

**BIOSTIMULATION OF CHEMICALLY TREATED PETROLEUM
HYDROCARBON POLLUTED SOIL.**

**THIS THESIS IS SUBMITTED TO THE UNIVERSITY OF GHANA,
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DECLARATION

On my honour, I hereby humbly declare that with the exception of references cited in this study which have been duly acknowledged, this thesis is the result of a detailed and painstaking research undertaken by me under effective supervision; and that neither part nor whole of it has been presented elsewhere in pursuance of the award of another degree.

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DEDICATION

This project is first of all dedicated to Jehovah God Almighty. It is also dedicated to the family of Masen Kafui Koranteng. It is finally dedicated to the environment and people of the Ahanta West District coastline who remain vulnerable to potential major oil spills from exploration and production activities in the Jubilee and other nearby offshore oil fields.



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The completion of this thesis would have not been possible without the immense contributions, suggestions and directions from my supervisory team: Dr Daniel Nukpezah, and Dr Ted Nii Yemoh Annang. I am highly grateful for their guidance, encouragement and assistance, and say God richly bless them.

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ABSTRACT

Environmental and social challenges from oil spills remain an industry concern, prompting studies into effective cleanup approaches. The use of H₂O₂ and biostimulation have gained popularity in recent times. This study investigated four key issues on adopting H₂O₂ and biostimulation in oil cleanup. First, was to identify the optimal percentage concentration of H₂O₂, needed to oxidise petroleum hydrocarbon contamination in coastal soil from the Ahanta West District. The second was to evaluate the potential of enhancing the soil treatment process by biostimulating the pre-oxidised contaminated soil using chemical fertilizer. The third was to compare and evaluate which treatment method was cost-effective over a period of 24 days. Finally, the study investigated perceptions, knowledge and expectations of three coastal communities (Dixcove, Akwidaa and Cape Three Points) on oil spills clean-up response. Pristine coastal soil from Cape Three Points was spiked with crude oil from TEN oil field. Treatment with different concentrations of either 6%, 30%, or 60% H₂O₂, or a combination of either one of the H₂O₂ concentrations and a chemical fertilizer as biostimulant was undertaken. Laboratory tests were conducted on soil samples over a 24 day period on total petroleum hydrocarbon levels (GC-MS), polycyclic aromatic hydrocarbon levels (GC-MS), and nutrient levels (nitrogen, phosphorus and potassium). The study established that treatment with 30% or 60% H₂O₂ over a 3 day period was the most optimally efficient remediation approach, while biostimulating soil pretreated with high H₂O₂ concentration does not significantly improve natural treatment potential of the soil within a period of 24 days. The most cost-effective treatment approach was the use of 6% hydrogen peroxide. The study further established that critical gaps existed in community knowledge and understanding on oil spill cleanup duration.

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CHAPTER ONE

INTRODUCTION

1.1 BACKGROUND

1.1.1 Oil industry and spills

Petroleum/Crude Oil constitutes approximately 34 percent of the world's energy needs, according to (World Energy Council, 2013)World Energy Council (2013). Worldwide, in excess of 20 million tonnes of petroleum products are used daily (Fingas, 2015). This heavy dependence on petroleum drives the growth of the upstream, midstream, and downstream oil and gas industry globally. The upstream sector is characterised by exploration, development and production of oil and gas. The midstream is often grouped with the downstream sector and together consist of the gathering, processing/refining, transportation, storage, and marketing aspects of the oil and gas industry.

Occasionally, oil spills occur as a result of activities within the upstream, midstream, and downstream sectors with the upstream sector contributing an estimated 5% of oil pollution to the sea, while natural seeps from oil reservoirs constitute about 50% of oil pollution in the sea (Fingas, 2015). The midstream oil and gas sector contributes 45% of oil pollution to the sea, with oil tankers and pipelines being major contributors (Inkpen & Moffett, 2011).

Accidental spills may occur during offshore oil and gas exploration/prospecting or from shipping vessels (mostly oil tankers) (Andersson et al., 2016; Wawryk, 2014). Evidence points to the fact that shoreline ecosystems across the world are impacted

negatively by many offshore oil spills (Duke, 2016; Schiel et al., 2015; Defeoa et al., 2009; Nwilo & Badejo, 2005; Pezeshkia et al., 2000).

These impacts include, the suppression of microbial activity and diversity (especially aerobes) due to the displacement of soil air and water by the oil, the reduction in water infiltration capacity of the polluted soil, the poisoning of native soil macro-organism by toxic compounds in the oil, and the bio-magnification of toxins along the food chain (Levine, 2016; Acosta-González et al., 2015). Effects of petroleum hydrocarbon pollutants on the environment are often difficult to isolate, as wind, water and other environmental elements easily transport mobile petroleum hydrocarbon pollutants to neighbouring ecosystems (Alloway & Ayres, 1997). This implies that an offshore oil spill can have environmental consequences on neighbouring terrestrial ecosystems and *vice versa*.

When an oil spill occurs offshore, the oil is dispersed by the ocean current. During this period of transport, oil weathering processes (OWP) degrade the spilt oil. A small concentration of the oil dissolves into the seawater, while heavier fractions sink to the bottom of the ocean. The volatile constituents of the remaining floating oil are evaporated by the action of wind and sunlight. Photolysis further breaks down some portions of the oil constituents, which may then be evaporated by wind and sunlight. Eventually, nearby coastlines may be contaminated with what is termed “weathered oil” (Mishra & Kumar, 2015). In other instances, tar balls or tar mats, which are formed through the adhesion of weathered oil droplets, are deposited along the shoreline (Fingas, 2015). The nature of the oil (viscosity, API, chemical composition, density) and the type of soil at the beach can

influence the level of contamination. Oil hardly penetrates fine-grained sand beaches but may percolate down to several centimetres in gravel beaches (Hayes et al., 1992).

Due to the adverse environmental and often socio-economic impacts associated with oil spills, clean-up efforts are taken seriously and undertaken quickly if possible. A well planned and executed clean-up can totally mitigate the expected adverse effects of an oil spill (Fingas, 2015).

To ensure minimal impact to shorelines require that more oil is recovered from the water surface after an offshore oil spill. Cleaning up an oil spill offshore is relatively easier and cheaper than onshore clean-up (Fingas, 2015; Dagmar, 1999). Aroh, et al., (2010) point to the fact that oil spill events need to be documented and reported early enough for prompt attention by regulatory agencies in order to protect and enhance the quality of the environment.

To adequately respond to an oil spill, certain factors need to be probed. These factors include; the physical properties of the oil and how they will be changing with time; how these changes will affect the oil's behaviour and fate in the environment; how the oil will interact with water to form emulsion; the possibility of the oil submerging into water; the toxicity of the oil to marine, aquatic and coastal life (Fingas, 2015).

Generally, the first response to an oil spill offshore is to physically contain the oil or divert it from sensitive areas. Other methods of clean-up employ chemical or biological agents and methods (Fingas, 2015). The cheapest clean-up approach is to passively allow natural factors like sunlight, wind, and biological metabolism, to slowly remove the oil from the environment, but this may not be the best option in large spill incidents.

1.1.2 Physical clean-up:

Because oil easily floats on water, it forms a slick which is a few millimetres thick on the water surface. Skimmer equipment can be employed to collect oil from the water surface, or polyurethane foam to absorb the oil after booms have been used to contain the oil (Canevari, 1969). This clean-up approach can however be quite ineffective under high seas conditions of strong winds (Fingas, 2015).

In the case of tar balls polluting a beach, physical clean-up can be done with machines or hand picking (Fingas, 2015). For *ex-situ* treatment, the entire top layer of polluted beach sand is removed and replaced with fresh unpolluted sand in some instances. The polluted sand removed, can be heated in a combustion chamber to remove the oil from it (Riser-Roberts, 1998).

1.1.3 Chemical clean-up:

The use of chemical dispersants to clean up oil spills became popular due to their effectiveness in dispersing heavy and weathered oil (Lessard & DeMarco, 2000). Extensive laboratory testing and field trials show that dispersants work on a similar principle as kitchen washing liquids (contain molecules with a water-compatible "hydrophilic" end and an oil-compatible "lipophilic" end). This breaks up large globs of the oil into smaller droplets, by lowering the interfacial tension of the oil and preventing the droplets from clinging to each other (Cressey, 2010; Lessard & DeMarco, 2000). Smaller oil droplets increase the surface area of the oil to enable oil-degrading microbes present in the environment to quickly break down the oil (Cressey, 2010; Swannell & Daniel, 1999).

Widely used and most effective dispersants include Corexit 9500 and Corexit EC9527A (Hayes et al., 1992). As at 2010, over a million litres of these two dispersants had been used in the Gulf of Mexico oil spill clean-up alone (Cressey, 2010). Long term effects of using Corexit at the scale used today is somewhat unknown. However, it is suspected that the dispersant is inherently toxic to various life forms, including humans (Cressey, 2010). A review of the safety data sheet for Corexit reveals the main/active components as 2-butoxyethanol, a proprietary organic sulfonate, and propylene glycol (Nalco, 2008). 2-butoxyethanol is carcinogenic in animals and may be in humans as well (Siesky et al., 2002; Elliott & Ashby, 1997).

An added controversy to the use of Corexit and other dispersants like Arcochem D609, Dasic LTS, and Conco K (K), arises from the possibility of increased exposure of aquatic and coastal species to toxic components in oil through the dispersion process. Studies have supported evidence that marine species, and shoreline flora and fauna are exposed to harmful compounds in oil after dispersants are applied to the oil (Chapman et al., 2007; Ramachandran et al., 2004; Thorhaug & Marcus, 1987).

For over a century, many applications in chemical oxidation of organic contaminants in water and wastewater treatment using agents like ozone, permanganate, Fenton's Reagent, and persulphate, have been made. What remains relatively less exploited, is the chemical oxidation of organic contaminants in soil treatment (Goi et al., 2009). Hydrogen peroxide is a known effective oxidizer of petroleum hydrocarbons in soil (Direct & Thacker, 2010; Goi et al., 2009; Lehr, 2002). Though higher concentration can rapidly oxidise heavy hydrocarbon constituents, high concentrations of the chemical can disrupt native microbial activity, affecting natural soil contaminant degradation capacity (Xu et al.,

2016). This constitutes a trade-off, however, the cost of treatment with higher concentrations of the chemical may be higher.

Degradation of any contaminant (example Polycyclic Aromatic Hydrocarbons, Petroleum Hydrocarbons, Organophosphates or Organochlorides) in soil with hydrogen peroxide is either by direct oxidation by the peroxide and/or free radicals (hydroxyl radicals $^{\bullet}\text{OH}$), Superoxide anion ($\text{O}_2^{\bullet-}$), hydroperoxyl radical (HO_2^{\bullet}), and hydroperoxide anion (HO_2^-). The presence of transition metals (Fe, Cu, Zn, .) in soil catalyses the formation of these radicals (Goi et al., 2009). Thus, the treatment of contaminated soil with hydrogen peroxide would require no addition of soluble iron catalyst. As a side advantage, aerobic biodegradation of contaminants can benefit from the presence of oxygen released during hydrogen peroxide decomposition (Fingas, 2015).

Hydrogen peroxide decomposes readily, hence it does not accumulate in the food chain. It has little to no issues associated with groundwater or surface water pollution. It is also not classified as a carcinogen according to the United States Agency for Toxic Substances and Disease Registry (US ATSDR) since 2002.

1.1.4 Biological clean-up:

The use of microbes in the remediation of oil spills is quite common among all bioremediation approaches, and the most suited for tropical regions. This is partly due to the lower cost in using the approach, as well as the ability of microbes to easily adapt to changing environmental conditions (Vidali, 2001).

In a study by Saini and Arya (2016), plant survival in soil contaminated with crude oil was enhanced by biotreating the soil with bacteria (namely *Pseudomonas fluorescen*

and *Bacillus subtilis*). Another study by Becker et al., (2016), simply used fertiliser to stimulate native microbes in a contaminated soil, and achieved the removal of *n*-alkanes to trace levels, while isoalkanes were totally degraded after 42 days. Using a bacterial consortium of mainly *Pseudomonas sp.*, together with fertiliser and rice husk, Xu et al., (2016) decontaminated soil containing *n*-alkanes, and polycyclic aromatic hydrocarbons (PAHs), at an efficiency of 95%.

Phytoremediation of soil contaminated with crude oil is also an area where a lot of studies are being conducted. Not many plant species have shown success in remediating oil pollution, but the few that do are able to remove appreciable levels of hydrocarbons from the soil. Ikeura et al., (2016), investigated the ability of thirty-three different flowering plants to clean-up oil contaminated soil, but only four species including *Mimosa*, *Zinnia*, *Gazania*, and Cypress, recorded successes in the study. According to them, "The total petroleum hydrocarbon concentration of the soils in which the 4 species of plants were grown decreased by 45–49% by the 180th day".

Literature indicates that microbial remediation is generally time conserving than phytoremediation. This is based on the fact that microbes have more metabolic pathways compared to plants. Also, microbes grow and multiply in a shorter period of time than higher plants, hence ensuring increased metabolic activity in the soil to break down oil contamination (Sylvia et al., 2005; Cerniglia, 1984)

1.1.5 The cost of clean-up:

A universal per/unit clean-up cost may be unrealistic in a number of occasions, as factors that affect cost are complex and interrelated. Conditions prevailing at any spill site may be

unique as well. Factors like the location characteristics and affected areas of the spill, the type of oil spilt, local and national laws, and clean-up strategy, greatly influence the cost of clean-up. Clean-up cost for shoreline can be as much as 20 times higher than for offshore for example (Dagmar, 1999).

Clean-ups that primarily involve a dispersant approach only, are cheaper than those that use a variety of methods (Dagmar, 1999). As at 1997, the average cost of cleaning a tonne of spilt oil in Africa was estimated US\$1,078. Europe averaged US\$8,595/tonne, USA averaged US\$73,156/tonne, and Asia averaged US\$15,005/tonne (Dagmar, 1999). With an average inflation rate of 16% in Ghana from the year 1997 to 2016, the average cost of cleaning up a tonne of oil spilt today can be predicted to be US\$18,085 (US\$61.5/gallon). This assumption is based on Dagmar (1999) initial estimation for Africa.

1.1.6 Community engagement

The extractive industries, including the oil industry, is often associated with community development, most especially infrastructural and economic and social development of communities in close proximity to or within whose jurisdiction the extraction takes place. Development of these communities could result in positive and/or negative impacts on the well-being of individuals and the community at large (Brasier et al., 2011). In recognition of these possible impacts, governments and industry players make efforts to engage prone communities in order to help them address the issues that may arise and avoid unnecessary conflicts.

Conflicts between communities and the extractive industry are in most cases borne out of misunderstood and underappreciated expectations of the community, by both

Government and the extractive companies. In the case of the Niger Delta, Nigeria, the perceptions of local communities that inform their expectation of the government and the oil industry have had little consideration in policy formulation, resulting in the challenges that are continually observed in the region (Idemudia & Ite, 2006). The *Exxon Valdez* oil spill similarly encountered incensement and vengeance from affected communities in 1989, as the communities felt ExxonMobil (especially top management) showed little regard towards their concerns after the spill incident. ExxonMobil consequently paid greatly for that dispute and disconnect with the community. Idemudia & Ite (2006) argue that, until the expectations of local communities are taken critically into consideration by government and the oil industry, community interventions will continue to fail to achieve their intended goals.

Oil spills do not only affect the environment, but may also affect human health directly and indirectly (McCoy & Salerno, 2010). It is in this vein that the public's concern and voice on oil spills and their clean-up is crucial. Recent spill incidents across the globe and their associated consequences have escalated community concerns about the oil industry (Forrest & Mays, 1997). A study conducted by Palinkas et al., (1993), suggests negative sociocultural and psychological impacts, such as drug abuse, domestic violence, general anxiety disorder, depression, post-traumatic stress disorder, and a perceived decline in health status, may have an increased occurrence in a community following an oil spill. The study reveals that “persons between the ages of 18-44 years were particularly at risk for the three psychiatric disorders following an oil spill” (Palinkas et al., 1993).

1.2 PROBLEM STATEMENT

For the past six years, the oil and gas sector in Ghana has developed and gained more significance to the economy of the country (Annan & Edu-Afful, 2015). Ghana's major oil discovery is a 36.5° API Sweet Crude with a 1,000–1,200 gas-to-oil ratio and little sulphur content by international standards (Sunu-Attah, 2009). The oil discoveries are located in the Deepwater Tano and West Cape Three Points blocks, located 60 km off the coast of Cape Three Points (IBP Inc, 2016). Oil spills from these offshore areas could end up on the eastern shoreline of Ghana due to north-eastern direction of waves along the national coast, and would result in devastating environmental impacts. Offshore oil spills commonly affect organisms close to the water surface and onshore (Sumaila, et al., 2012).

The Ahanta West District in the Western Region of Ghana has the closest shorelines to these offshore blocks (Yalley et al., 2012). These shorelines are sandy in nature with capes and bays that attract many tourists and economic activity to the area. It is also characterised by popular and ecologically sensitive lagoons like Ehonle, Mabowodindo, Akpluho, Mfuma and Nana Pete, which serve as habitats and nursery sites for a diversity of fish, shrimps, mollusc, and crab species (GSS, 2014; Armah et al., 2004). The sandy shores of the Cape Three Points area serve as nesting grounds for sea turtles and habitats for species including the ghost crab, isopods, amphipods, mysid, mole crab, polychaetes, bivalves and gastropods (Armah et al., 2004). Up to 141 diverse trees, shrub, grass and sedge species have been documented to be found along the coast in the district (Armah et al., 2004).

Fortunately, no major oil spill event has been recorded from the oil fields in the country, with the exception of low toxicity oil based mud spilt by Kosmos Energy in the

Jubilee Field in December 2009 and March 2010 (Ghana EPA, 2010). Contingencies have however been put in place, by State Agencies (Ministry of Environment, Science, Technology and Innovation, EPA) to ensure proper management and response to any oil spill events, that may occur in the future (Sakyi et al., 2012). The National Oil Spill Contingency Plan is an example of such contingency plan. The contingency plan clearly makes provision for the use of chemical dispersants and agents for spill clean-up.

Using chemical dispersants in a clean-up exercise yields timely and efficient results. However, most chemical agents negatively impact the ecology of the soil, especially microbial activity (Pietroski et al., 2015; Cressey, 2010; Foght & Westlake, 1982). Ecosystem services including soil water quality improvement and soil primary productivity can be affected in this regard (Roger et al., 2016; Barrios, 2007).

