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Diesel Spill Retention Modeling of Niger Delta Soil

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ABSTRACT
This research is aimed at modeling the retention of diesel spill in Niger Delta soil. The objectives are to monitor the retention of diesel at given soil depths, different contaminant volumes and rainfall intensities; and develop a model that will describe the retention of diesel in the unsaturated soil zone at different spill scenarios. Retained diesel spills in soil causes problems which include: contamination of soils, bioaccumulation of hydrocarbon in humans resulting in carcinogenesis, mutagenesis, destruction and the extinction of plants and animals. The method used in generating the experimental design was response surface method, which uses two (2) independent variables - contaminant volume and rainfall intensity; and a constant variable known as soil depth. XLSAT software was used to develop the models for leached and retained total petroleum hydrocarbon (TPH) following release on ground surface. The soil was artificially contaminated with different contaminant volumes of 50ml, 225ml and 400ml of diesel. Varying rainfall intensities of 5mm/hr, 7.5mm/hr and 10mm/hr were simulated on the soil depth of 1000m. Results showed variations in the retention of diesel with the independent and constant variables. The results further showed that the TPH ranged from 633.91m1 to 1.58E+05m1 with the lowest washout concentration of 1.52E+05m1 obtained when contaminant concentration was 50m1 at rainfall intensity of 10mm/hr; and highest washout concentration of 2672.89m1 obtained when contaminant volume was 400m1 at rainfall intensity of 7.5mm/hr. The model was used to fit the retention of diesel in silty clay soil after accidental release with correlation coefficient of 0.9501. The Ministry of Environment in alliance with the Niger Delta Development Commission (NOSDRA) and other sister agencies should adopt the developed model in diesel oil spill reclamation in Niger Delta soil.

KEYWORDS: Retention model, diesel fuel, gas chromatography, leached concentration.

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I. INTRODUCTION

Water-oil fluid interaction in soil possesses some constraints in soil which include soil and ground water contamination (Ericson, 2017), destruction of animals and plants (Richard , John, Sarah, Lawrence, Jackson, Matthew, Julianne, Sandro and Dale, 2017), acute and chronic infection of humans living in the contaminated zones (Ruben , Oksana , Chen., Einav ,Tirza and Yosef ,2018), destruction of aquatic lives (Zock, 2017), destruction of the ecosystem (Bautista, and Rahman, 2016), extinction of plants and animals (Laffon, Pásaro and Valdiglesias,2016). Oil spills in Bori are mainly caused by accidents, ruptured pipelines and spillages caused by loss of containment (UNEP report, 2011). Diesel is the major petroleum product used in the area by the polytechnic, banks, hotels, restaurants and eateries due to lack of power in the area (Otu and Oloidi,2018; Oluwaniyi, 2018). This accounts for the reason why it is used as the petroleum product for this research. Oil spillages deteriorate soil properties and impair plant growth (Fowzia and ANM2018).

This study is aimed at developing a retention model of water-oil fluid interaction in Niger Delta soil with specific objectives to monitor the retention of diesel at given soil depths, monitor the retention of diesel in the unsaturated zone following the release of different volumes of diesel on soil, assess the impact of various rainfall intensities on the transport and retention of diesel, develop a model that will describe retention of diesel in the unsaturated soil zone at different release scenarios (Ugwoha, Nwankwo and Okoronkwo, 2016).

Whenever there is a spill, some spilled products infiltrate into the groundwater and contaminate it as in the case of Ogali in Eleme in

Ogoni, while some portions of it remain in the soil and cause damages to plants and animals (UNEP report, 2011). In this research, oil spill locations in Bori metropolis shall be identified; soil samples shall be obtained from the areas and tested in the laboratory to classify them. Sieve analysis, liquid limit, plastic limit, plasticity index, organic content and moisture content tests shall be done to help classify the soil. Permeability and infiltration tests will also be done to determine the K/D factor of the soil (Yang, Yang, Du and Lei, 2018). Three basic apparatuses shall be fabricated to help simulate rainfall at varying intensities, contaminate the soil at varying contaminant volumes and obtain the leached and retained concentration. The apparatuses include an auger rig undisturbed soil collector, lysimeter with a mesocosm and a rainfall simulator. Surface response method shall be used to obtain the experimental design for the number of runs and samples to be tested. After the simulations, gas chromatography would be used to test for total petroleum hydrocarbon (TPH) present in the leached and retained concentrations of the samples. Surface response method and excel stats shall be used to develop the model for leached and retained concentrations.

