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Studies on the Variation of Selected Organic Contaminants in Soil and Surface Water Surrounding Tank Farms in Oghareki – Oghara Community, Delta State, Nigeria

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ABSTRACT

This study investigates the levels of selected organic contaminants in soil and surface water surrounding tank farms in the Oghareki community of Delta State, Nigeria. The objectives were to assess the concentrations of volatile organic compounds (VOCs), total petroleum hydrocarbons (TPHs), oil and grease (O and G) in both soil and surface water, considering variations in distances from the tank farms. Additionally, the study employed pollution index models to evaluate the contamination factor, pollution load index, geo-accumulation (Igeo), anthropogenicity and enrichment factor. Soil and water samples were collected at distances ranging from 100 meters to 1 kilometer from the tank farms. Each sample was analyzed for VOCs and TPHs using Gas Chromatography with a Flame Ionization Detector (GC/FID) while O and G with a UV/visible spectrophotometer. The data obtained were presented as mean values from triplicate analyses. Results for organic contaminants in surface water indicated O and G levels ranging from 0.004±0.001 to 0.007±0.001 mg/L; TPHs ranged from 3.319±0.026 to 4.835±0.011 mg/L; and VOCs ranged from 0.122±0.001 to 0.354±0.016 mg/L. In soil analyses, organic contaminants showed mean O and G levels ranging from 0.06±0.001 to 0.927±0.092 mg/kg; mean TPHs ranged from 2.884±0.051 to 7.481±0.150 mg/kg; and mean VOCs ranged from 0.369±0.005 to 1.043±0.081 mg/kg. The study found significant contamination factors, geo-accumulation values, anthropogenicity, and enrichment factors in both soil and surface water. Comparisons with control samples indicated that the soil and surface water around the tank farms were contaminated with organic contaminants, although the results remained within the acceptable limits set by the Nigerian Midstream and Downstream Petroleum Regulatory Authority (NMDPRA) for soil and surface water in Nigeria.

Key words: Volatile organic compounds, total petroleum hydrocarbons, oil and grease, tank farms, pollution, contamination.

INTRODUCTION

Environmental pollution is introduction of unwanted and harmful substances into water; air and soil which can negatively impact human well-being. As urbanization increases and industries evolve, traditional manufacturing processes are changing, causing rise in pollution levels from various industries in urban areas (Wang *et. al.,* 2024). In industrial areas, organic compounds (VOCs in particular) are major concern in various contaminants and pollutants. These organic substances include polycyclic aromatic hydrocarbons which / total petroleum hydrocarbons are commonly used as raw materials / products, and / or intermediates in the chemical or metallurgical and petrochemical industries (Ren *et. al.,* 2018).

Organic pollutants / contaminants exhibit high mobility and persistence when they are introduced into environment by volatilization; leaching; dripping, and / or leakage either during production process, through transportation, and means of storage which leads to serious damage to the enabling environment as environmental problems caused due to industrial organic pollutants / contaminants are rising all over the world (Li *et. al.,* 2016)

Most organic contaminants / pollutants originate from various sources and encompass a diverse array of compounds. The majority of the contaminants and / or pollutants are VOCs, oils and greases, including TPHs. These are classified due to their volatile, toxic, irriting, teratogenic, and carcinogenic nature, making them to be significantly contributing to environmental pollution and widespread issues today (Moufawad *et. al.,* 2022). Addressing issues of pollution associated with organic pollution and contamination industries is an urgent and critical issues since the assessment, remediation, and control of pollution is now an immediate need in the environmental and protection sectors (Wang *et. al.,* 2024).

Water being vital in all aspects of human life on earth comprises two thirds of the body's total volume (Mugisha and Ma, 2021). Water pollution primarily arises from anthropogenic factor, agricultural practices, industrialization, inadequate supply of water and facilities for sewage treatment. Key contributors to this issue include the tannery; distillery; petroleum; pulp, paper; food; textile; iron; steel and the nuclear industries. These sectors often release toxicants that organic / inorganic origin, including harmful solvents and VOCs during their production process (Lin et al., 2022). When these wastes are introduced or discharged into the nearby environment when there is improper treatment, they would inevitably lead to water pollution (Chowdhary et al., 2020). Most organic / inorganic contaminants and pollutants found in untreated wastewater are primarily released by industrial sectors, which are major contributors to the harmful contaminants (Chen et al., 2019). As urbanization has increased, so has the volume of untreated wastewater produced by industrial production (Wu et al., 2020). Additionally, the impact of industrialization on water pollution is significantly influenced by certain direct investment, with a positive relationship observed between industrial water pollution and certain direct investment in developing nations (Lin et al., 2022).

Pollution of soil is noticed when toxic chemicals, known to pollutants and contaminants, are available in soil at high amounts that pose risk to human and the ecosystem. Even when certain contaminants are naturally present found in soil, pollution is still considered to exist if their levels exceed what is typically expected, regardless of whether those concentrations are high enough to be harmful (Environmental Pollution Center (EPC), 2024).

