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# Impact of Groundwater Flow Direction and Sediment Properties on Oil Spill Areas in Ahoada West, Rivers State, Nigeria

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***Authors' contributions***

*This work was carried out in collaboration between both authors. Authors JLE and EA conceptualized the study and contributed to the writing and formatting. Author JLE handled the data processing, with author EA assisting in the review process. The final version of the manuscript was collaboratively written by both authors. Both authors read and approved the final manuscript.*

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## ABSTRACT

This study examines the impact of groundwater flow direction and sediment properties on oil spill areas in the Ahoada West Local Government Area of Nigeria. The research involved the selection of six boreholes, with one each in the oil-affected regions of Joinkrama 4 and Akinima. Various tools such as water level meters, handheld GPS devices, and tripod drilling equipment were employed to collect sediment samples from the topsoil, 3m and 6m depths. Data were gathered by measuring the static water level in the boreholes and the ground surface elevation relative to the average sea level of the region. ArcGIS software was used to analyze the data and generate groundwater flow direction maps. Sieve analysis was conducted, and Microsoft Excel was used to calculate and plot the grain size of the samples. The study reveals a groundwater flow direction

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from the north to the southeast in the study area. To assess the potential impact of the oil spill, grain size values and their interpretation were analyzed in Joinkrama 4 and Akinima. The sediment characteristics varied with depth, with Joinkrama 4 exhibiting coarse silt, very fine sand, and very coarse sand, while Akinima displayed very fine sand and fine sand. Sediment sorting characteristics were also evaluated, with Joinkrama 4 showing poor to moderate sorting and Akinima displaying moderately sorted sediments. These findings offer awareness into sediment properties and oil spill migration pathways, aiding environmental management, remediation, and research, and improving understanding of impacts to guide effective strategies and policy-making.

*Keywords: Groundwater flow direction; sediment properties; oil spill areas; mean grain size; sorting coefficient.*

## 1. INTRODUCTION

Oil spills are a major environmental concern, resulting in the release of significant quantities of crude oil into ecosystems. Such spills can have detrimental effects on aquatic life, vegetation, and human health and can also cause long-term economic and social impacts on affected communities [1]. Nigeria, as one of Africa's largest oil producers, has experienced several high-profile oil spills, predominantly in the Niger Delta region [2]. These incidents have led to severe environmental degradation and have placed immense pressure on local communities that rely on the affected ecosystems for their livelihoods. To effectively address the challenges posed by oil spills, it is crucial to understand the factors that influence the distribution and extent of contamination. Groundwater flow direction and sediment properties are two critical factors that can significantly impact the spread and persistence of oil spill areas. Groundwater, as an essential component of the hydrological cycle, plays a vital role in transporting and dispersing contaminants in the subsurface environment [3]. Understanding the direction of groundwater flow can help identify potential pathways for oil migration and inform the design of remediation strategies [4]. Additionally, sediment properties, such as grain size distribution, organic content, and permeability, can influence the fate and transport of oil in the environment [5]. To estimate the impact of an oil spill on the marine ecosystem, it is necessary to evaluate the movement and transformation of petroleum hydrocarbons from sediments into water columns [6]. In this research, the sediments, including clay, silt, sand, and gravel, were formed by river and marine processes and comprise a multi-aquifer system with distinct geological features and ages [7]. Consequently, studying the properties of sediments in oil spill areas can provide valuable information about the potential for oil remobilization and the persistence of contamination. The Ahoada West Local Government Area Rivers State, located in Nigeria's oil-rich Niger Delta region, has experienced numerous oil spill incidents in recent years. Despite the environmental and socio-economic significance of the area, there is limited research focused on understanding the factors that influence the distribution and persistence of oil spill areas in this region. Therefore, this study aims to investigate the influence of groundwater flow direction and sediment properties on oil spill areas in the Ahoada West Local Government Area. This study's objectives are limited to characterisation of the hydrogeological conditions in the study area, including groundwater flow patterns, aquifer properties, and potential pathways for oil migration; focusing on grain size distribution such as the Mean grain size and soring.

## 2. MATERIALS AND METHODS

### 2.1 Location of Study Area

The location of the study area is found in Ahoada West Local Government Area of Rivers State, Nigeria. These communities are situated on the eastern side of the Orashi River, a significant river in the Niger Delta region. Joinkrama 4 is located at approximately 4.8265° N, 6.0665° E, while Akinima is positioned around 5.1046° N, 6.4529° E. The study area has a generally low-lying topography, with altitudes ranging from below sea level in the southwestern part to about 39 meters inland [8]. Access to the area is relatively easy through roads and footpaths, and there are hydrocarbon flow stations owned by the Shell Petroleum Development Company (SPDC) and the Nigeria Agip Oil Company (NAOC) in the vicinity [8].

