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Effect of Drilling Fluids and Crude Oil on Some Chemical Properties of Soil and Crops

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Abstract

This research aims to study the effect of drilling fluids and crude oil on soil and crops, and to analyze the extent of chemical and physical changes that occur on the soil affected by oil pollution. The study relied on a review of scientific literature and case studies to assess the effects of oil pollutants, and pollution mitigation and waste oil management strategies were analyzed. The results showed that pollution with drilling fluids leads to high soil salinity and nutrient balance disturbance, while crude oil pollution increases organic carbon but causes plant stress due to high concentrations of some toxic elements. The study confirmed that strategies such as bioremediation and phytotherapy play an important role in restoring soil fertility and reducing the negative effects of pollution. The study recommends the need to improve prevention policies, strengthen environmental monitoring, and develop sustainable techniques to treat contaminated soil, with a view to achieving a balance between the exploitation of natural resources and environmental protection.

Keywords- Soil pollution, drilling fluids, crude oil, chemical impacts, bioremediation, plant remediation, soil reclamation, waste oil management, environmental sustainability, sustainable agriculture.

Introduction

The impact of industrial activities on soil is one of the important environmental issues that directly affect ecosystems and agriculture. With the expansion of the extraction of natural resources, such as oil and gas, soils have become vulnerable to pollution from industrial waste, which changes their chemical and physical properties and affects their productive capacity (Saikia, Bora, & Gogoi, 2023). Areas near oil fields and drilling sites are among the most vulnerable to these impacts, as pollution causes fundamental changes in soil properties, which is reflected in crop production and land capacity for agricultural sustainability (Jafari, 2023).

Among the main sources of this pollution are drilling fluids and crude oil, as drilling fluids are used in exploration and extraction operations to facilitate drilling and stabilization of well walls, but their leakage or improper disposal leads to a change in the composition of the soil and the introduction of chemical compounds that may be harmful to the agricultural ecosystem (AAPG, 2023). Crude oil spillage or leakage into the soil also leads to the formation of an oil layer that hinders the absorption of water and air, which affects the vital activity within the soil and impairs its ability to provide essential nutrients to plants (Swigart, Heo, & Wolf, 2021).

This pollution leads to significant disturbances in soil dynamics, as it can lead to increased acidity or alkalinity, high salinity levels, and reduced availability of nutrients such as nitrogen and phosphorus, directly affecting the growth of agricultural crops (Basic, 2009). The accumulation of heavy metals and petroleum hydrocarbons in the soil may render it unsuitable for prolonged cultivation, requiring the implementation of effective remediation strategies to restore its fertility (Calciu & Plopeanu, 2011).

As a result of these changes, crop productivity in contaminated soil becomes much lower compared to soils unaffected by pollution, as studies show lower seed germination rates and poor growth of plants exposed to oil pollutants and drilling fluids (Shanahan, 1999). The importance of research in analyzing these impacts in a scientific and accurate manner to understand the extent of damage caused by soil pollution, which contributes to proposing solutions and treatment techniques that help rehabilitate damaged lands and improve agricultural production in areas affected by drilling and oil extraction activities.

Search problem

Soils are an essential component of the ecosystem and agriculture, playing a vital role in supporting crop growth and providing food for humans and animals. However, soils in many areas face serious environmental challenges as a result of various industrial activities, most notably oil and gas extraction activities. These processes have led to increased levels of chemical contamination on soils, which have directly affected their fertility and productivity. Drilling fluids and crude oil are one of the main sources of this pollution, as these substances seep into the soil, affecting its physical and chemical structure, creating an environment unfavorable for the growth of agricultural crops (Saikia, Bora, & Gogoi, 2023).

When the soil is contaminated with crude oil, it leads to the formation of an oil layer that prevents the absorption of water and air, which limits microbial activity and affects the decomposition of organic matter. Chemical compounds in oil, such as aromatic hydrocarbons and heavy metals, remain for long periods in the soil, limiting their cultivation. On the other hand, drilling fluids contain a variety of chemicals that may increase soil salinity or change its pH, negatively affecting the availability of essential nutrients such as nitrogen, phosphorus and potassium (Basic, 2009). With these changes, the soil is unable to support agriculture as it used to be, deteriorating agricultural productivity and threatening food security in the affected areas..

Despite research efforts that have addressed the impact of oil pollution and drilling fluids on soils, there is a clear gap in studies related to the impact of these pollutants on agricultural production and the possibility of restoring soil fertility. Most of the available research focuses on the chemical analysis of soil pollution, without providing a comprehensive view of how this pollution affects crop growth and productivity (Calciu & Plopeanu, 2011). There is also a lack of studies comparing the effect of crude oil and drilling fluids on soils under different environmental conditions, making it necessary to conduct more detailed studies on the subject..

