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Mycoremediation and Soil Quality of Hydrocarbon Impacted Sites At Abandoned Artisanal Refining In Ahuda East Local and Ogba Egbema L.G.A, River State, Nigeria

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Abstract **Original Research Article**

Oil pollution from artisanal refining has posed significant environmental challenges in the Niger Delta, Nigeria, contaminating soils with polycyclic aromatic hydrocarbons (PAHs) and heavy metals. This study evaluated the bioremediation potential of two white-rot mushrooms, Lentinus subnudus and Calocybe indica, on crude oil-contaminated soils from Ahoada West (AWS) and Ogba Egbema (OES), compared to non-contaminated control soils. A 2 × 3 factorial experiment in a completely randomized design (CRD) with three replicates was established, comprising two fungal species (Lentinus subnudus and Calocybe indica) and three soil categories (AWS contaminated soil, OES contaminated soil, and non-contaminated control soil). Soil samples (250 g each) were placed in experimental pots, inoculated with 50 g of mushroom spawn prepared on Potato Dextrose Agar (PDA), and incubated for 12 weeks. Sampling was carried out biweekly to monitor PAH concentrations, nine heavy metals (iron, Fe; manganese, Mn; copper, Cu; zinc, Zn; chromium, Cr; cadmium, Cd; lead, Pb; nickel, Ni; and vanadium, V), and selected soil physicochemical parameters. Data obtained were subjected to analysis of variance (ANOVA), and means were separated using the least significant difference (LSD) at 5%. Results indicated that Lentinus subnudus reduced PAH levels in AWS and OES soils by 54.2% and 61.5%, respectively, while Calocybe indica achieved reductions of 63.4% and 68.7% over the 12-week period. Heavy metal concentrations also declined significantly; for example, copper residues decreased by 48.2–79.0%, and zinc by 42.5–75.1%, depending on the fungal species and soil type. Both fungi enhanced microbial community abundance and diversity, facilitating pollutant degradation and improving soil quality. These findings demonstrate that Lentinus subnudus and Calocybe indica are effective, eco-friendly agents for the bioremediation of PAH- and heavy metal-contaminated soils, offering sustainable strategies for soil reclamation in tropical oil-impacted environments.

Keywords: Mycoremediation, Lentinus subnudus, Calocybe indica, PAHs, Heavy metals.

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INTRODUCTION

The oil sector is both the main stay of the Nigerian economy and a major source of land degradation in Nigeria's Niger-Delta region. Hydrocarbon contamination caused by petrochemical industrial activities is one of the world's most serious

environmental challenges today. Oil pollution has been an issue in Nigeria since the beginning of oil exploration and the development of the petroleum industry with accidental releases of these petroleum products over the years, severely impacting the environment and local communities (Azuka et al., 2023). Recent studies confirms that from 2015 to 2021 alone, there were 4919 oil spills recorded, highlighting ongoing challenges due to sabotage, technical blunders, and infrastructural failures due to poor maintenance (Morocco-Clake, 2023). Exposure to some of these poisonous substances, especially those localised in polluted environments, can results to a various forms of health issues ranging from respiratory problems to carcinogenic effects. Prolonged contact with chemicals such as polycyclic aromatic hydrocarbons (PAHs), heavy metals, or other pollutants commonly associated with oil spills and industrial activities, can increase the risk of cancer, neurological damage, respiratory conditions as well as reproductive health problems and developmental disorders in children. Ite et al. (2018) affirms that most individuals living in oil-polluted areas have been found to experience higher rates of cancer due to the carcinogenic compounds released into the air, soil, and water. When considerable volumes of pollutants are present, current disposal methods such as cremation or burial in unsafe landfills can become prohibitively expensive.

Because of the harmful effects of pollution on the ecosystem, there has been a rise in environmental awareness and vigilance in the Niger Delta. Nigeria's population, urbanization, and industrial activities have all increased dramatically in recent years (Eze and Okpokwasili, 2010). Oil contamination impacts on the environment, particularly on soil quality, has been a major source of worry in Nigeria and among regulatory organizations worldwide. The actual and potential uses of soil are determined by its quality. For example, the concentration of heavy metals in soil meant for agricultural use affects its quality, according to Ukpebor and Unuigbe (2003); Osibanjo *et al*. (2013) found that Nigerian crude oil has significant levels of iron, copper, zinc, lead, and mercury. Heavy metals, according to Harrison (2018), can pose a hazard to vegetation and animals, lowering the quality of human existence. Exploration, exploitation, and transportation of crude oil and its processed constituent products throughout the world has a negative impact on the environment. Oil spills have contaminated drinking water sources, fisheries, agricultural farm lands, and farm produce, affecting the health and productivity of agricultural lands; corroding metal roofs, causing permanent damage to vulnerable ecological areas such as the mangrove and freshwater wetlands; and corroding metal roofs, causing permanent damage to vulnerable ecological areas such as the mangrove and freshwater wetlands (UNDP, 2006).

