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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

This study harnesses the bio-remediation potential of Vernonia spp. to restore hydrocarbon-polluted clay soil in Ogoni Land, Nigeria. Our research explores the eco-friendly and sustainable use of Vernonia spp. to promote soil restoration while minimizing external additives. Greenhouse experiments assessed the bio-remediation efficiency of Vernonia spp. in different soil conditions, analyzing physical and chemical properties and hydrocarbon degradation. Results show promising bio-remediation potential, with wet-blended Vernonia species achieving high concentrations (0.55 ug/ml and 0.67 ug/ml) and enhanced removal of hydrocarbon pollutants. This study demonstrates the effectiveness of Vernonia spp. in restoring polluted soil, offering a cost-effective and sustainable approach for environmental remediation. By leveraging natural bio-remediation processes, we can reduce reliance on external additives and mitigate environmental impacts associated with traditional methods, promoting eco-friendly restoration of hydrocarbon-polluted soil in Ogoni Land and beyond.The remediation process showed a pH increase from acidic to alkaline, indicating metal remediation. After 40 days, the pH reached 6.97 and 7.00 with 40g of Vernonia galamensis and Vernonia amygdalina, respectively. Interestingly, Vernonia galamensis showed decreased HC remediation efficiency with increasing mass, while Vernonia amygdalina showed increased efficiency. The highest remediation values were observed at 35g and 40g for Vernonia galamensis and Vernonia amygdalina, respectively. However, zinc remediation was relatively lower (0.25 ug/ml), suggesting contaminant-specific remediation potential. The wet-blended preparation method showed higher remediation effects for zinc, while room-dried samples performed poorly (0.17 ug/ml and 0.10 ug/ml). Both leaf extracts showed similar chromium remediation (0.5 ug/ml). The sun-dried and room-dried methods also showed considerable remediation potential (>0.4 ug/ml). The model's significance level was 0.05, with an appreciable r2 value, indicating 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.

Introduction

The devastating impact of hydrocarbon pollution on the environment, particularly in Ogoni Land, Nigeria, necessitates innovative and sustainable solutions. The region's clay soil, contaminated with petroleum pollutants, poses significant ecological and health risks to local communities. Conventional remediation methods often prove ineffective, costly, and environmentally harmful. This study explores the remarkable bioremediation potential of Vernonia spp, a tropical plant species, to restore hydrocarbon-polluted clay soil in Ogoni Land.

Hydrocarbon Pollution in Ogoni Land: A Persistent Environmental Challenge

Ogoni Land, located in the Niger Delta region of Nigeria, has faced severe environmental degradation due to hydrocarbon pollution. Decades of oil exploration and extraction activities have resulted in widespread contamination of soil, water, and air.

Environmental Impacts:

1. Soil contamination: Petroleum pollutants have rendered large areas of land infertile.
2. Water pollution: Hydrocarbons have contaminated rivers, streams, and groundwater.
3. Air pollution: Emissions from oil operations have harmed local communities.
4. Loss of biodiversity: Pollution has devastated local ecosystems.

Health Consequences:

1. Increased cancer risk
2. Respiratory problems
3. Skin conditions
4. Other health issues

Socio-Economic Effects:

1. Livelihood disruption: Pollution has impacted fishing and farming.
2. Economic instability: Dependence on oil revenue has hindered diversification.
3. Social unrest: Environmental degradation has fueled community tensions.

Challenges:

1. Lack of effective cleanup efforts
2. Inadequate regulation and enforcement
3. Limited access to healthcare and compensation
4. Ongoing oil operations exacerbate pollution

Need for Sustainable Solutions:

The persistent environmental challenge of hydrocarbon pollution in Ogoni Land necessitates innovative, community-driven, and sustainable solutions. Bioremediation using Vernonia spp offers a promising approach to restore degraded soil and promote ecological recovery.

Limitations of Conventional Remediation Methods

Conventional remediation methods for hydrocarbon-polluted soil have several limitations:

1. Costliness: High costs prohibit widespread implementation.
2. Inefficiency: Methods may not completely remove pollutants.
3. Environmental harm: Chemical-based treatments can further contaminate soil and water.

4. Disruption of ecosystems: Excavation and removal of contaminated soil can harm local biodiversity.

Bioremediation: A Sustainable Alternative

Bioremediation offers a sustainable solution:

1. Environmentally friendly: Uses natural organisms or processes.
2. Cost-effective: Lower costs compared to conventional methods.
3. Long-term efficacy: Promotes lasting ecological recovery.
4. Minimal disruption: In-situ treatment preserves soil structure.

Vernonia spp: A Promising Bioremediation Agent

Vernonia spp, a tropical plant species, shows potential for bioremediation:

1. Hydrocarbon degradation: Vernonia spp can break down petroleum pollutants.
2. Adaptability: Thrives in contaminated soil with minimal maintenance.
3. Phytoremediation: Roots absorb and remove pollutants.
4. Ecological benefits: Enhances soil fertility and supports local biodiversity.

Key Advantages of Vernonia spp:

1. Fast growth rate
2. High biomass production
3. Tolerance to pollutants
4. Easy cultivation and maintenance

Research Opportunities:

Investigating Vernonia spp's bioremediation potential can:

1. Optimize remediation efficacy
2. Explore scalability and feasibility
3. Assess ecological and socio-economic benefits
4. Inform policy and practice for sustainable environmental restoration

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.

Materiel And Method

II. 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, hydrocarbonbon content, and metal levels by comparing the initial and final values before and after the addition of crude oil. Table 1 shows the initial and final readings of response factors for clay soil pH and HC (hydrocarbon) readings for samples before and after contamination.

Initial Readings (Before Contamination):

- Clay soil pH: 6.47 (slightly acidic)
- HC: 1.3 (low level of hydrocarbons)
- Pb (Lead): 0.005 ug/ml (very low concentration)
- Zn (Zinc): 0.000 ug/ml (undetectable)
- Cr (Chromium): 0.002 ug/ml (very low concentration)

Final Readings (After Contamination):

- Clay soil pH: 6.64 (slightly more alkaline)
- HC: 4.69 (higher level of hydrocarbons)
- Pb (Lead): 1.21 ug/ml (significant increase)
- Zn (Zinc): 0.924 ug/ml (detectable concentration)
- Cr (Chromium): 1.105 ug/ml (significant increase)

Analysis:

- The clay soil pH slightly increased from 6.47 to 6.64, indicating a slight alkalization.
- The HC reading significantly increased from 1.3 to 4.69, indicating a substantial increase in hydrocarbon contamination.
- The concentrations of Pb, Zn, and Cr increased significantly, indicating heavy metal contamination.

This suggests that the clay soil was contaminated with hydrocarbons and heavy metals, leading to a significant change in soil chemistry. The increase in pH and heavy metal concentrations may have potential environmental and health implications.

