

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

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 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 provide valuable insights into the sediment properties and potential pathways for the migration of oil spills in the study area, contributing to a comprehensive understanding of the environmental impact.

Keywords: Groundwater flow direction, Sediment properties, Oil spill areas, Mean grain size, Sorting coefficient.

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.

MATERIAL AND METHODS

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].

Geology of the Study area

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

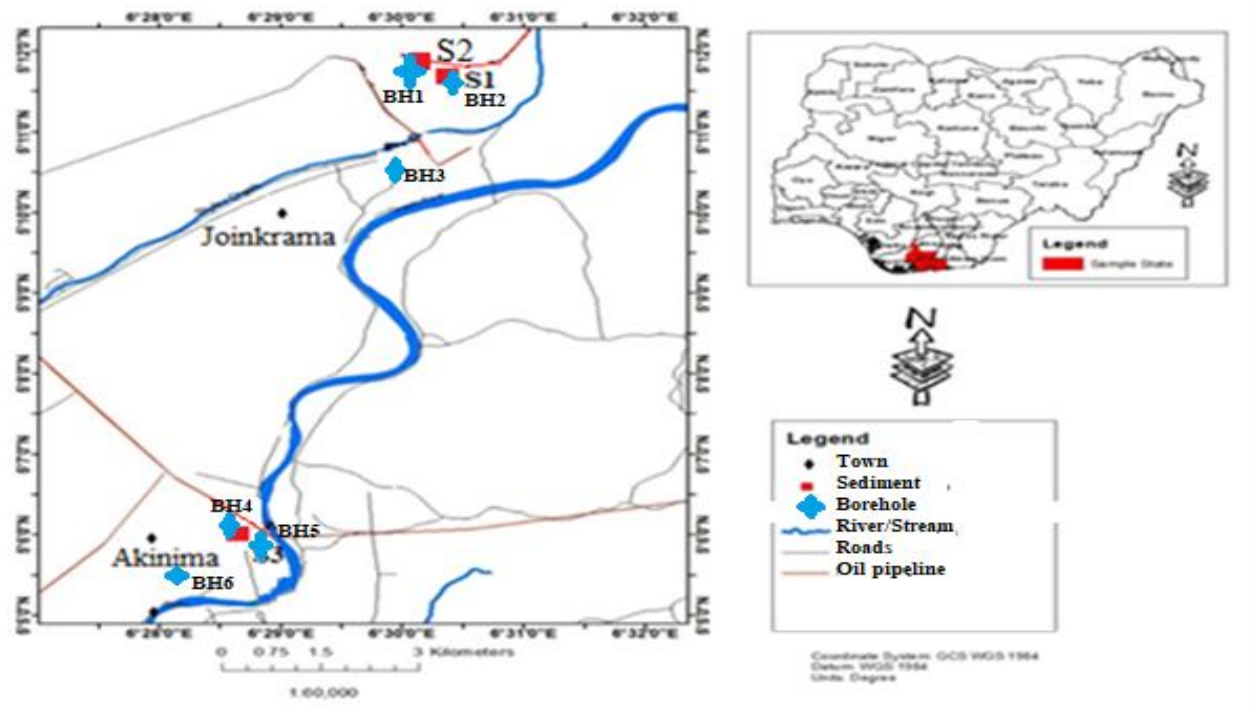


Figure 1: Study area map

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.

Dataprocessing

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.

RESULTS AND DISCUSSION

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.