Oil spillages deteriorate soil properties and impair the growth of plants (Fowzia and ANM 2018). The work of Obire and Nwaubeta (2018) described the effects of refined petroleum hydrocarbon on the physiochemical and bacteriological characteristics of soil. Brakorenko and Korotchenko (2016); Richard, John, Sarah, Lawrence, Jackson, Matthew, Julianne, Sandro and Dale(2017); Aniefiok, Thomas, Clement, Ekpedeme and Iniemem (2018); Mohammadi, Dehestani, Aff, Shooshpasha and Asadollahi (2015) discussed the impacts of petroleum products on soil. The work of Sharma, Muskan, Ojha and Shukla (2018) dwelled on the effects of contaminant transport in soils.

II. MATERIALS

The materials used for this research include: rain fall simulator, lysimeter with a mesocosm., diesel, auger rig undisturbed soil collector, soil samples and RSM Excel Stat. Program.

2.1 METHODS

The following methods were deployed:

2.1.1 Experimental Setup

A simple laboratory experiment was done to model the retention of petroleum products in sandy soil. The experiment used was designed and reported by Ugwoha et al (2016) with little modifications. Soil samples were collected undisturbed using an undisturbed auger rig soil collector. The soil collector was firmly positioned and anchored to the link between the base of the hammer and the top of the soil collector. The verticality of the auger rig was ensured using a spirit level. The collector was then driven using 20kg hammer to a 1000mm depth. The collector was properly removed and its base guided with a net after driving the mesocosm to the desired depth. The mesocosm was clamped on a lysimeter where varying rainfall intensities were simulated at 5mm/h, 7.5mm/hr and 10mm/hr. Varying proportions of diesel contaminant were also spilled into the mesocosm before turning on the calibrated rainfall simulator.

After contaminating the entire soil and simulation of rainfall, the washouts were properly collected and recorded after 1hr 45 minutes for a particular experiment. The contaminants were properly extracted from the soil and water. The extracted diesel was then injected into a gas chromatography to determine its total petroleum hydrocarbon (TPH).

2.1.2 ANALYSIS OF SAMPLE

Total petroleum hydrocarbons (TPHs) were analyzed with GC-FID methods using a gas chromatography.

2.1.3 GAS CHROMATOGRAPHY

The collected sample extract was injected into the Gas Chromatography Flame Ionization Detector (GC-FID). 1µl of concentrated petroleum hydrocarbon sample extract was injected through a rubber septum into the column by means of hypodermic syringe. The various fractions of the aliphatic compounds (C_8-C_{40}) are automatically detected as it emerges from the column. The results were expressed in mg/l.

2.1.4 RESPONSE SURFACE METHOD (RSM)

XLSAT software using RSM method of a full factorial design with 3 levels was used to generate the number of observations or experimental runs required to develop a transport model. It was used to optimize the output variables which in this case were retained and leached concentrations. The input variables include soil height (1000mm), diesel contaminant (50ml, 225ml and 400ml) and rainfall intensities ranging from 5mm/hr to 10mm/hr; since the soil depth is constant it was neglected. Nine (9) observations/experimental runs were generated as presented in Table 1.

2.1.5 MODEL ASSUMPTIONS

The following assumptions were made in development of the model:

i. The soil is a silty clay soil common in Bori - Ogoni land.

ii. The rainfall intensity was simulated to vary from 5mm/hr to7.5mm/hr to 10mm/hr.
iii. The soil depth is 1000mm.
iv. The diesel contaminant volume varies from 50ml to 400ml.