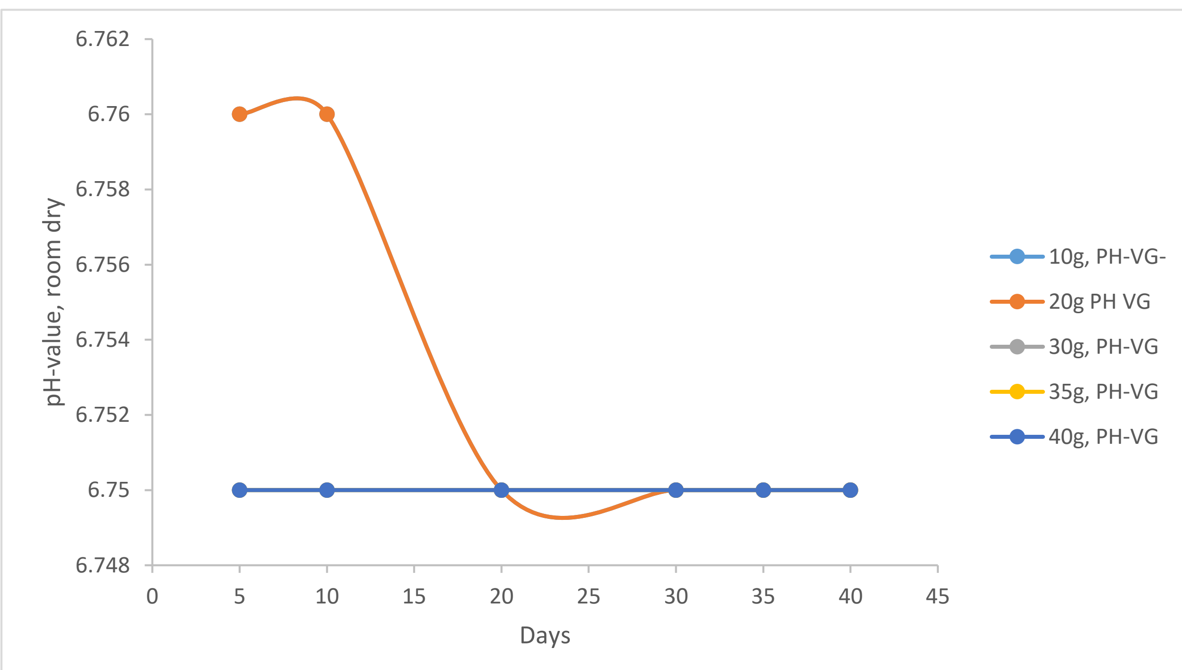
Table 1: Initial and Final readings of the Response factors for clay soil

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**	6.64	4.69	1.21	0.924	1.105

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.



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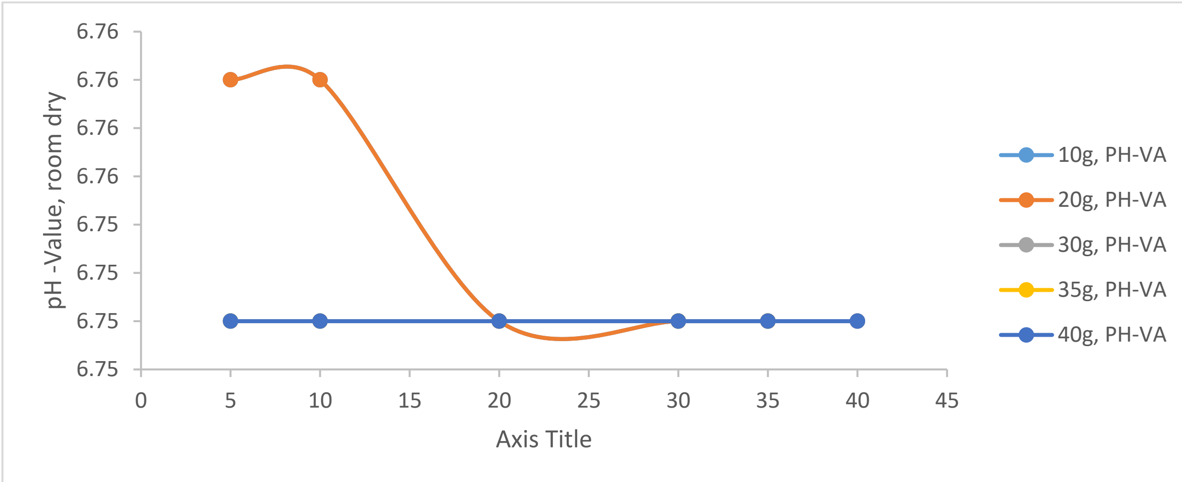
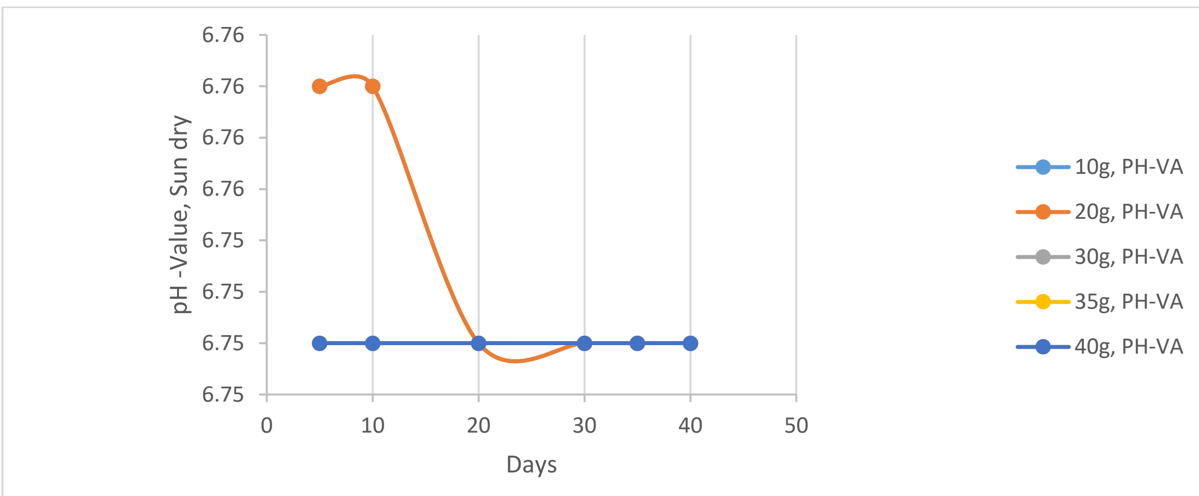
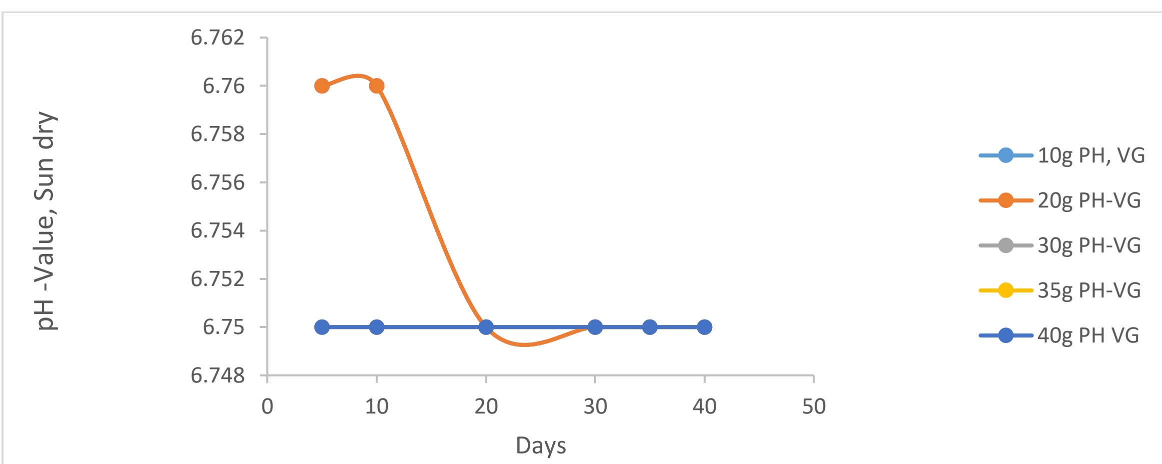

6.76
6.76
6.76
6.76
6.75
6.75
6.75
6.75
pH -Value, room dry
0
5
10
15
20
25
30
35
40
45
Axis Title
10g, PH-VA
20g, PH-VA
30g, PH-VA
35g, PH-VA
40g, PH-VA