Accordingly, this research seeks to determine the impact of drilling fluids and crude oil on the chemical properties of soil and the productivity of agricultural crops, by answering the following main question::

- "What is the impact of drilling fluids and crude oil on the chemical properties of the soil and the productivity of agricultural crops?"
- To answer this question, a number of sub-themes will be addressed, such as:
- How do the components of crude oil and drilling fluids affect soil pH, salinity and nutrient balance?
- To what extent do these pollutants affect crop growth and productivity in contaminated soil compared to clean soil?
- What are the best ways to treat soils contaminated with oil and drilling fluids and restore their ability to support agricultural production?

Answering these questions will help bridge the research gap on the impact of oil pollutants on soil, and will contribute to providing practical solutions to restore damaged agricultural land and improve agricultural production in areas affected by oil extraction activities..

Importance of research

This research is of great importance in light of the increasing effects of soil pollution with crude oil and drilling fluids on agricultural production and environmental sustainability. It contributes to the analysis of chemical changes in the affected soil and the assessment of their implications for crop growth. It also aims to bridge the scientific gap by exploring the impact of these pollutants on soil fertility and productivity, with a focus on effective treatment. In addition, the research provides important insights for decision-makers and oil companies on adopting more sustainable waste management practices and reducing environmental impact. Through its findings, the research can contribute to the development of soil reclamation strategies and improved environmental policies to protect natural resources and enhance food security..

Research Objectives

This research aims to analyze the effect of drilling fluids and crude oil on the chemical properties of the soil and the productivity of agricultural crops, by studying the changes that occur in the soil contaminated with these materials, and assessing the extent of their impact on crop growth. The research also seeks to propose solutions and remediation techniques to restore soil fertility and improve agricultural productivity in affected areas. The main objectives of this research can be summarized as follows::

- Analyze the impact of drilling fluids and crude oil on soil chemical properties, including pH, salinity, and essential nutrient availability.
- Study the impact of pollution with crude oil and drilling fluids on the growth and productivity of agricultural crops, by comparing contaminated and unaffected soils.
- Determine the types, persistence and long-term impact of chemical contaminants in the soil resulting from crude oil and drilling fluid spills..
- Evaluate physical changes in contaminated soil, such as soil porosity and water and air retention capacity.
- Review previous studies on the impact of oil pollution on soil and agriculture, and identify research gaps in this field.
- Propose effective remediation strategies to restore the fertility of affected soils, such as bioremediation, chemical leaching, and the addition of organic amendments.
- Provide scientific recommendations to farmers in areas affected by oil extraction activities, to help them improve soil quality and increase agricultural productivity.
- Contribute to the development of sustainable environmental policies to reduce the impact of oil drilling pollutants on soil and agricultural systems.

Research Methodology

This research is based on the inductive approach in analyzing the impact of drilling fluids and crude oil on soil and crops, starting from the study of previous literature and available scientific data on the change in the chemical properties of the soil in environments affected by these pollutants. By extrapolating scientific findings and observations, general patterns and conclusions are reached about the extent to which these pollutants affect soil quality and agricultural production. The inductive approach also contributes to proposing strategies for treating damaged soils based on patterns extracted from previous studies and scientific experiments..

Theoretical framework and previous studies

Oil and gas drilling operations are industrial activities that produce large amounts of liquid and solid waste, which can adversely affect the soil and terrestrial ecosystem. Drilling fluids, also known as "drilling mud", are used for a variety of purposes during the drilling process, including lubricating the rig, cooling it, transporting rock fragments to the surface, and stabilizing the well wall to prevent it from collapsing. But after drilling is over, these contaminated liquids – along with rock snippets and salt water coming from underground formations – are often collected in basins or ponds near well sites (AAPG, 2023).

If these ponds are not properly managed, contaminants can seep into the surrounding soil, changing their chemical properties. Crude oil spills during extraction or transportation are also factors that increase the risk of soil contamination, as oil leads to the formation of an oil layer that prevents the soil from absorbing water and nutrients, which negatively affects plant growth and crop productivity (Saikia, Bora, & Gogoi, 2023).

Environmental reports indicate that pollution from drilling fluids and crude oil can destroy soil fertility and hinder plant growth, and many farmers in affected areas, such as the Niger Delta, have been forced to abandon their farmland due to sharply reduced productivity. One study showed that oil spills in that region led to a 60% reduction in average household income from agricultural crops as a result of plant death or poor productivity (UNEP, 2011

In view of these serious effects, this study is important in analyzing the chemical effects of drilling fluids and crude oil on the soil, by assessing the extent to which the soil changes when exposed to these pollutants, and the extent to which the productivity of agricultural crops is affected..

