. This elevation is attributed to the natural association of nickel with crude oil and refining residues, i

n addition to emissions from combustion and fuel leaks, which is consistent with what [5] noted in his study on the Beji refinery, where petroleum activities were identified as the primary source of nickel accumulation in the soils surrounding the refineries.

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1. **Table 4. shows the total concentration of heavy metals at the sampling sites in milligrams per kilogram mgkg^{-1}**

Maximum permissible limit mgkg^{-1}	Chemical element	T
85	(Pb) Lead	1
50	(Ni) Nickel	2
3	(Cd) Cadmium	3
50	(Co) Cobalt	4
100	(Cu) Copper	5

Table (5) Maximum permissible limits for heavy metal concentrations in soil According to the World Health Organization mg kg^{-1} [24]

Cu mg kg^{-1}	Co mg kg^{-1}	Cd mgkg^{-1}	Ni kg^{-1}	mgPb mg kg^{-1}	Sample Code
22.7	13.76	3.6	98.46	10.25	S_1
24.78	14.07	2.78	144.45	12.72	S_2
42.87	13.05	0.8	151.3	13.37	S_3
38.57	7.77	0.27	148.67	29.43	S_4
37.41	10.55	1.48	115.58	18.74	S_5
34.11	11.77	4.46	148.94	13.7	S_{21}
38.27	10.03	5.16	165.8	14.32	S_{22}
35.07	10.21	4.37	166.96	22.25	S_{23}
30.86	3.01	3.53	156.34	16.31	S_{24}
29.04	0.94	4.68	93.14	10.27	S_{25}
27.16	0.82	0.34	92.2	9.03	S_{12}
27.18	0.83	0.24	113.42	12.41	S_{13}
41.03	7.21	0.32	130.11	12.3	S_{14}
19.55	12.76	0.27	122.67	16.33	S_{15}

Cadmium (Cd) showed moderate to localized contamination, with some locations within the refinery exceeding the permissible limit of 3 mg/kg, while others remained within safe limits. This behavior is attributed to cadmium's high mobility and its tendency to accumulate as a result of industrial emissions, which is consistent with the findings of [25] and [8], who confirmed that cadmium is one of the elements most affected by oil-related industrial activities compared to other heavy metals. In contrast,

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for copper (Cu), concentrations were recorded within globally accepted limits. It's relatively low levels are attributed to the fact that it is a basic element that tends to bind to organic matter and clay minerals in the soil, thereby reducing its free accumulation, in addition to the fact that their sources in the region are mostly naturalwith limited human contributions, as explained by[21] Lead (Pb) and cobalt (Co)

recorded relatively low concentrations compared to standard limits, all falling within the normal range for uncontaminated soils. The low lead levels are attributed to the limited direct industrial sources in the region during the current period, in addition to its tendency to bind strongly to fine soil particles, while the low cobalt levels are due to its geological nature and the fact that it is an associated element of primary minerals without direct industrial sources to elevate it, as noted by [25].

3-2 Contamination Factor

The results of the contamination factor shown in Table 6 for soil elements in the study area indicate a clear variation among the elements, with lead (Pb) recording low to moderate contamination levels (0.90–2.94) Table 2, while nickel (Ni) showed high contamination in all samples (3.32–6.01) with one very high case, indicating a clear industrial impact.

Table 6. Pollution factor values for soil samples from the study area for all heavy metals

Sample locations	Cu_CF	Co_CF	Cd_CF	Ni_CF	Pb_CF	Sample
Outside the company near the drainage channel	2.7549	1.3282	6.1017	3.5443	1.024	S_1
	3.0073	1.3581	4.7119	5.1998	1.2707	S_2
	5.2027	1.2597	1.3559	5.4464	1.3357	S_3
	4.6808	0.75	0.4576	5.3517	2.9401	S_4
	4.54	1.0183	2.5085	4.1605	1.8721	S_5
Inside the company near the fuel tanks	4.1396	1.1361	7.5593	5.3614	1.3686	S_{21}
	4.6444	0.9681	8.7458	5.9683	1.4306	S_{22}
	4.2561	0.9855	7.4068	6.0101	2.2228	S_{23}
	3.7451	0.2905	5.9831	5.6278	1.6294	S_{24}
	3.5243	0.0907	7.9322	3.3528	1.026	S_{25}
Neighboring areas near the village of Al-Bu Jawari	3.2961	0.0792	0.5763	3.3189	0.9021	S_{12}
	3.2985	0.0801	0.4068	4.0828	1.2398	S_{13}
	4.9794	0.6959	0.5424	4.6836	1.2288	S_{14}
	2.3726	1.2317	0.4576	4.4158	1.6314	S_{15}