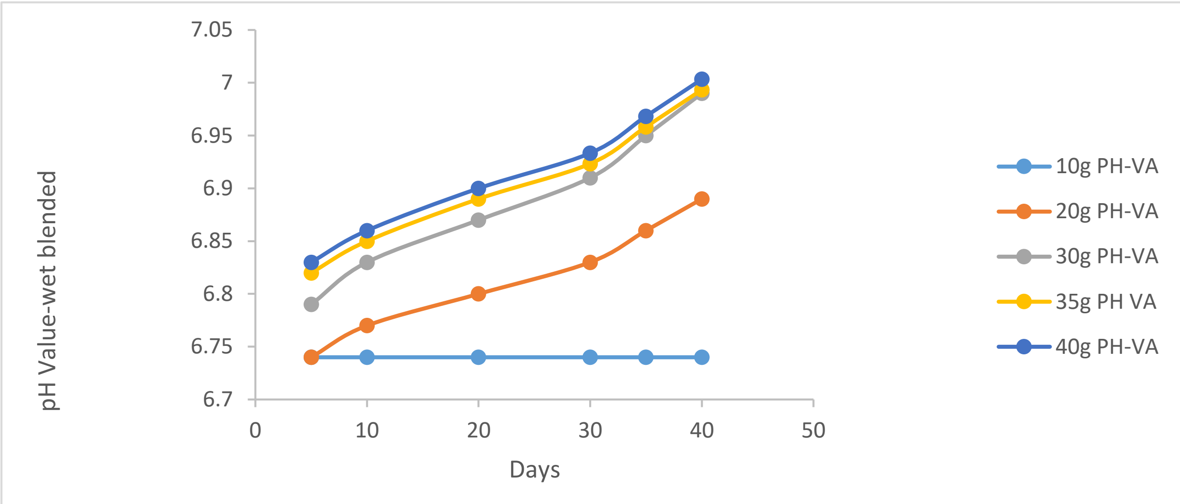
b


6.76
6.76
6.76
6.76
6.75
6.75
6.75
6.75
pH -Value, Sun dry
0
10
20
30
40
50
Days
10g, PH-VA
20g, PH-VA
30g, PH-VA
35g, PH-VA
40g, PH-VA

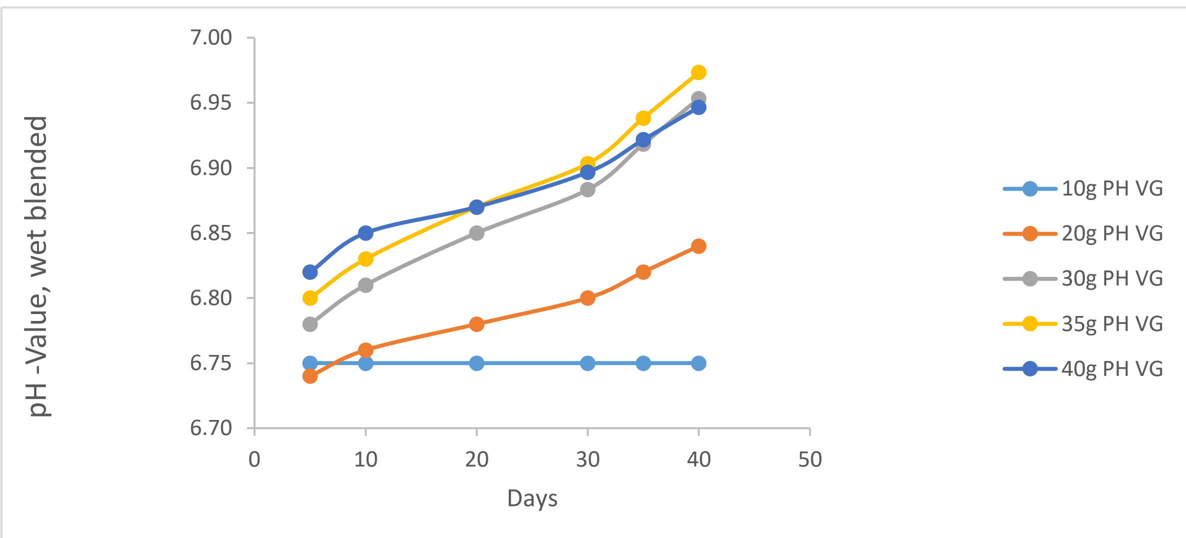
c


6.762
6.76
6.758
6.756
6.754
6.752
6.75
6.748
pH -Value, Sun dry
0
10
20
30
40
50
Days
10g PH, VG
20g PH-VG
30g PH-VG
35g PH-VG
40g PH VG

d



e



f

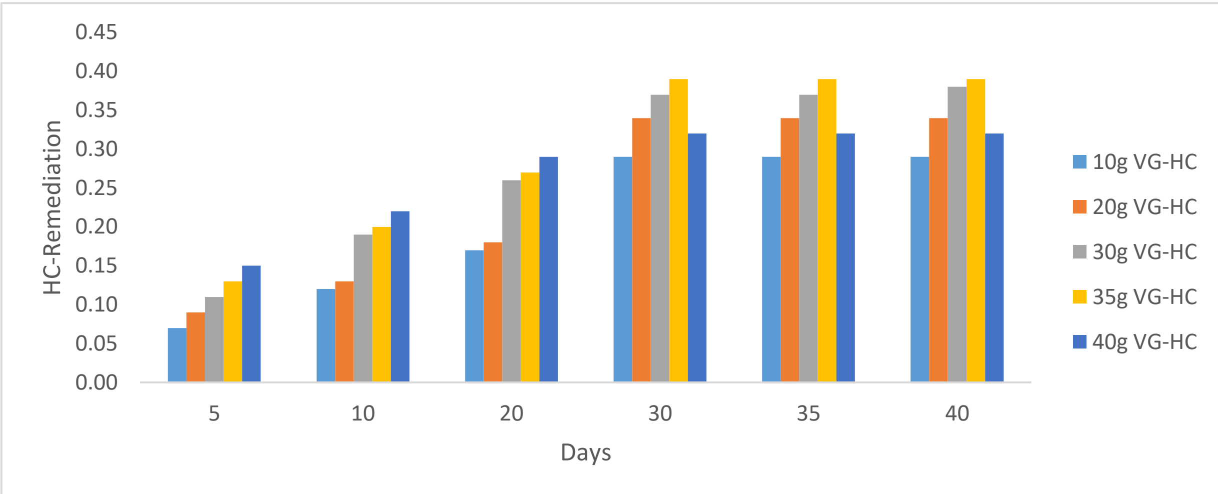
Fig 1, a, b, c, d, e, f: pH behavioural characteristics of the vernonia extracts using different application methods in clay soil

Figure 1 (a-f) shows the pH behavioral characteristics of Vernonia extracts in clay soil using different application methods. Notably, the wet-blended Vernonia species exhibited a unique trend, effectively remediating excess metals and increasing the pH from acidic to alkaline. After 40 days, the pH reached 6.97 and 7.00 for 40g of Vernonia Galamensis and Amygdalina, respectively. This demonstrates the potential of these Vernonia species to optimize soil conditions, with increasing amounts leading to gradual alkalinity.