Soil plays a crucial role in human health in several ways. About 78% of global calorie per capita intakes are from crops directly grown in soil, while about 20% is from terrestrial sources of food that depend on soil indirectly. Additionally, soil is the significant source of nutrients and serves as natural filter, helping to remove contaminants and pollutants from water (Münzel *et. al.,* 2023)

The aim of this research is to determine the presence of organic contaminants in soil and surface water (river water) around tank with objectives to determine total volatile organic compounds, total petroleum hydrocarbons and oil and grease in soil and water (river water) surrounding tank farms in Oghareki Community.

METHODOLOGY

Study location

This research was carried out at Oghareki – Oghara community located at Ethiope West Local Government Area in Delta State of Nigeria. Oghareki-Oghara is situated at Latitude 5°57'2"N, and Longitude 5°38'25"E. Oghareki is home to a river that originates from the River Ethiope, a clear freshwater source that flows over 100 kilometers from its starting point in Umuaja of Ukwuani Local Government Council. This river passes Abraka to Mosogar and Sapele before reaching the study location (Oghareki), where it empties into the Benin River. The river is heavily utilized by local residents for recreational / occupational activities, including fishing, washing, bathing, swimming, and domestic purposes. However, it also poses challenges, as it overflows its banks periodically, carrying domestic / industrial wastes and runoff during the rainy season.

The river is flanked by nine different tank farms, including Rain Oil, Cybernetics Oil and Gas, Dutchess Energy, Nepal Oil and Gas, Othinel Brooks Energy, Prudent Energy and Gas Black Light Enegry and Fredo Energy Limited. These facilities receive / discharge various petroleum products, such as petrol, diesel, and kerosene on a daily basis. The discharge occurs through jetties built along the riverbank, often resulting in leaks that contaminate both the river and the surrounding soil.

Additional activities surrounding the river are dredging; bunkering; and illegal crude oil refining on nearby farms. The transportation of illicit gasoline products by boat in the river, along with human activities has contributed to contamination of the soil and surface water. These practices have raised significant concerns among local residents who rely on the river and soil for their daily needs, as they have led to pollution and adverse environmental impacts since their inception.

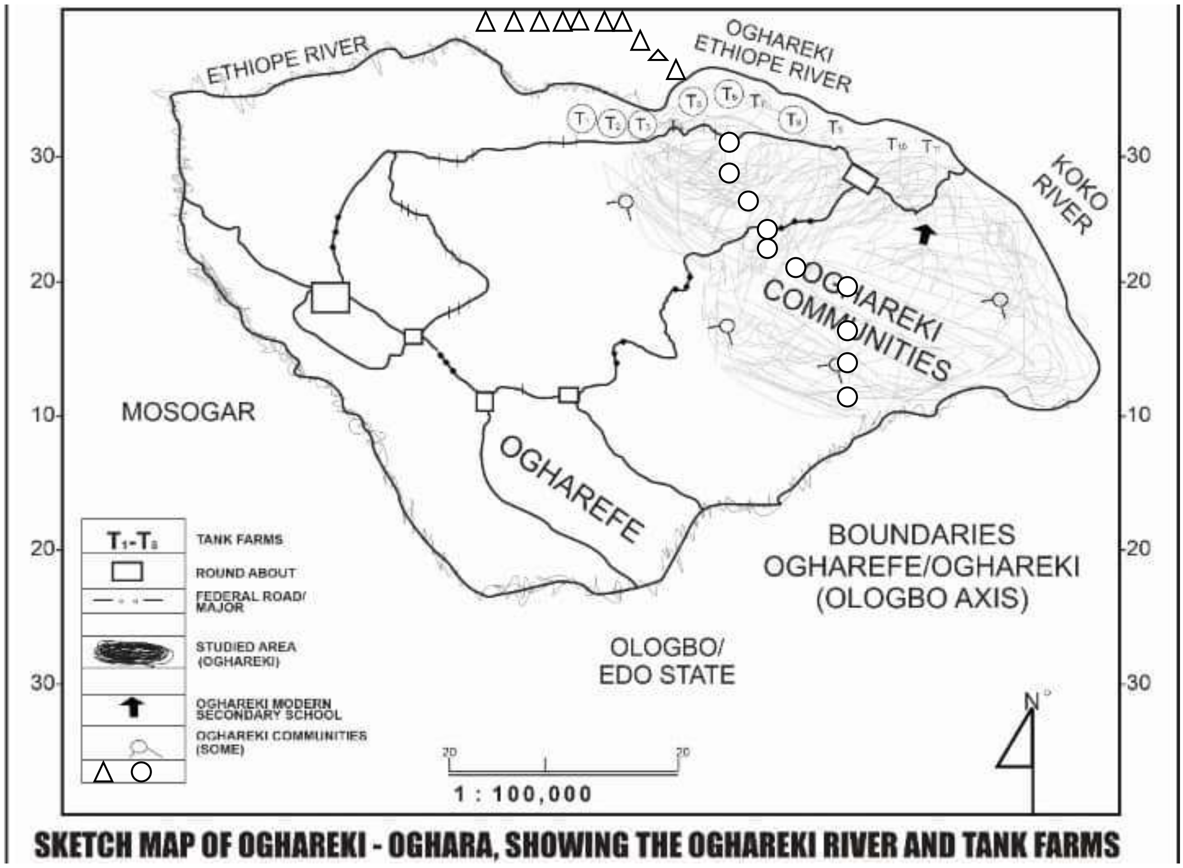

Figure 1: Map of Oghara showing study locations

Key: T_1- Rain Oil; T_2- Cybernetics Oil and Gas; T_3- Dutchess Energy; T_4- Nepal Oil and Gas Ltd; T_5- Othiel Brooks Energy; T_6- Prudent Energy and Gas; T_7- Black Light Energy and T_8- Frado Energy Ltd

