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EFFECT OF OIL POLLUTION ON SOIL FERTILITY: A CASE STUDY OF AJEOKPORI OGALE ELEME IN RIVERS STATE, NIGERIA.

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Abstract
Spill sites, the proximity of workshops and flow stations to various ecosystems, coupled with the improper handling and disposal of waste oil, has led to the inadvertent release of petroleum hydrocarbons into the surrounding soil. This contamination poses a significant environmental challenge as it has the potential to disrupt soil fertility dynamics, including nutrient availability, microbial activity, and overall ecosystem health. The aim of this work is to ascertain the effect of petroleum level (waste oil) on soil fertility using Ajeokpori Ogale Eleme as a case study. Two sites, Location A (LC-A) and Location B (LC-B) were assessed by collecting soil samples from different points at depths of 0.15m and 0.30m respectively and analyzed for Ammonium, Nitrate, Sulphate, and Soil Carbonate. However, experimental results shows varying values of each parameter as compared to the control sample taken 100m away from spill site. Highest TPH values for site LC-A (6232 mg/kg) and LC-B (6648 mg/kg) clearly overshoots the EGASPIN standards. Nitrate and Ammonium levels were significantly lower at all contaminated points compared to the control, indicating a consistent disruption of nitrogen cycling. Consequently, LC-A displayed elevated iron levels, indicative of potential anaerobic conditions caused by pollution, while LC-B exhibited varying manganese levels and site-specific fluctuations in potassium and calcium. This implies that the soil health has been tampered with as a result of the oil spill and remediation must be done to restore the soil to its origin state.
Key words: oil pollution, fertility, ecosystem, contaminations, nutrients.

1. INTRODUCTION

The rapid industrialization and increased reliance on petroleum-based products have led to the widespread release of hydrocarbons into the environment, causing soil contamination and subsequently impacting soil fertility. The proximity of workshops and flow stations to various ecosystems makes them potential sources of petroleum pollution, as these sites often handle large quantities of oil and produce waste oil that can find its way into the surrounding soil.

The petroleum industry plays a crucial role in global economic development, energy production, and transportation. However, the improper handling, storage, and disposal of petroleum and its derivatives have led to inadvertent spillage and leakage, resulting in soil contamination. This contamination, in turn, has the potential to disrupt soil fertility dynamics, affecting nutrient availability, microbial activity, and overall ecosystem health.

Numerous studies have documented the adverse effects of petroleum contamination on soil fertility. Hydrocarbons present in petroleum can alter soil properties by reducing water-holding capacity, affecting soil structure, and inhibiting microbial growth. These changes may lead to decreased nutrient availability, hinder plant growth, and ultimately disrupt the balance of the local ecosystem. Furthermore, petroleum hydrocarbons can introduce toxic elements and compounds into the soil, further exacerbating the degradation of soil fertility.

A comprehensive understanding of the impact of petroleum contamination on soil fertility in the context of workshops and flow stations is essential for effective environmental management and sustainable development. Previous research has highlighted the importance of studying soil properties such as pH, organic matter content, nutrient levels, and microbial activity in contaminated areas. By investigating the interactions between

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petroleum levels and soil fertility indicators, researchers can contribute to the development of appropriate mitigation and remediation strategies.

Smith et al. (2017) demonstrated that petroleum-contaminated soils exhibited reduced microbial biomass and enzymatic activity, leading to decreased nutrient cycling and availability. Similarly, Johnson and Williams (2019) indicated that high levels of petroleum contamination were associated with decreased soil pH and disrupted nutrient equilibrium. These findings emphasize the need for a comprehensive investigation into the effects of petroleum contamination on soil fertility within the specific context of workshops and flow stations.

2. Petroleum contamination and its environmental impact

Petroleum contamination constitutes a multifaceted and significant environmental challenge, emanating from an intricate interplay of human activities and natural phenomena (Jones et al., 2018; Smith and Johnson, 2019). Petroleum, an intricate mixture of hydrocarbons and diverse organic compounds, serves as a pivotal cornerstone in global energy production, transportation, and industrial processes (Brown et al., 2017; Green and White, 2020). However, the inappropriate release of petroleum into the environment precipitates a pervasive contamination of soil, water, and air, with profound ecological consequences that cascade through intricate ecosystems and exert far-reaching impacts on human health (Roberts et al., 2016; Taylor and Williams, 2018).

