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Impact of rainfall on natural attenuation of diesel and waste oil within urban base transceiver stations

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ABSTRACT

BACKGROUND AND OBJECTIVES: *Very low grid power penetration in some urban areas has led to telecoms companies investing massively in the deployment of diesel generators (DGs). These deployments have led to diesel and waste oil spill at base transceiver station (BTS) sites during maintenance cycles, impacting the environment and human activities. The objective of this study is to evaluate the impact of different rainfall intensities on the amount of waste oil and diesel leached or retained in the soil during natural attenuation.

METHODS: The soil at base transceiver station was analyzed using response surface methodology (RSM). The experiment was carried out following the design of experiment approach with a 3^3 factorial. Three factors include contaminant volume, rainfall intensity, and soil depth on which the two response variables (leached and retained were utilized.

FINDINGS: It was observed that rainfall intensities at 5mm/hr, 7.25, 9, and 10mm/hr has a significant impact on the amount of waste oil leached (1611.63mg/l) and retained (15888.9%) in the soil, though the amount of oil leached is inversely proportional to the amount retained as affected by different rainfall intensities considered in this work. Additionally, it was observed that rainfall intensity increases as the amount of oil leached decreases at higher soil depth while the amount of oil retained increases at lower soil depth. However, the significance of the impact of the different rainfall intensities is dependent on the soil depth.

CONCLUSION: The regression coefficient was found to be 72 % for waste oil retained and 67 % for the leached amount, hence the quadratic model developed in this study, demonstrated a higher accuracy for %retained rather than the amount of oil leached. However, this implies that the model is reliable, dependable, effective and accurate and thus recommended for use.

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INTRODUCTION

Telecoms companies have invested a lot in providing power to Base Transceiver Stations (BTS) sites to serve growing customers (Olukolajo *et al.,* 2013; Patti and Siana, 2016). This necessitated the deployment of diesel generators to BTS sites for the provision of suitable power for the equipment (Roy, 2008). This is more so due to the epileptic nature of the National grid and sometimes non-availability of power at some remote locations. In addition to Diesel Generators, Telecommunication companies have invested massively on alternative energy solutions by the deployment of solar panels, hybrid solutions, and direct current diesel generators (Turletti *et al.,* 1999; Martin, 2006). Diesel engines represent one of the technological basements of today's economy. Their usage is so diverse and widespread that their direct or indirect contribution is included in almost every product or service. However, the utilization of diesel engines results also in undesired impacts, particularly because their widespread usage takes on disturbing dimensions. Although they show a higher level of fuel use efficiency compared to the gasoline engines, the diesel exhaust gases contain significantly higher concentrations of the most dangerous substances like the particulates (Godwin and Bassey, 2009; Satish, 2012) which have been the scientifically proven cause of some of the most severe diseases and may even lead to premature death (Shivendra and Hardik, 2017). The use of DGs in powering BTS has its drawbacks when compared to alternative energy, which includes but not limited to diesel and oil spillage especially during maintenance cycles. The process of utilizing these products associated with human mismanagement leads to the spill of these products in the environment in and around many BTS sites (Aderoju *et al.,* 2014). Unfortunately, most of the BTS sites are close to human habitation/infrastructure (NCC 2014). These products tend to impact negatively into surroundings affecting water, soil, and atmospheric air (Joo *et al.,* 2008). Similarly, the use of diesel and engine oil for maintenance and power of DGs has been established to impact negatively on the environment once they are mismanaged; groundwater contamination, disease conditions, soil deterioration, and air quality alterations are possible problems that are likely to be associated with the mismanagement of these products at BTS sites (Bello, 2010) . These liquids that are generated during DG maintenance, site diesel transportation, and refueling, have been proven to contain harmful and toxic compounds or substances such as Polychlorinated Biphenyls (PCBs), benzene, arsenic, Polycyclic Aromatic Hydrocarbons (PAHs), lead, zinc, cadmium and other substances that adversely impact soil, groundwater, and environment. At BTS sites, the effect of temperature, and effective remediation mechanisms that could be adopted to reduce, remediate and possibly eliminate impact on the environment as much as possible and avoid litigations and fines. Although, the chemical composition of waste engine oil depends on many factors. These factors include the process of refining the crude oil, additives in the oil, the amount of time the oil worked in the engine, type of crude oil, etc. while Diesel in soil has been known to contain PAHs and PCBs. Polycyclic Aromatic Hydrocarbons (PAHs) are persistent organic pollutants (POPs) that are resistant to degradation and remain in the environment for longer periods (Mudge and Pereira, 1999; Venkata *et al.,* 2009; Berkhout and Hertin, 2012) and have the potential to cause adverse environmental effects (Kordybach, 1999). PAHs have unique stable structures to persist in the environment (Sugiura *et al*., 1997) and highly hydrophobic, so these have a strong attraction to soil particles (Sung *et al*., 2001). Also, used engine oil and diesel which are often discharged indiscriminately on the soil have been attributed to transport downwards and pollute the underground water, including high chances of migrating even into fish ponds, as has been observed. However, biodegradation rates are highest for the saturates, followed by the light aromatics, with high-molecular-weight aromatics and polar compounds exhibiting extremely low rates of degradation (Cooney and Silver, 1985; Reisinger *et al*., 1995; Rowland *et al*., 2000; IMO, 2004).

It is therefore imperative to ascertain the impact of the leaching rates of diesel and waste engine oil mismanagement at these BTS sites and as well determine the level of impact of such spill on the environment vis-à-vis different soil types concerning the Niger Delta and to ascertain the impact of weather (Rainy and dry seasons) on the leaching rates of spilled diesel and waste engine oil. This helps the Telecoms companies to determine the extent to which environmental deterioration. This study seeks to investigate the impact of rainfall intensity on diesel and engine oil leaching in soil from Base Transceiver

Stations. The current study has been carried out in Bayelsa State in 2019.