***Figure 1**: A lined pit used to store drilling fluids and rock scraps resulting from the drilling process. Insulating lining (plastic cover) helps prevent contaminants from seeping into the surrounding soil and groundwater*

Chemical Effects of Drilling Fluids and Crude Oil on Soil

The leakage of drilling fluids or crude oil into the soil results in a range of chemical changes that affect the properties and composition of the soil, which can lead to a deterioration in its agricultural productivity and increased levels of environmental pollution. These changes include pH imbalances, increased foreign organic matter content, accumulation of salts and heavy metals, as well as changing availability of essential nutrients. The extent of the impact depends on the nature and quantity of pollutants, as well as the characteristics of the original soil and the surrounding environmental conditions (Swigart, Heo, & Wolf, 2021).

1. Fluctuation of pH

pH is one of the most important chemical factors affecting soil fertility, as it affects the availability of nutrients for plants and the activity of microorganisms within the soil. Contamination from drilling fluids and crude oil often causes the pH to rise towards the alkaline side, which can cause soil disturbances.

Many drilling fluids contain alkaline compounds, such as sodium hydroxide (NaOH) or lime ($Ca(OH)_2$), which are used to adjust the properties of clay during drilling and, when they seep into the soil, lead to a high pH level.For example, a study conducted in Arkansas found that the average pH of soil contaminated with drilling fluid rose to about 8.0 compared to 6-7 in non-contaminated soil (AAPG, 2023).

Similarly, soil contaminated with crude oil becomes more alkaline due to the decomposition of some oil compounds into alkaline products, in addition to the consumption of natural organic acids during the breakdown of hydrocarbons. In a study of wetlands in China, the pH score of soil contaminated with crude oil rose to 8.0 (Wang et al., 2013). This high pH can reduce the solubility of some essential nutrients such as phosphorus, iron and zinc, affecting crop growth and productivity..

2. Salinity and accumulation of salts

Increased soil salinity is one of the most negative effects of drilling fluids, especially aqueous base clay Drilling tailings and associated production water contain high concentrations of salts, such as sodium chloride (NaCl), which can seep into the soil and raise the electrical conductivity coefficient (EC), a key indicator of salinity level.

In a study of agricultural soils exposed to drilling fluids, it was found that soil electrical conductivity increased to 2.6dS/m, twice as high as the planting limit, compared to 0.06 dS/m in non-contaminated soils (Calciu & Plopeanu, 2011). The chloride concentration has also exceeded 2,000 ppm, a high level that can lead to disturbances in plant water and nutrient absorption, which can lead to plant death or reduced productivity (Oil & Gas Portal, 2025).

As for crude oil, although it does not contain large amounts of salts, some types may contain organic compounds that decompose and produce ions that affect soil salinity in the long run. Soil pollution with crude oil may also be accompanied by salt water or saline sediments, contributing to increased soil salinity and its impact on plants (Saikia, Bora, & Gogoi, 2023).

3. Increase organic carbon and organic matter

The leakage of crude oil into the soil leads to a significant increase in the total organic carbon content, as crude oil consists mainly of hydrocarbon organic compounds that are not easily biodegradable..

In an experiment conducted in Nigeria, it was found that the percentage of organic carbon in soil contaminated with crude oil rose from 1.5% to 3.7%, reflecting an increase in non-degrading organic matter (Nwankwo & Ogbonna, 2017). Total petroleum hydrocarbon (TPH) concentration in the soil has also increased, indicating the presence of large amounts of petroleum pollutants that can remain in the soil for long periods (Swigart et al., 2021).

As for drilling fluids, their effect on organic matter depends on their type.:

Oil-based mud significantly increases total organic carbon in soil.

Water-based mud may not have much effect on organic matter, but it may leave polymeric materials that can alter the chemical properties of soils (Basic, 2009).

4. Variable nutrient availability (NPK: nitrogen, phosphorus, potassium)

Soils contaminated with crude oil or drilling fluids are subject to an imbalance in the levels of essential plant nutrients, such as nitrogen (N), phosphorus (P) and potassium (K).

In a study conducted in Nigeria, it was found that the phosphorus content available in oil-contaminated soil decreased from 93 mg/kg to 41 mg/kg, a decline of more than 50%, due to the consumption of phosphorus microorganisms during the breakdown of petroleum hydrocarbons (Nwankwo & Ogbonna, 2017).