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As a study by [22] on the soil and sediments of the Karamian area showed, lead concentrations were lower than those of some other elements, such as nickel, and were mostly classified as low to moderate contamination. Cadmium (Cd), however, was the most concerning, with values ranging from very low to very high (0.40–8.74), and particularly high values recorded within the company near fuel tanks, indicating a direct industrial source. [23] in India noted that cadmium is one of the few elements that accumulates naturally in soil, and that elevated concentrations are directly linked to human activities, particularly the mining industry and the combustion of fossil fuels. Furthermore, [11] in Maysan Governorate that cadmium concentrations in agricultural soils near industrial areas exceeded permissible global limits, making cadmium a prominent indicator of industrial pollution. In contrast, cobalt (Co) recorded low to moderate levels (0.079–1.358), indicating that it is the least impactful element. [11] found in Maysan Governorate that cobalt remained one of the least hazardous elements, while copper (Cu) showed moderate to high contamination (2.37–5.20) in all samples, confirming its susceptibility to the impact of oil activities. [6] notes that copper is one of the elements whose concentrations typically rise in environments near oil refineries and industrial sources as a result of gaseous emissions and industrial dust

deposits. The elements can be ranked by pollution severity as follows: Cd > Ni > Cu > Pb > Co, indicating that cadmium and

nickel are the primary pollutants in the studied soil.

3-3 Enrichment Factor

The enrichment factor (EF) results for soil elements in the study area, shown in Table 7, revealed a clear variation in the levels of impact from industrial activities, with lead (Pb) showing slight to moderate enrichment (0.78–2.55) (Table 3), with values decreasing with distance from pollution sources. Nickel (Ni), on the other hand, showed moderate to moderate–severe enrichment (2.99–7.01), with the highest values within the company near the fuel tanks, indicating a direct industrial impact. These results are consistent with the findings of a study) [14], which showed that nickel in Beiji soil mostly ranges from moderate to significant enrichment. These results also agree with those reported by [7], where high nickel levels were recorded as a result of industrial and human impacts.

Table 7. Enrichment factor values for soil samples from the study area for all heavy metals.

Sample locations	Cu_EF	Co_EF	Cd_EF	Ni_EF	Pb_EF	Sample
Outside the company near the drainage channel	3.4205	1.6491	7.576	4.4006	1.2714	S_1
	2.3986	1.0832	3.7581	4.1473	1.0135	S_2
	4.3123	1.0441	1.1239	4.5143	1.1071	S_3
	4.0755	0.653	0.3984	4.6596	2.5599	S_4
	4.2585	0.9552	2.3529	3.9026	1.756	S_5
Inside the company near	3.0912	0.8484	5.645	4.0037	1.022	S_{21}

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the fuel tanks	3.4526	0.7197	6.5015	4.4368	1.0635	S_{22}
	3.0814	0.7135	5.3625	4.3513	1.6093	S_{23}
	4.6638	0.3618	7.4506	7.0082	2.029	S_{24}
	4.05	0.1043	9.1154	3.8529	1.179	S_{25}
Neighboring areas near the village of Al-Bu Jawari	4.7959	0.1152	0.8385	4.8291	1.3126	S_{12}
	3.6431	0.0885	0.4493	4.5092	1.3692	S_{13}
	3.1866	0.4454	0.3471	2.9973	0.7864	S_{14}
	1.7178	0.8917	0.3313	3.197	1.1811	S_{15}

