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Original Article

Modelling the Effect of Decomposed Raffia Palm Trunk on the Bioremediation of Oil based Drill Cuttings

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Abstract *- This study determines the modelling effect of Decomposed Raffia Palm for degradation of oil-based drill cuttings bioremediation. The experiment was conducted at the Rivers Institute of Agricultural Research and Training (RIART) at Rivers State University, Port Harcourt. Samples of oil-based drill cuttings were bulk in eleven reactors with four replications (T1, T2, T3-T11). The physicochemical properties of the initial drill cuttings were analyzed. Also, the physiochemical properties of the oil-based drill cuttings of Decomposed Raffia Palm are as follows: Total Petroleum Hydrocarbon, Benzene Toluene Ethylene Xylene and Polycyclic Aromatic Hydrocarbon were analyzed in the laboratory before and after treatments. Total Petroleum Hydrocarbon, Benzene Toluene Ethylene Xylene and Petroleum Aromatic Hydrocarbon reduction were drastically reduced in all treatment options at the end of 16 weeks of remediation. Results also displayed a high coefficient of determination of (R^2) of 0.9593, 0.87890.and 9902in all the treatment options. The formulated models were for Total Petroleum Hydrocarbon (TPH), Benzene Toluene Ethylbenzene Xylene (BTEX) and Polycyclic Aromatic Hydrocarbon (PAH). The results of the experimental tests were plotted against the period to obtain the constant (β) in the predicted models. The models showed good agreement between experimental data and the predicted data. The model used was simple nonlinear regression, and it was validated by graphical comparison, as well as with Root Mean Square Error (RMSE) and Residual Prediction of Deviation (RPD). Results displayed a high coefficient of determination $R^{2,}$ low Root Mean Square Error (RMSE) and excellent Residue Prediction of Deviation (RPD). However, it recommended that the model (simple nonlinear regression) be used for predicting the degradation rate of Total Petroleum Hydrocarbon (TPH), Polycyclic Aromatic Hydrocarbon (PAH) and Benzene Toluene Ethylbenzene Xylene (BTEX) in oil-based drill cuttings contamination treated with decomposed respectively.*

Keywords *- Bioremediation, Biodegradation, Oil-Based Drill Cuttings and Decomposed Raffia Palm.*

1. Introduction

The incidence of environmental pollution due to the high rate of drilling of petroleum hydrocarbon-related activities has been linked to accidental discharge of spill leaks, vandalization and corrosion of crude oil pipes (Uba *et al.*, 2019). The high demand for petroleum hydrocarbon-related products as a source of energy has led to heavy dependence, which has caused severe industrialization damage in the area of land (soil), water and air (Koshlaf & Ball, 2017). Environmental pollution as a result of drilling operations has come to stay as it is not only a local challenge but globally, including the Niger Delta areas of Nigeria crude where oil exploration and exploitation activities take place. Crude oil exploration in the Niger Delta, Nigeria, has become a curse, not a blessing, due to an increase in oil spills arising from human activities like oil bunkering, accidental discharge, sabotage, pipeline facilities corrosion, negligence to oil pipeline from multinational companies etc. (Radhakrishnan *et al.*, 2023). Oil-based drilling cutting on the environment, accidental or not, causes many threats to the environment and damage to the ecosystem due to toxic substances found in crude oil. The major compounds found in oil-based drill cutting that are dangerous to the environment are aliphatic and aromatic hydrocarbons. The aliphatic hydrocarbon is easily degradable compared to aromatic hydrocarbon (Adnam *et al.*, (2018). Oil-based drill cutting is a fragment of petroleum hydrocarbon produced during drilling operations. Owing to their small diameters (2–5 mm), nearly all the cuttings thrown on land become incorporated into the soil in a thin, even layer. When well cuttings are abandoned and become saturated with oil during drilling, they threaten the onshore and offshore habitats (Ihuoma *et al.*, 2013). Enuneku and Ayobahan (2014) reported that numerous additives in the discharged drilling muds can be environmentally hazardous. In order to mitigate this problem, physical, chemical, and thermal remediation methods have been implemented. Various treatment methods, including cutting re-injection, stabilization/solidification, extraction and washing, heating, desorption, land farming, and bioremediation, are advised before disposal (Karen & Jonathan, 2018).

Because of their inability to eradicate the petroleum hydrocarbon from the breast, the physical, chemical and thermal methods are minimal at the end of remediation, and there are still traces of contaminants during the process. However, these processes need high energy consumption, specialized machinery, and high capital and technical know-how. Thus, the use and application of biological treatment in the remediation of oil-based drill cutting pollution is a subject of research study due to its environmental sustainability and less cost effective (Catalina *et al*., 2020).

Bioremediation does not disturb surrounding communities as much as other cleanup techniques. The conversion of toxins and pollutants into water and innocuous gases like carbon dioxide is the primary reason the bioremediation process produces so few hazardous consequences. Bioremediation refers to the treatment and recovery of contaminated environment during cleanup exercises. The process applies the principle of using microorganisms, decomposed raffia palm trunks and agro-wastes to remove contaminants from oil-based drill cuttings pollution (Engbulueso *et al*., 2021).