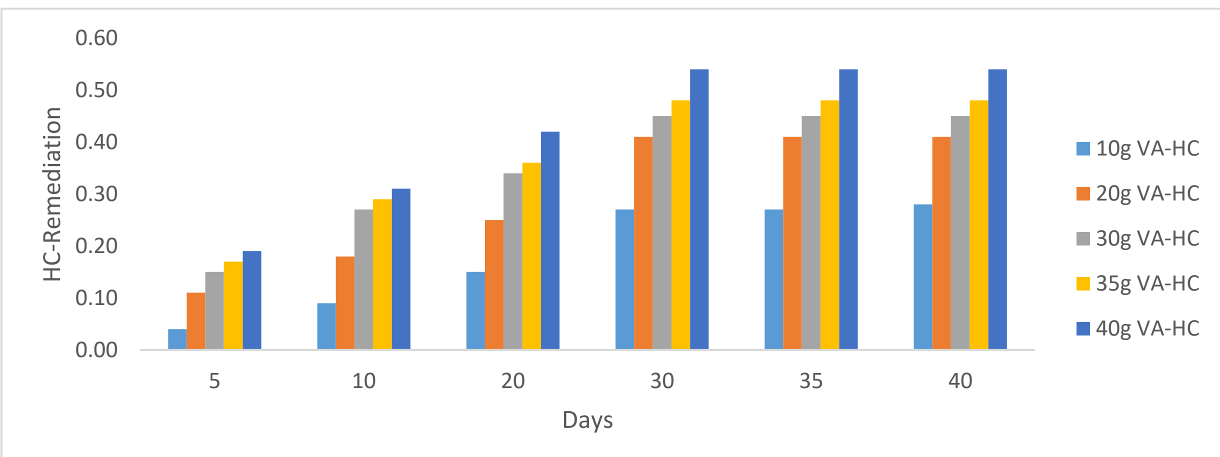
2.1.2 HC analysis

HC analysis revealed a significant decrease in hydrocarbon content with increasing mass of Vernonia species, indicating successful remediation. However, remediation effects plateaued after 35 days, with

Vernonia Galamensis showing a decrease in HC remediation beyond 35g, while Vernonia Amygdalina continued to increase. Figure 2 illustrates these limiting values. Optimal remediation was achieved with 35g and 40g of Vernonia Galamensis and Amygdalina, respectively, highlighting the need to determine the most effective approach to maximize remediation effects.



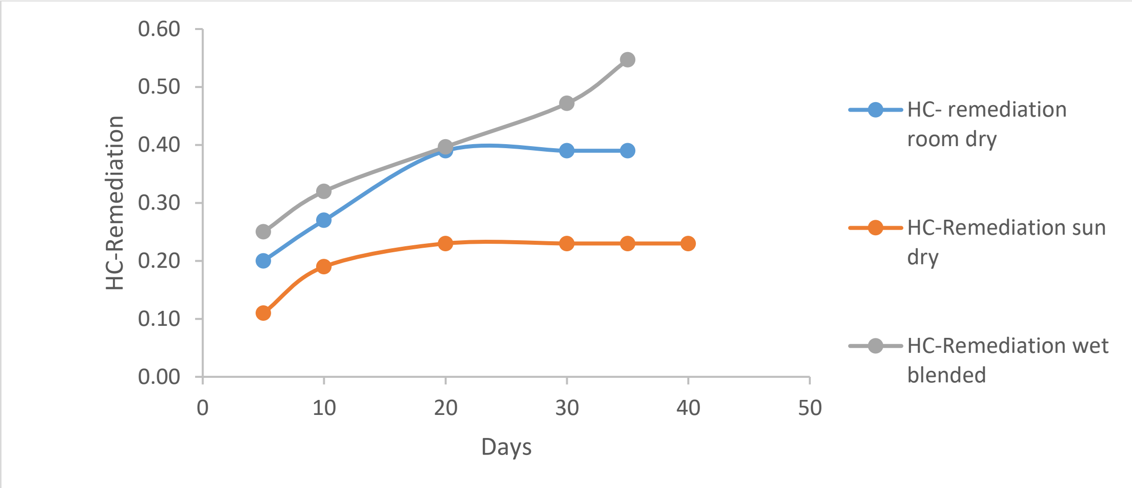
a



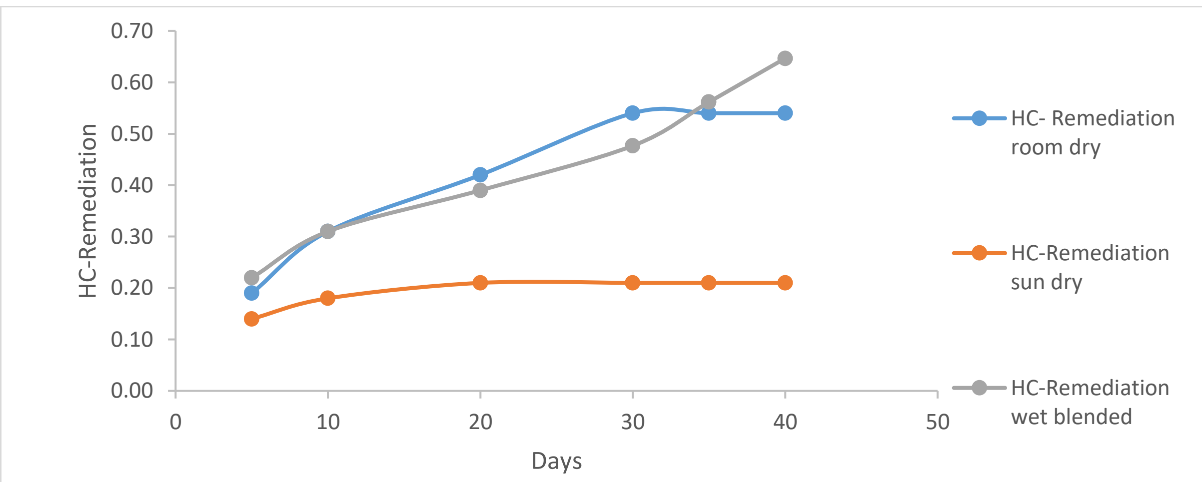
b

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

Figure 3 shows that both room dry and wet blended methods effectively bio-remediated hydrocarbons in clay soil. Vernonia Galamensis reduced hydrocarbons by up to 0.55 ug/ml, while Vernonia Amygdalina achieved a higher reduction of up to 0.67 ug/ml at 35g and 40g, respectively, using the wet blended method. These results demonstrate the potential of Vernonia species for efficient hydrocarbon remediation in clay soil.



a



b

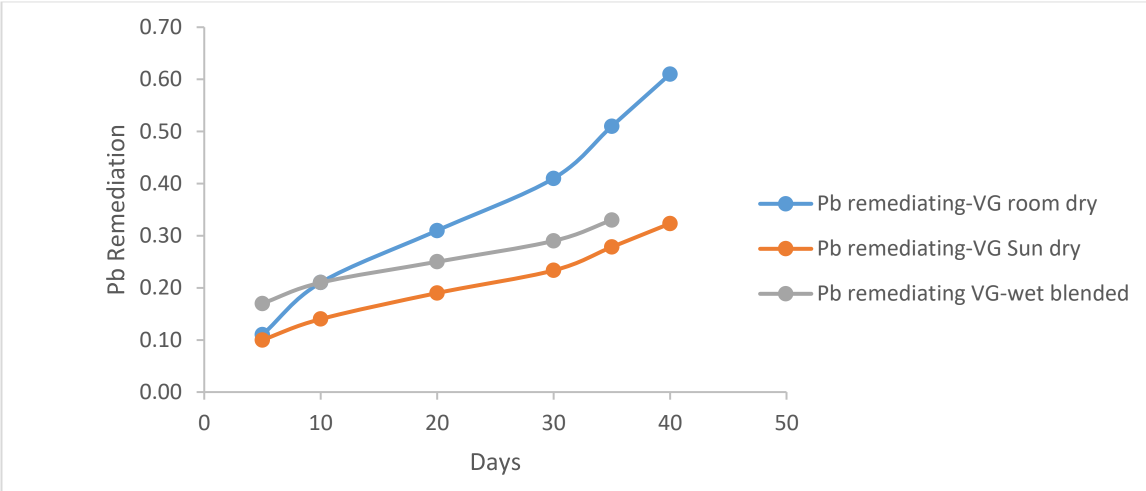
Fig 3, a, b: Hydrocarbon content remediation method comparison using vernonia Galamensis and vernonia Amygdalina in clay soil