In the scenario where chemical agents are to be employed in an oil spill clean-up, proper planning is required to balance the trade-off between clean-up efficiency and ecological stability. Ensuring higher clean-up efficiency often requires the application of high concentration of chemical oxidant to the soil. On the other hand, high concentrations of these chemical oxidants can either kill soil biota or heavily alter soil chemistry such that soil biota is unable to adapt and survive (Xu et al., 2016). The challenge then becomes determining the optimal concentration of chemical oxidant (in this case hydrogen peroxide) to use in quickly degrading large amounts of the hydrocarbons in a short period of time, and a way to biostimulate the partially treated soil for natural processes to take over and complete the clean-up.

Studies have been conducted to test the efficiency of combining chemical and biological methods for treating soil contaminated with petroleum hydrocarbons (Rosik-

Dulewska et al., 2015). However literature on the treatment of Ghanaian soils using this combined treatment approach has been limited, with focus mainly on heavy metal contaminated soils (Osei & Ahmed, 2013). Those that focused on treating petroleum contaminated soils either approached the treatment by chemical oxidation means or by biological means only (Fei-Baffoe et al., 2016; Ameko et al., 2013; Osei-Twumasi, 2011; Odokuma and Inor 2002).

Though no major oil spill has been recorded from Ghana's oil fields, the possibility of the event occurring creates concern for coastal communities that are likely to be impacted economically, socially, and environmentally. Cleaning up oil spills requires various parties including government, industry, and society, to play roles that are either assigned or expected of them. Failure of any party to adequately recognise and play their role effectively may lead to conflicts developing between parties involved or affected by an oil spill.

The Coastal Resources Centre (2013) reported that coastal communities in the Ahanta West District have a perception that government has given them inadequate attention and representation over the years. This is because the various expectations of the communities have not been met to their satisfaction. These expectations range from government's role in the provision of infrastructure, electricity, pipe-borne water, toilets, health posts, and waste management system (Coastal Resources Centre, 2013). Unfortunately, there is very little documentation of the expectations that these coastal communities have, regarding what their role and government's roles and responsibilities must be during an oil spill, especially the clean-up of the spill. Documentation of such

expectation could help in future decision making to avert conflicts during oil spill response in the area.

1.3 JUSTIFICATION

A review of literature revealed dearth of information on potential chemical clean-up of an oil spill along the shoreline of the Ahanta West District; the Ghana National Oil Spill Contingency Plan is among the few documentations on potential chemical clean-up of Ghanaian coastlines contaminated by oil spills. Hydrogen peroxide is a chemical which has shown positive results in the breakdown of crude oil (Direct & Thacker, 2010; Lehr, 2002), while its use only has few environmental repercussions compared to other chemical oxidants (US ATSDR, 2002). However, no studies have been conducted to test its potential application to coastal soil (Acric Ferralsol Ferric) from the Ahanta West District in the case of an oil spill.

While bioremediation (both bioaugmentation and biostimulation) has the potential to effectively degrade petroleum hydrocarbons in coastal soil (Acosta-González et al., 2015), biostimulation may yield more effective results than bioaugmentation in treating soil contaminated with a complex mixture of petroleum hydrocarbons (Willey, 2007). This makes biostimulation a more favourable option than bioaugmentation in the case where only one of the two methods is to be chosen and applied.

It is beneficial to investigate the potential of enhancing the efficiency of treating hydrocarbon contaminated soil, through a combined treatment approaches of chemical oxidation (hydrogen peroxide) and biostimulation. This investigation could yield a time

sensitive clean-up approach with few ecological setbacks compared with other approaches that currently exist.

The existence of such scientific study on the Ahanta West District coastline would serve as a decision support tool, for both state and private agencies, tasked to respond to oil spills in the district and its environs. The continued existence of this gap in knowledge could prove to be problematic in the event of a major oil spill in the area.

1.4 RESEARCH QUESTIONS

1. What level of efficiency can be achieved by synergising a chemical treatment and biological treatment in an oil spill clean-up?
2. What concentration of hydrogen peroxide would result in optimal efficiency in the treatment of hydrocarbon contaminated soil?
3. What economic cost will be associated with this clean-up approach?
4. What are the expectations of the Cape Three Points, Akwidaa, and Dixcove communities regarding their roles and government's roles during oil spill clean-up?

1.5 HYPOTHESIS

1. A combination of chemical treatment and biostimulation of oil impacted soil will have the same mean Petroleum Hydrocarbon concentration as a chemically treated alone soil.

2. A combination of chemical treatment and biostimulation of oil impacted soil will have the same mean Petroleum Hydrocarbon concentration as a biostimulated alone soil.
3. Higher concentrations of hydrogen peroxide in a spill clean-up results in lower Petroleum Hydrocarbon levels in soil.

1.6 OBJECTIVES

The study seeks to investigate combining chemical oxidation and biostimulation to efficiently clean-up shoreline soil from the Ahanta West District polluted with crude oil. Specific objectives include:

1. To determine the most optimal concentration of hydrogen peroxide to break down petroleum hydrocarbons in soil within a period of 24 days.
2. To investigate the potential of biostimulation in enhancing the efficiency of a chemically treated soil.
3. To evaluate the cost-effectiveness of adopting a chemical and/or biostimulation approach in treating petroleum hydrocarbon contaminated soil.
4. To investigate Cape Three Points, Akwidaa, and Dixcove communities' expectations regarding their roles and government's role in oil spill clean-up.

CHAPTER TWO

LITERATURE REVIEW

2.1 CRUDE OIL

Crude oil is a naturally occurring non-renewable resource primarily composed of hydrocarbons. It is a yellowish black liquid in appearance and found in geological formations beneath the earth surface (Simanzhenkov & Idem, 2013). Crude oil is formed when organic material is buried under sedimentary rocks under high pressure and temperature conditions for a very long period of time. The basic elemental composition of crude is carbon, hydrogen, nitrogen, oxygen, sulphur, and metals. Many compounds of different molecular sizes and classes constitute crude oil, with instances of 17,500 different compounds being found in some oils (Fingas, 2015).

Differences in chemical composition of the buried organic material account for the discovery of numerous varieties of crude oils across different geographical locations in the world (Fingas, 2015; Peters et al., 2013; Aldahik, 2010; Hitchon & Filby, 1984; Snowdon & Powell, 1979). The variation in the composition of crude oil results in certain unique characteristics of oil from different locations around the world. These unique characteristics influence the behaviour of oil and its fate when it is spilt in the environment (Fingas, 2015).

A common but old method of classifying oil is by the SARA classification (Saturates, Aromatics, Resins, and Asphaltenes) (Fingas, 2015). However, the petroleum industry often adopts references to geographical locations to descriptively classify crude oils. This is because oil from reservoirs in the same region is likely to have similar

composition and properties (Fingas, 2015). Over 160 different oils are traded on the market but the most popular are the West Texas Intermediate, Brent Blend, and OPEC Basket (Fingas, 2015; He et al., 2010; Lin & Tamvakis, 2001; Horsnell & Mabro, 1993).

In Ghana, major oil discoveries have been located in the Deepwater Tano and West Cape Three Points blocks, located 60 km off the coast of Cape Three Points (IBP Inc, 2016). The oil discovered is a 36.5° API Sweet Crude having a 1,000–1,200 gas-to-oil ratio and little sulphur content by international standards (Sunu-Attah, 2009).

2.1.1 Exploration and production

Just like exploring any other mineral resource, oil exploration begins when certain geophysical characteristics are detected within an environment. Surface features like rock, soil types, reservoir rock and entrapment, are critical pointers that geologists consider when exploring for oil (Society of Petroleum Engineers, 2001).

Initial exploration activities include gravity survey, magnetic survey, and passive seismic or regional seismic reflection surveys (Society of Petroleum Engineers, 2001). Any area of interest discovered is subjected to further seismic surveys until a prospect is discovered. An exploration well is then drilled to confirm the presence or absence of the oil (Society of Petroleum Engineers, 2001).

Prior to the 1970s, explosive charges were used in seismic surveys during exploration. However, the distractive and low effectiveness of this technique led to the development of the "Airgun detonation" technology. Together with modern computers, this new exploration technology can be used to develop 3D images of underlying rock structures (U.S. Department of Labor, 1993).

Currently, the number one producer of oil in the world is Russia (above 10.5 million barrels per day) followed by Saudi Arabia (approximately 10 million barrels per day), and United States of America (9.2 million barrels per day) (US Energy Information Administration, 2016).

In Africa (Nigeria, Angola, Algeria, Egypt, Libya, Ghana, etc), oil exploration is often carried out by international companies, mostly American and European ones, due to the expensive, resource intensive, and high-risk nature of oil exploration (Leonard, 1992). Oil exploration in Ghana goes as far back as 1898 with little success. However, the establishment of Ghana National Petroleum Corporation (GNPC) by the government in 1983 created the avenue to attract more oil and gas exploration and production companies to Ghana. Eventually, significant oil and gas accumulations were discovered in 2007 and commercial production commenced in what is known as the Jubilee field in 2010 (GNPC, 2016).

According to the US Energy Information Administration (2016), Ghana's average oil production per day was 7,200 barrels (in 2010), 77,000 (in 2011), 78,000 (in 2012), 98,000 (in 2013), 105,000 (in 2014), and 102,400 (in 2015). Comparatively, the country's oil production is no match to the major oil producers in the world.

2.1.2 Transportation and Processing

The transport of petroleum is either by means of rail cars, trucks, marine tanker vessels, or through pipelines. This sector is very critical in the value chain of the oil and gas industry. In principle, pipelines and tanker vessels are used to convey oil from its point of production (offshore) to an onshore storage or processing facility. This sort of transportation is often

undertaken on the international level and has a considerable level of risks associated with it. The key risk of concern during transportation and processing of oil is spillage into the sea (Fingas, 2015; US EPA, 2008). Rail cars and trucks are used extensively in the distribution of semi-refined and refined petroleum products to various markets mostly locally and on few occasions internationally. Processing of oil and gas in Ghana is primarily by the Tema Oil Refinery and the Atuabo Gas Processing Plant (Oxford Business Group, 2014). While the Bulk Oil Storage and Transportation Company Limited (BOST), and private companies like COMEXAS Group undertake oil and gas transportation activities.

2.2 OIL SPILL INCIDENTS

Evidence points to the fact that shoreline ecosystems across the world are impacted negatively by many offshore oil spills (Duke, 2016; Schiel et al., 2015; Defeo et al., 2009; Nwilo & Badejo, 2005; Pezeshkia et al., 2000). Offshore oil spills commonly affect organisms living close to the water surface and onshore (Sumaila et al., 2012).

The largest oil spill ever recorded did not occur by accident, but rather a deliberate act of the 1990-1991 Gulf war. Iraqi forces in an effort to stop American soldiers from landing opened an offshore oil terminal valve and dumped oil from tankers. An estimated 380-520 million gallons of oil was spilt, resulting in a 10 cm thick oil slick spreading across 10,360 km² in the Persian Gulf (Khadduri & Ghareeb, 2001). Extensive damages were caused to coastal salt marshes and mangroves, diversity and community structure of intertidal biota, and seabird populations (Price, 1998). Twelve years after the spill, soil

collected from the area contained polycyclic aromatic hydrocarbons at concentrations that pose significant ecological effects (Bejarano & Michel, 2010).

In Africa, the largest recorded oil spill occurred in the Bonga Field, Nigeria, with nearly 2 million gallons of oil spilt (Kostianoy et al., 2014). In Ishiagu, Ebonyi State, Nigeria, acts of vandalism resulted in damages to oil pipelines, spilling hundreds of thousands of barrels of crude oil into the environment. Consequently, water quality of freshwater ecosystems was degraded, affecting fish spawning and aquatic invertebrates' habitats, and eventually lowering food web productivity (Aroh et al., 2010).

The sinking of MV Treasure off the western coast of South Africa resulted in the spillage of approximately 84,420 gallons of oil. It is regarded as South Africa's worst oil spill incident. Though small in amount in comparison to other spill incidents across the globe, the spill resulted in over 20,000 penguins being oiled and approximately 2,000 died (Crawford *et al.*, 2010; Wolfaardt et al., 2010).

The situation in Ghana is rather respectable with no major oil spill event recorded in the six years of oil and gas production. Kosmos Energy however during their exploration stages spilt about 706 barrels of low toxicity oil-based mud in the Jubilee Field in December 2009 and March 2010 (EPA, 2010). Tullow Ghana Ltd is regarded to be operating safely without incidents offshore in the Jubilee Fields (Obeng-Odoom, 2014).

Based on the Jubilee Field Environmental Impact Assessment report by Tullow Ghana Limited (2009), shorelines west to Cape Three Points are most likely (1% - 15%) to be oiled by an offshore spill than shorelines to the east of Cape Three Points (1% - 10%). The report also indicates that spilt oil from the field could quickly reach the shoreline of Ghana within the shortest possible time of 1 to 2 days, but under normal circumstances

would take up to 4.5 days to reach the shoreline. Figure 2.2.1 shows a large spill of 20,000 tonnes could end up oiling some 100km of shoreline west of Cape Three Points, with some oil possibly beaching at large stretches of coastline east to Cape Three Points (Tullow Ghana Limited, 2009).



Figure 2.2.1: Trajectory of 168-hour spill of 20,000 Tonnes Crude from Jubilee field

Source: Tullow Ghana Limited, 2009

2.3 EFFECTS OF OIL SPILLS ON THE ENVIRONMENT

2.3.1 *Oil effects on marine life*

The immediate effects of an offshore spill are on the marine environment. Water quality within the immediate environment of the spill will be compromised, while marine organisms that frequently utilise the ocean subsurface and surface would be greatly impacted (Tullow Ghana Limited, 2009). Deeper dwelling organisms in the sea may not be immediately affected as they can easily migrate away from the contaminated area.

2.3.2 *Oil effects on soil*

Ocean current and prevailing wind may cause spilt oil to beach along the coastline and contaminate the coastal soil and ecology. Oil contamination in soil differs from what is observed in aquatic environments, as oil vertically infiltrates the soil subsurface easily. While infiltrating the soil, some of the toxic oil components will be sorbed, which could lead to a persistent source of contamination in the soil. Volatile organic compounds may be confined in the soil matrix for prolonged periods of time, posing a significant toxic risk to soil organisms (Willey, 2007).

Top soils are rich in organic matter, nutrients (nitrogen, phosphorous, calcium, iron, and magnesium), water, and air. This makes it ideal to serve as a home for different living organisms. These components of soil need to exist and interact in a certain balanced state in order to adequately support soil biota. Crude oil, however, is capable of disrupting that balance by displacing air and reducing the water holding and infiltration capacity of soil. This creates a limiting condition of low available soil air and water to support life in the soil. The biological decomposition of petroleum hydrocarbons also consumes oxygen and other essential nutrients (example nitrogen) present in soil (upsetting the carbon-nitrogen

balance), which hitherto would have supported the growth of soil biota (George, 2005). In other instances, nitrogen compounds such as quinolone, isoquinoline, pyridine, pyrrole, indole, and carbazole may be found in crude oils (Wauquier, 1995), as well as organophosphorus and potassium based compounds which may be found at very low levels in some crude oils (Alford et al., 2014; Gedansky et al., 1960). The breakdown of these crude oil types in soil can potentially release nitrogen, phosphorus and potassium into the soil, thereby increasing the concentration of nutrients in the soil.

Crude oil has a complex composition with some molecules being long chained and others being short chained. The resistance to degradation of these molecules is dependent on the structure and molecular weight of the molecule, such that increase in alkane chain length translates to a corresponding increase in resistance to degradation (George, 2005). Crude oil containing longer chained molecules are more viscous than those with shorter chained molecules. Viscosity of oil is key to the fate and persistence of petroleum contamination in soil. Some components are readily degraded by bacteria and others are not. In essence, heavy crude oils (highly viscous) pose a persistence challenge than lighter crude oils in soil.

2.3.3 Oil effects on Animals

The coastline of Ghana serves as nesting and feeding grounds to about some 20,000 seabird and coastal bird species. Coastal wetlands and lagoons are the most important nesting and feeding grounds for these birds. A few of these wetlands and lagoons are found within coastline likely to be oiled in an event of an oil spill (Tullow Ghana Limited, 2009). In the case where nesting and feeding sites get oiled, bird population may be at risk; through the

compromise in their insulating capability of their feathers as it gets stained by the oil, the toxic effect from consuming oiled and contaminated food, and the destruction of their habitat and food sources (Fingas, 2015).

Meinz, as cited by Akutam (2012) reports that substances in crude oil such as heavy metals, polycyclic aromatic hydrocarbons and chemical additives including amines, phenols, benzenes, Ca, Zn, Pb, Ba, Mn, P, and S, pose a health risk to living organisms that ingest or metabolise crude.

Biomagnification is a significant risk to organisms at the top of the food chain like humans. At elevated levels of toxins in the human system, various health implication may arise. It becomes more critical for pregnant and nursing mothers as these toxins may easily be transferred to the unborn baby through the placenta or the nursing baby through breast milk (McGuinness & Dowling, 2009).

2.3.4 Oil effects on coastal plants

Tidal force disperses crude oil spilt offshore into coastal marsh and mangroves, resulting in the contamination of aerial roots and sediments. The crude covering roots inhibits the normal breathing process of the mangrove roots, creating a problem of subsurface root asphyxiation. This intends compromises the normal salt exclusion process of the mangrove, resulting in a build-up of excess salt that ultimately stresses the plant. Excessive stress on the mangrove plants will lead to their death and the eventual destruction of the mangrove (Akutam, 2012).

2.4 TREATMENT OF HYDROCARBON CONTAMINATED SOILS

2.4.1 Use of Hydrogen Peroxide

Hydrogen peroxide is a non-accumulating chemical oxidant with no issues of bioaccumulation in the food chain, or pollution in groundwater/surface. It is also not classified as a carcinogen according to the United States Agency for Toxic Substances and Disease Registry (US ATSDR) since 2002.

Degradation of hydrocarbons in soil with hydrogen peroxide is either through direct oxidation by the peroxide and/or free radicals (hydroxyl radicals $^*\text{OH}$), Superoxide anion (O_2^{*-}), hydroperoxyl radical (HO_2^{*-}), and hydroperoxide anion (HO_2^-). Most organic chemicals react quickly with hydroxyl radical when dissolved in water, though non-aqueous phase liquids like crude oil show marginal reactivity with hydroxyl radical (Watts et al., 1999; Sedlak and Andren, 1994).

The efficiency of hydrogen peroxide in treating hydrocarbon contaminated sites worldwide have shown varied results. Bissey et al. (2006), studied factors contributing to observed variations in efficiently treating hydrocarbon contaminated soil with hydrogen peroxide, and concluded that ineffective combination of reactive oxygen species, ineffective catalysis, minimal contact of reactive oxygen species with pollutants, and inhibitory effects of soil organic matter were the main factors causing the observed variations. It is also proven by Bissey et al. (2006) that soil with pH as low as 3 achieve higher efficiency of treatment with hydrogen peroxide compared to neutral pH soil. This is because, at pH 3, soil organic matter has little impact on hydroxyl radical activity and does not prevent its generation. However, lower soil pH enhances hydrogen peroxide

decomposition and may eventually affect the efficiency of treatment in the long run (Bissey et al., 2006).