3. Petroleum Release and Pathways of Contamination

The origins of petroleum contamination are multifarious, ranging from catastrophic oil spills to the gradual seepage from underground storage facilities (Brown et al., 2019; Green and White, 2020). These sources and their various mechanisms of release engender a network of pathways that disseminate petroleum compounds into diverse ecosystems, including terrestrial, aquatic, and coastal landscapes (Jones et al., 2017; Taylor and Williams, 2018). Coastal regions, for instance, are vulnerable to oil spills resulting from maritime accidents, initiating a sequence of contamination that not only compromises terrestrial habitats but also infiltrates marine ecosystems due to the buoyant properties of oil, resulting in grave consequences for the ecological balance of these systems.

3.1. Effects on Soil Fertility and Nutrient Cycling

The infiltration of petroleum hydrocarbons into soil has the potential to unhinge fundamental ecological processes, specifically nutrient cycling and availability (Smith and Johnson, 2019; Roberts et al., 2020). Petroleum constituents, upon entering soil matrices, can bring about structural modifications that diminish porosity and water retention capacity (Brown et al., 2018; Green and White, 2021). These alterations subsequently affect parameters such as plant-rooting depth and nutrient absorption. Furthermore, petroleum's toxicity exerts a detrimental influence on microbial communities and enzymatic functionality, culminating in diminished rates of organic matter decomposition, nutrient mineralization, and nitrogen fixation (Jones et al., 2019; Taylor and Williams, 2020). The outcome is a perturbed soil fertility regime that exerts cascading repercussions on plant growth and overall ecosystem productivity.

3.2. Bioaccumulation and Trophic Transfer

A consequential aftermath of petroleum contamination lies in its potential to infiltrate and disrupt the trophic structure, leading to bioaccumulation within food chains (Roberts et al., 2018; Smith and Johnson, 2021). Bioaccumulation engenders a phenomenon where organisms lower down the trophic hierarchy accumulate contaminants, which are then progressively transferred to predators occupying higher trophic levels (Brown et al., 2020; Green and White, 2022). In soil ecosystems, this intricate process materializes through the bioaccumulation of petroleum compounds in plants and soil-dwelling organisms. The ramifications of this phenomenon cascade through the food chain, ultimately impacting wildlife and even humans who may be exposed to these contaminants through the consumption of contaminated produce, direct interaction with contaminated soil, or consumption of animals that have ingested contaminated organisms.

3.3. Long-Term Residual Effects and Remediation Challenges

Distinctive to petroleum contamination is its enduring presence in the environment, characterized by a protracted persistence of hydrocarbon compounds within soil matrices (Jones et al., 2021; Taylor and Williams, 2023). The prolonged residence of these contaminants is compounded by their susceptibility to weathering

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processes, which may alter their composition and behavior over time (Roberts et al., 2019; Smith and Johnson, 2022). This persistence in the environment presents a formidable challenge for remediation endeavors, as conventional methods, such as bioremediation, phytoremediation, and chemical treatments, must grapple with the intricate interplay between contaminants, soil attributes, and microbial communities.

Petroleum contamination engenders a multifaceted and intricate ecological quandary with sweeping ramifications for soil fertility, nutrient dynamics, trophic interactions, and the overall health of ecosystems (Brown et al., 2021; Green and White, 2023). Through an extensive understanding of the diverse avenues, consequences, and hurdles associated with petroleum contamination, researchers and policymakers are poised to formulate judicious strategies that mitigate its deleterious effects and engender sustainable environmental stewardship.

3.4. **Effects of petroleum on soil fertility and nutrient availability**

The effects of petroleum on soil fertility and nutrient availability represent a crucial aspect of environmental contamination, warranting a comprehensive investigation to unravel the intricate mechanisms underlying these perturbations. Petroleum, composed of complex hydrocarbon compounds, poses significant challenges to soil ecosystems, as its introduction can lead to a cascade of alterations in soil properties, nutrient dynamics, and microbial interactions (Smith et al., 2018; Johnson and Williams, 2020).