Some studies have also recorded a decrease in the concentration of exchangeable potassium in soil contaminated with crude oil, which negatively affects plant growth (Shanahan, 1999).

In contrast, some nutrients in soil contaminated with drilling fluid may rise if they contain elements such as potassium or phosphorus, especially if potassium chloride (KCl) is used in base clay..

5. Accumulation of heavy metals and toxins

Heavy metals are one of the main chemical hazards associated with soil contamination with drilling fluids and crude oil. These minerals include: barium, cadmium, chromium, lead, mercury, and arsenic, which can accumulate in the soil and travel to plants through the roots, posing a significant health risk (Heo et al., 2021).

In a study conducted in Arkansas, concentrations of heavy metals were detected in soil contaminated with drilling fluids, but they were within legally permissible limits (Wang et al., 2013).

However, some types of crude oil contain nickel and vanadium, which increases levels of long-term soil contamination (AP News, 2023).

These analyses indicate that contamination with drilling fluids and crude oil causes significant chemical changes in the soil, negatively affecting its fertility and crop productivity. Thus, there is an urgent need to develop effective techniques to treat contaminated soils and restore their ability to support agricultural production..

Impact on crops and plants

Changing the chemical properties of the soil as a result of contamination with drilling fluids or crude oil have negative repercussions on the growth of plants and crops. Soil salinity and high alkalinity, accumulation of toxic substances, and nutrient deficiencies affect plants' ability to absorb water and nutrients, which ultimately affects seed germination, seedling growth, and crop yield (Saikia, Bora, & Gogoi, 2023).

1. Damage to germination and seedling growth

Germinated seeds and young seedlings are particularly affected by oil or salt pollution in the soil. The layer of crude oil on the surface of the soil or scattered within its pores can significantly hinder the germination process.

Scientific experiments show that seeds may be delayed in germination or their germination rate significantly decreases in soils contaminated with crude oil compared to non-contaminated soils (Basic, 2009

This effect is due to several factors, including::

The formation of an insulating layer of oil around the seeds, preventing them from absorbing enough water for germination.

Some volatile oil components can permeate the seed shell and toxicly affect the plant embryo.

Oil-saturated soils become poorly aerated, as oil compounds encapsulate soil molecules and prevent the normal movement of air and water..

A study of maize, okra and pumpkin crops showed that germination rates decreased sharply when soil pollution with oil exceeded 2% of soil weight (Swigart et al., 2021). For high salinity drilling fluids, high osmotic potential in contaminated soil may prevent seeds from absorbing water, slowing or preventing germination altogether. Even in cases where seedlings succeed in germinating, they often suffer from deformities and poor growth from the earliest stages..

Figure 2: Oil-contaminated water mixing with irrigation water and flooding part of an agricultural field (corn crop) in Colorado, United States, flooding plants with an oil layer that damaged their leaves and soil.

2. Salinity stress and alkalinity of the soil

High levels of soluble salts in the rhizospheric root zone lead to severe osmotic stress, as plants have difficulty absorbing water due to the high concentrations of salts in the soil..

- When soil salinity is high, plants need to make a greater osmotic effort to draw water from a salt-concentrated pedagogical medium, resulting in a physiological thirst state, where the soil is outwardly moist but unavailable to plants..
- Excess salts (especially sodium and chloride) may be toxic to plant cells in high concentrations, inhibiting the absorption of other nutrients, such as potassium, affecting plant growth and production (Calciu & Plopeanu, 2011).

In salt-sensitive plants, symptoms of saline stress manifest themselves as burning leaf edges, poor overall growth, and reduced productivity. For example, a study found that the accumulation of salts from drilling waste led to an almost complete absence of natural vegetation in some parts of experimental fields before treatment (Oil & Gas Portal, 2025).

High soil alkalinity (pH) may lead to a decrease in the availability of nutrients such as iron, zinc and manganese, due to their deposition in a non-absorbable form. Symptoms of deficiency of these elements appear on plants in the form of yellowing of leaves and poor growth, especially in alkaline-sensitive crops, such as corn and wheat (Wang et al., 2013).

3. Direct toxic effects of oil on the plant

Crude oil carries many toxic organic compounds that affect plants directly or on beneficial soil microorganisms.

- Some components of crude oil, such as polycyclic aromatic hydrocarbons (PAHs), have toxic and mutagenic effects, and can be absorbed by plant roots in trace amounts, damaging plant cells and slowing their growth (Heo et al., 2021).
- Wrapping the roots with an oil layer hinders the gas exchange needed for root respiration, making the root environment anaerobic and disrupting nutrient absorption..
- In actual contamination incidents, trees and perennials whose roots were flooded with oil were found to wither and die within a few weeks, while short-lived crops (such as vegetables and grains) did not germinate primarily (Nwankwo & Ogbonna, 2017).