The aggressive action of hydrogen peroxide in breaking down contaminants in soil results in an increase in the surface area of both the soil material being treated (through air bubbles) and the hydrocarbons present in the soil. This increase in surface area enhances microbial access to the pollutants in the soil and hence an increase in the breakdown of the pollutants by microbial activity (Goi *et al.*, 2009). As a side advantage, aerobic biodegradation of hydrocarbons has been shown to benefit from the presence of oxygen released during hydrogen peroxide decomposition (Fingas, 2015)

Goi et al., (2009) conducted studies on the potential of hydrogen peroxide to treat hydrocarbon (chlorophenols, PAH, diesel and transformer oil) contamination in soil (sand and peat). Their study showed that concentration of hydrocarbon contamination in soil can be drastically reduced in 3 days when the soil is treated with hydrogen peroxide. Their study suggest that addition of moderate doses of the peroxide to the soil produces the best treatment results, and also creates the opportunity for biodegradation to take over the treatment process after chemical oxidation. Their study focused on examining the volume ratio of hydrogen peroxide to contaminated soil, that would produce the most efficient treatment of the soil. The study was however silent on the appropriate percentage concentration of hydrogen peroxide solution that would produce an optimal level of treatment within a period of 3 day.

This gap in literature on the optimal percentage concentration of hydrogen peroxide needed to efficiently reduce the concentration of hydrocarbons in soil is critical, and the present study hopes to contribute to filling that gap.

2.4.2 Bioremediation

The breakdown of hydrocarbons by naturally present soil microbes is the principal means by which the environment gets rid of petroleum contamination (Willey, 2007). Enhancing the process by which soil microbes naturally degrade contaminants via the manipulation of the contaminated media, is what is referred to as bioremediation (Pilon-Smits, 2005). Bioremediation has been regarded as the most effective and cost-efficient means of treating soils contaminated with petroleum hydrocarbons (Susarla et al., 2002).

Bioremediation can be done either in-situ or ex-situ. With in-situ treatment, no excavation of the soil is done, however, a means of supplying oxygen and nutrients to the subsurface soil may be required, while protecting ground water resources in some cases (Pilon-Smits, 2005). Ex-situ involves the excavation of the contaminated soil and treatment on-site or at an off-site facility (Pilon-Smits, 2005). Choosing which method to use often is dependent on the degree of infiltration of contamination into the soil. For contamination occurring just in the upper layers of the soil, an ex-situ treatment approach can be employed. Contaminations occurring deep into the soil may require an in-situ approach, partly due to the cost of excavation (Macek et al., 2000). Though in-situ treatment is cost effective, ensuring the appropriate level of treatment of the soil can be challenging. Ex-situ has more control over the treatment process to desired levels (Macek et al., 2000).

The actual process of bioremediation is classified into two methods, Biostimulation and Bioaugmentation (Pilon-Smits, 2005). In biostimulation, the ability of indigenous microbes to break down contaminants is enhanced by physical or chemical manipulation

of the contaminated medium. Bioaugmentation introduces special microbes that are known for their ability to biodegrade the contaminants of concern (Pilon-Smits, 2005).

Microorganisms capable of degrading petroleum hydrocarbons are in abundance in soil. Heterotrophs like yeast, moulds and bacteria are the predominant petroleum degrading microorganisms (Willey, 2007). Other studies have shown some species of earthworms are capable of degrading petroleum hydrocarbons (Coon, 2005). The presence of petroleum contamination in the soil causes a reduction in microbial diversity mainly due to selection and dominance of oil-degrading microbes (Gerhardt et al., 2009; Wenzel, 2009). A large majority of hydrocarbon-degrading microorganisms identified in field and laboratory studies are aerobic (Fingas, 2015). These include *Pseudomonas sp.*, *Bacillus sp.*, *Rhodococcus sp.*, *Cyanobacterium sp.*, *Proteus sp.*, *Acinetobacter sp.*, *Flavobacterium sp.*, *Moraxella sp.*, *Candida sp.*, *Lumbricus sp.*, and *Coriolus sp.*

Willey (2007) argues that when it comes to effectively treating petroleum hydrocarbon contaminated soils, biostimulation may yield more effective results than bioaugmentation. This is because crude oil contains a wide variety of chemical compounds that a single or few microbial isolates may not be able to completely degrade. While specific microbes are only capable of degrading specific petroleum hydrocarbons as seen in bioaugmentation, an entire community of soil microbes will be capable of degrading more components of the petroleum as seen in biostimulation (Willey, 2007).

Biochemical and environmental factors can strongly influence the rate of bioremediating a contaminated site (Pilon-Smits, 2005). Studies show that temperature influences the physical and chemical nature of oil, microbial metabolism, and composition of the microbial community in soil (Willey, 2007). Lower temperatures slow down

biodegradation while higher temperature speeds up the process (Fingas, 2015). It is reported by Mohammed et al. (2012) that peak petroleum hydrocarbon biodegradation occurs between 10 and 30°C. Similarly, peak biodegradation occurs at pH 6.5–8.0 (Cunningham et al., 1995), however, pH in soil can vary as much as 2.5 to 11.0 due to soil chemistry (Willey, 2007).

The heavy presence of hydrogen peroxide in a soil can limit natural bioremediation processes in the soil to some extent, as the growth of some microbial population is affected. Hydrogen peroxide has been documented to impact soil microbial population by either physical or chemical means (Rosik-Dulewska et al., 2015). The aggressive impact of hydrogen peroxide results in the inhibited development of eukaryotic organisms while prokaryotic microorganism survive and grow. It inhibits the growth of yeast, fungi, and actinomycetes populations (Rosik-Dulewska et al., 2015). Bacteria's ability to survive the presence of hydrogen peroxide in soil is predominantly by gram-positive bacteria (Rosik-Dulewska et al., 2015).

Little information exists on the influence of salinity on biodegradation of petroleum, however, a simulation of an oil-field brine soil environment (Salt concentrations above 1%) inhibited oil degradation by 20–44% (Johnson et al., 2004). Nutrients like nitrogen and phosphorus are equally essential in biodegrading petroleum hydrocarbons. Cunningham et al., (1995), report a carbon to nitrogen ratio of 200:1 to 9:1 will enhance biodegradation of hydrocarbons in soil. A carbon to nitrogen to phosphorus ratio of 100:10:1 to 100:1:0.5 is recommended by the U.S. Environmental Protection Agency for bioremediation (Fingas, 2015). To ensure the availability of petroleum hydrocarbons for microbial action and dissolution of the by-products of degradation, the optimum moisture content must be 50–

70% of the water-holding capacity of the soil (Pilon-Smits, 2005). Below 30% of the water holding capacity of soil will limit hydrocarbon biodegradation (Willey, 2007). For in-situ bioremediation, it is not recommended to treat soils that have a permeability less than 10–4 cm/s (Mohammad et al., 2012). Due to the importance of water in the process of biodegradation, a restriction of its movement in the soil matrix will hinder the rate of bioremediation of the contaminated soil. Contaminated soils with either a high clay content or organic matter content may possibly render hydrophobic organic compounds, such as polycyclic aromatic hydrocarbons unavailable to microorganisms to biodegrade (Gogoi et al., 2003).

Bioremediation studies by Nelson et al. (1994), on a site contaminated with petroleum hydrocarbons recorded varying degrees of success in reducing various components of the petroleum mixture in the soil, after the site was subjected to in-situ enhanced bioremediation technology involving a mixture of hydrogen peroxide and inorganic nutrients (nitrogen, phosphorus and potassium). Their study mainly focused on using hydrogen peroxide as a source of oxygen for aerobic microbes in the contaminated soil to use in breaking down the petroleum hydrocarbons present, and not as an oxidising agent to directly remove the petroleum hydrocarbons in the soil. Similar studies have been carried out by Menendez-Vega et al. (2007), and Zawierucha & Malina (2011), that focused on using hydrogen peroxide as an agent to boost dissolve oxygen level in the bioremediation of petroleum contaminated soil.

Though these studies points to the fact that the presence of hydrogen peroxide in contaminated soil can enhance the process of bioremediation, they failed to examine the full potential of partially treating petroleum hydrocarbon contaminated soil with hydrogen

peroxide, and then subsequently enhancing bioremediation processes to complete the soil treatment.

2.5 NATIONAL OIL SPILL CONTINGENCY PLAN

The ecological social and economic impacts associated with oil spills can be costly, such that appropriate contingency planning is required to adequately manage the risk. Ensuring "zero risks" of oil spills is the expectation of the general public, though the concept is almost utopian with current practices and available technologies (Fingas, 2015).

Since 1986, Ghana's National Oil Spill Contingency Plan has been in Operation to safeguard the country's preparedness in response to oil pollution incidents. The contingency plan has seen a number of amendments since then and combines national resources with those from shipping and oil exploration and production companies. The aim of the plan is to protect Ghana's marine and coastal environment from spills or to minimise the impacts from spills occurring within the country's territory, or spills from neighbouring countries that are transported into the country by the action of wind, ocean currents or natural drainage (Ghana EPA, 2010).

The contingency plan adopts a three-tier system for oil spill preparation and response. This tier system is based on the amount of oil that is spilt, such that, spills between 1 – 10 tonnes are classified as Tier 1, spills within 10 – 1000 tonnes are classified as Tier 2, and spills above 1000 tonnes are classified as Tier 3. The Oil industry and shipping ports are responsible for handling Tier 1 spills, while the nation's Environmental Protection Agency (EPA) handles Tier 2 and Tier 3 spills. However, in the case whereby a party responsible

for a Tier 1 spill is inadequately resourced to respond to the spill, EPA will facilitate the usage of all appropriate in-country resources as required (Ghana EPA, 2010).

Per the NOSCP, any response to an oil spill must be justified by its Net Environmental Benefit. In other words, analysing the advantages and disadvantages of carrying out a set of actions (example dispersant spraying), or identifying the possible consequences of not taking the course of action (the impact of doing nothing) (Ghana EPA, 2010).

Response options outlined in the NOSCP are surveillance, control and recovery, application of a dispersant, in-situ burning, shoreline clean-up, and bioremediation (Ghana EPA, 2010).

2.6 PETROLEUM HYDROCARBON CONTAMINATED SOIL REMEDICATION STUDIES IN GHANA

Studies conducted in Ghana show the potential to treat soil/mud contaminated with petroleum hydrocarbons using biostimulation methods (Fei-Baffoe et al., 2016). Drill mud with significant petroleum hydrocarbon concentration from offshore oilfields in Ghana was subjected to biostimulation via nutrient addition. Results showed a 98% reduction in TPH levels after three weeks and 99.5% after seven weeks (Fei-Baffoe et al., 2016).

Naturally-present oil-degrading microbes that have been identified and studied in the country include *Trichothecium*, *Trichoderma*, *Aspergillus niger*, *Fusarium*, and *Penicillium* sp (Ameko et al., 2013). Odokuma and Inor (2002), reported in their study that, greater bioremediation rates of petroleum hydrocarbon polluted soils can be achieved when nitrogen-fixing bacteria were used instead of inorganic nutrient (fertiliser).

CHAPTER THREE

METHODOLOGY

3.1 STUDY AREA

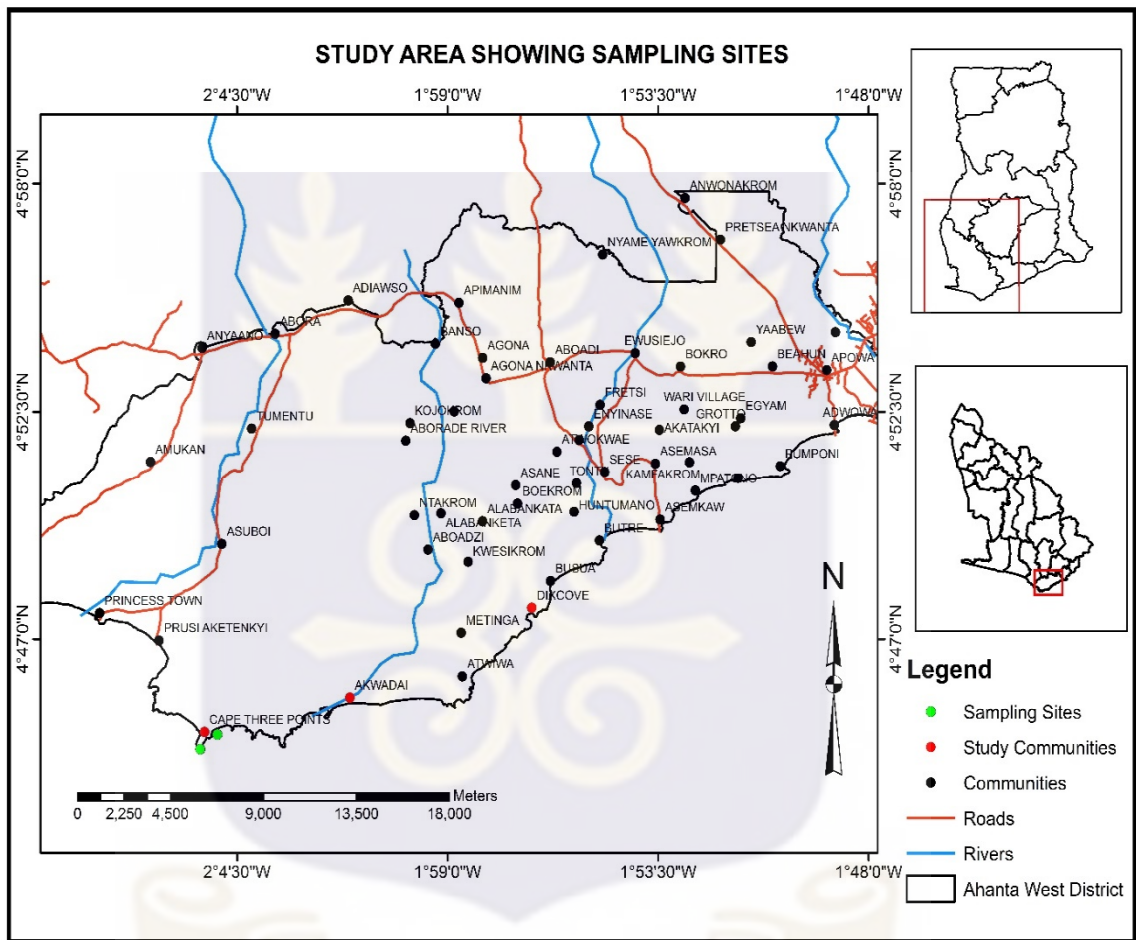


Figure 3.12.6.1: Map of study area showing site of soil collection

The Ahanta West District in the Western Region of Ghana has a population of 106,215, making up 4.5% of the entire region's population. More than 75% of persons above 15 years in the district are economically active, with the majority (36.4%) engaged in agriculture, forestry and fishery. The district is located in the south-western equatorial climatic zone of Ghana, the wettest region of the country, with mean high and low

temperatures of 34°C and 20°C, respectively. The district lies within the coastal belt of the country with its sandy coastline having features such as capes and bays, especially at Cape Three Points (GSS, 2014).

Four rock and soil types underlie the district. These are the lower Birimian, Dixcove granite, Cape Coast granite and Tarkwaian. More than half of the soil consists of Cape Coast granitic soils which are very rich in minerals. Large deposits of gold and traces of iron and kaolin are found in the district. Considerable clay deposits can also be found in parts of the district, particularly around Beahu area (GSS, 2014).

Ahanta West District is among the promising and endowed districts with tourism potentials in Ghana. Tourist attractions include forts, ecotourism forest reserves, Green Turtle, and Safari Beaches (GSS, 2014). The district has the closest shorelines to Ghana's major oil and gas discoveries located in the Deepwater Tano and West Cape Three Points blocks (Yalley et al., 2012). These shorelines are sandy in nature with capes and bays that attracts many tourists and economic activity to the area.

Most of the lagoons along the coastline of Ghana are situated in the western and central coastline. This includes the Cape Three Points area which has lagoons serving as habitats and nursery sites for a diversity of fish, shrimps, mollusc, and crabs species (Armah et al., 2004). It is known that the sandy shores of the Cape Three Points area serve as nesting grounds for sea turtles and habitats for species including the ghost crab, isopods, amphipods, mysid, mole crab, polychaetes, bivalves and gastropods (Armah et al., 2004). Up to 141 diverse trees, shrub, grass and sedge species have been documented to be found along the coast in the district (Armah et al., 2004).

Yalley et al. (2012) reported that the value of land in the district, particularly in close proximity to the Cape Three Points had increased in value by some 2000% from 2007 to 2011, due to the anticipated boost in economic activity in the area. Land use patterns in areas close to Cape Three Points is gradually changing from agriculture based to non-agriculture and is reported by Yalley et al. (2012) to be a potential threat to the livelihoods of the inhabitants of the area going forward.

3.2 COASTAL SOIL SAMPLING (Phase 1)

Pristine topsoil samples were collected from the supratidal zone of a beach at Cape Three Points as seen in Figure 3.1.1. According to Issaka et al. (2012), the sampled soil falls under the classification (World Reference Base) Acric Ferralsol (Ferric), also known locally as Yakasi series. The soil was collected at an average depth of 0 – 15 cm with a shovel into a large 50-litre plastic container and transported to a laboratory in Accra for use in the study. The sand sample collected was a mixture of finely textured whitish-brown and reddish-brown sand, which was partially moist with sea water. The organic carbon content of the soil was determined in the laboratory to constitute 4% of the soil mass while pH of the soil was 6.1.

The soil sample was stored in a plastic container under constant room temperature of 23°C prior to spill simulation.

3.3 SPILL SIMULATION AND SOIL REMEDIATION (Phase 2)

3.3.1 *Material acquisition*

A quantity of crude oil from the Tweneboa, Enyenra, Ntomme (TEN) oil fields in Ghana with an API of 36.5° was acquired from the Tema Oil Refinery. The crude oil collected was used in the spill simulation in the laboratory. Two liters each of three different concentrations of Hydrogen Peroxide (6%, 30%, and 60% v/v) were purchased for this study. A litre of liquid chemical fertilizer (Boost Xtra) was also purchased to be used as a bio-stimulant in the study (see Appendix D for composition of chemical fertilizer). The liquid chemical fertilizer was preferred for the study as it was much easier to effectively apply and mix it with the contaminated soil than granular/solid chemical fertilizers.