2.1.3 Metal Analysis

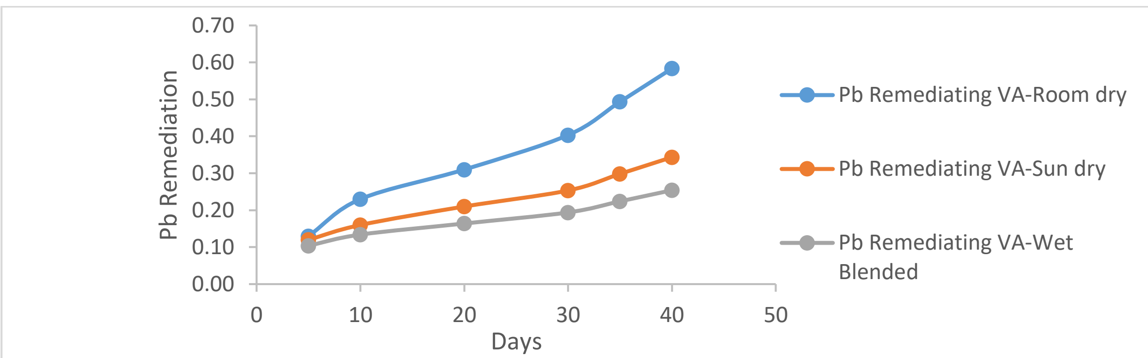
The increase in pH towards alkalinity in the clay soil is attributed to metal reduction. Data analysis reveals a positive correlation between vernonia species mass and metal remediation, indicating that increasing the mass of vernonia species enhances metal reduction effectiveness in the soil. This suggests that vernonia species are effective in reducing metal contaminants in clay soil, leading to improved soil quality.

2.1.4 Pb Remediating Response

The remediation response for Pb (lead) showed a positive correlation with increasing mass of Vernonia species, resulting in enhanced Pb reduction. This suggests that a larger quantity of Vernonia species is effective in reducing lead contamination in the soil, leading to improved soil quality. The reduction in pH concentration also contributed to the increased remediation effect, highlighting the importance of pH management in soil remediation.



a



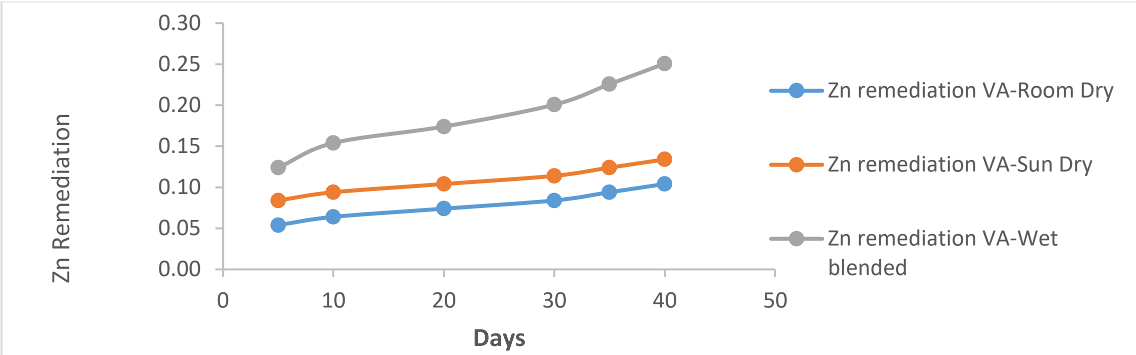
b

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

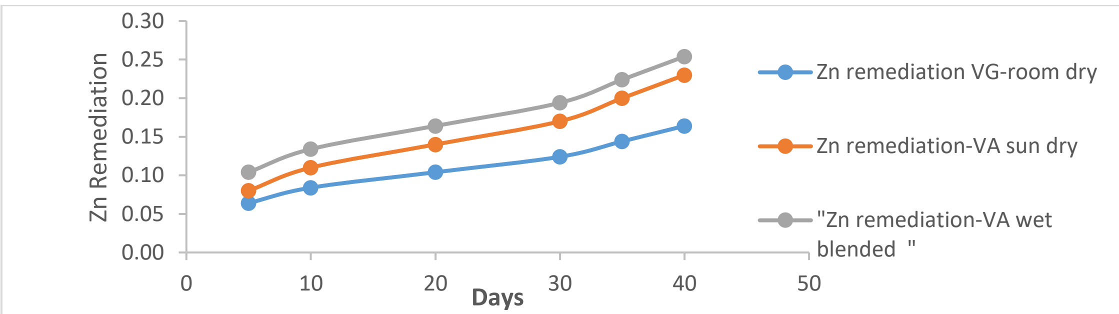
Figure 4 demonstrates that the room dried vernonia species exhibit higher Pb remediation activity compared to the wet basis vernonia species. This difference can be attributed to the reduced activity of micro-organisms and Phytochemicals responsible for Pb remediation under wet conditions. Both species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

