

# Prediction of the Fate of Spent Engine Oil Spill from a Base Transceiver Station in the Unsaturated Zone

**Keywords:** RSM optimization; Spent engine oil; BTS; Leached; Retained

## Abstract

In this study, Response Surface Methodology (RSM) was employed to predict the amount of spent engine oil leached/retained in the soil after spilling from generators in a telecommunication base station. The experiment was performed at 27 runs based on RSM design with three independent variables, i.e., soil depth, rainfall intensity and contaminant volume. The ANOVA results show that at the 95% confidence level, the interactions of contaminant volume with soil depth and rainfall intensity significantly affect the amount of spent engine oil leached/retained. Additionally, a second-order polynomial equation was developed to relate the leached/retained used oil and the independent variables. An optimization carried out showed that the contaminant volume decreases with the amount of spent oil leached. At 50 ml contaminant volume, the amount of oil leached gave 2675.55 mg/l while soil depth is 90cm at a rainfall intensity of 5mm/hr, while 9033.68% of oil is retained in the soil. Minimizing the amount of spent engine oil retained at 4550.4%, the contaminant volume is given as 50ml, and soil depth shows 53.5cm while 7092.1mg/l was leached. The model was validated by comparing experimental data and predicted values, which showed a good agreement as well as %error computation. The fitted model shows a good agreement between predicted and experimental data at  $R^2$  of 0.9587 and 0.9849 for used oil leached/retained. The analysis shows there is a good relationship between the actual and predicted leached and retained concentrations producing a line of best fit with high correlation coefficient and predictive relevance. This implies that the developed model can adequately predict the transport of spent engine oil in the unsaturated zone.

## Introduction

The use of Diesel Generators (DGs) in powering telecommunication Base Transceiver Stations (BTS) has its drawbacks when compared to alternative energy, which includes but not limited to diesel and oil spillage especially during maintenance cycles [1]. The process of utilizing these products associated with human mismanagement leads to a spill of these products in the environment in and around many BTS sites. Unfortunately, most of the BTS sites are close to human habitation/infrastructure. These products tend to impact negatively on the surroundings affecting water, soil and atmospheric air [2]. The increasing litigation by individuals and sealing of some BTS sites by the regulator (National environmental standards regulations and enforcement agency, NESREA) over the indiscriminate disposition of diesel and waste engine oil by Telecom BTS sites operators is a major cause of concern to the Telecoms operators and infrastructure providers today. However, 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



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mismanaged. Groundwater contamination, disease conditions, soil deterioration, and air quality alterations are possible problems that are likely to be associated with the mismanagement of the products at BTS sites [3]. These liquids that are generated during DG maintenance, site diesel transportation and refueling [4], 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 [5]. To protect and ensure the sustainability of the environment, there is a need to ascertain the impact of the leaching of spent engine oil at these BTS sites. This is required as spilled petroleum products have an adverse effect on the environment according to [6]. There are limited existing information on spent engine oil spill at base transceiver stations on analysis of the impact of spent engine oil at BTS sites on soils. Studies have shown that adverse effects of oil spills when one comes in contact with it could be hemotoxic and hepatotoxic, and could cause infertility and cancer [7]. The negative impact of oil spill include pollution of air and water, loss of soil fertility, and environmental damage of host communities [8]. Response Surface Methodology (RSM), as a statistical analysis approach, is an efficient and widely used methodology to analyze the simultaneous application of different factors or treatment technologies in the oil spill process [9,10]. However, the present study is aimed at predicting the leaching of spent engine oil in polluted soil at base transceiver station sites. Understanding the fate of spent oil at base transceiver station sites will provide insight into predicting contamination risks and extent of contamination. This will provide telecommunications companies broader view and understanding into the problem, will guide their decisions on investments in better management of energy equipment for BTS power, and other possible decisions on environmentally friendly alternatives.

