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An Overview of Oil Spill Containment: The Niger Delta Perspective

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ABSTRACT

Deliberate efforts have been made for over two decades now to mitigate the ruins of oiling in the Niger Delta by trying to build scientific bridges across her troubled waters. Beyond the data, this article seeks to inspire, at least in part, thoughts and discussion around oil spill research exploits and successes. “Containment” in this perspective stretches beyond clean-up and remediation, to nipping the bud of contentions arising from post-impact disputes. The unambiguous admission of forensic evidence through molecular fingerprints of oil discourages the incidents arising from induced-spills, knowing that sources of these spills are traceable via their genetic markers. Fresh and stale oil spills present contentious challenges of determining source-contaminant; abandoned sites with weathered spills, are difficult to distinguish from stale oil, due to their visible semblances of colour and sense of smell. These challenges can only be resolved with the use of genetic signatures. Biomarker signatures are considered valid for these purposes because they can detect the source of the spill on the basis that crude oils contain chemical fossils whose fate and origin can be detected by these biomolecules, which are ancient constituents of the fugitive oil. Within the stable carbon-carbon skeleton of these molecules are embodied their ancestral flora and fauna that were deposited during the sedimentary processes that generated the crude oil. Stable biomarkers (fingerprints) arising therefrom rely on the precursor-product relationship that exist between the source molecules. Therefore, should contentions arise, genetic markers can be to put to good use towards environmental justice and communal harmony. This further discourages activities leading to such contentions.

1. INTRODUCTION

Nigeria is the largest oil domain in sub-Saharan Africa and the eleventh largest in the world, owing to her production and consumption capacity. In the last quarter of 2019, the country had an estimated 37.0 billion barrels of proven crude oil reserves, and in the first quarter of 2022, the country recorded an average daily production of 1.49 million barrels per day (mbpd), accounting for 6.63% of the total GDP. Despite losing about 50% of its crude oil to theft and other unscrupulous activities, the country still remains one of Africa's key producers of crude oil, producing high value, low sulphur crude, which accounts for over 30% of the continent's reserves [1]. This crude oil is largely produced in the Niger Delta region, the proliferous hub of the oil-bearing regions in Nigeria.

The Niger Delta (fig 1) is one of the biggest deltas in the world. It cuts across over 800 oil-producing towns in southern Nigeria and extends along a huge coastal plain that covers an estimated land mass of more than 70,000 square kilometers. As a result, the area is teeming with companies that produce effluent, such as oil refineries, petrochemical plants, LNG facilities, fertilizer factories, steel plants, and more. Aside from its vast petroleum reserves, the area has a number of valuable natural resources, including a mangrove forest—the biggest in Africa and the third largest in the world—a vast freshwater swamp forest, a rich biodiversity, and endemism centers. It is possible to classify the province's hydrology into two broad categories: freshwater and brackish water (although less salty than seawater). All of these ecological features make the Niger Delta one of the ten most important wetlands and marine ecosystems in the world, which confers on the region, a marked peculiarity of global significance

However, the vast oil and gas endowment of the region have precipitated numerous contamination and pollution effects arising from conventional and artisanal mining of the natural resources. There is an average of 221 oil spills per year in the region, which has become synonymous with pollution and contamination due to the vast network of more than 900 producing oil wells, 100 flow stations, more than 1,500 kilometres of trunk lines, and around 45,000 kilometres of oil and gas flow lines.

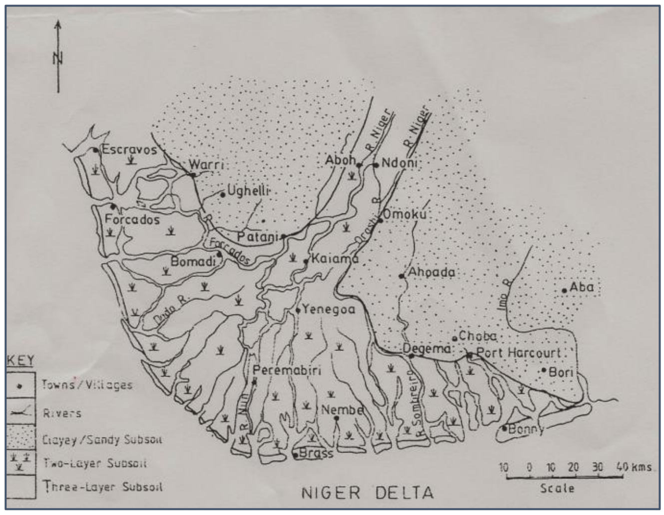

Figure 1*. A representative map of the Niger Delta province with an index map of Nigeria showing the region in the southern part of the country*

These spills have concomitant effects across the environmental value chain [1][2].

