Geophysical and Geochemical Assessment of Oil Spillage in Agbura Area, Yenagoa Local Government Area of Bayelsa State, Nigeria

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ABSTRACT

Oil spillage, a major environmental challenge in Niger Delta Region of Nigeria alters soil quality, degrades ecosystem and poses threat to community health and economy. This study aims at analyzing the geophysical and geochemical effects of oil spillage on soil in Agbura Area, Yenagoa Local Government Area of Bayelsa State. Vertical electrical sounding (VES) and geochemical analyses of soil samples within the spill impacted zone and outside the zone of impact as control were used in the study. The VES data were interpreted using IPI2Win Software while soil samples were analysed for pH, electrical conductivity (EC), total petroleum hydrocarbon (TPH) and selected heavy metals such as copper (Cu), nickel (Ni), lead (Pb), chromium (Cr) and cadmium (Cd). Three geoelectric sections were delineated in each of the ten (10) VES points sampled. Anomalous layer resistivities ranging between 2.8 Ω"m" and 21.5 Ω"m" were recorded within the impacted zones compared with 77.8 Ω"m" and 680.8 Ω"m" in the unimpacted (control) zones within the same vicinity. Geochemical analyses revealed a spike between 136.099" mg\/kg" and 2708.349" mg\/kg" in total petroleum hydrocarbon (TPH) in spill impacted zone compared with a range of 53.185" mg\/kg" and 55.421" mg\/kg" in the unimpacted (control) zones. Heavy metals such as lead (Pb), copper (Cu), nickel (Ni), chromium (Cr) and cadmium (Cd) were detected in very high concentration in the spill impacted zones compared with the concentration in the unimpacted zones. A spike in electrical conductivity (EC) range between 0.84" dS\/m" and 5.01" dS\/m" was observed in the impacted zones compared with a range between 0.051" dS\/m" and 0.62" dS\/m" in the unimpacted (control) zones. The notably anomalous low resistivities and high EC in the spill impacted zones were attributed to long-term degradation of the spilled hydrocarbon by natural attenuation and microbial activities which enriched pore water with ionic species. This study has revealed that the spillage in Agbura Area has caused substantial geophysical and geochemical changes, leading to degradation of the soil.

KEYWORDS

Oil spillage, Agbura Area, Geophysical Analysis, Geochemical Analysis, Soil contamination

I. INTRODUCTION

Nigeria’s economy is highly dependent on her huge oil and gas deposits found mainly in the Niger Delta region of the country (Ikhumetse et al., 2022). The exploration and exploitation of this "black gold" has resulted to a great deal of environmental degradation due to oil spillages leading to negative effects on community health and livelihood (Nwankwo and Ogagarue, 2011; Udo and Fayemi, 1975; Osuji and Nwoye, 2007).

Oil spillage is the accidental or deliberate release of petroleum products or its products such

as crude oil, kerosene, diesel, gasoline, etc into the environment, mainly water and land. Oil spillages are not new to Nigeria owing to a plethora of causes including equipment failure, transportation lapses, sabotage, illegal bunkering activities, etc. Whenever oil spillage occurs, it affects the soil, water bodies and life generally within the spill-impacted zone and its environs by introducing pollutants into the environment. Chronic oil pollution can lead to long-term degradation of the soil structure and function, hence the need for comprehensive and localized studies of oil impacted areas in the Niger Delta (Nwankwo and Ogagarue, 2011). Oil spillage leads to reduced soil permeability and reduction in microbial population (Osuji and Nwoye, 2007). Udo and Fayemi (1975) observed that soil aeration and water retention capacity are adversely affected by oil spillage.

Agbura, an agrarian and fishing community in Yenagoa Local Government Area of Bayelsa State, Nigeria has experienced repeated oil spillages due primarily to pipeline failures and illegal oil bunkering activities. These spills have direct effect on the quality of water and soil function within the locality. In summary, oil spillage is the principal cause of water and soil pollution (Holliger et al., 1997), hence providing site-specific data on the spillage in Agbura Area is imperative for risk evaluation, remediation planning and ecological recovery. This research was an attempt to mirror the geophysical and geochemical effects of oil spillage in Agbura Area.