Sample collection

Soil sample collection

Soils were collected at ten points, ranging from 100 meters to 1 kilometer away from the tank farms, and from a control site (a virgin farmland), resulting in a total of eleven locations. Soil samples were collected at depth 0-15cm and 15-30cm with the use of soil auger. Each representative sample was created by mixing soil from both depths. The soil were put in black polythene bags, labeled and transported to the laboratory for further chemical analyses.

Water sample collection

Surface waters were collected at ten sampling points situated between 100 meters and 1 kilometer (at interval of 100 meters from the tank farms and a control site free from industrial activities. Surface water were gathered using previously cleaned glass bottles that had been treated with an acid and further rinsed using distilled water. Surface water samples were collected at depth of 5 cm and combined to create a one-liter sample. Samples were then taken to laboratory in an iced cooler in other to maintain a temperature of 4°C (Kpee and Bekjee, 2021).

Extraction of soil samples for TPHs and VOCs analysis

50g each of soil samples were dried in an open laboratory for approximately twelve hours and then stored at room temperature before extraction. A 5g of each soil was measured in a beaker followed by the 2g anhydrous sodium sulfate (Na_2SO_4) and was stirred to ensure complete removal of any moisture. Next, 50mL of a 50:50 (acetone/dichloromethane) mixture was added, and the solution was stirred for ten minutes using a magnetic stirrer. It was then allowed to sit for an additional thirty minutes to facilitate settling. The resulting extract was decanted into a clean beaker and transferred to a round-bottom flask connected to a rotary evaporator, where it was concentrated to approximately 10mL. This extracts were reserved for TPHs and VOCs analyses. To analyze TPHs and VOCs, the concentrate was shared into two parts: one for aliphatic and the other was for aromatics. For the aliphatic, 25mL n-hexane solution and for the aliphatic, 25mL of dichloromethane was added respectively. The two solutions were separately concentrated with addition of some amounts of sodium sulfate (anhydrous) to remove traces of water. The concentrates were then injected into a GC/FID each at a time (ASTM, 2015).

Extraction of water for the determination of VOCs and TPHs

50mL of the surface water sample was measured into separatory funnel with a measuring cylinder. Next, 50 milliliters of a 50:50 acetone/dichloromethane mixture was added, corked and agitated for a period of five minutes. After shaking, the mixture stood for approximately ten minutes for the organic layer to separate. This organic layer was then collected in a beaker and covered with foil. The organic extract was concentrated with rotary evaporator and the resulting concentrate was divided into two portions: one for aliphatic and the other was for aromatics. For the aliphatics, 25mL n-hexane solution while for the aliphatics, 25mL of dichloromethane was added. The two solutions were separately concentrated with addition of some amounts of sodium sulfate (anhydrous) to remove traces of water. The resulting concentrates were then injected into a gas chromatograph with a flame ionization detector each at a time (ASTM, 2015).

Extraction of soil samples for oil and grease analyses

A 5g of air dried soil were measured in a beaker, followed by 25 mL n-hexane. The mixture was stirred vigorously with magnetic stirrer for ten minutes. After stirring, the soil-n-hexane mixture was decanted into a clean, dry beaker. The resulting mixture was centrifuged to obtain a clear solution, which was reserved for oil and, grease analysis (ASTM 2015)

Extraction of surface water for oil and grease analyses

A 100 mL water sample was placed in a separatory funnel, and was followed by 50 mL of n-hexane. The mixture was vigorously shaken for approximately ten minutes. The resulting solution was then transferred to centrifuge tube and was centrifuged. The upper layer of the centrifuged sample was collected for determination of oil and grease content in the water. This procedure was repeated for all water samples (ASTM, 2015)

Quality assurance / quality control

Rigorous quality assurance and / or quality control procedure was implemented during both sampling and laboratory analysis. Containers for samples were thoroughly sterilized while all equipments were calibrated. Concentrations of the targeted parameters in laboratory or procedural blanks were all below limit of detection (LOD) and limit of quantification (LOQ)