An estimated 0.7-1.7 million tonnes of petroleum is released into the world's seas, rivers, and oceans every year as a result of human activity. When oil spills happen on land, they impact the soil ecology. However, in totally aquatic situations, the oil may float on the water's surface and be carried to shorelines by the wind and waves. When offshore, it affects the surface water and its bottom sediments. The spilled oil contains hydrocarbons and these hydrocarbons are complex chemical molecules containing paraffins (normal alkanes), naphthenes (cyclic alkanes), monoaromatics (mono aromatic hydrocarbons like benzene, toluene, ethylbenzene and xylene), polycyclic aromatic hydrocarbons, PAHs (such as naphthalene and benzopyrene) and non-hydrocarbon compounds of Nitrogen, sulphur, oxygen and metals [3].

There is no gainsaying that the Niger Delta has witnessed increasing community pressure over proffered compensation and subsequent litigations following the despoliation of the environment by oil spills [4]. Away from the several rights activism, youth restiveness and other forms of environmental advocacies, legal alternatives via litigations have proved to be beneficial in addressing the issues of oil spill contention. However, doing this effectively requires the use of fingerprints which serve as admissible exhibits in the legal milieu. These fingerprints are molecular markers which carry genetic signatures of the contentious spilled oil that can be tendered as proof of evidence of the contaminant's source. The molecular markers rely on the precursor-product relationship of the oil which provides correlatable identities of the fugitive oil. Why rely on use of diagnostic biomolecules or molecular markers? Crude oil, being a fluid, possesses chemical fossils; its past life, in terms of its origin and fate, cannot therefore be detected by visual or microscopic examination, like macro, micro and trace fossils (which by the way, is the exclusive preserve of palaeontologists, palynologists and sedimentologists), but can rather be detected with sustainable biomolecules which themselves are ancestral constituents of the fugitive oil [5,6].

In a period of over two decades now, our team has been making deliberate efforts at mitigating the ruins of oiling in the Niger Delta and building scientific bridges across its troubled waters. For instance, in 2010, we reported the revegetation of the mangrove systems of Nembe after the devastating impact of oil pollution, and subsequently the Ogoniland reclamation in line with UNEP recommendations Also in 2023, we looked at the remediation prospects of emerging PAHs [7].

2. OVERVIEW OF OIL SPILLS

Oil spill is the unregulated discharge of crude oil into the atmosphere due to malfunctioning machinery, accidents during operations, or deliberate acts of vandalism against oil refineries. According to research conducted by the National Academy of Sciences and the United States National Resource Council, the exploration and production of oil and gas accounts for around 3% of the total oil that finds its way into the world's seas, ranking it as the fourth-largest contributor. Natural seeps account for 46% of the total, followed by oil consumers via storm drains, water vehicles, and sewers at 37%, and petroleum transportation at 11%. The Niger Delta area of Nigeria is one of the five most devastated ecosystems globally due to oil and gas extraction and exploration. Research indicates that between 9 and 13 million barrels of oil were spilt during a 50-year period. Oil spills associated can be categorised into three: minor, medium and major spills. Recorded incidents of major spills in the Niger Delta include the Escravos oil spill of 1978 where about 300000 barrels of crude spilled into the coastal zone of Delta State of Nigeria. Forcados tank failure of 1978 is another major spill of about 580,000 barrels, followed by the Funiwa-5 blow-out of 1980 that spilled an estimated 400,000 barrels, which spread through 321 villages of the Niger Delta, affecting a population of 320,000 people. Other minor-medium categories of spill include the Abudu Pipeline spill of 1982 (18,818 barrels) and the Idoho spill of 1998 (40,000 barrels). It is usually difficult to trace the source of the spill where there is either a mystery spill or comingled spills. A 'Mystery Spill' refers to crude oil leaks from unknown sources, while a comingled spill refers to oil spill where there are many oil firms operating near each other [8][9]. The most recent mystery and comingled spills in the Niger Delta is the Foropa spill that occurred in January 2024 along the Atlantic coastline of Bayelsa State which impacted fishing in the area and affected fishing settlements in the Foropa community of Niger Delta. In all, the year 2008 and 2009 witnessed two of the largest oil spills in the Ogoni Division which spilled a total of 82,939,170 litres of oil for 149 days [11].

