J Open
http://dx.doi.org/10.70728/jopen.be.0126.006

ARTICLE

Soil Contamination with Petroleum Hydrocarbons and Its Environmental Impact

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Abstract

Soil contamination by petroleum hydrocarbons presents a serious environmental challenge, particularly in Uzbekistan's industrial regions. This study investigates contamination levels in agricultural soils surrounding oil storage facilities and extraction sites, focusing on their chemical composition, heavy metal accumulation, and ecological impact. Chromatographic analysis identified hydrocarbons such as pentane (20.9%), 2-hexene (22.9%), and heptane (10.27%) at depths of up to 42 cm in the soil. Arsenic levels were detected at 17.5 times the permissible limit near oil storage facilities, further increasing environmental risks. Biodiversity loss was observed, particularly affecting species such as *Artemisia scoparia* and *Ferula kuhistanica*. The findings underscore the need for integrated remediation strategies, including bioremediation and policy regulations, to mitigate long-term environmental damage.

Keywords: soil contamination, petroleum hydrocarbons, heavy metals, environmental remediation, bioremediation, pollution control.

Citation
Zafarjon Jabbarov, Urol Nomozov, Feruza Reymova, & Nurmukhammad Zafarjonov (2026). Soil Contamination with Petroleum Hydrocarbons and Its Environmental Impact . J Open, 02(01), 35–45.

Submitted: February, 2026
Accepted: March, 2026
Published: March, 2026

Vol. 02, **No.** 01, 2026.
10.70728/jopen.be.0126.006

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1 Introduction

The extensive use of petroleum hydrocarbons worldwide has resulted in severe environmental pollution, impacting soils, surface water, and groundwater [1]. As a result, several soil properties, including pH levels, microbial communities, soil microaggregates, and anthropogenic carbon content, have undergone significant changes [2–6]. Oil pollution has been observed to impact the oxidation, metabolism, physiology, and morphology of plants, ultimately affecting their productivity [7, 8]. Petroleum hydrocarbon contamination severely damages soil functions and microbial diversity [9, 10]. These hydrocarbons, consisting of complex organic pollutants-including alkanes, cycloalkanes, mono-, bi-, and polyaromatic compounds, resins, and asphaltenes-exhibit toxic effects on the environment and contribute to serious ecological issues [11–15].

Human activities are a major source of petroleum hydrocarbon pollution, with contamination primarily occurring during oil extraction, transportation, and storage, leading to losses amounting to millions of tons per year [16–20]. Additionally, oil-contaminated soils often contain heavy metals such as zinc (Zn), lead (Pb), cadmium (Cd), and chromium (Cr), which further exacerbate environmental hazards [21–24].

Oil pollution poses a significant environmental threat worldwide, including in China [25–27]. Petroleum spills have the potential to spread far beyond their original sites, adversely affecting forest vegetation and reducing productivity [28, 29]. A decrease in plant yield following petroleum contamination is not necessarily due to hydrocarbon accumulation in plant tissues but rather to reduced soil fertility, which negatively impacts plant growth [30]. Some plant species absorb petroleum hydrocarbons from the soil, causing potential harm to animals and humans [31]. For example, *Salicornia fragilis* has been found to accumulate hydrocarbons such as naphthalene, phenanthrene, pyrene, and benzopyrene in coastal salt-marsh soils [32]. Additionally, polycyclic aromatic hydrocarbons (PAHs) have been detected in plant tissues at varying concentrations, including 9.02–334.81 ng/g in roots, 8.45–336.52 ng/g in straw, and 10.70–406.32 ng/g in leaves [33]. As PAH contamination increases in soil, heavy metal pollution also tends to rise [34].

Petroleum hydrocarbon pollution negatively affects plant growth and development [35–40], ultimately impacting food safety [41]. *Secale cereale* L., a key cereal crop in Eastern and Northern Europe, is relatively resistant to environmental stress factors. However, oil pollution induces stress in the plant, reducing low-molecular-weight antioxidants such as proline, non-protein thiols, ascorbic acid, and phenolic compounds [42]. Studies on the effects of fuel oil (0.3–4%) on plant species such as *Lactuca sativa* L., *Hordeum vulgare* L., and *Trifolium* spp. have demonstrated that petroleum hydrocarbons inhibit seed germination and hinder plant growth [43]. Additionally, *Oryza sativa* L. has been found to absorb total hydrocarbons and PAHs from soils artificially contaminated with petroleum hydrocarbons at concentrations of 0, 1,000, 5,000, 10,000, and 15,000 mg/kg, with hydrocarbon accumulation increasing as contamination levels rise [44, 45].

Different fractions of petroleum products affect plant communities differently: light fractions cause the destruction of existing plant communities, while dark fractions lead to structural changes in species composition. Among various plant families, Poaceae species exhibit the highest resistance to oil pollution [46]. Severe negative effects have been observed in the physiological parameters of *Avena sativa* L. at gasoline concentrations as low as 6% [47]. Furthermore, an increase in heterotrophic and hydrocarbon-degrading bacteria has been reported around the roots of maize and soybean plants in diesel-contaminated soils [48].

Certain plant species, particularly those from the Asteraceae family, play a crucial role in reducing soil petroleum concentrations by thriving in oil-contaminated environments [49]. In addition, species such as Medicago sativa L. and Lotus corniculatus L. have been identified as effective in remediating petroleum-polluted soils [50]. Mimosa bimucronata, M. flocculosa, and M. scabrella var. aspericarpa have also demonstrated resilience to contamination and the ability to enhance bioremediation processes [51]. However, oil contamination is often accompanied by sodium chloride salts from mining activities, which further degrade soil properties, harm plants, and disrupt soil microbiota [52]. Soil health is a critical factor in ensuring optimal plant growth and productivity [2, 6].