Analyses of TPHs and VOCs in surface water and soil samples

Surface water and soil surrounding the tank farms were prepared and tested for total volatile organic compounds and total petroleum hydrocarbons by using gas chromatograph with flame ionization detector (GC/FID). 5 µL aliquot, each from the extracted sample, was injected into the GC column, which featured a programmed temperature vaporizing with an inlet and a column measuring 30mm / 250µm in internal diameter, a film of 0.25µm thickness. The carrier gas was helium, initially set at 10 psi pressure for 10 minutes, then gradually increased to 18 psi at of 0.2 psi rate per minute. After initial holding temperature for 5minutes, the temperature of the oven was raised from 5°C - 180°C at 10°C rate per minute, then to 230°C at 6°C rate per minute, and finally raised to 300°C at 3°C per minute, where it was left for five minutes. The temperature interface of the GC was 290°C with Electron Impact mass spectrometer calibrated using decafluorotriphenyl phosphine which was operated in ion mode, with the temperature of ion source at 230°C while the quadrupole temperature was at 150°C. Acquisition of data was managed by Turbomass ChemStation. The FID identified the contaminants present in each samples, and the concentrations of the total organic components were quantified in µg/L for water samples and mg/kg for soil samples.

Analyses of oil and grease in surface water and soil samples

Surface water and soil extracts were analyzed for presence of oil and grease using a UV/Visible spectrophotometer (HACK DR 2000). This involved measuring a specific amount of each extract, placing it in the sample compartment of the Uv/visible spectrophotometer while the absorbances were read at 410nm wavelength.

Pollution index models

To assess surface water and soil contamination levels data from the organic / inorganic contaminants were utilized to estimate the contamination factor (CF), pollution load index, geoaccumulation index and anthropogenicity (Apn).

Contamination factor (CF)

This metric was utilized to evaluate the contamination level in the surface water and soil samples as reported by Hamed et al. (2023). Contamination factor is calculated by finding the ratio the concentration of the contaminant being studied and its background value as illustrated below.

$$CF = \frac{Cm}{Cb}$$

In this context, Cm represents concentration of contaminants in soil or water, while Cb denotes background values of contaminants under analyses. The background values were sourced from the Nigerian Midstream and Downstream Petroleum Regulatory Authority, with the following target values (measured in mg/kg for soil and mg/L for water): VOCs (1.00); TPHs (50.00); and oil and grease (40.00) (NMDPRA, 2021).

Geoaccumulation index (Igeo)

Level of heavy metal contamination in surface water and soil was estimated with this index. It helps in monitoring natural environmental variations as well as minor human impacts. This index which was introduced by Muller and referenced by Verla et al. (2017), was calculated using the following formula:

$$Igeo = log2\,(\frac{Cm}{1.5Cb})$$

In this context, Cm is concentration of the contaminant in sample and Cb denotes background level of contaminant being analyzed. Factor of 1.5 accounts for background matrix corrections related to lithogenic effects. The background values referenced are with regards to the global average values of contaminants found in shale. The specific background values for O and G, TPHs and VOCs are 0.055; 0.055 and 0.02 respectively (Edori and Kpee, 2017).

Anthropogenicity (Apn)

This method was employed to assess the effects of man's activities on the environment, ecosystems and, the natural resources. This determines anthropogenic impact of contaminants concentrations in water and soil. This assessment is conducted using the following expression:

$$Apn = \frac{\mu}{Cb} \, x \, 100$$

In this context, μ represents the measured concentration of contaminants in sample and Cb refers to background value derived from global concentration in shale, as utilized in estimating Igeo (Edori and Kpee, 2017).

Enrichment factor

This factor was utilized to evaluate level of enrichment in water and soil environments. The enrichment factor of both water and soil was determined using the formula below:

$$EF = \frac{\left(\frac{Ci}{Fe}\right) sample}{\left(\frac{Cb}{Fe}\right) background}$$

In this context, Ci represents the concentrations of contaminants being analyzed, while Cb denotes the background's concentration of contaminants of interest. $\left(\frac{Ci}{Fe}\right)$ is ratio of the concentration of contaminant in sample to concentration of iron for same sample. Similarly, $\left(\frac{Cb}{Fe}\right)$ indicates the ratio of concentration of the contaminant in the background to concentration of iron also in the background.

Table 1: Mean organic contaminants (mg/L) in soil around tank farms in Oghareki community

Distance	O and G	TPH	VOCs
Control	<0.001a	2.974k	0.034f
100m	0.004a	4.478e	0.286b
200m	0.006a	4.184h	0.204d
300m	0.004a	4.278f	0.336a
400m	0.005a	3.847i	0.189d
500m	0.006a	4.521d	0.122e
600m	0.005a	4.750b	0.354a
700m	0.005a	4.249g	0.244c
800m	0.006a	4.835a	0.178d
900m	0.007a	3.319j	0.128e
1km	0.006a	4.688c	0.128e
NMDPRA (2021)	40.00	0.05 – 0.60	1.00

Table 2: Mean organic contaminants (mg/kg) found in soil around tank farms in Oghareki community

Distance	O and G	TPH	VOC
Control	0.001b	2.884k	0.014h
100m	0.927a	6.546e	0.387g
200m	0.008b	4.988j	0.425f
300m	0.006b	6.203g	1.043a
400m	0.008b	6.336f	0.369g
500m	0.009b	6.625d	0.542e
600m	0.006b	6.802c	0.542e
700m	0.006b	5.830h	0.611d
800m	0.006b	6.914b	0.645c
900m	0.006b	5.278i	0.788b
1km	0.006b	7.481a	0.564e
NMDPRA (2021)	50.00	50.00	50.00