Artisanal refinery also known as “illegal refinery” or “makeshift refinery,” is an illegal bunkering operation operating in the Niger Delta. The waste from these artisanal refineries has been dumped into our water bodies and on the mainland. Organic chemicals, inorganic complexes, and other non-biodegradable substances make up the majority of the waste (Deng *et al*., 2007). The release of untreated industrial waste into the environment has an impact on the quality of soil and ground water, and is widely regarded as harmful to soil use (Qazilbash, *et al*., 2006). These contaminants not only degrade the quality of soil and groundwater, but they also cause serious health issues (Karthikeyan *et al*., 2010). There is a growing sense of worldwide resolve around the degradation of the environment caused by chemical arrangements utilised in numerous operations (Palaniappan *et al*., 2009). Heavy metal has invaded most settings as a result of the ever-increasing activities linked with local petroleum refining. Because of their non-biodegradability, low solubility, and toxicity for carcinogenic and mutagenesis effects, heavy metal pollution might cause significant harm to public health and the ecosystem. Soil properties involved in soil-plant-water relationship have been degraded by activities in artisanal refineries and include texture, infiltration, hydraulic conductivity, moisture content, pH and density, which affect root and leaf development and plant growth and yield (Michael and Ojha, 2006).

Activities within artisanal refineries lead to serious contamination of the soil within which poses a serious threat to the ecosystem and due to the adverse effect of these contaminants on the environment and

as such, it becomes imperative to carry out remediation (clean up) exercise on the soil to remove the contaminants. Many technologies ranging from chemical, physical and biological technologies have been employed to remediate hydrocarbon contaminated soils. Mechanical and chemical methods generally used to remove hydrocarbons from contaminated sites have limited effectiveness and can be expensive (Das and Chandran, 2011).

Mycoremediation can be an economical, eco-friendly, and effective strategy to combat the ever-increasing problem of soil and water pollution (Nahid and Mannan, 2020). Robust growth of fungus, vast hyphal network, production of versatile extracellular ligninolytic enzymes, high surface area to volume ratio, resistance to heavy metals, adaptability to fluctuating pH and temperature and presence of metal-binding proteins; fungi are an ideal candidate for the remediation of various pollutants (Khan *et al*., 2019). Among all the microbes, fungi can be the most efficient removers of pollutants due to the relatively higher tolerance to pollutants, large surface to volume ratio, robust nature in comparison to bacteria and algae (Sigh *et al*., 2015). Biosorption, bioaccumulation, and biovolatilization are the principles often used by fungi to transform pollutants (Igiri*et al*., 2018). Biosorption is a passive (metabolically independent) process that can be performed by live cells or dead biomass, whereas bioaccumulation is active (metabolically dependent) process occurring in live cells (Fomina *et al*., 2014). Biovolatilization involves the conversion of inorganic and organic compounds into their volatile derivatives by intracellular enzymatic reactions (Urik *et al*., 2007).

The thrust of this study was to assess the level of soil degradation in abandoned artisanal refining sites and carrying out a mycoremediation process to re-mediate the polluted soil.

Study Area

Ogba Egbema Ndoni (OES)

Ogba Egbema Ndoni is a Local Government Area in the northern part of Rivers State, Nigeria, with its headquarters at Omoku, a major town in the region. The LGA is geographically positioned at about latitude 5° 20′ 38″ N and longitude 6° 39′ 24″ E, and covers an area of approximately 1,621 km², making it one of the larger administrative units in the state. Its estimated population reflects a culturally diverse community predominantly consisting of the Ogba, Egbema, and Ndoni ethnic groups.

Like much of the Niger Delta, Ogba Egbema Ndoni experiences a tropical monsoon climate, characterized by high humidity, warm temperatures, and substantial rainfall throughout most of the year. The mean annual climate for this region shows average temperatures around 26–27 °C and humidity levels near 84 %, with heavy precipitation especially from March through October. The wet season peaks in mid-year and contributes to the lush vegetation and fertile soils that support agriculture and natural ecosystems.