2 Materials and Methods

The Surkhandarya region, which serves as the research area, is located in the southern part of the Republic of Uzbekistan and is characterized by multiple sources of oil hydrocarbon pollution. The study was conducted on soils affected by two different pollution sources: Area 1: Irrigated pale gray soils surrounding the Kumkurgan branch of "Termiz Neft Baza LLC", distributed in warm and hot subtropical low mountains and sub-mountain slopes of the Surkhandarya region. Area 2: Irrigated gray-meadow soils in the vicinity of the "Janubiy Mirshodi" oil field, which include weak and moderately saline soils in the semi-desert region of the Surkhandarya region. Soil profiles were excavated, and samples were collected at distances of 0.2 km, 3.0 km, 5.0 km, and 8.0 km from both the oil field and the oil storage facility.

Soil sampling, storage, and laboratory analyses were carried out following GOST 17.4.3.01–83 for determining the concentration of oil and oil products in the soil, in accordance with the international standard RD.118.3897485.13–92. Heavy metal analysis in the soil was performed using a multi-element, highly sensitive mass-spectral method based on the fluorimetric technique via ICP-MS. The composition of hydrocarbons in the soil was determined using gas chromatography.

3 Results

Contamination of Soils with Petroleum Hydrocarbons

Soil contamination by petroleum hydrocarbons in the

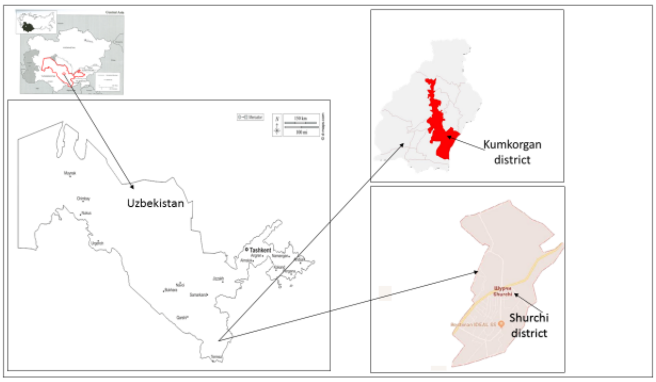

Figure 1. The areas of Surkhandarya region

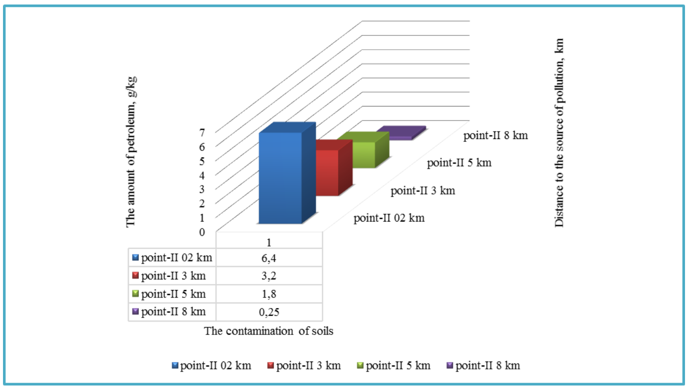

Figure 3. The state of soil contamination with oil hydrocarbons around the oil mine

research area varies depending on the activities of both the oil field and the oil storage facility. An oil storage facility is located in Study area-1 of the research site. During the summer months, temperatures ranging from 55 to 60°C contribute to the combustion of petroleum hydrocarbons, exacerbating environmental pollution. Analysis of soil samples revealed significant contamination levels, exceeding the permissible limit (PL) (Figure 2). Soil contamination near the oil storage facility was assessed, showing that at a 0.2 km distance from the contamination source, petroleum hydrocarbon levels reached 9.8 g/kg, which is 9.8 times higher than the PL. Further analysis showed that petroleum hydrocarbon concentrations in soil samples taken at distances of 3 km, 5 km, and 9 km were 7.2 g/kg, 5.1 g/kg, and 1.9 g/kg, respectively.

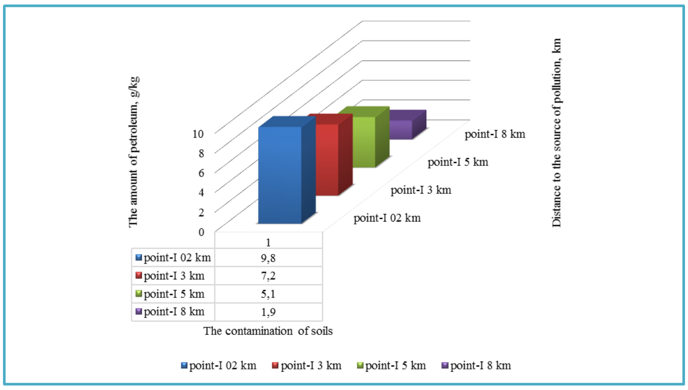

Figure 2. Soil contamination with petroleum hydrocarbons around the oil storage facility, g/kg

In another part of the research area, there is an oil field; the pollution from the oil field is relatively low, due to the accumulation of oil hydrocarbons in the soil over the years; their amount has exceeded the PL indicator (Figure 3).

The results indicate that hydrocarbon contamination is significantly high in soils surrounding the oil field. At a distance of 0.2 km, the soil contained 6.4 g/kg of petroleum hydrocarbons, which is 6.4 times higher than the permissible limit (PL). At 3 km, the contamination level was 3.2 g/kg, exceeding the PL by 3.2 times. However, at 8 km, the petroleum hydrocarbon concentration was found to be below the Regional Environmental Contamination Hazard Unit (REChU) index, indicating that the soil in this area was not contaminated. The findings also highlight variations in pollution sources contributing to soil contamination. A comparative analysis between the oil storage facility and the oil field revealed that the negative environmental impact of the oil storage facility is greater than that of the oil field, suggesting that long-term storage of petroleum products has a more severe effect on soil contamination.