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)

Joinkrama4 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 Figure 2. The calculated hydraulic gradient of 0.0016 m shows the slow movement of contamination, and Figure 3 shows the flow direction is from the North towards the South-East. This finding is supported by Figure 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 = $\frac{\text{BH 1 (H)} - \text{BH3 (L)}}{\text{Length between BH4 - BH6}}$

$$= \frac{14.8 \text{ m} - 13.5 \text{ m}}{489.17 \text{ m}} = 0.0016 \text{ m}$$

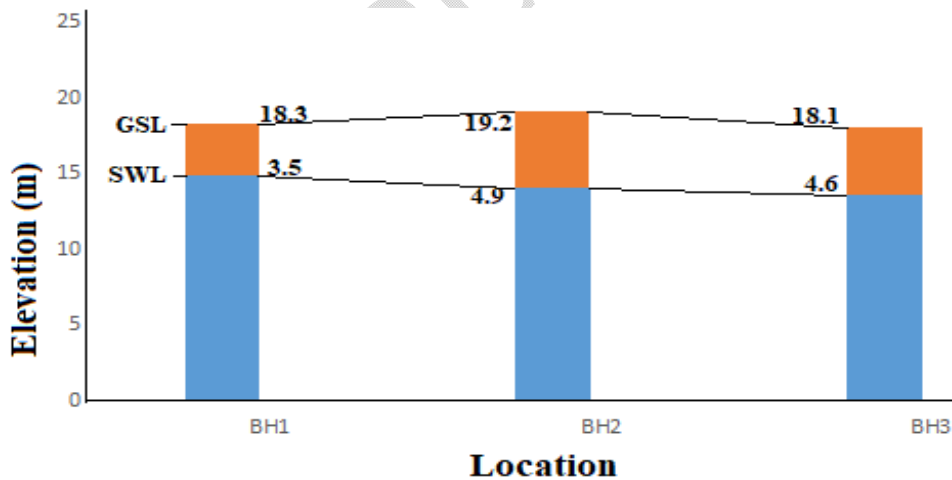


Figure 2: Joinkrama4 borehole and elevation plot

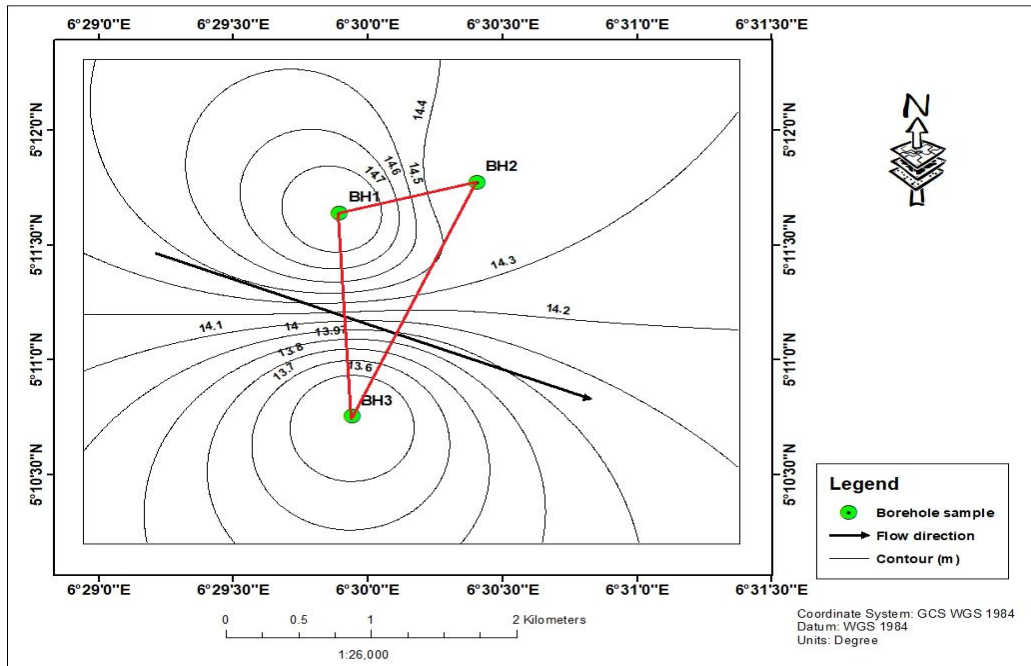


Figure 3: Joinkrama4 Groundwater flow direction

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 Figure 4, respectively. The calculated hydraulic gradient of 0.004 m indicates slow movement of groundwater flow direction in the area. Figure 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 = $\frac{BH4 (H) - BH6 (L)}{\text{Length between BH4 - BH6}}$

$$= \frac{13.6 \text{ m} - 8.36 \text{ m}}{1311.12 \text{ m}} = 0.004 \text{ m}$$

