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Potential Benefits of Applying "Omics" Technology in Cleaning up Incessant Crude Oil Spillages in the Niger Delta Region of Nigeria

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Authors' contributions

This work was carried out in collaboration between all authors. All authors designed the study and wrote the first draft of the manuscript. Authors UOE and UUU managed the literature searches. All authors read and approved the final manuscript.

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ABSTRACT

There have been reported cases of incessant crude oil spills leading to severe instances of hydrocarbon pollution in many parts of the Niger Delta region of Nigeria. The United Nations Environmental Programme (UNEP) in 2011 reported widespread hydrocarbon contamination in Ogoniland severely impacting many components of the environment. Some clean up and remediation methods including bioremediation, thermal treatment, and soil vapour extraction amongst others have been suggested as panacea to the restoration of the severely polluted environments in the region. Amongst these methods, bioremediation stands out. Interestingly omics based techniques have been shown to be amendable to bioremediation with a number of potential benefits. This review paper examines the potential benefits of the omics based technologies in the remediation of hydrocarbon polluted sites in the Niger Delta region of Nigeria.

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1. INTRODUCTION

Administratively, the Niger Delta is made up of nine (9) states and is located on the Gulf of Guinea on the West Coast of West Africa. The region holds the highest cultural and social diversity in Nigeria. Economically, it is the most important region because of her abundance of crude oil deposits. Crude oil exploration is responsible for over three-quarter of Nigeria's foreign earnings [1,2]. Sadly, these enormous benefits have come at the expense of the Niger Delta environment. The region's environment is degraded from incessant and unremeditated crude oil spillages.

Crude oil spillages occur daily in the Niger Delta [3]. So bad is the situation in the region that it is estimated that for over half a century, 9 - 13 million barrels of crude oil (about 1.5 million tonnes) have been spilled into the Niger Delta environment [4]. This is equivalent to one Exxon-Valdez spill each year for over half of a century. Unlike the Exxon-Valdez spill that released about 40 million liters of crude oil into the environment and was remediated promptly, spillages in the Niger Delta usually do not get cleaned up years after they have happened. Locally and internationally, these spillages have not gone unnoticed. A clear case in this regard is the United Nation Environmental Programme (UNEP) report of 2011 on Ogoniland crude oil spillage [5]. So pervasive was the spillage that it was estimated that it would require $ 30 billion dollars in clean-up efforts that are estimated to last 3 decades [5].

The Executive Director of UNEP, Erik Solheim described pollution in Ogoniland as one of the biggest environmental catastrophe anywhere in the world [5]. Pervasive death of flora and fauna from crude oil spills are common place in the Niger Delta region [5]. Oil contaminations also have adverse effects on agriculture, tourism, recreation, and aesthetics of the impacted area. In addition, hydrocarbons as environmental pollutants are highly toxic and carcinogenic with strong odour emissions, not readily degradable and are persistent in the environment posing serious ecological and health risks [5].

Increasing attention has therefore been directed toward research into environmental strategies and technologies to mitigate the impacts and remediate hydrocarbon contaminated ecosystems. The use of biotechnological strategies based on the indigenous microbial communities to biodegrade organic pollutant has emerged and are of particular relevance. Microbial degradation of hydrocarbons is a predominant mechanism for natural attenuation at hydrocarbon contaminated site. This ability which is largely limited to the ubiquitous hydrocarbonoclastic bacteria and fungi is dependent on outstanding capability of these microbes to degrade these hydrocarbons and other pollutants. Biostimulation and bioaugmentation are the two main strategies of bioremediation [6,7].

Molecular based techniques have also emerged that are amendable to bioremediation with other environmental applications [8]. Although the impact of the incessant oil spills is ravaging the Niger Delta region enormously, a lot of opportunities lie ahead especially in this era of "omics" and advances in molecular ecology. Thus, this paper is aimed at reviewing the potential benefits of deploying "omics" based technology in cleaning up the Niger Delta region.