### 2.2 Geology of the Study Area

Geologically, the study area is situated on the southwestern flank of the Niger Delta region,

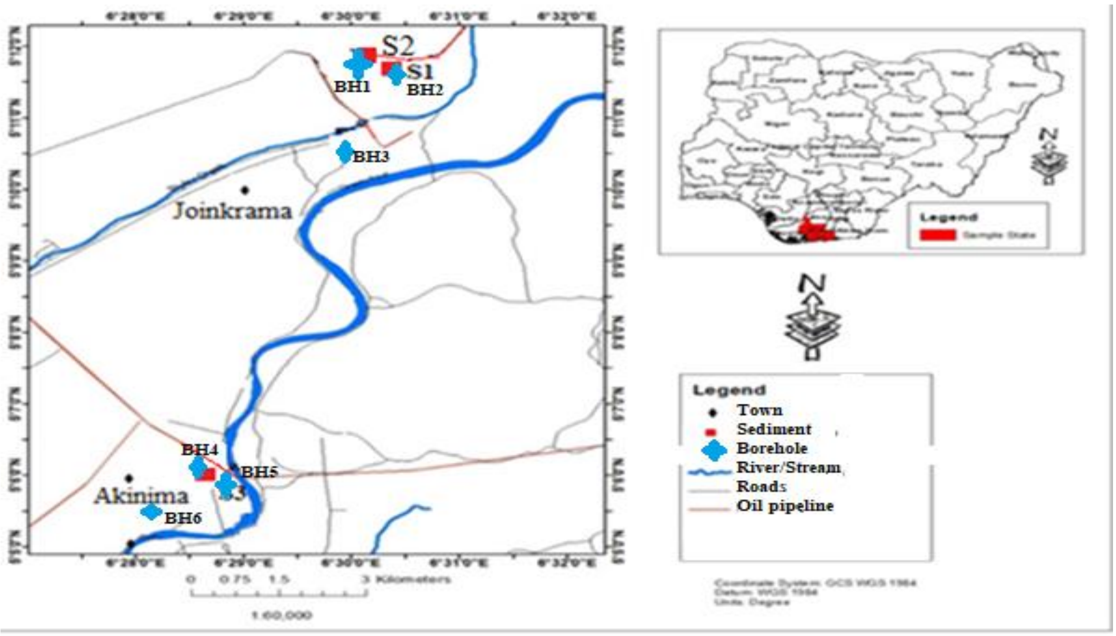

**Fig. 1. Study area map**

which originated from a failed rift junction between the South American and African plates during the late Jurassic to mid-Cretaceous period [9]. The Niger Delta Basin spans an extensive area of over 105,000 km² [10]. The primary geological formations in the study area include the Akata Formation, Agbada Formation, and Benin Formation.

The Akata Formation, dating from the Paleocene to the Holocene, is the basal lithostratigraphic unit in the Niger Delta region [11]. It comprises thick shales, turbidite sands, and smaller amounts of silt and clay. This formation represents deep marine deposits and includes plant remains near its contact with the overlying Agbada Formation. The Akata Formation also features a diverse microfauna, including planktonic foraminifera, indicative of a shallow marine shelf depositional environment [12]. The formation's thickness ranges from 0 to 6,000 meters and is primarily located subsea, not visible at the shoreline [13,14].

## 2.3 Data Collection

The study utilizes data from monitoring wells, namely BH1, BH2, and BH3 in Joinkrama 4, and BH4, BH5, and BH6 in Akinima using Hand held global positioning system to acquire the coordinate and Elevation of each borehole and also dip meter is used to measure the static water level in each borehole. The hydraulic head measurements are provided for each well, which allow for the calculation of the hydraulic gradient. The resulting hydraulic gradient values are used to determine the groundwater flow direction. Additionally, sediment sample using tripod drilling equipment were used to collected samples in Joinkram 4 (two borehole) and one borehole at Akinima at various depths interval top soil, 3m and 6m in oil impact locations.

## 2.4 Data Processing

Microsoft Excel was utilized to assess the data obtained from the field survey and classify it into different categories by utilizing three borehole measurements, which were subsequently imported into the ArcGIS software environment. In ArcMap, the hydraulic heads at each location were connected with straight lines, and the distances between them were calculated using the measuring tool. Additionally, contours of the water table were created by connecting points with equal increments of elevation difference using lines of identical values. By examining the perpendicular lines intersecting the straight lines joining the height increments, the direction of the greatest elevation change, indicating the flow of groundwater from higher to lower areas, was determined. The resulting map illustrates various patterns in the direction of groundwater flow within the research area. This digital map serves as a valuable resource for developing numerical groundwater flow models or managing aquifers within a geographic information system. While sediment was analyzed for mean grain size and sorting coefficient values. Mean grain size provides insights into the sediment texture, while the sorting coefficient indicates the degree of grain size variation within the sediment. The samples were collected using a standardized procedure and analyzed in the laboratory to understand the hydrogeological characteristics of the area.

## 3. RESULTS AND DISCUSSION

### 3.1 Groundwater Flow Direction

Groundwater flow direction is the direction in which groundwater moves within an aquifer or a groundwater system. It is determined by the hydraulic gradient, which is the slope of the water table or the potentiometric surface [15]. This directional flow can significantly influence the transport and migration of contaminants, including oil, in the subsurface. Understanding the groundwater flow direction helps identify potential pathways for oil migration and aids in developing appropriate containment and remediation strategies.