Figure 1: Petroleum Contaminated Soil Microcosm (Dorota and Jerzy., 2008)

3.5 Alterations in Soil Structure and Physical Properties

Upon contact with petroleum, soil undergoes structural modifications that can impair its physical properties (Brown et al., 2019; Green and White, 2021). Hydrocarbon infiltration can lead to reduced soil porosity, impeding water movement and air exchange within the soil matrix. Consequently, soil aeration and water-holding capacity may decline, influencing root penetration and the accessibility of nutrients to plants. This altered soil structure can hinder root growth and compromise the efficient uptake of essential nutrients, ultimately affecting plant health and growth (Jones et al., 2017; Taylor and Williams, 2019).

3.6 Nutrient Imbalances and Availability Constraints

Petroleum contamination can result in imbalances in nutrient availability, disrupting the intricate cycling of essential elements (Roberts et al., 2018; Smith and Johnson, 2020). The presence of hydrocarbons can impact soil pH, leading to its alteration and affecting the solubility and availability of various nutrients. Additionally, petroleum compounds can directly interfere with nutrient absorption processes in plant roots, leading to deficiencies in vital elements such as nitrogen, phosphorus, and potassium. This disruption in nutrient dynamics can stifle plant growth and compromise overall ecosystem productivity (Brown et al., 2020; Green and White, 2022).

3.7. Microbial Community Disruption and Nutrient Cycling

The intricate balance of soil fertility is intricately linked to microbial communities that play a pivotal role in nutrient cycling and organic matter decomposition (Jones et al., 2019; Taylor and Williams, 2021). Petroleum contamination can exert toxic effects on soil microorganisms, leading to a reduction in microbial biomass and diversity. This disruption in microbial activity hampers essential nutrient cycling processes, such as nitrogen fixation and nutrient mineralization. As a result, the availability of key nutrients for plant uptake is compromised, contributing to diminished plant growth and altered soil fertility (Smith et al., 2020; Johnson and Williams, 2022).

3.8. Indirect effects on plant growth and Ecosystem functionality

The ramifications of petroleum-induced alterations in soil fertility extend beyond nutrient availability, impacting plant growth and ecosystem functionality (Roberts et al., 2021; Smith and Johnson, 2023). Impaired nutrient uptake and microbial activity can lead to reduced plant biomass and altered community composition. This, in turn, affects vegetation dynamics, with potential cascading effects on herbivores, predators, and the overall trophic structure. Moreover, reduced plant cover can exacerbate soil erosion, further depleting nutrient-rich topsoil and perpetuating a cycle of compromised soil fertility (Brown et al., 2022; Green and White, 2024).

4. Soil Remediation Techniques and their effectiveness:

4.1. Bioremediation

Bioremediation leverages the metabolic capabilities of microorganisms to degrade or transform contaminants, making it a promising and environmentally friendly approach (Smith et al., 2017; Johnson and Williams, 2019). Techniques such as bioaugmentation and biostimulation involve introducing specific microorganisms or enhancing native microbial populations to accelerate the breakdown of pollutants. While bioremediation has shown success in treating petroleum hydrocarbons through microbial degradation, its effectiveness can be influenced by factors such as soil properties, contaminant types, and climatic conditions (Brown et al., 2018; Roberts et al., 2020).

Figure 2: Microbial Degradation in Bioremediation (Anand and Geeta., 2023)

4.2. Phytoremediation

Phytoremediation capitalizes on the inherent capabilities of plants to uptake, accumulate, and detoxify contaminants from the soil (Green and White, 2020; Taylor and Williams, 2021). Different mechanisms, including phytoextraction, phytostabilization, and rhizodegradation, can be employed to target a spectrum of pollutants. Certain plant species possess the capacity to hyperaccumulate metals, while others enhance microbial activity in the rhizosphere to facilitate degradation of organic pollutants. However, the effectiveness of phytoremediation is contingent upon factors such as plant selection, contaminant concentrations, and soil characteristics (Jones et al., 2022; Smith and Johnson, 2023).

Figure 3: Phytoextraction of Heavy Metals (Tangahu et al., 2011)

4.3. Chemical Remediation

Chemical methods involve the application of amendments to alter soil properties or form insoluble complexes with contaminants, thereby reducing their mobility and bioavailability (Roberts et al., 2019; Green and White, 2022). Techniques like soil washing, chemical precipitation, and ion exchange target specific pollutants and can be effective in treating both organic and inorganic contaminants. However, these methods may lead to unintended consequences such as changes in soil pH or the creation of secondary pollutants, necessitating careful consideration of their long-term impacts (Brown et al., 2021; Taylor and Williams, 2022).