3.3.2 *Spill simulation*

The study involved a spill simulation in a laboratory to test the efficiency of the clean-up approaches to be adopted. Spill simulation involved the collection of pristine beach sand (Acric Ferralsol) from the Ahanta West District. The soil collected was air dried at room temperature. The pH, nutrient and background organic carbon of the soil was then determined. A plastic container was filled with 16kg of the beach sand and contaminated with 1.9 litres of crude from the TEN oil fields. This constituted approximately 18.2% v/v of crude/soil. With an API of 36.5, the density of the crude oil used was 0.8422g/cm³. This implied that 1600.18g of crude oil was added to the 16kg of soil. The volume of oil added represented a heavily polluted soil (100mg/kg), as soil with hydrocarbon concentrations higher than 98mg/kg of soil is considered to be polluted (Marinos & Koukis, 1997). The soil contamination procedure was replicated twice, and all three samples of contaminated soil was left undisturbed for up to 24 hours to create the normal condition of spill

response time, and to allow the oil to properly percolate the soil. Concentration of the oil constituents in the triplicate contaminated soil after the 24 hour period was verified through sampling (day 0 sampling) and laboratory analysis.



Figure 3.3.1: Weighing and contamination of soil sample with crude oil

Each of the triplicate contaminated soil was then divided into eight separate plastic containers labelled C, F, H1, H2, H3, H1F, H2F, and H3F accordingly. For the first triplicate, the labels were preceded by the number 1 (example 1C, 1F, 1H1, 1H2, etc.). Similarly, the second triplicate was labelled with the number 2 preceding (example 2C, 2F, 2H1, 2H3, etc.) and the third triplicate with the number 3 preceding (example 3C, 3F, 3H1, 3H3, etc.). The contaminated soil in containers C were not given any form of treatment and served as the control for the study. Contaminated soil in containers F were treated with 300ml of the chemical fertiliser (Appendix D) and mixed thoroughly to achieve proper treatment efficiency (volume of fertiliser to oil ratio 1.3:1). The soil in containers H1 and H1F were treated with 6% H_2O_2 . Containers H2 and H2F were treated with 30% H_2O_2 , while soil in containers H3 and H3F were treated with 60% H_2O_2 . The treatment was such that, a volume of 79ml of hydrogen peroxide was added to the contaminated soil after every

24 hours, for 3 days (total of 237ml) as recommended by Goi et al. (2009). This ensured a total volume ratio of 1:1 H₂O₂/crude oil.

After 72 hours of treatment with hydrogen peroxide, the chemical fertiliser (Appendix D) was added to containers H1F, H2F, and H3F, to test the biostimulation potential of the pre-treated soil. A total of 100ml of the fertiliser was added to each of the three groups of containers as shown below;

Where H1= 6% hydrogen peroxide, H2 = 30% hydrogen peroxide, H3 = 60% hydrogen peroxide, F = Fertilizer, C = control (no hydrogen peroxide and fertilizer added).

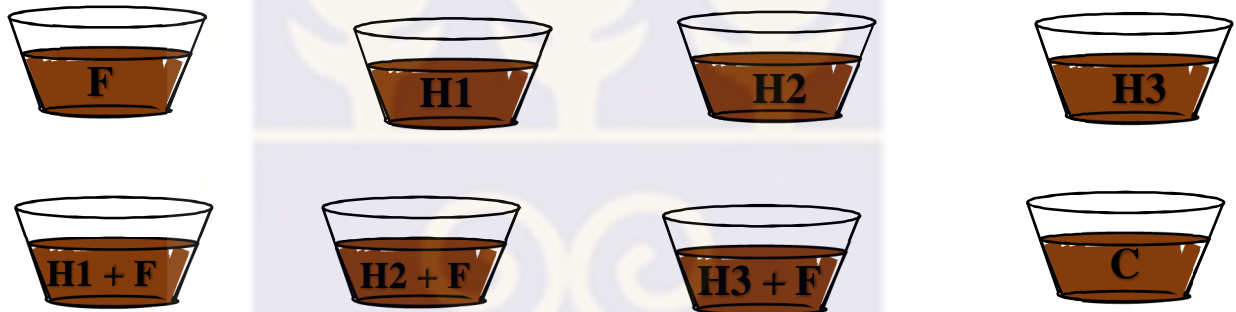


Figure 3.3.2: Diagram of treatment methods employed during the study

3.3.3 Contaminated soil sampling

Before applying treatment to the contaminated soils, samples of the contaminated soil were taken to be tested in the laboratory to determine the concentration of petroleum hydrocarbons in the soil (day 0 sample). After applying first treatments to the polluted soil, samples were collected after 1 day, 3 days, 10 days, 17 days, and 24 days for analysis of the concentration of petroleum hydrocarbons in the soil. An improvised hand soil auger was used in collecting soil samples from each setup and placed in transparent sealed plastic



Figure 3.3.3: Taking of soil samples for laboratory analysis.

bags. Samples were stored in cold air-tight containers and transported to the laboratory. Samples were then stored in a laboratory freezer at -15°C in the case where tests were not carried out immediately.

A total of 121 composite samples were collected and analysed in this study. This number consisted of 24 samples collected from the spill setups on five different sampling days and one sample collected from the hydrocarbon contaminated soil prior to the start of treatment.

3.4 SAMPLE EXTRACTION AND INSTRUMENTAL ANALYSIS

(Phase 3)

Hydrocarbon contaminated soil samples collected during the treatment period underwent a number of chemical testing in the laboratory. Chemical tests were conducted on the soil samples collected to determine their pH (prior to treatment because the efficiency of H₂O₂ in decontaminating soil is pH dependent), Nitrogen Phosphorus and Potassium (NPK) levels (prior to treatment and after treatment), Total Organic Carbon content (prior to treatment), and Polycyclic aromatic hydrocarbon level and Total Petroleum Hydrocarbon (TPH) content (throughout the treatment period).

3.4.1 pH

To determine the pH of the soil, 10g of the soil was mixed with 20ml of distilled water (ratio of 1:2) in a glass beaker. The mixing was done in 15 minutes intervals till a slurry was obtained after an hour. The slurry was allowed to stand to ensure the pH of the mixture was stabilised and to enable the suspended soil to particles to settle. Once the particles settled, the pH meter (OHRUS ST10) was calibrated using pH 4 and 7 buffers. The glass rod and electrodes of the pH meter were submerged into the slurry, ensuring that electrodes were in good contact with the solution. The electrode stayed in the slurry for more than 30 seconds to get a stabilised pH reading on the meter and pH values recorded. The electrode was cleaned with deionized water and shaken before dipping into another sample.

3.4.2 Nitrogen

The nitrogen content in soil samples was tested using the Kjeldahl method. Using this method, a gramme of soil sample was weighed and placed in a digestion tube which was then placed in a fume hood. Adequate catalyst tablets were added to supply 9g of K₂SO₄ and 0.42g HgO. Then 15ml of sulfuric acid was added. A block digester was preheated to 410°C and the digestion tube was placed in it. Digestion was allowed to take place for 45 minutes, and the tubes removed to allow to cool for 10 minutes in the fume hood. Twenty five millilitres of distilled water was added and then transferred to a 100ml volumetric flask.

Five millilitres of the solution was taken and placed in Markham distillation apparatus, and 5ml of 40% NaOH solution was added. It was then distilled into 5ml of 2% boric acid in a 100ml flask. In the process, the colour of the solution changed from dark-blue to light-green. Titration was performed against 0.01 M HCL (Bremner, 1965)(Bremner, 1965) till the colour changed from green to red at the end point. Using the titre value, the % nitrogen was calculated with the formula:

$$N\% = \frac{\text{Titre (value)} \times N \text{ NHCL} \times \text{Molar wt of Nitrogen} \times \text{Final volume } \%}{\text{Wt of Sample} \times \text{aliquot taken} \times 1000}$$

N NHCL = 0.01, Molar wt of Nitrogen = 14, final volume = 100, Wt of samples = 1g, Aliquot taken = 5ml

3.4.3 Phosphorus

0.5g of air dried soil samples was digested with 10ml of 0.2M HNO₃ in a 50ml quartz vessel using microwave digestion for 6.5 minutes at 175°C. After the digested sample cooled down, it was filtered through Whatman N0 42 filter paper into a 100ml volumetric

flask and made up to the volume. An aliquot of 1 ml plus 30ml of distilled water was taken into a 50ml flask and preceded for colour development.

Two drops of P-nitrophenol followed by one drop of ammonium hydroxide was added to develop the yellow colour. 8ml of ascorbic acid was added to bring the colour to light blue. A sample was then taken to the spectrophotometer for reading. Phosphorus content was calculated using the formula:

$$= \frac{(\text{Spectrophotometer readings} - \text{Blank}) \times \text{Volume of extract} \times \text{Dilution factor}}{\text{Wt of Sample} \times \text{Volume of Aliquot}}$$

3.4.4 Potassium

After soil samples were air dried, 0.5g of it was digested with 3ml conc. HNO₃ in Folin-Wu tubes in an electrically heated block for 1 hour at 145°C. Then 4ml of HClO₄ was added and heated to 240°C for an additional hour. Using Inductively Coupled Plasma-Atomic Emission Spectroscopy (ICP-AES), the concentration of Potassium was determined in the digested soil sample.

3.4.5 Total Organic Carbon

Using the wet combustion method (Walkley & Black, 1934), 0.5g of soil sample was placed into a 250ml conical flask and 10ml of 1N K₂Cr₂O₇ solution was added to it. The conical flask was placed in a fume hood and 20mls of concentrated H₂SO₄ was added to the flask. It was swirled strongly by hand for 1 minute and then allowed to stand on a sheet of asbestos for 30 minutes. Distilled water (100ml), orthophosphoric acid (10ml), and barium diphenylamine sulphonate indicator (2ml) were added to the conical flask.

Residual dichromate remaining in the solution after oxidation of organic materials in the soil was titrated against 0.2 M Ferrous Ammonium Sulphate solution until the colour changed to blue and finally to green at the end point. The organic carbon content was calculated by the formula:

$$= \frac{[V - (N \times T)] \times 0.3}{W}$$

V = Volume of potassium dichromate (10ml)

N = Normality of Ferrous Ammonium Sulphate (0.2)

T = Titre Value

W = Weight of sample (0.5)

The organic matter content value was derived from the organic carbon by multiplying the figure by 1.724 (Nelson and Sommers, 1982)

3.4.6 *Petroleum Hydrocarbon and Polycyclic aromatic hydrocarbons*

Laboratory analysis of TPH and PAH in soil samples was based on US EPA Methods 8081A, 614 and 8141A. It commenced with the extraction of the analyte from the soil samples. For each soil sample, 10g was weighed and placed in a separating funnel, and 10ml of acetonitrile solvent was added to it. The separating funnel was then placed in an ultrasonic bath (Clifton SW3H) and sonication was carried out for two minutes. After sonication, an additional 10ml of acetonitrile was added to the sample in the separating funnel. The separating funnel was then placed in a Shaker (IKA HS 501) and vigorously shaken for 30 minutes. The sonication and shaking ensured proper dissolution of polycyclic aromatic hydrocarbons and petroleum hydrocarbons in the soil sample into the acetonitrile (solvent). The acetonitrile was then pipetted out of the separating funnel, and the extract

cleaned using silica column in a Teflon tube (Strata solid phase extraction) into a round bottom flask.

After cleaning the extract, the acetonitrile was evaporated from the extract using a Rotary Evaporator (Buchi B-491). One millilitre (1ml) of ethyl acetate was added to the evaporated extract before analysis of the sample was done.

Gas Chromatography was used to determine the petroleum hydrocarbon (C9-C44) concentration and 16 polycyclic aromatic hydrocarbons (PAH) of each sample in ppm (Speight, 2015). As a result of the concentration procedure carried out using the Rotary Evaporator, only carbon compounds in the range of C9 – C44 could be captured by the Gas Chromatography as Petroleum Hydrocarbons in each sample tested. This is a limitation of the instrumental method used in the study as crude oil used for the study contained petroleum hydrocarbon compounds with more than 44 carbon atoms.

Polycyclic aromatic hydrocarbons tested for in the samples are naphthalene, pyrene, fluorene, acenaphthalene, acenaphthene, phenanthrene, anthracene, fluoranthene, benzo(a)anthracene, chrysene, benzo(b)fluoranthene, benzo(k)fluoranthene, benzo(a)pyrene, Indeno(1,2,3-c,d)pyrene, dibenzo(a,h)anthracene, and benzo(g,h,i)perylene.

3.5 STAKEHOLDER AND PUBLIC SURVEY (Phase 4)

A number of stakeholders were engaged through either focus group discussion, face to face interview or questionnaire administration. These stakeholders included management and technical persons from the Ghana Environmental Protection Agency (EPA), fishermen, and community members of the study area. Three coastal communities eastward of the Jubilee

oil fields with appreciable socioeconomic activity in the Ahanta West District were surveyed during the study. These communities are Dixcove, Akwidaa and Cape Three Points.

The questionnaires and interviews were structured to probe four key issues: i) Demographic and background information of respondents, ii) Occupation of respondents, iii) Verify existence of oil spills in the study area and measures taken to respond to them, iv) Probe government, the private sector, and community involvement in oil spill response. In total, 60 copies of questionnaires were administered in the study communities during the study period.

A face to face interview with a resource person at the Petroleum Department of the Environmental Protection Agency was conducted. This interview was undertaken to understand the agency's role in the oil and gas industry, the occurrence of oil spills, vulnerability of coastal communities and measures put in place to protect them, and the official oil spill response protocols of the agency.

Appendices I and II shows details of the questionnaire and interview guide.

3.6 DATA ANALYSIS (Phase 5)

Using data acquired from the questionnaires administered, a binary logistic regression was conducted based on five dependent factors. These factors were:

- I. Respondents' expectation on the duration of a clean-up exercise.
- II. Respondents' expectation of the government providing funds to be used in an oil spill clean-up exercise.

- III. Respondents' expectation of the government providing technical support during an oil spill clean-up exercise.
- IV. Respondents' expectation of the government providing logistical support during an oil spill clean-up exercise.
- V. Respondents' expectation of the government providing oversight during an oil spill clean-up exercise.

The predictor factors that were used in the model were age, gender, residing community, resident time in a community, and occupation.

Cross tabulation analysis was conducted to further evaluate the trends in respondents' biodata and their expectations of government listed above. Analysis of variance (ANOVA) was conducted on data acquired from laboratory results, to test the hypothesis that the different soil treatment approaches resulted in different levels of efficiency in decontaminating the hydrocarbon contaminated soil. Graphs of the data acquired from laboratory tests were analysed to evaluate which treatment method efficiently removed hydrocarbons from the contaminated soil.

The cost-effectiveness of each treatment method was determined using the data on the total polycyclic aromatic hydrocarbons removed from the soil and the cost of acquiring materials to undertake a particular treatment.

$$\text{Cost effectiveness} = \frac{\text{Total PAH removed}}{\text{Cost}}$$

3.7 QUALITY ASSURANCE AND QUALITY CONTROL

The entire spill simulation and soil treatment process was carried out in triplicate. This was to prevent experimental bias or some random error in the results of the study. To ensure

accurate reading from the pH meter, the device was standardised by using a 7.0 pH buffer standard solution.

PAH-certified reference materials from Dr Ehrenstorfer GmbH which had 26 different standard PAHs was used as standards for all extracts from soil samples analysed using GC/MS.



CHAPTER FOUR

RESULTS

4.1 COASTAL SOIL SAMPLING

4.1.1 Soil properties

Beach sand [Acrylic Ferralsol (Ferric)] that was collected from Cape Three Points in the Ahanta West District and used for the study had the physical and chemical properties shown in Table 4.1.1.

Table 4.1.1: Physicochemical properties of coastal soil sampled

Physicochemical property	Description
Colour	Brown
Texture	Coarse
Permeability	Rapid
Porosity	Large pores
Water holding capacity	Minimal
pH	6.1
Nitrogen content	0.092%
Phosphorus content	0.131%
Potassium content	0.154%
Organic carbon content	4.4%

4.2 SPILL SIMULATION AND SOIL REMEDIATION

The contaminated soil exhibited varied physical responses to each type of treatment that was undertaken in the study. Immediately hydrogen peroxide was added to the contaminated soil, the crude oil was displaced by the hydrogen peroxide from the soil matrix onto the soil surface (Appendix E, figure 7.5.2). Air bubbles then began to emerge out of the floating oil and from within the soil matrix (Appendix E, figure 7.5.3). This observation was made on all the 3 days that hydrogen peroxide was added to treat the contaminated soil. The higher the concentration of hydrogen peroxide used, the more vigorous the air bubbles emerged. The bubbling lasted longer for soils treated with 60% hydrogen peroxide than those treated with 30% and 6% hydrogen peroxide. Within 20 minutes after addition of the peroxide, the soil increased in temperature with the hottest being those treated with 60% hydrogen peroxide. The heat generated by the reaction resulted in the release of what appeared to be water vapour from the soil matrix (Appendix E, figure 6.5.4). Again, there was more vapour released from the soil treated with 60% hydrogen peroxide, which is to be expected as that reaction generated the most heat.

Contaminated soils treated with 60% hydrogen peroxide and 30% hydrogen peroxide appeared dried up after 30 minutes of adding the peroxide (Appendix E, Figure 7.5.5) which is a strong indication of the extent of petroleum hydrocarbon decontamination that had occurred in the soil at that stage of the treatment period.

Soil that was only treated with chemical fertiliser did not exhibit any visible physical reaction. It remained relatively dry in appearance throughout the period of experimentation (Appendix E, Figure 7.5.6). On the contrary, soil that was previously treated with hydrogen peroxide and then subsequently treated with chemical fertiliser

behaved and appeared differently from those that only received hydrogen peroxide treatment. This observation was made 2 days after the chemical fertiliser was added to soil pre-treated with hydrogen peroxide. The addition of fertiliser to the pre-treated soil caused the crude oil in the soil to be displaced onto the surface of the soil. The lower the concentration of hydrogen peroxide used in the initial treatment, the more crude oil was displaced to the surface of the soil (Appendix E, Figure 7.5.7).

Figure 4.2.1 and Figure 4.2.3 below show changing levels of petroleum hydrocarbons and PAH respectively in the eight different treatment set-ups over the 24 day study period. Generally an increasing trend in concentrations of TPH is observed while a decreasing trend in PAH is observed in all treatment set-ups. A bar graph showing the specific amount of petroleum hydrocarbons (C9-C44) and polycyclic aromatic hydrocarbons degraded by each treatment method over the 24 day study period is presented in Figure 4.2.2 and Figure 4.2.4 respectively.