MATERIALS AND METHODS

Description of the study area

Bayelsa is a state in southern Nigeria in the core Niger Delta region, between Delta State and Rivers State. Its capital is Yenagoa, the Latitude and longitude coordinates are 4.664030, 6.036987. The main language spoken is Ijaw with dialects such as Kolukuma, Mein, Bomu, Nembe, Epie-Atisa, and Ogbia. Like the rest of Nigeria, English is the official language. The state was formed in 1996 from part of Rivers State and is thus one of the newest states of the Nigerian federation. Bayelsa has a riverine and estuarine setting. Many communities are almost (and in some cases) surrounded by water, making them inaccessible by road. The state is home to the Edumanom Forest Reserve, in June 2008 the last known site for chimpanzees in the Niger Delta. Rainfall in Bayelsa State varies in quantity from one area to another. The state experiences the equatorial type of climate in the southern the most part and tropical rain towards the northern parts. Rain occurs generally every month of the year with a heavy downpour. The state experiences high rainfall but this decreases from south to north. Akassa town in the state has the highest rainfall record in Nigeria. The climate is tropical i.e. wet and the dry season. The amount of rainfall is adequate for all-year-round crop production. The wet season is not less than 340 days. The mean monthly temperature is in the range are of 25°C to 31°C. The mean maximum monthly temperatures range from 26°C to 31°C. The mean annual temperature is uniform for the entire Bayelsa State. The hottest months are from December to April. The difference between the wet season and dry season on temperatures is about 2°C at the most. The relative humidity is high in the state throughout the year and decreases slightly in the dry season. Like any other state in the Niger Delta, the vegetation of Bayelsa State is composed of four ecological logical zones. These include coastal barrier island forests, mangrove forests, freshwater swamp e.g. forests, and lowland rain forests. These different or vegetation types are associated with the various soil units in the area, and they constitute part of the complex Niger Delta ecosystems. Parts of the freshwater swamp forests in the state constitute the home of several threatened and even endangered for plant and animal species. There are coastal barrier highland forests and mangrove forests. Coastal barrier highland forest vegetation is restricted to the narrow ridges along

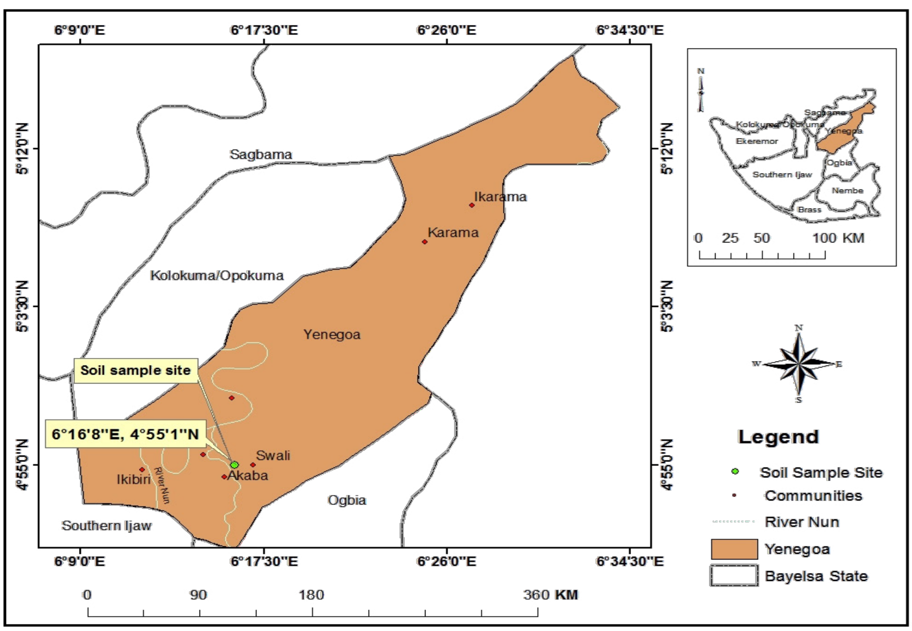


Fig. 1. Map of study area showing the BTS sites

Table 1. Physical characteristics of the soil at different sites

BTS site	Coordinates	Clay	Silt	Sand	Gravel
Oloibiri	4.6748° N, 6.3133° E				
Amasoma	4.9731° N, 6.1090° E				
Ogbia	4.6901° N, 6.3213° E				
Otuoke	4.7944° N, 6.3146° E				
Agudama	5.0167° N, 6.2667° E				

***Dark blue = clay, *Light green = Silt, *Blue = sand**

Table 2. Experimental design and level of independent process variables

Independent variables	Unit	Factors	Coded level		
			-1	0	+1
Contaminant volume	ml	A	50	200	350
Rainfall intensity	mm/hr	B	5	7.5	10
Soil depth	cm	C	30	60	90

the coast. This vegetation belt is characterized by low salinity-tolerant freshwater plants. Sometimes of the *Avicinia species* of mangroves prevail in this vegetation. The study area is shown in Fig. 1.

The soil characteristics show that the locations are dominated by silt and sand respectively.

Design of experiment (DOE)

The experimental design was set up using DOE software Version 11.0.1. using 3^3 factorials. The variables and their range are given in Table 1. The variables are coded as contaminant volume (A), rainfall intensity (B), and soil depth (C) as designed in the study. Although, each factor in Central Composite Design (Ahmadi *et al.,* 2005) has five stages and grouped into three design points, which are identified as two stages of factorial points, well-defined as 1 and -1, (axial points), and a (center point) defined as 0 as shown in Table 2. However, the center points are primarily repetitive trial arrays closer to the center of factor space to endorse the best prediction potential. In the present study, there are 27 experimental runs (Table 3).

Experimental procedure

Sample collection

A galvanized steel mesocosm was constructed to collect soil undisturbed (ASTM 2005). Three sets of 300mm, 600mm and 900mm height diameter galvanized steel pipes were constructed to produce the mesocosm used in this study. Before the collection of the soil sample in any of the base transceiver station sites, the topsoil was cleared to a reasonable depth. The galvanized steel mesocosm, hammered with the aid of a fabricated auger rig, was used to directly collect undisturbed soil samples. 5 samples each were obtained from the study location, 1 sample from each site within the state. The collected soil samples were further analyzed in the laboratory to determine the predominant soil type at the BTS within the study area where the samples were obtained. The soil samples were analyzed and predominant soil types were obtained utilizing grain size analysis using the hydrometer method. The waste engine oil was collected during the frequent maintenance of the diesel generators used to power the base transceiver station sites (BTS). The waste engine oil sample was collected using plastic bottles that were prepared by initial rinsing with the waste engine oil to be collected and then filled almost completely, while the diesel sample used for this contamination experiment was obtained from a regular fuel station. Both the waste engine oil and diesel samples were properly labeled and immediately transported to the laboratory under room temperature. The experiment followed a full factorial design of 3^n, where 'n' is the number of variables. Three variables were considered, namely: soil depth within the range of 30cm – 90cm, contaminant volume 50 – 350ml, and rainfall intensity 5 – 10mm/hr. Waste engine oil and diesel were the contaminants utilized separately and in their combination. Hence, 33 resulted in twenty-seven (27) experimental runs. The selected rainfall intensity values were chosen to replicate rainfall patterns recorded in each of the considered Niger Delta states, as was obtained from the Nigerian Meteorological

Agency, NIMET. The following materials were used, (1) galvanized steel mesocosm, (2) auger rig, (3) measuring cylinders, (4) mini lysimeter, (5) rainfall simulator, (6) gas chromatography, (7) plumbing fittings (like union, valves, adaptors, pipes, elbows), (8) calibrated buckets, and (10) stopwatch.