## Materials and Methods

### Study area

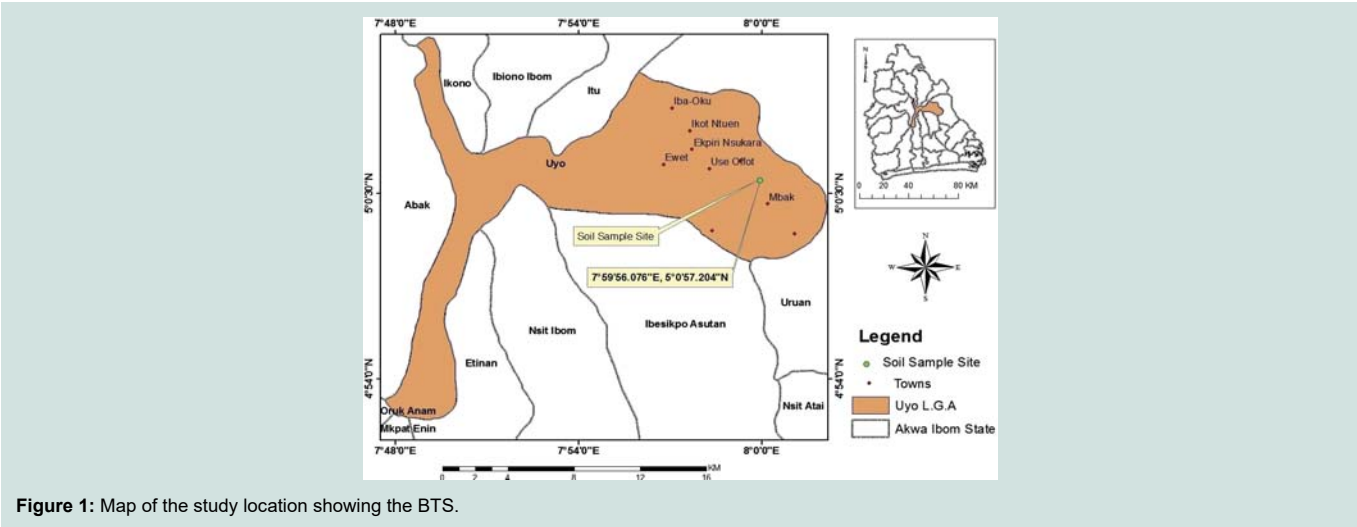


Figure 1: Map of the study location showing the BTS.

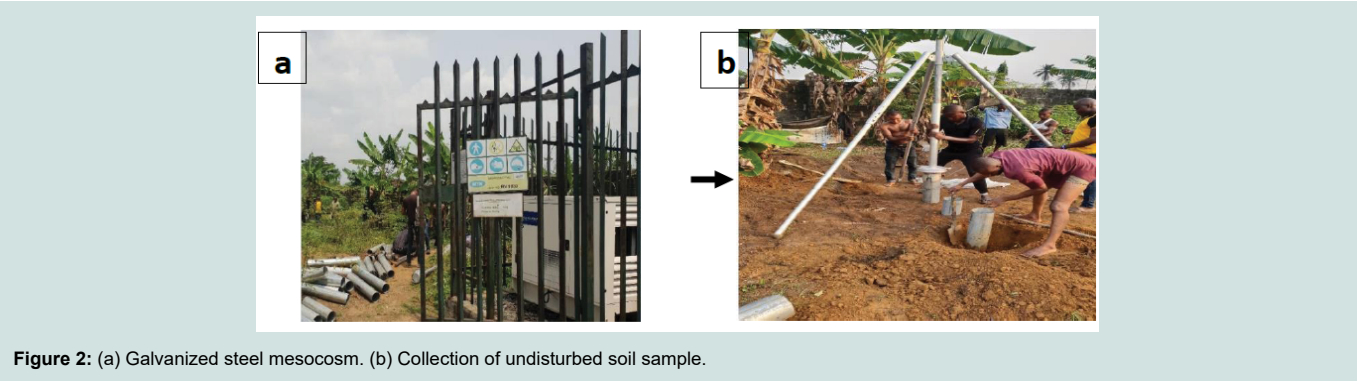


Figure 2: (a) Galvanized steel mesocosm. (b) Collection of undisturbed soil sample.

Table 1: Description of sampling sites and soil properties.

BTS site	Coordinates	Clay	Silt	Sand	Gravel
Ikot Ekpene	5.1744° N, 7.7145° E				
Oron	4.8074° N, 8.2377° E				
Uyo	5.0377° N, 7.9128° E				
Abak	5.0033° N, 7.7743° E				
Eket	4.6467° N, 7.9429° E				

Soil samples around base transceiver station sites in Akwa-Ibom state were collected using a fabricated auger rig. However, the geographical coordinates of the BTS site where the inherent soil samples were collected are between latitude 4.9057° N and longitude 7.8537° E. This location was selected based on the occurrence of oil spill from diesel generators at the BTS and accessibility to the spilled sites (see map of the BTS in Figure1).

Collection of soil samples and grain size analysis

A galvanized steel mesocosm was constructed to collect soil undisturbed. Three sets of 300 mm, 600 mm and 900mm height diameter galvanized steel pipes were constructed to produce the mesocosm used in this study. Before the collection of soil samples at the base transceiver station sites, the topsoil was cleared to a depth of 20 cm [11]. The galvanized steel mesocosm, hammered with the aid of a fabricated auger rig, was used to directly collect undisturbed soil samples, as seen in (Figure 2). Five (5) samples were obtained from