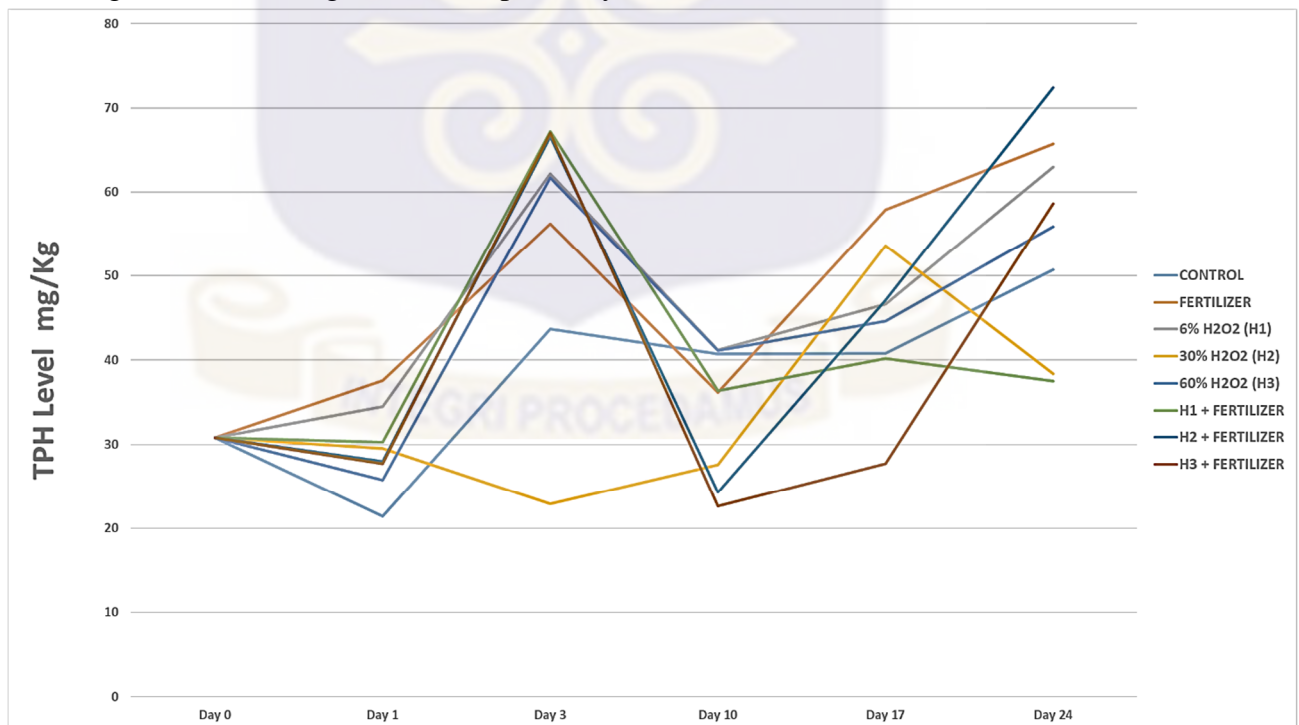


Figure 4.2.1: Graph of Petroleum Hydrocarbon (C9-C44) levels in treated contaminated soil samples over a 24 day period

The figures show that treatment involving 60% hydrogen peroxide and fertilizer (as biostimulant) recorded the highest removal of petroleum hydrocarbons and PAH. More detailed results on PAH and TPH levels in soils subjected to the different treatment methods over the 24 days study period are presented in Appendix F.

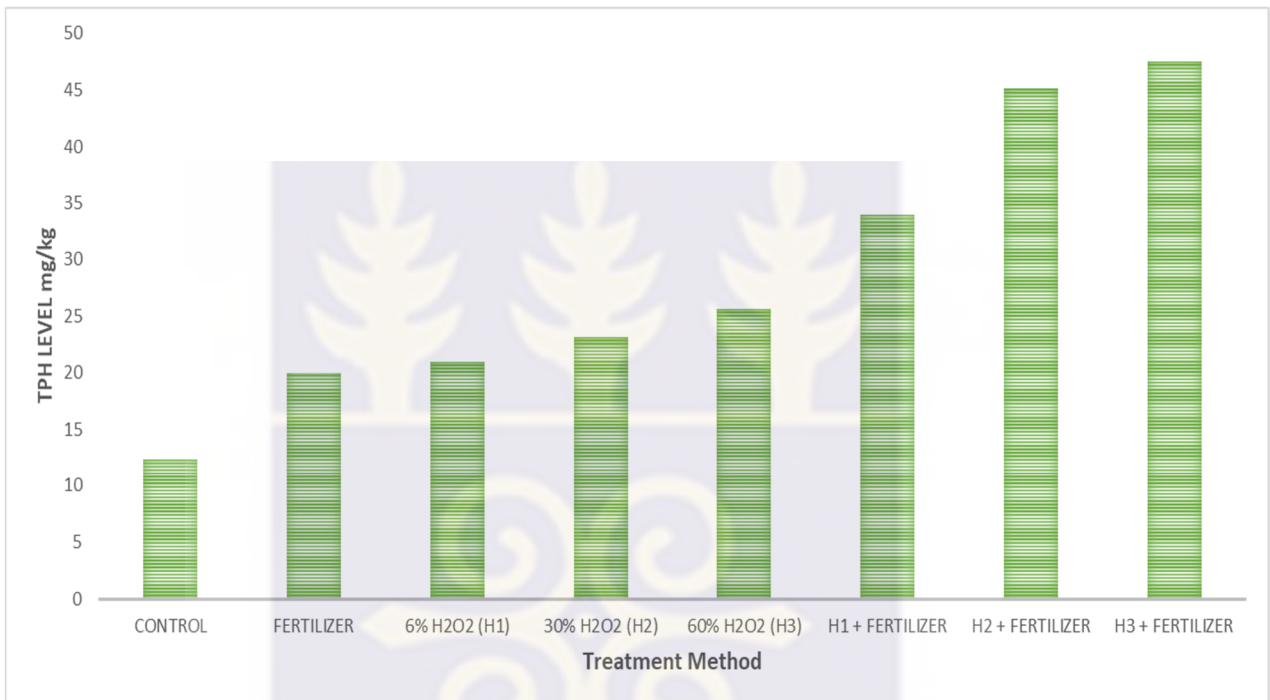


Figure 4.2.2: Petroleum Hydrocarbon (C9-C44) removed from the various treatment setups over the study period of 24 days

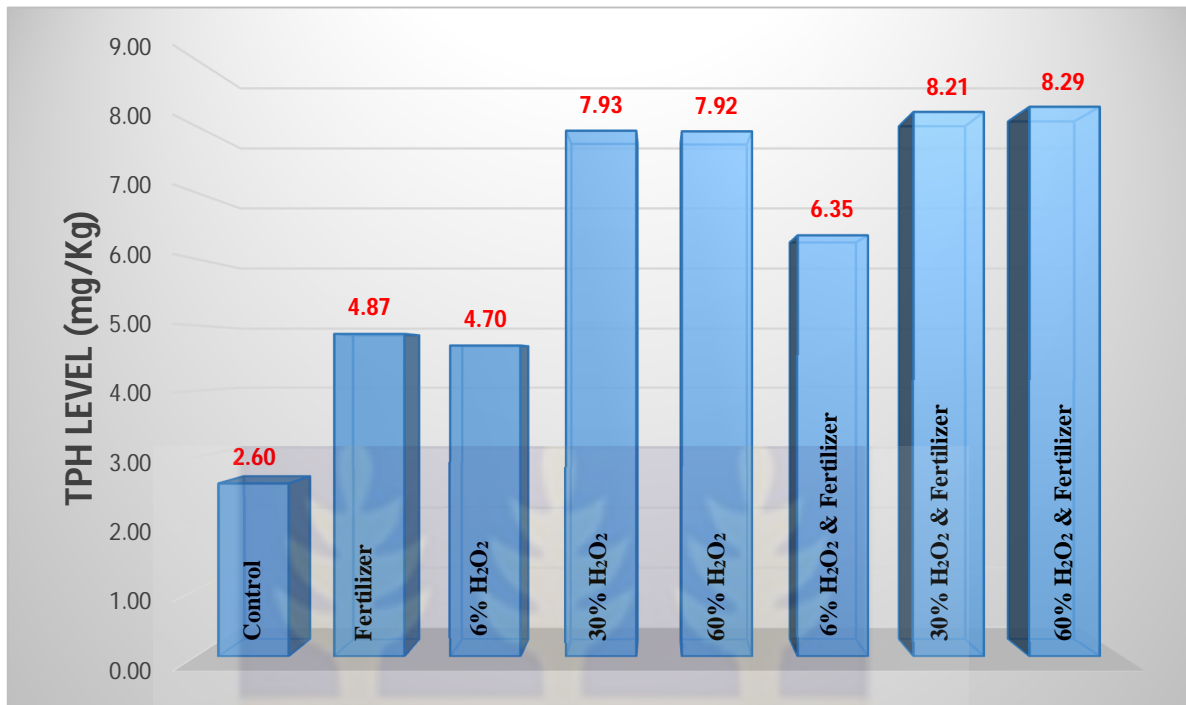


Figure 4.2.4: Total PAH removed from the various treatment setups over the study period of 24 days

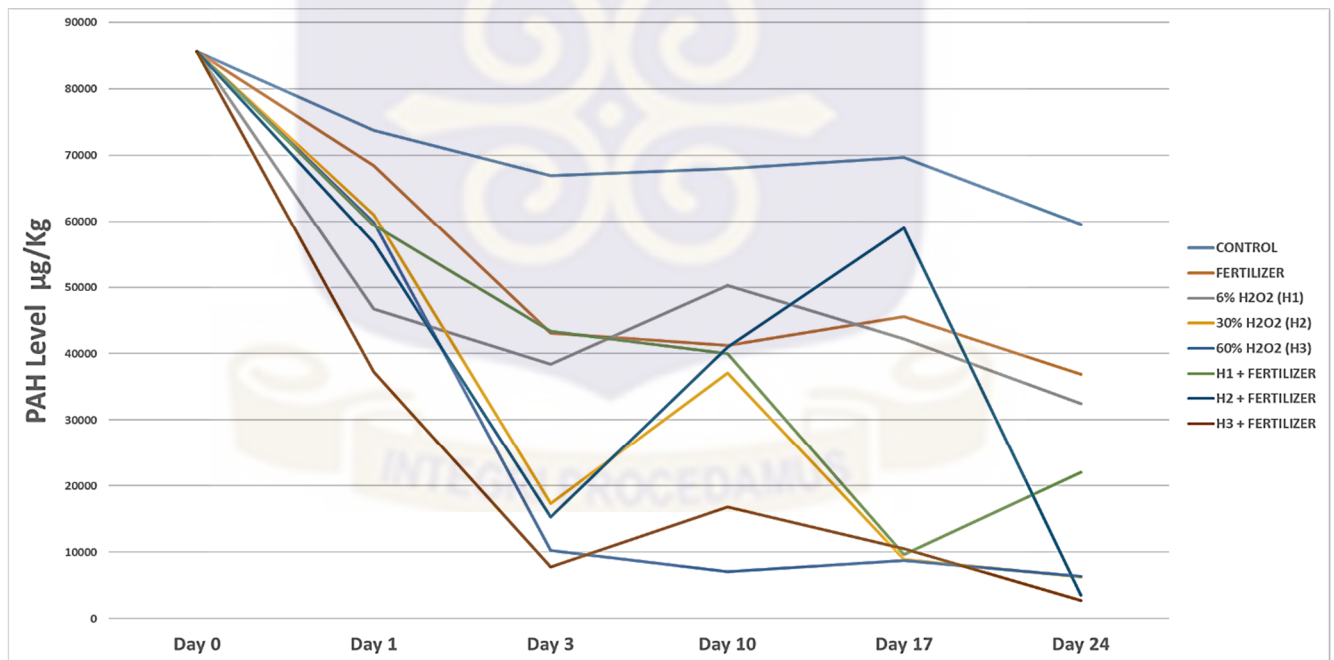


Figure 4.2.3: Graph of Polycyclic Aromatic Hydrocarbon levels in treated contaminated soil samples over a 24 day period

Results from laboratory analysis conducted on nitrogen, phosphorus and potassium levels in contaminated soil samples collected over the treatment period have been presented in Table 4.2.1 below. The table shows a general increase in the levels of nitrogen, phosphorus, and potassium over the study period in all soil samples collected from the different treatment set-ups.

Table 4.2.1: Results of nitrogen, phosphorus and potassium content in soil samples from the various treatment setups

		CONTROL	FERTILIZER	6% H ₂ O ₂ (H1)	30% H ₂ O ₂ (H2)	60% H ₂ O ₂ (H3)	H1 + FERTILIZER	H2 + FERTILIZER	H3 + FERTILIZER
POTASSIUM	Initial concentration (mg/kg)	1.54	1.54	1.54	1.54	1.54	1.54	1.54	1.54
	Week 1 concentration (mg/kg)	N/A	90.6	N/A	N/A	N/A	30.2	30.2	30.2
	Week 4 concentration (mg/kg)	5.35	33.03	4.458	4.208	5.228	58.6	46.96	57.87
PHOSPHORUS	Initial concentration (mg/kg)	1.31	1.31	1.31	1.31	1.31	1.31	1.31	1.31
	Week 1 concentration (mg/kg)	N/A	90.6	N/A	N/A	N/A	30.2	30.2	30.2
	Week 4 concentration (mg/kg)	4.1	10.2	4.1	6.2	4.8	22.3	14.8	20.2
NITROGEN	Initial concentration (mg/kg)	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92
	Week 1 concentration (mg/kg)	N/A	90.6	N/A	N/A	N/A	30.2	30.2	30.2
	Week 4 concentration (mg/kg)	0.196	29.12	38.08	52.08	10.08	14.84	33.6	7

*Initial concentration refers to concentration of nutrient in the soil prior to spill simulation

* N/A = No samples collected for analysis

The level of PAH removed from the contaminated soil by each treatment method was compared with the cost of undertaking each treatment method. This comparison is represented in ratio form in Table 4.2.2. The ratio values are an indication of the cost-effectiveness of each treatment method where higher values indicate higher cost-effectiveness. The table shows that 6% hydrogen peroxide is the most cost effective treatment method while a combined treatment of 60% hydrogen peroxide and chemical fertilizer is the least cost effective.

Table 4.2.2: Cost effectiveness of the various treatment methods employed in the study.

	Fertilizer	6% H ₂ O ₂ only	30% H ₂ O ₂ only	60% H ₂ O ₂ only	6% H ₂ O ₂ & fertilizer	30% H ₂ O ₂ & fertilizer	60% H ₂ O ₂ & fertilizer
PAH removed (mg)	4.87	4.7	7.93	7.92	6.35	8.21	8.29
COST (GHC)	12	4.74	18.96	35.55	8.74	22.94	39.55
PAH per COST ratio	0.405	0.991	0.418	0.223	0.727	0.358	0.21

*higher PAH/Cost ratio signify a more cost effective treatment method.

Results of the analysis of variance (Anova) conducted on data on petroleum hydrocarbon and PAH levels in the contaminated soils from the various treatment set-ups have been presented in Table 4.4.1 and Table 4.4.2 respectively. The Anova results show no statistically significant difference in PAH and petroleum hydrocarbon levels in the different treatment methods over the 24 day study period at a confidence level of 95%.

Table 4.2.3: Anova results for concentration of Petroleum Hydrocarbon in the various soil treatment setups

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	946.173	7	135.168	.647	.714
Within Groups	8352.772	40	208.819		
Total	9298.945	47			

*significant (P<0.05)

Table 4.2.4: Anova results for concentration of polycyclic aromatic hydrocarbons in the various treatment setups

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	8265844609.601	7	1180834944.229	1.715	.133
Within Groups	27549210428.706	40	688730260.718		
Total	35815055038.308	47			

*significant (P<0.05)

4.3 STAKEHOLDER AND PUBLIC SURVEY

4.3.1 *Background and demographic characteristics of respondents*

Interviews and questionnaires administered during the field survey reveal 78% of all respondents were males while 22% were females. More than half of the respondents (62%) were forty years old or younger, with individuals in their 20's forming the majority (approximately 33%) of the entire respondent population (Figure 4.3.1). Most of the respondents (74%) have lived in the surveyed community for more than 10 years (Figure 4.3.2). This predates the commencement of offshore oil production in the region and hence their views and response can be regarded as reliable. Fishing (72%) and trading (16%) were identified to be the main occupation of the respondents (Figure 4.3.3). A total of 75% of all respondents depended on beach/sea as their source of livelihood (Figure 4.3.4). 23% indicated they used the beach every day (Figure 4.3.5).

