EQA - International Journal of Environmental Quality
ISSN 2281-4485 - Vol. 59 (2024): 42-48
Journal homepage: https://eqa.unibo.it/

published by

Experimental modelling of contaminant migration of spent engine oil in a Lateritic soil within Nekede Mechanic Village

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Article info
Received 13/11/2023; received in revised form 8/12/2023; accepted 29/12/2024
DOI: 10.6092/issn.2281-4485/18452

Abstract
In his pursuit of meaning in life, man has simultaneously generated substances that, under improper management, have a harmful impact on the environment. Villages with mechanics are extremely important to society. Nevertheless, in developing nations, inexperienced MV operators and lax policies continue to cast a shadow over efforts to preserve ecologically friendly mechanic villages. The operations in the MVs release PAHs, heavy metals, and other hazardous materials that pose substantial risks to the environment and public health. Determining the levels of PAHs, Pb, Cd, and Ni emitted from Spent Engine Oils in the study area is the main goal of this research project because these substances may be spread through soil strata due to the area's high rainfall density, high rate of infiltration, and favourable geologic conditions. Prior to SEO contamination, a soil sample was taken at Nekede Mechanical Village in order to determine its physico-chemical characteristics. An auto-mechanic shop provided a sample of SEO for evaluation of the active ingredients and components as well as for use in an experimental/simulation setup with a hollow plastic cylinder. According to analytical results, there were 51.73329 parts per million (ppm) of 16 polycyclic aromatic hydrocarbons (PAHs) in the sample of spent engine oil that was taken from the research region. Three specific heavy metal concentrations were also assessed, revealing lead (Pb) at 112.04 mg/L, cadmium (Cd) at 3.020 mg/L, and nickel at 2.130 mg/L. The experiment demonstrated how the volume of SEO components decreased as they moved through the soil. The acquired results demonstrated that when water or rainfall mobilised the SEO component, it might migrate through the study area's soil. Therefore, it is important to support ecologically friendly mechanic villages and appropriate waste management.

Keywords
Modelling, Contaminants, Mechanic Village (MV), heavy metals, Spent Engine Oil (SEO).

Introduction

Since lubricating oil is a byproduct of vacuum distilling crude oil, it is a necessary petroleum product that helps to lower the frictional forces between metal surfaces in engines. After engines and generators have been serviced and drained, spent lubricating engine oil (SLEO) is typically extracted (Anoliefo and Vwioko, 2001; Ogbe et al., 2006). Due to its inadequate aeration, spent engine oil when applied to soil produces an unsuitable environment for life in the soil. It causes in the soil, nitrogen immobilisation, and pH reduction (Achuba and Peretiemo-Clarke, 2008). The microbial populations in soil can undergo significant changes when used motor oil spills. The biological cycles in the soil may be impacted by these modifications. Used motor oil in the soil prevents plants from growing and

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raises the metal content of the ones that do survive. Bacteria are extremely mutagenic to used motor oil. This can be explained by the fact that, during engine operation, oil is contaminated with metals and combustion dust; which in turn leads to an increase in it's PAH content. Specifically, the amount of benzo(a)-pyrene in the oil increases significantly during motor operation. Used motor oil and it's PAH fraction are able to induce carcinomas. In aquatic environments, used motor oil provokes a change in the microbial communities and decreases the primary production of phytoplankton. Heavy metals from Spent Engine Oil can be transformed into the aqueous phase by bacterial activity. The transfer involves an increase in heavy metal mobility and, in consequence, their toxicity. Ibe and Uzoukwu, (2001) revealed the depth to the water table (10-24m), aquifer thickness and subsurface geology of the study area thus revealing its groundwater distribution as well as its potential as a substitute to the surface water resources. This implies that the groundwater resources of the area are close to the surface. Indiscriminate discharge of SEO is in no doubt endangers the groundwater resources of the study area and their neighbouring communities. Nwachukwu *et al.,*(2012) in Linking institutions and neighborhood communities with irrigation within the study area arrived at the conclusion that the groundwater flow direction of the study area connects three major High institutions of higher learning with their host communities and this poses serious environmental and health concern The study area is located within the eastern part of Nigeria, with climate characterized by high humidity (80 -100%). The area has a moderate high temperature of 25 – 27^{0}C with a mean annual rainfall of about 2250 – 2500 mm; the vegetation is typically rain forest, although some parts consist of guinea savannah (Nwachukwu *et al.,* 2010). Vertical electrical soundings carried out in the study area revealed that the study area is underlain by coastal sands (Benin formation); the Thickness of the aquifer ranges from 20-80 m yielding 0.31, the thick extensive aquifer has a transmissivity of $2.8x10^{-2}$ m^2/s^{-1} to $3.3x10^{-1}$ m^2/s^{-1} and storativity of $1.44x10^{-4}$ to $1.68x10^{-3}$ m/s^{-1} values (Ibe and Uzoukwu, 2001).

