
ECO-FRIENDLY INNOVATION: HARNESSING THE REMARKABLE BIO REMEDIATION POTENTIAL OF VERNONIA SPP FOR SUSTAINABLE RESTORATION OF HYDROCARBON- POLLUTED CLAY SOIL IN OGONI LAND NIGERIA.

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Article

Eco-Friendly Innovation: Harnessing the Remarkable Bio Remediation Potential of *Vernonia* Spp. for Sustainable Restoration of Hydrocarbon-Polluted Clay Soil in Ogoni Land Nigeria

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Abstract: Harnessing the Remarkable Bio-Remediation Potential of *Vernonia* spp. for the Sustainable Restoration of Hydrocarbon-Polluted Clay Soil in Ogoni Land, Nigeria This study explores the potential of utilizing *Vernonia* spp. for eco-friendly bio-remediation of hydrocarbon-polluted clay soil in Ogoni Land, Nigeria. The aim is to find a sustainable and effective solution that promotes the restoration of the polluted soil while minimizing the use of external additives. The process of bio-remediation can occur naturally, through natural attenuation or intrinsic bio-remediation. However, it has been observed that in certain cases, the addition of fertilizers, oxygen, or organic matter is required to enhance the effectiveness of bio-remediation. In this research, we focus on the bio-remediation potential of *Vernonia* spp., a native plant species known for its strong phytoremediation abilities. By harnessing the remarkable bio-remediation properties of *Vernonia* spp., we seek to restore the hydrocarbon-polluted clay soil in Ogoni Land in an environmentally friendly and sustainable manner. Our methodology involves conducting greenhouse experiments to assess the bio-remediation efficiency of *Vernonia* spp. in different soil conditions. We will analyze the soil's physical and chemical properties, as well as the degradation of hydrocarbons over time. The experimental results will provide valuable insights into the effectiveness of *Vernonia* spp. in removing hydrocarbon pollutants from clay soil. Through this study, we aim to develop a cost-effective and sustainable approach to restore hydrocarbon-polluted clay soil in Ogoni Land. By leveraging the natural bio-remediation potential of *Vernonia* spp., we can potentially reduce the reliance on external additives, thus minimizing the environmental impact associated with traditional remediation methods. The research article explores methods to promote the growth of pollution-eating microbes in order to enhance bio-remediation. Bio-remediation refers to the use of naturally occurring organisms to break down harmful substances into less toxic or non-toxic forms. In situ bio-remediation involves treating the contaminated material directly at the site, while ex-situ bio-remediation involves removing the contaminated material for treatment elsewhere. This study specifically investigates ex-situ bio-remediation techniques for hydrocarbon-contaminated clay soil. The researchers found that the application of room dry and wet blended bitter leaf showed promising results in the bio-remediation of hydrocarbons in the clay soil. Using *Vernonia galamensis*, a concentration as high as 0.55 ug/ml was achieved, while *Vernonia amygdalina* yielded a concentration as high as 0.67 ug/ml when applied at 35g and 40g respectively, based on the wet blended approach. These findings highlight the effectiveness of wet blended *Vernonia* species in the bio-remediation process. During the remediation process of the clay soil, the pH levels showed a trend of increasing from acidic to normal to alkaline. This can be attributed to the remediation of excessive metals present in the soil. After 40 days, the pH of the clay soil reached 6.97 when treated with 40 grams of *Vernonia galamensis*, and 7.00 when treated with 40 grams of *Vernonia amygdalina*. Interestingly, while the remediation efficiency of HC (hydrocarbon) decreased with increasing mass of *Vernonia galamensis*, the remediation efficiency of HC increased when using *Vernonia amygdalina*. These observations highlight the varying effects of different *Vernonia* species on hydrocarbon remediation. The highest remediation values were observed when using *Vernonia galamensis* at 35g and *Vernonia amygdalina* at 40g. These particular amounts of these *Vernonia* species

demonstrated effective remediation of the targeted pollutants. However, in comparison to other metals, the remediation effects were relatively lower for zinc (Zn), with only approximately 0.25 ug/ml being remediated. This suggests that the remediation potential of the Vernonia species may vary depending on the specific contaminant. The higher remediation effects observed for Zn metal in the soil can be attributed to the wet blended preparation method of the Vernonia species. In contrast, the room dried Vernonia species exhibited the lowest performance in remediating the soil, with approximately 0.17 ug/ml and 0.10 ug/ml remediation for galamensis and amygdalina, respectively. Both Vernonia leaf extracts achieved a remediation of 0.5 ug/ml for chromium. The sun dried and room dried methods also showed considerable remediation potential, with values above 0.4 ug/ml. The level of significance for the model was attained at 0.05, and the r2 value was appreciable. These findings indicate the effectiveness of different preparation methods and Vernonia species in soil remediation

Keywords: bio-remediation; phytoremediation; Vernonia spp.; hydrocarbon pollution; clay soil; Ogoni Land; sustainable restoration; eco-friendly innovation

1. INTRODUCTION

The history of oil operations in Ogoniland is indeed significant. In 1957, Shell discovered oil in Bomu, Ogoniland, and subsequently proceeded to extract oil from 96 oil wells, establishing 9 oil fields in the region. This extraction continued from 1958 until late 1993 when protests by the Ogoni people against Shell's practices led to the company ceasing its operations in Ogoniland. Despite Shell's presence in Ogoniland for 35 years, the oil production from this region accounted for only a small fraction, approximately 3%, of their overall production. However, during the period of 1976 to 1991, there were approximately 3,000 oil spills reported in Ogoniland alone. These spills have had a detrimental impact on the environment, affecting the land, water, and livelihoods of the local communities. Addressing the environmental consequences of these oil spills and working towards the remediation and restoration of Ogoniland is crucial for the well-being of the affected communities. By conducting research and implementing innovative solutions like bio-remediation, we hope to contribute to the healing and recovery of Ogoniland, fostering a sustainable and resilient future for the region.

The high number of oil spills in Ogoniland is indeed alarming. In the 15-year period from 1976 to 1991, Ogoniland alone accounted for approximately 3,000 oil spills, which represents a staggering 40% of the total spills by Shell in its global operations. It is important to note that these spills occurred within an area of approximately 1,050 square kilometers. This concentration of spills within such a relatively small region highlights the significant environmental impact and challenges faced by the communities in Ogoniland. Addressing these environmental issues and promoting sustainable practices is crucial for the well-being and future of the affected communities.