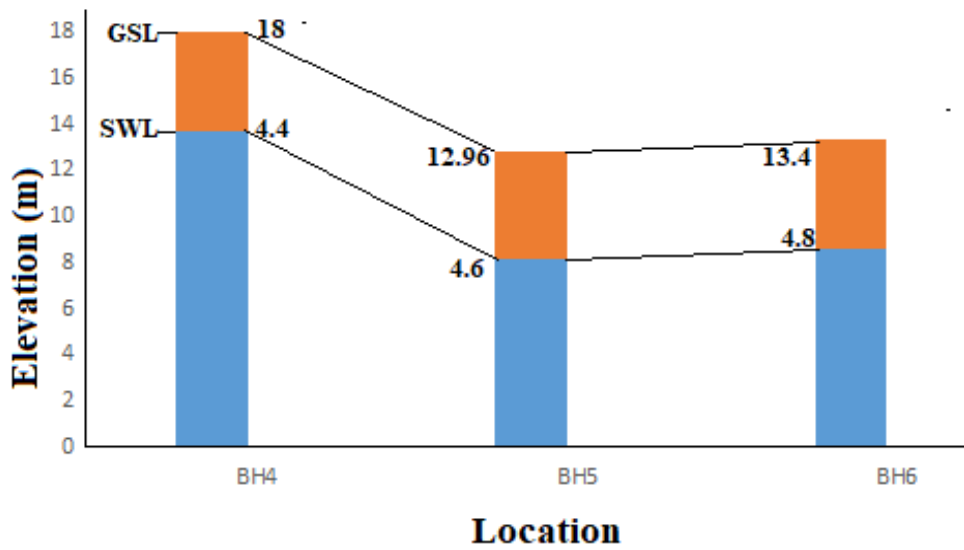


Figure 4: Akinima borehole and elevation plot

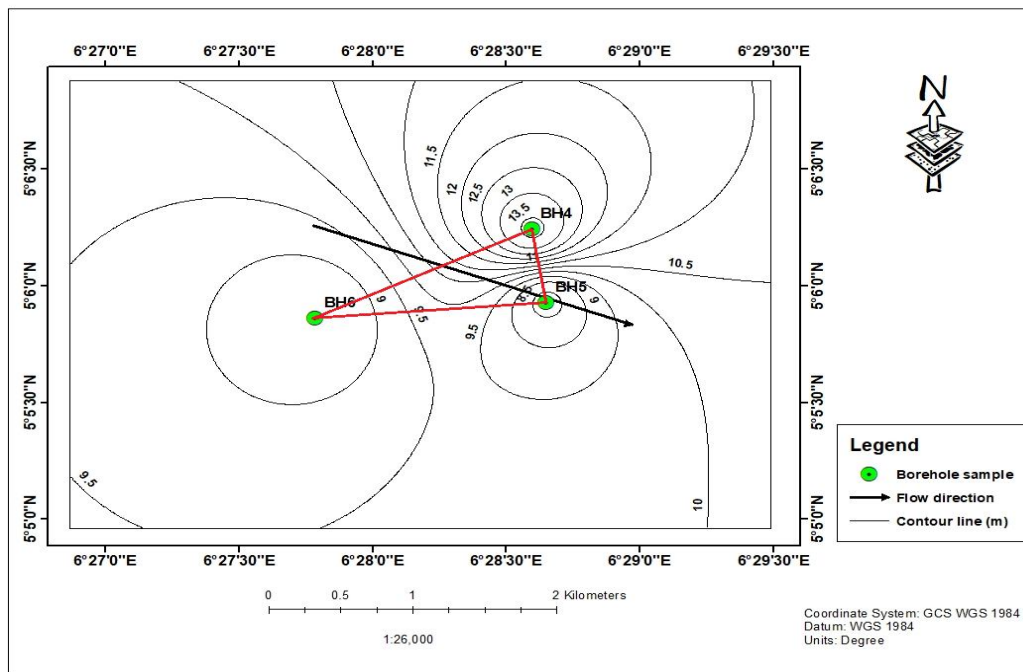


Figure 5: Akinima Groundwater flow direction

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 Figures 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.