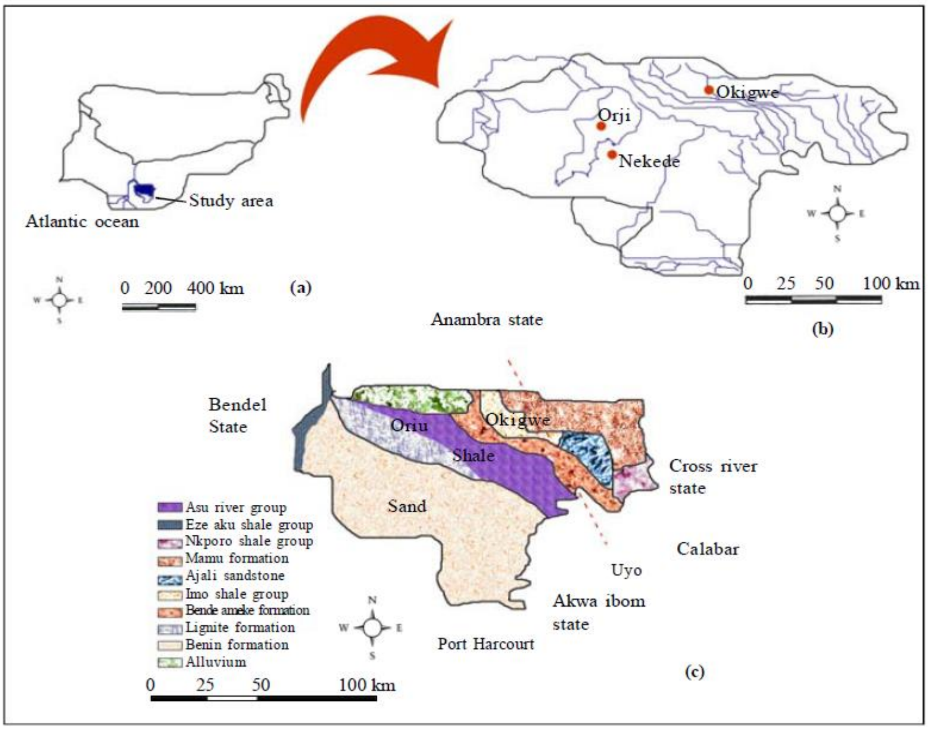


Figure 1
Map of Nigeria showing the study area;
b. Drainage map of study area;
c. Geologic map of Imo River Basin (Nwachukwu et al., 2010).

Methodology

Sample Collection and Preparation

The sample collection was done in May, which is the period that ushers in the dense rainy season. Undisturbed Sub-soil sample (Lateritic Soil) was collected within the study site from an unpolluted point using a core cylinder at a depth of 35cm below the existing ground surface. This depth was adopted in order to isolate humus and unwanted materials. Part of this

DOI: 10.6092/issn.2281-4485/18452

sample was used to firstly determine the Geotechnical and Physico-Chemical properties of the control Soil sample.