2.1. Causes of oil spills in the region

Oil spills can result from natural disasters such as hurricanes, storms and earthquakes. Natural seepage, (i.e., oil-leaks from the subsurface to the surface as a result of natural causes) or the crashing of tankers and barges, are not very common in the Niger Delta due to its geoformation. However, the Niger Delta has witnessed incidents of oil-well blow outs such as the Bomu-2 oil Well blow-out of 1972 and Funiwa-5 blow-out of 1980. Blow outs do occur as a result of equipment failure or possible kicks from over pressured drilling zones. There are also instances of pipeline leaks (cf: Fig. 2) as a result of corrosion and other cases of operational mishaps. Further, there are mystery spills, whose immediate causes and sources are not known. Such spills mostly occur as a result of what we have often referred to "unsighted fingers of sabotage". Equipment failures and malfunctions are another significant challenge. Offshore drilling operations rely on complex machinery, pipelines, and control systems. Failure or malfunction of critical equipment, such as blowout preventers or subsea pipelines, can result in oil spills. Regular maintenance, inspection, and testing of equipment are imperative to identify and address potential failures before they occur. Contingency plans must be in place to respond quickly and effectively to equipment malfunctions, minimizing the likelihood and impact of oil spills. In the course of offshore drilling, conflagrations or fire explosions may also ensue blow-outs or any form of ignition of oil vapours present in drilling sites, crude oil being highly flammable. The consequences of fires and explosions can be severe, potentially causing fatalities, injuries, and extensive damage to infrastructure. To mitigate these risks, stringent fire detection and suppression systems must be in place, along with regular inspections and maintenance of safety equipment [12].

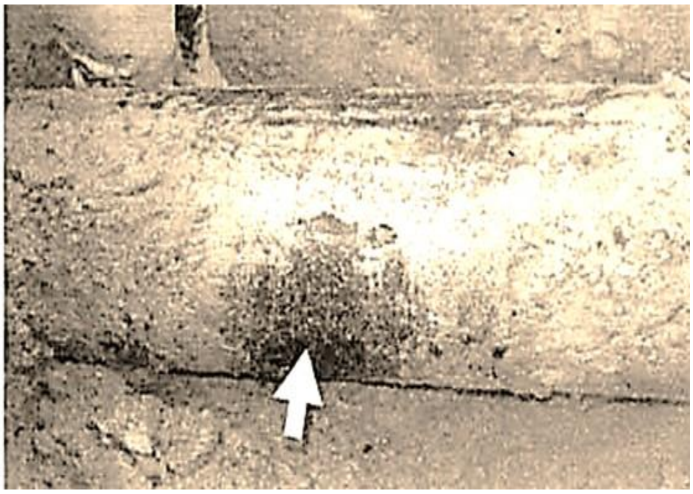

Figure 2*. A section of an oil pipeline in an oilfield in the Niger Delta showing point of oil leak* [13].

2.2. Effects of oil spills in the region

The discharge of refined petroleum products and crude oil into the Niger Delta's land and water environments has created a permanent danger to all kinds of life. The region's agricultural farmlands are notoriously susceptible to oil leaks. Oil spills have a significant impact on the local flora and wildlife, which in turn impacts agricultural and ecological output [11]. The coastal Niger Delta region is of great concern due to the region's rich biodiversity and fragile ecosystems. Oil spills have devastating effects on marine and coastal environments. The contamination of water bodies can lead to the disruption of aquatic ecosystems, killing marine life, and affecting the reproductive cycles of species. Mangroves, which serve as critical habitats for various species, can be smothered and killed by oil, leading to the loss of biodiversity and the degradation of coastal ecosystems. Oil which floats on surface water settles with the tide, and smothers both breathing and feeder roots [14]. The spills also knock-off resident microorganisms responsible for fertility of soil The contamination of coastal areas also has adverse impacts on local communities that rely on fishing and tourism as a source of livelihood. The economic repercussions can be significant, with decreased fish stocks, damage to tourism infrastructure, and a loss of revenue for local businesses. Figures 3 and 4 show the decolouration and outer oil-film coating associated with oiling of land and vegetation [15-17].

Figure 3. *A photographic plate of the despoliation of land and vegetation after the Kiminini oil spill in the Niger Delta captured during a reconnaissance survey of spill impacted sites in Bayelsa State*

Figure 4. *Effect of oiling on the mangrove floor and stilt propping roots of Rhizophora spp. at Nembe creek in the Niger Delta* [18].