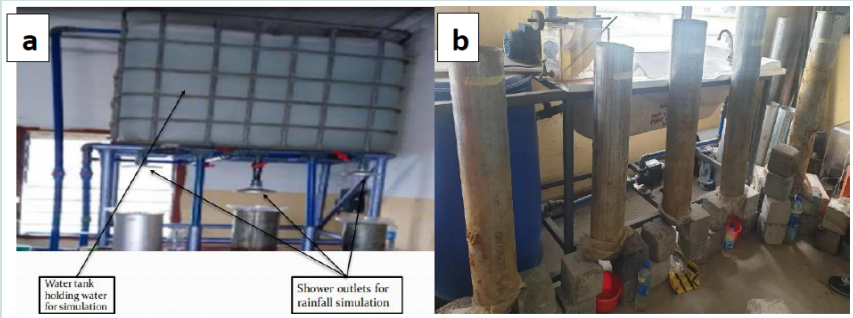
the study location. The collected soil samples were further analyzed in the laboratory to determine the predominant soil type at the BTS in each site where the samples were obtained. The soil samples were analyzed and predominant soil types obtained utilizing grain size analysis using the hydrometer method. The laboratory analysis was carried out at the Civil and Environmental Engineering Laboratory, University of Port Harcourt.

The soil was characterized and classified into clay, silt, sand, and gravel as shown in (Table 1).

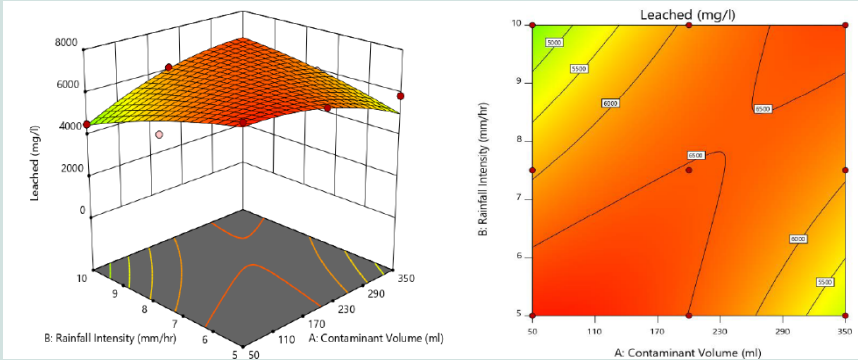
For every randomly selected BTS within the study location, the soil samples were extracted at various depths of 30, 60 and 90 cm, as is consistent with the design of the experiment. For every 30 cm depth, 9 samples of undisturbed soil were collected. Similarly, for each of 60 cm and 90 cm depth, 9 samples of undisturbed soil were collected. The collected soil samples were transported for contamination, rainfall simulation and other relevant experiments.



**Figure 3:** Collection of spent engine oil sample during maintenance of diesel generator used at BTS site.



**Figure 4:** (a) Rainfall simulation set-up and (b) Contamination of undisturbed soil samples in galvanized steel mesocosms and collection of leachates.



**Figure 5:** Effect of rainfall intensity and contaminant volume on leached (A) 3D surface plot (B) 2D contour plot.

**Design of experiment**

A 3<sup>3</sup> full factorial design of experiment was applied to investigate the influence of the independent variables on leached and retained amount of spent engine oil in the soil. Factor levels were chosen by considering the operational limits of the experimental setup. Response Surface Methodology (RSM) was employed in the design of experiment. The experimental design was carried out in XLSTAT 2019 while the response surface analysis was computed using design

expert version 11 by stat-ease.

The independent parameters which include the contaminant volume, rainfall intensity and soil depth were selected using a 3<sup>3</sup> experimental design in XLSTAT 2019 software. The selected rainfall intensity values were chosen to replicate rainfall patterns recorded in each of the considered sites within the study location, as was obtained from the Nigerian Meteorological Agency (NIMET).

**Collection of spent engine oil**

**Table 2:** Spent engine oil leaching and retention in soil as affected by independent variables.

Runs	$X_1$ (ml)	$X_2$ (mm/hr)	$X_3$ (cm)
1	50	5	30
2	200	5	30
3	350	5	30
4	50	7.5	30
5	200	7.5	30
6	350	7.5	30
7	50	10	30
8	200	10	30
9	350	10	30
10	50	5	60
11	200	5	60
12	350	5	60
13	50	7.5	60
14	200	7.5	60
15	350	7.5	60
16	50	10	60
17	200	10	60
18	350	10	60
19	50	5	90
20	200	5	90
21	350	5	90
22	50	7.5	90
23	200	7.5	90
24	350	7.5	90
25	50	10	90
26	200	10	90
27	350	10	90

The spent engine oil was collected during the frequent maintenance of the diesel generators used to power the Base Transceiver Station sites (BTS). The spent engine oil sample was collected using plastic bottles. The bottles were initially rinsed with the waste engine oil before the actual collection as shown in (Figure 3). The spent engine oil was the contaminant utilized in the experiment.