Chromatographic Analysis of Petroleum Hydrocarbons in Soils

Chromatographic analysis identified 109 types of organic pollutants in hydrocarbon-contaminated soils surrounding the oil storage facility. Among these, the most prevalent compounds were:

- 2-Hexene (E): 29.17%
- 1-Hexene, 3,4-dimethyl: 22.96%
- Pentane, 3-methylene: 20.91%
- 2,2,5,5-Tetramethyl hexane: 12.28%

These compounds are highly volatile substances, contributing to increased contamination levels in the surrounding environment. Comparative analysis revealed that hydrocarbon concentrations were higher in the soils around the oil storage facility than in those near the oil field. This is likely due to the long-term storage of various petroleum products, which has led to the gradual accumulation of these hydrocarbons in the soil over the years. As a result, this prolonged exposure has significantly altered the physical and chemical properties of the soil (Table 1).

Table 1. Chromatographic analysis of petroleum-contaminated soils near the oil storage facility

No	Hydrocarbon Name	Volatile Time (minutes)	Amount (%)
1	Pentane, 3-methylene	3.632	20.910
2	1-Hexene, 3,4-dimethyl	3.703	22.958
3	2-Hexene, (E)	3.755	29.172
4	n-Hexane	3.810	1.198
5	n-Hexane	3.832	1.943
6	Hexane, 2,2,5,5-tetramethyl	3.903	12.283
7	Benzene, 1-ethyl-3-methyl	8.541	0.043
8	Benzene, 1,2,3-trimethyl	8.718	0.024
9	Benzene, 1,2,4-trimethyl	9.030	0.008
10	Benzene, 1-ethyl-3-methyl	9.388	0.052
11	Decane	9.483	0.136
12	Octane, 2,6-dimethyl	10.099	0.023
13	2,4-Nonadiyne	10.179	0.009
14	Benzene, 1-methyl-3-propyl	10.960	0.050
15	Bicyclo[3.2.1]oct-2-ene, 3-methyl-4-methylene	11.078	0.062
16	Benzene, 1,2,3,4-tetramethyl	11.153	0.049
17	Heptadecane, 7-methyl	11.255	0.061
18	Benzene, 1,4-diethyl	11.427	0.074
19	o-Cymene	11.690	0.015
20	Benzene, 1-ethyl-2,3-dimethyl	11.739	0.018
21	Undecane	12.271	0.257
22	17-Pentatriacontene	12.770	0.040
23	Benzene, 1,2,4,5-tetramethyl	13.816	0.185
24	2,3-Dimethyldecane	13.938	0.064
25	Undecane, 2-methyl	14.059	0.099

When the same situation was detected in the soils around the oil mine, a slightly less polluted state was observed, it was found that the level of soil pollution with oil hydrocarbons and various organic pollutants around the oil mine was a little less (Table 2).

According to the analysis results, the soil contaminated with petroleum hydrocarbons near the oil field contained 51 types of organic compounds. Among these, the most prevalent hydrocarbons were:

- 2-Hexene (Z): 35.63%
- Cyclohexane: 26.37%
- 3-Methyl-2-pentene: 22.24%
- Heptane, 2,2-dimethyl: 10.28%

The chromatographic analysis further confirms the presence of volatile hydrocarbons in the contaminated soil. The chromatographic image below provides a visual representation of the distribution and composition of these hydrocarbons.

Soil Contamination with Heavy Metals

Table 2. Chromatographic analysis of soils around an oil mine in the II-study area

No	Hydrocarbon Name	Volatile Time (minutes)	Amount (%)
1	2-Pentene, 3-methyl-, (Z)	3.623	22.239
2	Cyclohexane	3.696	26.365
3	2-Hexene, (Z)-	3.745	35.628
4	n-Hexane	3.812	1.823
5	Heptane, 2,2-dimethyl	3.894	10.279
6	Decane	9.477	0.032
7	Decane	12.259	0.061
8	Benzene, 1,2,4,5-tetramethyl	13.811	0.056
9	Dodecane	15.060	0.085
10	Tridecane	17.747	0.125
11	Carbonic acid, nonyl prop-1-en-2-yl ester	20.305	0.087
12	Undecane	21.815	0.026
13	Tetracosane	22.724	0.124
14	Hexadecane	25.019	0.105
15	Heptadecane	27.617	0.075
16	Octadecane	31.002	0.101
17	Methoxyacetic acid, 3-tetradecyl ester	31.272	0.099
18	Nonadecane	33.346	0.064
19	Eicosane	35.016	0.065
20	Heneicosane	36.359	0.084
21	Docosane	37.504	0.061
22	Octadecane, 1-(ethenyloxy)	37.894	0.044
23	Tricosane	38.522	0.059
24	1-Chloroeicosane	38.863	0.013
25	Tetracosane	39.444	0.075

The operation of oil fields and storage facilities not only leads to contamination with petroleum hydrocarbons but also contributes to the accumulation of heavy metals and other hazardous substances in the soil. In this study, the contamination levels of various heavy metals and trace elements were analyzed in the research area. The investigated elements included Li, Be, B, Se, V, Cr, Co, Ni, Cu, Zn, Ga, As, Se, Mo, Ag, Cd, In, Sn, Sb, La, Cs, Te, Eu, Tb, Ta, Pb, U, and Ti (Figure 4). The findings highlight the complex nature of soil contamination in regions affected by oil pollution, where both organic pollutants (hydrocarbons) and inorganic contaminants (heavy metals) contribute to environmental degradation.