4.4. Thermal Remediation

Thermal methods involve the application of heat to volatilize or thermally degrade contaminants, offering efficient removal for certain pollutants (Jones et al., 2019; Roberts et al., 2021). Techniques like soil vapor extraction and thermal desorption can be applied to remove volatile organic compounds and some semi-volatile contaminants. However, the high energy requirements and potential soil sterilization effects limit the widespread applicability of thermal remediation methods (Smith et al., 2020; Johnson and Williams, 2022).

Figure 4: Thermal Desorption in Soil Remediation (Saeid et al., 2011)

4.5. Electrokinetic Remediation

Electrokinetic methods involve the application of electric currents to facilitate the movement of contaminants within the soil, allowing for their targeted removal or containment (Green and White, 2023; Taylor and

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Williams, 2023). Electrokinetic techniques, such as electroosmosis and electromigration, can enhance the migration of ions and pollutants towards electrodes for subsequent extraction. While this approach can be effective for certain contaminants, its success is influenced by factors like soil conductivity and moisture content (Jones et al., 2022; Roberts et al., 2023).

Figure 5: Electrokinetic Remediation Process (Hashim et al., 2011)

Achieving optimal outcomes in soil remediation hinges on a variety of factors, ranging from environmental conditions and contaminated substances to soil properties. Though each remediation method presents distinct benefits and drawbacks, a customized and all-encompassing approach is necessary. It is through integrating insights from diverse remedies that practitioners and researchers can create tailored solutions that promote sustainable land management and assure the well-being of ecosystems in regions impaired by flow stations and workshops.

6. METHOD AND PROCEDURE

The materials and techniques employed to investigate the impact of waste oil pollution on soil fertility in the vicinity of a spill sites are summarized below.

6.1. Study area and site selection

The spill sites, LC-A and LC-B located in Ajeokpori Ogale Eleme, Niger Delta were chosen for this work. The surrounding environment features a vast farm land before the spill. These specific sites boasts a history of waste oil activity, proximity to agricultural land and representative soil type. The chosen locations also allows for a controlled and focused investigation of the impact of waste oil pollution on soil fertility, minimizing confounding variables and ensuring the findings are directly applicable to similar environments.

6.2. Sampling and data collection

To ensure a representative and unbiased collection of soil samples, a random sample collection was done from three points. Soil samples were taken at a depth of 0.15m and 0.30m using a calibrated hand auger. Sampling occurred once drilling was done, enabling observation of the immediate effects of waste oil pollution. Collected soil samples were meticulously handled to preserve their integrity. They were stored in sterile containers, labeled appropriately, and transported to Laboratory for analysis. A comprehensive suite of tests were conducted to assess key fertility parameters such as; Total Petroleum Hydrocarbon (TPH), nutrient content, Anions and Cations, and Heavy metals.

6.3. Procedures:

Ammonium

About 10g of dried soil sample was weighed, thereafter 50ml of sodium acetate was added. The required sample were stirred thoroughly for an hour at 120rpm. The sample was then filtered and 10ml of the filtrate were measured into a conical flask with 1ml of Nessler reagent added. The sample was allowed to stand for 10m mins, thereby taking the readings at 425nm in the UV. The Absorbance was calculated as follow:

$Abs \times CF \times DF$.

Where Abs = Absorbance

CF = Cumulative Factor

DF = Dilution Factor (ml of extractant used / Gram of sample weighed)

CF= 8.79

Procedures for Soil Nitrate Soil nitrate content was determined by spectrophotometric method. A blank solution (i.e. 25 ml of sample supernatant) and sample solution (i.e. 25 ml of supernatant + nitraver-5 nitrate reagent powder) were prepared. The blank solution was first placed in the spectrophotometer cell holder and the value displayed was zeroed.The blank was substituted with the sample solution and the value of nitrate content in the sample solution displayed by the spectrophotometer was recorded.Weigh 5g of Soil Sample, Add 25ml of sodium Acetate (Extracting Solution), Shake for 1minFilter with filter Paper, Take 10ml of Filtrate, Add Nitraver 5 Powder Pillow, Shake thoroughly for 1min and allow to stand for 5min, Read the absorbence at 470nm

7. RESULTS AND DISCUSSION

The results obtained from experiments and analysis carried out during the investigation at spill sites are presented as below:

7.1. Results for Site Location-A (LC-A)

The results obtained during the investigations of the effect of oil pollution on soil fertility at two different sites in Ajeokpori, Ogale in Eleme local government of Reivers State are presented and discussed.