The success of that method relies on the degradation in the presence of indigenous microorganisms (Adnam *et al*., 2018). Depending on the researcher's interest, bioremediation can apply biostimulation or bioaugmentation processes to some causes. Both processes, i.e. biostimulation and bioaugmentation, can be used. Biostimulation is the application of agro-wastes (organic fertilizers) and inorganic fertilizers to treat oil-based drill cutting's environmental pollution to enhance bioremediation or degradation of contaminants. At the same time, bioaugmentation refers to introducing microorganisms into the contaminated environment to enhance the remediation process (Stepanova *et al*., 2022). Nweke *et al.* (2024b) revealed that bioremediation does not use any dangerous chemicals but added nutrients that aid microbial growth. Therefore, This research exploits the use of modelling the effect of decomposed raffia palm trunk bioremediation solution as nutrients, which serves as a source of biostimulation in the remediation of oil-based drill cuttings pollution of the environment.

The role of decomposed raffia palm as a nutrient in bioremediation is very essential. The introduced nutrients help stimulate microbial activities, which leads to the reduction or removal of pollutants from contaminated environments. Raffia palm decomposed; as a fertilizer derived from the palm wine tree, it is beneficial for mulching soils (Nweke *et al.,* 2023). Decomposed raffia palm is used as an NPK fertilizer alternative, it has been demonstrated to be an excellent adsorbent in flue gas desulfurization. (Udoh et al., 2014 reported that a decomposed raffia trunk has a high potential for being used as an insulating material in engineering applications in building designs, kitchen utensils, and electrical insulation materials. It is an African palm product obtained when the fresh raffia trunk is exposed to air, placed beneath a tree where there is restricted sunshine and absorbed moisture content to allow adequate degradation to take place for a period of four to six months, fostering total decomposition to occur. Decomposed raffia palm has reasonable amounts of phosphorus, calcium, magnesium, and potassium, which impact crop growth. It is fundamental and hygroscopic (pH 12.0) (Nweke *et al*., 2024a). Furthermore, the degraded content of decomposed raffia palm acts as a good bio-stimulant due to the high level of organic nutrients it contains, such as nitrogen, phosphorus and potassium and reacts strongly to an oil-based drill cutting contaminated environment (Nweke *et al*., 2024b).

Decomposed raffia palm trunk used as bio-stimulant improves soil fertility and raises agricultural yields, providing a safe, economical, environmentally beneficial, and naturally sustainable way by acting as an organic fertilizer. Additionally, it reduces the price of importing inorganic fertilizers for bioremediation. This will guarantee food security and raise Nigerians' standard of living (Amajuoyi &Wemedo 2015). The study by Gbosidom and Teme (2015) used oil palm bunkash to ameliorate crude oil-polluted soils, which enhanced a significant percentage reduction of total hydrocarbon content and a reduction of TPH by increasing soil pH values with an increase in treatment levels. Nweke *et al.*, 2024b studied the effectiveness of raffia palm trunks in eliminating oil-based drill cuttings from our environment. Their study recorded significant success with a total reduction of Total Petroleum Hydrocarbon (TPH), Polycyclic Aromatic Hydrocarbon (PAH) and Benzene Toluene Ethylene Xylene (BTEX.

2. Materials And Method

2.1. Study Area

The study was conducted at the Demonstration Farm, Rivers State University Nkpolu, Orowuurkwu, Port Harcourt, Nigeria. The study area has a mean temperature of 24^{o}C and 30^{o}C, low and high, respectively. The location is characterized by an annual rainfall of 3000mm, typical of a tropical rainforest (Ayotamuno *et al.* 2006). The vegetative cover is a tropical rain forest with longitude and latitude of 5^{o}19'N and 6^{o}28'E. The institution is in the heart of the state capital, Port Harcourt, South-South, Nigeria. The state is known to be one of Nigeria's states that produce the highest amount of oils.

2.2. Material Selection

- Oil-based drill cutting was collected with plastic rubber from Boskel Nigeria Limited, Aba Road, Rivers State, at a room temperature of 25^{0C}
- Decomposed raffia palm was obtained from a fresh raffia palm trunk after being kept for 6 months at room temperature for proper decomposition.
- Compost tea was generated from a larva cast of a dry raffia palm.