To achieve the aim of this research, an interdisciplinary approach of both geophysical and geochemical methods were employed. Non-invasive Electrical Resistivity survey was used to map the subsurface. Hydrocarbons usually exhibit high resistivities in natural environment, however, the resistivities tend to reduce with time due to microbial degradation that enriches the pore water with ionic species resulting to increased electrical conductivity (Ehirim et al., 2016). Geophysical signatures were compared between the responses from the spill-impacted zone against the responses from the unimpacted (control) zones within the same vicinity. Soil samples were also collected and analysed for physicochemical parameters such as pH, electrical conductivity (EC), total petroleum hydrocarbon (TPH) and selected heavy metals comprising copper (Cu), nickel (Ni), lead (Pb), chromium (Cr) and cadmium (Cd). The above mentioned physicochemical parameters are critical indicators of soil health. pH, EC, TPH and selected heavy metals were analysed in soil samples within the spill-impacted zone and results compared with those analysed in the unimpacted (control) zones within the same vicinity. Results emanating from this research is projected to be of help in assessing the effects of oil spillage in Agbura Area, Bayelsa State, Nigeria.

II. STUDY AREA

Agbura Area is located between longitudes 6.246°E and 6.288°E and latitudes 4.832°N and 4.874°N and within the coastal region of the recent Niger Delta (Fig 3.1). Niger Delta has an area extent of about 100 km^2 and has a tropical rain forest climate with two distinct seasons: wet (April – October) and dry (November – March) (Akpokodje, 1986). Akpokodje (1986) reported that mean annual rainfall is around 4500 mm with about 85% within the wet season serving as major source of the groundwater recharge. Streams, lakes and rivers within the study area are Kolo creek, Epie creek, Nun River etc. These water bodies form a network that empties into the Atlantic Ocean through the Nun River Estuary. The study area is mostly

submerged during the wet season where flood water ranges from 0.5 to 4 metres deep (Akpokodje, 1986).

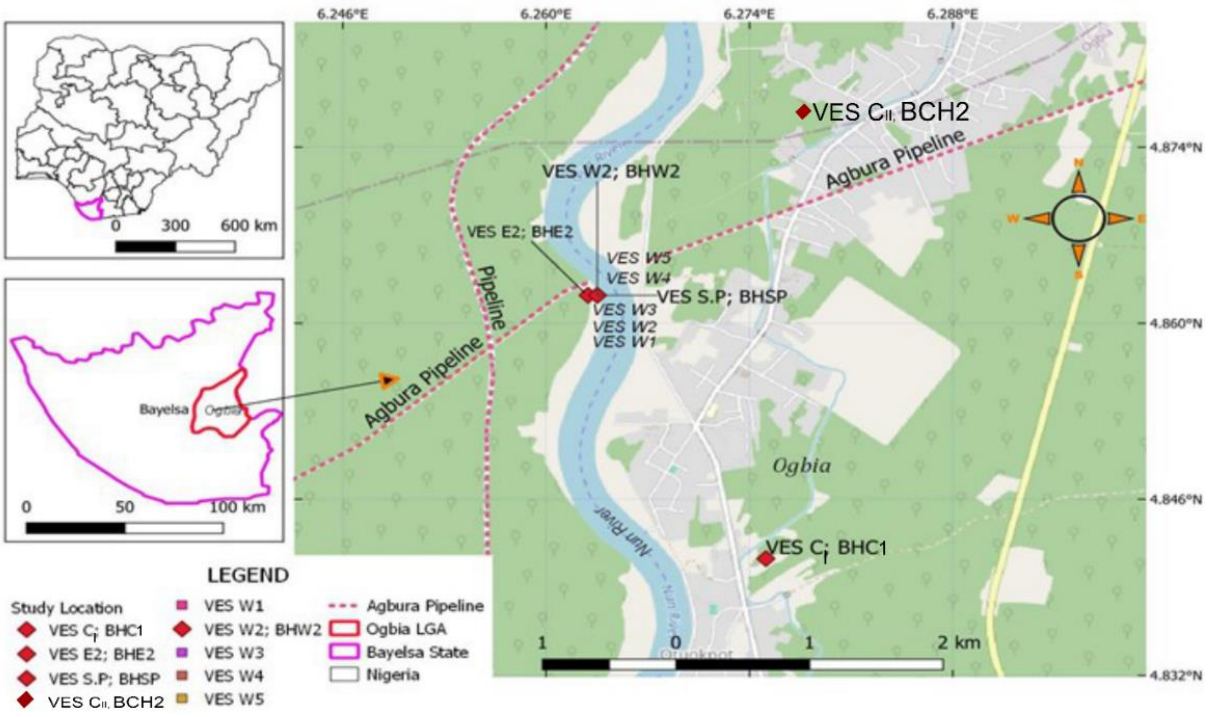


Figure. 1: Map of Agbura showing study locations.