### 3.2 Joinkrama 4 Groundwater Flow Direction

The Hydraulic head measurements in Joinkrama 4 indicated values of 14.8 m, 14.3 m, and 13.5 m for BH1, BH2, and BH3, respectively, in Fig. 2. The calculated hydraulic gradient of 0.0016 m shows the slow movement of contamination, and Fig. 3 shows the flow direction is from the North towards the South-East. This finding is supported by Fig. 3, which visually depicts the flow direction. Consequently, contaminants in the Joinkrama 4 area are likely to migrate in the same direction.

BH 1 Hydraulic head (H) = 14.8 m
BH 3 Hydraulic head (L) = 13.5 m
Distance between BH 1 to BH 3 = 489.17 m
Hydraulic Gradient = (BH 1 (H) – BH3 (L))/(Length between BH4 – BH6)
= 14.8 m – 13.5 m / 489.17 m = 0.0016 m

**Table 1. parameter for Groundwater flow direction of study area.**

| Borehole sample | Town | LAT | LONG | GSE | SWL | Hydraulic Head (HH) |
|---|---|---|---|---|---|---|
| BH1 | Joinkrama 4 | 5.19402 | 6.49827 | 18.3 | 3.5 | 14.8 |
| BH2 | | 5.19626 | 6.50678 | 19.2 | 4.9 | 14.3 |
| BH3 | | 5.17925 | 6.49905 | 18.1 | 4.6 | 13.5 |
| BH4 | Akinima | 5.104092 | 6.476654 | 18 | 4.4 | 13.6 |
| BH5 | | 5.098837 | 6.47753 | 13.4 | 4.8 | 8.6 |
| BH6 | | 5.097718 | 6.463111 | 12.96 | 4.6 | 8.36 |