Simulation / Experimentation

The experiment (Fig. 2 and 3) involves using a set-up consisting of a hollow plastic cylinder with an inside diameter of 10.5 cm and a length of 25 cm. The soil sample was then compressed into the cylinder down to 10 cm or 15 cm when measuring from the bottom with a hand-held or manual piston to assume the in-situ state. As soon as the soil sample was in place, an impermeable Plastic Plate was placed at the base of the cylinder (directly below the soil layer). A 10 cm height of source solution con--tainning Spent Engine/ waste Crankcase oil was thoroughly mixed with water so as to maintain a uniform concentration throughout the source reservoir and then discharged on top of the soil layer. Howe-ver, the water was meant to aid and mobilize the migration of the contaminants of the Spent Engine oil. After a period of 15 days have elapsed for migration to take place (Fig. 3), the set-up was taken apart and the soil layer was sectioned into three different categories (Top =0-5cm, Middle = 5-10cm, Bottom = 10-15cm) to de-termine the vertical distribution of the stated spent engine oil contaminants. Samples of each of the va-rious sections were collected to determine the con-centration of Polycyclic Aromatic Hydrocarbons (PAHs). The effluent was collected and analysed for the concentration of PAHs and the three stated heavy metals.

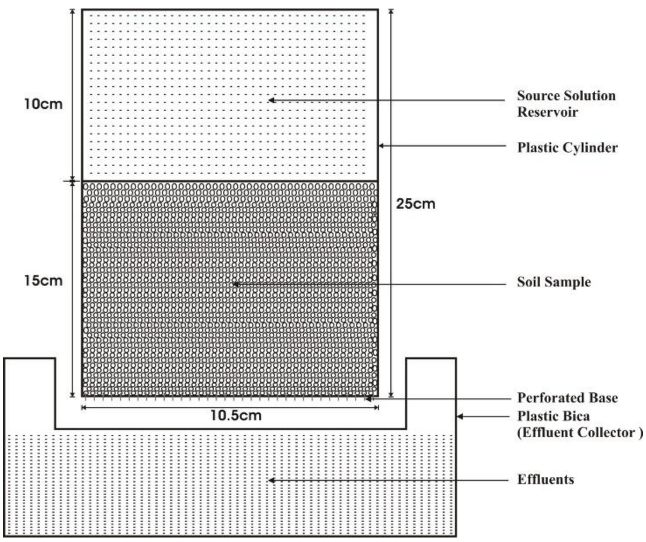


Figure 2. *The simulation set-up for contaminant migration and modelling.*

Laboratory Analysis

The physico-chemical properties of soil sample (Moisture Content, Particle/Grain size Distribution Analysis, Specific Gravity, Shear strength, Hydraulic Conductivity, Porosity, Bulk and Dry Density) were analysed using BS 1377 (1990), Shear Strength was determined using direct shear testing of soils, ASTM (American Society for Testing and Materials) STP no. 131, as reported by (Scott, 1980). Hence, the PAHs content in SEO were determined using Gas Chromatography–Mass Spectrometry (GC–MS) based on US EPA method 8100 (EPA, 1984). The three stated Heavy metals were analysed using the Inductively Coupled Plasma-Atomic Emission Spectrometry (ICP-AES). Teresa *et al.,* (2005), Lazaro *et al.*, (2000), Franklin Associates (1985) and EPA document SW-013 have all confirmed the adequacy of digestion method with ICP-AES.