III. MATERIALS AND METHODS

Eight (8) vertical electrical soundings (VES) (Schlumberger Array) were carried out within the spill-impacted zone and two (2) VES (Schlumberger Array) outside the zone of impact within the same vicinity were undertaken as control. Equipment used for VES include Abem Tetrameter, electrodes (two current and two potential electrodes), cables, GPS, crocodile clips, machete, measuring tape, rope, hammer alongside other auxiliary equipment e.g. notebooks, pens etc. The VES results were interpreted with IP2 win software.

Soil samples were collected from five different points at two different depths (topsoil and subsoil) within the zones of impact and extra two samples outside the zones of impact as control at two different depths (topsoil and subsoil) within the same vicinity. Equipment used for the soil sampling include hand auger, hand trowels, sampling bags, GPS and other auxiliary sampling equipment like markers, notebooks and pens. The samples were labelled, stored in a cooler and taken to the laboratory within 24 hours.

For ease of identification and clarity in this research, the VES points are labelled as follows:

- VES $S \cdot P$: For the station closest to the primary source of spill.
- VES E_2 And VES E_4: for VES stations east of the primary source of spill.
- VES W_1, VES W_2, VES W_3, VES W_4 and VES W_5: for VES stations west of the primary source of spill.
- VES C_1 And VES C_2: are control VES stations.

- Sample collection points are labelled as follows:
- BH S · P: For the point closest to the primary source of spill.
- BH E_2 And BH E_4: for points east of the primary source of spill.
- BH W_2 And BH W_4: for points west of the primary source of spill.
- BH C_1 And BH C_2: for points outside the spill impacted zone (Control).

IV. RESULTS AND DISCUSSION

A. Electrical Resistivity Results

Eight (8) vertical electrical sounding (VES) were undertaken within the spill impacted zone. Two (2) additional VES were taken about five hundred meters south and north respectively of the primary point of spill outside the zone of impact as control VES. Five (5) HA-type curves and three A-type curves were observed in the VES curves within the spill impacted zone while a K-type and HA-type curves were observed in the unexpected (Control) VES. Below is a summary of the geophysical signatures obtained in the Study Area.