Characteristics of sediment samples at different depths.

Mean Grain Size:

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 (Figure 6), while the 3m and 6m depths showed very fine sand and very coarse sand, respectively in Figure 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.

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

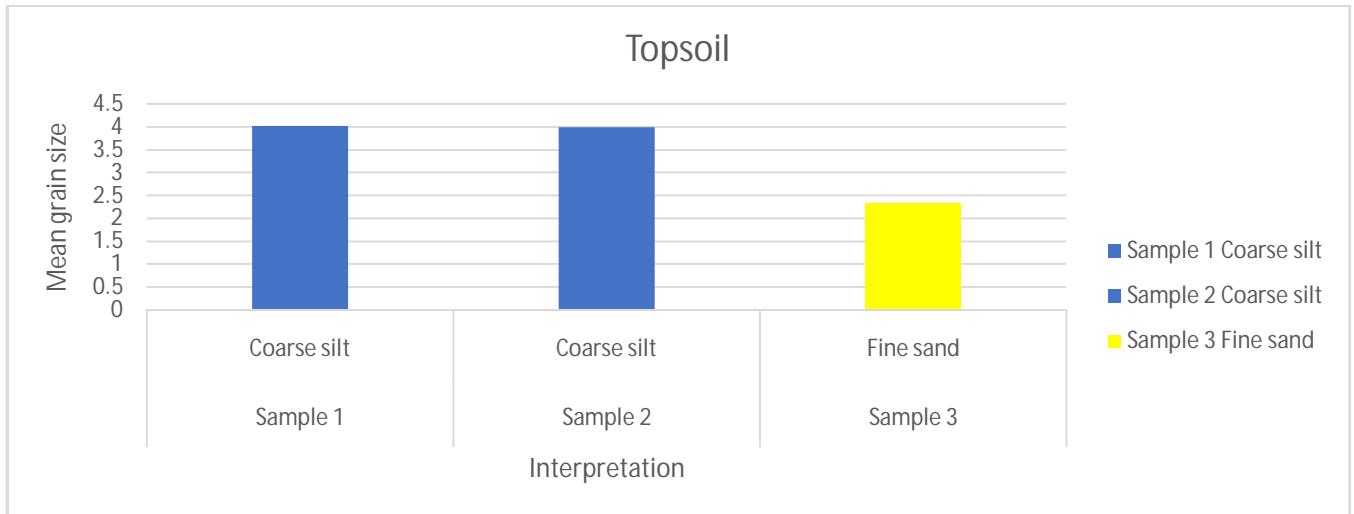


Figure 6: The graphical representation of the mean grain size distribution for top soils.