III. RESULTS AND DISCUSSIONS

The results are presented and discussed below.

3.1 RETAINED CONCENTRATIONS OF TOTAL PETROLEUM HYDROCARBONS (TPHS) FROM COLLECTED SOIL SAMPLES

Generally, the concentrations of TPH retained increased with increased volume of contaminant and decreased with increased rainfall intensity as shown in table 3.1

Table 3.1. Retained concentrations of TPH for various rainfall intensities and contamination volumes

Observation	Sort order	Run order	Repetition	Contam. vol	Rainfall intensity	Retained
Obs1	1	1	1	50	5	21.13
Obs2	2	2	1	225	5	27.63
Obs3	3	3	1	400	5	30.56
Obs4	4	4	1	50	7.5	15.1
Obs5	5	5	1	225	7.5	21.98
Obs6	6	6	1	400	7.5	556.17
Obs7	7	7	1	50	10	24.9
Obs8	8	8	1	225	10	21.24
Obs9	9	9	1	400	10	27.89

Discussion of the result in table 3.1

i. Generally, the concentrations of TPH retained increased with increased contaminant volume and decreased with increased rainfall intensity as shown in Table 3.1. This implies that more diesel will be retained in the soil with increased diesel spill and less diesel will be retained with increased rainfall intensity due to the soil k/d factor (Yang, Yang, Duand Lei, 2018).

3.2 RETAINED CONCENTRATIONS OF DIESEL

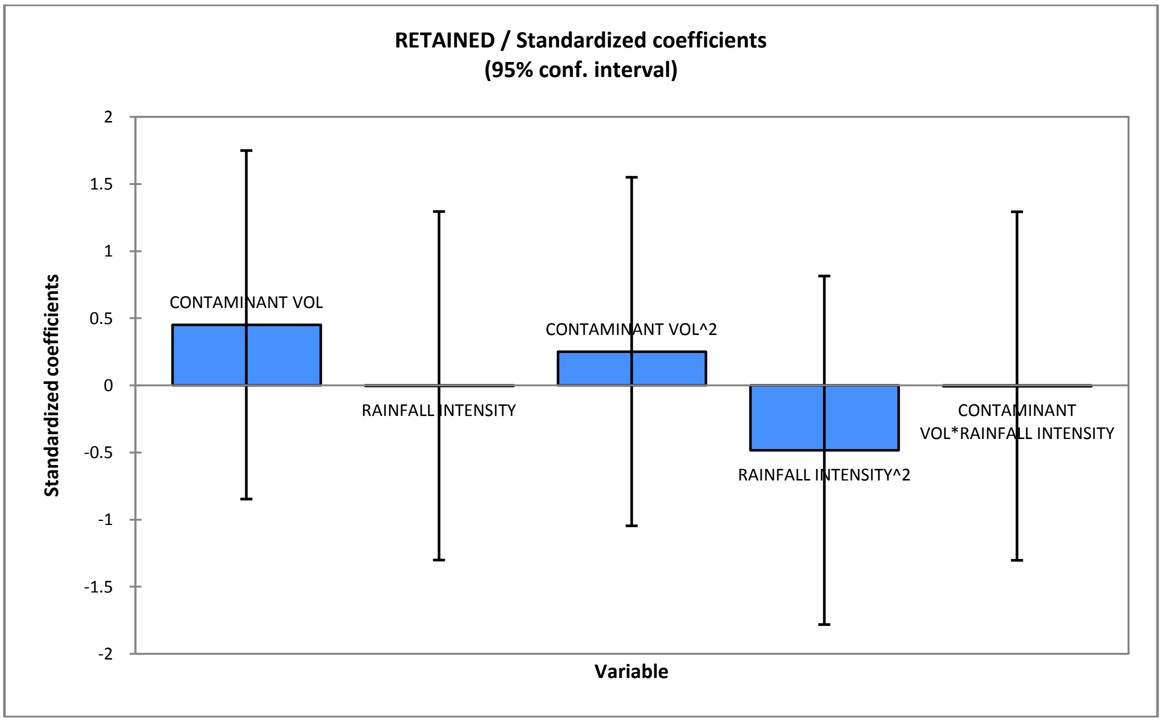

Figure 3.1.Wash out / Standardized coefficients

Discussion of the result in figure 3.1

i. The standardized coefficient of the contaminant volume, contaminant vol^2 and rainfall intensity^2 of 0.5, 0.25 and -0.5 respectively should be taken more seriously in terms of retained concentration of diesel spill because they are higher compared to rainfall intensity and contaminant vol * rainfall intensity as shown in Figure 3.1.