"In response to the Ogoni people's court case against the Shell petroleum development company (SPDC) in the Ogoni community, there has been an increase in efforts to find effective technologies for soil remediation. The oil spillage has resulted in the introduction of foreign substances such as olefins, bituminous materials, heavy metals, and other Sulphuric compounds into the soil."The contamination of the soil in Ogoni land has had detrimental effects on farming activities, rendering it unsuitable for agricultural purposes. This issue has also been exacerbated by erosion, which has further spread the contamination and made the soil unusable. If prompt action is not taken, the consequences will be severe: the land in Ogoni will remain infertile for an estimated period of 500 years, if not indefinitely. This poses a significant threat to not only the current Ogoni population but also their future generations, their economy, and the sustainable use of their natural resources.

Successfully achieving the aim and objectives of this study will provide valuable information to institutions regarding the optimization of bio-remedial activity using bitter-leaf and other bio-remediation. This knowledge will bring hope to not only the Ogoni people but also to other areas grappling with polluted soils. Moreover, it will stimulate further research and development in this

field by contributing to the existing knowledge base. By advancing our understanding of bio-remediation, we can work towards creating a cleaner and healthier environment for all.

Eco-Friendly Innovation: Harnessing the Remarkable Bio-Remediation Potential of Vernonia spp. for Sustainable Restoration of Hydrocarbon-Polluted Clay Soil in Ogoni Land, Nigeria. Alignment with UN SDGs:

1. **Goal 3: Good Health and Well-being:** By utilizing Vernonia spp. for bio-remediation, the research contributes to improving the health and well-being of the communities in Ogoni Land by reducing the harmful effects of hydrocarbon pollution on the environment and human health.
2. **Goal 6: Clean Water and Sanitation:** Restoring hydrocarbon-polluted clay soil through bio-remediation helps protect water sources from contamination, ensuring clean and sustainable water supply for the community.
3. **Goal 9: Industry, Innovation, and Infrastructure:** The research presents an eco-friendly innovation that harnesses the bio-remediation potential of Vernonia spp., providing a sustainable solution for restoring polluted soil and promoting sustainable practices in the industry.
4. **Goal 13: Climate Action:** By addressing hydrocarbon pollution and restoring the clay soil, the research contributes to climate action by mitigating the negative environmental impacts and promoting sustainable land use practices.
5. **Goal 15: Life on Land:** The research focuses on restoring the clay soil in Ogoni Land, which is essential for preserving biodiversity, promoting sustainable agriculture, and ensuring the long-term health of ecosystems in the area. Significance:

The research holds significant importance in several ways:

1. **Environmental Restoration:** By harnessing the bio-remediation potential of Vernonia spp., the research offers a sustainable and eco-friendly approach to restoring hydrocarbon-polluted clay soil. This has long-term benefits for the environment and ecosystems in Ogoni Land.
2. **Health and Well-being:** The restoration of hydrocarbon-polluted soil helps protect human health by reducing the exposure to harmful pollutants and toxins. This contributes to the overall well-being and quality of life for the communities living in the affected area.
3. **Sustainable Development:** The research aligns with the principles of sustainable development by providing a solution that balances environmental, social, and economic aspects. It promotes sustainable land use practices and contributes to the achievement of multiple UN SDGs.
4. **Community Empowerment:** Implementing bio-remediation techniques using Vernonia spp. can create opportunities for local communities to actively participate in the restoration process, fostering community engagement, and promoting sustainable development at the grassroots level. In summary, the research on harnessing the bio-remediation potential of Vernonia spp. for restoring hydrocarbon-polluted clay soil in Ogoni Land, Nigeria, aligns with various UN SDGs. It carries significant implications for environmental restoration, human health, sustainable development, and community empowerment.

2. LABORATORY ANALYSIS:

2.1. Clay Soil Bio Remedial Analysis

The study involved collecting clay soil samples and mixing them with bonny light crude oil to simulate the conditions found in the study area. We then measured the changes in pH, hydrocarbon content, and metal levels by comparing the initial and final values before and after the addition of crude oil. Table 1 provides a record of the initial and final conditions of these factors

Table 1. Initial and Final readings of the Response factors for clay soil.

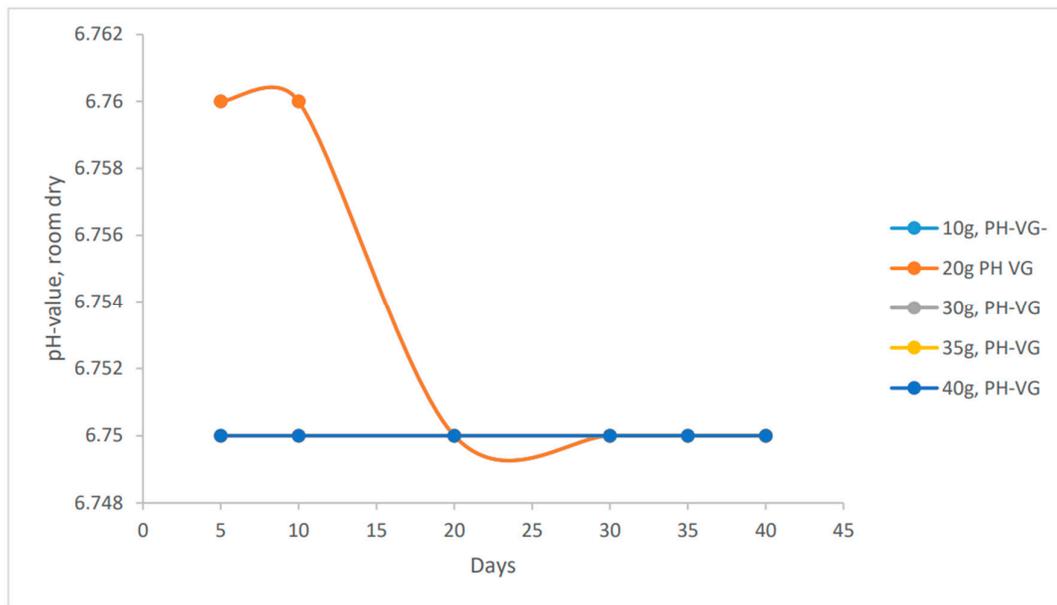
pH and HC readings for samples before contaminant					
Initial Content sample	pH	HC	Pb (ug/ml)	Zn (ug/ml)	Cr(ug/ml)
Clay soil, Csi	6.47	1.3	0.005	0.000	0.002
pH and HC readings for samples after contaminant					
Final Content sample	pH	HC	Pb (ug/ml)	Zn (ug/ml)	Cr(ug/ml)