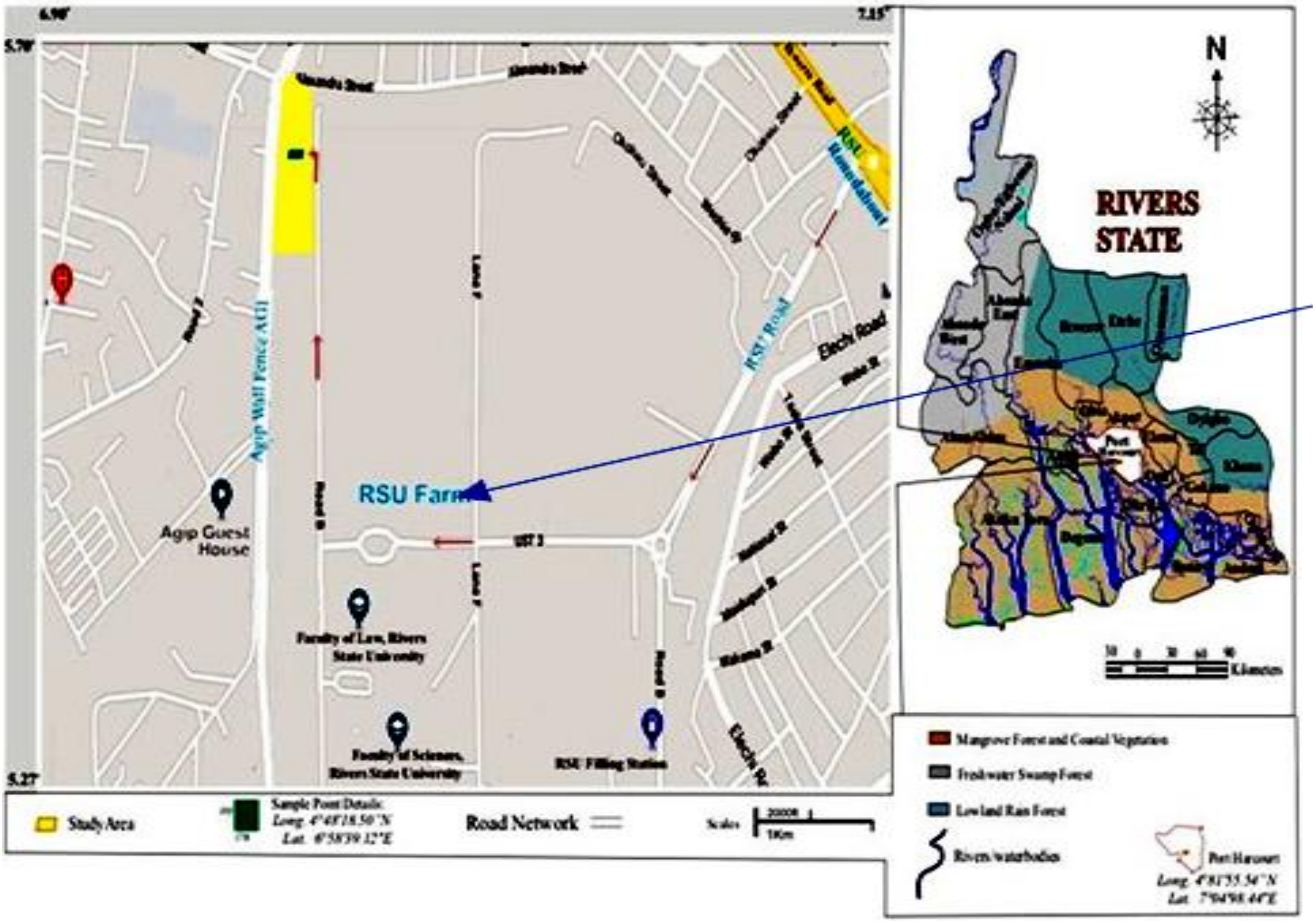

Fig. 1 Google map of the niger delta containing rivers state the study area

2.3. Preparation of Specimens

2.3.1. Oil-Based Drill Cuttings

80 liters of untreated oil-based drill cuttings were used for the research with high TPH, PAH and BTEX content, as shown in Table 1. After that, the untreated oil-based drilling cuttings samples were treated with the decomposed raffia palm at different treatment levels using a mix ratio 2:1 according to Akpofure (2011) and Okparanma *et al*. (2018).

2.3.2. Decomposed Raffia Palm Trunk

The hand towel was used to prepare the decomposed and oil-based drill cutting mixture. The mixture was under the provisions of BS12-1991

2.4. Experimental Design

The experiment was carried out using the randomized complete block Design (RCBD). The design contained decomposed raffia palm and was replicated four times to treat oil-based drill cuttings. Compost tea raffia palm was used as source of irrigation (liquid fertilizer) to improve tilling for aeration except for the control, the contents were thoroughly mixed to obtain a composite mixture, after which they were safeguarded and kept at room temperature for four weeks, samples were taken and analyzed for total petroleum hydrocarbon (TPH), benzene toluene ethylbenzene and xylene (BTEX) and polycyclic aromatic hydrocarbon (PAH), biodegradation from oil-based drill cuttings.