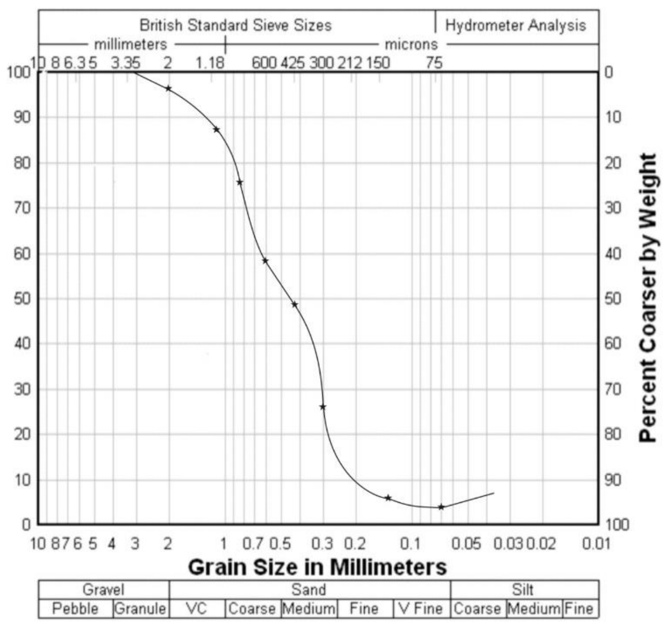


Figure 3. *Grain Size Distribution Graph* (Summary): Gravel = 3.2%; Sand = 92.1%; Fines = 4.7%

Results

The Lab analysis of the active ingredients of the SEO show the total volume of polycyclic aromatic hydrocarbons (PAHs) in the Spent Engine Oil sample to be 51.73329 ppm, as seen in Table 2. The concentrations of the three heavy metals that were chosen are shown in Table 1 as follows: lead (Pb) 112.041, cadmium (Cd) 3.020, and nickel (Ni) 2.130,

DOI: 10.6092/issn.2281-4485/18452

all the three heavy metals are expressed in mg/L. Table 3 shows the variation of physico-chemical properties of the Lateritic Soil Sample, with hydraulic conductivity (k) of 4.0x10^-2 cm/s. Figure 4 portrays Grain Size Distribution Graph which reveals that 92.1% of the soil sample (study area soil) is coarse lateritic sand (a few centimetre away from the top soil). The total volume of PAH in the top soil section, middle soil section, and bottom soil section, following contamination and migration (Table 2) were 6.21451 ppm, 0.960736 ppm, and 0.776947 ppm, respectively. After experiment, the leachate/effluent was found to have a total volume of 0.353345 ppm of PAHs (Table 2). In Table 1, the concentrations of the chosen heavy metals in the leachate/effluent were seen follows: lead (Pb) 0.449, cadmium (Cd) 0.071, and nickel (Ni) 0.020, expressed in mg/l.

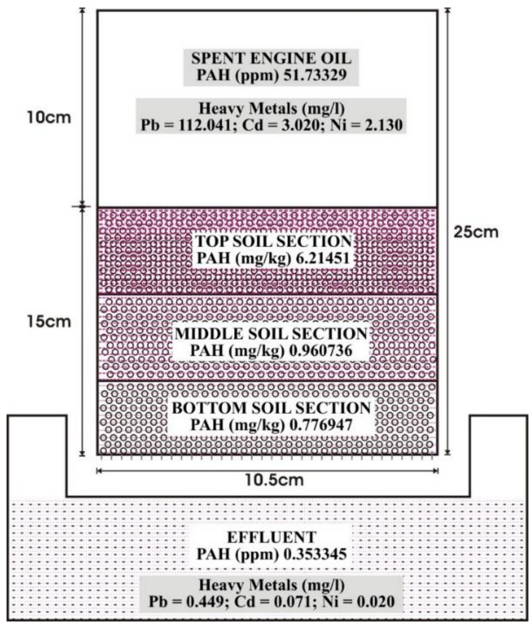


Figure 3. *The simulation set-up for contaminant migration and modelling*

Heavy metals

The results in Table 1 show the concentrations (in mg/L) of the three heavy metals in SEO before and after contamination. The first analysis was on the SEO, to determine the concentration of the heavy metals before contamination and migration as well. The second analysis was on the leachate, to determine the survivability and amount of the heavy metals that could survive the migration process through 15cm (volume) of soil sample within 15 days. Significant reduction is observed in the concentration of the three heavy metals. The study