2. POTENTIAL BENEFITS

As highlighted in the flow chart below (Fig. 1), a number of benefits accrue in omics based technology to all stakeholders and these are as discussed briefly below. Some of the opportunities hidden in the spillages include the discovery of pathways and enzymes, finding and optimizing innovative ways of bioremediation, the discovery of new isolates and phylotypes, linking diversity loss and pollution status to disease and poor health outcomes, and formulation of new policy directions that will mitigate future and further environmental degradation. These benefits are discussed briefly below (Fig. 1).

3. NOVEL HYDROCARBON DEGRADATION PATHWAYS/ENZYMES VIA METAGENOMICS

Metagenomics provides a means of assessing the totality of the genetic pool of all the microbes in a given environment in a culture independent fashion [9,10]. The introduction of xenobiotics such as those based on petroleum hydrocarbon into an environment has been shown to affect biodiversity in a number of ways. It reduces biodiversity and selects organisms with the ability or genes to degrade such xenobiotics [3,11,12].

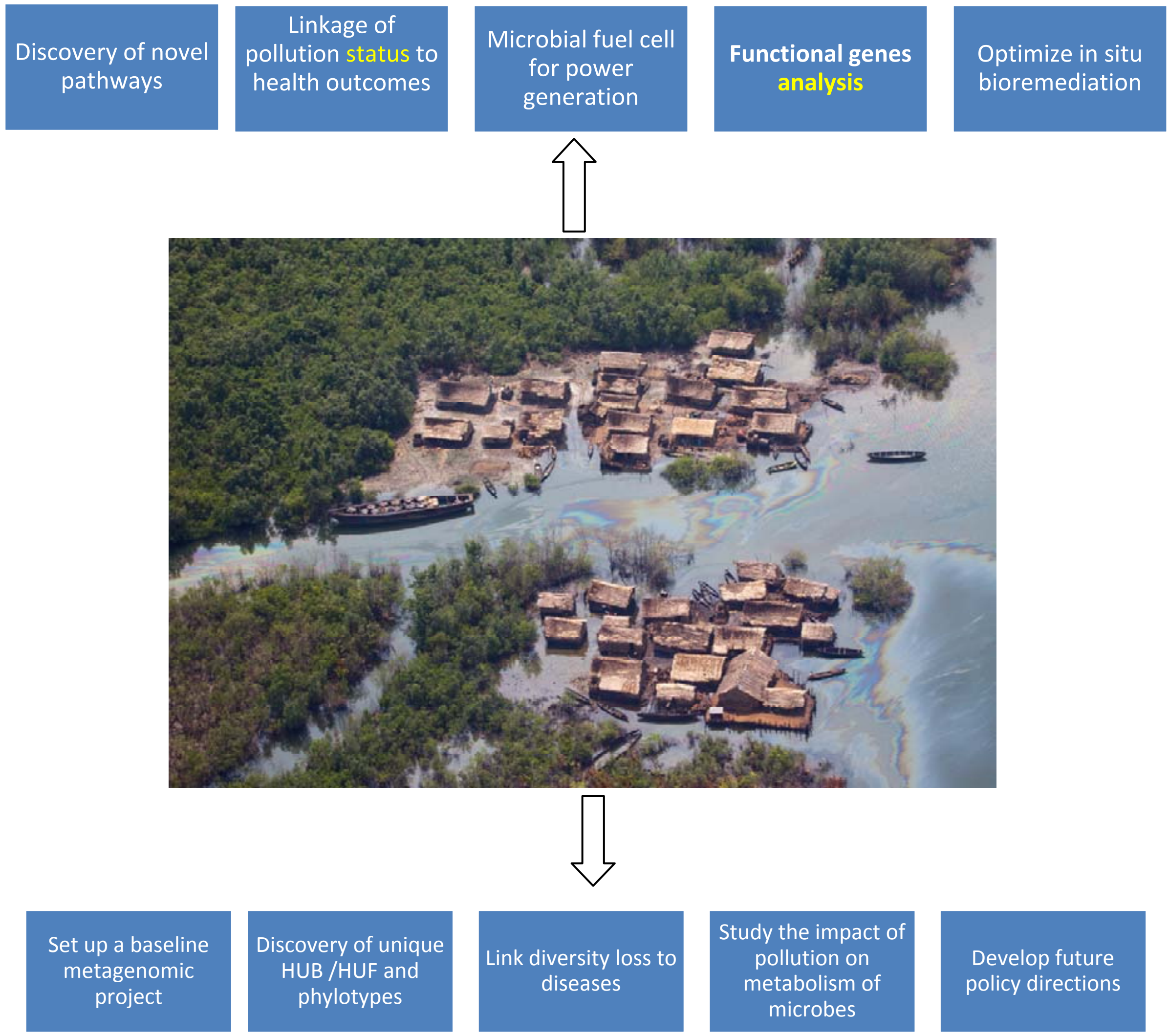

Fig. 1. Potential benefits to the Niger Delta. HUB/HUF represents hydrocarbon utilizing bacteria and fungi, respectively. Arial picture source is UNEP 2011 report.

Petroleum based hydrocarbons have been shown to be degraded via aerobic and anaerobic pathways [13,14]. Much of what is known about these pathways have come from the culturable minority based studies thus masking the potential role of the unculturable majority in degradation of petroleum based hydrocarbons. Using metagenomics, genes associated with hydrocarbon degradation in extreme environments such as benzoate, xylene, toluene, and benzene have been discovered using 16s rRNA amplicon sequencing and these were dominated by *Pseudomonas stutzeri* and *Acidovorax* species [15]. In another study, Sierra-Garcia and coworkers [16], using functionally driven metagenomics showed novel genes arrangements belonging to different pathways in petroleum reservoirs. Foght [17] have also shown some insights into the anaerobic degradation of hydrocarbon to methane and carbon IV oxide from oil sands using metagenomics. Metabolic pathways of certain hydrocarbon-degrading bacteria from the Deepwater Horizon blowout in 2010 in the Gulf of Mexico (one of the largest marine oil spills) have been worked out [18]. Despite all the oil spillages, there exists no study or studies at the time of press that has exploited same in the discovery of novel pathways in the region.