Rainfall simulator set-up

The rainfall simulator was constructed to imitate the rainfall pattern of Bayelsa state, using the data obtained from the Nigerian Meteorological Agency (NIMET). The obtained rainfall data were used in calibrating the rainfall simulator to produce 5mm/hr, 7.5mm/hr, and 10mm/hr rainfall intensities, for different volumes of spilled diesel, used engine oil and a combination of both. The rain simulator was made of a rubber tank of 1000L capacity constructed on a squared shape 75mm galvanized steel tank stand, as seen in Plate 3.6. Also, a 37.5mm horsepower surface water pump was utilized for continuous refilling of the tank using 37.5 inches PVC pipe, in conjunction with some plumbing fittings like union, valves, adaptors, pipes, elbows; to hold firmly. To create avenues for the simulated rainfall on soil samples, three showerheads were also connected using 37.5 to 12.5'' reducers, 12.5 inches PVC pipes, union, valves, elbow, adaptors, and other plumbing pipe fittings. The showerheads were mounted on a 25mm diameter galvanized steel pipe welded to a 20mm steel base plate to ensure the effective stability of the shower headstands. Three transparent 5L plastic calibrated buckets were provided to collect the water during the simulation. One of the 1000L and 2000L measuring plastic cylinders were also provided to measure the amount of rainfall. A stopwatch was provided to measure the duration of rainfall when the valves were opened for water inflow. Therefore, the intensity of the simulated rainfall was obtained as the height of rainfall collected within a 150mm diameter pipe, per hour of rainfall.

Mesocosm set-up for sample collection

Some galvanized steel mesocosms were constructed to collect soil samples in an undisturbed condition. Three sets of 300mm, 600mm and 900mm diameter of galvanized steel pipes were constructed to produce a mesocosm. The mesocosms were used to directly collect soil samples using a fabricated auger rig undisturbed soil collector. Upon collection from the field, the mesocosms containing the soil samples were carefully transported to the laboratory for contamination and rainfall simulation experiments. Clips were also produced to hold the mesocosms in place on a table while being contaminated and rainfall patterns simulated. The sets of 600mm diameter holes were constructed to install the 300/600 and 900mm high mesocosms that have the same diameter. The bottoms of the mesocosms were protected with a net to prevent erosion and sieve the washout with the aid of a fabricated galvanized steel clips. Simulated rainfall at various intensities (5mm/hr, 7.5mm/hr, 10mm/hr) and volume of contaminants (50ml, 200ml, 350ml) were introduced to the undisturbed soil in the mesocosm. Leachates were collected using plastic containers placed at the bottom of the elevated steel mesocosms.

Total Petroleum Hydrocarbon (TPH)

The main objective of the TPH test is to determine the rate of penetration of the contaminants into the soil at BTS sites and to assess the rate of pollution of petroleum products in the soil at BTS sites (Chaillan *et al.,* 2006). To determine the actual effect and the rate of pollution of these petroleum products, we have to look at water (H_20) and soil since it has to do with the environment. The presence of used engine oil and diesel in water can be easily identified due to density disposition. However, simple chemical analysis is used as a mode of separation by using an extraction solvent to determine its hydrocarbon content. The use of this extraction solvent is to digest hydrocarbon content and aid the separation process. Hexane was used as the extraction solvent.

Procedure for water hydrocarbon extraction using hexane as a hydrocarbon solvent

The following materials were used; (1) gas chromatography (2) separation funnel (3) beaker (4) measuring cylinder of 100ml and 50ml (5) bottle (6) beaker stand and (7) masking tape. The water contaminant samples were gotten from different depths within the study location. The contaminant samples were poured into different plastic rubbers and labeled for proper identification. The H_20 samples were then transported to the laboratory in Rivers state university, Nigeria. A sample labeled OBS (H_20: leachates) and hydrocarbon solvent (Hexane) were measured at a ratio of 2:1. The samples were mixed in a plastic bottle and agitated aggressively for about 10 - 30 minutes. The mixture was then placed on a clamp stand (H_20 + Hexane) after pouring into a separation funnel to allow the mixture to occupy their space based on their density. This process is also known as the stage of decantation. The Mixture was then left in the separation funnel. Undisturbed for about 20 minutes to enable the different layers to be formed properly. The Hexane digested the contaminant and occupied the upper layer while the H_20 which has a higher density occupied the lower layer. The separation funnel was released gradually and H_20 which occupied the lower layer was discarded. The second stage of the separation process was done, by adding 25ml of hexane (C_6 H_{14}) to the new sample. This mixture was then agitated aggressively for about 10 minutes and purred into the separation funnel. The Mixture was left undisturbed for 10 minutes. The separation funnel was released gradually and the remaining water content was discarded appropriately. The sample was then poured into the receiver carefully and labeled according to the identification mode of the sample. The sample in the receiver was then introduced into the gas chromatography. The above procedure was done respectively for each of the contaminant samples collected at different depths and areas.

Procedure for soil hydrocarbon extraction water content determination by oven dry method

A clean, non-corrosive dry dish was obtained and its weight was determined. Using a balance (with minimum sensitivity to weight the samples to an accuracy of 0.04% of the weight of soil taken. This comes to a sensitivity of 0.01g. The required quantity of a representative undisturbed soil sample was taken and placed on the container. The weight of the container and the wet soil were determined. The container with wet soil was placed in the oven with its lid removed for 24 hours maintaining a temperature of 105˚C (slightly > the boiling point of water). The container now containing dry soil was then cooled in a desecrator with the lid closed. The weight of dry soil with the container and lid was determined. The oven-