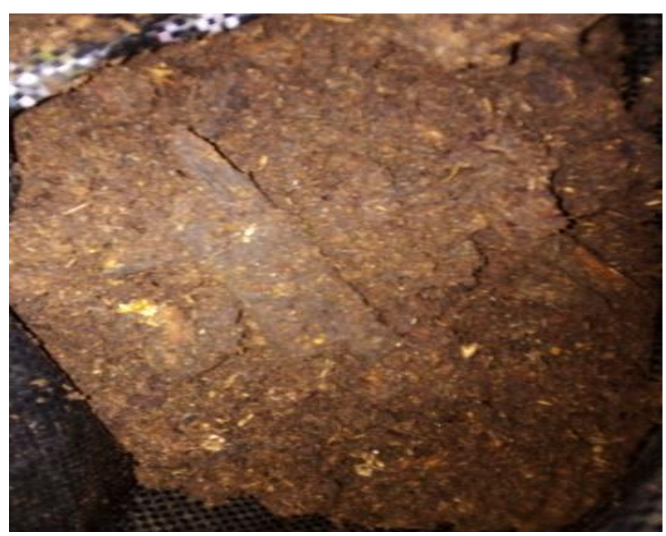

Plate 1. Decomposed raffia palm

2.5. Statistical Analysis

The percentage reduction of TPH, TPAH, and BTEX was determined as significant and non-significance at the 5% and 1% probability levels using single factor experimental analysis of variance (ANOVA) on the various replications of the experimental cells.

This was done because bioremediation is a time-dependent process. To confirm the acceptability and reliability of the model technique utilized for this analysis, a simple non-linear regression model analysis was performed to analyze the link between time (weeks) and several measurable oil-based drill cutting properties.

$$C_f = \alpha e^{-\beta w} \quad (1)$$

Where:

C_f = Final concentration of contaminant, ms/Kg,

w = Time of oil-based drill cutting contaminant degradation, periods. Where w is in equation

(2)

α = Intercept of the line on the y-axis

β= The regression coefficient (slope of the line) or the amount of change in concentration for each unit change w.

The validity (goodness of fit) of the oil-based drill cutting contaminants degradation models was tested by comparison with the experimental data and the modelling efficiency as estimated using the following parameters: coefficient of determination (R^2), Root Mean Square Error (RMSE), and RPD to check the error difference as represented in equation

$$RMSE = \sqrt{\frac{\sum_{i-1}^{i-N}\left(C_{o_m} - C_{o_p}\right)^2}{N}} \quad (3)$$

Where:

C_{o_m} = measured oil-based drill cutting contaminant (mg/kg)

C_{o_p} = predicted oil-based drill cutting contaminant (mg/kg)

N = Number of samples

3. Result And Discussion

3.1. TPH, PAH and BTEX Model Calibration

The TPH, PAH and BTEX degradation models at constant treatment of decomposed raffia palm trunk at different remediation periods of 0, 4, 8, 12 and 16 weeks were established for predicting the degradation of TPH, PAH and BTEX in oil-based drill cuttings treated with decomposed of raffia palm. The TPH, PAH and BTEX concentrations are shown in Tables 5, 6 and 7.

The established constant (β) model was calculated and fitted into the developed TPH, PAH and BTEX degradation model. These results exhibited the acceptability and the agreement with minimum error, demonstrating the acceptability and reliability of the model. It aligns with the study of Mohammed *et al.* (2020, Farahat & El-Gendy. (2007) and Agarry *et al.* (2013) used kinetic modelling and half-life study of adsorptive bioremediation of diesel in a contaminated environment, equivalent to a simple nonlinear regression model.

3.2. Validation of the Model

Prediction and validation upon which particular problems are solved rely on the authenticity of the established model equation. Figures (2, 3 and 4) show the graphical comparison between predicted and experimented TPH, PAH and BTEX concentrations on the oil-based drill cuttings treated with decomposed raffia palm.

The model result has a higher affiliation with experimented results from the remediation process with the coefficient of determination (R^2) as 0.9593, 0.87890.and 9902.

Additionally, the predicted model values and experiment results based on the model equations were linked graphically, as shown in Figures (2, 3 and 4). The graph analysis showed a near alignment of the curves between the model-predicted and experimented TPH, PAH and BTEX concentration of the remediated oil-based drill cuttings with decomposed raffia palm. Results of the established model for TPH, PAH and BTEX degradation equation for oil-based drill cuttings contamination remediated with decomposed raffia palm was performed by replacing the results generated from the experimented results as shown in Tables 5,6 and 7.

The Root Mean Square Error (RMSE) of predicted and experimented TPH, PAH and BTEX concentrations are summarized in Tables 2,3 and 4. The error analysis shows the difference between the predicted model results and the measured values ranging from – 374.17to 1800.9, -7.66 to 15.78 and 0.0571 to 0.081, while the RMSE were 1066.08, 7.976 and 0.044835.

The residual prediction deviation (RPD) is the factor that indicates the precision behaviours of the prediction in comparison with the average composition of all the samples. RPD values recorded maximum results at 4.5, 5.1 and 7.2, as shown in Tables 2,3 and 4. This indicates that RPD greater than 3.0 are considered excellent according to Saeys *et al.* (2005), Kodaira & Shibusawa (2013 and Minasny *et al.* (2009) as cited in Jesús *et al.* (2014).

This confirms the reliability and acceptability of the model. The ANOVA result for the effect of decomposed raffia palm on the TPH concentration is shown in Figure 2-4. It is apparent that there were significant differences in the treatment means 5% level at 1% significant levels. It may suggest that with 99% confidence, the difference in treatment means was due to the decomposed raffia palm applied.

