Petroleum hydrocarbon contaminated groundwater remediation using 21st century technology: Baruwa community, Lagos State Nigeria as a case study

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Abstract. This research focused on geo-environmental site assessment and remediation of contaminated soil/groundwater. Baruwa community is the study site and it is located at Alimosho Local government area of Lagos State, Nigeria. About 350 hand dug wells for domestic water supply are in the community, all the wells are contaminated with petroleum product from leaking underground pipeline that transverse the community. Free hydrocarbon product thickness up to 0.72m was found on top of the groundwater in the hand dug wells. The main objective of the project was to take a hectare (100m x 100m) of the most contaminated area and remediate the groundwater to permissible level using the most up-to-date equipment and technology. Integrated Remediation Approach (IRA) was utilized; this involves physical and chemical method. The physical method involves the use of skimming-off technology that draws out the pure non-aqueous phase liquid (PNAPL) from the hand-dug wells. Chemical method adopted was in-situ chemical oxidation (ISCO), which involves injecting oxidizing agent (KMnO4) to the groundwater in the hand dug wells. Notable depletion in the values of TPH from a maximum of 500ppm to 20, 0, 25, 6, 6, 0.7 ppm for the six monitored wells during the 30 weeks of observation.

Keywords: Geoenvironmental, Groundwater, Hydrocarbon, Skimming-Off, Chemical oxidation.

1. Introduction
From the survey of [1], 65 million Nigerians have been estimated to be without adequate possibility of getting good drinking water. Groundwater is said to be water that is present underground [2]. It represents all the water present in the soil’s space and fissures within geological formations that come from precipitation either directly by infiltration or indirectly from rivers [3]. The standard of drinking water consume by people is a strong determinant of people’s health [4]. Appropriate distribution and supply of safe quality drinking water is universally recognized as a basic human need and it is assumed to be indispensable. Groundwater is assumed to be fresh water and it account for about 95 percent of fresh water resources. Consequently, water is the most essential and precious of all natural resources and groundwater is a salient source of water supply. It plays a cardinal role in all sphere of human life [5]. The
excessive and immeasurable utilization of groundwater can be described by the simplicity of accessibilty, effective preservation from contaminants compared to surface water, less subject to seasonal changes [6] and also low cost of production [7]. These benefits make groundwater a water that can be supply in large scale [6]. Human activities has increase the rate of environmental degradation currently experience throughout the world today. In all continents, living creatures including humans are affected by oil exploration. An oil spill is the accidental release of petroleum product into the environment. The effects of oil contamination are very enormous.

The primary objectives of site decontamination is to restore soil and groundwater quality. In site remediation, appraisal of the limit of technical expertise, existing government regulations, environmental protection desired and economics is very important. Numerous technologies to remediate sites exist, namely, excavation, air stripping, carbon bed adsorption, incineration (thermal destruction), bioremediation, soil vapour venting and natural attenuation [8]. In Situ Chemical Oxidation (ISCO) has been one of the method used for the remedy of chlorinated organic solvents and petroleum hydrocarbons for over three decades [9]. While the biostimulation-based methods are generally slow, the in-situ chemical oxidation (ISCO), by which organic contaminants can be break up or metamorphose into more biodegradable forms, is considered fast [10]. The ISCO techniques have mostly been adopted in the USA, whereas in Europe, technological and regulatory restrictions have limited their use [11].

2. Materials and Methods
2.1. Description of Study Area
Baruwa community lies in Latitude 6° 35’ N, Longitude 3° 16’ E. The community is about 42 metres above the sea level. And is located at the Lagos suburb in Alimosho Local Government Area of Lagos State; South Western Nigeria (Figure 1). This community suffered from the ruptured pipelines of NNPC/PPMC that occurred within the year 1994 and 1996. The leakage of petroleum product from the pipeline that transversed the community went unchecked for several weeks and contaminated the underground water bodies, polluting wells and boreholes, thus rendering the waters unsuitable for consumption.

![Figure 1. Map of Nigeria showing Lagos State indicating Baruwa the case Study Site](image-url)
2.2 Equipment and Field Tools used on Field

2.2.1 Oil/Water Characterization

The procedure was carried out according to the ASTM procedures for monitoring of hydrocarbons contaminated sites. (ASTM E1943 - 98(2015)). The oil/water interface meter (Figure 2), was used to determine the depth to the surface of liquid, the thickness of the pure phase hydrocarbon and the water in the monitoring wells.

![Figure 2. Oil/Water Interface Meter](image)

2.2.2 Recovery of Less Non-Aqueous Liquid (LNAPL) from the Contaminated Wells

This method is known as pre-ISCO mass recovery technology. The oil skimmer (Figure 3) works utilizing the basic physical principles of surface tension and relative density. Once the rotating belt turns, it passes through the floating layer of oil at the surface.

![Figure 3. Model 8 Oil Skimmer](image)

2.2.3 In-situ Chemical Oxidation (ISCO)

Potassium permanganate was used as the oxidizing agent for the remediation of contaminant of concern (COC) during the research. Batching of the oxidant at 5% concentration was adopted, i.e., 50 gramms of KMnO₄ to 1litre of water [12]. The injection of potassium permanganate was done by gravity feed to the monitoring wells within the pilot test area.