Table 3. Showing the factor combinations and response variables

Run	A: Contaminant Volume (ml)	B: Rainfall Intensity (mm/hr)	C: Soil Depth (cm)	Retained %	Leached (mg/l)
1	50	5	30	4323.5	5134.8
2	200	5	30	5757.12	6233.24
3	350	5	30	6997.67	1000.55
4	50	7.5	30	3876.58	4129.46
5	200	7.5	30	4263.63	4920.93
6	350	7.5	30	4286.54	5011.82
7	50	10	30	2566.2	4411.9
8	200	10	30	4100.95	5348.81
9	350	10	30	5400.4	6258.93
10	50	5	60	3611.11	9899.03
11	200	5	60	3000.93	9898.57
12	350	5	60	1948.55	1295.36
13	50	7.5	60	4073.51	4351.02
14	200	7.5	60	4062.42	6239.91
15	350	7.5	60	3424.62	9459.96
16	50	10	60	10241	3366.1
17	200	10	60	3182.42	4718.02
18	350	10	60	3133.51	5499.92
19	50	5	90	9840.72	1077.77
20	200	5	90	9503.42	1211.91
21	350	5	90	9414.47	1241.97
22	50	7.5	90	9361.51	1365.76
23	200	7.5	90	9214.53	1444.96
24	350	7.5	90	9161.53	1492.45
25	50	10	90	8776.96	1340.34
26	200	10	90	8999.99	1545.03
27	350	10	90	15888.9	1611.63

drying temperature of 105˚C is suitable for most of the soils. A temperature higher than that should not be used as it breaks the crystal structure of the soil and caused evaporation of structural water. For soils containing other minerals, there is losing bound water of hydration (adsorbed water) which gets evaporated at 110˚C, hence a lower temperature of 80˚C should not be used for oven drying of such soils.

RESULTS AND DISCUSSION

The following results were obtained for the amount of waste oil and diesel retained and leached in the soil after the 27 experimental runs carried during the study period (Table 3).

The model F-value of 5.03 implies the model is significant. There is only a 0.21% chance that an F-value this large could occur due to noise. P-values < 0.0500 indicate model terms are significant. In this case C, C^2 are significant model terms. Values greater than 0.1000 indicate the model terms are not significant as shown in Table 4. If there are many insignificant model terms (not counting those required to support hierarchy), model reduction may improve the model. Although, the predicted R^2 of 0.1947 is not as close to the adjusted R^2 of 0.5827 as one might normally expect; i.e. the difference is more than 0.2. This may indicate a large block effect or a possible problem with your model and/or data. Things to consider are model reduction, response transformation, outliers, etc. All empirical models should be tested by doing confirmation runs. Model Precision measures the signal to noise ratio. A ratio greater than 4 is desirable. The ratio of 6.837 indicates an adequate signal. This model can be used to navigate the design space. See the coefficients in terms of the coded factors in Table 5.

Table 4. ANOVA for quadratic model, response 1: %retained (R^2 = 0.7272)

Source	SS*	Df**	MS***	F-value	p-value	Remarks
Model	2.129E+08	9	2.365E+07	5.03	0.0021	significant
A-Contaminant Volume	4.950E+05	1	4.950E+05	0.1054	0.7494	
B-Rainfall Intensity	3.461E+06	1	3.461E+06	0.7367	0.4027	
C-Soil Depth	1.312E+08	1	1.312E+08	27.92	< 0.0001	significant
AB	4.231E+05	1	4.231E+05	0.0901	0.7677	
AC	26824.78	1	26824.78	0.0057	0.9406	
BC	8.197E+06	1	8.197E+06	1.74	0.2040	
A^2	2.737E+06	1	2.737E+06	0.5825	0.4558	
B^2	3.245E+06	1	3.245E+06	0.6908	0.4174	
C^2	6.311E+07	1	6.311E+07	13.43	0.0019	significant
Residual	7.987E+07	17	4.698E+06			
Corrected Total	2.927E+08	26				

* sum of square, ** degree of freedom, *** mean square

Table 5. Coefficients in terms of coded factors, %retained

Factor	Coefficient Estimate	df	Standard Error	95% CI Low	95% CI High	VIF*
Intercept	3134.81	1	1103.64	806.32	5463.29	
A-Contaminant Volume	165.84	1	510.89	-912.04	1243.71	1.0000
B-Rainfall Intensity	438.49	1	510.89	-639.39	1516.37	1.0000
C-Soil Depth	2699.41	1	510.89	1621.53	3777.29	1.0000
AB	187.77	1	625.71	-1132.36	1507.90	1.0000
AC	47.28	1	625.71	-1272.85	1367.41	1.0000
BC	826.50	1	625.71	-493.63	2146.62	1.0000
A^2	675.36	1	884.88	-1191.58	2542.30	1.0000
B^2	735.45	1	884.88	-1131.49	2602.39	1.0000
C^2	3243.24	1	884.88	1376.30	5110.18	1.0000

*Variance Inflation Factor

The coefficient estimate represents the expected change in response per unit change in factor value when all remaining factors are held constant. The intercept in an orthogonal design is the overall average response of all the runs. The coefficients are adjustments around that average based on the factor settings. When the factors are orthogonal, that is the VIFs are 1; VIFs greater than 1 indicate multi-collinearity, the higher the VIF the more severe the correlation of factors. As a rough rule, VIFs < 10 are tolerable.

$$\%R = 22828.2 - 15.3A - 2351.0B - 427.2C + 0.5AB + 0.01AC + 11.0BC + 0.03A^2 + 117.7B^2 + 3.6C^2 \quad (1)$$

The equation in terms of actual factors can be used to make predictions about the response for given levels of each factor (Eq. 1). Here, the levels should be specified in the original units for each factor. This equation should not be used to determine the relative impact of each factor because the coefficients are scaled to accommodate the units of each factor and the intercept is not at the center of the design space. Table 6 shows the comparison between experimental and predicted values of the diesel and waste oil degradation. However, the ANOVA for the quadratic model is shown in Table 7.