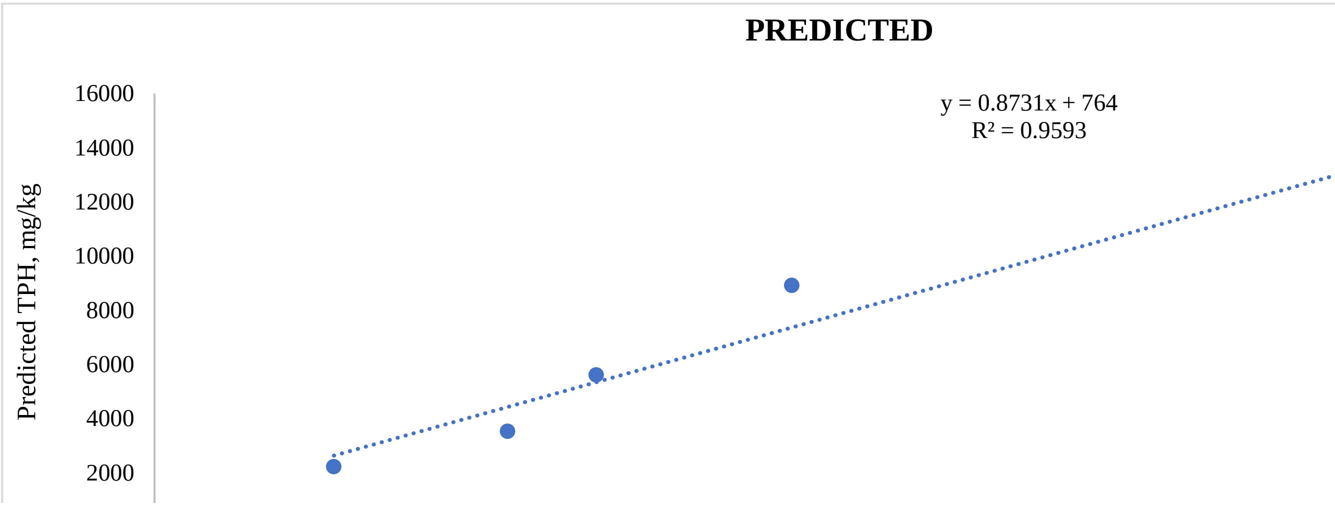

Fig. 2 Comparison of predicted and experimented effect of decomposed raffia palm on TPH concentration on Oil-Based drill cuttings

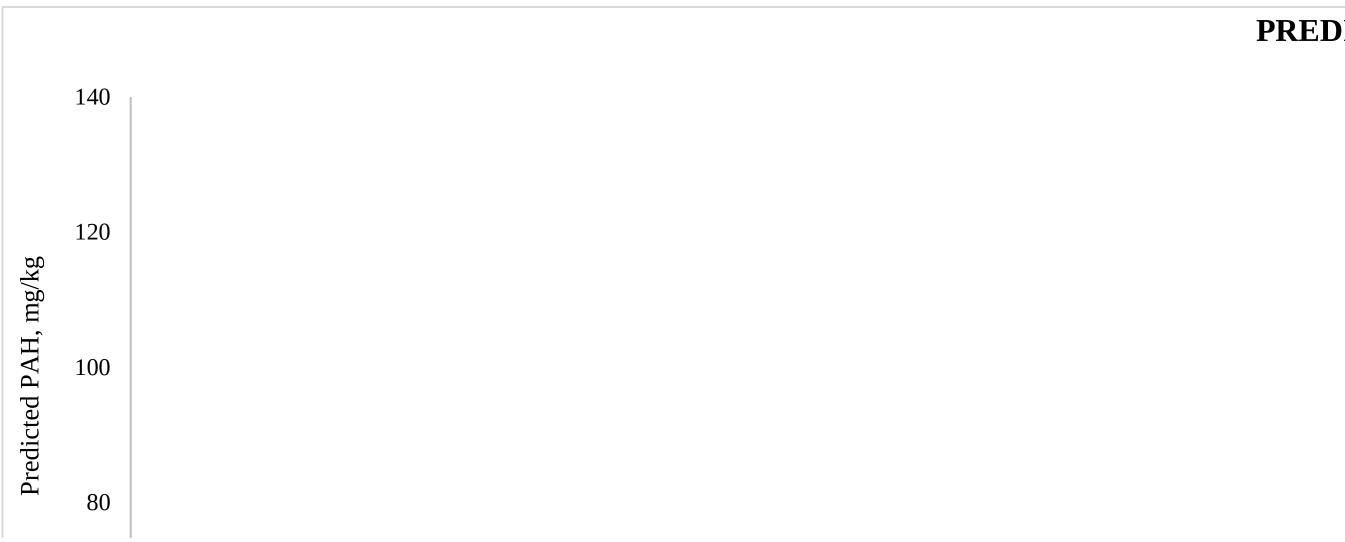

Fig. 3 Comparison of predicted and experimented effects of decomposed raffia palm on PAH concentration on Oil-Based drill cuttings