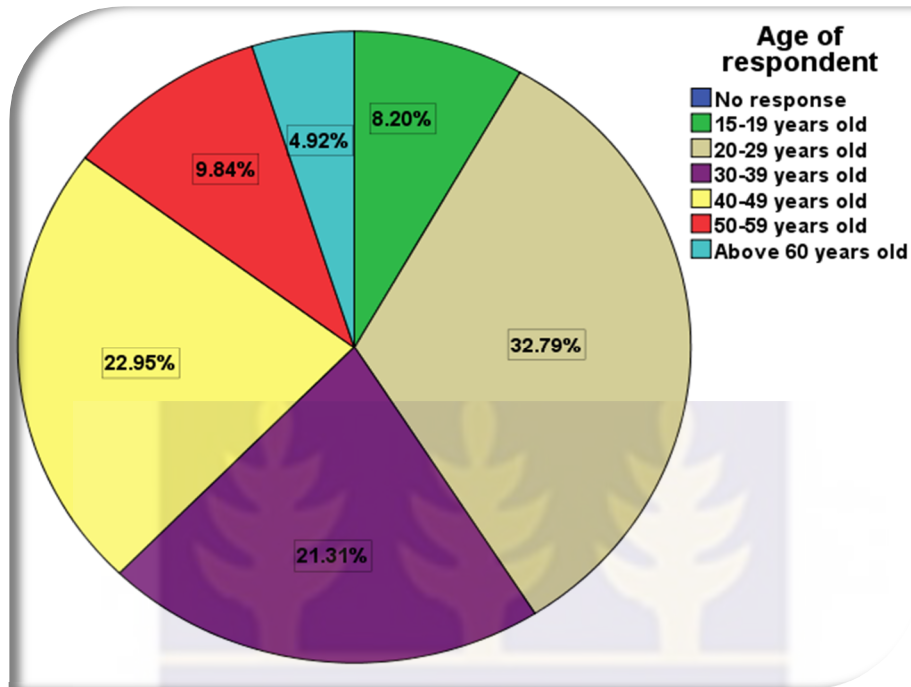


Figure 4.3.1: Age distribution of respondents

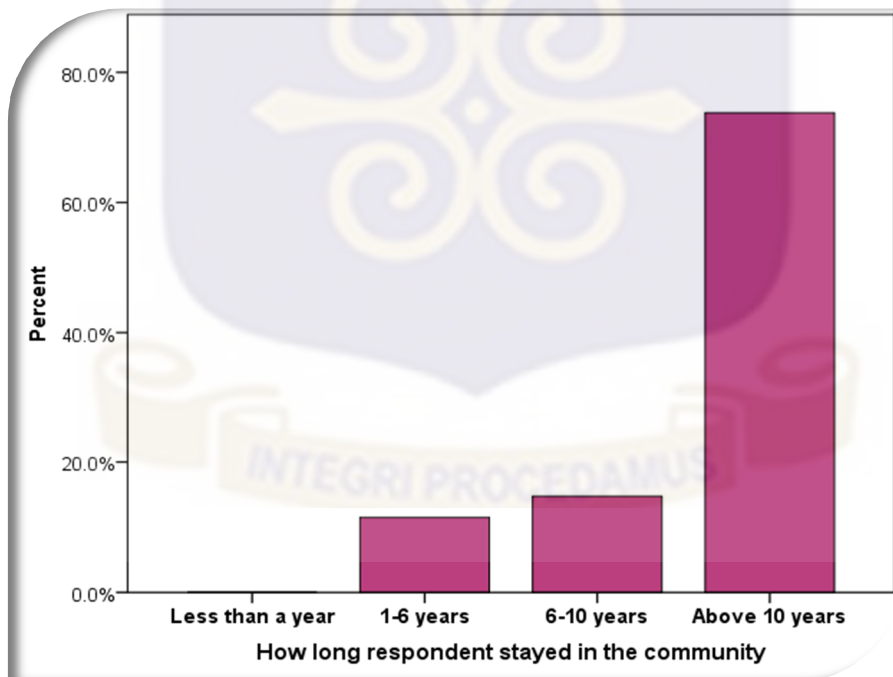


Figure 4.3.2: Distribution of respondents residence time in surveyed communities

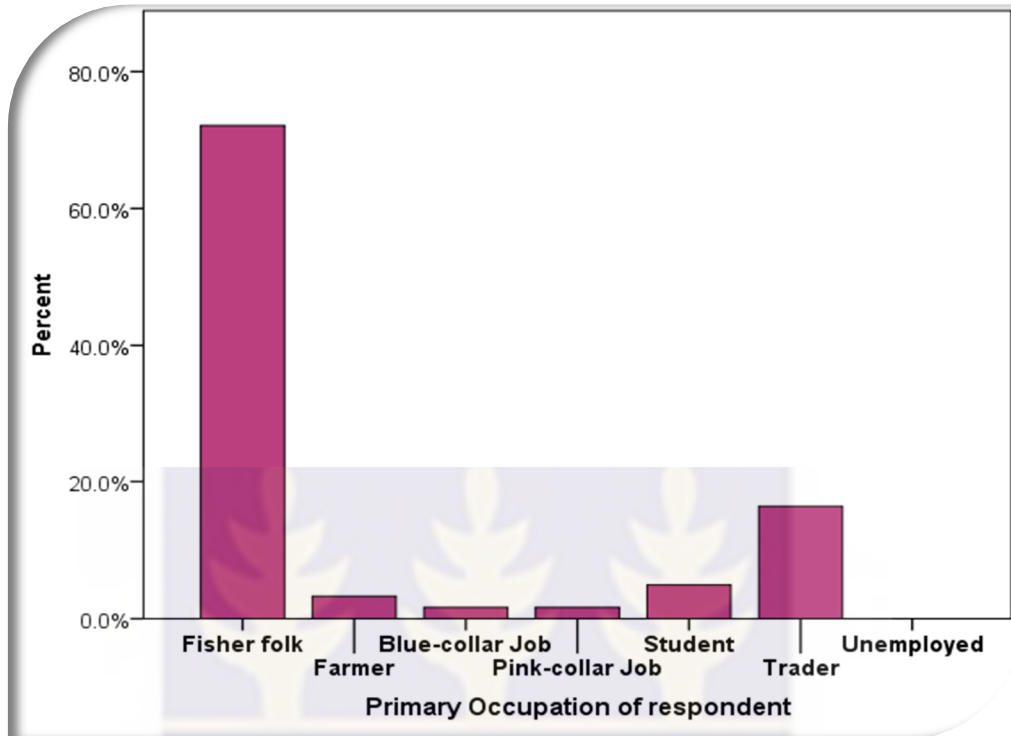


Figure 4.3.3: Distribution of occupation of respondents in surveyed communities

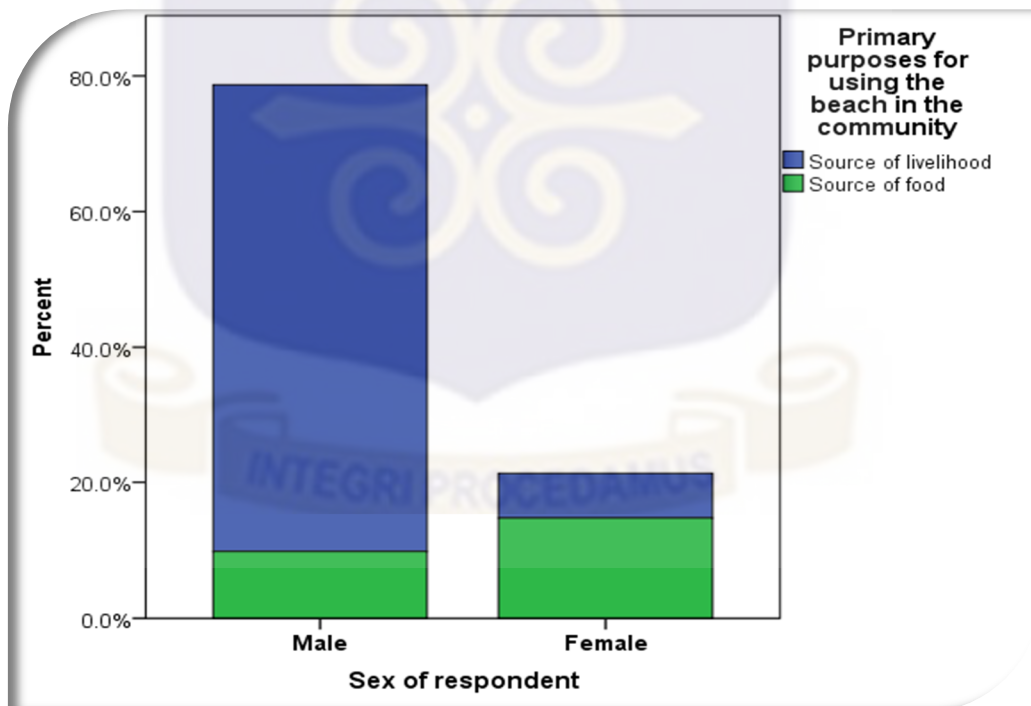


Figure 4.3.4: Distribution of respondents according to their sex and primary purpose for using the beach in their community

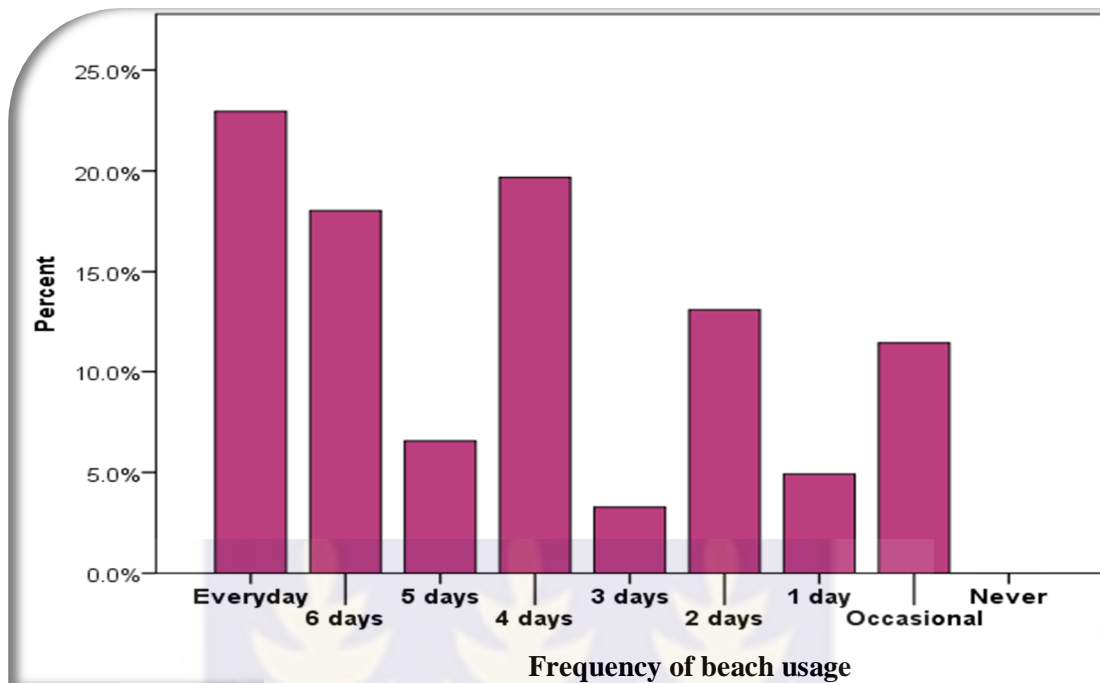


Figure 4.3.5: Distribution of number of days in a week respondents use the beach in their community

4.3.2 Oil spill survey

Information on respondent's observation of an oil spill along the beach, their community's preparedness to respond to a major oil spill along the beach, and engagement with the community by Government or Oil Company regarding oil spill response is presented in figures 4.3.6 – 4.3.9. The data shows that no oil spill has been witnessed along the beaches in the various coastal communities surveyed. No respondent was able to confirm the existence of a plan or measure put in place by their local community to respond to any future oil spill that would be observed along their beach. Approximately 89% of respondents indicated that government and some oil companies engaged their community on social intervention programmes and community development projects. None of the

respondents was able to confirm any engagement of the community by Government or oil companies regarding oil spill response measures.



Figure 4.3.6: Respondents' awareness of the occurrence of an oil spill along the beach

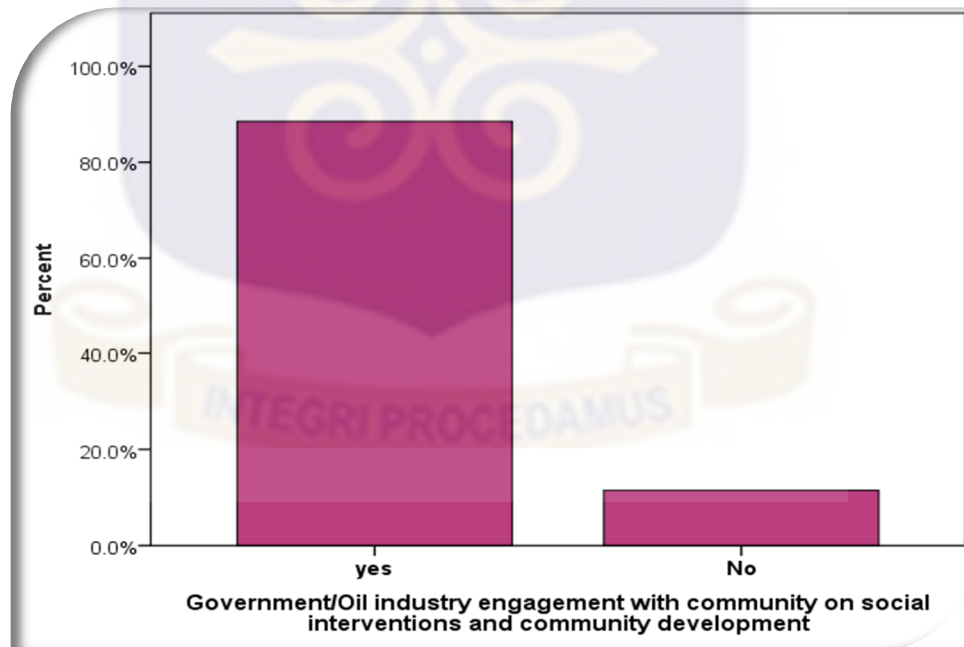


Figure 4.3.7: Respondents' awareness of Government engagement with community on social interventions and community development

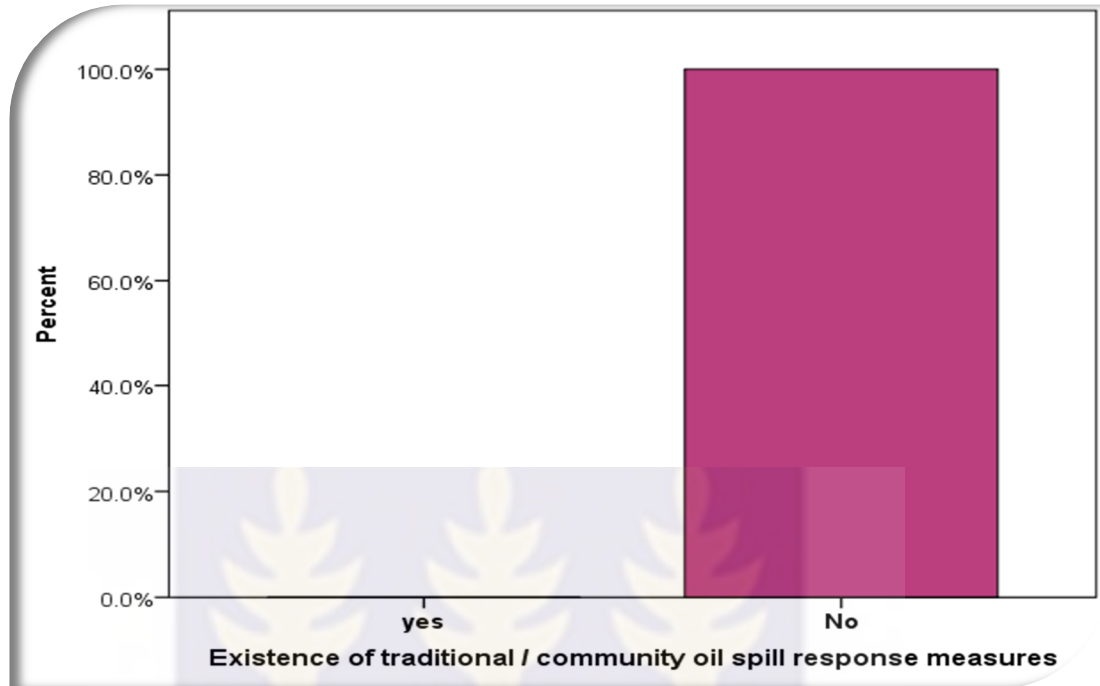


Figure 4.3.8: Respondents' awareness of a community oil spill response measure

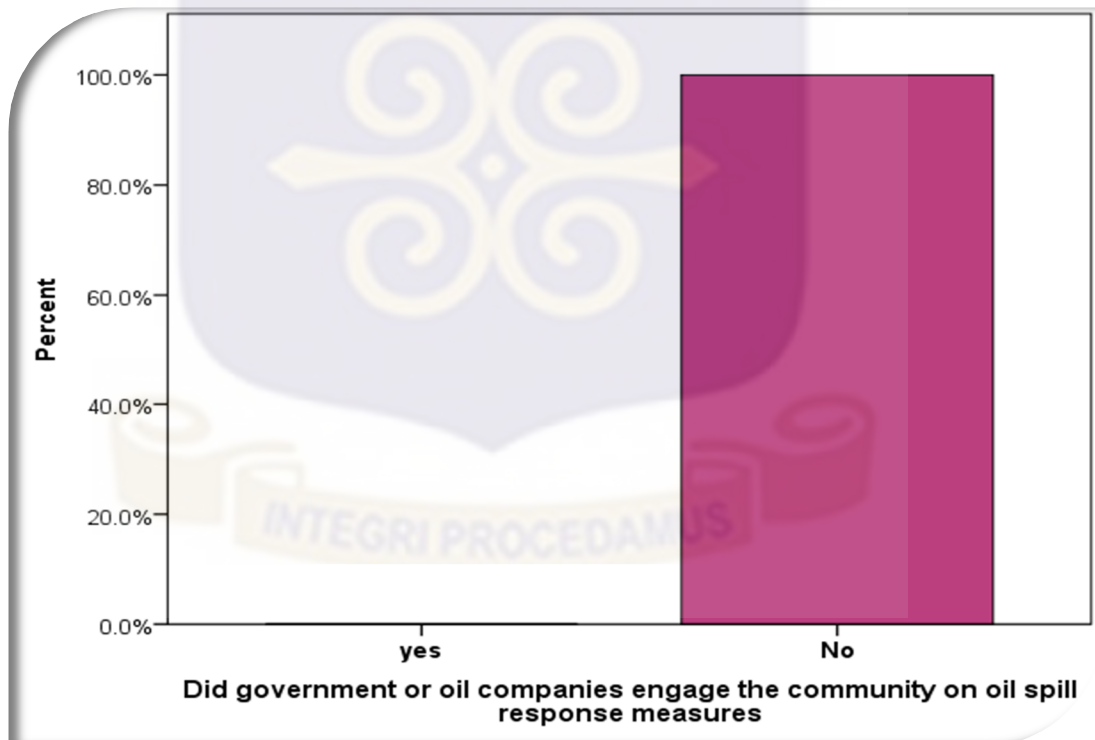


Figure 4.3.9: Respondents' response on Government engagement with community on oil spill response measures.

Respondents expectations on oil clean-up duration and roles government and its agencies

must play in the case of any oil spill response in the area are presented in Figures 4.3.10 – 4.3.15. The results showed that approximately 40% of respondents expect a major oil clean up exercise along the beach in their community to last for up to a month, while 3% of respondents believe such an exercise could last for up to six months. Respondent views are divided on government's role during an oil spill response, with the majority (56% approximately) indicating government needs to provide logistical support during any oil spill response measure. A total of 36% of respondents indicated that the ecology of the coastline was most important to them in any oil clean-up efforts, ahead of costs that would be incurred and time that would be spent in cleaning up the spill.