The model F-value of 3.90 implies the model is significant. There is only a 0.76% chance that an F-value this large could occur due to noise. P-values < 0.0500 indicate model terms are significant. In this case, C, AB, C^2 are significant model terms. Values > 0.1000 indicate the model terms are not significant. If there are many insignificant model terms (not counting those required to support hierarchy), model reduction may improve your model. The predicted R^2 of 0.1888 is not as close to the adjusted R^2 of 0.5010 as one might normally expect; i.e. the difference is more than 0.2. This may indicate a large block effect or a possible problem with your model and/or data. Things to consider are model reduction, response transformation, outliers, etc. All empirical models should be tested by doing confirmation runs. Model Precision measures the signal to noise ratio. A ratio greater than 4 is desirable. However, the ratio of 6.869 indicates an adequate signal. This model can be used to navigate the design space. See coefficients

Table 6. Showing the experimental and predicted values for % retained diesel and waste oil in the soil

Run order	Experimental value	Predicted value	Residual
1	4323.50	5546.66	-1223.16
2	5757.12	4802.09	955.03
3	6997.67	5408.24	1589.43
4	3876.58	4235.44	-358.86
5	4263.63	3678.64	584.99
6	4286.54	4472.55	-186.01
7	2566.20	4395.12	-1828.92
8	4100.95	4026.08	74.87
9	5400.40	5007.77	392.63
10	3611.11	4129.06	-517.95
11	3000.93	3431.76	-430.83
12	1948.55	4085.19	-2136.64
13	4073.51	3644.33	429.18
14	4062.42	3134.81	927.61
15	3424.62	3976.00	-551.38
16	10241.05	4630.51	5610.54
17	3182.42	4308.75	-1126.33
18	3133.51	5337.71	-2204.20
19	9840.72	9197.94	642.78
20	9503.42	8547.92	955.50
21	9414.47	9248.63	165.84
22	9361.51	9539.71	-178.20
23	9214.53	9077.46	137.07
24	9161.53	9965.94	-804.41
25	8776.96	11352.38	-2575.42
26	8999.99	11077.90	-2077.91
27	15888.88	12154.14	3734.74

in terms of coded factors, amount of waste oil, and diesel leached in Table 8.

The coefficient estimate represents the expected change in response per unit change in factor value when all remaining factors are held constant. The intercept in an orthogonal design is the overall average response of all the runs. The coefficients are adjustments around that average based on the factor settings. When the factors are orthogonal the VIFs are 1; VIFs > 1 there is an indication of multi-collinearity, the higher the VIF the more severe the correlation of factors. As a rough rule, VIFs < 10 are tolerable. Additionally, Table 9 shows the experimental and predicted values, amount of waste oil, and diesel leached. The model in Eq. 2 can be used to make predictions based on the coded factors.

$$L = 6855.4 - 122.4A - 160.70B - 1673.26C + 1402.15AB + 163.9AC - 223.81BC - 843.0A^2 - 318.81B^2 - 3037.C^2 \quad (2)$$

Effect of rainfall intensities on the response variables

In this study, the result of the designed experiment from a 3^3 factorial was analyzed in design expert software (stat-ease software version 11) to determine the effect of one of the factors, rainfall intensity on the amount of a combination waste oil and diesel retained and leached in the soil studied. To show the effects, the analysis was subject to several conditions or constraints as follows, rainfall intensity was taken as 5mm/hr, 7.25, 9, and 10mm/hr respectively to measure the corresponding impact on the response variables. Oil spilled in the coastal zone may be remediated through biodegradation by naturally occurring bacteria, (Ebuehi *et al.,* 2005; Abu and Dike, 2008; Bravo-Linares *et al.,* 2012) that the rate of degradation may differ within the intertidal area due to many environmental factors (Mudge and Pereira, 1999; Wang and Stout, 2007). In this study, rainfall intensity has played a vital role in the entire degradation process (Ghazali *et al.,* 2004).

In Fig. 2 the cook's distance is shown, residual and normal plots of the amount of waste oil diesel leached or retained in the soil. Cook's distance is used to identify the points that negatively affect the

Table 7. ANOVA for quadratic model, response 2: amount of waste oil and diesel leached (mg/l) (R^2 = 0.6737)

Source	SS	df	MS	F-value	p-value	Remarks
Model	1.359E+08	9	1.510E+07	3.90	0.0076	significant
A-Contaminant Volume	2.698E+05	1	2.698E+05	0.0697	0.7949	
B-Rainfall Intensity	4.648E+05	1	4.648E+05	0.1201	0.7332	
C-Soil Depth	5.040E+07	1	5.040E+07	13.02	0.0022	significant
AB	2.359E+07	1	2.359E+07	6.10	0.0245	significant
AC	3.224E+05	1	3.224E+05	0.0833	0.7764	
BC	6.011E+05	1	6.011E+05	0.1553	0.6984	
A^2	4.264E+06	1	4.264E+06	1.10	0.3086	
B^2	6.099E+05	1	6.099E+05	0.1576	0.6963	
C^2	5.536E+07	1	5.536E+07	14.30	0.0015	significant
Residual	6.580E+07	17	3.870E+06			
Corrected Total	2.017E+08	26				

Table 8. Coefficients in terms of coded factors, amount of waste oil and diesel leached (mg/l)

Factor	Coefficient Estimate	df	Standard Error	95% CI Low	95% CI High	VIF
Intercept	6855.42	1	1001.72	4741.98	8968.86	
A-Contaminant Volume	-122.42	1	463.71	-1100.76	855.91	1.0000
B-Rainfall Intensity	-160.70	1	463.71	-1139.03	817.64	1.0000
C-Soil Depth	-1673.26	1	463.71	-2651.59	-694.92	1.0000
AB	1402.15	1	567.92	203.95	2600.36	1.0000
AC	163.92	1	567.92	-1034.29	1362.13	1.0000
BC	-223.81	1	567.92	-1422.02	974.40	1.0000
A^2	-843.00	1	803.16	-2537.52	851.53	1.0000
B^2	-318.81	1	803.16	-2013.34	1375.71	1.0000
C^2	-3037.42	1	803.16	-4731.94	-1342.89	1.0000

Table 9. Showing the experimental and predicted values, amount of waste oil and diesel leached (mg/l)