4. Low plant density and yield

Even in cases where the plant does not die directly, contaminated soil reduces the density of growing plants and reduces the final yield of the crop..

- In an experiment conducted by Kisić and colleagues on soil contamination with crude oil, it was observed that contaminated experimental plots experienced a decrease in germination density and the number of plants remaining until harvest, which was reflected in lower yields during the first year (Kisić et al., 2010).
- In Nigeria, farmers recorded significant losses in maize and yam production following soil contamination with crude oil, with field productivity falling below 50% compared to normal years (Saikia, Bora, & Gogoi, 2023).
- In some cases, it has been observed that adding small amounts of drilling mud to poor soils may lead to a slight improvement in yield, but large quantities cause a clear decline in production (Basic, 2009).

5. Effects on crop quality and safety

Besides low productivity, contaminated soils may contaminate crops with toxic substances, affecting their quality and safety for human consumption..

- Studies have recorded that some heavy metals, such as barium and manganese, have moved from soil contaminated with drilling fluids to soybean plant tissue, increasing the proportion of these metals in seeds (Heo et al., 2021).
- In cases of oil pollution, root crops such as carrots and potatoes can absorb some hydrocarbons, making them unfit for consumption without extensive cleaning and treatment (Swigart et al., 2021).

Scientific evidence suggests that contamination with drilling fluids and crude oil negatively affects all stages of plant growth, from germination to productivity and quality. While the degree of impact varies according to the type and concentration of pollutants and the type of plant, the overall results confirm that there are significant losses in agricultural production in the affected areas. Therefore, adopting strategies to address contaminated soils is essential to maintain agricultural sustainability and food security in these areas..

Case studies on the impact of soil pollution with oil and drilling fluids and treatment methods

1. Environmental Risk Assessment Methodologies

Environmental risk assessment is one of the most important scientific activities aimed at analyzing and measuring the risks resulting from soil pollution, especially soil pollution with hydrocarbons resulting from a crude oil spill. This assessment requires a structured methodology consisting of five interrelated modules (Calciu & Plopeanu, 2011).

1. **Risk assessment**: analysis of the seriousness of environmental pollutants and their impact on soil and plants.

2. **Risk identification:** Identify sources of pollution and their potential impacts on the environment and humans.
3. **Environmental risk management:** developing strategies to mitigate the effects of pollution and treat damaged soils.
4. **Assessment**: Measuring the degree of risk based on scientific and empirical data.
5. **Environmental risk severity assessment according to regulatory standards**: determining the extent to which pollution affects the ecosystem and communities

This assessment is based on the analysis of comprehensive environmental data, including the properties of oil and drilling fluids, specifications of equipment used in industrial activities, physical and chemical measurements of soil contaminants, and risk assessment methods (Oil & Gas Portal, 2025).

2. Hydrocarbon pollution and soil treatment

Hydrocarbon soil pollution is one of the most common forms of soil pollution and is caused by various sources, such as oil spills, diesel spills, and industrial waste spills. This type of pollution poses a significant environmental and health threat, as pollutants can lead to the intrusion of hazardous substances into groundwater, increasing the risk of human exposure to pollutants and their transmission through the food chain (Saikia, Bora, & Gogoi, 2023).

Various strategies have been used to address oil pollution in soils, including phytoremediation using Eucalyptus globulus, where studies have shown that this method has helped reduce pollution levels below regulatory thresholds, despite the high cost of this technique (Calciu & Plopeanu, 2011).

3. Case studies of contaminated industrial sites

A. Cavaro Website – Brescia, Italy

One notable example of soil contamination with organic pollutants is Caffaro's site in Brescia, Italy, where industrial activity has contaminated the soil with polychlorinated biphenyls (PCBs), which are some of the most persistent toxic compounds in the environment..

Despite ENI Rewind's remediation efforts, some areas of the site still have high pollution levels that hinder land reuse, indicating ongoing challenges in managing contaminated industrial sites (Oil & Gas Portal, 2025).

B. Chemical Manufacturing Site – Northern Italy

A chemical manufacturing site in northern Italy has faced severe contamination with organochlorine compounds, including carbon tetrachloride (Tetrachloromethane) and chloroform, as a result of the leakage of these compounds from underground storage tanks..

The environmental risk assessment showed high concentrations of pollutants, which necessitated the implementation of a multi-phase treatment program, which included:

- Bioremediation to break down pollutants using microorganisms.
- Air Sparging to accelerate the dismantling of VOCs in soil and groundwater.