### Experimental set-up and procedures

The experimental set-up consists of 2 major aspects (1) Rainfall simulator set-up, and (2) Mesocosm set-up.

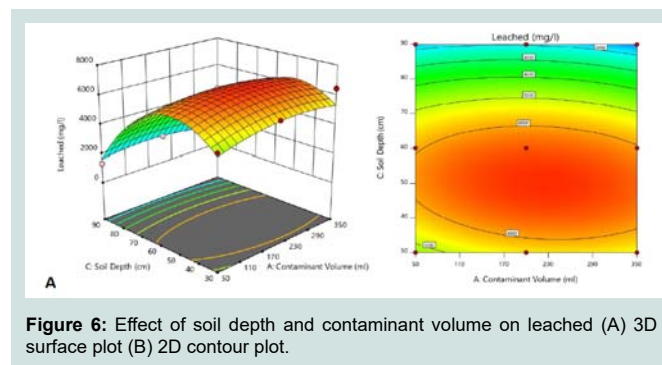
**Rainfall simulator set-up:** The rain simulator was made of a rubber tank of 1000L capacity constructed to imitate the rainfall pattern of the study location using the data obtained from NIMET. The obtained rainfall data were used in calibrating the rainfall simulator to produce 5 mm/hr, 7.5 mm/hr and 10 mm/hr rainfall intensities, for different volumes of the spent engine oil. Also, a 37.5 mm 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 and elbows.

Three shower heads were also connected using 37.5 to 12.5 inches reducers, 12.5 inches PVC pipes, union, valves, elbow, adaptors and plug and cap. The showerheads were mounted on a 25 mm diameter galvanized steel pipe welded to a 20 mm steel base plate to ensure the stability of the shower headstands. Also, 3 transparent 5L plastic calibrated buckets were used to collect the water during the simulation. Two measuring plastic cylinders (1000L and 2000L) were used to measure the amount of rainfall. A stopwatch was used

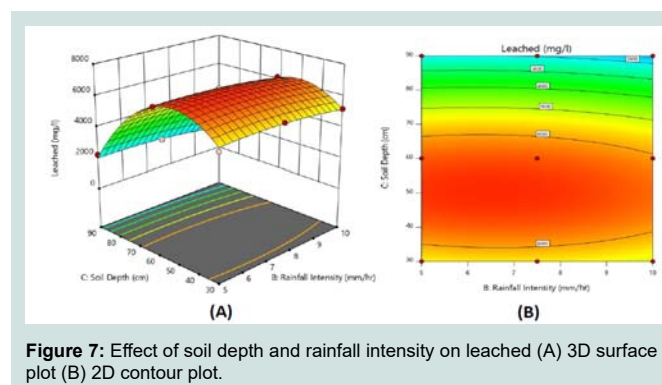
to measure the duration of rainfall when the valves were opened for water inflow. Simulated rainfall at various intensities (5 mm/hr, 7.5 mm/hr, 10 mm/hr) and volume of contaminants (50 ml, 200 ml, 350 ml) were introduced to the undisturbed soil in the mesocosm. Therefore, the intensity of the simulated rainfall was obtained as the height of rainfall collected within a 150 mm diameter pipe per hour of rainfall (Figure 4a).

**Mesocosm set-up:** Some galvanized steel mesocosms were constructed to collect soil samples in an undisturbed condition. Three sets of galvanized steel pipes of 300mm, 600mm and 900mm diameters were constructed for use as mesocosm. The waste engine oil was collected using plastic bottles during the frequent maintenance of the diesel generators used to power the Base Transceiver Station sites (BTS) and added separately in the different containers as stated in the experimental design and thoroughly mixed and left undisturbed for 48 hours to allow the volatilization of toxic compounds of the oil [12]. Following the rainfall simulation explained in the previous subsection. Clips were employed to hold the mesocosms in place on a table while being contaminated and rainfall patterns simulated. The 600 mm diameter holes were constructed to install the 600 mm and 900 mm high mesocosms that have the same diameter as the constructed hole. The base of the mesocosm was protected with a net to prevent erosion and sieve the washout with the aid of a fabricated galvanized steel clips. Leachates were collected using plastic containers placed at the base of the elevated steel mesocosms following the 27 experimental runs (Figure 4b).