*Ground surface elevation (GSE) and Static water level (SWL)*

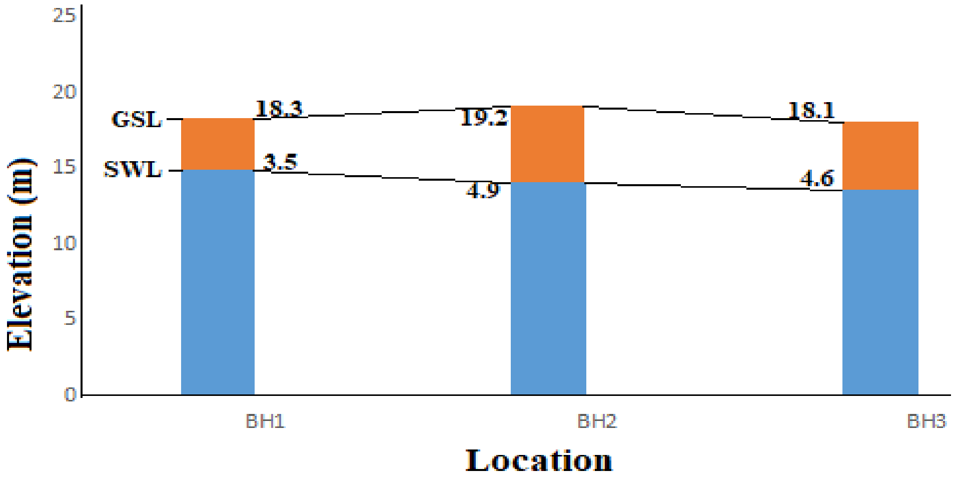

**Fig. 2. Joinkrama 4 borehole and elevation plot**

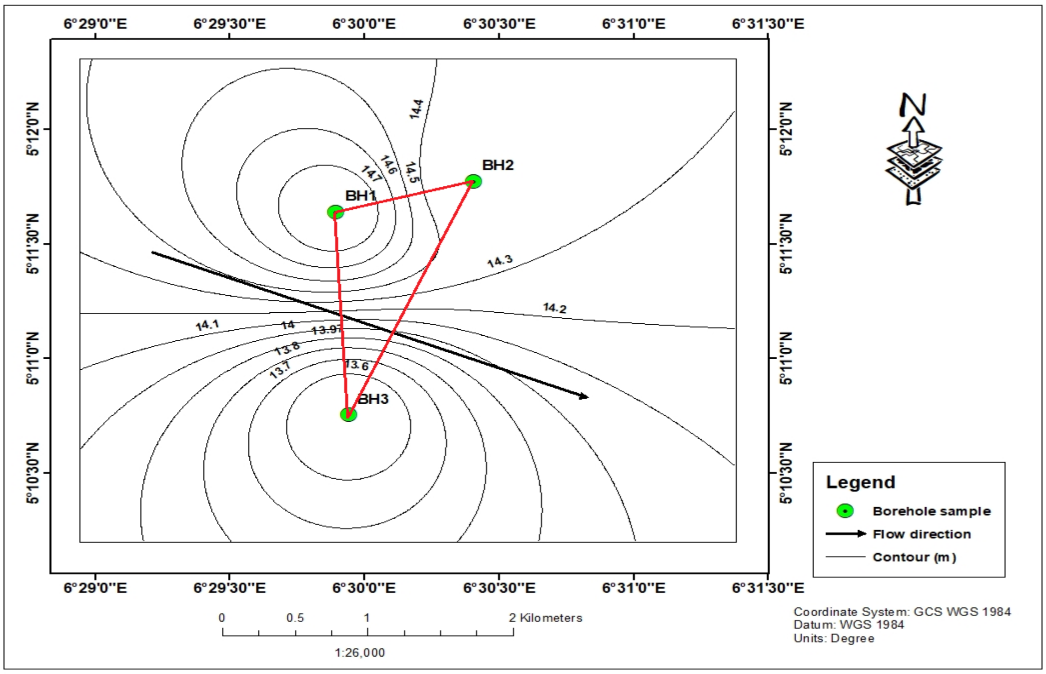

**Fig. 3. Joinkrama 4 Groundwater flow direction**

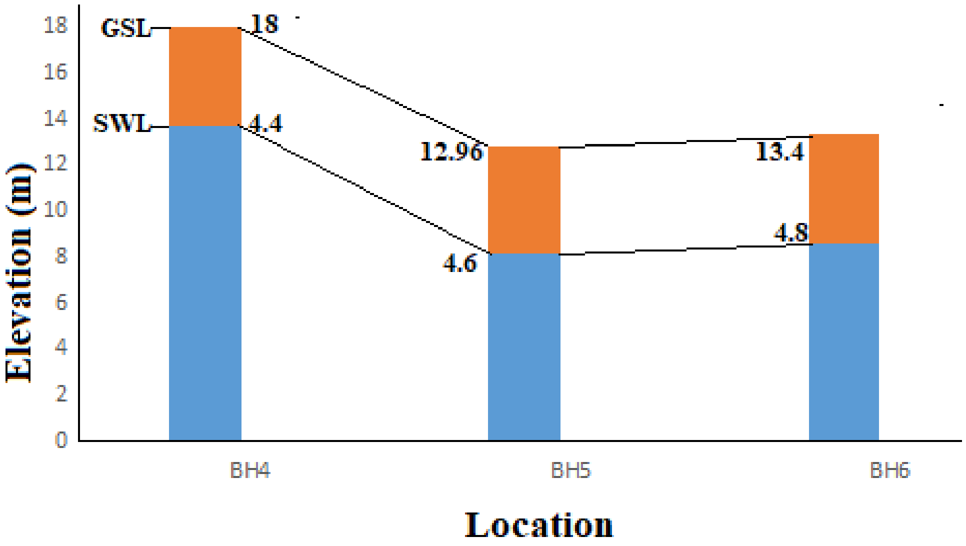

**Fig. 4. Akinima borehole and elevation plot**

### 3.3 Akinima Groundwater Flow Direction

In Akinima, hydraulic head measurements for BH4, BH5, and BH6 were 13.6 m, 8.6 m, and 8.36 m, as seen in Fig. 4, respectively. The calculated hydraulic gradient of 0.004 m indicates slow movement of groundwater flow direction in the area. Fig. 5 visually illustrates the flow direction, which is from the North towards the South-East, consistent with the findings in Joinkrama 4. Therefore, contaminants in the Akinima area are expected to migrate in the same direction.

BH 4 Hydraulic head (H)= 13.6 m
BH 6
Hydraulic head (L) = 8.36 m
Distance between BH 4 to BH 6 = 1311.12 m
Hydraulic Gradient = BH4 (H) – BH6 (L) / Length between BH4 – BH6
= 13.6 m – 8.36 m / 1311.12 m = 0.004 m