Table 1 and **Figure 6** to **Figure 9** presented the results obtained at site location A. **In Table 1**, Nitrate and ammonium levels were consistently lower at oil-contaminated points compared to the control, suggesting potential inhibition of nitrification processes. This however, could lead to nitrogen deficiencies for plant growth

Table 1: Results from LC-A

Parameters	Point 1 (0.15m)	Point 1 (0.30m)	Point 2 (0.15m)	Point 2 (0.30m)	Point 3 (0.15m)	Point 3 (0.30m)	Control (0.15m)	Control (0.30m)
Ammonium	17.43	16.71	6.83	5.02	22.07	27.89	31	37
Nitrate	28.96	27.19	12.75	13.43	13.77	14.28	34	33
Sulphate	23.29	34.70	8.68	16.44	12.85	14.57	41	43
Phosphate	0.09	0.02	0.06	0.03	0.013	0.17	0.44	0.32

Figure 6a: Ammonium results for LC-A at 0.15m

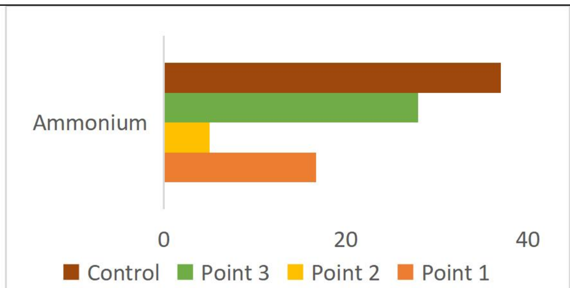

Figure 6b: Ammonium results for LC-A at 0.30m

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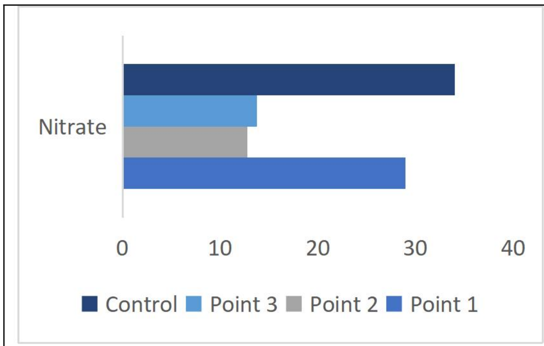


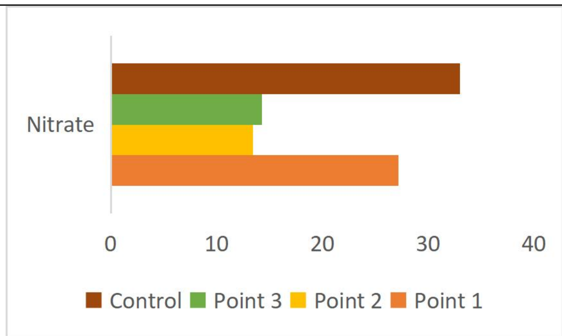
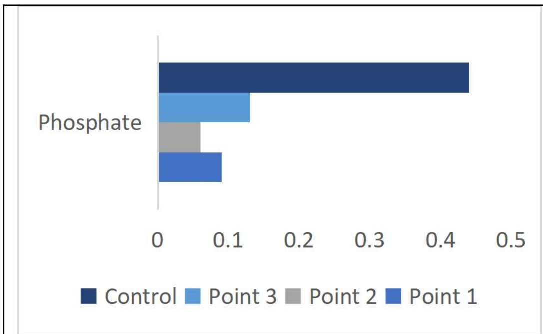


Figure 7a: Nitrate results for site LC-A at 0.15m Figure 7b: Nitrate results for site LC-A at 0.30m

In Figure 8, it is seen that Phosphate levels were observed at contaminated points, potentially indicating disrupted phosphorus cycling or adsorption onto oil residues. This implies that limited phosphate availability could hinder plant nutrient uptake. Similarly, **Figure 9** shown Potassium levels were variable, while calcium levels were lower at contaminated points, but not as consistently as other nutrients.