ii. From figure 3.1, since the standardized coefficient of the contaminant volume is highest at 0.25, it implies that increased contaminant volume of the spilled diesel will result in increased quantity of retained diesel concentration in the soil.

iii. Based on figure 3.1, the rainfall intensity is approximately zero. This implies that increased rainfall intensity will result in decreased amount of retained concentration. Hence, rainfall intensity can be used to reclaim contaminated soil.

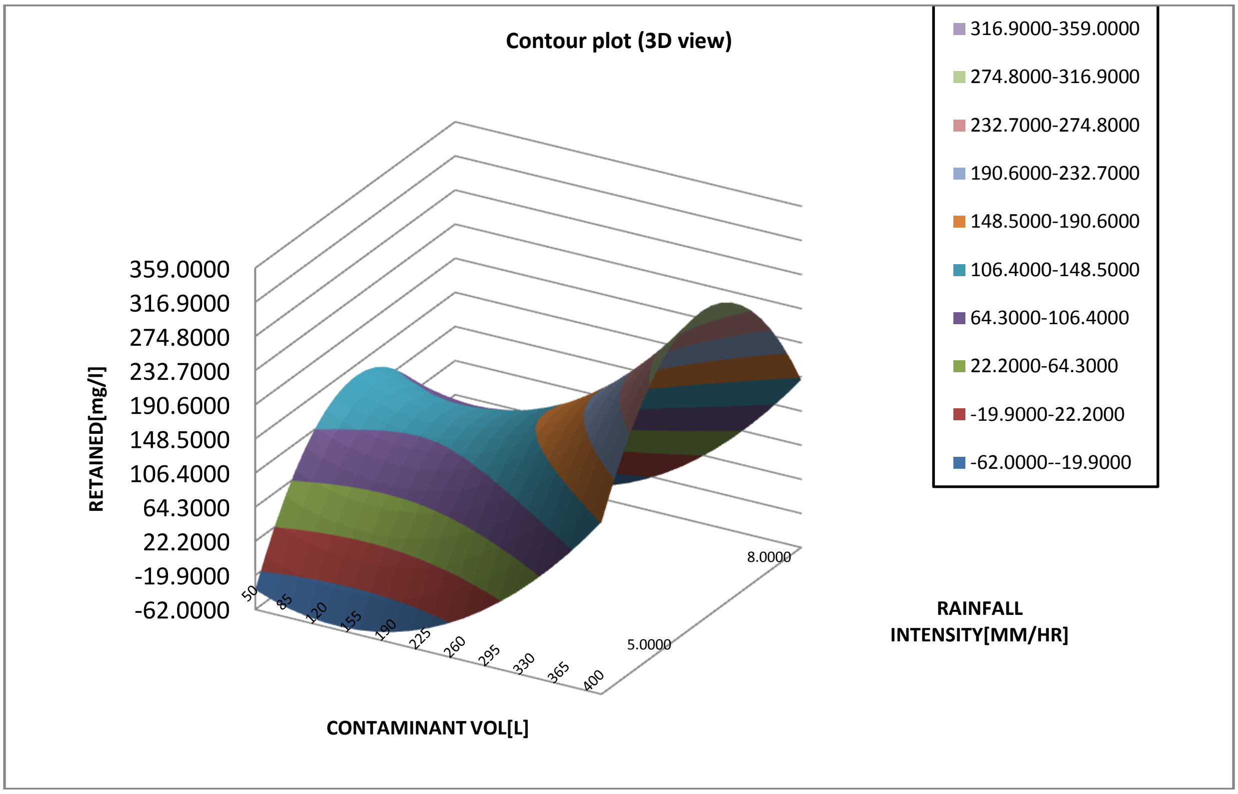

Figure 3.2.Contour plot (3D view)