**Determination soil hydrocarbon extraction water content:** This test was used to determine the weight of a wet sample along with the container for 24 hours in an oven and then determine the weight of

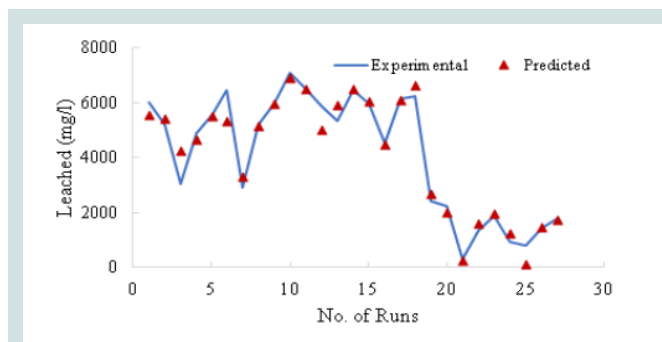


**Figure 6:** Effect of soil depth and contaminant volume on leached (A) 3D surface plot (B) 2D contour plot.

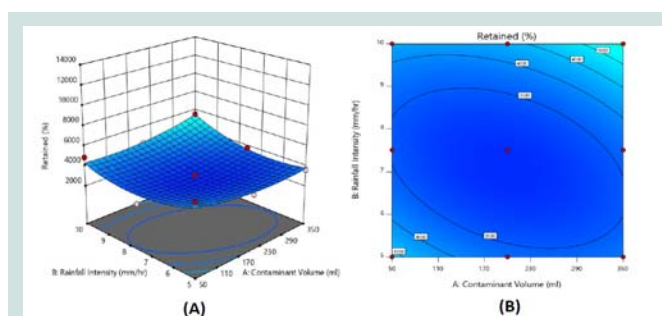


**Figure 7:** Effect of soil depth and rainfall intensity on leached (A) 3D surface plot (B) 2D contour plot.

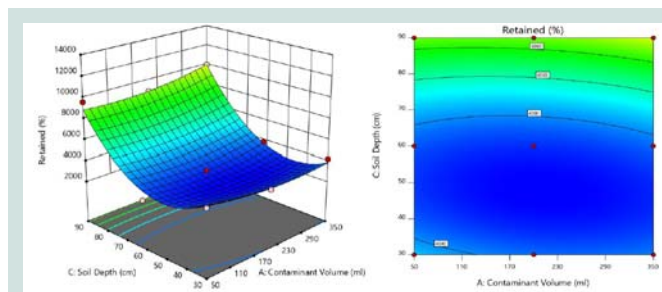




**Figure 8:** Validation of predicted retained used oil with experimental values.



**Figure 9:** Effect of contaminant volume and rainfall intensity on retained (A) 3D surface plot (B) 2D contour plot.



**Figure 10:** Effect of contaminant volume and soil depth on retained (A) 3D surface plot (B) 2D contour plot.

a dry soil sample. A clean dry non-corrodible container was gotten and the 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 0.01 g. The required quantity of a representative undisturbed soil sample was taken and placed on the container. The container with wet soil was placed in the oven with its lid removed for 24 hours maintaining a temperature of 105°C (slightly above the boiling point of water). The container containing the dry soil was then cooled in a desecrator with the lid closed. However, the oven drying temperature of 105°C is suitable for most of the soils.

#### Determination of Total Petroleum Hydrocarbon (TPH):

The TPH test was used to determine the rate of penetration of the contaminants into the soil at BTS sites and also, the rate of pollution of petroleum products in the at BTS sites in the study area. Gas chromatography was used to determine the total petroleum

hydrocarbon content that are in their straight chain, and also the poly-aromatic hydrocarbon content which are heavier class of hydrocarbon starting from Benzene which have a double like chemical structure.

## Results and Discussion

### Experimental result

The experimental result for the response parameters as well as the independent variables as shown in (Table 2), follows the 27 runs from the experimental design.

### Baseline concentrations of total petroleum hydrocarbons (TPH)

The baseline concentration of TPH after 27 experimental runs at a retention time of 20mins is shown in (Table 3).

### Leached TPH concentrations

(Table 4).

### Relationship between leached TPH concentrations and independent variables

The relationship between the TPH leached and the independent variables has been described using second order polynomial or a quadratic equation which predicts the leached concentration at different soil depth, rainfall intensity and the volume of contaminant present in the soil. The following graphs from Figure 5-7 shows the interaction between independent variables on the leached TPH concentration. The effects of the factors on the response were measured using a 3D surface plot and contour plots which indicates the interaction between the variables. It shows the factors (soil depth and rainfall intensity, contaminant volume) significantly affects the

**Table 3:** Baseline concentration of total petroleum hydrocarbon (TPH).

Experimental runs	TPH Retained in Soil (mg/kg)	TPH Leached (mg/kg)
1	559.83	4335.27
2	7590.66	4371.74
3	6745.15	3567.08
4	3476.65	2987.45
5	1181.01	5126.64
6	2388.98	4325.21
7	4106.18	2980.17
8	10015.43	2584.93
9	9674.84	7025.31
10	3177.68	6276.74
11	3237.37	11270.28
12	3859.60	8999.23
13	3950.03	9596.43
14	2769.12	3895.52
15	3279.35	5465.66
16	9933.33	3621.32
17	87568.33	4018.2
18	4026.93	477.21
19	3753.09	4853.15
20	3820.23	3627.22
21	9804.49	6709.51
22	7654.11	4234.93
23	10377.87	9869.42
24	1577.23	17165.23
25	249.32	5876.12
26	5234.68	4398.11
27	3904.11	1109.28