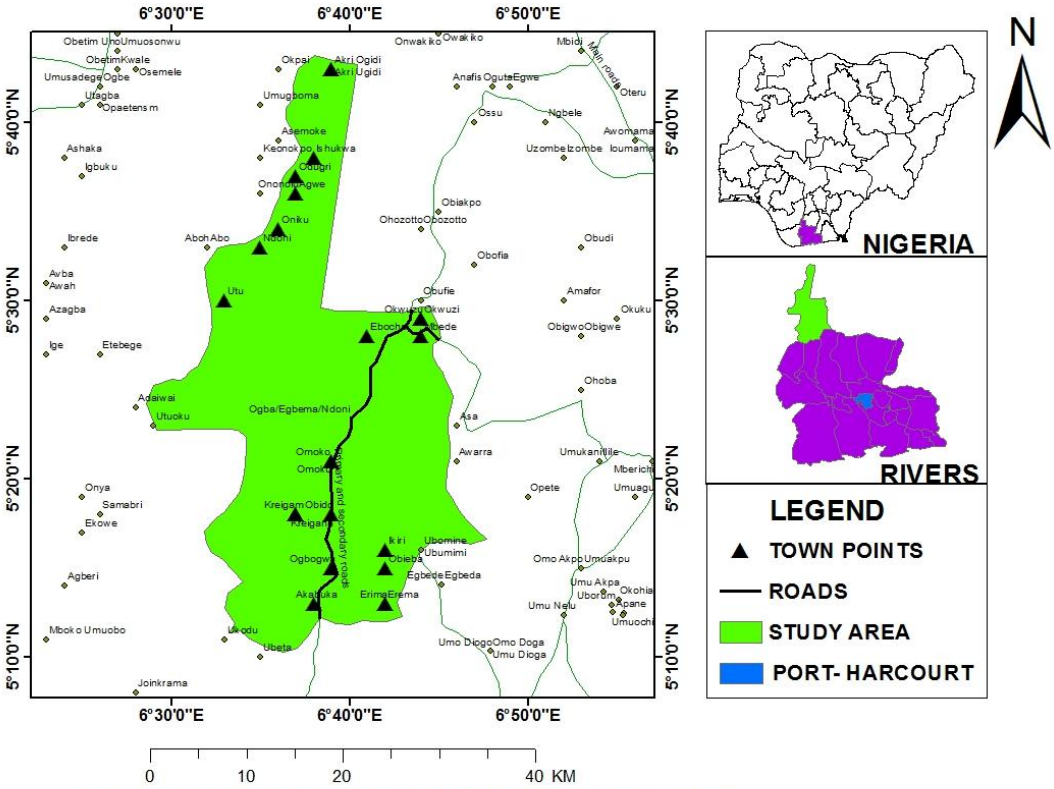


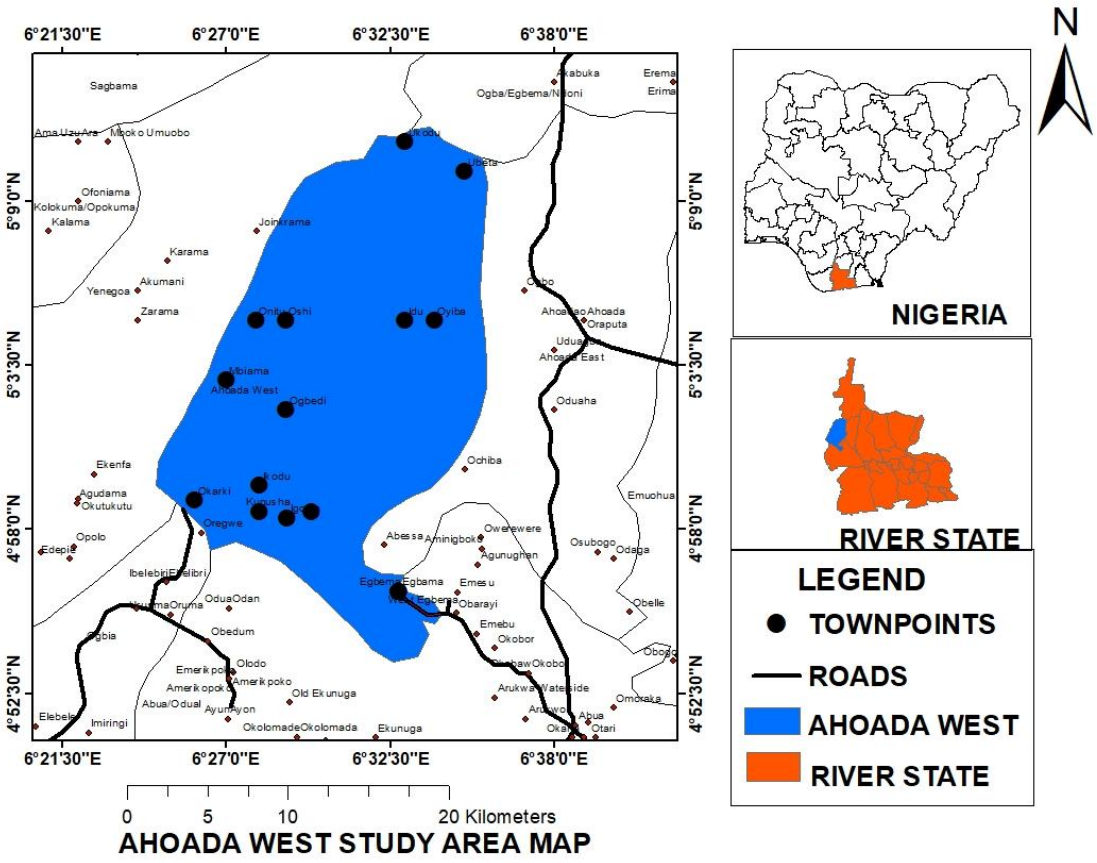
FIG. 1. OGBA /EGBEMA /NDONI STUDY AREA MAP

Source: OSGOF (2023).

Ogba/Egbema/Indoni Study Area Map.

.Ahoada West Local Government Area (Rivers State, Nigeria)

Ahoada West is a Local Government Area located in the northwestern part of Rivers State, Nigeria, with its administrative headquarters at Akinima. The LGA lies within the freshwater belt of the Niger Delta and is geographically positioned at approximately latitude 5° 06′ N and longitude 6° 39′ E. It covers an estimated land area of about 403 km². The population comprises predominantly the Ekpeye ethnic group, alongside other Niger Delta communities, reflecting the rich cultural heritage and traditional institutions characteristic of the region.



Google Earth imagery (2024)

Fig 2. Showing the study area with strategic sampling locations

. Sample Collection

MATERIAL AND METHOD

The soil samples for this study was collected from crude oil contaminated sites of Ahuda East Local government area and Ogba Egbema Local government area as well as from non-contaminated site all in Rivers state.

PHYSICAL AND CHEMICAL SOIL ANALYSIS

Soil samples obtained from 0-15cm, 15-30cm, and 30-45cm depths were air-dried and passed through a 2 mm sieve. (0–15cm depth) obtained was air dried and passed through a 2 mm sieve. Particle size distribution of the soil samples was analyzed by combination of wet sieving and hydrometer techniques (Bouyoucos 1962) using calgon as the dispersing agent. The soil organic carbon content was determined by dichromate wet oxidation methods of Walkey and Black (1934). Total nitrogen was determined by Kjeldahl digestion methods of Bray and Kurtz (1945). Exchangeable bases was extracted with 1 mole of Ammonium acetate (NH4OAC pH7). Potassium and sodium in the extracts will be determined by Flame photometric technique (AOAC 1975), while calcium and magnesium were determined by Versemate EDTA titration methods (Jackson 1962). Soil pH was determined in water using a Pye Unicam pH meter (AOAC 1975) and electrical conductivity, was determined as described by Jackson (1962). Heavy Metals in soil (e.g., Fe, Mn, Zn, Cu, Cr, Cd, Pb, Ni