4. INDUSTRIAL ENZYME PROSPECTING

Globally, there is a great demand for enzymes or biocatalysts that are better in term of performance and more environmentally friendly than inorganic catalysts [19,20]. All environments whether pristine or impacted or aquatic or terrestrial, can support microbial populations that interact in complex fashion with biotechnological potentials [20]. Interestingly, genomic-based techniques now exist that are adaptable to chemistry specific high throughput expression assays [19]. Around the world and as can be seen in the figure below (Fig. 2), there are a lot of metagenomic studies as at 2015. Although a few studies have emerged from Nigeria from 2015 onwards that have used metagenomics [3,10], none is based on enzyme prospecting to the best of our knowledge. Nigeria is still largely behind in this regard despite the enormous benefits [10]. Enzyme prospecting is still in its infancy and as expected some bottlenecks have been identified thus far. These include poor performance in non-natural environment, lack or reliable bioinformatics pipeline to perform data analysis amongst others [30].

5. PETROLEUM-BASED HYDROCARBON BIODEGRADATION ENZYMES

Biodegradation or bioremediation of xenobiotics such as petroleum hydrocarbons is principled on the outstanding ability of microorganisms to elaborate enzymes that can utilize those hydrocarbons as a carbon source to form biomass and complete mineralization to less toxic forms [21,22]. The importance of enzymes in bioremediation process is seen as a valuable alternative as enzymes are a lot easier to work with than whole organisms in extreme environments and more acceptable than genetically modified organisms [21].

The map below indicates the various metagenomic studies around the world as of 2015 that used latitude and longitude to describe study site. As can be seen in the picture, the whole of West Africa has been left behind in this noble pursuit.