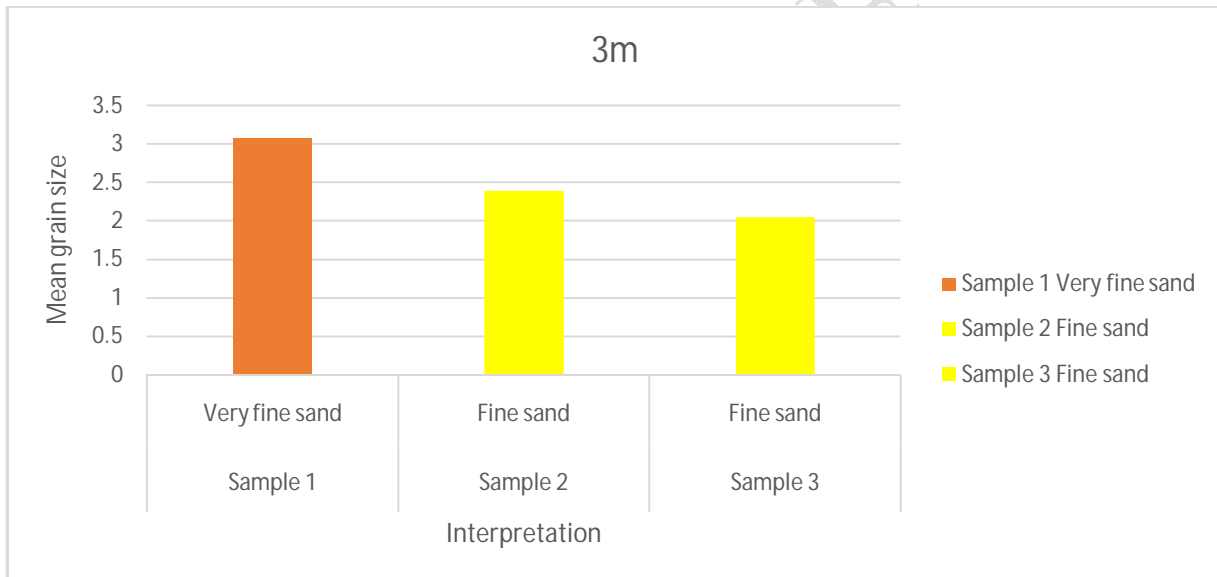


Figure 7: The graphical representation of the mean grain size distribution 3 m.

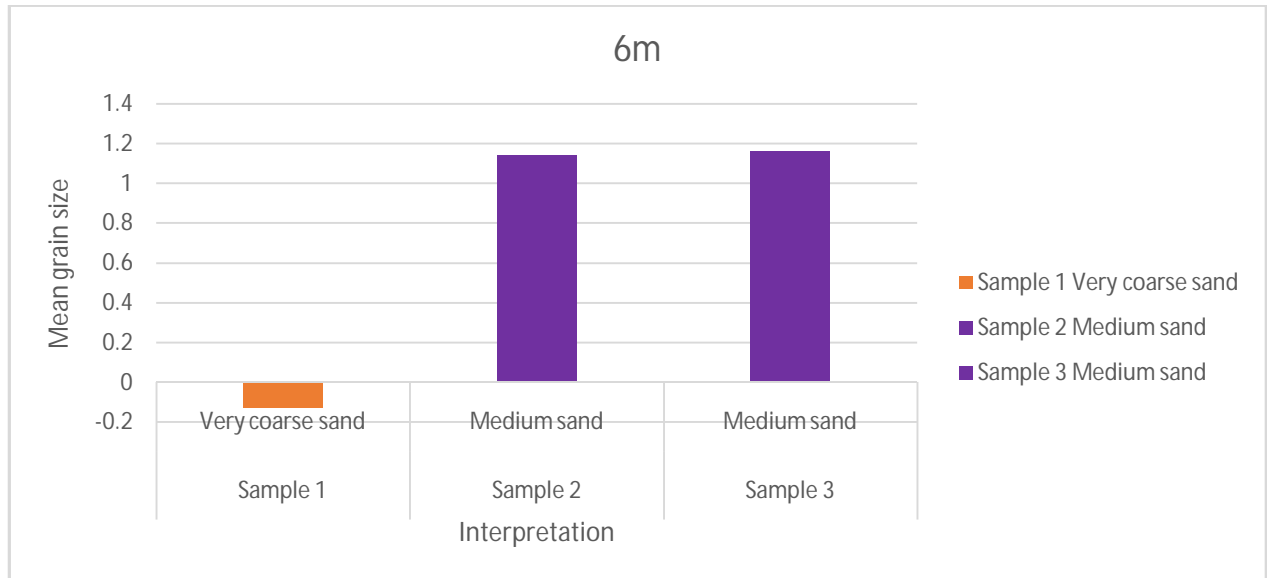


Figure 8: The graphical representation of the mean grain size distribution for 6 m.