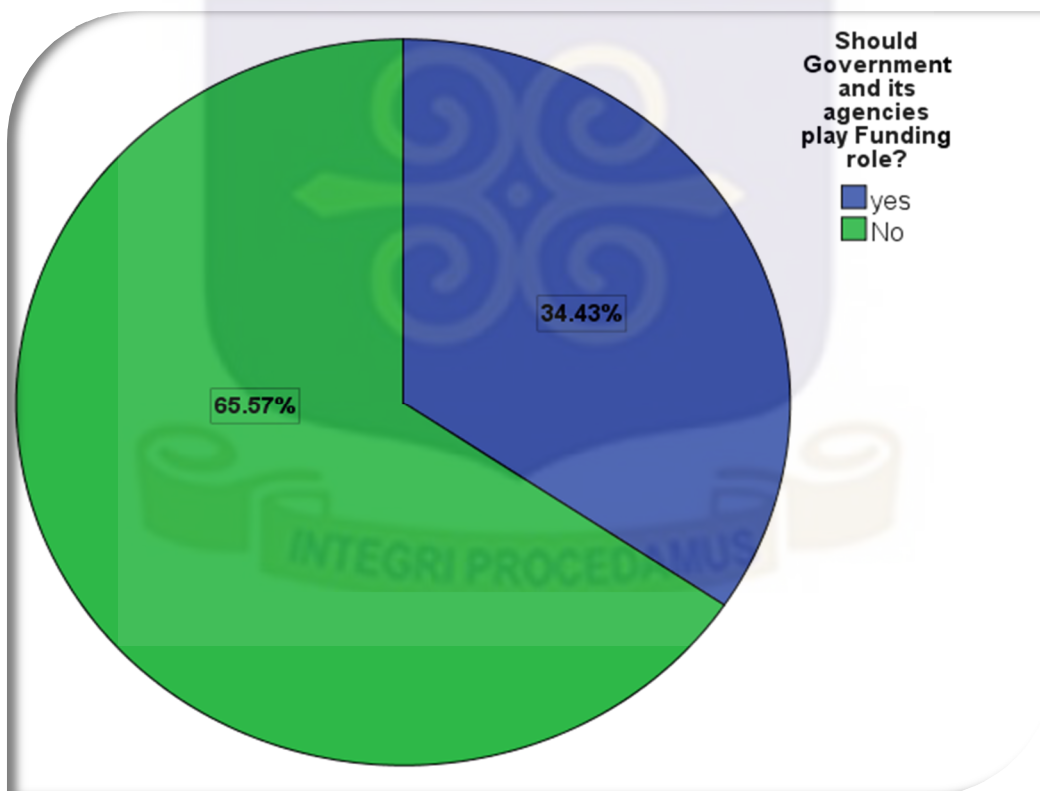


Figure 4.3.10: Respondents' view on Government funding role in oil spill response

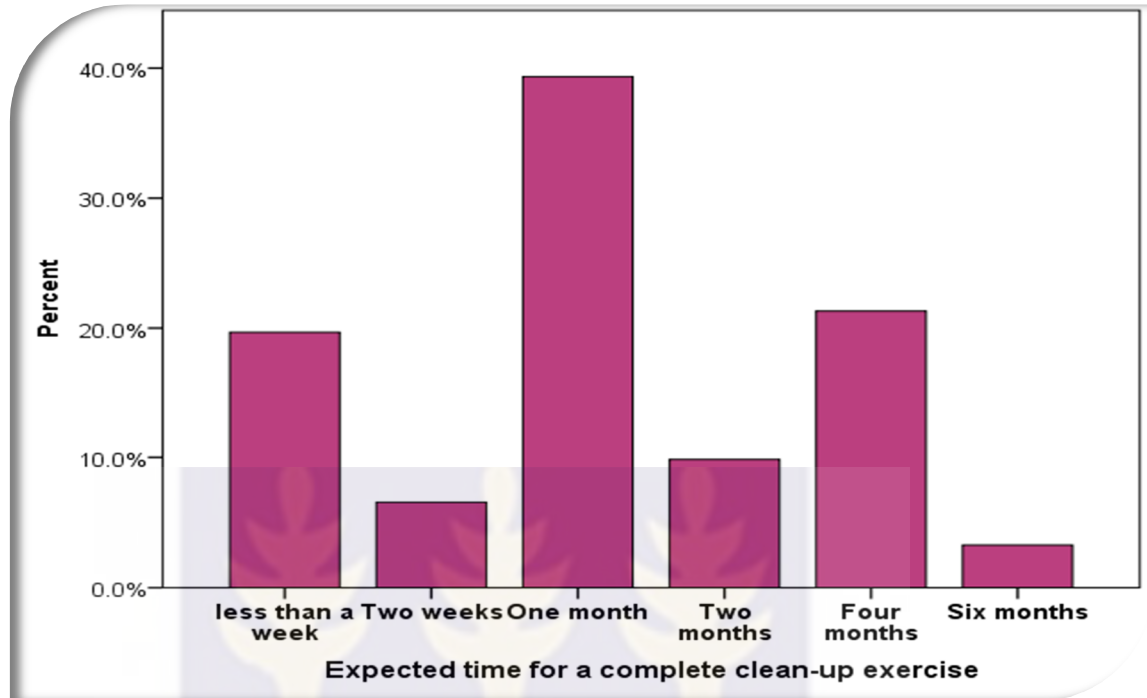


Figure 4.3.11: Respondents' expected duration for a cleanup exercise along the beach

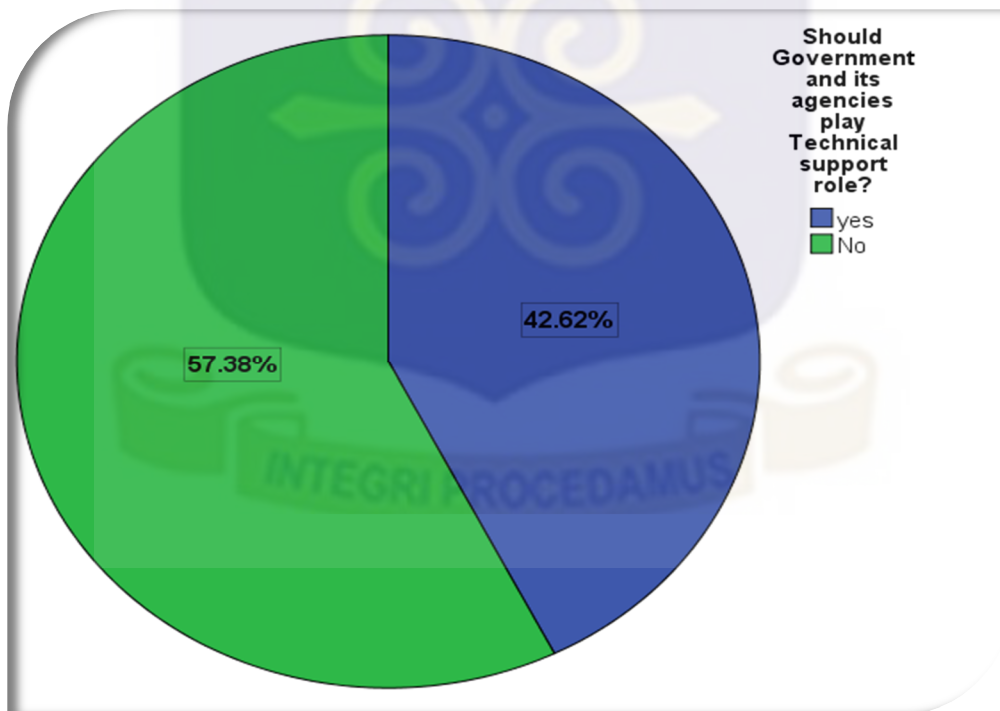


Figure 4.3.12: Respondents' view on Government technical support role in oil spill response

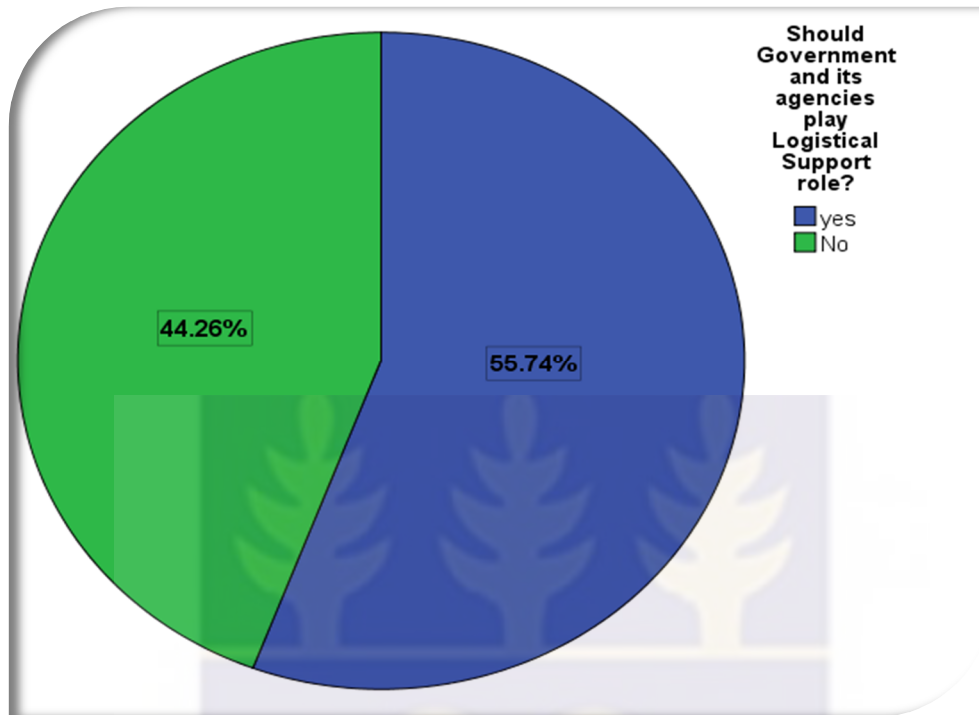


Figure 4.3.13: Respondents' view on Government logistical support role in oil spill response

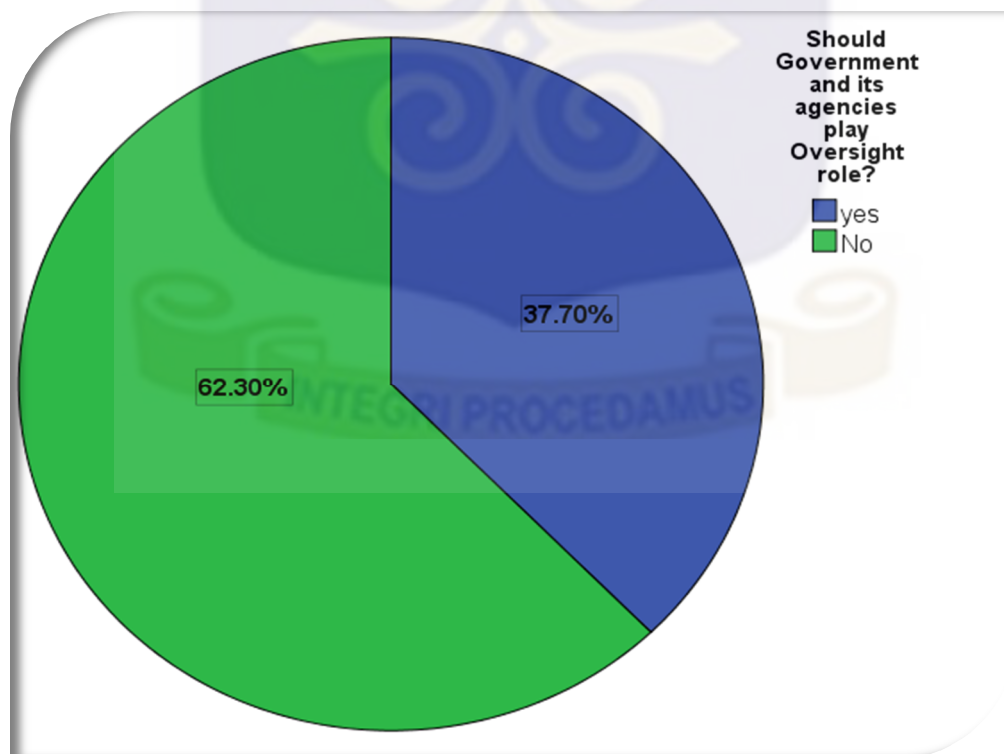


Figure 4.3.14: Respondents' view on Government oversight role in oil spill response

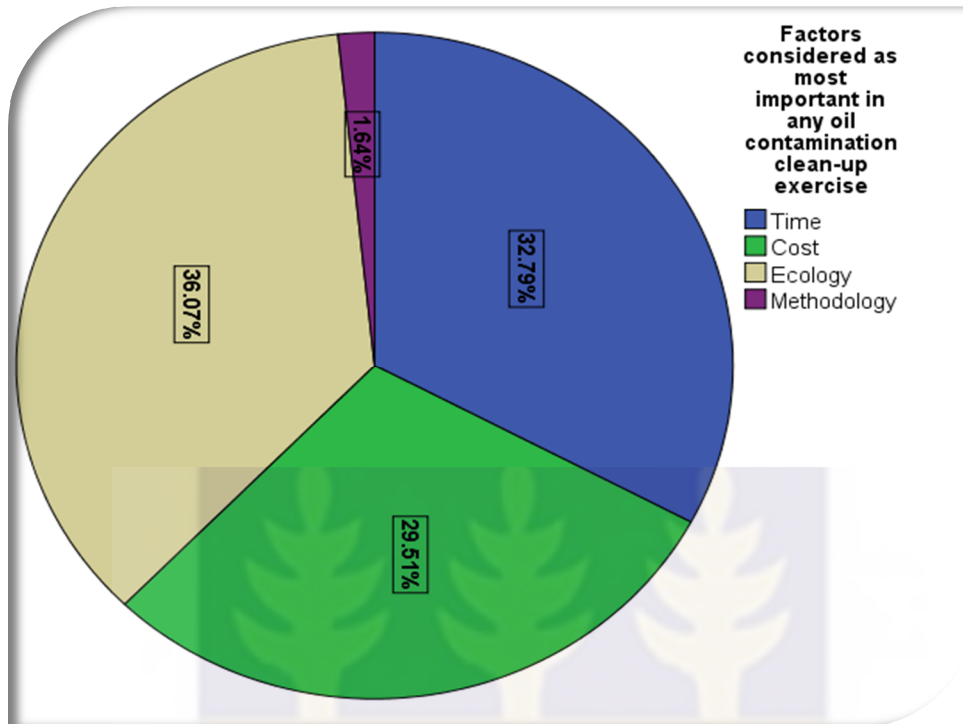


Figure 4.3.15: Respondents' perspective on the most important factor during and oil spill clean-up

Key points from the face to face interview with a resources person from the Environmental Protection Agency of Ghana are presented in Table 4.3.1 below. The table highlights the agency's role in the oil and gas industry, the occurrence of oil spills, vulnerability of coastal communities and measures put in place to protect them, and the official oil spill response protocols of the agency. Further details are presented in Appendix B.

Table 4.3.1: Key points from interview with resource person from Ghana EPA

Issue of discussion	Key Remark
Role of the EPA in Oil & Gas industry	<ul style="list-style-type: none"> • Regulating and granting of environmental permits to all players of the industry. • Monitoring of environmental performance of various players in the oil & gas industry.
How long EPA has been engaged in the Oil & Gas industry	<ul style="list-style-type: none"> • EPA's role in the industry extends as far back as forty years when it was established as a council.
Vulnerable coastal communities in the case an oil spill	<ul style="list-style-type: none"> • The issue of community vulnerability is quite a complicated one as many factors increase or decrease a community's vulnerability. • Factors like time of oil spill, weather conditions and the direction of the ocean current increase or decrease vulnerability of communities to oil spills. • Environmental Sensitivity Atlas of EPA shows most vulnerable communities along the coast. • Six coastal districts have been identified by the EPA as most sensitive and includes the Ahanta West District
Measures to protect vulnerable communities	<ul style="list-style-type: none"> • Awareness creation programmes are carried out by the EPA in the six most sensitive districts • Scheduled visits to the oil fields are arranged occasionally between EPA and oil field operators to conduct environmental monitoring.
Community responsibility during spill response	<ul style="list-style-type: none"> • The only expectation of the EPA for any community is for them to report the occurrence or sighting of any oil spill. • The agency has not provided any technical training to coastal communities in anticipation to respond to an oil spill. • Individuals in some selected coastal communities have been trained by oil companies to assist them in the clean-up of an oil spill. • EPA has not conducted independent verifications of these reported training of individuals in coastal communities by the oil production companies.
Oil spill history	<ul style="list-style-type: none"> • There hasn't been any recorded oil spill. • Only Cosmos spilled drilling mud during oil exploration in 2010

<p>EPA response protocols for any scale of offshore oil spill</p>	<ul style="list-style-type: none"> • The National Oil Spill Contingency Plan stipulates the protocol to be followed in responding to any oil spill. • Any spill that occurs is to be reported to the EPA immediately. • After a spill is reported, the agency quickly brings together relevant national and private institutions to address the spill. • These institutions include the National Disaster Management Organisation (NADMO), Fire Service, Military, and Ghana Health service. • The first response is to ensure that the oil doesn't beach. • In the instance where beaching of the oil is likely to occur, the oil must be diverted to the least sensitive beach for clean-up. • Clean-up response includes the use of dispersants (Corexit), booms and skimmers. • In the case of major oil spills (tier 3), EPA is to immediately contact Oil Spill Response Limited (UK) for assistance. • The priority of the agency is to quickly clean-up oil spills to avoid incurring unnecessary environmental, economic and social costs
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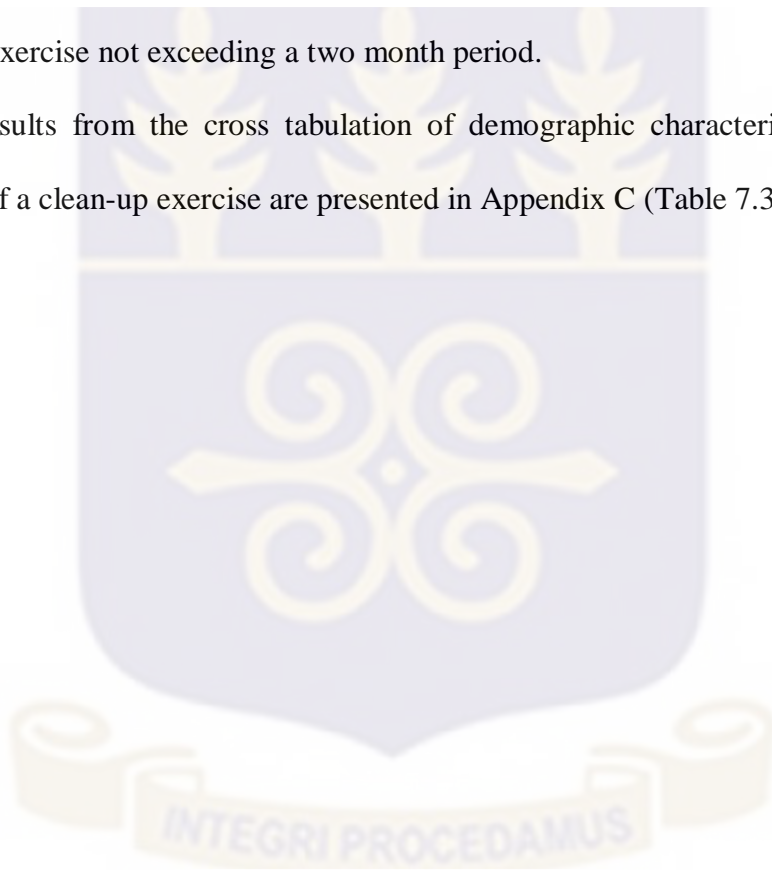
4.4 STATISTICAL ANALYSIS FROM COMMUNITY SURVEY

Full details from the analysis on correlation between demographic characteristics of respondents and their use of the beach in their community are presented in Appendix C (Tables 7.3.1 and Table 7.3.2). A key point to note from the correlation analysis is that 72% of respondents were fishermen, while there exists very little correlation between the age of respondents and how often they use the beach. It is also observed from the results that there

exists a minimal correlation between gender and how often the beach is utilised (Table 7.3.2), such that males in the communities are likely to use the beach more often than females.