Clay soil, Csf	6.644.69	1.21	0.924	1.105
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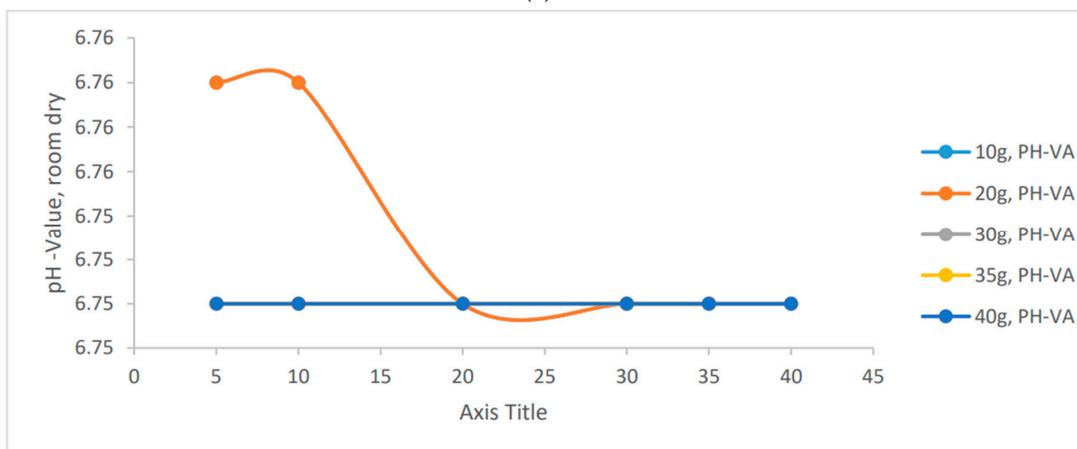
To conduct the experiment, we will be using a total of 30 batch reactors. These reactors will enable us to make various observations throughout the experiment.

2.1. pH Analysis

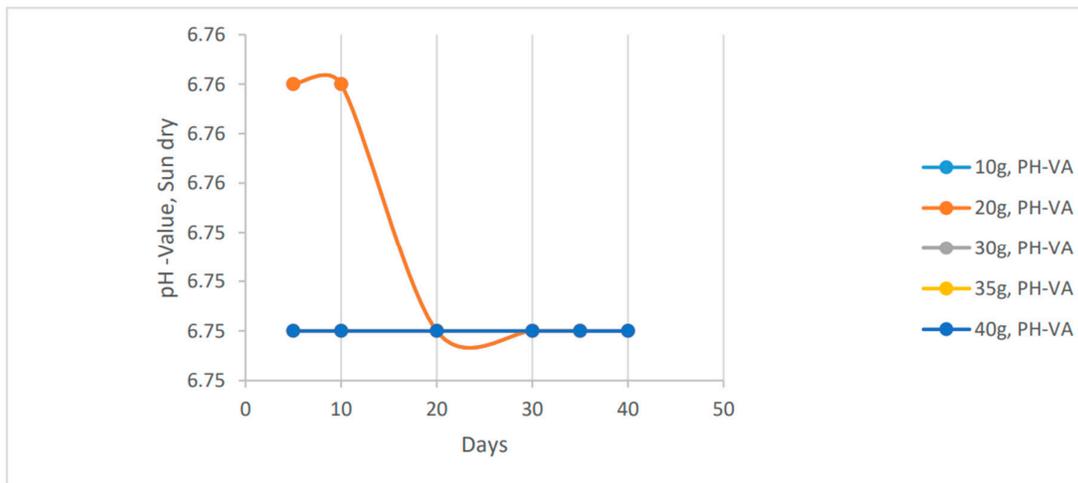
"To assess the stability or instability of pH in clay soil, it is necessary to analyze each scenario and determine whether the varying quantities of species have an impact on the pH value. This analysis aims to investigate how different masses of species may influence the stability of pH in the soil.



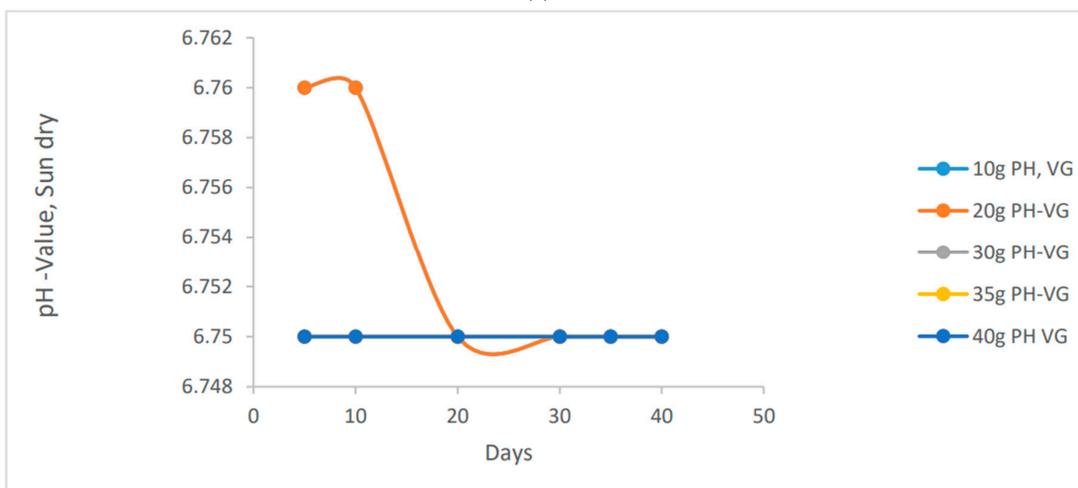
(a)



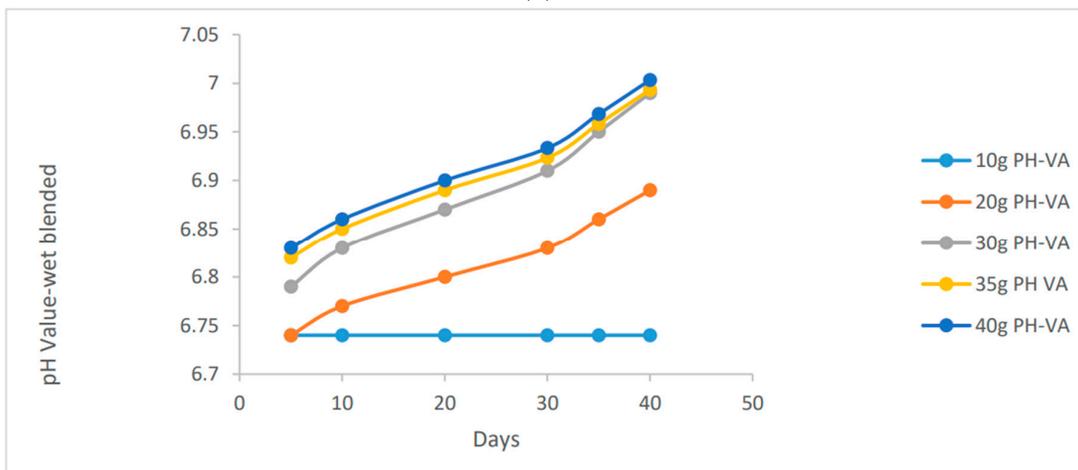
(b)