and V) were determined by the perchloric acid digestion method as described by Udo (1986) and the concentration of the metals was also be measured with Unican Solar System 919 Atomic Absorption Spectrophotometer (AAS) (Udosen 1991



Plate 1: Depicts a section of land affected by hydrocarbon contamination. The soil in the area appears darkened, with patches of oil visibly seeping through the ground surface

EXPERIMENTAL SET UP

All soil samples was taken to soil science laboratory, Babcock University to set up the experiment. A 2 x 3 factorial arrangement on a Completely Randomized Design (CRD) which was replicated 3 times and was used to set up the experiment. The treatment combination included 2 factors, where factor one was made up of 3 levels of soil namely; Control (non-contaminated soil), Crude oil contaminated soil from Ahuda East (AES), Crude oil contaminated soil from Ogba Egbema (OES), while factor two was made up of the two test mushrooms– Lentinus subnudus and Calocybe indica

BIOREMEDIATION SET UP

Tissue culture of the freshly collected mushroom was prepared by cutting the tip of the stalk after removing the pileus and placed on sterilized Potato Dextrose Agar (PDA) medium. This was carried out under sterile condition in a laminar air flow in soil science laboratory, Babcock University. The pure cultures of

isolate was maintained on sterilized potato dextrose agar (PDA) slants and subsequently transferred to PDA plates and incubated at 25°C to obtain a good mycelial growth. This was later be used for mushroom spawn formation using suitable standard substrates.Two hundred and fifty grams of crude oil contaminated soil and non-contaminated soil samples were transferred into cleaned and dried 475 ml mayonnaise bottles. Fifty grams each of mushroom spawns was used to overlay the soil samples. Non-contaminated soil was used as the control experiment with respect to total hydrocarbon bacterial and other bacterial species present in comparison to those in crude oil contaminated soil.