Test was carried out on the groundwater samples before the introduction of potassium permanganate to the groundwater (Pre-injection test), this was done to ascertain the concentration of COC, subsequently water samples were taken periodically after the injection of oxidant (Post- injection test) in order to
monitor the rate of reduction of COC per time. Unique portable hydrocarbon analyzer (PHA) (Plate 1) was utilized for the purpose of monitoring the concentration of COC per time at in-situ. [13]

Plate 1. Water Samples Testing with Petroleum Hydrocarbon Analyser Meter

2.2.4 Biostimulation of chemically oxidized groundwater
Nitrogenous Fertilizer was used in the oxidized contaminated groundwater at the same concentration established for chemical oxidation, i.e., 5%. Plate counts were used for measurement of the microbes that are present in the sample that will grow on the media used, under the conditions incubated [14].

3. Results and Discussions
3.1. Hydrocarbon Thickness Characterization before Remediation
Figure 4 presents the level of Light Non-Aqueous Phase Liquid (LNAPL) thicknesses of all the six wells monitored. The product thickness in the wells varies from 0.491m to 0.001m in 2014. Highest thickness of free hydrocarbon was found in W17 (Shodehinde well) and the least recorded in W44 (Lasu Faremi) and W41 (Pa Oyewole). From [15] research, it was observed that the reduction of LNAPL from 0.72 m to 0.491 shows that natural attenuation is feasible and attainable, this is in accordance with the concept of natural attenuation by [16] and [17].

Figure 4. Thicknesses of Light Non-Aqueous Phase Liquid (LNAPL) Prior to Remediation (2014)
3.2. Total Petroleum Hydrocarbon Concentration Characteristics Prior ISCO

Figure 5 depicts the concentration of the TPH, the TPH was measured at in-situ with the Petroleum Hydrocarbon Analyzers, the control sample recorded 0 ppm value showing clearly of absence of contaminants in the control well which is off the contaminated zone (see Figure 1), the wells within the pilot test area recorded values ranges from 243 ppm to 512 ppm, W20 (Baale well) recorded the least contaminant concentration of 243 ppm in May 2015 before the commencement of ISCO follow by Oyewole with value of 296 ppm. Ajayi well recorded the highest value of 501 ppm in May 2015.

![Figure 5. Real-Time TPH Concentration in Wells Using PHA-100 Hydrocarbon Analyzer before ISCO](image)

Figures 6 to 8 show the plots of TPH values for W35, W20, W17, W41, W44 and W53 respectively for the observation period of 30 weeks. For W35 (Kamila), the TPH value decreased significantly from 350 ppm before the injection of oxidant to 20 ppm at the 30th week after injection (3/12/2015). W20 (Baale) reduced from 299 ppm to 167 ppm on the 12th week after injection (29/7/2015). The TPH value of W17 (Shodeinde) diminished from 324 ppm to 25 ppm on the 30th week (3/12/2015) after injection; also W41 (Oyewole) reduced from 300 ppm to 6 ppm on the same 30th week after injection. For W44 (Faremi) TPH value before introduction of the oxidant was 319 ppm and significantly reduced to 6 ppm at 30th week after injection of oxidant likewise W53 (Ajayi) reduced from 512 ppm to 0.7 ppm after 30th weeks of oxidation. Thus, most of the petroleum hydrocarbon contamination had been removed by chemical oxidation after 30 weeks of injection of potassium permanganate.

The continuous degradation of the COC even at 30th weeks of monitoring shows the persistence of the KMnO₄ in the subsurface, this trend is in agreement with previous research carried out by ([17]; [18]). The results obviously shows that treatment of the pollutants over a much shorter time frame has demonstrated in the research of bench treatability of petroleum contaminant in Three dimensional (3D) laboratory sand tank by Ola et al., (2015). The results reviewed that the reduction efficiency of ISCO on the COC during the remediation was high with the level of the degradation of the COC.
Figure 6. Isopach of Total Petroleum Hydrocarbon Concentration for Monitoring Wells in May 7th, 2015 (Zero week of ISCO) in mg/l.

Figure 7. Isopach of Total Petroleum Hydrocarbon Concentration for Monitoring Wells in July 21st, 2015 (11th week of ISCO) in mg/l.

Figure 8. Isopach of Total Petroleum Hydrocarbon Concentration for Monitoring Wells in December 3rd, 2015 (30th week of ISCO) in mg/l.

4. Conclusion

i. From the isopach plots, the thickness of hydrocarbon (LNAPL) reduced significantly in all the six wells from 2006 to 2014, because of natural attenuation. i.e., 0.72 to 0.098; 0.35 to 0.001, 0.73 to 0.491, 0.65 to 0.221, 0.53 to 0.001, 0.120 to 0.033 in W20, W41, W17, W35, W44, and W53 respectively.

ii. Over 800 litres of pure phase hydrocarbon (LNAPL) floating on the groundwater was skimmed off.

iii. There were significant reductions in the values of TPH in the groundwater from a maximum of 500 ppm to 20, 0, 25, 6, 6, 0.7 ppm for the six monitoring wells with the injection of 50 grammes/litres potassium permanganate (KMnO₄) as the oxidizing agent for a period of 30 weeks.
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