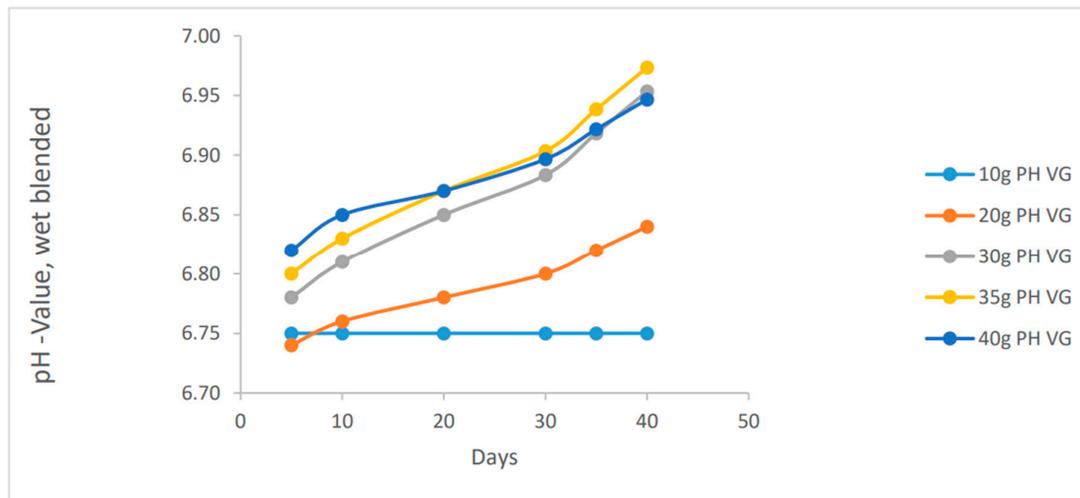
(c)



(d)



(e)



(f)

Figure 1. a, b, c, d, e, f: pH behavioural characteristics of the vernonia extracts using different application methods in clay soil.

It's fascinating to observe the stability of pH values in various methods of preparation. In contrast to the other methods, the wet blended vernonia species showed an interesting trend. As the wet blended vernonia species interacted with the soil, it effectively remediated the excess metals present. Consequently, the pH gradually increased, transitioning from acidic to normal to alkaline. Specifically, after 40 days, the pH of the clay soil reached a value of 6.97 for 40 grams of vernonia *Galamensis* and 7.00 for vernonia *amygdalina*. This indicates the positive impact of these vernonia species in optimizing soil conditions.

"Increasing the amount of vernonia species in the clay soil will gradually raise its alkalinity

2.1.2. HC analysis

"Furthermore, there was a noticeable decrease in hydrocarbon content, indicating successful remediation, as the mass of vernonia species increased. However, it is worth noting that the remediation effects reached a plateau and remained constant after the 35th day. Specifically, while the addition of more mass led to a decrease in HC remediation for vernonia *Galamensis*, vernonia *Amygdalina* continued to exhibit an increase. These observations are illustrated in Figure 2, which demonstrates the limiting values of hydrocarbon content remediation." "The most significant remediation values were achieved using 35g and 40g of vernonia *Galamensis* and vernonia *Amygdalina*, respectively. This emphasizes the importance of determining the most effective approach to maximize the remediation effects. Let's explore further to identify the optimal strategy.

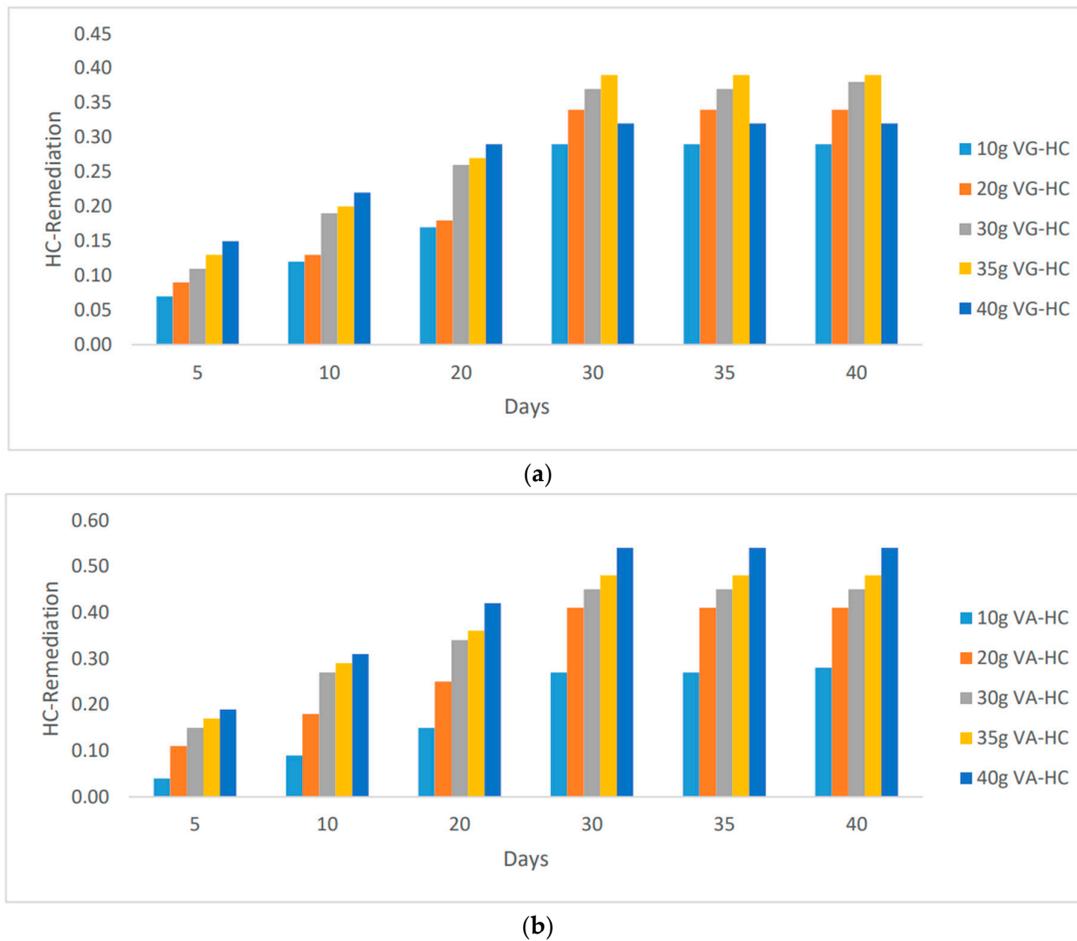
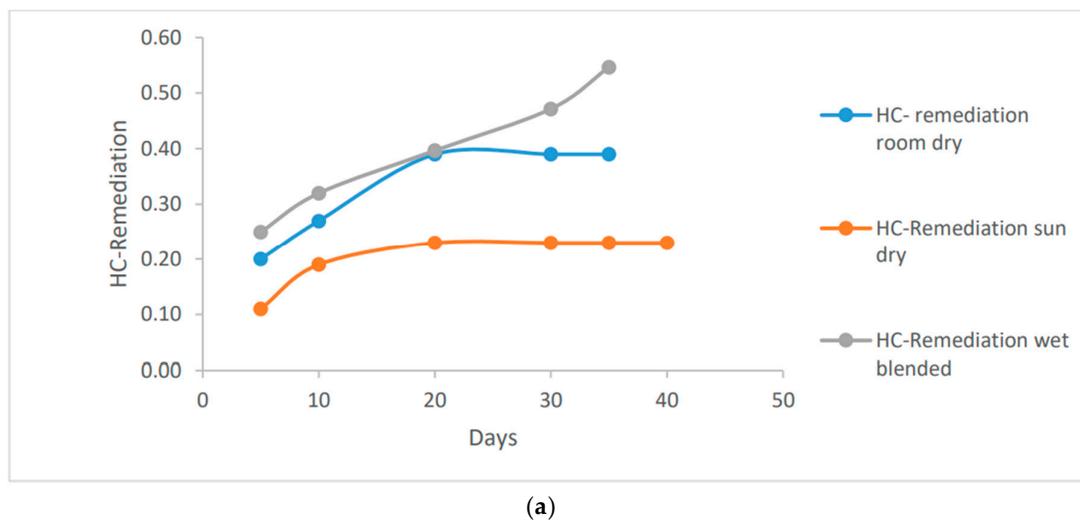