DATA COLLECTION

Data were collected from the microcosm setup at 2 weeks interval for 4 months in both contaminated and non-contaminated soils to check the level of bioremediation that was achieved by either of the two species of mushroom which were used.



STATISTICAL ANALYSIS

The data was presented in table format, allowing for the identification of trends over time. This approach focused on understanding the observable changes in soil quality and the effectiveness of mycoremediation strategies at the impacted sites. Observational design was adopted, where qualitative insights were deemed sufficient to highlight the impacts of the interventions on soil quality while means was separated using the Least Significant Difference at 5%

Physiochemical properties of Contaminated Soil before Treatment

The result in table 1 shows the result of the physicochemical and heavy metal analysis of the contaminated soil before treatment.

The soil pH differed significantly among the treatments (LSD = 0.1). AWS had a near-neutral pH (7.1), whereas OES was strongly acidic (4.7), and the control was moderately acidic (5.4). The near-neutral pH in AWS indicates improved buffering capacity and the presence of sufficient base cations, which

create favorable conditions for nutrient availability and microbial activity. In contrast, the strongly acidic OES likely resulted from the accumulation of organic acids and leaching of base cations, which can immobilize essential nutrients such as phosphorus and potassium. These findings align with Barrow and Hartemink (2023), who emphasized that soil pH is a master variable controlling nutrient solubility, microbial activity, and overall soil fertility. The observed pH differences suggest that AWS could enhance crop growth potential by maintaining a favorable chemical environment, whereas OES may require corrective measures such as liming to optimize productivity.

Organic carbon (OC) and total nitrogen (N) also varied markedly among treatments (LSD = 0.4 for OC; LSD = 0.0 for N). AWS had the highest OC (21.0 g/kg), followed by OES (17.0 g/kg), while the control was extremely low (2.0 g/kg). This pattern reflects the effectiveness of organic amendments in increasing soil organic matter, which improves water retention, soil aggregation, and cation exchange capacity, all of which are critical for sustaining soil fertility. Interestingly, OES recorded the highest N content (2.0 g/kg), likely due to slower mineralization under acidic conditions, which slows nitrogen loss via leaching or volatilization. Organic amendments such as AWS and OES provide substrate for microbial activity, enhancing nitrogen cycling over time (Osakwe et al., 2024). The combination of high OC and moderate N under AWS suggests better long-term nutrient retention and improved soil fertility status compared with both OES and the control.

Available phosphorus (Bray P) was significantly influenced by soil pH and organic matter content (LSD = 0.4). AWS recorded the highest P availability (3.7 ppm), while OES and the control had very low values (0.2 and 0.5 ppm, respectively). This is expected because P availability is strongly pH-dependent; in acidic soils like OES, phosphate ions are easily fixed by Fe^{3+} and Al^{3+}, rendering them unavailable to plants. The high organic matter content in AWS likely reduced P fixation through complexation and competition for adsorption sites, facilitating greater P release into the soil solution (On the tropical soils; 2022). These findings indicate that AWS not only improves the nutrient pool but also enhances the bioavailability of critical macronutrients for crop uptake.

Soil physical properties, including bulk density and moisture content, reflected treatment effects on soil structure. Bulk density was highest in the control (1.6 g/cm³) and lowest in OES (1.3 g/cm³), with AWS intermediate (1.4 g/cm³). The lower bulk density in amended soils is attributable to improved aggregation and porosity resulting from organic matter incorporation. This increase in porosity is also reflected in the higher moisture content in OES (18.4%) and AWS (11.3%) compared with the control (11.8%), indicating enhanced water retention, which can buffer plants against water stress. These physical improvements suggest that AWS and OES can promote better root growth and nutrient uptake, key factors for crop performance on degraded soils.