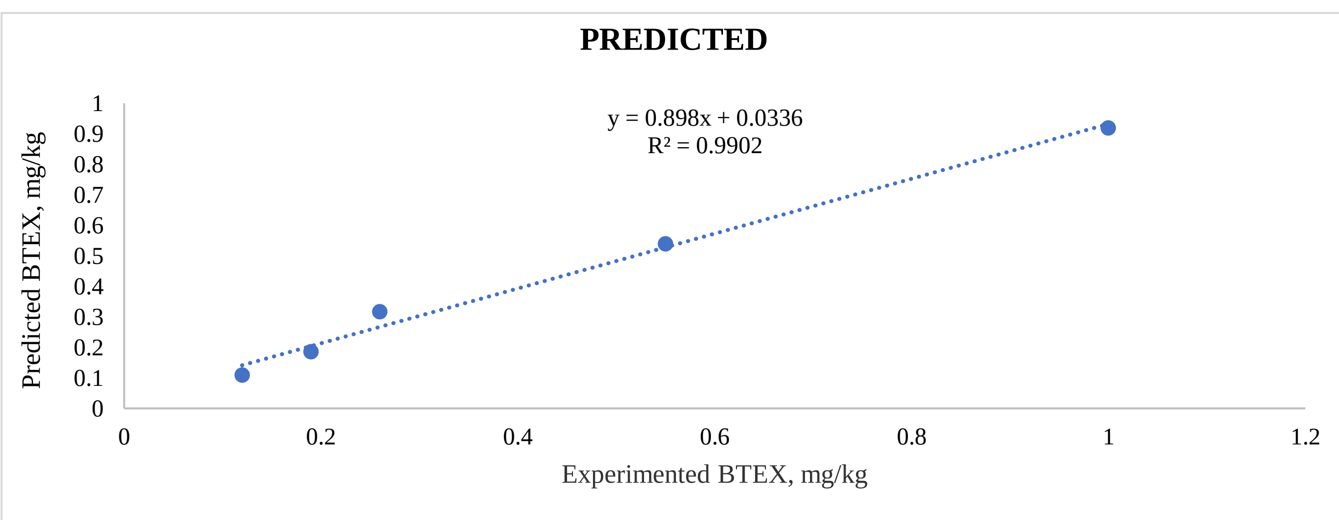

Fig. 4 Comparison of predicted and experimented effect of decomposed raffia palm on BTEX concentration on Oil-Based drill cuttings

Table 1. Effects of decomposed raffia palm trunk on Oil-Based drill cuttings bioremediation

Period (weeks)	Parameter									
	pH	EC (us/cm)	N (mg/kg)	P (mg/kg)	K (mg/kg)	OM (mg/kg)	TPH (mg/kg)	PAH (mg/kg)	BTEX (mg/kg)	BC (10^5cfɥ/g)
0	6.75	3509.43	175.49	140.38	152..58	58.49	15967.90	128.07	1.00	5.83
4	6.30	1657.87	82.89	66.31	72.08	27.63	7543.32	64.53	0.55	8.73
8	6.15	1148.72	57.44	45.95	49.94	19.15	5226.66	32.67	0.26	43.87
12	6.08	698.20	34.91	27.93	30.36	11.64	4176.79	24.82	0.19	20.72
16	6.03	466.30	23.31	18.65	20.27	7.77	2121.66	16.01	0.12	14.36

Table 2. Root mean square error and RPD of TPH computation of decomposed raffia palm trunk on Oil-Based drill cuttings bioremediation

Measured X	X	x – x	(X - x)^2	MSE	SD	Predicted	p - M	(P-M)^2	RMSE	Period, Weeks
15967.9	7007.27	8960.63	80292890	23126323	4808.98	14167	1800.9	3243241	1066.08	0
7343.32	7007.27	536.05	287349.6025			8907.69	-1364.37	1861505		4
5226.66	7007.27	-1780.61	3170571.972			5600.83	-374.17	140003.2		8
4176.79	7007.27	-2830.48	8011617.03			3521.6	655.19	429273.9		12
2121.66	7007.27	-4885.61	23869185.07			2214.25	-92.56	8567.354		16
34836.33			115631613.7			34411.37		5682591		
6967.266								1136518		
					RPD	4.5109				

Table 3. Root mean square error and RPD of PAH computation of decomposed raffia palm trunk on Oil-Based drill cuttings bioremediation

Measured X	X	x - x	(X - x)^2	MSE	SD	Predicted	p - M	(P-M)^2	RMSE	Period, Weeks
128.07	53.22	74.85	5602.5225	1668.777	40.85067	112.29	15.78	249.0084	7.976	0
64.53	53.22	11.31	127.9161			67.29	-2.76	7.6176		4
32.67	53.22	-20.55	422.3025			49.32	-7.66	58.6756		8
24.82	53.22	-28.4	806.56			24.17	0.65	0.4225		12
16.01	53.22	-37.21	1384.5842			14.49	1.52	2.3104		16
266.1			8343.8853			267.56		318.0345		
53.22								63.6069		
					RPD	5.121698				

Table 4. Root mean square error and RPD of BTEX computation of decomposed raffia palm trunk on Oil-Based drill cuttings bioremediation