Figure 2. a, b: Hydrocarbon content remediation using vernonia extracts of different masses in different days in clay soil.

Based on the data presented in Figure 3, it is evident that both room dry and wet blended methods were highly effective in bio-remediating the hydrocarbon content in the clay soil. The use of *Vernonia Galamensis* resulted in a significant reduction of up to 0.55 $\mu\text{g/ml}$, while *Vernonia Amygdalina* achieved an even higher reduction of up to 0.67 $\mu\text{g/ml}$. These impressive results were observed at 35g and 40g respectively on the wet blended basis.



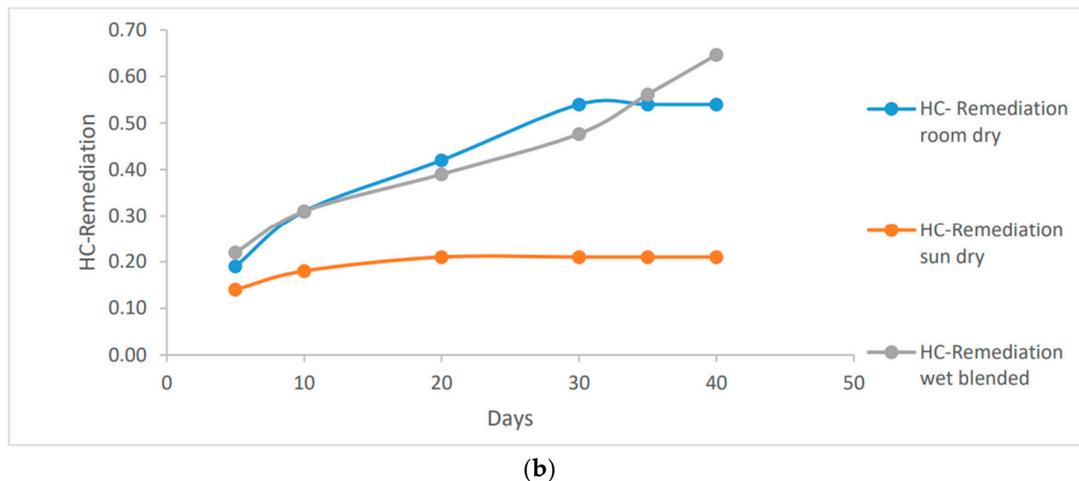


Figure 3. a, b: Hydrocarbon content remediation method comparison using vernonia Galamensis and vernonia Amygdalina in clay soil.