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 Figure 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.

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

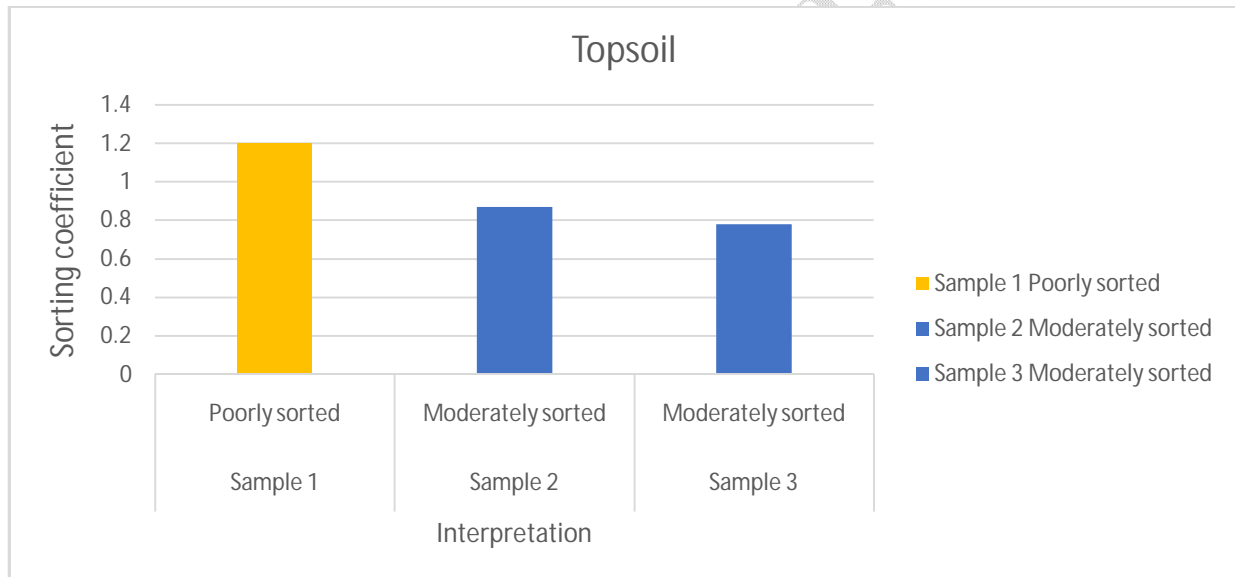


Figure 9: The graphical representation of the sorting coefficient for topsoil.