Discussion of the result in figure 2

i. Figure 3.2 showed the 3D view of the developed model.

ii. The least contaminant volume spans within the range of -62 and 19.9 mg/l while the highest contamination spans within the range of 316.9 and 359 mg/l.

iii. The contour plot showed the highest and lowest leached concentrations with green and blue colours respectively. See the 3D view of the contour plot in figure 3.2

3.4 RETAINED CONCENTRATION MODEL

The retained concentration model developed presented below shows that contaminant volume had the highest coefficient compared to the rainfall intensity.

$$RC = 138.41111+92.24833*Cv - 0.88167*RI + 89.00833*Cv^2 - 172.19167*RI^2 - 1.61000*Cv*RI \quad 1$$

Where *Cv*= contaminant volume, *RI*= Rainfall intensity, *RC*= Retained Concentration

Discussion of the result in equation 1

i. The retained concentration model presented in equation 1 showed that contaminant volume had the highest coefficient of 92.25 compared to of rainfall intensity which is 0.88.

ii. This implies that zero tolerance to diesel spill will prevent impacting on the groundwater quality (Richard, John, Sarah, Lawrence, Jackson, Matthew, Julianne, Sandro and Dale, 2017) and (Zock, 2017).

MODEL VALIDATION

The model was validated using Pearson's product moment correlation coefficient, r. The similarity between the actual and predicted retained concentration showed that good relationship exists because the retained concentration clustered around the trend line given a line of best fit with a coefficient of 0.9501. This implies that the developed retention model can adequately predict the retention of diesel in unsaturated soil zone of Khana after a spill (Ugwoha et al., 2016) and (Chegenizadeh and Hamid, 2018).

IV. CONCLUSION

Generally, the concentrations of TPH retained increases with increased contaminant volume and decreases with increased rainfall intensity as shown in Table 3.1.This implies that more diesel will be retained in the soil with increased diesel spill and less diesel will be retained with increased rainfall intensity due to the soil k/d factor (Yang, Yang, Duand Lei, 2018).

The standardized coefficient of the contaminant volume, contaminant vol^2 and rainfall intensity^2 of 0.5, 0.25 and -0.5 respectively should be taken more seriously in terms of retained concentration of diesel spill because they are higher compared to rainfall intensity and contaminant vol * rainfall intensity as shown in Figure 1.

The retained concentration model presented in equation 1 showed that contaminant volume had the highest coefficient of 92.25 compared to the rainfall intensity of 0.88. This implies that zero tolerance to diesel spill will prevent impacting on the groundwater quality (Richard, John, Sarah, Lawrence, Jackson, Matthew, Julianne, Sandro and Dale, 2017) and (Zock, 2017).

The relationship between the actual and predicted retained concentration shows that a good relationship exists between them since the retained concentration clustered around the trend line given a line of best fit with a correlation coefficient of 0.9501. This implies that the developed retention model can adequately predict the retention of diesel in the unsaturated zone following release (Ugwoha et al., 2016) and (Chegenizadeh and Hamid, 2014).

V. RECOMMENDATION

It is recommended that Khana Local Government Area in alliance with National Oil Spill Detection Regulation Agency (NOSDRA) should implement the developed diesel leached concentration model as it will help to optimally reclaim oil spilled land.

VI. CONTRIBUTION TO KNOWLEDGE

Most studies involving petroleum hydrocarbons describe the impact, fate and transport of diesel in soil and groundwater. This research developed a model to predict the transport and retention of diesel in silty clay soil that is common in Bori region of Niger Delta region where most oil spill occurs. The best containment technique for cleanup of diesel contaminated soil in Ogoni land is obtainable.

This research work agrees with the implementation of environmental management system as per clause 5, 6,7, 8,9 and 10 of ISO14001:2015.

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