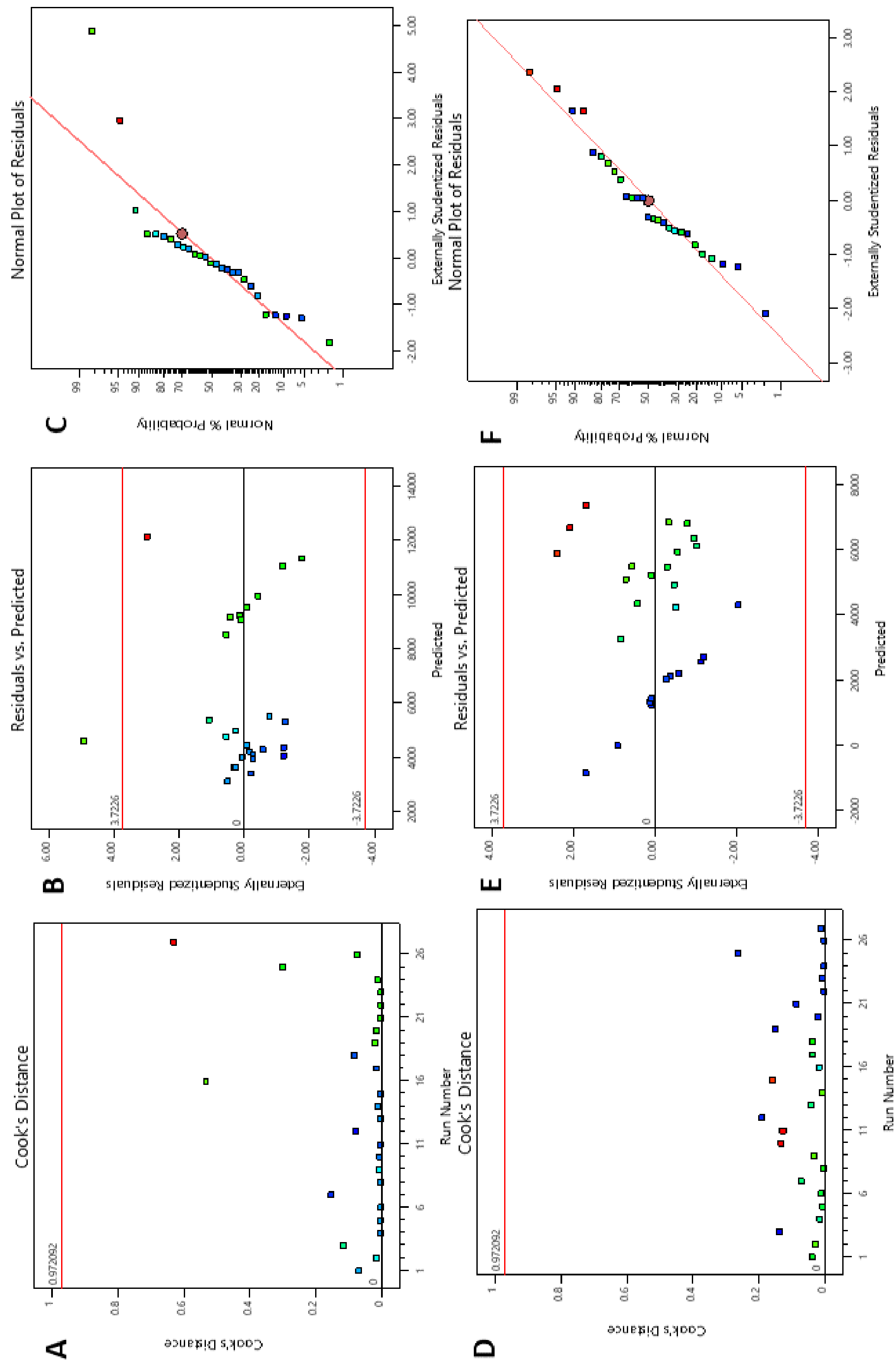
Run order	Experimental value	Predicted value	Residual
1	5134.80	5954.83	-820.03
2	6233.24	5109.33	1123.91
3	1000.55	2577.83	-1577.28
4	4129.46	4934.60	-805.14
5	4920.93	5491.26	-570.33
6	5011.82	4361.92	649.90
7	4411.90	3276.74	1135.16
8	5348.81	5235.56	113.25
9	6258.93	5508.37	750.56
10	9899.03	7378.88	2520.15
11	9898.57	6697.30	3201.27
12	1295.36	4329.72	-3034.36
13	4351.02	6134.84	-1783.82
14	6239.91	6855.42	-615.51
15	9459.96	5890.00	3569.96
16	3366.10	4253.18	-887.08
17	4718.02	6375.91	-1657.89
18	5499.92	6812.64	-1312.72
19	1077.77	2728.09	-1650.32
20	1211.91	2210.43	-998.52
21	1241.97	6.78	1235.19
22	1365.76	1260.25	105.51
23	1444.96	2144.74	-699.78
24	1492.45	1343.24	149.21
25	1340.34	-845.23	2185.57
26	1545.03	1441.43	103.60
27	1611.63	2042.08	-430.45

quadratic model in Eq. 1 and 2. Because of this, it was observed that 3 points affect the model amount of oil retained while 1 point affects the amount of oil leached (Figs. 2A and D). However, this outcome does not have a significant impact on the quadratic model. Again, as shown in Figs. 2B and 2E, residual is the difference between the experimental value of the dependent variables (retained and leached) and the predicted values of the same variable. However, the smaller the residual the stronger the correlation between predicted and experimental values. It was observed that the model describing the amount of waste oil and diesel leached has lower residuals. All points fall within the red lines as shown in Fig. 2E which is an indication that this model fits better or has a strong correlation than that of the amount of oil retained in the soil. Similarly, the normal plot vs the residual shows how the predicted (model) correlates with the experiment. In this case, the amount of oil leached fits better than the one retained (Figs. 2C and F) which confirms the previous plots in Figs. 2B and E.

Three-dimensional response surface plots were used to graphically represent the regression equation. It shows significant mutual interaction between the independent variable and the response (Zaheda et al., 2010). In Fig. 3 it was observed that at 5mm/hr rainfall intensity the amount of oil leached decreases at higher soil depth, the contaminant volume also decreases as shown in the 3D surface plots of Fig. 3A also in the contour plots. While the amount of oil retained in the soil increases as lower rainfall intensity. Similarly, the soil depth decreases as contaminant volume increases. Depending on soil type, nature of the pollutants, etc. An increase or reduction in rainfall, as well as changes in frequency and distribution of rainfall associated with climate change, can certainly affect soil microbial activity and, hence, microbial degradation of soil pollutants in natural attenuation (Itziar *et al.,* 2017).