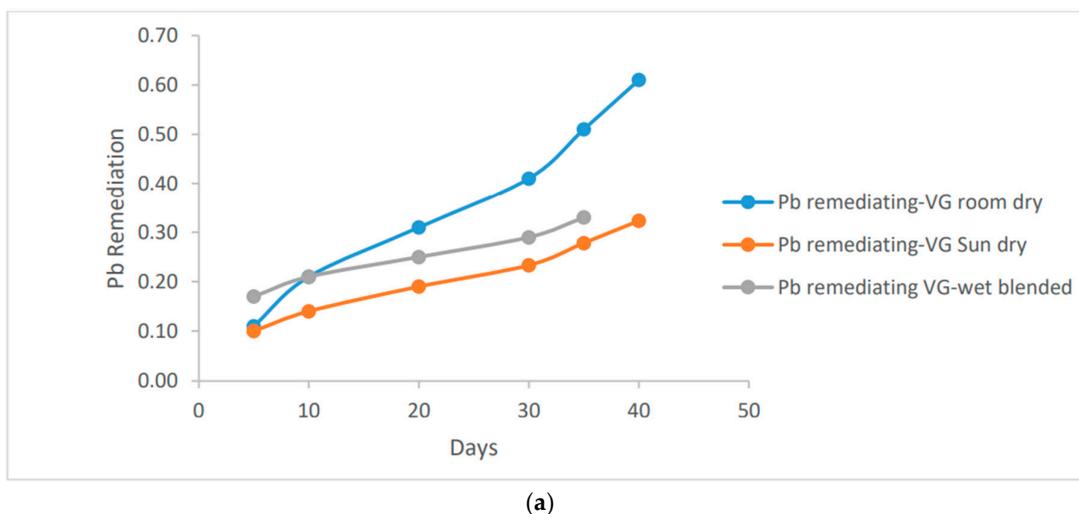
2.1.3. Metal Analysis

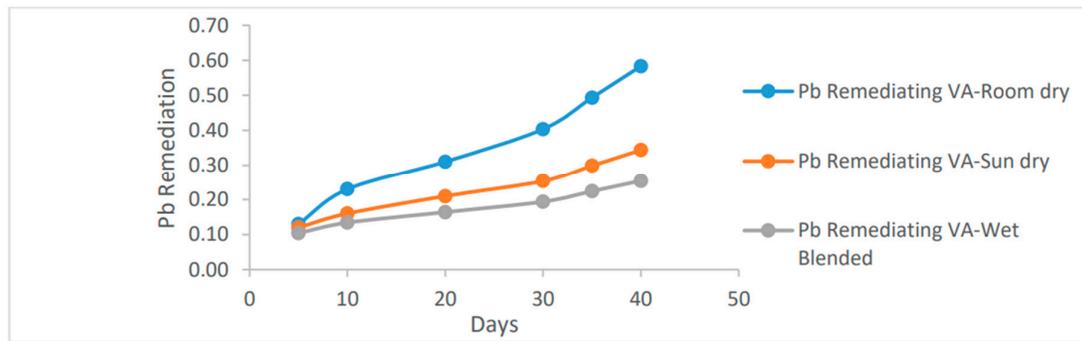
The increase in pH value towards the alkaline state in the clay soil can be attributed to the reduction of metals present. Hence, it is important to evaluate the potential of metal reduction in the soil. The data analysis indicates that a higher mass of vernonia species leads to a greater remediation of metals in the clay soil. This suggests that increasing the mass of vernonia species can enhance the effectiveness of metal reduction in the soil.

2.1.4. Pb Remediating Response

The positive impact of reducing pH concentration in the soil can be observed in the increased remediation effect. Specifically, as the mass of the vernonia species increases, there is a notable enhancement in the reduction of Pb (lead) in the soil. This indicates that a larger quantity of vernonia species contributes to a more significant reduction of lead contamination in the soil, thereby improving its overall quality.

Figure 4 demonstrates that the room dried vernonia species exhibit higher Pb remediation activity compared to the wet basis vernonia species. This difference can be attributed to the reduced activity of micro-organisms and Phytochemicals responsible for Pb remediation under wet conditions. Both species of vernonia leaf, however, achieved approximately 0.60 $\mu\text{g/ml}$ of Pb remediation, indicating that they are equally effective in reducing Pb contamination in the soil.



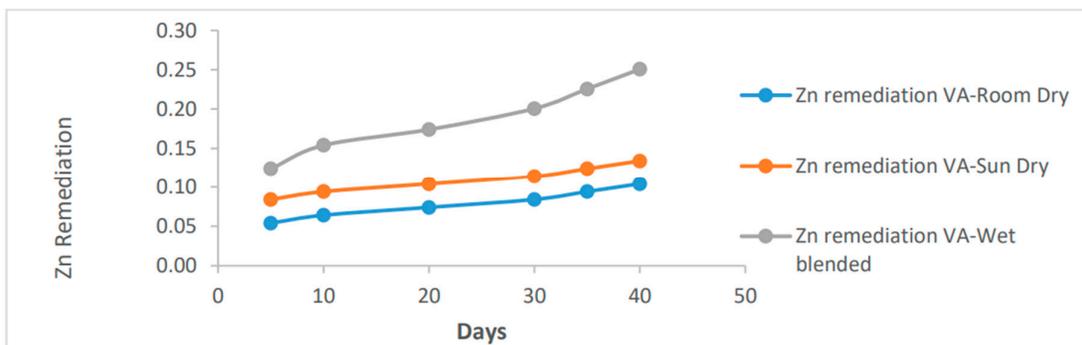


(b)

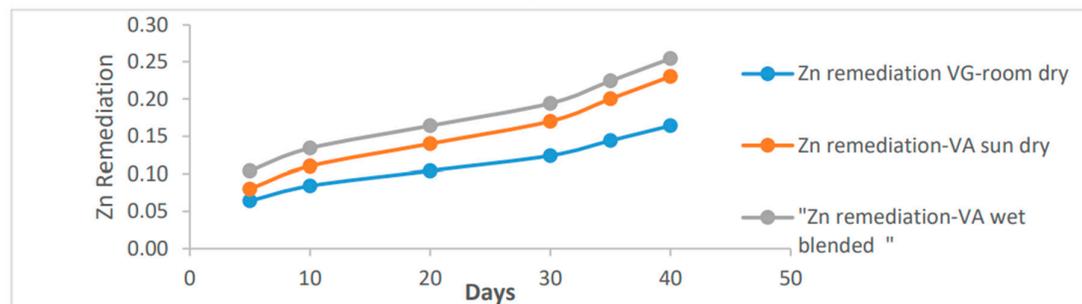
Figure 4. a, b: Pb remediation method comparison using *Vernonia galamensis* and *Vernonia amygdalina* in clay soil.

1.5. Zn Remediating Response

Similarly to Pb remediation, the presence of Zn in the clay soil can also be effectively remediated and reduced. Figure 5 highlights that the remediating effects on Zn, compared to other metals, are relatively lower. Approximately 0.25 ug/ml of Zn was successfully remediated, primarily attributed to the wet blended preparation of vernonia species. On the other hand, the room dried vernonia species exhibited the lowest performance in soil remediation for Zn, removing only about 0.17 ug/ml and 0.10 ug/ml for Galamensis and Amygdalina, respectively.



(a)

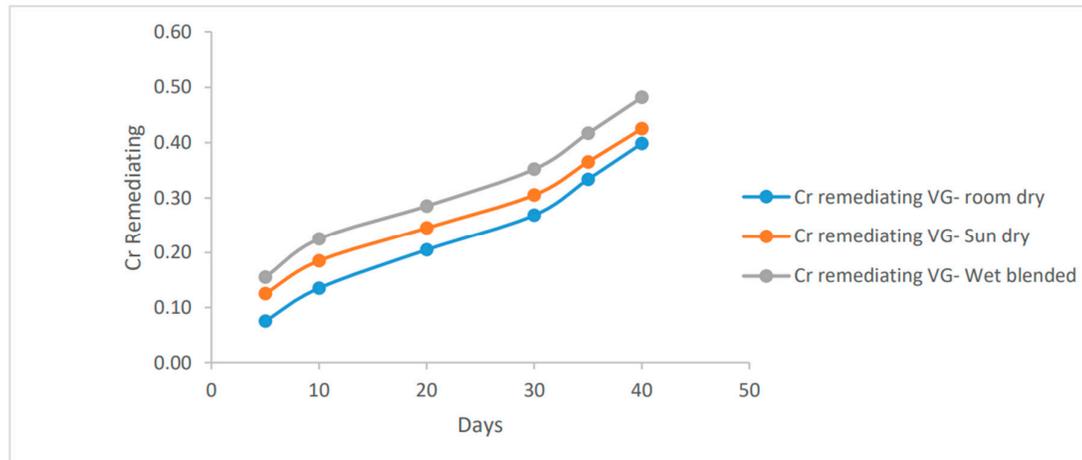


(b)