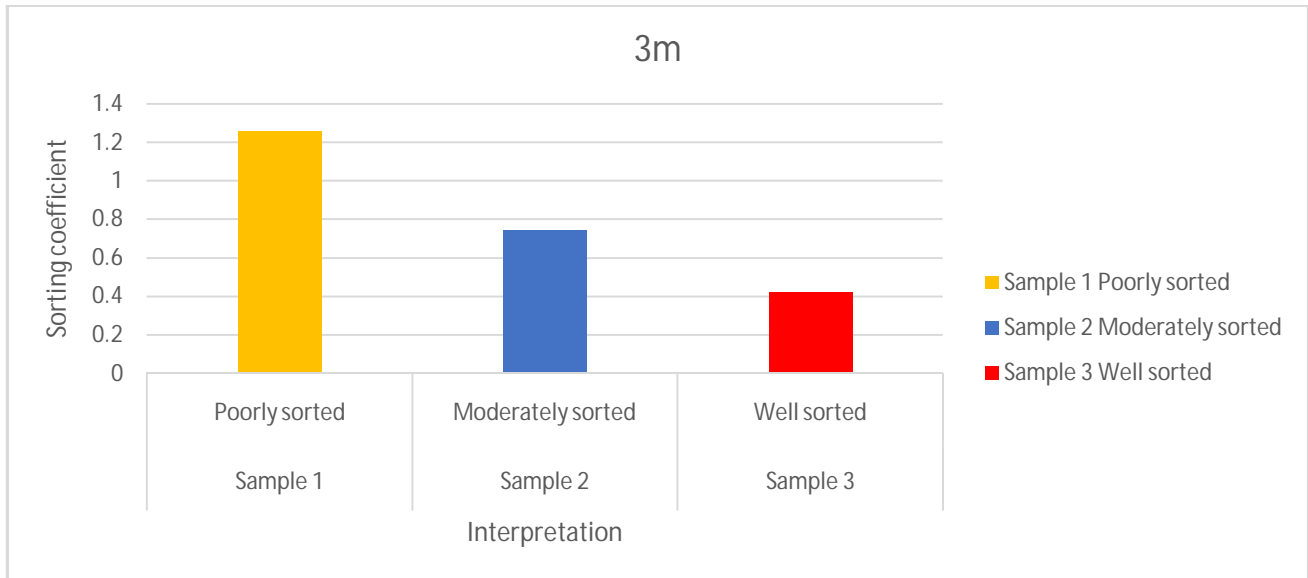


Figure 10: The graphical representation of the sorting coefficient for 3 m.

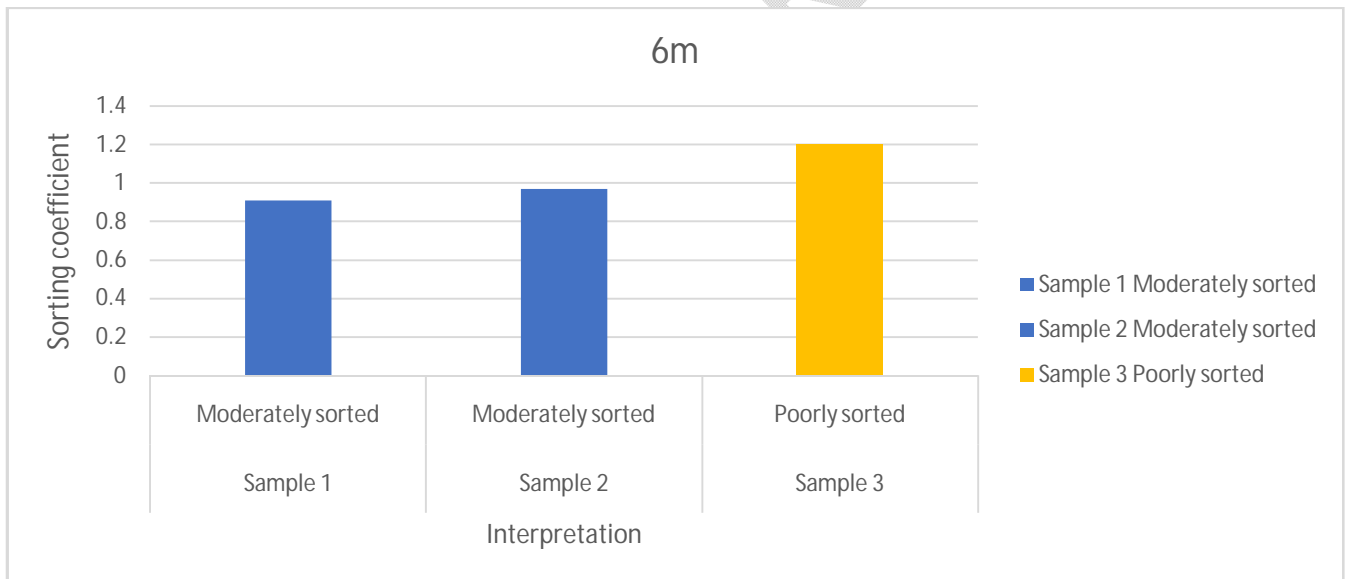


Figure 11: The graphical representation of the sorting coefficient for 6 m.

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.

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.

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