**Table 4:** Leached TPH concentration.

Experimental Runs	Leached TPH (mg/l)
1	6000.12
2	5197.29
3	3046.35
4	4883.67
5	5563.22
6	6449.88
7	2904.55
8	5184.63
9	5987.34
10	7097.4
11	6500.11
12	5870.47
13	5329
14	6478.55
15	5975.18
16	4534.22
17	6134.09
18	6231.16
19	2411.65
20	2215.06
21	301.11
22	1325.99
23	1897.12
24	911.873
25	800.23
26	1407.17
27	1779.3

response variables, leached TPH concentration.

As contaminant decreases there is a corresponding decrease in leached while rainfall intensity increases (Figure 4).

The factor interactions in Figure 5, as the leached increases, contaminant volume decreases while the rainfall intensity increases. Again, it was shown in Figure 6 that leached decreases as soil depth increases, the contaminant volume also decreases gradually as seen on the 3D plot.

Figure 6. It shows that as the soil depth increases the amount of used oil leached decreases significantly with a slight decrease in rainfall intensity as shown in the 3D plot of Figure 7A. Although, the ANOVA result showed that soil depth is the most significant variable affecting the leached. Therefore, the 3D plot confirms that soil depth affected the leached significantly.

Figure 6. It shows that as the soil depth increases the amount of used oil leached decreases significantly with a slight decrease in rainfall intensity as shown in the 3D plot of Figure 7A. Although, the ANOVA result showed that soil depth is the most significant variable affecting the leached. Therefore, the 3D plot confirms that soil depth affected the leached significantly.

The model F-value of 43.90 implies the model is significant. There is only a 0.01% chance that an F-value this large could occur due to noise. P-values < 0.05 indicate model terms are significant. In this case  $X_3$ ,  $X_1 X_2$ ,  $X_1^2$ ,  $X_3^2$  are significant model terms. Values greater than 0.1000 indicate the model terms are not significant (Table 5). Here, it appears that soil depth is the most significant variable affecting the leached as indicated by the p-value in (Table 3). However, the

coefficient of correlation between model and experiment shows a strong positive relationship ( $R^2=0.9587$ ), this is an agreement with the works of [13,14].

$$Y_1 = -538 - 6.8X_1 - 29X_2 + 330X_3 + 2.7X_1X_2 - 0.06X_1X_3 - 0.86X_2X_3 - 0.02X_1^2 - 35.8X_2^2 - 3.1X_3^2 \quad (1)$$

#### Leached TPH model validation

The model was validated by comparing experimental and predicted Vvalues, the error between model and experiment was determined (Table 5). The percentage error was calculated using the following formula:

$$\%Error = \frac{\text{Experimental value} - \text{Predicted value}}{\text{Predicted value}} \times 100 \quad (2)$$

From the Table 6 above it shows that the error between predicted and experimental values for retained and leached amount of used oil in the soil is minimal which ranges from -28.4% to 20.8% for leached and -25.8% to 13.4% respectively as shown in the table above.

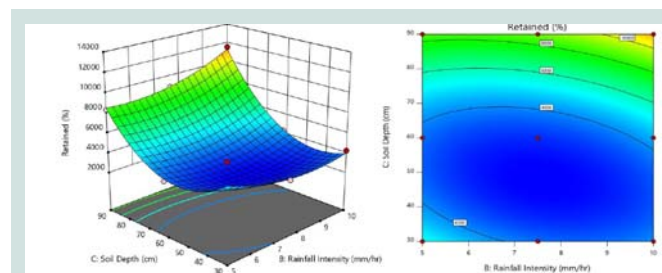
The graphs in Figure 7 show that the model is valid when compared with the experimental data for leached parameters.

#### Retained TPH concentrations

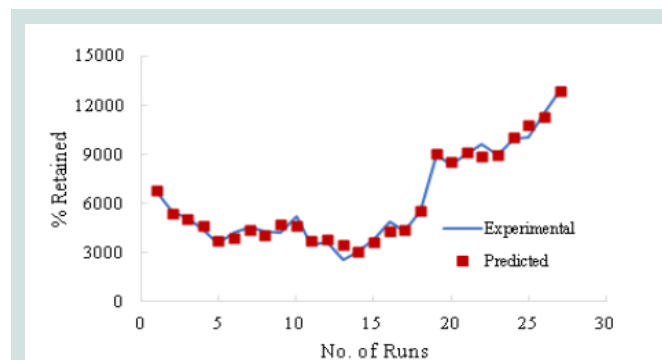
(Table 7).