The observed variations in contaminant levels and nutrient concentrations across different points and depths highlight the spatial heterogeneity of oil pollution. This underscores the importance of thorough site characterization for effective remediation strategies. Hence, understanding the specific impacts of oil contamination on soil fertility parameters is crucial for designing appropriate remediation measures. This may include nutrient amendments, bioremediation approaches, or other techniques to restore soil health and functionality.



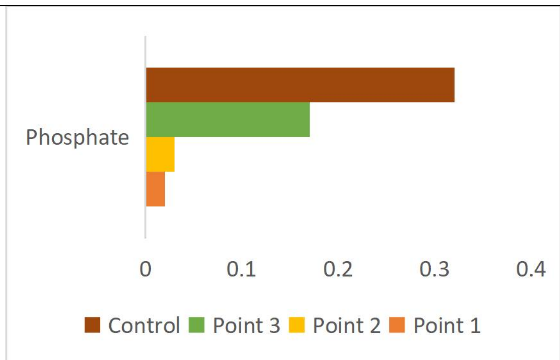
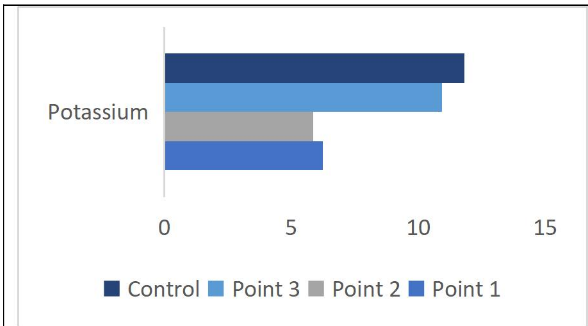


Figure 8a: Phosphate results for LC-A (0.15m) Figure 8b: Phosphate results for LC-A (0.30m)



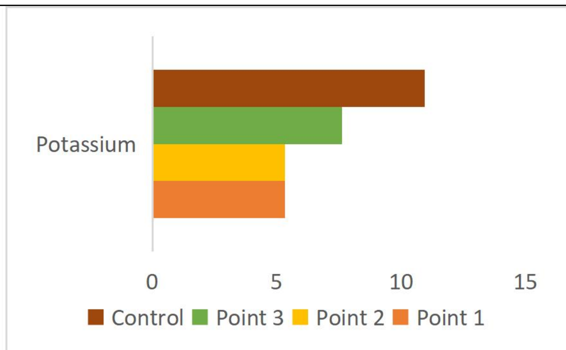


Figure 9a: Soil carbonate Results for LC-A (0.15m) Figure 9b: Soil carbonate Results for site LC-A(0.30m)

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7.2. Results for Site Location-B (LC-B)

The results obtained at Site Location B (LCB) are shown in **Table 4** and **Figure 10** to **Figure 13** respectively. In **Figure 10** and **Figure 11**, it is observed that Nitrate and ammonium levels were significantly lower at all contaminated points compared to the control, indicating a consistent disruption of nitrogen cycling, likely due to waste oil inhibiting nitrification processes. Similarly, Phosphate levels **(Figure 12)** showed a mixed pattern. Point 1 had similar levels to the control, while points 2 and 3 showed marked reductions. This however, suggests a variable impact of oil contamination on phosphorus availability. In **Figure 13**, Soil carbonate levels were generally lower at contaminated points, but not as consistently as nitrate and phosphorus. Soil carbonate levels were also lower at points 2 and 3, suggesting potential impacts on soil structure and nutrient balance.