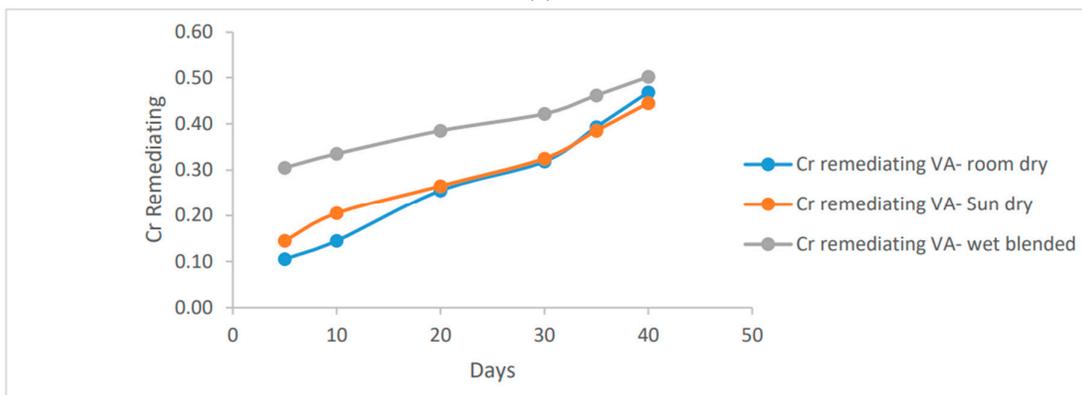
Figure 5. a, b: Zn remediation method comparison using *Vernonia galamensis* and *Vernonia amygdalina* in clay soil.

2.1.6. Cr remediating Response

When it comes to Chromium (Cr) remediation, the wet blended method exhibits slightly higher potential compared to other preparation methods. Although the difference is minimal, a remediation of 0.5 ug/ml of chromium was achieved using both forms of vernonia leaf extracts. The sun dry and room dry methods also demonstrated significant remediation potential, with values surpassing 0.4 ug/ml. Overall, all the methods show promise in effectively remediating chromium from the soil.



(a)



(b)

Figure 6. a, b: Cr remediation method comparison using vernonia Galamensis and vernonia Amygdalina in clay soil.

2.2 Developing a model to illustrate the individual remedial activity based on the data generated is a great idea. In this case, the measurable responses from the remediation process would be the concentrations of metals and hydrocarbon contents in the soil. The independent factors to consider would include the grams of Vernonia species applied and the duration of the remediation process (in days). Given that the wet blended method showed more promising remediation effects, you can focus on incorporating this approach into the model. By analyzing the data and considering the relationships between the independent factors (grams of Vernonia species and days taken) and the measurable responses (metal and hydrocarbon concentrations), you can develop a regression model or another appropriate statistical model to illustrate the individual remedial activity of the Vernonia extracts. Remember to consider the significance of the model, as indicated by the p-value, and the strength of the relationship, as indicated by the coefficient of determination (r^2). These statistical measures will help assess the reliability and validity of the mode

Modal- Prediction Analysis

Performing a multiple regression analysis using the least square method with the Minitab software is a great approach to develop your model. By utilizing this statistical software, you can effectively analyze the relationships between the independent factors (grams of Vernonia species and days taken) and the measurable responses (metal and hydrocarbon concentrations) in the contaminated soil

$$y_i = \beta_0 + \beta_1 x_{i1} + \beta_2 x_{i2} + \dots + \beta_k x_{ik} + u_i \quad \text{for } i = 1, \dots, n.$$

In matrix form, we can rewrite this model as

$$\begin{bmatrix} y_1 \\ y_2 \\ \vdots \\ y_n \end{bmatrix} = \begin{bmatrix} 1 & x_{11} & x_{12} & \dots & x_{1k} \\ 1 & x_{21} & x_{22} & \dots & x_{2k} \\ \vdots & \vdots & \vdots & \dots & \vdots \\ 1 & x_{n1} & x_{n2} & \dots & x_{nk} \end{bmatrix} \begin{bmatrix} \beta_0 \\ \beta_1 \\ \beta_2 \\ \vdots \\ \beta_k \end{bmatrix} + \begin{bmatrix} u_1 \\ u_2 \\ \vdots \\ u_n \end{bmatrix}$$

$n \times 1 \quad n \times (k+1) \quad (k+1) \times 1 \quad n \times 1$

$$Y = X\beta + u$$

We want to estimate β .

2.2.1. Model for Clay Soil

When it comes to the clay soil, a similar approach of conducting multiple regression analysis is performed using the Minitab software. (1) This analysis involves modelling Vernonia galamensis.

A. Regression Analysis: HC versus Time, Mass, pH

The regression equation is

$$\text{HC} = -6.59 + 0.00538 \text{ Time} + 0.00455 \text{ Mass} + 0.970 \text{ pH}$$

Predictor	Coef	SE Coef	T	P
Constant	-6.593	1.999	-3.300	0.003
Time	0.005381	0.001098	4.90	0.000
Mass	0.004554	0.001669	2.73	0.011
PH	0.9696	0.3016	3.22	0.003

$$S = 0.0422874 \quad R\text{-Sq} = 93.5\% \quad R\text{-Sq(adj)} = 92.7\%$$

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	3	0.66715	0.22238	124.36	0.000
Residual Error	26	0.04649	0.00179		
Total	29	0.71364			

B. Regression Analysis: Pb versus Time, Mass, pH

The regression equation is

$$\text{Pb} = 2.96 + 0.00782 \text{ Time} + 0.00324 \text{ Mass} - 0.443 \text{ pH}$$

Predictor	Coef	SE Coef	T	P
Constant	2.962	1.272	2.33	0.028
Time	0.00782100	0.000698411	11.200	0.000
Mass	0.003239	0.001061	3.05	0.005

PH	-0.4431	0.1918	-2.31	0.029
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S = 0.0268981 R-Sq = 91.9% R-Sq (adj) = 91.0%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	3	0.213513	0.071171	98.37	0.000
Residual Error	26	0.018811	0.000724		
Total	29	0.232324			