O and G = Oil and grease

TPH = Total petroleum hydrocarbon

VOC = Volatile organic compounds

The concentrations of oil and grease in surface water ranged from 0.004 - 0.007 mg/L across different distances. Notably, highest values of oil and grease, 0.007 mg/L, was recorded at 900 meters distance, while the 100-meter distance, expected to show the highest levels as a result of proximity to the tank farms, actually recorded low concentration of 0.004 mg/L. This inconsistency suggests that the concentration of oil and grease does not correlate directly with distance, likely due to the movement of floating oil sheens influenced by tides and the wake of passing boats. The control sample showed an oil and grease concentration below detection limit (<0.001 mg/L), indicating that all measured distances had higher levels, thus confirming contamination of the surface water. Statistical analysis showed no significant differences in oil and grease concentrations between the various distances or when compared to that of the control, suggesting minimal contamination.

Oil and grease concentration in the soil was found in the range of 0.06 to 0.927 mg/kg across different distances. Notably, oil and grease concentrations decreased with increase in distances. The highest concentration (0.927 mg/kg) was at 100 meters, while lowest (0.006 mg/kg) was found at 1 km. Interestingly, concentrations at 400 and 500 meters (0.008 and 0.009 mg/kg) were higher than that at 200 and 300 meters (0.008 and 0.006 mg/kg), while both 600 meters and 1 km recorded 0.006 mg/kg. This trend indicates that activities around the tank farms significantly impact the surrounding soil. All measured oil and grease levels were higher than those of the control, which had concentration of 0.001 mg/kg, suggesting contamination. Statistical analysis revealed significant differences in oil and grease concentrations at 100 meters compared to other distances (200 meters to 1 km) from the control site, indicating that soil closest to the tank farms is more contaminated, while those farther away show only slight contamination. Variations in contamination levels may be attributed to rainfall and sunlight, which can wash away or evaporate oil and grease from the soil surface. The observed differences in oil and grease concentrations can be linked to anthropogenic activities around the tank farms, including oil leaks during discharge, illegal refining (bunkering), and other natural phenomena that may exacerbate the presence of these contaminants.

Oil and its byproducts can enter water bodies from various sources throughout their lifecycle, including production, transportation, refining, and usage. Common pathways include sludge discharges from oil tankers, wastewater disposal from ships, accidental spills, and leaks from storage facilities and pipelines (Ekpu, 2020). Oil pollution can severely impact aquatic environments by forming a thin layer on the surface of water, which inhibits transfer of oxygen to aquatic life (Iyama et al., 2020). Oil and grease contamination in soil can increase water and nutrient availability and compaction, adversely affecting plant growth and development (Hauane et al., 2022). The phytotoxic effects vary based on soil and plant characteristics (Almansoory et al., 2020). Contaminated soil negatively impacts plants biomass and alters leaf and root structures. Understanding the impacts of oil and grease contamination on the growth of plant is crucial for conservation efforts and developing mitigation techniques. Additionally, oil is composed of compounds with toxic effects that can cause serious health issues, including heart disease, stunted growth and immune system effects and sometimes death (Hauane et al., 2022).

Total petroleum hydrocarbons (TPHs) concentrations ranged from 3.319 to 4.835 mg/L across the distances. The TPH levels did not show a clear trend with distance; highest value was obtained at 800 meters (4.835 mg/L), while lowest concentration was obtained at 900 meters (3.319 mg/L). All TPH concentrations exceeded the NMDPRA target of 0.05 mg/L, indicating contamination. Statistical analysis confirmed significant differences between TPH levels at various distances and compared to the control, further suggesting contamination due to activities from the tank farms.

The presence of TPHs in the surface water can result from petroleum product leaks from transportation vessels, barge operations at jetties, and other activities that contribute to fossil fuel deposits (Onwukeme and Etienajirhevwe, 2020). Additionally, sewage disposal, boat building, and bunkering activities may have contributed to the elevated TPHs levels, potentially harming aquatic organisms by depleting oxygen levels critical for spawning.

In the soil surrounding the tank farms, TPHs were detected in concentrations ranging from 2.884 to 7.481 mg/kg for distances of investigation. The total petroleum hydrocarbons concentrations in the soil did not also show a clear trend with distance; the observed highest concentration (7.481 mg/kg) was at 1 km, while the lowest (4.988 mg/kg) was at 200 meters. This was unexpected, as higher concentrations were anticipated closer to the tank farms. All TPHs levelsm in the soil were higher than the control site (2.88 mg/kg) but remained below the NMDPRA's targeted values (50 mg/kg). The differences in TPHs concentrations suggest contamination due to activities at the tank farms. Statistical analysis confirmed that TPH levels at the distances were significantly greater than those at the control, indicating contamination in the environment. This spatial distribution of contamination suggests that it is primarily anthropogenic.