The analysis revealed that, in general, heavy metal concentrations in the soils surrounding the oil field and oil storage facility did not exceed the permissible limit (PL) index. However, arsenic (As) contamination was found to be significantly elevated, exceeding the PL index by 14.5 times in soils near the oil field and by 17.5 times in soils near the oil storage facility. The lower concentrations of other heavy metals in the soil, below the PL indicator, are attributed to the composition of crude oil itself. The limited presence of heavy metals

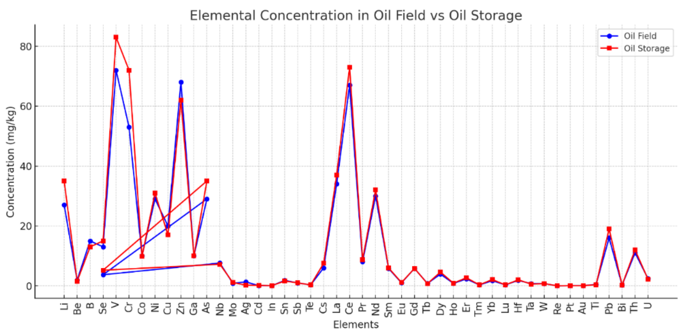

Figure 4. Soil pollution of the research area with heavy metals as a result of oil mine and oil storage facility activities

in petroleum, along with the mechanical compounds released during oil extraction, has resulted in reduced heavy metal contamination in certain areas.

Changes in Flora Under the Influence of Pollution

The research area has a rich and diverse flora, which with irrigated farming is a widely practiced. The annual precipitation of 350–400 mm, particularly during spring, autumn, and winter, has contributed to the widespread distribution of various plant species. However, the operation of the oil storage facility and oil field has had a negative impact on plant distribution. The effects of contamination are influenced by the pollution source and dits proximity to the affected area. The flora in the research area has been affected differently by the activities of the oil storage facility and the oil field, leading to variations in plant health and distribution. Under normal operational conditions, these pollution sources already impact plant life. However, in the event of an environmental disaster (such as an oil spill or leakage), the negative impact on vegetation can increase significantly, by several tens of times (Table 3).

The results indicate that the long-term operation of the oil storage facility, combined with constant temperature effects, has led to the release of volatile hydrocarbons, which in turn has negatively impacted plant life.

In the 0.2 km radius around the storage facility, the populations of plant species such as: *Artemisia scoparia, Psoralea drupacea, Perowskia scrophulaeifolia, Sanguisorba alpine, Ferula kuhistanica, Capparis herbacea, Rubia tinctorum* have significantly declined compared to the background (uncontaminated) area. This reduction is attributed to the cumulative negative effects of hydrocarbon emissions from the oil storage facility over the years.In the areas around the oil mine, the distribution of flora is different from the effect of the oil storage facility, and its negative impact is relatively

Table 3. Impacts of oil storage facility on surrounding vegetation

Plants	**Distances to the oil storage facility, km**					
	0.2	2	5	8	10	15
Artemisia scoparia	++	++	++	++	++	++
Psoralea drupacea	+	+	+	++	++	++
Salvia sclarea	+	+	++	++	++	++
Orthurus kokanicus	++	++	++	++	++	++
Achillea Biebersteinii	++	++	++	++	++	++
Ceterach officinarum	+	+	+	+	++	++
Perowskia scrophulaeifolia	+	+	+	++	++	++
Urtica dioica	++	++	++	++	++	++
Sanguisorba alpine	+	+	++	++	++	++
Artemisa absinthium	+	+	+	+	++	++
Glaucium fimbrilligerum	+	++	++	++	++	++
Peganum harmala	++	++	++	++	++	++
Ferula kuhistanica	+	+	+	+	++	++
Capparis herbacea	+	+	++	++	++	++
Rhamnus cathartica	++	++	++	++	++	++
Rubia tinctorum	+	+	+	+	++	++
Rhamnus cathartica	+	+	++	++	++	++

Explanation: (+) decrease, (++) normal

Table 4. The condition of the impact of the oil mine on the surrounding vegetation

Plants	**Changes in the distribution of vegetation around the oil field, by distance (km)**					
	0.2	2	5	8	10	15
Artemisia scoparia	+	++	++	++	++	++
Psoralea drupacea	+	+	++	++	++	++
Salvia sclarea	+	+	++	++	++	++
Orthurus kokanicus	++	++	++	++	++	++
Achillea biebersteinii	++	++	++	++	++	++
Ceterach officinarum	+	+	++	++	++	++
Perowskia scrophulaeifolia	+	+	++	++	++	++
Urtica dioica	++	++	++	++	++	++
Sanguisorba alpina	+	+	++	++	++	++
Artemisia absinthium	+	+	+	++	++	++
Glaucium fimbrilligerum	+	++	++	++	++	++
Peganum harmala	++	++	++	++	++	++
Ferula kuhistanica	+	+	++	++	++	++
Capparis herbacea	+	+	++	++	++	++
Rhamnus cathartica	++	++	++	++	++	++
Rubia tinctorum	+	+	+	+	++	++
Rhamnus cathartica	+	++	++	++	++	++

Explanation: (+) decrease, (++) normal less noticeable (Table 4).

The study found that vegetation distribution near the oil field differs from that around the oil storage facility. Specifically, the negative impact of the oil field on plant life is less severe than that of the oil storage facility. Notably, plant species such as: *Sanguisorba alpine*, *Artemisia absinthium*, *Ferula kuhistanica*, *Capparis herbacea* experienced a reduction in population, though the overall impact on other plant species was less significant. The weaker impact of the oil field on vegetation can be explained by the lower level of contamination in its vicinity. Unlike the oil storage facility, where hydrocarbons are continuously released into the environment, petroleum spills near the oil field are less frequent and typically affect a smaller area. However, in the event of a catastrophic spill, the localized environmental damage can be severe. The findings confirm that both oil storage facility and oil field activities cause long-term damage to surrounding flora, which has cascading effects on soil quality. Over time, the degradation of vegetation leads to: Reduction in soil biomass, humus, and organic carbon content. As a result, these negative impacts necessitate soil remediation and reclamation efforts to restore degraded land. Additionally, long-term exposure to salinity and chemical pollution stress exacerbates soil degradation, leading to reduced agricultural productivity and economic efficiency. Given these risks, it is crucial to develop and implement effective recultivation measures for these affected areas.