Cadmium (Cd) is considered the most dangerous, with concentrations ranging from slightly elevated to significantly elevated (0.33–9.11), and the highest values recorded within the company, making it a strong indicator of industrial pollution. These results are consistent with those reported by [11] in their assessment of soil contamination in some industrial areas of Iraq, where they confirmed that cadmium is one of the elements most affected by human and industrial activities, with relatively high enrichment levels recorded in environments affected by oil facilities and factories. In contrast, cobalt (Co) showed only slight enrichment (0.09–1.64) at all sites, indicating that it is minimally affected by industrial activities. In contrast, a study by [7] showed that the soil surrounding the Nasiriyah refinery in Dhi Qar Governorate recorded higher levels of cobalt enrichment, with EF-Co values ranging from moderate enrichment for most sites, while one sample in the Al-Gharraf area recorded a value within the range of slight enrichment**.** This increase may be attributed to the impact of direct oil emissions and industrial activities associated with refineries.

Copper (Cu), on the other hand, showed moderate enrichment (1.71–4.79) at most sites, indicating a noticeable impact, though less severe than that of cadmium and nickel. A study by [4] also showed that the EF-Cu index in agricultural lands surrounding the Al-Musayyib power plant in Babil Governorate ranged from 0.46 to 0.65, with an average of 0.54. The low values in this region are attributed to the absence of major industrial sources such as oil refineries and the fact that the impact is limited to energy-related activities.

In general, the elements can be ranked by enrichment intensity as follows: Cd > Ni > Cu > Pb > Co, confirming that cadmium and nickel are the main indicators of industrial pollution in the studied area.

Conclusion

Total nickel exceeded the permissible limit of 50 mg kg^{-1} at all sites, with concentrations of 166.96 – 92.20 mg/kg. Total cadmium also recorded localized exceedances of the 3 mg/kg limit, with values reaching 5.16 mg/kg. In contrast, total concentrations of lead, copper, and cobalt remained within standard limits, indicating that nickel and cadmium are the

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primary pollutants associated with petroleum activities in the study area.

Regarding the pollution factor index, the average values of heavy metals across all sites were as follows: lead, cadmium, nickel, cobalt, and copper had values of 1.5087, 4.7517, 3.9104, 0.8051, and 3.8887, respectively. As for the enrichment factor index, the values of the elements in the same order were: 1.3757, 4.3435, 3.6607, 0.6909, and 3.5819, respectively. The results regarding pollution criteria indicate that nickel and cadmium represent the elements with the highest cumulative risk.

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References

[1] Abdullah, Khairullah M. 2024. Evaluation and Study of Pollution in The Elements in The Baiji Refinery After the Recent Terrorist Operations. Journal for Research in Applied Sciences and Biotechnology, 3(1), 60–66.

[2] Abed, M. F., Altawash, B. S., & Ali, S.M. 2015. Environmental Assessment of Trace Elements Concentration and Distribution in Surface Soils at North Baiji City, Iraq. Iraqi Journal of Science, 56(4B), 3176–3187.

[3] Al-Dahash, A. M., Al-Tameemi, A. F.,&Al-Obaidi, H. K. 2021. Assessment of heavy metal pollution in soils around the Baiji oil refinery, Salah Al-Din, Iraq. Iraqi Journal of Science, 62(3), 1003–1015.

[4] Al-Hassoon, S. N. H., Al-Hayani, A. S. J. Z.,&Al-Obaidi, M. A. J. 2019. Copper adsorption in two different soil textures. Iraqi Journal of Agricultural Sciences, 50(2), 638–645. University of Baghdad – College of Agricultural Engineering Sciences.

[5] Al-Jaberi, M. H. 2015. Evaluation of heavy metal contamination in soils surrounding the Baiji oil refinery, Iraq. Iraqi Journal of Science, 56(2A), 1280–1295.

[6] Alloway, B. J. 2013. Heavy Metals in Soils: Trace Metals and Metalloids in Soils and their Bioavailability (3rd ed.). Springer, Dordrecht.