Measured X	X	x – x	(X - x)^2	MSE	SD	Predicted	p - M	(P-M)^2	RMSE	Period, Weeks
1	0.424	0.576	0.331776	0.104344	0.323	0.919	0.081	0.006561	0.044835	0
0.55	0.424	0.126	0.015876			0.5398	0.0102	0.000104		4
0.26	0.424	-0.164	0.026896			0.3171	-0.0571	0.00326		8
0.19	0.424	-0.234	0.054756			0.1863	0.0037	1.37E-05		12
0.12	0.422	-0.304	0.092416			0.1094	0.0106	0.000112		16
2.12			0.52172			2.0716		0.010052		
0.424								0.00201		
					RPD	7.204193				

Table 5. TPH simulation effects of decomposed raffia palm trunk on Oil-Based drill cuttings bioremediation

Period, Weeks	Co	e^{-Bt}	Co_1
0	14167	$e^{-0.1160)}$	14167
4	14167	$e^{-0.1164)}$	8907.69
8	14167	$e^{-0.116(8)}$	5600.83
12	14167	$e^{-0.116(12)}$	3521.60
16	14167	$e^{-0.116(16)}$	2214.25

Table 6. PAH simulation effects of decomposed raffia palm trunk on Oil-Based drill cuttings bioremediation

Period, Weeks	Co	e^{-Bt}	Co_1
0	112.29	$e^{-0.128(0)}$	112.29
4	112,29	$e^{-0.128(4)}$	67.29
8	112.29	$e^{-0.128(8)}$	40.33
12	112.29	$e^{-0.128(12)}$	24.17
16	112.29	$e^{-0.128(16)}$	14.49

Table 7. BTEX simulation effects of decomposed raffia palm trunk on Oil-Based drill cuttings bioremediation

Period, Weeks	Co	e^{-Bt}	Co_1
0	0.919	$e^{-0.133(0)}$	0.919
4	0.919	$e^{-0.133(4)}$	0.5398
8	0.919	$e^{-0.133(8)}$	0.3171
12	0.919	$e^{-0.133(12)}$	0.1863
16	0.919	$e^{-0.133(16)}$	0.1094

a)((Table Footnote)); b) *Source: Text follows*

4. Conclusion

The developed model was proposed to predict the oil-based drill cuttings' biodegradation as a cause of bioremediation $C_X = \alpha e^{\beta t}$.The constant (β) for the degradation of the pollutant to the treatment was developed for the treatment's levels. This study's Model prediction can be considered good, with a high coefficient of determination (R^2) and low RMSE and RPD. The results showed acceptable validity with both experimented and predicted results.

They proved the fact that the models can be used to predict the pollutant levels of TPH, PAH and BTEX on the oil-based drill cuttings at each of the different treatment levels without going through the tedious, rigorous and experiments, thereby reducing the time, cost and energy constraints in obtaining the experiment in the field.

The degraded raffia palm trunk should be utilized to investigate the presence of microbes in soil contaminated by crude oil and the bioremediation of oil-based drill cuttings through decomposition.

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References

[1] Adnan B. Al-Hawash et al., "Principle of Microbial Degradation of Petroleum Hydrocarbons in the Environment," *Egyptian Journal of Aquatic Research*, vol. 44, no. 2, pp. 71-76, 2018. [CrossRef] [Google Scholar] [Publisher Link]

[2] Samuel E Agarry, Mujidat O Aremu, and Oluwafunmilayo A Aworanti, "Kinetic Modelling and Half-life Study on Enhanced Soil Bioremediation of Bonny Light Crude Oil Amended with Crop and Animal-Derived Organic Wastes," *Journal of Petroleum and Environmental Biotechnology*, vol. 4, no. 2, pp. 1-11, 2013. [CrossRef] [Google Scholar] [Publisher Link]

[3] A. Amajuoyi Chinomso, and A. Wemedo Samuel, "Effect of Oil Palm Bunch Ash (Elaeis Guineensis) on the Bioremediation of Diesel Polluted Soil," *American Journal of Microbiology and Biotechnology*, vol. 2, no. 2, pp. 6-14, 2015. [Google Scholar] [Publisher Link]

[4] Rim-Rukeh Akpofure, "Biodegradation Potential of Oil-based Drill Cuttings Encapsulated with Cement in the Soil Environment," *Journal of Applied Science and Environmental Management*, vol. 15, no. 4, pp. 643-648, 2011. [Google Scholar] [Publisher Link]

[5] M. J. Ayotamuno, R. B. Kogbara, and J. C. Agumwamba, "Bioremediation of a Petroleum Hydrocarbon Polluted Agricultural Soil at Various Levels of Soil Tillage," *Nigerian Journal of Technology*, vol. 25, no. 1, pp. 44-51, 2006. [Google Scholar] [Publisher Link]

[6] Catalina Trejos-Delgado et al., "Oil Bioremediation in a Tropical Contaminated Soil Using a Reactor," *Brazilian Academy of Sciences*, vol. 92, no. 2, pp. 2-18, 2020. [CrossRef] [Google Scholar] [Publisher Link]