4 Discussion

Soil Contamination by Petroleum Hydrocarbons

The extent of petroleum hydrocarbon contamination in the research area varied depending on the two primary pollution sources: the oil storage facility and the oil field. Initially, contamination was concentrated in the 0–10 cm soil layer, but over the years, agricultural activities such as plowing and farming facilitated the downward migration of pollutants, reaching depths of 35–42 cm. The highest contamination was found near the oil storage facility, where hydrocarbons spread up to 9 km. In contrast, contamination from oil field operations was less extensive, affecting an area within 0.2–5 km. Importantly, in both cases, oil hydrocarbon pollution did not result from direct oil spills but rather from high-temperature evaporation and wind dispersion, which contributed to the gradual spread of hydrocarbons over time. The chemical composition of petroleum hydrocarbons also varied between the two locations:

Oil Storage Facility: A total of 109 types of organic pollutants were identified. 86.3% of these were composed of Pentane, 3-methylene, 1-Hexene, 3,4-dimethyl, 2-Hexene (E), n-Hexane, 2-Hexane, and Hexane 2,2,5,5-tetramethyl. Oil Field: Contained 51 types of organic pollutants, significantly fewer than the oil storage facility. 96.2% of the hydrocarbons identified were 2-Pentene, 3-methyl- (Z), Cyclohexane, 2-Hexene (Z), n-Hexane, and Heptane, 2,2-dimethyl.

The results suggest that the oil storage facility has a much greater impact on soil contamination. This is because crude oil from various regions with different chemical compositions is stored in the facility, leading to greater variation in hydrocarbon pollution. Consequently, the environmental impact of the oil storage facility on soil, air, and vegetation is more severe than that of the oil field. Additionally, the recultivation of contaminated soils around oil storage facilities is more challenging, given the prolonged exposure to hydrocarbons of diverse compositions.

Soil Contamination by Heavy Metals

The study also investigated the contamination of soil with heavy metals in the research area. The elements analyzed included Li, Be, B, Se, V, Cr, Co, Ni, Cu, Zn, Ga, As, Se, Mo, Ag, Cd, In, Sn, Sb, La, Cs, Te, Eu, Tb, Ta, Pb, U, and Ti.

Key findings: The only significantly elevated element was arsenic (As): 14.5 times higher than the permissible limit (PL) near the oil field. 17.5 times higher than the PL in soils near the oil storage facility. Other heavy metals and elements did not exceed contamination thresholds, indicating that no additional industrial pollution sources were present in the research area. Since groundwater is located below 10 meters, no other external sources were identified as contributors to arsenic contamination.

Impact of Pollution on Flora

The long-term operation of both the oil storage facility and the oil field has led to significant changes in plant distribution and biodiversity. Oil Storage Facility: A decline in plant populations was observed, with species such as: Artemisia scoparia, Psoralea drupacea, Salvia sclarea, Orthurus kokanicus, Achillea biebersteinii, Ceterach officinarum, Perowskia scrophulaeiifolia, Urtica dioica, Sanguisorba alpine, Artemisia absinthium, Glaucium fimbrilligerum, Peganum harmala, Ferula kuhistanica, Capparis herbacea, Rhamnus cathartica, and Rubia tinctorum. The continuous emission of volatile hydrocarbons has negatively impacted vegetation over time.

Oil Field: Plant reduction was observed, but to a lesser extent than around the oil storage facility. Species affected included:Artemisia scoparia, Psoralea drupacea, Perowskia scrophulaeiifolia, Sanguisorba alpine, Artemisia absinthium, Ferula kuhistanica, and Capparis herbacea. The lower level of pollution in this area suggests less impact on vegetation, as contamination events are more localized and less frequent. The findings confirm that the oil storage facility has a significantly greater negative impact on the surrounding ecosystem compared to the oil field. Over time, this has led to a decline in soil biomass, humus content, and organic carbon levels, ultimately reducing soil fertility and slowing the natural self-cleaning process of the soil. These factors necessitate effective recultivation and remediation strategies to restore the environmental balance and mitigate long-term damage. The oil storage facility has a greater impact on soil contamination, biodiversity loss, and soil degradation than the oil field. Petroleum hydrocarbon contamination around the oil storage facility extends up to 9 km, whereas oil field contamination is limited to 0.2–5 km. The chemical composition of hydrocarbons varies significantly, with more organic pollutants found near the oil storage facility. Arsenic (As) levels exceeded PL limits in both areas, but no contamination from other heavy metals was observed. Vegetation decline was more severe around the oil storage facility, necessitating urgent reclamation efforts. These results emphasize the importance of implementing recultivation measures, particularly around oil storage facilities, to mitigate long-term environmental damage and restore soil health.

5 Conclusion

Soil contamination by petroleum hydrocarbons differs between the oil storage facility and the oil field. The scale of contamination is significantly larger around the oil storage facility, with pollutants detected up to 8 km away, while the oil field contamination affects the 0–45 cm soil layer within a 5 km radius. In addition to petroleum hydrocarbons, the soil was also found to be contaminated with arsenic (As). The concentration of arsenic exceeded the permissible limit (PL) by: 14.5 times in soil near the oil field and by 17.5 times in soil near the oil storage facility. The presence of petroleum hydrocarbons has also altered plant distribution in the research area. The study found a reduction in key plant species due to contamination: Around the oil field:Artemisia scoparia, Psoralea drupacea, Perowskia scrophulaeiifolia, Sanguisorba alpine, Artemisia absinthium, Ferula kuhistanica, and Capparis herbacea experienced a decline. Around the oil storage facility: A more severe reduction was observed in Artemisia scoparia, Psoralea drupacea, Perowskia scrophulaeiifolia, Sanguisorba alpine, Ferula kuhistanica, Capparis herbacea, and Rubia tinctorum. The findings demonstrate that the oil storage facility has a more significant environmental impact on soil contamination and vegetation loss than the oil field. Therefore, implementing soil remediation and effective recultivation strategies are essential to mitigate long-term environmental damage and restore soil health in these affected areas.