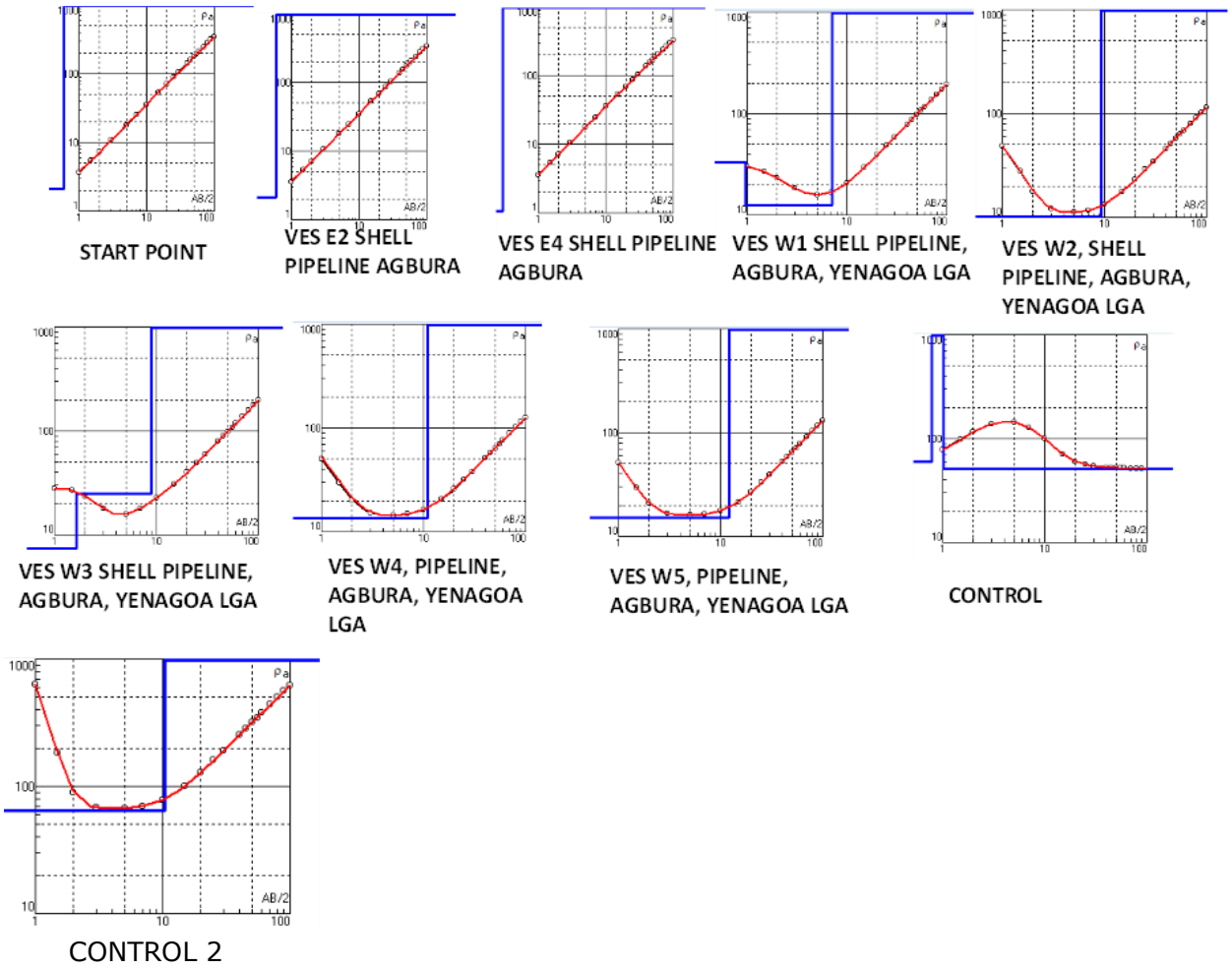


Figure. 2: Summary of VES Curve in the Study Area.

Table 1: Summary of Interpreted Layer Parameters for VES Stations in the Study Area

VES Station	Layer Resistivity ($\Omega \cdot m\Omega$)	Layer Thickness (m)	Depth (m)	Lithology
VES S · P	4.00	0.80	0.80	Organic top soil
	21.50	6.00	6.80	Silty clay
	55.00 − 270.00	Half space	50.60	Sand
VES E_2	2.80	0.60	0.60	Top soil
	19.50	5.50	6.10	Clay
	50.00 − 310.00	Half space	50.00	Sand
VES E_4	3.20	0.60	0.60	Top soil
	20.50	5.00	5.60	Clay
	50.00 − 310.00	Half space	50.00	Sand
VES W_1	30.10	0.80	0.80	Top soil
	17.00	6.50	7.30	Clay
	200.00	Half space	50.00	Sand
VES W_2	40.10	0.90	0.90	Top soil
	11.00	10.50	11.40	Clay
	130.00	Half space	50.00	Sand
VES W_3	26.00	0.90	0.90	Top soil
	16.00	7.50	8.40	Clay
	210.00	Half space	50.00	Sand
VES W_4	40.00	0.90	0.90	Top soil
	15.00	9.00	9.90	Clay
	150.00	Half space	50.00	Sand
VES W_5	40.00	1.00	1.00	Top soil
	17.00	8.90	9.90	Clay
	152.00	Half space	50.00	Sand
VES C_1	680.80	1.20	1.20	Top soil (Sandy hard soil)
	60.80	2.30	3.50	Sandy clay
	678.20	Half space	50.00	Sand
VES C_2	77.80	0.90	0.90	Top soil
	178.80	10.90	10.90	Clay
	51.00	Half space	50.00	Sand