Exchangeable base cations (Ca, Mg, K) were highest in AWS (Ca = 1092.8 ppm, Mg = 494.3 ppm, K = 270.6 ppm), indicating enhanced fertility relative to OES and control soils (LSD for Ca = 71.3 ppm; Mg = 9.2 ppm; K = 4.9 ppm). High base cation levels are critical for maintaining soil pH, supporting plant nutrition, and improving cation exchange capacity. The low K content in OES (53.4 ppm) highlights the effect of acidic conditions on K leaching and reduced availability. Organic matter in AWS likely increased cation retention and reduced leaching losses, consistent with Tang and Zhang (2024), who reported thalt organic amendments improve nutrient retention in tropical soils. Sodium concentrations were similar across treatments, suggesting minimal risk of sodicity

Micronutrients and heavy metals also responded to treatment differences. Manganese was reduced in OES (15.6 ppm) relative to AWS and the control, reflecting lower availability under acidic conditions. Lead and cadmium mobility increased in OES, while AWS retained these metals at lower bioavailable concentrations due to complexation with organic matter and higher pH, reducing potential toxicity (Cui et al., 2024). Interestingly, cobalt and nickel were higher in AWS, suggesting improved retention of certain micronutrients under near-neutral pH and high organic matter. These patterns indicate that AWS not only improves soil fertility but also

moderates heavy-metal dynamics, promoting safer nutrient availability for plants.

Overall, AWS consistently enhanced soil chemical and physical properties, improving pH, organic carbon, available phosphorus, base cation status, and heavy-metal stabilization. OES improved organic carbon and nitrogen but remained strongly acidic, limiting nutrient availability and increasing metal mobility. The control soil showed low fertility and poor physical structure, emphasizing the importance of organic amendments in degraded tropical soils. These results highlight that careful management of organic amendments can restore soil fertility, optimize nutrient availability, and reduce environmental risks associated with heavy metals, supporting sustainable crop production

Physicochemical and heavy metal analysis of the contaminated soil before treatment

		Treatments			
Parameters		AWS	OES	Control	$LSD_{0.05}$
Ph		7.1	4.7	5.4	0.1
N	g/kg	1.0	2.0	1.1	0.0
Bray p	ppm	3.7	0.2	0.5	0.4
OC	g/kg	21.0	17.0	2.0	0.4
MC	%	11.3	18.4	11.8	0.2
Sulphur	ppm	0.5	0.5	1.1	0.0
Bulk density	g/cm3	1.4	1.3	1.6	0.0
E.C.	(us/cm)	458.0	23.7	95.0	5.8
Sand	g/kg	910.0	950.0	750.0	Ns
Clay	g/kg	70.0	50.0	190.0	Ns
Silt	g/kg	20.0	00.0	60.0	Ns
Ca	ppm	1092.8	495.1	496.7	71.3
Mg	ppm	494.3	212.0	416.7	9.2
K	ppm	270.6	53.4	292.5	4.9
Na	ppm	41.0	34.5	42.0	Ns
Mn	ppm	55.4	15.6	55.1	0.6
Pb	ppm	1.7	1.2	2.0	0.0
Ni	ppm	4.4	2.1	3.5	1.3
Cr	ppm	0.0	0.0	0.0	ns
Co	ppm	29.3	7.0	3.4	0.2
Cd	ppm	1.4	2.3	1.5	0.6

$LSD_{(0.05)}$: Least significant difference at 5 % level of probability, ns: not significant

The baseline physicochemical properties and heavy metal concentrations of the contaminated soil before treatment are presented in Table 4.1. The analysis revealed significant variations p<= 0.05 across key chemical parameters among treatment setups (AWS, OES, and Control). Soil pH differed significantly (LSD = 0.1), with AWS exhibiting a near-neutral pH (7.1).

Table 2: Myco-remediation of Polycyclic Aromatic Hydrocarbon compounds present in contaminated soil obtained from Ahoada West L.G.A by Lentinus subnudus and Calocybe indica at different weeks

PAH	5^1 WK 4	5^2 WK4	5^1 WK 8	5^2 WK 8	5^1 WK 12	5^2 WK 12	6^1 WK 4	6^2 WK 4	6^1 WK 8	6^2 WK8	6^1 WK 12	6^2 WK 12
FLUORENE	4.49064	3.9209	1.80744	4.68714	0.235933	0.608195	0.363906	1.81571	2.80469	0.693209	1.584298	0.257178
ANTHRACENE	0.722836	0.398573	0.1018	0.092488	0.023138	1.01907	0.129284	1.59154	0.404942	0.470435	0.267113	0.022777
ACENAPHTHENE	0.274657	0.303625	0.091932	0.310587	0.183295	0.12649	0.037864	0.249617	0.1174950	0.083763	0.077679	0.16669
PHENANTHRANE	1.55636	0.198492	0.07477	0.309732	0.021065	0.286085	0.252322	1.18487	0.474554	0.544949	0.028735	0.054707
FLUORANTHENE	1.96378	0.426097	0.995164	0.509814	0.16343	1.26626	0.683862	2.22669	0.553668	0.135783	0.618765	0.096948
PYRENE	64.03083	47.6804	48.77576	35.95459	10.34703	28.52019	13.19563	86.89476	76.80165	38.67704	44.99864	3.4049