6. OPTIMIZING BIOREMEDIATION

Microbes are the main drivers of bioremediation and shifts in microbial community composition may impact the fate of a contaminant in an environment [23,24]. In addition to the structural composition changes, an array of other factors such as nature of the contaminant and environmental factors also drive the process [25,26]. Given the complexity of bioremediation process, it is important to understand these complex interactions if bioremediation is to be optimized. In order to resolve this impasse, environmental system biology approach has been proposed and deployed [26-29]. Interestingly, this approach employs several "omics" approaches such as metagenomics, metatranscriptomics, and metaproteomics [11]. Given the incessant oil spillage, a number of laboratory-based bioremediation and bioaugmentation studies have emerged from the Niger Delta in an attempt to restore the region [29-33]. However, none of the bioremediation strategy has been optimized using system biology and "omics" techniques.

7. MICROBIAL FUEL CELLS

The adequate power supply has been identified as an inevitable prerequisite for any nation development [34,35]. Despite reform upon reform, Nigeria as a country is still grappling with poor and unstable electricity generation since independence and as at 2014, the generation of electricity was still below 4,000 MWh [34,36]. By 2030, it is estimated that the energy demands would be 297,900 MW. In order to boost the energy production and distribution, alternative power sources have been suggested such as nuclear energy, wind energy, solar energy, and so on. Although these sources are really laudable, a number of demerits in them have made them unattractive at the moment. A microbial fuel cell (MFC) is an electrochemical system whose reaction is thermodynamically spontaneous, favourable and leads to the production of electricity [14]. Interestingly, MFC utilizes microbes and can operate aerobically or anaerobically, with a single microbe or a microbial consortium that catalyzes the anodic oxidation of substrates with concomitant electricity generation when connected to a resistor via a circuit to the cathode. In addition to the bioelectricity generated, the biodegradability of the substrate is also achieved at the anode [37]. As far Nigeria is concerned there is a serious dearth of studies on MFC [38-40].

In a recent study, the biodegradation of hydrocarbons were tested with a mixture of phenanthrene and benzene under different operating conditions that affect biodegradation of petroleum hydrocarbons [14]. The conditions selected for the study were temperature, various substrate concentrations, supplementation with surfactants, and cathodic electron acceptor type. The results showed 80-98% biodegradation and a maximum power generation of 10 mWm^{-2}. In another study, phenanthrene contaminated soils were also investigated. The results showed 86% and 95% reduction of phenanthrene and bromate with simultaneous power generation of about

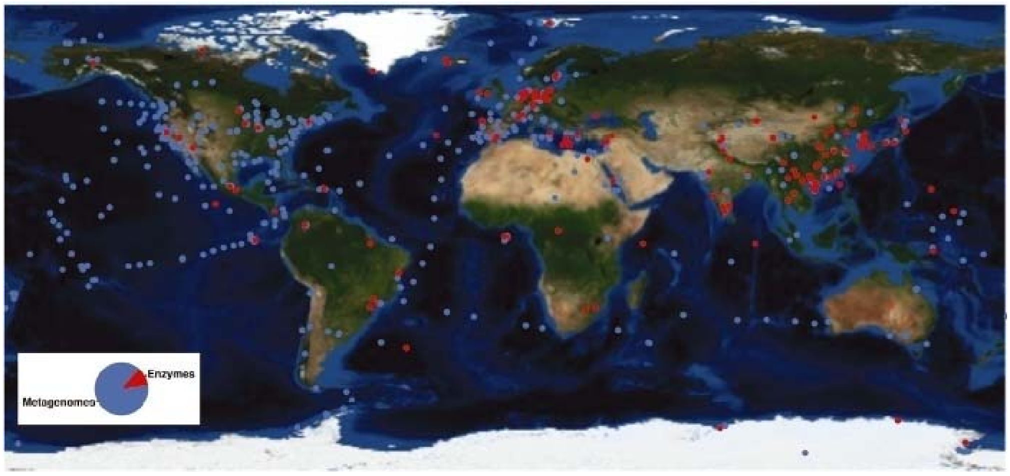

Fig. 2. A survey of metagenomic studies performed worldwide (Source: Ferrer et al. 2015) [18]

4.69 mWm^{-2} with their designed MFC system [14]. As far as the Niger Delta region of Nigeria is concern, it is estimated that since exploration activities began, about 9 to 13 million barrels of crude oil seepage have been reported thus far. Furthermore, the report revealed benzene and PAHs levels of 1,800 and 500 times higher than World Health Organization permissible limits (5 $\mu g\ L^{-1}$ and 10 $\mu g\ L^{-1}$) [5].