#### Relationship between retained TPH concentrations and independent variables

The following graphs from Figure 9-11 shows the relationship between independent variables on the leached TPH concentration. The effects of the factors on the response were measured using a 3D surface plot and contour plots which indicates the interaction between the variables. It shows the factors (soil depth and rainfall intensity,



**Figure 11:** Effect of rainfall intensity and soil depth on retained (A) 3D surface plot (B) 2D contour plot.



**Figure 12:** Validation of predicted retained used oil with experimental values.

**Table 5:** Analysis of variance for the amount of spent engine oil leached ( $R^2 = 0.9587$ ).

Source	Sum of Squares	df	Mean Square	F-value	p-value
$Y_1$	1.20E+08	9	1.33E+07	43.9	< 0.0001*
$X_1$	89018.64	1	89018.64	0.294	0.5947
$X_2$	7.51E+05	1	7.51E+05	2.48	0.1337
$X_3$	5.75E+07	1	5.75E+07	189.89	< 0.0001*
$X_1X_2$	1.21E+07	1	1.21E+07	39.97	< 0.0001*
$X_1X_3$	8.75E+05	1	8.75E+05	2.89	0.1073
$X_2X_3$	49906.95	1	49906.95	0.1648	0.6898
$X_1^2$	1.61E+06	1	1.61E+06	5.31	0.0341*
$X_2^2$	3.00E+05	1	3.00E+05	0.9918	0.3333
$X_3^2$	4.64E+07	1	4.64E+07	153.13	< 0.0001*
Residual	5.15E+06	17	3.03E+05		
Cor Total	1.25E+08	26			

\*significant terms

**Table 6:** Experiment verification under the optimum condition for the amount of used oil retained.

Run order	Leached (mg/l)		
	Exp	PD	%Error
1	6000.12	5580.61	7.517279
2	5197.29	5434.33	-4.36190
3	3046.35	4253.05	-28.3726
4	4883.67	4660.36	4.791690
5	5563.22	5518.26	0.814750
6	6449.88	5341.15	20.75826
7	2904.55	3292.71	-11.7885
8	5184.63	5154.77	0.579269
9	5987.34	5981.83	0.092112
10	7097.40	6907.73	2.745765
11	6500.11	6491.39	0.134332
12	5870.47	5040.04	16.47665
13	5329.00	5923.00	-10.0287
14	6478.55	6510.82	-0.49564
15	5975.18	6063.65	-1.45902
16	4534.22	4490.85	0.965741
17	6134.09	6082.85	0.842368
18	6231.16	6639.84	-6.15497
19	2411.65	2675.55	-9.86339
20	2215.06	1989.14	11.35767
21	301.11	267.720	12.47199
22	1325.99	1626.33	-18.4673
23	1897.12	1944.08	-2.41554
24	911.870	1226.84	-25.6733
25	800.230	1029.69	-22.2844
26	1407.17	1451.61	-3.06143
27	1779.30	1738.54	2.344496

Exp: Experimental values; PD: Predicted values from statistical model.

contaminant volume) significantly affects the response variables, the TPH concentration retained in the soil.

The 3D surface and contour plots in indicate that the effect of Contaminant volume Figures 9, Rainfall intensity and Soil depth on retained (%) and leached (mg/l). It was observed study that a lower rate of %retained was attained with lower rainfall intensity.

In the 3D surface and contour plots in Figures 10 indicates that the effect of Contaminant volume, and Soil depth on retained (%). It was observed that a higher rate of %retained was attained with higher soil depth. It shows that as rainfall intensity increases, the retained also increases at lower soil depth. However, the interaction between

soil depth and rainfall intensity on retained shows that, retained increases as rainfall intensity while soil depth reduces (Figure 11).

#### Retained TPH model

The model F-value of 123.42 implies the model is significant. There is only a 0.01% chance that an F-value this large could occur due to noise. P-values < 0.05 indicate model terms are significant. In this case  $X_2$ ,  $X_3$ ,  $X_1X_2$ ,  $X_1X_3$ ,  $X_2X_3$ ,  $X_1^2$ ,  $X_2^2$ ,  $X_3^2$  are significant model terms. Values greater than 0.1000 indicate the model terms are not significant (Table 8). However, the p-values suggest that rainfall intensity and soil depth are the most significant variables affecting the retained. The coefficient of correlation shows a strong and positive relationship between the experiment and the model ( $R^2=0.9849$ ).