Table 1: *Variation of heavy metals levels in SEO and the leachate*

Heavy Metals	Samples	
	Spent Engine Oil	Leachate
Lead (Pb) (mg/l)	112.041	0.449
Cadmium (Cd) (mg/l)	3.020	0.071
Nickel (Ni) (mg/l)	2.130	0.020

reveals that it was only 0.40% of the total lead concentration in the SEO could migrate through the setup. While about 99.5% of total lead concentration in the SEO was retained in the soil; about 2.4% of the total Cadmium concentration made it through the soil setup, while about 97% of Cadmium retained; and about 0.94% of total Nickel concentration in the SEO made it through the soil setup while about 99% of Nickel was retained. This implies that out of the three heavy metals investigated, greater quantity of lead was retained, and greater volume of Cadmium could migrate through the soil setup. This however, reveals that greater quantity of the heavy metals was soaked into the soil macro and micro pores as a result of *sorption*. Moreover, other factors that influence contaminant migration like volatilisation and Chemical reactions such as Cosolvation and Ionization, Solubility, Dissolution, Precipitation, Complexation Reactions, Ion-Exchange Reactions, Redox reaction and Biodegradation could also have been responsible for the reduction experienced in concentration of the heavy metals.

PAH

Table 2 shows the results of the PAH analysis carried out in the SEO and different sections of the soil setup (Top Soil, Middle soil, Bottom Soil), including the leachate as seen in Figure 3. The results revealed a progressive decrease in the total concentration of the 16 PAHs analyzed. From the results, about 0.7% of the total PAHs concentration could migrate through the 15cm (volume) soil setup, having about 99% retained in the soil setup. Progressive reduction in concentration was observed as the PAHs migrate through the different sections of the Soil sample; hence SEO ingredients /compositions are diminished as the contaminants migrate through soil strata. However, the quantity of PAH retained could be associated with *Sorption*, Volatilisation and Chemical reactions which are

DOI: 10.6092/issn.2281-4485/18452

factors that determine the fate of contaminant migration. Figures 5, 6, 7, 8 and 9 shows the Calibration Graph of PAHs concentrations in Spent Engine Oil sample, Top soil section, Middle Soil section, Bottom Soil section and the Leachate/effluent respectively.

Table 2. *Variation of PAHs levels in SEO and soil samples*

PAH	SEO (ppm)	Top Soil Section (mg/kg)	Middle Soil Section (mg/kg)	Bottom Soil Section (mg/kg)	Leachate (ppm)
Naphthalene	-	0.00217230	0.000112861	0.0000765056	0.000161800
Acenaphthylene	-	0.00144358	0.000124772	-	0.0000688745
Acenaphthene	-	0.00131266	0.00000495026	-	0.000216701
Fluorene	0.0272516	0.00128501	-	-	0.000156191
Phenanthrene	0.00979949	0.000788181	-	-	0.0000903799
Anthracene	0.00614084	0.000969393	-	-	0.0000769509
Fluoranthene	0.00400379	0.000910302	-	-	0.0000448101
Pyrene	0.0133084	0.000417246	-	-	0.0000501766
Benz(a)anthracene	0.0106483	0.00144980	0.000185811	-	0.000101565
Chrysene	0.0113188	0.00113175	0.0000338790	0.0000338587	0.000159790
Benzo(b)fluoranthene	42.11787	1.95670	0.386980	0.331366	0.303164
Benzo(k)fluoranthene	0.00781340	0.00102969	0.000255068	0.000202583	0.0001037333
Benzo(a)pyrene	0.0203918	0.00349596	0.000867740	0.000766596	0.000354431
Indeno(1,2,3-cd)pyrene	9.49395	4.23604	0.572059	0.444453	0.0483413
Dibenz(a,h)anthracene	0.00311372	0.000793751	0.0000704069	0.0000403909	0.0000913619
Benzo(g,h,i)perylene	0.00767274	0.00456813	0.0000412574	0.00000799256	0.000129809
Total	51.73329	6.21451	0.960736	0.776947	0.353345