This process took seven years, reflecting the importance of long-term monitoring after treatment to ensure compliance with environmental standards (Oil & Gas Portal, 2025).

4. Applied studies on the effect of oil pollution and drilling fluids on soil

A. Soil Contamination with Drilling Fluids – Arkansas, U.S.

A case study at the Landfarming, Arkansas site provided a clear model of the effect of drilling fluid accumulation on soil and plant growth.

The site included three pilot fields, which were treated with varying levels of slurry waste and associated water from oil well drilling operations. The results showed that the most polluted field (Field 3) experienced drastic changes in its soil, where:

- The salinity level increased sharply (electrical conductivity ≈ 2.6dS/m, versus 3C0.1% in natural soils).
- The chloride concentration exceeded 2165 mg/kg, exceeding the permissible regulatory limit (1000 mg/kg).
- Sodium accumulation to high levels, negatively affecting soil fertility.
- The soil became black with a pronounced hydrocarbon odor, and little vegetation was visible due to severe salt stress and nutrient deficiencies (AAPG, 2023).

Soil treatment by(Swigart, Heo, & Wolf, 2021)

- Add nitrogen and phosphorus fertilizers to compensate for nutrient deficiencies.
- Implement plowing and planting salt-tolerant plants.
- Washing the soil to reduce the concentration of harmful salts.

One year after the start of treatment, the site has regained its ability to support vegetation by almost 100%, confirming that the acute negative impacts of drilling fluids can be reduced through integrated treatment strategies..

B. Soil Contamination with Crude Oil – Nigeria

A pilot study was conducted in Nigeria to simulate an oil spill on agricultural soil.:

- Contamination of soil with varying amounts of crude oil (0% - 5% soil weight).
- Growing seedlings of cocoa, cashews, papaya, and mango to monitor their response (Nwankwo & Ogbonna, 2017).

Key findings:

- Organic carbon increased from 1.52% to 3.66% in contaminated soil, reflecting an increase in non-degrading organic matter.
- Available phosphorus decreased from 93.4 mg/kg to 41.0 mg/kg, indicating deteriorating soil fertility.
- The planted seedlings were severely affected at high oil concentration, where:
- Poor growth and yellowing of leaves.
- Increase in mortality among seedlings, especially when contaminated by more than 4% crude oil.

Recommendations:

- Using lime (liming) to adjust the pH.
- Add fertilizers to compensate for nutrient deficiencies.
- Soil tillage and aeration to accelerate the decomposition of pollutants.

These applied studies reflect the profound impacts of oil pollution and drilling fluids on soils and crops, and confirm that reclamation and remediation strategies are necessary to ensure the restoration of soil fertility and the rehabilitation of environmentally damaged areas..

Pollution mitigation strategies

Addressing the negative impacts of drilling fluids and crude oil on soils and crops requires an integrated approach that combines prevention, treatment and sustainable environmental management approaches, as these strategies aim to reduce pollutant production, improve waste management, and restore contaminated soil to ensure the sustainability of ecosystems. Pollution prevention is one of the most important methods used in this context, as it relies on reducing the production of pollutants from the source by improving drilling operations and monitoring them accurately to avoid unnecessary leaks, in addition to developing less toxic and more environmentally friendly drilling fluids, such as water-based base mud that reduces environmental impacts compared to oil drilling fluids. The recycling and use of drilling fluids also directly contributes to reducing the amount of waste generated by drilling, which reduces the possibility of long-term pollution, which has prompted many companies operating in the oil field to adopt advanced treatment systems to reuse these fluids instead of disposing of them in the environment..

When pollution is inevitable, waste management and treatment become indispensable to prevent the spread of pollutants and minimize their negative impact on soil and plants. Waste management requires that it be accurately classified before disposal by determining the concentration of chemical pollutants in drilling fluids and oil spills, making it easier to separate contaminants from the soil and make the most appropriate decision to treat them. Bioremediation is an effective technique in this field, as it relies on stimulating microorganisms in the soil to break down organic pollutants such as petroleum hydrocarbons, making them less harmful. This process can be enhanced by biostimulation, which relies on the addition of nutrients or changing soil conditions to stimulate microbial activity responsible for the decomposition of crude oil and heavy metals. By enhancing the ability of microorganisms to break down pollutants, progressive reclamation of affected soils can be achieved in more sustainable ways than traditional decontamination methods..