Petroleum hydrocarbon pollution can lead to anoxic conditions, adversely affecting marine organisms by reducing dissolved oxygen levels, which could be fatal. The health effects of PAHs exposure depends on the amount absorbed, exposure duration, and individual responses while short term effects are less clear, long term exposure to low PAH levels has been linked to cancer in laboratory animals, with benzo(a)pyrene being a notable carcinogen (Agbaire and Tubotu, 2021). Researches on employees exposed to polycyclic aromatic hydrocarbons have shown increased risks of various cancers, although these findings are limited due to concurrent exposure to other carcinogens while animal studies indicate potential reproductive / developmental effects from polycyclic aromatic hydrocarbons exposure, such effects is yet to be observed in humans (IDPH, 2022).

Results of volatile organic compounds (VOCs) in surface water from 0.122 to 0.354 mg/L across distances. All VOC levels were below the NMDPRA target value of 1.00 mg/L, but they were higher than the control (0.034 mg/L), with the highest VOC concentration (0.354 mg/L) recorded at distances of 600 meters and the lowest (0.122 mg/L) at distance of 500 meters. The VOC concentrations were spatially dispersed and did not correlate with distance from the tank farms. Statistical analyses indicated significant differences between VOC levels and the control, confirming surface water contamination with organic compounds.

VOCs were detected in the soil around the Oghareki tank farms, with concentrations ranging from 0.369 to 1.043 mg/kg. The VOC concentrations in the soil did not also show a clear trend with distance; the highest value (1.043 mg/kg) was recorded at 300 meters, while the lowest (0.369 mg/kg) was at 400 meters. The expected high concentration at 100 meters was only 0.387 mg/kg, while the 1 km distance recorded 0.564 mg/kg. All VOC levels were higher than the control site (0.014 mg/kg), indicating contamination of the soil. Statistical analysis revealed significant differences between VOC concentrations at various distances and the control site, confirming pollution around the tank farms. This contamination likely stems from activities such as petroleum product leaks during discharge, diesel fumes, and illegal bunkering, as well as natural phenomena that may release VOCs into the atmosphere and subsequently into the soil during rainfall.

Concerns regarding VOCs include their potential carcinogenicity and harmful effects on the circulatory and nervous systems, particularly when contaminated food is consumed (ATSDR, 2014). VOCs are significant water contaminants that can cause various health issues, including cancer, genetic mutations, eye irritation, dizziness, and loss of memory (Xin et al., 2022). The domestic use of inadequate treated volatile organic compounds contaminated ground and surface water poses risks to health of humans, with vinyl chloride and trichloroethylene being among the most carcinogenic / toxic volatile organic compounds.

Table 3: Correlation among the organic contaminants in soil around tank farms of Oghareki community

	O and G	TPHs	VOCs
O and G	1		
TPHs	0.13	1	
OCs	-0.013	0.516	1

Table 4: Correlation between organic contaminants in surface water around tank farms in Oghareki community

	Oil and grease	TPH	VOC
Oil and grease	1		
TPH	0.0014	1	
VOCs	0.164	0.389	1

Table 3 above illustrates correlation among organic contaminants present in the surrounding surface water. Observations indicate that there is no significant relationship among the contaminants regarding their contributions to surface water pollution; each parameter appears to affect the contamination independently and spatially. This suggests that the surface water contamination is anthropogenic, stemming from human activities in the area. Further observations and statistical analyses revealed that volatile organic compounds (VOCs) showed a 16.4% correlation with oil and grease and a 39% correlation with TPHs. In contrast, the TPHs exhibited only a 0.14% correlation with oil and grease. The minimal or nonexistent correlations among all the organic contaminants were consistent, regardless of the proximity to the tank farms or the time of year during the investigations. This indicates that the sources of contamination may vary, potentially including anthropogenic activities related to the tank farms, bunkering operations, sand dredging, and the runoff of fertilizers and pesticides into the water due to rainfall-induced erosion.

Table 4 above presents the correlation results for the organic contaminants detected in the soil surrounding the tank farm. The findings indicated that there is no significant correlation among the organic contaminants. Specifically, total petroleum hydrocarbons exhibited a 13% correlation with oil and grease. In contrast, the relationship between volatile organic compounds and oil and grease is negative, showing a minimal correlation of -1.3%. However, volatile organic compounds demonstrated a positive correlation of 51.6% with total petroleum hydrocarbons.

Table 5: Principal components among organic contaminants in surface water around tank farms of Oghareki community

	Principal 1	**Principal 2**	**Principal 3**
O and G	0.277	0.921	0.273
TPH	0.651	-0.389	0.652
VOC	0.707	-0.002	-0.708
Eigen value	1.423	0.999	0.578
Proportion	0.474	0.333	0.193

Table 6: Principal components analyses of organic contaminants soil around tank farms of Oghareki community

	Principal 1	**Principal 2**	**Principal 3**
O and G	0.157	0.969	0.187
TPHs	0.709	0.021	-0.705
VOCs	0.689	-0.243	0.684
Eigen value	1.529	1.006	0.465
Proportion	0.509	0.335	0.155

Table 5 above presents the results of principal component among the organic contaminants in the surface water, highlighting their individual contributions of contamination surrounding the tank farms. Between the detected organic contaminants, the volatile organic compounds accounted for largest share, contributing 71% of the contaminants in surface water followed by the total petroleum hydrocarbons at 65.1% and oil and grease had the lowest contribution at 28%.