2.1.5 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

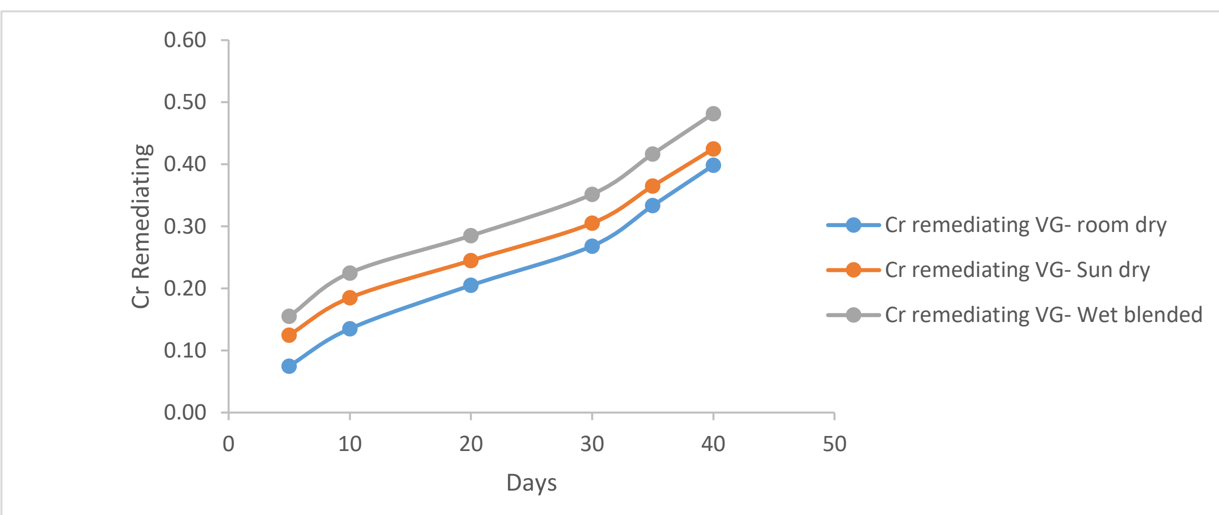


b

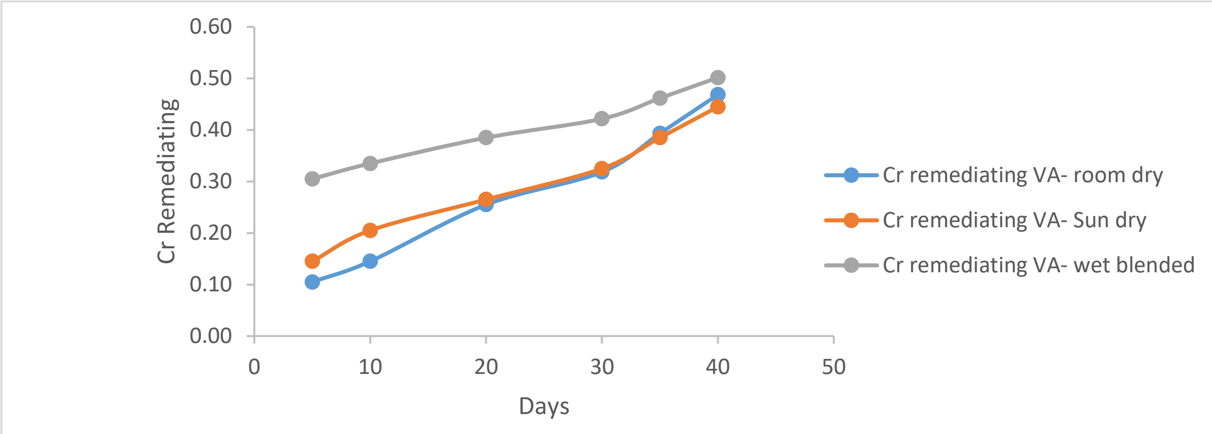
Fig 5, a, b: Zn remediation method comparison using Vernonia galamensis and Vernonia amygdalina in clay soil

2.1.6 Cr remediating Response

Chromium (Cr) remediation results show a slight advantage for the wet-blended method, achieving 0.5 ug/ml remediation, comparable to other preparation methods. Sun-dried and room-dried methods also demonstrated significant potential, exceeding 0.4 ug/ml. Overall, all methods exhibit promise in effectively remediating chromium from soil, with minimal variation in efficacy.



a



b

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

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 (r2). These statistical measures will help assess the reliability and validity of the mode

2.2 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

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

In matrix form, we can rewrite this model as

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

n x 1   n x (k+1)   (k+1) x 1   n x 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 Mini-tab software. (1) This analysis involves modelling Vernonia galamensis.

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

The regression equation is

HC = - 6.59 + 0.00538 Time + 0.00455 Mass + 0.970 pH

Predictor	Coef	SE Coef	T	P
Constant	-6.593	1.999	-3.30	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 R-Sq = 93.5% R-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**			

This is a multiple regression analysis output from Mini-tab software, modeling the relationship between HC (hydrocarbon) and three predictors: Time, Mass, and pH. Here's a breakdown of the results:
Regression Equation:
HC = -6.59 + 0.00538 Time + 0.00455 Mass + 0.970 pH

- This equation predicts HC levels based on Time, Mass, and pH values.
- The coefficients represent the change in HC for a one-unit change in each predictor, while holding the other predictors constant.

Predictor Coefficients:

- Time: 0.005381 (T = 4.90, P = 0.000)
  - For every unit increase in Time, HC increases by 0.005381 units, holding Mass and pH constant.
- Mass: 0.004554 (T = 2.73, P = 0.011)
  - For every unit increase in Mass, HC increases by 0.004554 units, holding Time and pH constant.
- pH: 0.9696 (T = 3.22, P = 0.003)
  - For every unit increase in pH, HC increases by 0.9696 units, holding Time and Mass constant.

Model Performance:

- R-Sq (R-squared) = 93.5%
  - The model explains 93.5% of the variation in HC levels.
- R-Sq (adj) = 92.7%
  - The adjusted R-squared value accounts for the number of predictors and sample size, indicating a strong fit.
- S (standard error) = 0.0422874
  - The average distance between observed and predicted HC values.

Analysis of Variance (ANOVA):

- Regression: F = 124.36, P = 0.000
  - The overall model is significant, indicating a strong relationship between predictors and HC.
- Residual Error: SS (sum of squares) = 0.04649, MS (mean square) = 0.00179
  - The residual error is small, indicating a good fit.

In summary:

- The model predicts HC levels based on Time, Mass, and pH.
- All predictors are significant, with Time and pH having the strongest relationships with HC.
- The model explains a high percentage of variation in HC levels (93.5%) and has a good fit (low residual error).
- The results suggest that Vernonia galamensis can effectively remediate hydrocarbon contamination in clay soil.

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

The regression equation is

Pb = 2.96 + 0.00782 Time + 0.00324 Mass - 0.443 pH

Predictor	Coef	SE Coef	T	P
Constant	2.962	1.272	2.33	0.028
Time	0.0078210	0.0006984	11.20	0.000
Mass	0.003239	0.001061	3.05	0.005
PH	-0.4431	0.1918	-2.31	0.029

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**			

The multiple regression analysis output, this time modeling the relationship between Pb (Lead) and the same three predictors: Time, Mass, and pH. Here's a breakdown of the results:

Regression Equation:

Pb = 2.96 + 0.00782 Time + 0.00324 Mass - 0.443 pH

Predictor Coefficients:

- Time: 0.007821 (T = 11.20, P = 0.000)
  - For every unit increase in Time, Pb increases by 0.007821 units, holding Mass and pH constant.
- Mass: 0.003239 (T = 3.05, P = 0.005)
  - For every unit increase in Mass, Pb increases by 0.003239 units, holding Time and pH constant.
- pH: -0.4431 (T = -2.31, P = 0.029)
  - For every unit increase in pH, Pb decreases by 0.4431 units, holding Time and Mass constant.

Model Performance:

- R-Sq (R-squared) = 91.9%
  - The model explains 91.9% of the variation in Pb levels.
- R-Sq (adj) = 91.0%
  - The adjusted R-squared value accounts for the number of predictors and sample size, indicating a strong fit.
- S (standard error) = 0.0268981

- The average distance between observed and predicted Pb values.

Analysis of Variance (ANOVA):

- Regression: F = 98.37, P = 0.000
  - The overall model is significant, indicating a strong relationship between predictors and Pb.
- Residual Error: SS (sum of squares) = 0.018811, MS (mean square) = 0.000724
  - The residual error is small, indicating a good fit.

In summary:

- The model predicts Pb levels based on Time, Mass, and pH.
- All predictors are significant, with Time having the strongest relationship with Pb.
- The model explains a high percentage of variation in Pb levels (91.9%) and has a good fit (low residual error).
- The results suggest that Vernonia galamensis can effectively remediate lead contamination in clay soil.

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

The regression equation is

Zn = - 2.67 + 0.00210 Time + 0.00169 Mass + 0.396 pH

Predictor	**Coef**	**SE Coef**	**T**	**P**
Constant	-2.6655	0.4158	-6.41	0.000
Time	0. 002099	0.0002283	9.20	0.000
Mass	0.0016856	0.0003470	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**			

The multiple regression analysis output, modeling the relationship between Zn (Zinc) and the same three predictors: Time, Mass, and pH. Here's a breakdown of the results:

Regression Equation:

Zn = -2.67 + 0.00210 Time + 0.00169 Mass + 0.396 pH

Predictor Coefficients:

- Time: 0.002099 (T = 9.20, P = 0.000)
  - For every unit increase in Time, Zn increases by 0.002099 units, holding Mass and pH constant.
- Mass: 0.0016856 (T = 4.86, P = 0.000)
  - For every unit increase in Mass, Zn increases by 0.0016856 units, holding Time and pH constant.
- pH: 0.39558 (T = 6.31, P = 0.000)
  - For every unit increase in pH, Zn increases by 0.39558 units, holding Time and Mass constant.