Author Contributions: Conceptualization, Z.J.; methodology, F.R.; software, Z.J., U.N.; validation, U.N., F.R.; formal analysis, F.R.; investigation, Z.J.; resources, Z.J.; data curation, N.Z.; writing–original draft preparation, Z.J.; writing–review and editing, Z.J.; visualization, U.N.; supervision, Z.J.; project administration, Z.J.; funding acquisition, Z.J. All authors have read and agreed to the published version of the manuscript.

Funding: The authors declare that no funds, grants, or other financial support were received during the preparation of this manuscript.

Institutional Review Board Statement: This research did not include any experiments involving human participants or animals, so Institutional Review Board (IRB) approval was not necessary.

Informed Consent Statement: This study did not involve human subjects; therefore, informed consent was not required.

Data Availability Statement: Data supporting the report's findings can be found here.

Acknowledgments: The authors would like to express their sincere gratitude to Associate Professor **Khasanboy Abdunazarov** of Kokand State University for his valuable comments on the study results and for his assistance in the publication of this paper.

Conflicts of Interest: The authors declare no conflicts of interest related to this study.

References

[1] Ossai, I. C., Ahmed, A., Hassan, A., & Hamid, F. S. (2020). Remediation of soil and water contaminated with petroleum hydrocarbon: A review. Environmental Technology amp; Innovation, 17, 100526. [Scopus]

[2] Jabbarov, Z., Abdrakhmanov, T., Pulatov, A., Kováčik, P., & Pirmatov, K. (2019). Change in the Parameters of Soils Contaminated by Oil and Oil Products.

Agriculture (Pol'nohospodárstvo), 65(3), 88–98. [Crossref]
[3] Karkush, M. O., & Abdulkareem, M. S. (2019). Deep remediation and improvement of soil contaminated with residues oil using lime piles. International Journal of Environmental Science and Technology, 16(11), 7197–7206. [Scopus]
[4] Ambaye, T. G., Chebbi, A., Formicola, F., Prasad, S., Gomez, F. H., Franzetti, A., & Vaccari, M. (2022). Remediation of soil polluted with petroleum hydrocarbons and its reuse for agriculture: Recent progress, challenges, and perspectives. Chemosphere, 293, 133572. [Scopus]
[5] Mahmud, M. S., & Chong, K. P. (2022). Effects of Liming on Soil Properties and Its Roles in Increasing the Productivity and Profitability of the Oil Palm Industry in Malaysia. Agriculture, 12(3), 322. [Scopus]
[6] Kholdorov, S., Jabbarov, Z., & Shamsiddinov, T. (2023). Soil governance: A review of the current legislative framework for managing soil resources in Uzbekistan. Soil Security, 13, 100105. [Scopus]
[7] Haider, F. U., Ejaz, M., Cheema, S. A., Khan, M. I., Zhao, B., Liqun, C., Salim, M. A., Naveed, M., Khan, N., Núñez-Delgado, A., & Mustafa, A. (2021). Phytotoxicity of petroleum hydrocarbons: Sources, impacts and remediation strategies. Environmental Research, 197, 111031. [Scopus]
[8] Ruley, J. A., Amoding, A., Tumuhairwe, J. B., & Basamba, T. A. (2022). Rhizoremediation of petroleum hydrocarbon–contaminated soils: A systematic review of mutualism between phytoremediation species and soil living microorganisms. Phytoremediation, 263–296. [Scopus]
[9] Ilyas, N., Shoukat, U., Saeed, M., Akhtar, N., Yasmin, H., Khan, W., & Iqbal, S. (2021). Comparison of plant growth and remediation potential of pyrochar and thermal desorption for crude oil-contaminated soils. Scientific Reports, 11(1). [Scopus]
[10] Gao, H., Wu, M., Liu, H., Xu, Y., & Liu, Z. (2022). Effect of petroleum hydrocarbon pollution levels on the soil microecosystem and ecological function. Environmental Pollution, 293, 118511. [Scopus]
[11] Zhang, T., Liu, Y., Zhong, S., & Zhang, L. (2020). AOPs-based remediation of petroleum hydrocarbons-contaminated soils: Efficiency, influencing factors and environmental impacts. Chemosphere, 246, 125726. [Scopus]
[12] Hoang, S. A., Sarkar, B., Seshadri, B., Lamb, D., Wijesekara, H., Vithanage, M., Liyanage, C., Kolivabandara, P. A., Rinklebe, J., Lam, S. S., Vinu, A., Wang, H., Kirkham, M. B., & Bolan, N. S. (2021). Mitigation of petroleum-hydrocarbon-contaminated hazardous soils using organic amendments: A review. Journal of Hazardous Materials, 416, 125702. [Scopus]
[13] Tucci, M., Cruz Viggi, C., Esteve Núñez, A., Schievano, A., Rabaey, K., & Aulenta, F. (2021). Empowering electroactive microorganisms for soil remediation: Challenges in the bioelectrochemical removal of petroleum hydrocarbons. Chemical Engineering Journal, 419, 130008. [Scopus]
[14] Stepanova, A. Y., Gladkov, E. A., Osipova, E. S., Gladkova, O. V., & Tereshonok, D. V. (2022). Bioremediation of Soil from Petroleum Contamination. Processes, 10(6), 1224. [Scopus]
[15] Ali, N., Erinle, K. O., Sher, A. A., Zaib-un-Nisa, Hakimi, S. S., Afzal, B., & Ashraf, Y. M. (2023). Soil Liming Ameliorates Crude Oil Stress and Promotes Biochemical Indices and Photosynthetic and Antioxidant Enzyme Activities in Lemongrass (Cymbopogon citratus). Journal of Soil Science and Plant Nutrition, 23(3), 4034–4043. [Scopus]
[16] Galvez-Cloutier, R., Guesdon, G., & Fonchain, A. (2014). Lac-Mégantic: analyse de l'urgence environnementale, bilan et évaluation des impacts. Canadian Journal of Civil Engineering, 41(6), 531–539. [Scopus]
[17] Arjoon, K., & Speight, J. G. (2020). Chemical and Physical Analysis of a Petroleum Hydrocarbon Contamination on a Soil Sample to Determine Its Natural Degradation Feasibility. Inventions, 5(3), 43. [Scopus]
[18] Alotaibi, F., Hijri, M., & St-Arnaud, M. (2021). Overview of Approaches to Improve Rhizoremediation of Petroleum Hydrocarbon-Contaminated Soils. Applied Microbiology, 1(2), 329–351. [Scopus]
[19] Apulu, O. G., Potravny, I. M., & Sukhorukova, I. V. (2021). Methods of justification and selection of technologies for remediation of oil-contaminated land. Ecology and industry of Russia, 25(6), 38-43. [Google Scholar]
[20] Feng, L., Jiang, X., Huang, Y., Wen, D., Fu, T., & Fu, R. (2021). Petroleum hydrocarbon-contaminated soil bioremediation assisted by isolated bacterial consortium and sophorolipid. Environmental Pollution, 273, 116476. [Scopus]
[21] Li, Q., You, P., Hu, Q., Leng, B., Wang, J., Chen, J., Wan, S., Wang, B., Yuan, C., Zhou, R., & Ouyang, K. (2020). Effects of co-contamination of heavy metals and total petroleum hydrocarbons on soil bacterial community and function network reconstitution. Ecotoxicology and Environmental Safety, 204, 111083. [Scopus]
[22] Saran, A., Fernandez, L., Cora, F., Savio, M., Thijs, S., Vangronsveld, J., & Merini, L. J. (2019). Phytostabilization of Pb and Cd polluted soils using Helianthus petiolaris as pioneer aromatic plant species. International Journal of Phytoremediation, 22(5), 459–467. [Scopus]
[23] Steliga, T., & Kluk, D. (2021). Assessment of the Suitability of Melilotus officinalis for Phytoremediation of Soil Contaminated with