Table 7 presents the results of principal component analyses (PCA) regarding the organic components in the soil surrounding the tank farms of the Oghareki community. The analysis identified oil and grease, volatile organic compounds, and total petroleum hydrocarbons as the primary contributors to soil contamination. The findings revealed that total petroleum hydrocarbons were the most significant factor, accounting for 71% of the contamination, followed by volatile organic compounds at 69%. In contrast, oil and grease contributed the least, at 15.7%. The PCA observations indicated a relationship between VOCs and TPHs, as both significantly contributed to soil contamination. This contamination is likely a result of anthropogenic activities around the tank farms, including oil spills, discharges during the offloading of petroleum products, and other natural processes that can lead to soil degradation.

Table 7: Contamination factor of organic contaminants in soil around tank farms in Oghareki community for distances of investigations

Distance	Oil and grease	Total petroleum hydrocarbons	Volatile organic compounds
100m	0.0185	0.131	0.008
200m	0.0002	0.010	0.009
300m	0.0001	0.124	0.021
400m	0.0002	0.127	0.007
500m	0.0002	0.133	0.011
600m	0.0001	0.136	0.011
700m	0.0001	0.117	0.012
800m	0.0001	0.138	0.013
900m	0.0001	0.106	0.016
1km	0.0001	0.150	0.011
Mean	0.0031	0.117	0.012

Table 8: Contamination factor of organic contaminants in surface water around tank farms in Oghareki community for distances of investigations

Distance	Oil and grease	Total petroleum hydrocarbons	Volatile organic compounds
100m	0.0001	8.956	0.286
200m	0.0001	8.368	0.204
300m	0.0001	8.556	0.336
400m	0.0001	7.694	0.189
500m	0.0001	9.042	0.122
600m	0.0001	9.500	0.354
700m	0.0001	8.498	0.244
800m	0.0001	9.670	0.178
900m	0.0001	6.638	0.128
1km	0.0001	9.376	0.128
Mean	0.0001	8.730	0.217

Among organic contaminants, total petroleum hydrocarbons (TPH) had the highest contamination factor (CF), next was volatile organic compounds (VOCs), while the least was oil and grease for both time frames for the soil while the highest was TPHs followed by oil and grease while VOCs was the least. As cited by Verla et al. (2017), contamination factors are classified as <1, $1 \leq CF<3$, $3 \leq CF \leq 6$ and ≥ 6 for low contamination, moderate contamination, considerable contamination, and for very high contamination respectively. These results indicated that the surface water around the tank farms is very highly contaminated with TPHs, while oil and grease, as well as VOCs, show low contamination levels. In the soil, all the organic contaminants recorded low contamination.

Table 9: Geoaccumulation index (Igeo) of organic contaminants in surface water around tank farms in Oghareki community for distances of investigations

Distance	Oil and grease	Total petroleum hydrocarbons	Volatile organic compounds
100m	0.0010	16.340	2.870
200m	0.0016	15.267	2.047
300m	0.0010	15.611	3.372
400m	0.0013	14.037	1.896
500m	0.0016	16.496	1.224
600m	0.0013	17.332	3.552
700m	0.0013	15.504	2.448
800m	0.0016	17.642	1.786
900m	0.0018	12.111	1.284
1km	0.0016	17.105	1.284
Mean	0.0014	15.745	2.176

Table 10: Geoaccumulation index (Igeo) of organic contaminants in soil around tank farms in Oghareki community for distances

Distance	Oil and grease	Total petroleum hydrocarbons	Volatile organic compounds
100m	62.000	0.013	0.155
200m	0.540	0.100	0.171
300m	0.540	0.012	0.419
400m	0.540	0.013	0.148
500m	0.600	0.013	0.218
600m	0.400	0.014	0.218
700m	0.400	0.012	0.245
800m	0.400	0.014	0.259
900m	0.400	0.011	0.316
1km	0.400	0.015	0.226
Mean	6.568	0.022	0.238

Table 11: Anthropogenicity (Apn) of organic contaminants in surface water around tank farms in Oghareki community for distances

Distance	Oil and grease	Total petroleum hydrocarbons	Volatile organic compounds
100m	0.516	8414.82	1430.00
200m	0.774	7607.27	1020.00
300m	0.516	7778.17	1680.00
400m	0.645	6994.54	945.00
500m	0.774	8220.00	610.00
600m	0.645	8636.36	1770.00
700m	0.645	7725.54	1220.00
800m	0.774	8790.90	890.00
900m	0.903	6034.54	640.00
1km	0.774	8523.63	640.00
Mean	0.697	7872.48	1084.50