Oil spills also pose significant threats to birds and marine mammals. The existence of these creatures is dependent on environments that are both healthy and have clean water. Animals that rely on feathers and fur for flight, swimming, and temperature regulation are particularly vulnerable to oil spills because birds and marine mammals come into direct touch with the substance. Another risk is that eating meat that has been tainted with oil, which may cause internal bleeding, organ failure, or even death. Birds and marine mammals that rely on affected areas for feeding, breeding, or migration can suffer population declines and long-term reproductive impacts, affecting the overall health and diversity of these species. The toxic components of crude oil, such as the polycyclic aromatic hydrocarbons (PAHs), can interfere with hormonal systems and cause developmental abnormalities in embryos and larvae [19]. The effects of oil spills can persist in the environment for years or even decades. Oil residues can remain in sediments, persisting as a source of contamination and continuously impacting the surrounding ecosystem. This can lead to long-term ecological changes, such as altered community composition, reduced biodiversity, and shifts in species interactions. The recovery of affected ecosystems can be slow and challenging, requiring significant time and resources. In all, the spread and movement of oil spills pose a significant challenge in the offshore environment. The strong ocean currents can cause spilled oil to disperse over large areas, making containment and recovery efforts complex and challenging [20]. Oil spill containment and recovery techniques include the use of booms, skimmers, and dispersants, among others. To be sure, environmental variables, weather, and the magnitude and severity of the spill may all affect how well these tools work.

3. IDENTIFICATION OF GENETIC SIGNATURES OF POLLUTANT SOURCE

Identifying the genetic signatures from the chromatograms of comingled crude and refined petroleum (that is crude oil and petroleum product like diesel) or identifying stale spill can pose challenges. These challenges arise from the fact that both have base constituents of petroleum and similarities of parent source hydrocarbons. However, crude oil being a complex mixture of hydrocarbons, with a wide range of molecular weights and structures as well as high concentration of polar compounds such as asphaltenes and resins, possess a higher range hydrocarbon profile, with broad, unresolved humps in their chromatograms. On the other hand, refined oils such as diesel fuel (automotive gas oil) possess narrower carbon range (C_{10} – C_{26}), and fewer components as well as sharper, more resolved chromatographic peaks, indicating a more refined and processed product. Stale spills present similar phenotypic semblances as observed in the Ogale spill in the Eleme axis of Rivers State. Reconnaissance at many spill sites in Niger Delta showed that several years after the contamination of the ground water (boreholes), the stench and colour of spilled-oil-in-water were physically indistinguishable from stale oil-in-water.

4. LIMITATIONS OF SOME BIOMARKER MOLECULES

Though molecular biomarkers can estimate the degree of weathering and determine pollution source, there are skepticisms over the stability of some under intense weathering conditions. For instance, studies have shown that pristane and phytane cannot be used for correlation purposes under intense activities of weathering owing to unstable structural configurations. Wittaker et al. [21] and Osuji et al [22] have shown that pristane/phytane ratios may not be consistent enough to be used in locating the source of a contaminant. Again, owing to modifications of their fingerprints by ‘unfavourable’ environmental conditions, their diagnostic ratios might not be absolute for correlation purposes. Yet, pristane and phytane still provide a descriptive picture of the oil and information on the extent of weathering; in other words, the ratio of pristane to phytane can still be a source indicator. Similar studies on oil-source correlations by Seifert and Moldowan [23], McCallum et al. [24] and others, on the absolute reliability of biomarker application, also revealed some limitations. In this perspective, biomarker applications were been found to be limited to maturation levels before and up to the end of the oil-generation window. This is because as the oil is buried deeper, higher temperatures are encountered, and the biomarkers are cracked to smaller molecules and gradually disappear. Thus, the biomarkers most commonly used in such evaluations are the normal steranes, diasteranes, mono- and tri-aromatic steranes, and the tricyclic, tetracyclic, and pentacyclic terpanes.

5. CONCLUSION

Reconnaissance of oilfields in Niger Delta over the years has shown minor to major spills and appurtenant effects on terrestrial and aquatic ecosystems. Some of the spills have become stale and weathered over a long period of time, and pose challenges of physical recognition of the contaminant or its refined products, like diesel fuel. Apart from such issues of comingling, there are also contentions arising from mystery spills, all of which lead to agitations and community pressure. Interventions with the genetic markers of the fugitive oils provide proof of evidence of the source of contaminant, admissible in the legal milieu. Biomarkers though traditionally employed in petroleum prospecting and characterization can be used to resolve such contentious issues of the oil-spill-source contaminant.

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Conflict of Interest Declaration

The authors declare that they have no competing interests to declare that are relevant to the content of this article.

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