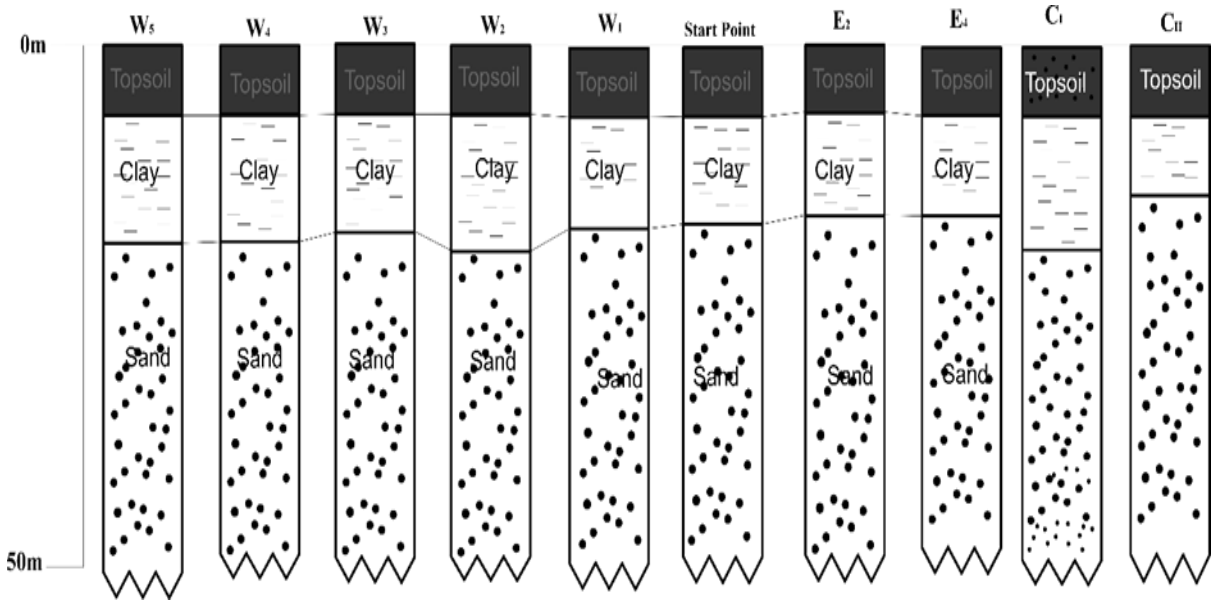


Figure 3: Lithological correlation of the VES stations in the Study Area

V. DISCUSSION OF VES RESULTS

Oil spillage raises the resistivity of the spill impacted soils compared to those of unimpeached soils. This is achieved by a reduction in soil porosity due to crude clogging on the soil, hence dewatering of the soil. However, with time, microbial activities increase soil porosity. This increase in porosity increases soil moisture content, hence a remarkable increase in conductivity. As conductivity increases as the spill ages, resistivity reduces. Agbura oil spill took place in March 2021 as reported by the Premium Times Newspaper of 3rd April, 2021. This research was undertaken in February, 2025 (4 years plus from the date of spill), hence can be categorized as an aging spill site where microbial activities and attenuation is expected to significantly reduce the resistivity of the contaminated zone.

A. Resistivity of Unimpeached (Control) Zones

Two (2) control VES were taken about 500 meters South and North respectively of the primary spill station point (VES $S \cdot P$) and labelled VES C_1 for the station South and VES C_2 for the station North of VES $S \cdot P$. Three geo electrical layers were delineated in each of the two control VES stations with resistivity's ranging between $51.00\,\Omega \cdot m$ to $680.80\,\Omega \cdot m$.

B. Resistivity of Spill Impacted Zone

Resistivity of layers within the spill impacted zone shows anomalous low resistivity's compared to resistivity in the unimpeached (control) zone. A resistivity range of 2.80 Ω-m to 310.00 Ω-m in the spill impacted zone. This low resistivity anomaly in the spill impacted zone is in agreement with Sauck (2000) for resistivity of an aging spill site.

C. Resistivity of Soil Profiles East of the Impact Zone

Two (2) VES points were located east of the primary spill point (VES S.P). These are VES E_2 and VES E_4. The resistivity of the soil profiles east of the primary spill point ranges from

2.80 Ω-m to 310.00 Ω-m. These points consist of soil with organic rich top soils with layer thickness of 0.60 m in both VES E_2 and VES E_4. The second layer consists of silty clay of thickness 5.50 m (VES E_2) and 5.00m (VES E_4). The third layer east of the primary spill point consists of sand with a fining upward sequence.