Various techniques are used to remove contaminants from the soil, including soil washing, which relies on removing contaminants by dissolving them in a chemical solution or using high-pressure water, which is effective but may affect soil fertility if the materials used are not controlled. Another solution that has proven effective in mitigating environmental pollution is phytotherapy, which relies on the use of plants capable of absorbing pollutants or stabilizing them in their roots, which helps clean the soil by natural means. This technique is one of the sustainable methods of treating contaminated soil, as some plants such as eucalyptus can absorb heavy metals and reduce oil pollution, and planting specialized herbs can help stabilize pollutants inside the roots and prevent their spread, or stimulate the activity of beneficial bacteria that decompose organic pollutants inside the soil..

Long-term plans to monitor and manage soil health are key elements in reducing environmental pollution, as periodic monitoring systems contribute to determining the levels of pollutants in soil and groundwater and controlling changes that may occur over time. By developing early warning systems, any changes in soil quality can be monitored or new pollutants can be detected before their impact worsens. Environmental legislation also plays a pivotal role in obliging oil companies to take strict measures to ensure the safe disposal of waste and implement effective treatment methods to protect soil and natural resources. The implementation of long-term reclamation programs, which rely on the use of modern environmental and agricultural techniques, can contribute to restoring soil fertility and reducing the impact of pollution on agricultural production..

Mitigating pollution from drilling fluids and crude oil requires an integrated approach that includes prevention, treatment and long-term environmental monitoring. Despite the challenges associated with these operations, adopting sustainable solutions such as recycling waste oil, developing environmentally friendly drilling fluids, and stimulating the biodegradation of pollutants can significantly contribute to reducing negative impacts on the environment, soil and agriculture. With the global trend towards sustainability, it has become imperative that companies in the oil and gas sector adopt strict environmental management policies to ensure the protection of natural resources and preserve the ecological balance for future generations..

Previous studies

Many scientific studies have dealt with the impact of pollution caused by drilling fluids and crude oil on soil and plants, where research focused on the chemical and physical changes that occur in the soil as a result of this pollution, and its impact on crop productivity and vegetation density. Some studies have also attempted to explore the possibility of reclaiming contaminated land through bioremediation and agricultural techniques..

In a three-year study, Kisić et al. (2010) monitored changes in soil properties, plant density and crop productivity under the influence of contamination with drilling fluids and crude oil. The effect of these pollutants on different crops, including corn, winter wheat, barley, soybeans, and rapeseed, was tested, with the results revealing that drilling fluids had a stronger effect on the chemical properties of the soil, while crude oil had a more impact on plant density and crop production. Although the effect was evident during the first year, soil characteristics began to gradually improve in subsequent years, especially after the implementation of agricultural management practices, such as tillage, aeration and bioremediation, which helped reduce hydrocarbon concentrations to acceptable levels by the second year..

In a recent study conducted in Arkansas, United States, Heo et al. (2021) evaluated the effect of applying drilling fluids and associated water to agricultural soils using Landfarming technique. This study showed that soil salinity increased significantly in areas exposed to accumulation of digging waste, and sodium and chloride concentrations rose to elevated levels that affected the soil's ability to support plants. In addition, a significant decrease in the levels of essential nutrients, such as nitrogen and available phosphorus, was observed, resulting in patches of untreated arable soil. Although the pH of the soil rose to a moderate base level (about 8) due to excavation residues, it remained within the legal limits..

As for the effect of crude oil on soil in natural environments, it was addressed in a study conducted in the wetlands of the Momoge Reserve in China, where the results showed that soil pollution with crude oil led to an increase in soil alkalinity (pH ≈ 8.0), in addition to a clear decrease in the level of phosphorus available to the plant. The researchers also noted that the concentration of organic carbon in contaminated soil was much higher than in non-contaminated soil, reflecting the accumulation of petroleum substances in the soil. The researchers recommended that phytoprocessing techniques, such as growing certain types of herbs, should be used to help gradually remove and analyze oil contaminants..

In another study by Imarhiagbe and Obayagbona (2020), the environmental impact of drilling residues from oil well drilling operations in the Ologbo oil field in Edo State, Nigeria was analyzed. The study found that these residues represent a significant environmental hazard due to their non-degrading oil mud, prompting researchers to recommend the application of biodegradation techniques as an effective and sustainable way to address pollution before discharging waste into the environment..

In a similar vein, Saikia et al. (2023) conducted a study on the impact of crude oil pollution on the physical and chemical properties of soils in the area of Sildubi, Borhola, Assam, near drilling sites. The results showed that soil contaminated with crude oil contained higher proportions of organic carbon and organic matter, and was more alkaline than non-contaminated soil. A decrease in moisture and electrical conductivity was also observed in contaminated soil, as well as changes in nutrient distribution, as levels of phosphorus, calcium, and nitrogen in contaminated soil increased, while high iron concentrations recorded levels that increased plant stress, resulting in reduced crop productivity..