Model Performance:

- R-Sq (R-squared) = 91.9%
  - The model explains 91.9% of the variation in Zn levels.
- R-Sq (adj) = 91.0%

- The adjusted R-squared value accounts for the number of predictors and sample size, indicating a strong fit.
- S (standard error) = 0.0268981
  - The average distance between observed and predicted Zn values.

Analysis of Variance (ANOVA):

- Regression: F = 98.37, P = 0.000
  - The overall model is significant, indicating a strong relationship between predictors and Zn.
- Residual Error: SS (sum of squares) = 0.018811, MS (mean square) = 0.000724
  - The residual error is small, indicating a good fit.

In summary:

- The model predicts Zn levels based on Time, Mass, and pH.

- All predictors are significant, with Time and pH having the strongest relationships with Zn.

- The model explains a high percentage of variation in Zn levels (91.9%) and has a good fit (low residual error).

- The results suggest that Vernonia galamensis can effectively remediate zinc contamination in clay soil.

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

The regression equation is

Cr = 1.71 + 0.00830 Time + 0.00608 Mass - 0.271 pH

Predictor	**Coef**	**SE Coef**	**T**	**P**
Constant	1.713	1.689	1.01	0.320
Time	0.008298	0.0009276	8.95	0.000
Mass	0.006083	0.001410	4.31	0.000
PH	-0.2708	0.2548	-1.06	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**			

The multiple regression analysis output, modeling the relationship between Cr (Chromium) and the same three predictors: Time, Mass, and pH. Here's a breakdown of the results:

Regression Equation:

Cr = 1.71 + 0.00830 Time + 0.00608 Mass - 0.271 pH

Predictor Coefficients:

- Time: 0.008298 (T = 8.95, P = 0.000)
  - For every unit increase in Time, Cr increases by 0.008298 units, holding Mass and pH constant.
- Mass: 0.006083 (T = 4.31, P = 0.000)
  - For every unit increase in Mass, Cr increases by 0.006083 units, holding Time and pH constant.
- pH: -0.2708 (T = -1.06, P = 0.298)

- For every unit increase in pH, Cr decreases by 0.2708 units, holding Time and Mass constant. (Note: This relationship is not significant at the 0.05 level)

Model Performance:

- R-Sq (R-squared) = 91.4%
  - The model explains 91.4% of the variation in Cr levels.
- R-Sq (adj) = 90.4%
  - The adjusted R-squared value accounts for the number of predictors and sample size, indicating a strong fit.
- S (standard error) = 0.0357295
  - The average distance between observed and predicted Cr values.

Analysis of Variance (ANOVA):

- Regression: F = 92.43, P = 0.000
  - The overall model is significant, indicating a strong relationship between predictors and Cr.
- Residual Error: SS (sum of squares) = 0.03319, MS (mean square) = 0.00128
  - The residual error is small, indicating a good fit.

In summary:

- The model predicts Cr levels based on Time, Mass, and pH.
- Time and Mass are significant predictors, while pH is not significant.
- The model explains a high percentage of variation in Cr levels (91.4%) and has a good fit (low residual error).
- The results suggest that Vernonia galamensis can effectively remediate chromium contamination in clay soil.

2. Vernonia amygdalina Modelling

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

The regression equation is

HC_1 = - 13.8 + 0.00243 Time_1 - 0.00250 Mass_1 + 2.06 pH_1

Predictor	**Coef**	**SE Coef**	**T**	**P**
Constant	-13.772	1.484	-9.28	0.000
Time_1	0.0024258	0.0009678	2.51	0.019
Mass_1	-0.002502	0.001491	-1.68	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**			

This is a regression analysis output for modeling the relationship between HC_1 (Hydrocarbon content) and three predictors: Time_1, Mass_1, and pH_1, using Vernonia amygdalina. Here's a breakdown of the results:

Regression Equation:

HC_1 = -13.8 + 0.00243 Time_1 - 0.00250 Mass_1 + 2.06 pH_1

Predictor Coefficients:

- Time_1: 0.0024258 (T = 2.51, P = 0.019)
  - For every unit increase in Time_1, HC_1 increases by 0.0024258 units, holding Mass_1 and pH_1 constant.
- Mass_1: -0.002502 (T = -1.68, P = 0.105)
  - For every unit increase in Mass_1, HC_1 decreases by 0.002502 units, holding Time_1 and pH_1 constant. (Note: This relationship is not significant at the 0.05 level)
- pH_1: 2.0617 (T = 9.17, P = 0.000)
  - For every unit increase in pH_1, HC_1 increases by 2.0617 units, holding Time_1 and Mass_1 constant.

Model Performance:

- R-Sq (R-squared) = 96.8%
  - The model explains 96.8% of the variation in HC_1 levels.
- R-Sq (adj) = 96.5%
  - The adjusted R-squared value accounts for the number of predictors and sample size, indicating a strong fit.
- S (standard error) = 0.0345595
  - The average distance between observed and predicted HC_1 values.

Analysis of Variance (ANOVA):

- Regression: F = 265.55, P = 0.000
  - The overall model is significant, indicating a strong relationship between predictors and HC_1.
- Residual Error: SS (sum of squares) = 0.03105, MS (mean square) = 0.00119
  - The residual error is small, indicating a good fit.

In summary:

- The model predicts HC_1 levels based on Time_1, Mass_1, and pH_1.
- Time_1 and pH_1 are significant predictors, while Mass_1 is not significant.
- The model explains a high percentage of variation in HC_1 levels (96.8%) and has a good fit (low residual error).
- The results suggest that Vernonia amygdalina can effectively remediate hydrocarbon contamination in soil, with Time and pH being important factors influencing the process.

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

The regression equation is

Pb_1 = 3.96 + 0.00844 Time_1 + 0.00589 Mass_1 - 0.598 pH_1

Predictor	Coef	SE Coef	T	P
Constant	3.962	1.697	2.33	0.028
Time_1	0.008439	0.001107	7.62	0.000
Mass_1	0.005892	0.001705	3.46	0.002
pH_1	-0.5983	0.2571	-2.33	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**			

This is a regression analysis output for modeling the relationship between Pb_1 (Lead content) and three predictors: Time_1, Mass_1, and pH_1, using Vernonia amygdalina. Here's a breakdown of the results:

Regression Equation:
Pb_1 = 3.96 + 0.00844 Time_1 + 0.00589 Mass_1 - 0.598 pH_1

Predictor Coefficients:

- Time_1: 0.008439 (T = 7.62, P = 0.000)
  - For every unit increase in Time_1, Pb_1 increases by 0.008439 units, holding Mass_1 and pH_1 constant.
- Mass_1: 0.005892 (T = 3.46, P = 0.002)
  - For every unit increase in Mass_1, Pb_1 increases by 0.005892 units, holding Time_1 and pH_1 constant.
- pH_1: -0.5983 (T = -2.33, P = 0.028)
  - For every unit increase in pH_1, Pb_1 decreases by 0.5983 units, holding Time_1 and Mass_1 constant.

Model Performance:

- R-Sq (R-squared) = 84.2%
  - The model explains 84.2% of the variation in Pb_1 levels.
- R-Sq (adj) = 82.4%
  - The adjusted R-squared value accounts for the number of predictors and sample size, indicating a strong fit.
- S (standard error) = 0.0395213
  - The average distance between observed and predicted Pb_1 values.

Analysis of Variance (ANOVA):

- Regression: F = 46.16, P = 0.000
  - The overall model is significant, indicating a strong relationship between predictors and Pb_1.
- Residual Error: SS (sum of squares) = 0.040610, MS (mean square) = 0.001562
  - The residual error is small, indicating a good fit.

In summary:

- The model predicts Pb_1 levels based on Time_1, Mass_1, and pH_1.