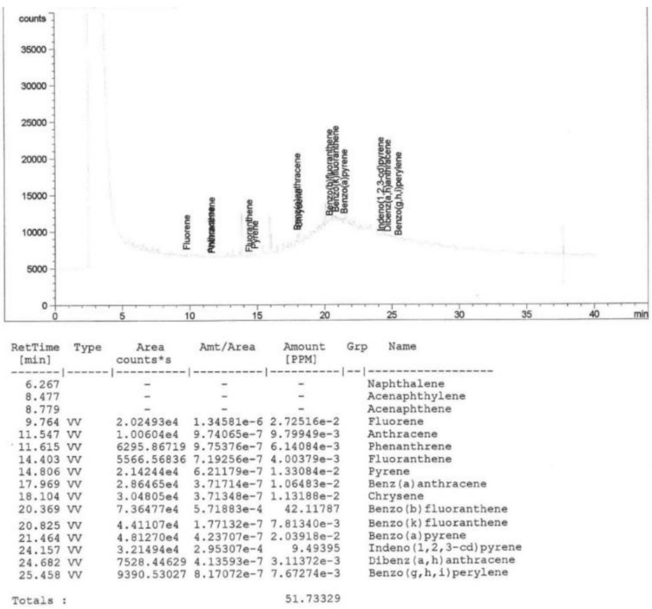


Figure 5. *Calibration graph of PAHs in spent engine oil.*

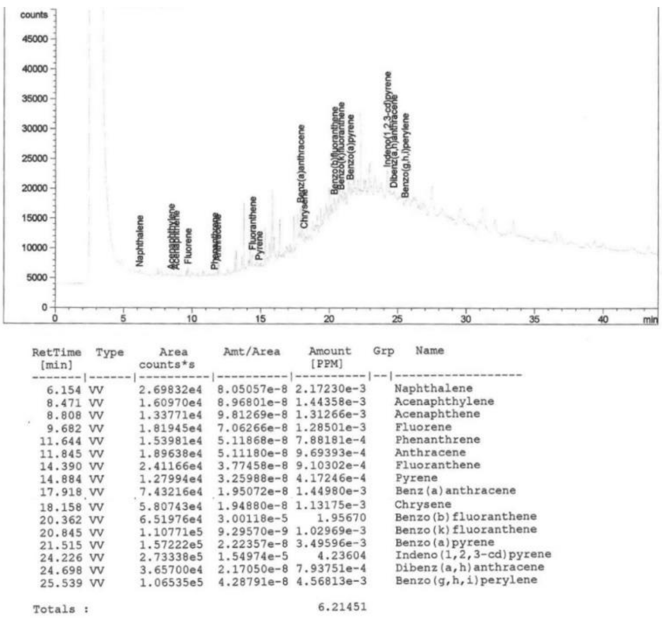
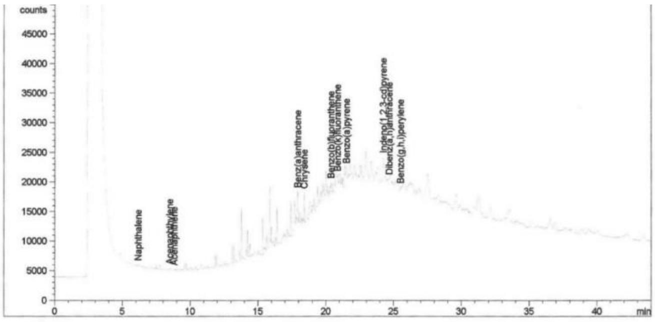