8. SET UP A NOVEL METAGENOMICS PROJECT

Metagenomics has various applications far beyond environmental ecology [3]. The impact that incessant oil spillages have on the Niger Delta microflora and macroflora and by extension the various ecosystems is still elusive. This is largely because field-based and laboratory studies coming out from the region are based on culturable techniques. These techniques do not capture the unculturable majority that is known to play prominent roles in the ecosystem. Around the world, huge metagenomic studies have been carried out that have produced enormous and useful data. Such studies include the Sargassso sea study [41] and several other environments [42]. As can be seen from Fig. 2, very few studies have employed metagenomics in the description of biodiversities in polluted and non-polluted sites in the country as a whole.

9. LINK DIVERSITY LOSS AND POLLUTION TO DISEASE

At the zenith of the oil boom (1970), life expectancy in the Niger Delta was placed at 60 years but as at 2000, this had reduced to 46.8 years [43]. This drastic reduction in the life expectancy is not completely unconnected to the pollution of the region following years of unchecked oil spillages. In a recent study, high levels of disease symptoms and environmental distress such as worry, annoyance and intolerance were associated with oil pollution amongst 600 participants drawn from five local government areas in Akwa Ibom State, one of the highest oil producers in the Niger Delta [44]. In an earlier study, a number of health challenges were associated with the 1996 oil spillage in Eastern Obolo with higher prevalence in groups exposed to crude oil spillage. The health complaints were a headache, nausea, vomiting, diarrhoea, sore eyes, cough, itching skin, amongst others [45].

Alterations of human microbiome have been linked with a number of diseases including pelvic inflammatory and non-inflammatory diseases [46,47]. Increasing evidence suggests that environmental stressors that disturb this delicate microbiome balance may be driving various disease states such as infectious gastroenteritis, obesity, and gastroenteritis cancer [48]. In a recent study, air pollution with particulate matter was shown to alter gut microbiome and immune functions in normal and inflammatory states [46]. Similar studies are lacking in the region in this direction.

10. UNIQUE PHYLOTYPES AND IMPACT OF POLLUTION ON THE METABOLISM OF MICROBES

Crude oil is known to be toxic to living organisms be it microscopic and macroscopic [47]. Furthermore, studies have shown that crude oil spillage or pollution brings about selection of crude degraders and also succession [48]. This dynamics is best captured with molecular than cultural based studies [10,52]. Metagenomics has basically two approaches namely structural and functional metagenomics. Structural metagenomics allows for the discovery of unique phylotypes following next-generation sequencing and bioinformatic analysis. Functional metagenomics, on the other hand, allows for the assessment of the various metabolisms of a given site at the time of sampling. A number of pipelines exist that are used for functional genes analysis [3,53,54]. Thus far, a few studies exist that have used metagenomics to discover unique phylotypes and metabolism dynamics from the Niger Delta environment [3,10].

11. DEVELOP FUTURE POLICY DIRECTION

There is no a doubt that the Niger Delta is in dire need of an effective and strategic cleanup and remediation plan. In order to achieve this, there is a need for a clear policy direction that will guide the future handling of crude oil spillages. Lessons learned from Ogoniland and other oil producing communities spillages should be integrated into this policy and possibly into the Petroleum Industry Bill.

12. CONCLUSION

Metagenomics and other “omics” based technologies have numerous environmental and ecological applications as highlighted in this review paper that has remained elusive to the Niger Delta region. The restoration of the region is inevitably important not just to the Nigerian economy but to the inhabitants of the region. Although serious pollution concerns have been raised over the years, future restoration studies should bear in mind the potential benefits such as raised herein.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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