The equation in terms of actual factors can be used to make

**Table 7:** Retained TPH concentration.

Experimental Runs	%Retained
1	6677.34
2	5498.05
3	5167.67
4	4389.32
5	3570.32
6	4201.23
7	4571.74
8	4259.67
9	4190.04
10	5199.89
11	3476.06
12	3654.22
13	2564.87
14	3082.12
15	3762.45
16	4870.28
17	4302.45
18	5547.21
19	8953.21
20	8383.15
21	9083.5
22	9633.85
23	8923.75
24	10000.3
25	10012
26	11543.5
27	12976.8

**Table 8:** Analysis of variance for the amount of spent engine oil retained ( $R^2 = 0.9849$ ).

Experimental Runs	%Retained
1	6677.34
2	5498.05
3	5167.67
4	4389.32
5	3570.32
6	4201.23
7	4571.74
8	4259.67
9	4190.04
10	5199.89
11	3476.06
12	3654.22
13	2564.87
14	3082.12
15	3762.45
16	4870.28
17	4302.45
18	5547.21
19	8953.21
20	8383.15
21	9083.5
22	9633.85
23	8923.75
24	10000.3
25	10012
26	11543.5
27	12976.8

\*significant terms.

predictions about the response for given levels of each factor. However, these results conform with that of who used RSM to optimize Bambara nut kernel yield with 3 factors (independent variables) [14].

$$Y_2 = 29284 - 25X_1 - 3381X_2 - 475X_3 + 1.4X_1X_2 + 0.1X_1X_3 + 13.8X_2X_3 + 0.02X_1^2 + 161X_2^2 + 3.6X_3^2 \quad (3)$$

This work is in agreement with the report of, applied response surface methodology to oil spill remediation.

#### Retained TPH model validation

The model was validated by comparing experimental and predicted values, the error between model and experiment was determined (Table 9). The percentage error was calculated using the following formula [15].

$$\%Error = \frac{\text{Experimental value} - \text{Predicted value}}{\text{Predicted value}} \times 100 \quad (4)$$

The graphs in Figure 12 show that the model is valid when compared with the experimental data for retained parameters.

#### Conclusion

In this study, three sets of galvanized steel pipes of 300mm, 600mm and 900mm diameters were constructed for use as mesocosm. The waste engine oil was collected using plastic bottles during the frequent maintenance of the diesel generators used to power the Base Transceiver Station sites (BTS) and added separately in the different containers as stated in the experimental design and left undisturbed for 48 hours to allow the volatilization of toxic compounds of the

oil [12]. A replica lysimeter was constructed to hold the 300mm, 600mm and 900mm high mesocosms that have the same diameter as the constructed hole. The base of the mesocosm was protected with a net to prevent erosion and sieve the washout with the aid of a fabricated galvanized steel clips. Leachates were collected using plastic containers placed at the base of the elevated steel mesocosms following the 27 experimental runs (Figure 4b). The experiment followed a  $3^3$  full factorial design. RSM was employed to study the influence of the contaminant volume, rainfall intensity and soil depth on the amount of oil leached/retained, which showed there is a strong and positive correlation between predicted and experimental values, 0.9587 and 0.9849 for leached and retained respectively. However, the interaction between the different independent variables and their respective effects on the response was studied by analyzing the response surface contour plots [16]. According to [17], RSM procedure has some benefits like higher percentage yield, reduced process variability, closer confirmation for output response in target achievement. Consequently, it was observed that several factors such as soil depth, rainfall intensity and contaminant volume can significantly affect the amount of spent engine oil leached/retained in the unsaturated zone.

The analysis shows there is a good relationship between the actual and predicted lached and retained concentrations with the predicted value clustered around the experimental line as depicted in Figure 8 and 12 producing a line of best fit with high correlation coefficient and predictive relevance of 0.9587 and 0.9849 respectively. This

**Table 9:** Experiment verification under the optimum condition for the amount of used oil retained.

Run order	Retained (%)		
	Exp	PD	%Error
1	6677.34	6809.01	-1.93376
2	5498.05	5405.90	1.704619
3	5167.67	5044.76	2.436389
4	4389.32	4594.65	-4.46889
5	3570.32	3706.97	-3.68630
6	4201.23	3861.25	8.804921
7	4571.74	4392.55	4.079407
8	4259.67	4020.29	5.954297
9	4190.04	4690.00	-10.6601
10	5199.89	4637.10	12.13668
11	3476.06	3695.75	-5.94440
12	3654.22	3796.36	-3.74411
13	2564.87	3458.92	-25.8477
14	3082.12	3032.99	1.619854
15	3762.45	3649.02	3.108506
16	4870.28	4292.99	13.44727
17	4302.45	4382.48	-1.82613
18	5547.21	5513.94	0.60338
19	8953.21	9033.68	-0.89078
20	8383.15	8554.08	-1.99823
21	9083.50	9116.45	-0.36143
22	9633.85	8891.67	8.346913
23	8923.75	8927.49	-0.04189
24	10000.33	10005.28	-0.04947
25	10011.98	10761.91	-6.96837
26	11543.55	11313.16	2.036478
27	12976.78	12906.37	0.545545

Exp: Experimental values; PD: Predicted values from statistical model.



therefore implies that the developed model can adequately predict the transport of spent engine oil in the unsaturated zone.

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