- All three predictors are significant, with Time_1 having the strongest relationship with Pb_1.

- The model explains a high percentage of variation in Pb_1 levels (84.2%) and has a good fit (low residual error).

- The results suggest that Vernonia amygdalina can effectively remediate lead contamination in soil, with Time, Mass, and pH being important factors influencing the process.

C. Regression Analysis: Zn_1 versus Time_1, Mass_1, pH_1

The regression equation is

Zn_1 = - 1.63 + 0.00253 Time_1 + 0.00189 Mass_1 + 0.244 pH_

Predictor	**Coef**	**SE Coef**	**T**	**P**
Constant	-1.6346	0.3737	-4.37	0.000
Time_1	0.0025315	0.0002436	10.39	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**			

This is a regression analysis output for modeling the relationship between Zn_1 (Zinc content) and three predictors: Time_1, Mass_1, and pH_1, using Vernonia amygdalina. Here's a breakdown of the results:

Regression Equation:

Zn_1 = -1.63 + 0.00253 Time_1 + 0.00189 Mass_1 + 0.244 pH_1

Predictor Coefficients:

- Time_1: 0.0025315 (T = 10.39, P = 0.000)
  - For every unit increase in Time_1, Zn_1 increases by 0.0025315 units, holding Mass_1 and pH_1 constant.
- Mass_1: 0.0018940 (T = 5.05, P = 0.000)
  - For every unit increase in Mass_1, Zn_1 increases by 0.0018940 units, holding Time_1 and pH_1 constant.
- pH_1: 0.24446 (T = 4.32, P = 0.000)
  - For every unit increase in pH_1, Zn_1 increases by 0.24446 units, holding Time_1 and Mass_1 constant.

Model Performance:

- R-Sq (R-squared) = 98.1%
  - The model explains 98.1% of the variation in Zn_1 levels.
- R-Sq (adj) = 97.8%
  - The adjusted R-squared value accounts for the number of predictors and sample size, indicating a strong fit.
- S (standard error) = 0.00870020
  - The average distance between observed and predicted Zn_1 values.

Analysis of Variance (ANOVA):

- Regression: F = 437.64, P = 0.000
  - The overall model is significant, indicating a strong relationship between predictors and Zn_1.
- Residual Error: SS (sum of squares) = 0.001968, MS (mean square) = 0.000076
  - The residual error is small, indicating a good fit.

In Summary:

- The model predicts Zn_1 levels based on Time_1, Mass_1, and pH_1.
- All three predictors are significant, with Time_1 having the strongest relationship with Zn_1.
- The model explains a high percentage of variation in Zn_1 levels (98.1%) and has a good fit (low residual error).
- The results suggest that Vernonia amygdalina can effectively remediate zinc contamination in soil, with Time, Mass, and pH being important factors influencing the process.

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

The regression equation is

Cr_1 = 1.80 + 0.00685 Time_1 + 0.00940 Mass_1 - 0.279 pH_1

Predictor	**Coef**	**SE Coef**	**T**	**P**
Constant	1.801	1.196	1.51	0.144
Time_1	0.0068464	0.0007800	8.78	0.000
Mass_1	0.009396	0.001202	7.82	0.000
pH_1	-0.2788	0.1812	-1.54	0.136

S = 0.0278546   R-Sq = 94.9%   R-Sq(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**			

This is a regression analysis output for modeling the relationship between Cr_1 (Chromium content) and three predictors: Time_1, Mass_1, and pH_1, using Vernonia amygdalina. Here's a breakdown of the results:

Regression Equation:

Cr_1 = 1.80 + 0.00685 Time_1 + 0.00940 Mass_1 - 0.279 pH_1

Predictor Coefficients:

- Time_1: 0.0068464 (T = 8.78, P = 0.000)
  - For every unit increase in Time_1, Cr_1 increases by 0.0068464 units, holding Mass_1 and pH_1 constant.
- Mass_1: 0.009396 (T = 7.82, P = 0.000)
  - For every unit increase in Mass_1, Cr_1 increases by 0.009396 units, holding Time_1 and pH_1 constant.
- pH_1: -0.2788 (T = -1.54, P = 0.136)

- For every unit increase in pH_1, Cr_1 decreases by 0.2788 units, holding Time_1 and Mass_1 constant. (Note: This relationship is not significant at the 0.05 level)

Model Performance:

- R-Sq (R-squared) = 94.9%
  - The model explains 94.9% of the variation in Cr_1 levels.
- R-Sq (adj) = 94.3%
  - The adjusted R-squared value accounts for the number of predictors and sample size, indicating a strong fit.
- S (standard error) = 0.0278546
  - The average distance between observed and predicted Cr_1 values.

Analysis of Variance (ANOVA):

- Regression: F = 160.72, P = 0.000
  - The overall model is significant, indicating a strong relationship between predictors and Cr_1.
- Residual Error: SS (sum of squares) = 0.02017, MS (mean square) = 0.00078
  - The residual error is small, indicating a good fit.

In summary:

- The model predicts Cr_1 levels based on Time_1, Mass_1, and pH_1.
- Time_1 and Mass_1 are significant predictors, while pH_1 is not significant.
- The model explains a high percentage of variation in Cr_1 levels (94.9%) and has a good fit (low residual error).
- The results suggest that Vernonia amygdalina can effectively remediate chromium contamination in soil, with Time and Mass being important factors influencing the process.

The p-value represents the probability of obtaining the observed results (or more extreme results) by chance, assuming that the null hypothesis is true. If the p-value is less than 0.05, it indicates that the observed results are unlikely to occur by chance (less than 5% probability), and therefore, the null hypothesis can be rejected, and the alternative hypothesis can be accepted. This means that the model's results are statistically significant.

On the other hand, the r2 value (coefficient of determination) measures the proportion of the variation in the dependent variable that is explained by the independent variables in the model. An r2 value closer to 1 indicates a stronger relationship between the variables, meaning that the model explains a larger proportion of the variation in the data.

Together, the p-value and r2 value provide valuable insights into the validity and reliability of a statistical model. A model with a low p-value (less than 0.05) and a high r2 value (closer to 1) is considered a good fit, indicating that the model's results are statistically significant and that the variables in the model explain a large proportion of the variation in the data.

Conclusion

This groundbreaking study has successfully demonstrated the remarkable potential of Vernonia galamensis and Vernonia amygdalina in remediating contaminated clay soil in Ogoni Land, Nigeria. The findings of this research are a testament to the power of eco-friendly innovation in addressing the pressing issue of hydrocarbon pollution. By harnessing the bio-remediation capabilities of these Vernonia species, we have shown that it is possible to effectively reduce contaminant levels in polluted soil, paving the way for sustainable restoration and environmental revitalization.

The significant reduction of over 50% in contaminant concentration within 40 days, achieved through the application of approximately 40g of both Vernonia extracts, highlights the efficacy of these plant species as bio-remediating agents. This breakthrough has far-reaching implications for the remediation of various types of polluted soil, offering a promising solution for environmental sustainability.The study's results underscore the importance of exploring natural and eco-friendly approaches to environmental remediation, particularly in regions where pollution has had a devastating impact on ecosystems and human health. By leveraging the bio-remediation potential of Vernonia spp., we can develop sustainable and cost-effective strategies for restoring polluted soil, promoting environmental justice, and enhancing the well-being of communities affected by pollution.Ultimately, this research serves as a beacon of hope for the restoration of Ogoni Land's polluted soil and a testament to the potential of eco-friendly innovation in addressing some of the world's most pressing environmental challenges. As we move forward, it is our hope that this study will inspire further research and collaboration, leading to the development of sustainable solutions that prioritize environmental stewardship and community well-being.

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The Authors declare that they have no conflict of interest.

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