Petroleum Hydrocarbons (TPH and PAH), Zn, Pb and Cd Based on Toxicological Tests. Toxics, 9(7), 148. [Scopus]

[24] Aliboeva, M., Jabbarov, Z., Fakhrutdinova, M., & Pulatov, B. (2023). Soil organic carbon, NPK and carbonates as affected by topographic aspect at Chatkal state biosphere reserve mountains, Uzbekistan. THE THIRD INTERNATIONAL SCIENTIFIC CONFERENCE CONSTRUCTION MECHANICS, HYDRAULICS AND WATER RESOURCES ENGINEERING (CONMECHYDRO 2021 AS), 2612, 030025. [Scopus]

[25] Dong, Z.-L., Wang, B.-S., & Li, J. (2020). Effects of Petroleum Hydrocarbon Contamination on Soil Bacterial Diversity in the Permafrost Region of the Qinghai-Tibetan Plateau. Soil and Sediment Contamination: An International Journal, 29(3), 322–339. [Scopus]

[26] Wu, M., Zhao, Z., Cai, G., Duan, W., Wang, C., Cheng, G., & Wang, X. (2022). In situ evaluation of soil contaminated by total petroleum hydrocarbons using membrane interface probe: a case study from Nanjing, China. Bulletin of Engineering Geology and the Environment, 81(4). [Scopus]

[27] Wu, Y., Liu, X., Dong, Q., Xiao, M., Li, B., Topalović, O., Tao, Q., Tang, X., Huang, R., Chen, G., Li, H., Chen, Y., Feng, Y., & Wang, C. (2022). Remediation of petroleum hydrocarbons-contaminated soil: Analysis based on Chinese patents. Chemosphere, 297, 134173. [Scopus]

[28] Abdullah, S. R. S., Al-Baldawi, I. A., Almansoory, A. F., Purwanti, I. F., Al-Sbani, N. H., & Sharuddin, S. S. N. (2020). Plant-assisted remediation of hydrocarbons in water and soil: Application, mechanisms, challenges and opportunities. Chemosphere, 247, 125932. [Scopus]

[29] Ozigis, M. S., Kaduk, J. D., Jarvis, C. H., da Conceição Bispo, P., & Balzter, H. (2020). Detection of oil pollution impacts on vegetation using multifrequency SAR, multispectral images with fuzzy forest and random forest methods. Environmental Pollution, 256, 113360. [Scopus]

[30] Grifoni, M., Rosellini, I., Angelini, P., Petruzzelli, G., & Pezzarossa, B. (2020). The effect of residual hydrocarbons in soil following oil spillages on the growth of Zea mays plants. Environmental Pollution, 265, 114950. [Scopus]

[31] Hunt, L. J., Duca, D., Dan, T., & Knopper, L. D. (2019). Petroleum hydrocarbon (PHC) uptake in plants: A literature review. Environmental Pollution, 245, 472–484. [Scopus]

[32] Meudec, A., Dussauze, J., Deslandes, E., & Poupart, N. (2005). UPTAKE OF FOUR PAHS OCCURRING INTO AERIAL PLANT TISSUE ARTIFICIALLY EXPOSED TO HEAVY FUEL OIL IN SALICORNIA. International Oil Spill Conference Proceedings, 2005(1), 797–800. [Crossref]

[33] Yu, W., Kuang, S., & Zhao, L. (2013). Uptake, accumulation and translocation of polycyclic aromatic hydrocarbons by winter wheat cultured on oily sludge-amended soil. Chinese Journal of Geochemistry, 32(3), 295–302. [Scopus]

[34] Rajput, V., Minkina, T., Semenkov, I., Klink, G., Tarigholizadeh, S., & Sushkova, S. (2020). Phylogenetic analysis of hyperaccumulator plant species for heavy metals and polycyclic aromatic hydrocarbons. Environmental Geochemistry and Health, 43(4), 1629–1654. [Scopus]