D. Resistivity of Soil Profiles West of the Impact Zone

Five (5) VES points were located west of the primary spill point (VES S.P). These are VES W_1, VES W_2, VES W_3, VES W_4 and VES W_5. Resistivity of the soil profiles west of VES S.P range from 11.00 Ω-m to 210.00 Ω-m. The first layer in this zone is characterized by silty top soil of thickness ranging between 0.80m and 1.00m. The second geoelectric layer in this zone have a resistivity range of 11.00 Ω-m to 17.00 Ω-m. This zone is characterized by clay soil of thickness ranging between 6.50m to 10.5m.

The third layer in this zone has a resistivity range between 130.00 Ω-m to 210.00 Ω-m. It consists of sand with a fining upward sequence.

E. Effect of the Spill on the Soil in the Study Area

A comparison of the resistivity values of the soil profile between the control zones and those of the spill-impacted zone shows anomalously low resistivity in the zone of impact ($2.80\,\Omega \cdot \mathrm{m} - 310.00\,\Omega \cdot \mathrm{m}$) against $51.00\,\Omega \cdot \mathrm{m} - 680.80\,\Omega \cdot \mathrm{m}$ in the control zones. This observation is a geophysical signature of an aging spill site where resistivity reduces over time due to natural attenuation and biodegradation.

F. Soil Sampling Results

Soil samples were collected from five (5) points within the spill impacted zone and two (2) points outside the zone of impact as control. The samples were collected at two different depths, topsoil ($0 - 15$ cm) and subsoil ($75 - 100$ cm). The samples were collected with hand auger.

G. Selected Physicochemical Parameters of Soil Profile in the Study Area

Soil samples were analysed for pH, electrical conductivity (EC) and total petroleum hydrocarbon.

Table 2: Summary of Results of Physicochemical Parameters Analysed in the Study Area

Borehole	Description	pH	EC (dS/m)	TPH (mg/kg)
BH S · P	Topsoil	6.7	2.22	504.774
	Subsoil	6.9	1.01	2708.349
BH E_2	Topsoil	6.7	2.40	477.586
	Subsoil	6.7	1.61	2112.335

BH E_4	Topsoil	6.4	5.01	585.240
	Subsoil	6.6	2.45	2117.948
BH W_2	Topsoil	6.7	0.84	464.366
	Subsoil	6.9	1.01	613.202
BH W_4	Topsoil	6.5	2.22	136.099
	Subsoil	6.7	0.83	448.374
BH C_1	Topsoil	6.9	0.62	53.185
	Subsoil	6.9	0.61	53.188
BH C_2	Topsoil	6.7	0.64	54.113
	Subsoil	6.8	0.66	54.117

VI. DISCUSSION OF PH OF SOILS IN THE STUDY AREA

Soils contaminated by fresh spills usually have higher acidity (lower pHvalues) while the pH rises with time as biodegradation persists.

The pH of the soil in both the impacted and control zone (6.4–6.9) are close to neutrality. This result shows that the effect of the spill on the pH of the soil has waned down with time. This is in agreement with Umoren *et al.* (2019).

A. Discussion of Electrical Conductivity (Ec) In the Study Area

Hydrocarbon contamination changes the electrical conductivity of soil properties due mainly to age of the spill and microbial activities on the impacted soil. Fresh spills usually exhibit elevated resistivity (low EC). As biodegradation sets in, ionic species are introduced and weathering processes raises the bulk electrical conductivity of the contaminated soil.

There was notable elevation of EC in the spill impacted zone (0.83 dS/m $-$ 5.01 dS/m) compared to 0.61 dS/m $-$ 0.66 dS/m in the unexpected zone. The topsoil in each of the borehole points appears to be more conductive than those of the subsoil in the spill impacted zone, while the reverse is the case in the unexpected zones.

B. Discussion of Total Petroleum Hydrocarbon (Tph) Of Soil Samples in the Study Area

Total petroleum hydrocarbon (TPH) is a term that describes a large family of several hundred chemical compounds that originate from crude oil. It is much higher in freshly spilled sites than in aging spill sites. TPH reduces with time. As a spill site ages, the TPH continuously reduces due to biodegradation by microbial activities and may even reduce below regulatory bodies quality limit with time.