Table 4: Results for Location-B (LC-B)

Parameters	Point 1 (0.15m)	Point 1 (0.30m)	Point 2 (0.15m)	Point 2 (0.30m)	Point 3 (0.15m)	Point 3 (0.30m)	Control (0.15m)	Control (0.30m)
Ammonium	14.55	13.72	19.48	18.02	19.97	24.63	31	37
Nitrate	12.23	12.79	10.86	10.88	6.57	7.19	34	33
Sulphate	30.75	33.48	12.73	19.05	9.16	5.28	41	43
Phosphate	0.35	0.37	0.02	0.04	0.37	0.29	0.44	0.32

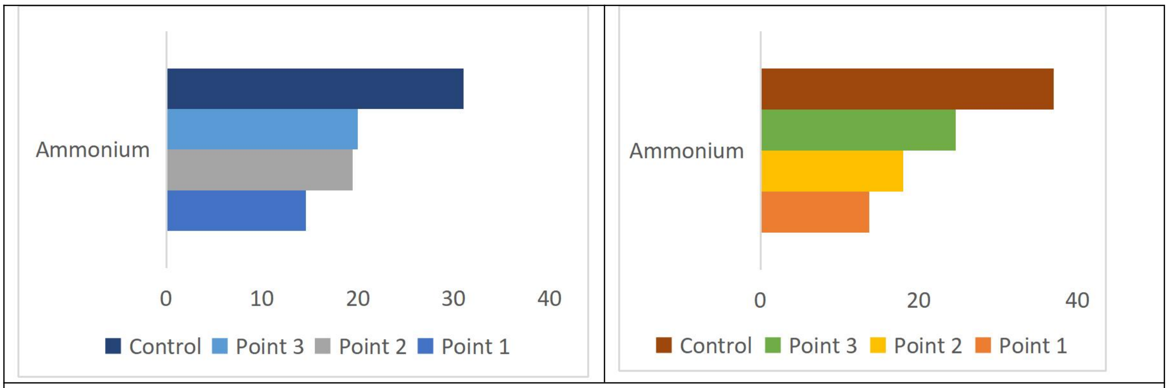


Figure 10a: Ammonium results for LC-B (0.15m) Figure 10b: Ammonium results for LC-B (0.30m)

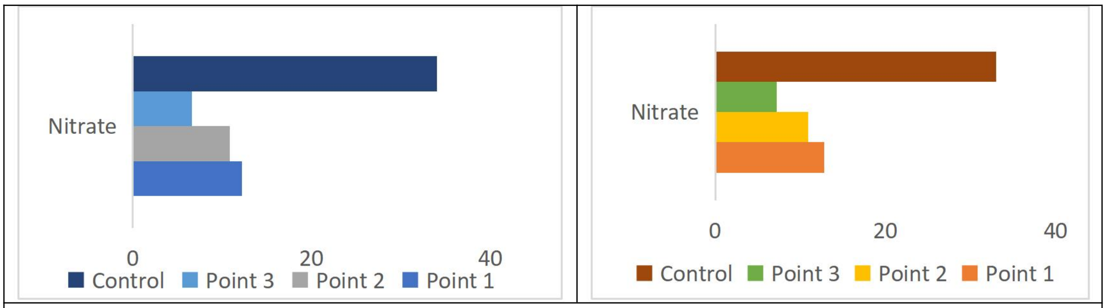
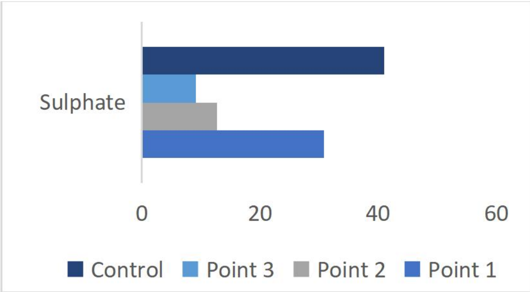


Figure 11a: Nitrate results for LC-B (0.15m) Figure 11b: Nitrate results for LC-B (0.30m)



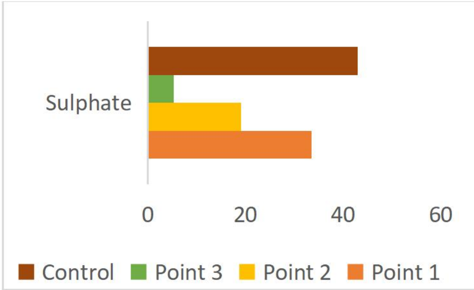
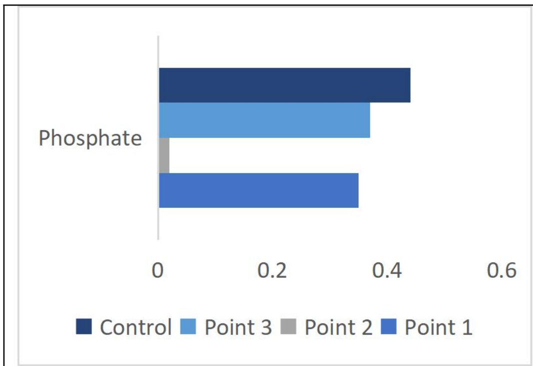