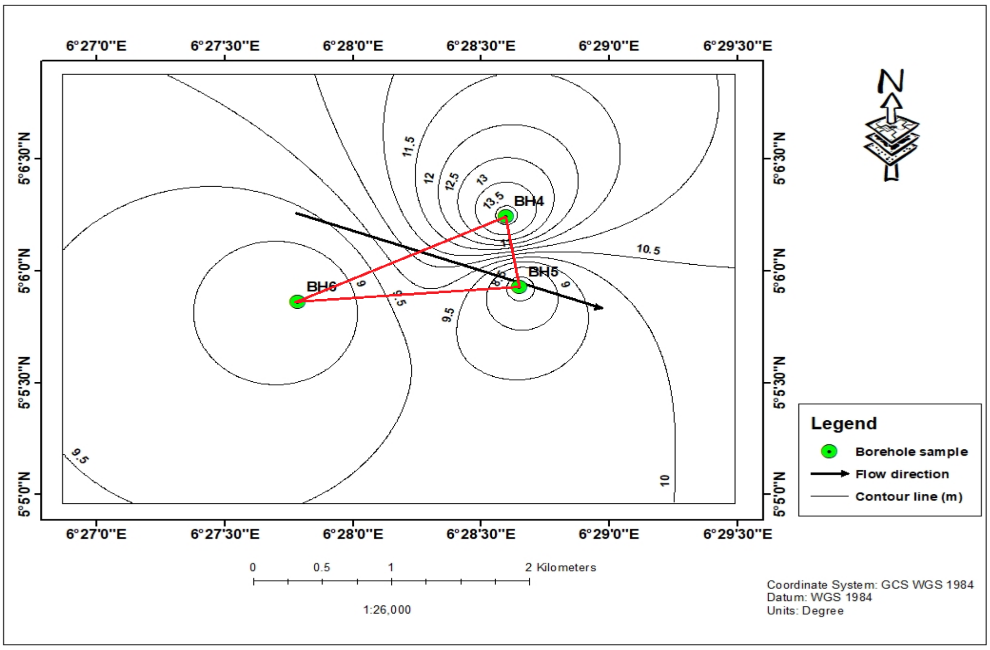

**Fig. 5. Akinima Groundwater flow direction**

**Table 2. Mean grain size value and Interpretation in Joinkrama 4 and Akinima**

| Sample code | Topsoil | Interpretation | 3m | Interpretation | 6m | Interpretation |
|---|---|---|---|---|---|---|
| Sample 1 | 4.03 | Coarse silt | 3.08 | Very fine sand | -0.13 | Very coarse sand |
| Sample 2 | 4 | Coarse silt | 2.39 | Fine sand | 1.14 | Medium sand |
| Sample 3 | 2.33 | Fine sand | 2.05 | Fine sand | 1.16 | Medium sand |

The presence of oil spills in the Joinkrama 4 and Akinima regions, as indicated by the monitored boreholes, demonstrates the potential risk to the surrounding environment. The slow movement of contamination suggests that the oil spills may spread gradually, affecting a larger area over time. Additionally, the influence of sediment properties on the migration pattern should be considered. Sediments with higher permeability may facilitate faster contaminant migration, while low-permeability sediments could act as barriers, impeding the spread of contaminants. The findings align with Figs. 3 and 5, which illustrate the flow direction from the North towards the South-East. This consistent pattern suggests a regional influence on groundwater flow and contamination migration. The information obtained from borehole monitoring and hydraulic head measurements can aid in the development of effective strategies for containing and remediating oil spills in the study area.

### 3.4 Characteristics of Sediment Samples at Different Depths

**Mean Grain Size:** Table 2 presents the mean grain size values for the sediment samples collected at different depths in Joinkrama 4 and Akinima. Sample 1 from Joinkrama 4 exhibited a coarse silt texture at the topsoil level (Fig. 6), while the 3m and 6m depths showed very fine sand and very coarse sand, respectively in Figs. 7 and 8. Sample 2 from Joinkrama 4 displayed a consistent coarse silt texture at all depths, whereas Sample 3 had a fine sand texture across all depths. In Akinima, Sample 1 exhibited a very fine sand texture at the topsoil level, while the 3m and 6m depths showed fine sand and medium sand, respectively. Sample 2 showed a consistent fine sand texture across all depths, and Sample 3 had a medium sand texture at all depths. The variation in mean grain size values indicates differences in sediment texture, which can influence the migration and distribution of oil spills. Coarse sediments tend to have lower porosity and permeability, potentially leading to increased surface runoff and limited infiltration, resulting in higher susceptibility to oil spill impacts. On the other hand, finer sediments may have higher porosity and permeability, allowing for greater infiltration and the potential for oil migration through groundwater pathways.