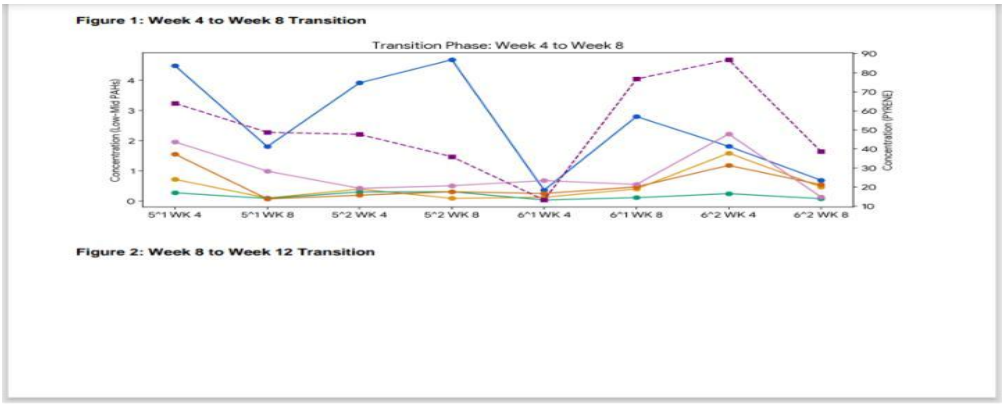




Table 3: Effect of myco-remediation of contaminated soil on Fungi population within the soil obtained from AWS and OES at different weeks as influenced by Lentinus subnudus and Calocybe indica

SOIL TYPE	WK0(10-3cfu/g)	WK0(10-4cfu/g)	WK4 (1)(10-3cfu/g)	WK4 (2)(10-3cfu/g)	WK4 (1)(10-4cfu/g)	WK4 (2)(10-4cfu/g)	WK8 (1)(10-3cfu/g)	WK8 (2)(10-3cfu/g)	WK8 (1)(10-4cfu/g)	WK8 (2)(10-4cfu/g)	WK12 (1)(10-3cfu/g)	WK12 (2)(10-3cfu/g)	WK12 (1)(10-4cfu/g)	WK12 (2)(10-4cfu/g)
AWS	1.7	3.7	6.3	7	5.7	5.3	8	5	5.3	3.7	7.3	5	5.7	4
OES	1.3	3.3	5.7	7	4.3	5.3	4.7	6	3.7	4.7	6.3	6.3	5.3	5
Control	2.7	4	5	8	4.3	6	4.7	6.7	3	5.3	4.3	7.3	3	6
$LSD_{0.05}$	Ns	ns	ns	Ns	ns	ns	2.2	ns	ns	ns	ns	1.2	ns	ns

Mycoremediation of heavy metal Zinc in contaminated soil obtained from both AWS and OES using *Lentinus subnudus* and *Calocybe indica* at different weeks

Soil type	wks0-Zn(ppm)	wks4-(1)Zn(ppm)	wks4-(2)Zn(ppm)	wks12-(1)Zn(ppm)	wks12-(2)Zn(ppm)
AWS	505.5	0.0066	0.0093	125.7	125.8
OES	22.1	0.0002	0.0005	22.7	31.8
Control	8.4	0.0005	0.0020	32.3	29.8
$LSD_{0.05}$	1.9	0.003	ns	4.8	18.4