[7] Eigbuluese Omohodion Gift, Amadi Benjamin Acho, and Okoro Samson Eruke, "Bioremediation of Crude Oil Polluted Soil Using Agro-Wastes from Plant Sources," *International Journal of Scientific and Engineering Research*, vol. 12, no. 6, pp. 195-202, 2021. [Google Scholar] [Publisher Link]

[8] A. A. Enuneku, and S. U. Ayobahan, "Sublethal Toxic Effects of Spent Oil Based Drilling Mud and Cuttings to Earthworm Aporrectodea Longa," *Journal of Applied Science and Environmental Management*, vol. 18, no. 4, pp. 615-620, 2014. [CrossRef] [Google Scholar] [Publisher Link]

[9] Laila A. Farahat, and Nour Sh. El-Gendy, "Comparative Kinetic Study of Different Bioremediation Processes for Soil Contaminated with Petroleum Hydrocarbons," *Material Science Research India*, vol. 4, no. 2, pp. 269-278, 2007. [CrossRef] [Google Scholar] [Publisher Link]

[10] V. L. Gbosidom, S. C. Teme, "The Use of Oil Palm Bunch Ash for Amelioration of Crude Oil Polluted Soils," *Journal of Natural Sciences Research*, vol. 5, no. 10, pp. 66-75, 2015. [Google Scholar] [Publisher Link]

[11] Iheoma M. Adekunle, *Emerging Trends in Natural Resources Utilization for Bioremediation of Oil-Based Drill Waste in Nigeria*, Biodegradation - Engineering and Technology, pp. 389-432, 2013. [CrossRef] [Google Scholar] [Publisher Link]

[12] Jesús Hernán Camacho-Tamayo et al., "Near-Infrared (NIR) Diffuse Reflectance Spectroscopy for The Prediction of Carbon and Nitrogen in an Oxisol," *Colombian Agronomy*, vol. 32, no. 1, pp. 86-94, 2014. [CrossRef] [Google Scholar] [Publisher Link]

[13] Karen McCosh, and Jonathan Getliff, "Drilling fluid Chemicals and Earthworm Toxicity," *10th Annual International Petroleum Environmental Conference*, 2003. [Google Scholar] [Publisher Link]

[14] Masakazu Kodaira, and Sakae Shibusawa, "Using a Mobile Real-Time Soil Visible-Near Infrared Sensor for High Resolution Soil Property Mapping," *Geoderma*, vol. 199, pp. 64-79, 2013. [CrossRef] [Google Scholar] [Publisher Link]

[15] Eman Koshlaf, and Andrew S. Ball, "Soil Bioremediation Approaches for Petroleum Hydrocarbon Polluted Environments," *AIMS Microbiology*, vol. 3, no. 1, pp. 25-49, 2017. [CrossRef] [Google Scholar] [Publisher Link]

[16] Budiman Minasny et al., "Regional Transferability of Mid-Infrared Diffuse Reflectance Spectroscopic Prediction for Soil Chemical Properties," *Geoderma*, vol. 153, no. 1-2, pp. 155-162, 2009. [CrossRef] [Google Scholar] [Publisher Link]

[17] Mohammed Abubakar Clarkson, Sani Isa Abubakar, and Nasiru Yahaya Ahmed, "Kinetic Modelling of Bioremediation of Diesel Clay Polluted Soil," *IOSR Journal of Environmental Science, Toxicology and Food Technology (IOSR-JESTFT)*, vol. 14, no. 9, pp. 33-37, 2020. [CrossRef] [Google Scholar] [Publisher Link]

[18] Arathi Radhakrishnan et al., "Bioremediation of Hydrocarbon Pollutants: Recent Promising Sustainable Approaches, Scope, and Challenges," *Journal of Sustainability*, vol. 15, no. 7, pp. 1-18, 2023. [CrossRef] [Google Scholar] [Publisher Link]

[19] W. Saeys, A.M. Mouazen, and H. Ramon, "Potential for Onsite and Online Analysis of Pig Manure Using Visible and Near Infrared Reflectance Spectroscopy," *Biosystems Engineering*, vol. 91, no. 4, pp. 393-402, 2005. [CrossRef] [Google Scholar] [Publisher Link]

[20] Anna Yurievna Stepanova et al., "Bioremediation of Soil from Petroleum Contamination," *Processes*, vol. 10, no. 6, pp. 1-17, 2022. [CrossRef] [Google Scholar] [Publisher Link]

[21] Bright Obidinma Uba et al., "Kinetic of Biodegradation of Total Petroleum Hydrocarbon in Diesel Contaminated Soil as Mediated by Organic and Inorganic Nutrients," *Animal Research International*, vol. 16, no. 2, pp. 3295-3307, 2019. [Google Scholar] [Publisher Link]

[22] Udoh Akinjoba, T. Abiola, and G. Eniola, "Production and Utilization of Organic Fertilizer Using Palms and Shea Tree as Source of Biomass," *African Journal of Crop Science*, vol. 2, no. 4, pp. 83-93. 2014. [Google Scholar] [Publisher Link]