Table 12: Anthropogenicity (Apn) of organic contaminants in soil around tank farms in Oghareki community for distances of investigations

Distance	Oil and grease	Total petroleum hydrocarbons	Volatile organic compounds
100m	0.306	6.550	77.400
200m	0.003	4.990	85.000
300m	0.002	6.200	208.600
400m	0.003	6.340	73.800
500m	0.003	6.630	108.400
600m	0.002	6.800	108.400
700m	0.002	5.830	122.200
800m	0.002	6.910	129.000
900m	0.002	5.280	157.600
1km	0.002	7.480	112.800
Mean	0.033	6.301	118.32

Geoaccumulation refers to natural deposition of contaminants / substances while anthropogenicity indicates human induced changes in water; soil; and air environment. The average geoaccumulation for oil and grease, total petroleum hydrocarbons and volatile organic compounds are 0.0014, 15.754 and 2.176 respectively for the surface water and 6.568, 0.022 and 0.238 respectively for the soil. on the other hand, hight anthropogenic values were obtained for all the contaminants in the soil and water environment which showed that the contamination of the environment is anthropogenic (due to the presence of the tank farms)

It is important to recognize that the natural accumulation of contaminants in soil can impact nutrient availability, alter soil composition and structure, and potentially harm ecosystems. In contrast, anthropogenic activities can change soil composition and fertility; actions such as deforestation, construction, and agriculture contribute to soil erosion and degradation, reduce soil biota, and disrupt ecosystem balance (Verla et al., 2017).

For surface water, geo-accumulation leads to sedimentation, affecting quality of water, habitats, and the aquatic life, as well as influencing water chemistry. Conversely, anthropogenicity results in water pollution through chemical runoff and eutrophication, which introduces excessive nutrients. Industrial and agricultural activities further release pollutants and cause water acidification. Accumulation of these contaminants in the soil and surface water is largely driven by anthropogenic activities. An increase in such activities will likely lead to a corresponding rise in the geoaccumulation of the contaminants in the soil and surface water (Verla et al., 2017).

Table 13: Enrichment factor of organic contaminants in surface water around tank farms in Oghareki community for distances

Distance	Oil and grease	Total petroleum hydrocarbons	Volatile organic compounds
100m	0.040	8.780	28.600
200m	0.060	8.204	20.400
300m	0.040	8.388	33.600
400m	0.050	7.543	18.900
500m	0.060	8.865	12.200
600m	0.050	9.314	35.400
700m	0.050	8.331	24.400
800m	0.060	9.480	17.800
900m	0.060	6.509	12.800
1km	0.060	9.192	12.800
Mean	0.053	8.461	21.69

Table 14: Enrichment factor of organic contaminants in soil around tank farms in Oghareki community for distances

Distance	Oil and grease	Total petroleum hydrocarbons	Volatile organic compounds
100m	0.185	13.090	0.008
200m	0.002	9.980	0.009
300m	0.001	12.410	0.001
400m	0.002	12.670	0.007
500m	0.002	13.250	0.011
600m	0.001	13.600	0.011
700m	0.001	11.680	0.012
800m	0.001	12.300	0.013
900m	0.001	10.560	0.016
1km	0.001	14.960	0.011
Mean	0.020	12.450	0.010

The average enrichment factor of oil and grease, total petroleum hydrocarbons and volatile organic compounds are 0.053, 8.461 and 21.69 for the surface water and 0.020, 12.450, 0.010 for the soil respectively. Overall, both soil and surface water surrounding the petroleum tank farms exhibit significant enrichment in the total petroleum hydrocarbon for both soil and surface water.. The enrichment factors, being substantially greater than one, suggest that the contamination originates from sources other than the local background levels of soil and water, likely due to anthropogenic or natural influences. High enrichment values in water can lead to issues such as eutrophication, toxicity, and significant alterations in water chemistry, while in soil, they may reduce fertility and structural integrity (Al-Dahar et al., 2023).

Generally, the soil surrounding the tank farms was found to be more concentrated with organic contaminants compared to the surface water. Both surface water and soil contained minimal amounts of oil and grease, with soil exhibiting a higher concentration. Soil can retain oil and grease on its surface and absorb it, making it less susceptible to being washed away during rainfall. In contrast, oil and grease in surface water can easily flow away and may dissolve under intense sunlight. Volatile organic compounds and total petroleum hydrocarbons were found in greater quantities in the soil than in the surface water across various months, seasons, and distances. The soil retains these substances for extended periods due to leaks during the transportation and discharge of petroleum products. Although some leakage occurs in surface water, the contaminants are carried away over long distances, resulting in lower concentrations compared to the soil. TPHs were more abundant than VOCs, as the latter are a subset of hydrocarbons that may be volatile. New strategies on pollution management such as improvement on wastewater treatment, adopting sustainable agriculture, regulating industrial discharges, promoting water conservation, implementation of green infrastructure, remediation of contaminated soil sites, sustainable land use and possible prevention of soil and water pollution should be ensued. The importance of managing soil and water pollution cannot be overstated; all must work to prevent the recurrence of the pollution issues we currently face.

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