TPH range (136.099 mg/kg $-$ 2708.349 mg/kg) in the spill impacted zone compared to TPH range of 53.185 mg/kg $-$ 54.117 mg/kg in the unexpected (control) zones shows how the spill has contaminated the soil in the impacted zone.

The subsoil in each of the sampled points within the spill impacted zone indicate that the contaminant concentration is higher than it is at the topsoil showing a downward migration pattern. For example, in BH $S \cdot P$, TPH is 2708.349 mg/kg in subsoil whereas it is 504.774 mg/kg (≈ 477.586 mg/kg) in topsoil. Similarly, it is 2112.333 mg/kg in the subsoil in BH E_2 while it is only 464.366 mg/kg in its topsoil. This downward migration pattern is consistent with all the sampled points. It is observed that the TPH of samples east of BH $S \cdot P$ are in higher concentration than those west of BH $S \cdot P$. TPH in BH E_2 and BH E_4 are 477.586 mg/kg (topsoil), 2112.333 mg/kg and 585.243 mg/kg (topsoil), 2117.948 mg/kg (subsoil) respectively compared to TPH of BH W_2 (464.366 mg/kg topsoil, 613.202 mg/kg subsoil) and BH W_4 (136.099 mg/kg topsoil, 448.374 mg/kg subsoil). Shows a lateral migration more toward the eastern points east of the primary spill point.

C. Selected Heavy Metals Analysis of the Study Area

Heavy metals analysed in the Study Area include Copper (Cu), Nickel (Ni), Lead (Pb), Chromium (Cr) and Cadmium (Cd). The table below shows the concentration of heavy metals analysed in the study Area.

Table 3: Table Showing Concentration of the Selected Heavy Metals Analysed in the Study Area

Borehole	Description	Copper (Cu) (mg/kg)	Nickel (Ni) (mg/kg)	Lead (Pb) (mg/kg)	Chromium (Cr) (mg/kg)	Cadmium (Cd) (mg/kg)
BH $S \cdot P$	Topsoil	10.01	12.34	22.60	12.69	1.01
	Subsoil	7.83	7.05	13.26	11.89	0.72
BH E_2	Topsoil	7.51	7.24	13.49	7.98	0.60
	Subsoil	6.85	9.34	10.52	6.99	0.54
BH W_2	Topsoil	8.32	7.33	12.06	7.06	0.54
	Subsoil	7.72	5.93	10.66	7.18	0.55
BH C_1	Topsoil	4.02	0.32	10.53	0.46	0.034
	Subsoil	3.72	0.17	6.22	0.41	0.022
BH C_2	Topsoil	4.05	0.31	7.14	0.47	0.037
	Subsoil	3.56	0.23	6.33	0.40	0.033
WHO Acceptable limit for heavy metals	-	36.00	35.00	85.00	100.00	0.80

D. Discussion of Heavy Metals Concentration in the Study Area

Heavy metals accumulation over time in a spill site is one of the greatest challenges in a spill-impacted soil. As heavier molecular mass of carbon breakdown in TPH, higher concentration of heavy metals are introduced into the environment. There is notable spike in concentration of all heavy metals analyzed in the zone of impact compared to the unimpeached (control) zone. However, the concentration of the heavy metals in both the zone of impact and control are below W.H.O acceptable limit. The topsoil in all the sampled points have higher concentration than those of the subsoil with the exception of chromium and cadmium in BH W_2 at the time this research was undertaken.

VII. CONCLUSION

Result of investigation confirms that oil spillage has caused notable geophysical and geochemical alterations in the soil within Agbura Area. Notable reduction in layers resistivity and spike in electrical conductivity are clear signatures for hydrocarbon-induced contamination. The elevated levels of heavy metals such as copper, nickel, lead, chromium and cadmium are indicative of a long term environmental stress and potential risk to the environment.

The combination of geophysical and geochemical methods to investigate the effects of the oil spillage in Agbura Area proved to be an effective approach for delineating contamination zones and assessing the level of soil degradation. It also confirms the inter-dependence of subsurface geophysical anomalies and surface physicochemical parameters in environmental studies.

RECOMMENDATIONS

- We recommend continuous geophysical and geochemical monitoring of the area to ascertain the contamination level.
- Further investigations should be embarked upon on the water bodies within the spill site and adjoining lands to monitor possible contaminants migration.
- Community awareness programmes should be embarked upon in the affected area and its environs.

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