Increasing the rainfall intensity to 7.25mm/hr, the amount of waste oil and diesel leached reduces, the soil depth increased significantly as the contaminant volume decreases. While the amount retained increases (Fig. 4) just like the first case Fig. 3. As

Fig. 2. Showing the (A) Cook's distance (B) Residual plot and (C) Normal plot for the amount of waste oil and diesel retained in the soil (D), (E) and (F) showing the plots on the effect of the amount of waste oil and diesel leached through the soil



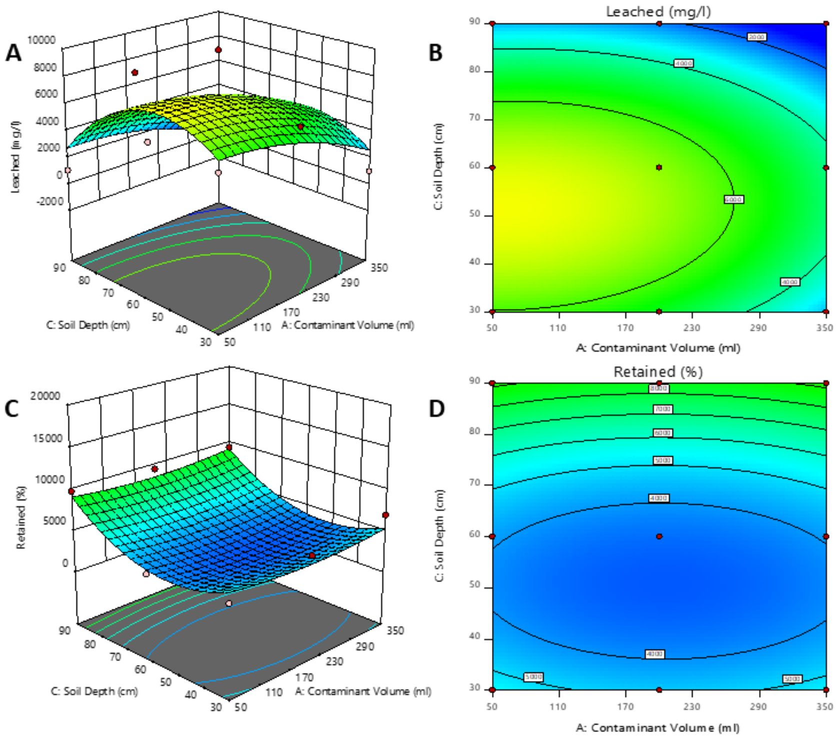


Fig. 3. Showing the 3D surface and contour plots (A, B) Effect of soil depth and contaminant volume on leached (C, D) effect of contaminant volume and soil depth on retained at 5mm/hr rainfall intensity.

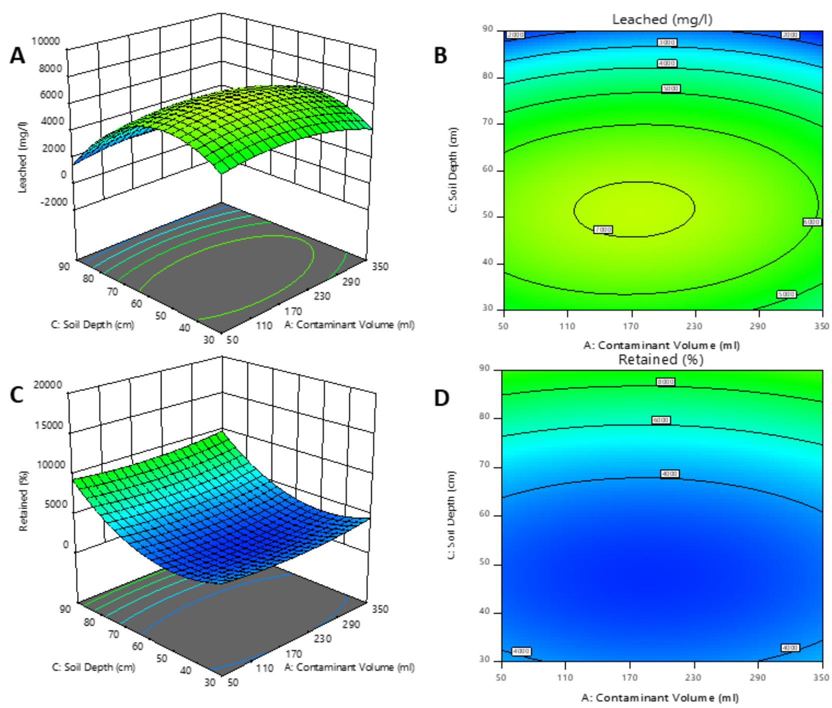


Fig. 4. Showing the 3D surface and contour plots (A, B) Effect of soil depth and contaminant volume on leached (C, D) effect of contaminant volume and soil depth on retained at 7.25mm/hr rainfall intensity.

shown in the 3D surface plots and contour graphs, soil depth decreases as contaminant volume increases. The amount of oil leached and retained in the soil is significantly impacted by rainfall intensities as shown in Figs. 3 and 4. Because many climate-induced (rainfall intensities) effects on soil microorganisms occur indirectly through changes in plant growth and physiology derived from increased atmospheric CO_2 concentrations and temperatures, the alteration of rainfall patterns, etc., with a concomitant effect on rhizoremediation performance (i.e. the plant-assisted microbial degradation of pollutants in the rhizosphere).

Again, in Fig. 5, It shows that at 9mm/hr rainfall there was a significant reduction in the amount of oil (waste oil and diesel) leached through the soil with higher soil depth as contaminant volume decreases (3D surface plots and contour graphs in Figs. 5A and B). Also, in Figs. 5C and D there is a significant increase in the amount of oil retained in the soil at lower soil depth and higher contaminant volume.

At 10mm/hr rainfall there was a significant reduction in the amount of oil (waste oil and diesel) leached through the soil with higher soil depth as contaminant volume decreases (3D surface plots and contour graphs in Figs. 6A and B). Also, in Figs. 6C and D there is a significant increase in the amount of oil retained in the soil at lower soil depth and higher contaminant volume.

Nevertheless, the significance of the impact of the different rainfall intensities is dependent on the soil depth. According to EPA (2017), aerobic biodegradation is most effective in soils that are relatively permeable to allow the transfer of oxygen to subsurface soils where the microorganisms are degrading the petroleum constituents. The EPA report stated that, the length of time required for oxygen to diffuse into the soil increases as the depth increases. The diffusion rate is also proportional to the air-filled porosity of the soil