C. Regression Analysis: Zn versus Time, Mass, pH

The regression equation is

$$\text{Zn} = -2.67 + 0.00210 \text{ Time} + 0.00169 \text{ Mass} + 0.396 \text{ pH}$$

Predictor	Coef	SE Coef	T	P
Constant	-2.6655	0.4158	-6.410	0.000
Time	0.002099	0.00022839	20.000	0.000
Mass	0.00168560	0.00034704	4.86	0.000
PH	0.39558	0.06271	6.31	0.000

S = 0.0268981 R-Sq = 91.9% R-Sq (adj) = 91.0%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	3	0.213513	0.071171	98.37	0.000
Residual Error	26	0.018811	0.000724		
Total	29	0.232324			

D. Regression Analysis: Cr versus Time, Mass, pH

The regression equation is

$$\text{Cr} = 1.71 + 0.00830 \text{ Time} + 0.00608 \text{ Mass} - 0.271 \text{ pH}$$

Predictor	Coef	SE Coef	T	P
Constant	1.713	1.689	1.01	0.320
Time	0.0082980	0.00092768	9.5	0.000
Mass	0.0060830	0.001410	4.31	0.000
PH	-0.2708	0.2548	-1.060	0.298

S = 0.0357295 R-Sq = 91.4% R-Sq (adj) = 90.4%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	3	0.35398	0.11799	92.43	0.000
Residual Error	26	0.03319	0.00128		
Total	29	0.38717			

2. Vernonia amygdalina Modelling

A. Regression Analysis: HC_1 versus Time_1, Mass_1, pH_1

The regression equation is

$$\text{HC}_1 = -13.8 + 0.00243 \text{ Time}_1 - 0.00250 \text{ Mass}_1 + 2.06 \text{ pH}_1$$

Predictor	Coef	SE Coef	T	P
Constant	-13.772	1.484	-9.280	0.000

Time_1	0.00242580	0.00096782	51	0.019
Mass_1	-0.002502	0.001491	-1.680	0.105
pH_1	2.0617	0.2248	9.17	0.000

S = 0.0345595 R-Sq = 96.8% R-Sq(adj) = 96.5%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	3	0.95150	0.31717	265.55	0.000
Residual Error	26	0.03105	0.00119		
Total	29	0.98255			

B. Regression Analysis: Pb_1 versus Time_1, Mass_1, pH_1

The regression equation is

$$\text{Pb}_1 = 3.96 + 0.00844 \text{ Time}_1 + 0.00589 \text{ Mass}_1 - 0.598 \text{ pH}_1$$

Predictor	Coef	SE Coef	T	P
Constant	3.962	1.697	2.33	0.028
Time_1	0.0084390	0.001107	7.62	0.000
Mass_1	0.0058920	0.001705	3.46	0.002
pH_1	-0.5983	0.2571	-2.330	0.028

S = 0.0395213 R-Sq = 84.2% R-Sq(adj) = 82.4%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	3	0.216307	0.072102	46.16	0.000
Residual Error	26	0.040610	0.001562		
Total	29	0.256917			

Regression Analysis: Zn_1 versus Time_1, Mass_1, pH_1

The regression equation is

$$\text{Zn}_1 = -1.63 + 0.00253 \text{ Time}_1 + 0.00189 \text{ Mass}_1 + 0.244 \text{ pH}_1$$

Predictor	Coef	SE Coef	T	P
Constant	-1.6346	0.3737	-4.370	0.000
Time_1	0.00253150	0.000243610	10.390	0.000
Mass_1	0.0018940	0.0003753	5.05	0.000
pH_1	0.24446	0.05659	4.32	0.000

S = 0.00870020 R-Sq = 98.1% R-Sq(adj) = 97.8%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	3	0.099379	0.033126	437.64	0.000
Residual Error	26	0.001968	0.000076		
Total	29	0.101347			

C. Regression Analysis: Cr_1 versus Time_1, Mass_1, pH_1

The regression equation is

$$\text{Cr}_1 = 1.80 + 0.00685 \text{ Time}_1 + 0.00940 \text{ Mass}_1 - 0.279 \text{ pH}_1$$

Predictor	Coef	SE Coef	T	P
Constant	1.801	1.196	1.51	0.144
Time_1	0.00684640	0.00078008	8.78	0.000
Mass_1	0.009396	0.001202	7.82	0.000
pH_1	-0.2788	0.1812	-1.540	0.136

$$S = 0.0278546 \quad R\text{-Sq} = 94.9\% \quad R\text{-Sq}(\text{adj}) = 94.3\%$$

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	3	0.37409	0.12470	160.72	0.000
Residual Error	26	0.02017	0.00078		
Total	29	0.39426			

In statistical analysis, the p-value is a crucial factor in determining the significance of a model. It represents the probability value and is used to assess whether the observed data supports the hypothesis being tested. In this case, for the model to be considered statistically significant, the overall p-value should be less than 0.05. This means that if the p-value is below 0.05, it suggests that the model's results are unlikely to occur by chance and therefore can be accepted with confidence. On the other hand, the r2 value, also known as the coefficient of determination, measures the strength of the relationship between variables in a model. It ranges from 0 to 1, with a higher value indicating a stronger relationship. An r2 value closer to 100% suggests that the variables in the model explain a larger proportion of the variation observed in the data, indicating a better fit of the model. Both the p-value and r2 value are important indicators in assessing the validity and reliability of a statistical model.

CONCLUSION

The analysis conducted in this study has demonstrated the successful remediation of contaminated clay soil using *Vernonia galamensis* and *Vernonia amygdalina*. The contamination of the soil involved the introduction of hydrocarbons and metals. The microorganisms, namely *Pseudomonas aeruginosa*, *Staphylococcus aureus*, and *Escherichia coli*, along with the phytochemicals present in the leaf extracts, played a crucial role in degrading the metals and hydrocarbon contents present in the soil. Through their combined action, these microorganisms and phytochemicals facilitated the remediation process, effectively reducing the levels of contaminants in the clay soil. This finding highlights the potential of *Vernonia galamensis* and *Vernonia amygdalina* as eco-friendly solutions for soil remediation.

Indeed, the findings from the study indicate that the application of approximately 40g of both *Vernonia* extracts resulted in a reduction of more than 50% of the contaminants concentration within 40 days across all soil samples. This demonstrates the effectiveness of both *Vernonia* extracts as bio-remediating agents for polluted soil. The significant reduction in contaminants over the given time period suggests that these *Vernonia* extracts have the potential to be utilized in the remediation of various types of polluted soil. Their ability to effectively reduce the concentration of contaminants makes them promising options for eco-friendly and sustainable soil remediation practices.

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