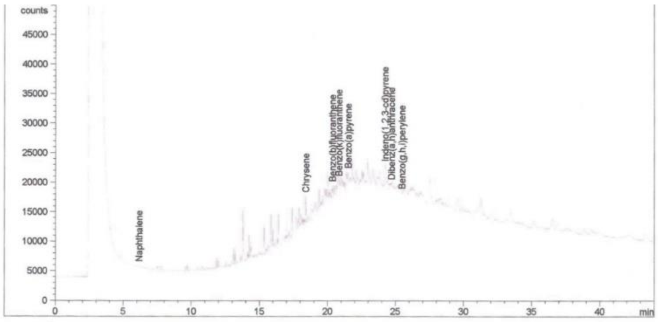
Figure 6. *Calibration graph of PAHs in top soil section.*

DOI: 10.6092/issn.2281-4485/18452



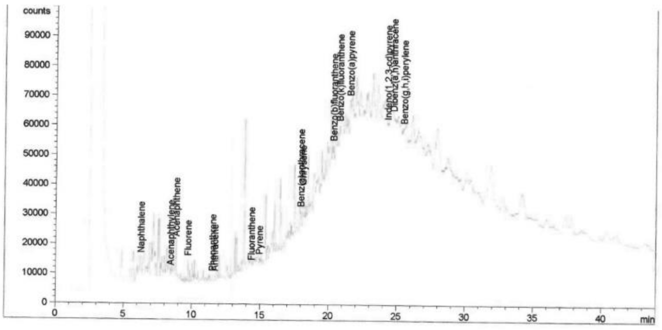
RetTime [min]	Type	Area counts*s	Amt/Area	Amount [PPM]	Grp	Name
6.157	BB X	1401.89612	8.05057e-8	1.12861e-4		Naphthalene
8.475	VV T	1391.29895	8.96801e-8	1.24772e-4		Acenaphthylene
8.820	BV T	50.44750	9.81269e-8	4.95026e-6		Acenaphthene
9.700		-	-	-		Fluorene
11.606		-	-	-		Phenanthrene
11.724		-	-	-		Anthracene
14.362		-	-	-		Fluoranthene
14.881		-	-	-		Pyrene
17.924	VV T	9525.26074	1.95072e-8	1.85811e-4		Benz(a)anthracene
18.416	VV T	1738.45728	1.94880e-8	3.38790e-5		Chrysene
20.376	VV T	1.28943e4	3.00118e-5	3.86980e-1		Benzo(b)fluoranthene
20.856	VV T	2.74394e4	9.29570e-9	2.55068e-4		Benzo(k)fluoranthene
21.528	VV T	3.90245e4	2.22357e-8	8.67740e-4		Benzo(a)pyrene
24.235	VV X	3.69131e4	1.54974e-5	5.72059e-1		Indeno(1,2,3-cd)pyrene
24.675	VV X	3243.81348	2.17050e-8	7.04069e-5		Dibenz(a,h)anthracene
25.510	VV T	962.17987	4.28791e-8	4.12574e-5		Benzo(g,h,i)perylene
Totals :				9.60736e-1		

Figure 7. *Calibration graph of PAHs in middle soil section.*



RetTime [min]	Type	Area counts*s	Amt/Area	Amount [PPM]	Grp	Name
6.160	VB X	950.31256	8.05057e-8	7.65056e-5		Naphthalene
8.477		-	-	-		Acenaphthylene
8.779		-	-	-		Acenaphthene
9.700		-	-	-		Fluorene
11.606		-	-	-		Phenanthrene
11.724		-	-	-		Anthracene
14.362		-	-	-		Fluoranthene
14.881		-	-	-		Pyrene
17.948		-	-	-		Benz(a)anthracene
18.413	VV T	1737.41821	1.94880e-8	3.38587e-5		Chrysene
20.370	VV T	1.10412e4	3.00118e-5	3.31366e-1		Benzo(b)fluoranthene
20.847	VV T	2.17932e4	9.29570e-9	2.02583e-4		Benzo(k)fluoranthene
21.513	VV T	3.44759e4	2.22357e-8	7.66596e-4		Benzo(a)pyrene
24.230	VV X	2.86791e4	1.54974e-5	4.44453e-1		Indeno(1,2,3-cd)pyrene
24.700	VV X	1860.90344	2.17050e-8	4.03909e-5		Dibenz(a,h)anthracene
25.466	BV X	186.39758	4.28791e-8	7.99256e-6		Benzo(g,h,i)perylene
Totals :				7.76947e-1		