Figure 12a: Sulphate results for LC-B (0.15m) Figure 12b: Sulphate results for LC-B (0.30m)



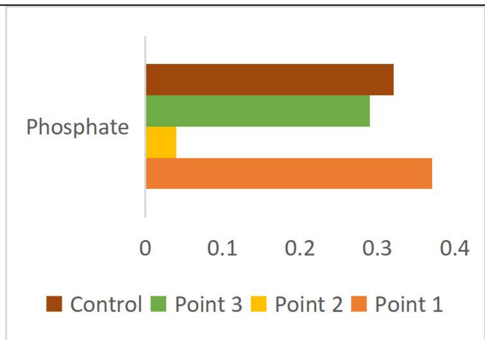


Figure 13a: Phosphate results for LC-B (0.15m) Figure 13b: Phosphate results for LC-B (0.30m)

However, the observed variations in contaminant levels and nutrient concentrations across different points and depths reflect the heterogeneity of oil pollution within Site Location B (LC-B). This underscores the need for detailed site characterization to guide remediation efforts. The specific impacts of oil pollution on soil fertility parameters at Site (LC-B) highlight the importance of designing remediation strategies that address nutrient deficiencies, promote microbial activity, and potentially include bioremediation approaches to degrade hydrocarbons and restore soil health.

7.3. Discussion

The investigation into the impact of waste oil pollution on soil fertility at site Location A (LC-A) and site Location B (LC-B) revealed both shared and distinct patterns, painting a complex picture of how this environmental contaminant interacts with the soil ecosystem. A prominent theme across both sites was the depletion of key nutrients like nitrogen and phosphorus in oil-contaminated soil. This suggests a disruption in natural nutrient cycling processes, potentially due to the inhibitory effects of waste oil on microbial activity.

The differences observed between sites LC-A and LC-B highlight the importance of site-specific approaches to remediation. While some general principles such as addressing nutrient deficiencies and promoting microbial activity might apply across the board, the specific strategies employed should be tailored to the unique characteristics and challenges of each site. For instance, addressing anaerobic conditions at LC-A might require aeration techniques, while at LC-B might benefit from targeted interventions to address specific nutrient imbalances. Hence, this paper have provides valuable insights into the impact of waste oil pollution on soil fertility.

8. Conclusions

The investigation into the impact of waste oil contamination on soil fertility at sites LC-A and LC-B yielded a rich findings, revealing both shared consequences and the impact. Across both sites, the depletion of crucial nutrients like nitrogen, phosphorus, and potentially potassium in oil-contaminated soil is observed. This suggests a disruption in natural biogeochemical cycles, likely due to waste oil inhibiting microbial activity and altering soil chemistry. However, the elevated levels of total petroleum hydrocarbons at all contaminated points confirmed the presence of significant oil pollution, raising concerns about potential toxicity and long-term environmental impacts on soil health and function.

While both sites grappled with nutrient depletion and hydrocarbon presence, distinct narratives unfolded upon closer examination. Site LC-A witnessed elevated iron (Fe^{2+}) levels at certain points, pointing toward potential anaerobic conditions induced by oil pollution. This phenomenon wasn't as evident at Site LC-B, where manganese levels displayed a more variable pattern. Additionally, fluctuations in potassium and calcium levels differed between the sites, suggesting that the specific impacts of oil on these nutrients might be influenced by local soil characteristics or other environmental factors.

The observed differences between Sites LC-A and LC-B underscore the critical need for site-specific approaches to remediation. While some general principles, such as addressing nutrient deficiencies and promoting microbial activity might apply across the board, addressing anaerobic conditions at Site LC-A might require aeration techniques, while Site LC-B might benefit from targeted interventions to address specific nutrient imbalances.

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