[35] Rusin, M., Gospodarek, J., Barczyk, G., & Nadgórska-Socha, A. (2018). Antioxidant responses of Triticum aestivum plants to petroleum-derived substances. Ecotoxicology, 27(10), 1353–1367. [Scopus]

[36] Ma, H., Wang, A., Zhang, M., Li, H., Du, S., Bai, L., Zhong, M., & Chen, S. (2018). Compared the physiological response of two petroleum-tolerant contrasting plants to petroleum stress. International Journal of Phytoremediation, 20(10), 1043–1048. [Scopus]

[37] Abdollahzadeh, T., Niazi, A., Moghadam, A., Heydarian, Z., Ghasemi-Fasaei, R., Kaviani, E., & Pourdad, N. (2018). Phytoremediation of petroleum-contaminated soil by Salicornia: from PSY activity to physiological and morphological communications. Environmental Technology, 40(21), 2789–2801. [Scopus]

[38] Odukoya, J., Lambert, R., & Sakrabani, R. (2019). Impact of Crude Oil on Yield and Phytochemical Composition of Selected Green Leafy Vegetables. International Journal of Vegetable Science, 25(6), 554–570. [Scopus]

[39] Guarino, C., Marziano, M., Tartaglia, M., Prigioniero, A., Postiglione, A., Scarano, P., & Sciarrillo, R. (2020). Poaceae with PGPR Bacteria and Arbuscular Mycorrhizae Partnerships as a Model System for Plant Microbiome Manipulation for Phytoremediation of Petroleum Hydrocarbons Contaminated Agricultural Soils. Agronomy, 10(4), 547. [Scopus]

[40] Walakulu Gamage, S. S., Masakorala, K., Brown, M. T., & Widana Gamage, S. M. K. (2020). Tolerance of Impatiens balsamina L., and Crotalaria retusa L. to grow on soil contaminated by used lubricating oil: A comparative study. Ecotoxicology and Environmental Safety, 188, 109911. [Scopus]

[41] Saran, A., Much, D., Vangronsveld, J., & Merini, L. (2023). Phytomanagement of trace element polluted fields with aromatic plants: supporting circular bio-economies. International Journal of Phytoremediation, 26(2), 169–177. [Scopus]

[42] Skrypnik, L., Maslennikov, P., Novikova, A., & Kozhikin, M. (2021). Effect of Crude Oil on Growth, Oxidative Stress and Response of Antioxidative System of Two Rye (Secale cereale L.) Varieties. Plants,

10(1), 157. [Scopus]

[43] Chaîneau, C. H., Morel, J. L., & Oudot, J. (1997). Phytotoxicity and Plant Uptake of Fuel Oil Hydrocarbons. Journal of Environmental Quality, 26(6), 1478–1483. Portico. [Crossref]

[44] Balasubramaniyam, A. (2015). The influence of plants in the remediation of petroleum hydrocarbon-contaminated sites. Pharm. Anal. Chem. Open Access, 1(1), 1000105. [ResearchGate]

[45] Patowary, R., Patowary, K., Devi, A., Kalita, M. C., & Deka, S. (2016). Uptake of Total Petroleum Hydrocarbon (TPH) and Polycyclic Aromatic Hydrocarbons (PAHs) by Oryza sativa L. Grown in Soil Contaminated with Crude Oil. Bulletin of Environmental Contamination and Toxicology, 98(1), 120–126. [Scopus]

[46] Issayeva, A., Mametova, A., Baiduisenova, T., Kossauova, A., Zhumakhanova, R., Zhumadulayeva, A., Ashirbayeva, S., & Patasheva, A. (2023). The Effect of Oil Pollution of the Gray Soils on Revegetation in the South of Kazakhstan. Journal of Ecological Engineering, 24(1), 28–33. [Crossref]

[47] Fedeli, R., Alexandrov, D., Celletti, S., Nafikova, E., & Loppi, S. (2022). Biochar improves the performance of Avena sativa L. grown in gasoline-polluted soils. Environmental Science and Pollution Research, 30(11), 28791–28802. [Scopus]

[48] Duru, N.C., Chimereze, N C. Anuforo-Sydney O, Ahamefula, U. O., & Nwafor, I.A. (2023). Effects of red guinea corn and soybean plants growing on diesel polluted soil on the total heterotrophic and diesel degrading microbes. World Journal of Advanced Research and Reviews, 18(2), 1355–1360. [Crossref]

[49] Prematuri, R., Mardatin, N. F., Irdiastuti, R., Turjaman, M., Wagatsuma, T., & Tawaraya, K. (2019). Petroleum hydrocarbons degradation in contaminated soil using the plants of the Aster family. Environmental Science and Pollution Research, 27(4), 4460–4467. [Scopus]

[50] Zuzolo, D., Guarino, C., Tartaglia, M., & Sciarrillo, R. (2021). Plant-Soil-Microbiota Combination for the Removal of Total Petroleum Hydrocarbons (TPH): An In-Field Experiment. Frontiers in Microbiology, 11. [Crossref]

[51] Miroshnychenko, I., Voitovych, O., Miroshnychenko, M., & Volosheniuk, O. (2022). Dynamics of Chernozem's self-cleaning from oil pollution over two years. International Journal of Environmental Studies, 80(2), 410–420. [Scopus]

[52] Kuzina, E. V., Rafikova, G. F., Mukhamatdyarova, S. R., Sharipova, Yu. Yu., & Korshunova, T. Yu. (2023). Biological Activity of Leached Chernozem under Oil and Sodium Chloride Pollution and the Effect of Treatment with Halotolerant Oil-Destructing Bacteria. Eurasian Soil Science, 56(1), 75–86. [Scopus]

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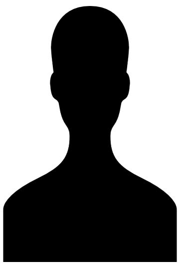

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