Figure 8. *Calibration Graph of PAHs in Bottom Soil Section.*



RetTime [min]	Type	Area counts*s	Amt/Area	Amount [PPM]	Grp	Name
6.255	VV	5.98401e4	2.70387e-9	1.61800e-4		Naphthalene
8.449	VV	2.28660e4	3.01209e-9	6.88745e-5		Acenaphthylene
8.834	VV	6.57506e4	3.29580e-9	2.16701e-4		Acenaphthene
9.716	VV	6.58441e4	2.37214e-9	1.56191e-4		Fluorene
11.521	VV	5.25705e4	1.71921e-9	9.03799e-5		Phenanthrene
11.689	VV	4.48196e4	1.71690e-9	7.69509e-5		Anthracene
14.368	VV	3.53456e4	1.26777e-9	4.48101e-5		Fluoranthene
14.938	VV	4.58276e4	1.09490e-9	5.01766e-5		Pyrene
17.958	VV	1.55017e5	6.55189e-10	1.01565e-4		Benz(a)anthracene
18.103	VV	2.44125e5	6.54543e-10	1.59790e-4		Chrysene
20.310	VV	3.00755e5	1.00801e-6	3.03164e-1		Benzo(b)fluoranthene
20.781	VV	4.39866e5	3.12215e-10	1.37333e-4		Benzo(k)fluoranthene
21.546	VV	4.74578e5	7.46834e-10	3.54431e-4		Benzo(a)pyrene
24.291	VV	9.28723e4	5.20514e-7	4.83413e-2		Indeno(1,2,3-cd)pyrene
24.727	VV	1.25324e5	7.29006e-10	9.13619e-5		Dibenz(a,h)anthracene
25.486	VV	9.01338e4	1.44018e-9	1.29809e-4		Benzo(g,h,i)perylene
Totals :				3.53345e-1		

Figura 9: *Calibration Graph of PAHs in the Leachate.*

Table 3. *Variation of physico-chemical properties of soil samples.*

Soil Properties	Results
Moisture Content w (%)	38.1
Bulk Density (mg/m^3)	1.84
Dry Density (mg/m^3)	0.36
Specific Gravity (GS)	2.63
Hydraulic Conductivity (k)	4.0x10^{-2}cm/s
Porosity (n) (%)	74
Shear Strength (τ) (KN/m^2)	90.6

Figure 10. *Picture of retained polluted storm water in Nekede Mechanic village.*

Figure 11. *Picture of Polluted Nekede Mechanic village during rainy season.*

DOI: 10.6092/issn.2281-4485/18452

Conclusion

The sandy component of the study area forms more than 90% of the sequence; therefore the permeability, the transmissivity and the storage coefficient are high with an excellent source of groundwater resources. This makes the area more vulnerable to contaminant migration via the soil. Figures 10 and 11 are the pictures taking from Nekede Mechanic Village that reveal the SEO floating on the ground during rainy season. Therefore, public awareness should be intensified, in the study area, on the detrimental effects of Spent Engine oil contamination and its indiscriminate disposal should be discouraged. The Recycling technology of the spent engine oil and the best global practices on management of Spent Engine Oil should be imbibed. The ground water table is identified to be near the surface, the pollutants in the spent engine oil will be mobilized by high rain fall and infiltration rate in the region to contaminate the ground water. Hence, making drinking water unsafe for the people in and around the region. The spillage of Spent engine oil on the Nekede mechanic village soil, results in direct pollution of Otamiri River the surface water body at close proximity to the mechanic village. Storm runoff carries high toxic constituents of the spent oil into the river which will lead to death of aquatic lives and danger to the health of the human populace who rely on the Otamiri River for their water needs.

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