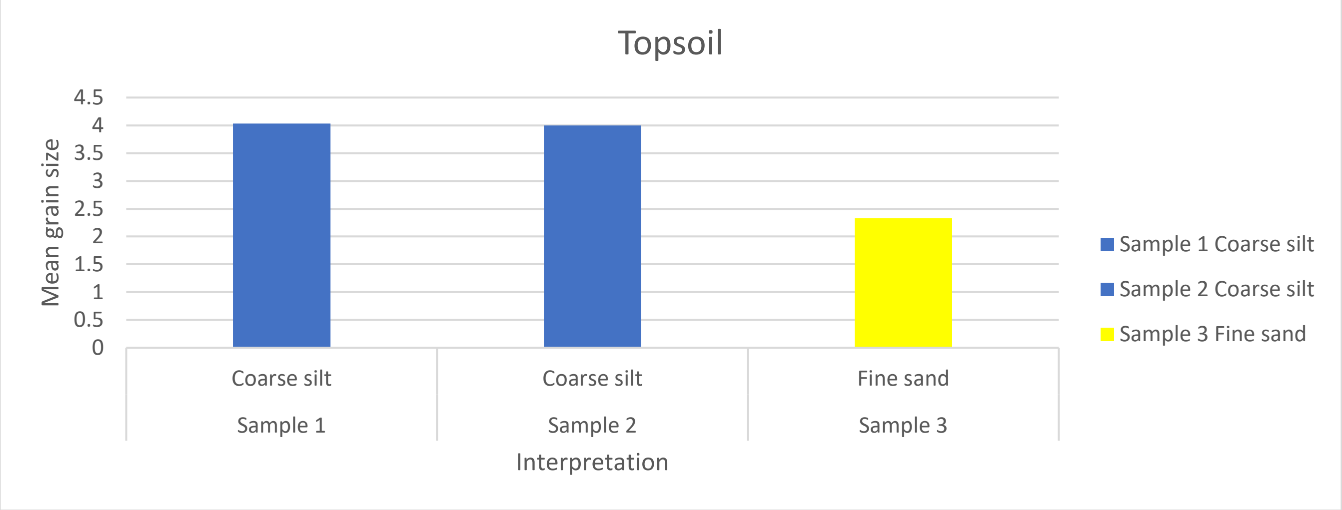

**Fig. 6. The graphical representation of the mean grain size distribution for top soils**

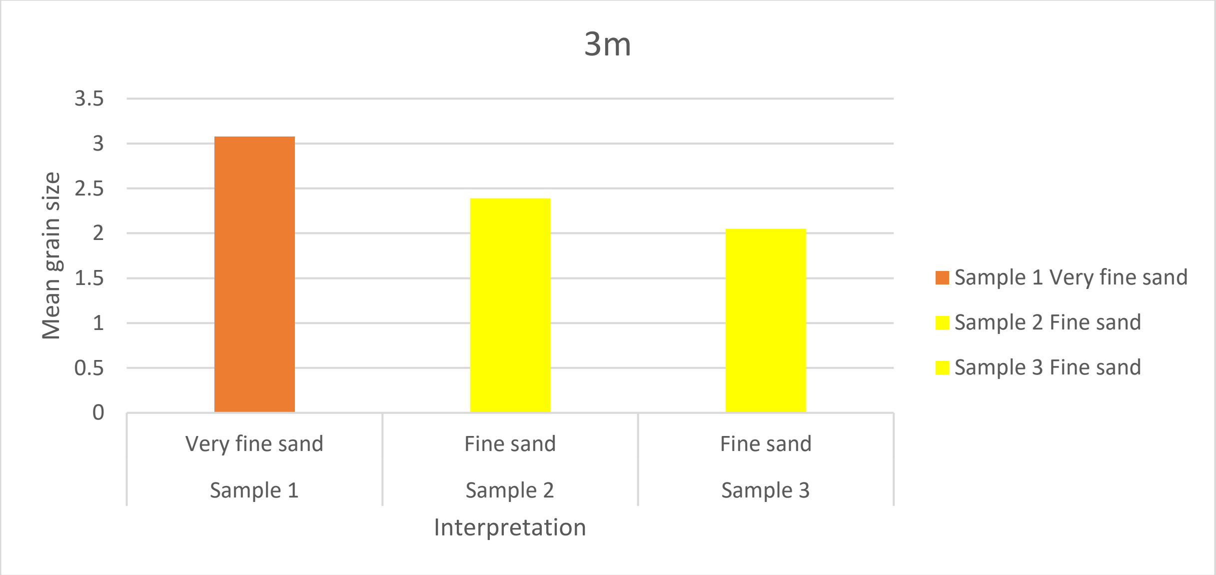

**Fig. 7. The graphical representation of the mean grain size distribution 3 m**

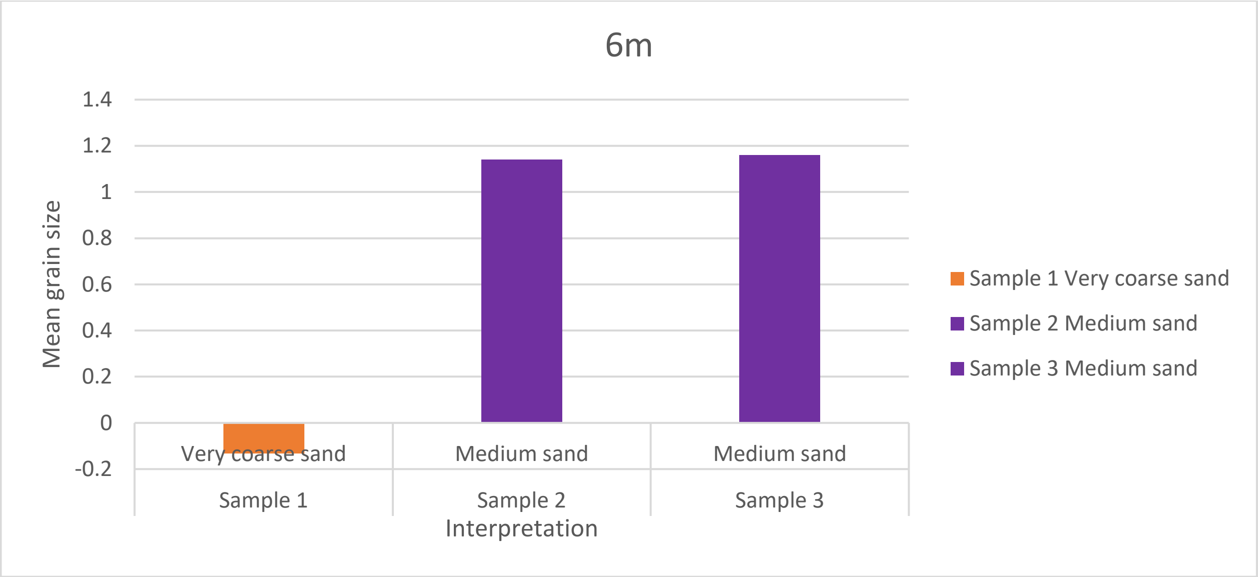

**Fig. 8. The graphical representation of the mean grain size distribution for 6 m**

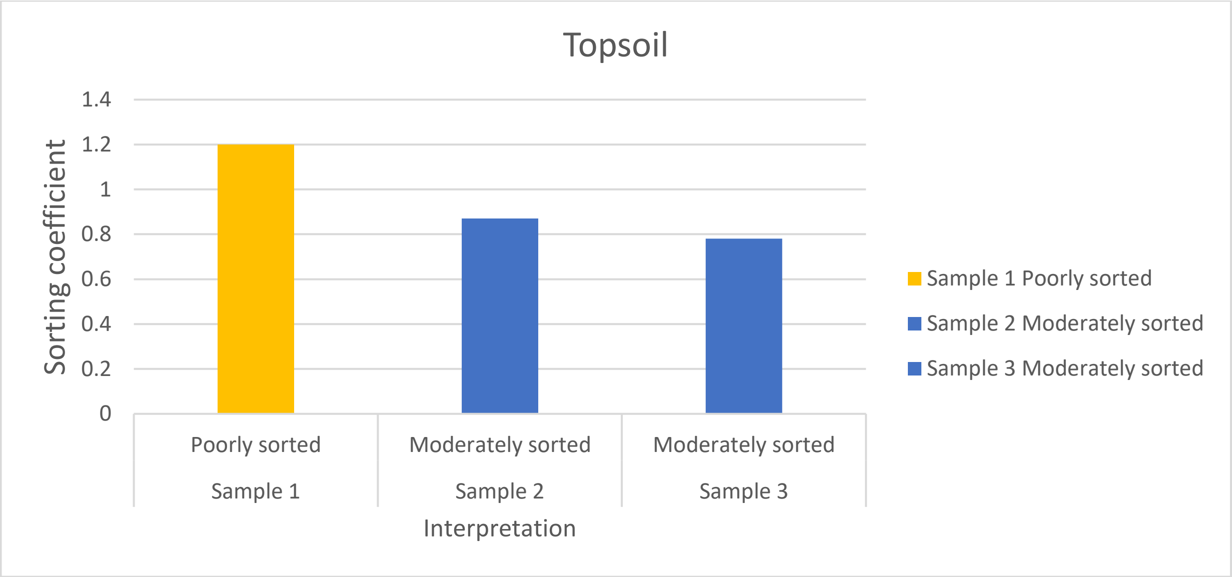

**Fig. 9. The graphical representation of the sorting coefficient for topsoil**

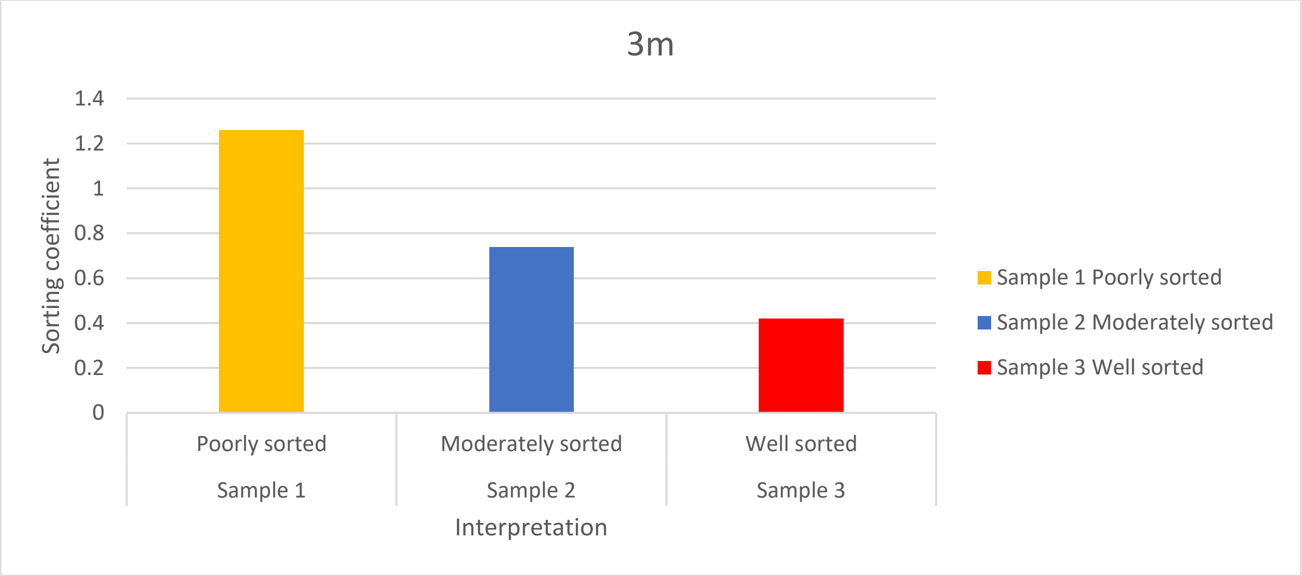

**Fig. 10. The graphical representation of the sorting coefficient for 3 m**

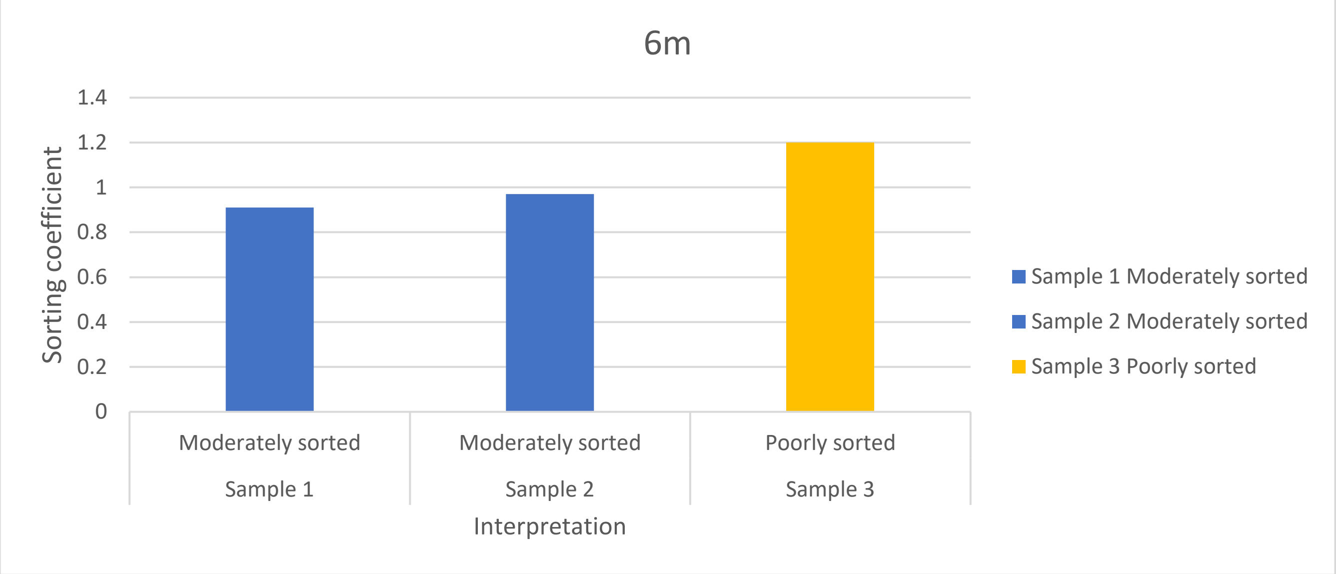

**Fig. 11. The graphical representation of the sorting coefficient for 6 m**

**Table 3. Sorting coefficient values and interpretation in Joinkrama 4 and Akinima**

| Sample code | Topsoil | Interpretation | 3m | Interpretation | 6m | Interpretation |
|---|---|---|---|---|---|---|
| Sample 1 | 1.2 | Poorly sorted | 1.26 | Poorly sorted | 0.91 | Moderately sorted |
| Sample 2 | 0.87 | Moderately sorted | 0.74 | Moderately sorted | 0.97 | Moderately sorted |
| Sample 3 | 0.78 | Moderately sorted | 0.42 | Well sorted | 1.2 | Poorly sorted |