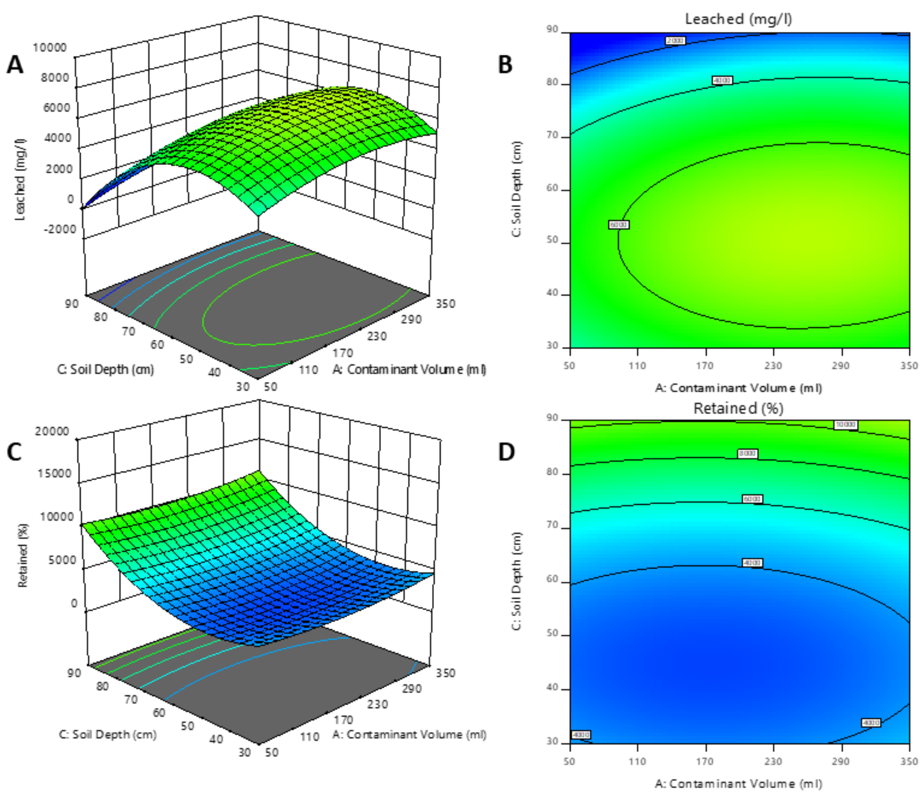


Fig. 5. Showing the 3D surface and contour plots (A, B) Effect of soil depth and contaminant volume on leached (C, D) effect of contaminant volume and soil depth on retained at 9mm/hr rainfall intensity.

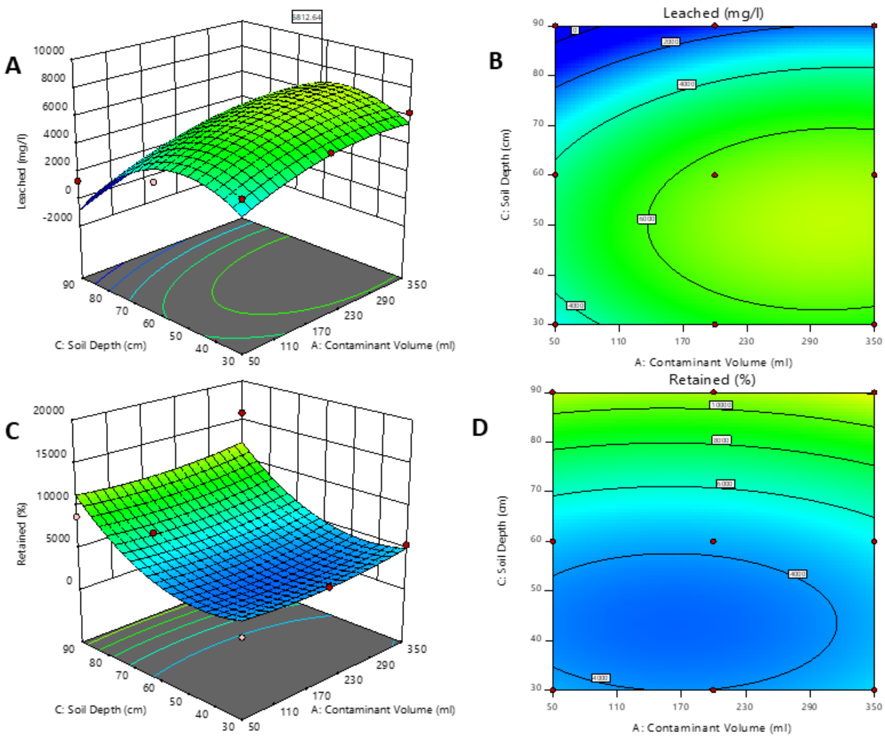


Fig. 6. Showing the 3D surface and contour plots (A, B) Effect of soil depth and contaminant volume on leached (C, D) effect of contaminant volume and soil depth on retained at 10mm/hr rainfall intensity (at the peak of the rainfall).

CONCLUSION

The current study investigated the factors affecting the amount of waste engine oil and diesel leached and retained in the soil after biodegradation Three independent variables were screened through statistical experimental design and RSM analysis to select the most significant variables that affected on oil degradation. Successively it was found that rainfall intensity has a significant impact on the amount of engine oil leached and retained in the soil. Although the amount of engine oil leached is inversely proportional to the amount retained as impacted by different rainfall intensities, it was observed that as the rainfall intensity increases, the amount of engine oil leached decreases at higher soil depth while the amount of engine oil retained increases at lower soil depth. Nevertheless, the significance of the impact of the different rainfall intensities is dependent on the soil depth. This means that the variation in soil depth also affects the process of rainfall intensity in reducing the amount of waste engine oil and diesel in the soil.

On the model validation, the residual shows the difference between the experimental value of the dependent variables (i.e. retained and leached) and the predicted values of the same variable. The lower the residual, is an indication of a significant relationship between predicted and experimental values. Additionally, It was observed that the model describing the amount of waste oil and diesel leached has lower residuals which indicates a high level of accuracy.

Therefore with the regresion coefficient at 72% for retained and 67% for leached concentrations, this implies that the quadratic model is accurate, effective and highly recommended for use.

AUTHOR CONTRIBUTIONS

Theophilus, O.N. commenced the process by conceptualizing and formulating the research idea, followed by data collection and cleaning, and was also extensively involved in reviewing literature and preparing the manuscript. Akaranta, O. reviewed and edited the final manuscript. Theophilus, O.N.

performed the data analysis, results interpretation, and discussion. Ugwoha, E. reviewed the analyzed data and helped in the data interpretation. Theophilus, O.N. did the proofreading and literature review.

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CONFLICT OF INTEREST

The authors declare that there is no conflict of interest regarding the publication of this manuscript. In addition, the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/or falsification, double publication and/or submission, and redundancy have been completely observed by the authors.

ABBREVIATIONS

BTS	Base transreceiver station
DGs	Diesel generators
DOE	Design of experiment
EPA	Environmental protection agency
NIMET	Nigerian meteorological agency
PAHs	Polycyclic aromatic hydrocarbons
PCBs	Polychlorinated biphenyls
POPs	Persistent organic pollutants
RSM	Response surface methodology

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