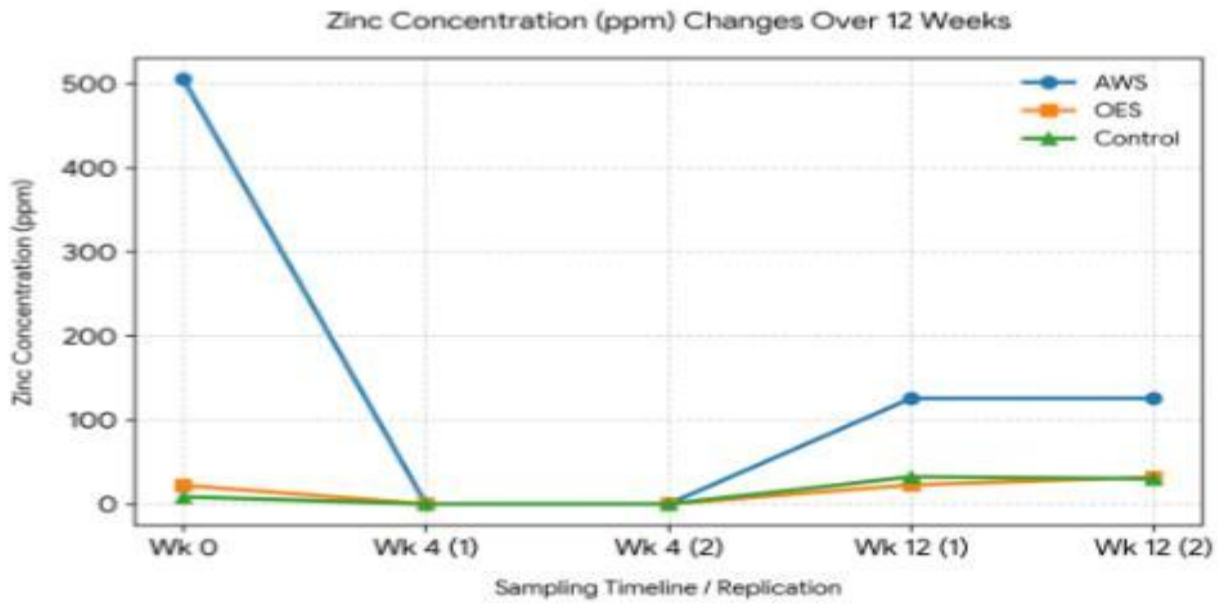


Table 4 shows the effect of myco-remediation of contaminated soil on Polycyclic Aromatic Hydrocarbon utilizing Fungi within the soil obtained from AWS and OES.

The 11.32% reduction in PAH-utilizing fungi at week 12 in AES following Lentinus subnudus treatment suggests a decline in specialist degraders as PAH concentrations decreased. This trend aligns with ecological principles where specialist microbial populations decline once their specific substrates become less abundant, signaling progress in contaminant depletion (Fallahi et al., 2023). Such declines can indicate successful degradation of targeted pollutants and a shift toward more generalist or residual microbial communities in soil.

Overall, the contrasting effects of Lentinus subnudus and Calocybe indica on fungal populations reflect species-specific responses influenced by soil properties, contaminant bioavailability, and temporal enzyme induction dynamics. L. subnudus exhibited strong early proliferation and contributed to reducing specialist PAH degraders, while C. indica showed more gradual but significant later growth. These findings are consistent with recent evidence that fungal bioremediation outcomes are highly dependent on both the fungal species used and the specific context of soil contamination (Torres-Farradá et al., 2024; Dai et al., 2023; Ahmad et al., 2024)

Conclusion

This study explored the effectiveness of myco-remediation on PAH-contaminated soils (AES and OES) using LS and CI fungal species as well as their influence on bacterial populations over a 12-week period. The findings exhibited the potential of both LS and CI fungi species to degrade PAHs in contaminated soil. However, the rate and efficiency varied across compounds and time regime. The fungi specie of LS exhibited consistency in the degradation of most compounds, especially for flourene and phenenthene as well as promoted early bacterial activity in PAH impacted AES, enabling improved soil enhancement. The specie of CI showed rapid degradation of anthracene and pyrene as well as demonstrating stimulation of bacteria growth. These variations highlight the species-specific nature of myco-remediation and its potential to enhance microbial activity in contaminated environments, though the efficiency is influenced by

the type of soil and fungal species used.

Both fungal species demonstrated the ability to degrade PAHs in contaminated soil at different rate and frequency in relation to the soil and contaminant type. LS fungi triggered rapid early bacterial proliferation, particularly in AES, while CI fungi showed a more consistent and prolonged effect in both soils. These results suggest that different fungal species can be strategically applied to optimize microbial activity during myco-remediation of contaminated sites.

Recommendations

Future studies should consider the following;

1. Explore the optimization of operational conditions such as fungal inoculum concentration, incubation time, moisture content, and nutrient amendments to improve remediation efficiency.

2. Explore the variation in temperature, pH, and oxygen levels to proffer insights into ideal conditions for LS and CI fungal species that will promote bacterial growth and PAH degradation better.

3. Comparing different process configuration of Batch and Column set-ups to understand their impacts on degradation rate

4. Testing in situ applications under different environmental conditions would help refine the myco-remediation process for broader, real-world effectiveness.

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