**Sorting Coefficient:** Table 3 presents the sorting coefficient values for the sediment samples collected at different depths in Joinkrama 4 and Akinima. Sample 1 from Joinkrama 4 exhibited a poorly sorted texture at all depths as seen in Figs. 9,10 and 11, while Sample 2 showed a moderately sorted texture across all depths. Sample 3 exhibited a moderately sorted texture at the topsoil and 3m depths, and a well-sorted texture at the 6m depth. In Akinima, Sample 1 displayed a poorly sorted texture at all depths, while Sample 2 and Sample 3 showed a moderately sorted texture at all depths. The sorting coefficient provides insights into the degree of sediment uniformity, which influences the connectivity of pores and can affect the transport and spread of contaminants such as oil spills. Poorly sorted sediments have a wide range of grain sizes, which can impede the movement of fluids, potentially leading to the accumulation of contaminants in localized areas. Conversely, well-sorted sediments have a narrower range of grain sizes, facilitating fluid flow and potentially spreading contaminants over a wider area.

Understanding the sediment properties in oil spill areas is crucial for assessing the potential impacts of oil contamination. The characteristics of sediment, such as grain size and sorting, can affect the behavior and fate of oil in the environment. Fine-grained sediments, for example, have a higher oil retention capacity compared to coarser sediments. By examining the groundwater flow direction and sediment properties, this study provides valuable information for environmental management and remediation efforts in the oil spill-affected areas. The findings can aid in designing effective strategies for oil spill cleanup, monitoring, and prevention in Ahoada West Local Government Area, Nigeria.

## 4. CONCLUSION

The findings of this study highlight the significance of groundwater flow direction and sediment properties in influencing the distribution and behavior of oil spill areas in Ahoada West Local Government Area, Nigeria. The consistent flow pattern from the north to the southeast indicates potential pathways for oil migration, aiding in the development of effective containment and remediation strategies. The variations in sediment properties, including mean grain size values and sorting coefficient values, provide insights into the depositional environments and processes that influence the fate and transport of oil spills. Understanding these factors can contribute to improved management and mitigation measures for oil spill incidents in the study area.

## DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of manuscripts.

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## COMPETING INTERESTS

Authors have declared that no competing interests exist.

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