[7] Al-Saad, H. T., Hassan, W. F.,&Abed, J. M. 2023. Assessment of Some Trace Elements in Surface Water and Soil Near Al-Nasiriyah Oil Refinery, Thi-Qar Governorate, Iraq. Iraqi Journal of Science, 64(1), 199–210.

[8] Bhardwaj, R., Gupta, A.,&Kaushal, R. 2020. Heavy metal contamination in soils around oil refineries of Jammu and Kashmir, India. Environmental Monitoring and Assessment, 192(8), 521.

[9] Davies, B. E. 1992. Inter-relationships between soil properties and the uptake of cadmium, copper, lead, and zinc from contaminated soils by radish (Raphanus sativus L.). Water, Air, and Soil Pollution, 63(3–4), 331–342.

[10] FAO. 1974. The Euphrates Pilot Irrigation Project: Methods of Soil Analysis. Gadeb Soil Laboratory (A Laboratory Manual).

[11] Farhan, A. H. 2020. Heavy metal contamination in agricultural soils of

Maysan Governorate, Iraq. Iraqi Journal of Science, 61(9), 2235–2246.

[12] Gee, G. W.,&Bauder, J. W. 1986. Particle-size analysis. In Methods of Soil Analysis: Part 1—Physical and Mineralogical Methods (pp. 383–411).

[13] Hakanson, L. 1980. Ecological risk index for aquatic pollution control: a sedimentological approach. Water Research, 14, 975–1001.

[14] Hayyood, E. M. A., Khalaf, A. A., & Obiad, M. M. 2024. Heavy metal maps of gypsiferous soil and its assessment using geomatic and pollution indices in Baiji City. In Proceedings of the 5th International Conference on Modern Technologies in Agricultural Sciences.

[15] Jackson, M. L. 1958. Soil Chemical Analysis. Englewood Cliffs: Prentice-Hall Inc., New Jersey, U.S.A.

[16] **Khaleel, A. S., & Khwedim, K. H. 2024.** Heavy metal content in the soil of Baiji Refinery and surrounding area, controlling its distribution factors. Iraqi Geological Journal, 57(2D).

[17] Muller, G. 1969. Index of Geoaccumulation in Sediments of the Rhine River. GeoJournal, 2, 108–118.

[18] Numaan, M. M., Kadhem, A. J., Moyel, M. S., Bayati, M. B., Sabeeh, N. N., Alabdraba, W. M. S., Abbas, A. H., Inniss, E. C.,&Fidalgo, M. M. 2024. A study on the possibility of using treated industrial wastewater from the North Refineries Company, Baiji, Iraq, for irrigation purposes. Tikrit Journal of Engineering Sciences, 31(4), 183–190.

[19] Rahman, M. M., Sultana, S.,&Hasan, M. 2021. Spatial distribution of heavy metals in refinery-adjacent soils of Bangladesh. Environmental Monitoring and Assessment, 193(9), 582.

[20] Rhoades, J. D. 1982. Cation exchange capacity. In Methods of Soil Analysis: Part 2. Chemical and Microbiological Properties (pp. 149–157).

[21] Richard, L. A. 1954. Diagnosis and Improvement of Saline and Alkaline Soils. U.S. Salinity Laboratory, U.S. Department of Agriculture Handbook 60, 160 p.

[22] Sarhat, R. S.,&Al-Obaidi, A. H. 2023. Assessment of heavy metal pollution in soils of Chamchamal District, Kurdistan Region, Iraq using contamination indices. Iraqi Geological Journal, 56(1D), 13–28.

[23] Srinivasa Gowd, S., & Govil, P. K. 2007. Distribution of heavy metals in surface water of the Ranipet industrial area, Tamil Nadu, India: An environmental geochemical approach. Chemosphere, 69(4), 633–642.

[24] WHO (World Health Organization). 2007. Guidelines for Assessing Soil Contamination by Heavy Metals. Geneva: WHO Press.

[25] Zheng, N., Liu, J., Wang, Q.,&Liang, Z. 2016). Heavy metal contamination in soils around petroleum refineries in Liaoning, China. Environmental Pollution, 214, 497–506.

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