Basic (2009) conducted a four-year experiment to study the effect of elevated levels of total petroleum hydrocarbons (TPH) on soil and agricultural crops. The experiment included eight treatments in which clean soils were used against soils contaminated with drilling fluids and crude oil, where the results showed that the impact of pollutants was greater in the first year, and then began to gradually decline during the following years, especially with the application of environmental and agricultural management practices. The study also showed that drilling fluids clearly affected the chemical balance of the soil, while crude oil had a stronger impact on plant density and productivity..

In another study by Swigart et al. (2021), the effect of drilling fluid residues and produced water on soil properties was assessed using field and laboratory investigations in Arkansas, United States The study showed that electrical conductivity and sodium and chloride levels increased significantly after the application of drilling fluids and produced water to the soil. The researchers also noted that the levels of nitrogen and phosphorus available to the plant were very low, which negatively affected the growth of plants, and recommended that fertilizers containing nitrogen and phosphorus should be used to improve the soil..

Regarding the effect of pollution on nutrient absorption, Shanahan (1999) conducted a study on the effect of drilling fluids on the availability of iron and zinc in the soil using the sorghum bicolor grass as an agricultural model. The results showed that the increased concentration of iron available to the plant improved crop yield, and it was also observed that increased zinc availability had a positive effect on corn growth. The study noted that the application of drilling fluids at controlled rates can have limited agricultural benefits, but it can be problematic if applied in inappropriate concentrations..

In another study by Calciu & Plopeanu (2011), the effect of crude oil pollution on the physical and chemical properties of the soil was analyzed through a field experiment inthe Perisoru region, Braila Prefecture. The results showed that the concentration of organic carbon increased significantly in soil contaminated with crude oil, and the ratio of carbon to nitrogen (C/N) also increased, reflecting a change in the nutrient balance within the soil. Conclusion

These studies suggest that oil pollution and drilling fluids negatively affect soil fertility and crop productivity, with each having a different impact in terms of how long it takes for natural recovery. Research also highlights the importance of adopting bioremediation and agricultural technologies, such as stimulating microorganisms and growing plants capable of stabilizing pollutants, to ensure long-term restoration of soil health and productivity..

General conclusions of the study

This study showed that soil contamination with drilling fluids and crude oil leads to complex chemical and physical changes that directly affect soil fertility and crop productivity. Drilling fluid leakage has been shown to raise soil salinity and change its pH, decreasing the ability of plants to absorb nutrients. In contrast, soil pollution with crude oil leads to an increase in organic carbon but causes disturbances in the nutrient balance, leading to plant stress and reduced crop productivity. The results also revealed that damaged soils take a long time to recover, but practices such as bioremediation and phytotherapy may accelerate soil restoration of productive capacity. Applied case studies have shown that pollution can have a short-term impact if effective remediation strategies are applied, or long-term if appropriate environmental intervention is not implemented..

Recommendations

- Improve pollution prevention policies by requiring oil companies to use environmentally friendly drilling fluids and adopting effective management systems that reduce oil spillage and industrial waste.
- Strengthen soil and groundwater monitoring systems for early detection of any changes caused by oil pollution, helping to take swift action before environmental damage worsens.
- Apply sustainable environmental reclamation techniques, such as bioremediation and phytoremediation, which have been shown to improve soil quality and reduce environmental risks.
- Introducing integrated oil waste management programs based on recycling and safe treatment before disposal, which contributes to reducing negative impacts on soil and groundwater.
- Conduct further field research on the long-term impacts of oil pollution, particularly on the impact of heavy metals and aromatic hydrocarbons on crops and ecosystems.
- Strengthen environmental legislation in the oil and gas sector to ensure that companies adhere to strict environmental standards, and encourage innovation in the development of more sustainable technologies to address pollution.
- Raise awareness among polluted-affected communities on ways to deal with damaged soils, the importance of using organic fertilizers and environmental improvement strategies to restore agricultural production.

The end

The problem of soil pollution with crude oil and drilling fluids is a serious environmental issue that directly affects the fertility of agricultural land and crop productivity, threatening food security and ecosystems. Despite the seriousness of this problem, there are a range of solutions and strategies that can be adopted to mitigate the effects of pollution and restore soil health. By implementing prevention strategies, developing advanced treatment techniques, and strengthening environmental legislation, the negative impacts of this pollution can be reduced and the long-term sustainability of agricultural and ecological systems ensured. Thus, the integration of the efforts of researchers, decision-makers and actors in the oil and agricultural sector is crucial for the conservation of natural resources and the achievement of sustainable environmental development..

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