Similarly, results from the binary logical regression on the various expectations of the community on the governments' roles during an oil spill (mentioned earlier in the methodology) have been presented in Appendix C (Table 7.3.4). The model recorded an accuracy of 77% in predicting the likelihood of age, gender, residing community, resident time in a community, and occupation, influencing a respondents' expectation of an oil spill clean-up exercise not exceeding a two month period.

Results from the cross tabulation of demographic characteristics and expected duration of a clean-up exercise are presented in Appendix C (Table 7.3.6 to Table 7.3.21).



CHAPTER FIVE

DISCUSSION

5.1 SOIL REMEDIATION: PHYSICAL OBSERVATIONS

The displacement of crude oil from the soil matrix upon the addition of hydrogen peroxide was principally because hydrogen peroxide has a higher density than crude oil (Simanzhenkov & Idem, 2013; Huckaba, 1947). The chemical reaction that took place between hydrogen peroxide and crude oil generated gases that vigorously bubbled out of the soil matrix (with some being trapped in the soil matrix), such that higher concentrations of the peroxide generated more gas release from the soil. This occurred because higher concentrations of the hydrogen peroxide contained more free radicals and anions that reacted with crude substances in the soil (Watts et al., 1999). The rapid increase in temperature of the soil being treated with hydrogen peroxide was expected as the reaction between hydrogen peroxide and crude oil is an exothermic reaction (Denisov & Afanas'ev, 2005; Martel, 2004; Hucknall, 1985).

The occurrence of these two physical responses of the contaminated soil to the hydrogen peroxide treatment is important in achieving higher treatment efficiency. First and foremost, the vigorous bubbling that occurs as the hydrogen peroxide percolates the soil matrix frees and breaks up the soil matrix to allow for oxygen (which is released from the breakdown of the peroxide) to mix up and enrich the soil. It also increases the surface area needed for the peroxide to come in contact with the crude oil to break it down. Secondly, the heat generated from the exothermic reaction creates the avenue for the lighter

constituents of the crude oil to be volatilised and evaporated out of the soil matrix, thereby partially reducing the volume of the crude oil present in the soil to be treated. Though these physical responses could possibly enhance the treatment of hydrocarbon contaminated soil, they pose a significant danger and health risk when the contaminated soil is treated on a large scale. The heat generated from the reaction alone can cause severe burns to persons handling the treatment if proper care is not taken, while the gaseous emissions could contain harmful volatile constituents of the crude oil which when inhaled could potentially result in respiratory and other serious problems.

The displacement of higher volumes of crude oil onto the soil surface 2 days after addition of fertilizer to soil pre-treated with lower concentration of hydrogen peroxide, could be attributed to the fact that, higher concentrations of hydrogen peroxide were able to break down more of the crude oil in the soil, leaving a little oil in the soil to be displaced to the top of the soil.

5.2 SOIL REMEDIATION: CHANGES IN NUTRIENTS LEVELS

Background nutrient (Nitrogen, Phosphorus, and Potassium) levels in the uncontaminated soil were recorded to be relatively low at the beginning of the study (Table 4.2.1). It is generally observed that the concentration of the nutrients considerably increased in all the treatment setups over the study period, which was quite contrary to what was anticipated prior to the start of treatment of the soil. This observation could be attributed to the fact that crude oil is comprised of some nitrogen, phosphorus and potassium based compounds (Simanzhenkov & Idem, 2013; Manrique *et al.*, 1997) which may have released these nutrients into the soil upon their degradation during the remediation process.

5.3 SOIL REMEDIATION: VARIATIONS IN TREATMENT EFFICIENCY

The concentration of petroleum hydrocarbon in the contaminated soil was expected to decrease over the study period as the soil was being treated, however, it is observed from Figure 4.2.1 that there was a general increase in petroleum hydrocarbon levels in the soils that were treated over the study period. A possible reason for this observation was the use of gas chromatography in testing for petroleum hydrocarbon levels. The gas chromatography method employed limited results to carbon molecules with up to 44 carbon atoms. Any hydrocarbon molecule present in the sample with more than 44 carbon atoms was not detected to be quantified as part of petroleum hydrocarbons in the samples in this study. However, crude oil used for the study contained petroleum hydrocarbon compounds with more than 44 carbon atoms. Over time, the heavier crude compounds (above C44) degraded to lighter crude compounds (below C44) due to the treatment applied to the soil. The breakdown of heavy crude compounds (above C44) by the hydrogen peroxide resulted in the gradual build-up in the concentration of relatively lighter crude compounds (C9 - C44) in the soil over the time period of the study.

Nonetheless Figure 4.2.2 which presents the amount of petroleum hydrocarbons (C9-C44) degraded in the contaminated soil, indicates that a combined treatment involving hydrogen peroxide and biostimulation yields the most efficient results in degrading petroleum hydrocarbons. It also shows that the higher the concentration of hydrogen peroxide used in the combined treatment, the more petroleum hydrocarbons were degraded in the contaminated soil. This was expected because higher concentrations of hydrogen

peroxide contained increasing amounts of free radicals (hydroxyl radicals *OH), superoxide anion (O_2^{*-}), hydroperoxyl radical (HO_2^{*-}), and hydroperoxide anion (HO_2^-) (Watts et al., 1999; Sedlak and Andren, 1994). These radicals quickly reacted to oxidise petroleum hydrocarbons in the contaminated soil. Even though higher concentrations of hydrogen peroxide contained increasing amounts of oxidising radicals, it didn't necessarily translate to exponential levels of degradation of petroleum hydrocarbons in the contaminated soil when higher hydrogen peroxide concentrations were used in treatment. This could be attributed to the rapid increase in temperature of the contaminated soils treated with higher concentrations of hydrogen peroxide. According to de Weert et al. (2014) high temperatures can affect the efficiency of oxidising contaminants of concern in soil because higher temperatures increase the availability of natural organic compounds in soil, which intend compete with the contaminant of concern for the oxidising agent. Based on the argument of de Weert et al. (2014), it can be argued that 60% hydrogen peroxide did not yield an exponential increase in degrading petroleum hydrocarbons in the contaminated soil, because natural organic compounds competed with the petroleum hydrocarbons in reacting with hydrogen peroxide, due to the increased temperature of the soil.

Based on the analysis of variance conducted on the total petroleum hydrocarbon levels in each treatment setup over the 24 day period (Table 4.2.3), there is no statistically significant difference (at a confidence level of 95%) between the petroleum hydrocarbon levels of the different treatment setups. This can be partly attributed to the general increase in the level of petroleum hydrocarbon (C9-C44) concentration in all treatment setups, resulting in statistically similar results across all treatment method. Nevertheless, it is not

an indication that all treatment setups possess equal ability to treat the contaminated soil, as is seen in Figure 4.2.2.

Similarly, the analysis of variance conducted on polycyclic aromatic hydrocarbon levels in each treatment setup over the 24 day study period (Table 4.2.4) showed no statistically significant difference in the treatment methods, at a confidence level of 95%. However, analysing the bar chart presented in Figure 4.2.4 revealed that treating the hydrocarbon contaminated soil with 60% H_2O_2 and then biostimulating the soil with chemical fertiliser yielded the highest level of PAH removal from the contaminated soil. Treating the hydrocarbon contaminated soil with only 6% hydrogen peroxide resulted in the least amount of PAH removal; almost twice lower than what was removed by 60% peroxide and biostimulation combined. This establishes that a combined treatment approach of pre-treatment with 60% H_2O_2 and biostimulation with chemical fertilizer is the most efficient treatment approach employed in this study.

It can also be observed from Figure 4.2.4 that biostimulating a chemically treated hydrocarbon contaminated soil can enhance the efficiency of treatment. In the case of hydrogen peroxide, biostimulation slightly enhanced the efficiency of treatment by less than 5% when higher concentration (30% and 60 %) of peroxide was used to initially treat hydrocarbon contaminated soil. When a low concentration of peroxide (6% concentration) was used in pre-treating the contaminated soil, biostimulation enhanced the treatment efficiency by 35%. It was suspected prior to the study that, pre-treatment with high concentrations of H_2O_2 would potentially heavily oxygenate the contaminated soil, such that the addition of nutrients would create an optimal condition that boosts the activities of native soil microbes in naturally degrading the petroleum hydrocarbons in the soil. On the

contrary, the high concentration of H_2O_2 may have limited the natural activities of soil microbes in breaking down the petroleum hydrocarbons in the soil. This limitation could have been through the lowering of the soil pH by the acidic H_2O_2 , or the oxidation and distraction of a large variety of the native soil microbes by the H_2O_2 . By extension, it is established by the study that biostimulation works effectively on petroleum hydrocarbon contaminated soil (Yakasi series) pre-treated with H_2O_2 of percentage concentration 6% or lower.

As reported by Bissey et al., (2006), soil with pH as low as 3 achieve higher efficiency of treatment with hydrogen peroxide compared to neutral pH soil. H_2O_2 is naturally acidic and hence works well within an acidic environment. It is very likely that the pH of the pristine coastal soil collected from the study area (pH 6.1) limited the potential of H_2O_2 to treat the contamination in the soil. Nonetheless, using a high concentration of hydrogen peroxide resulted in the breakdown of higher concentrations of PAH (not exponentially) in the contaminated soil as seen in Figure 4.2.9. There was very little difference in the amount of petroleum hydrocarbons and PAH that was degraded by 30% H_2O_2 and 60% H_2O_2 over the 24 day study period. This further supports the establishment that high concentrations of 30% and 60% hydrogen peroxide are very efficient in treating petroleum hydrocarbon contaminated coastal soil, specifically Acric Ferralsol (Ferric) soil from the Ahanta West District.

From Table 4.2.2 it is observed that the most cost efficient method of treatment was by treating the hydrocarbon contaminated soil with only 6% hydrogen peroxide. The cost of using 60% hydrogen peroxide for treatment was almost twice that of using 30% hydrogen peroxide for treatment. This greatly affected the cost effectiveness of using 60%

hydrogen peroxide in treating the hydrocarbon contaminated soil in the study. From Table 4.2.2 it is observed that using 60% hydrogen peroxide was the least economic method of treating the contaminated soil compared to other methods. The cost-effectiveness of using only 6%, 30% and 60% hydrogen peroxide was in the ratio 4.4: 1.9: 1 respectively. This implied that using 60% hydrogen peroxide was 4.4 times more expensive than using 6% hydrogen peroxide in treating the hydrocarbon contaminated soil over a period of 24 days. It is critical to also note that though using only 6% hydrogen peroxide to treat the hydrocarbon contaminated soil was the cheaper method, it is also the treatment method that yielded the least efficiency in treating the soil within the 24 day period of the study.

Furthermore, treatment involving only biostimulating the hydrocarbon contaminated soil proved to be more cost-effective than any other approach involving the use of 60% hydrogen peroxide. Biostimulation was 1.8 times more cost-effective than 60% hydrogen peroxide while recording relatively similar cost effectiveness as 30% hydrogen peroxide. A number of studies, including Susarla et al., (2002), show that adopting biological methods in treating contaminated soil yields more cost-effective results than other treatment approaches. It is not out of place that the adoption of biostimulation in this study yielded more cost-effectiveness than some of the treatment approaches adopted in the study. Biostimulating soil treated with 6% hydrogen peroxide enhanced the treatment efficiency of the contaminated soil, however, contrary to expectations on cost-effectiveness, it reduced the cost effectiveness of the treatment by 26.4%. Biostimulating the soil treated with 30% and 60% hydrogen peroxide also reduced the cost effectiveness of those chemical treatment approaches by 14.4% and 5.8% respectively. By this, it is established that biostimulation by means of fertilizer addition to treat petroleum

hydrocarbon contaminated soil is a cost-effective means of treatment, if and only if, it is not combined with other treatments such as hydrogen peroxide treatment.

5.4 STUDY COMMUNITY SURVEY

5.4.1 Background and demographic characteristics of respondents

The very minimal correlation between the age of respondents and how often they use the beach (Table 7.3.1) was expected as field observation indicated that fishing was the primary occupation of the majority of the population in these communities, though trading and farming served as a viable alternative in the communities (Figure 4.3.3). Both the young and old in the surveyed communities participated in fishing.

As a result of males in the communities having a higher probability of utilising the beach than females (Table 7.3.2), an event that inhibits the utilisation of the beach would potentially affect the male population severely than females. A major oil spill and pollution along the beach in these communities for instance would impact the livelihood of a large population of males. Consequently resulting in considerable economic hardship for many families, as males are generally the breadwinners of the family in these coastal communities (Adusah-Karikari, 2015; Egyir, 2012; Manu, 2011).

5.4.2 Oil spill incident and impact on the environment and society

None of the respondents engaged mentioned witnessing an oil spill that contaminated the coastline in their community (figure 4.3.6). In the assertion of some respondents from the Cape Three Points area, weathered oil (coal tar) used to wash ashore the beach years before oil and gas exploration and production commenced offshore. However such sightings of

coal tar have not been made since the offshore oil production commenced. The reason for this is unknown to respondents. Some respondents who are fishermen reported sighting oil spills at sea when they went fishing, but the spills were far away from shore and not large enough to be transported to the beach by the ocean waves.

People from Cape Three Points and neighbouring communities speculated that the offshore oil and gas industry was contributing to a proliferation of sargassum (which has a highly offensive smell) on their beaches. They pointed out that the weed hindered their work and caused them to have little success at catching fish. Though no evidence exists to support this claim, it is an indication of the likely impacts of the oil and gas industry to the shoreline ecosystem of coastal communities in the Ahanta West District. Ackah-Baidoo, (2013) also reported this claim by people from the Cape Three Points area.

5.4.3 Community's oil spill response and engagement

Critical analysis of the data on spill response and engagement indicate that none of the respondents could acknowledge the existence of any measures put in place by their community to respond to the beaching of oil along their shoreline (Figure 4.3.8). This relaxed approach by the communities may have resulted because no oil spill had been witnessed along the beach in the past (Figure 4.3.6). Consequently, the communities may be failing to fully recognise it as a potential risk that needed much attention at their level. As argued by Forrest & Mays, (1997), it is a common occurrence for communities to have an inadequate understanding of the environmental consequences of industrial activities, as industry players fail to carry out proper community education and sensitization on potential environmental risks.

As confirmed by majority of the respondents (Figure 4.3.7), Government agencies and some Oil and Gas companies have engaged their communities on a number of occasions to discuss various issues. Some of the key issues that characterised these engagements include; the establishment of scholarship opportunities for members of those communities; the availability of interest-free loans for community members; construction of boreholes and other water supply systems; cautioning of fishermen to abstain from prohibited areas around the oil fields; and the proliferation of Sargassum seaweed along the coastline, which is speculated to be dwindling fish catch of the fishermen in the area. In all engagements with the community by the Government/oil companies, the issue of measures to take at the community level in responding to an oil spill was never discussed, according to all respondents questioned (figure 4.3.9). This further confirms the argument by Forrest & Mays, (1997), that it is a common occurrence for authorities to inadequately educate the public (communities) on expected environmental consequences of an industrial activity such as oil exploration and production, in that way some communities become complacent to locally adopt strategies in effectively addressing the expected consequences.

Onwuteaka, (2016), argued from a Nigerian perspective that, government and the oil industry's efforts to clean-up oil spills are not encouraging, considering the number of spill sites recorded. Onwuteaka, (2016) reported that only 0.2% of spill sites in Nigeria have records of attempts at clean-up and remediation. He further argued for the need to discover innovative remediation technologies that are indigenous and cost effective. In support of Onwuteaka's argument, the Government of Ghana and the oil industry players in the country can adopt strategic measures that facilitate the ability of coastal communities

likely to be impacted by an oil spill, to locally clean-up and remediate spills by themselves, using indigenous approaches and technologies.

It is only reasonable that this level of varied expectations on clean-up duration is observed (Figure 4.3.11), considering the lack of engagement and education of the population in these communities by both government and oil companies on the subject. This, however, could pose a significant challenge and risk of conflict. In the event that an actual spill occurs along the beach that needed to be cleaned-up, community expectations may vastly vary from government/oil companies. If the majority of the population expect a clean-up exercise that normally would take up to six months to a year, to be conducted within a one month period, then certainly major conflicts on resource availability and utilisation may arise.

5.4.4 Community expectation for Government on oil spill response

Analysis of respondents' data on government's role when it comes to responding to oil spills in their communities (figure 4.3.10 - 4.3.14) reveal that respondents are greatly divided and do not have a clear consensus on the role government must play regarding response to an oil spill.

It can be observed that respondents want the government to train local community members in oil spill response techniques rather than completely taking over the role of cleaning up coastline contaminated with an oil spill. Some respondents claimed the government will fail to come to their community's aid in the event of an oil spill, citing how previous engagements and promises have not materialised.

The expectation of respondents for the government to play a technical support role (43% of respondents) and a logistical support role (56% of respondents) is based on the fact that the respondents feel local community members do not properly understand the science behind oil clean-up. They are convinced that government's technical support and provision of logistics required would be enough for them to clean up any oil spill encountered along their coastline. Some respondents also indicated that it would be a good job creation opportunity for the community members.

5.4.5 Community expectation on clean-up duration

In the event of a Tier 3 oil spill (spills above 1000 tonnes) that the oil may contaminate certain areas along the coast, a clean-up exercise would have to be carried out in a timely fashion. A number of factors may influence the duration and efficiency of the clean-up exercise, of which include the nature of the beach (sandy/stony), the weather conditions, chemical and physical properties of the oil that has contaminated the beach, the quantity of the oil contaminating the beach, and the quantity of the oil in the sea heading towards the beach (Fingas, 2015). Coastal communities are most likely to be affected by offshore spills, however, persons living in such communities may have little to no idea about the technicalities and factors that may influence the duration of a clean-up exercise. Expectations and assumptions on how long a clean-up exercise should last vary from person to person based on their understanding of the issue. This could be a potential source of conflict between communities and the authority undertaking the clean-up exercise. In this regard, respondents were questioned if they expected a clean-up exercise to last for two months or beyond.

According to the model (Table 7.3.4), older people above 60 years in contrast to the young below 20 years, were approximately 3 times more likely to expect clean-up to take less than two months to complete. The study established that most respondents (78.3%) who expected a clean-up exercise to last for a period of two months or less, were adults between the ages of 20 to 49 (Table 7.3.6). Females exhibited more likelihood of expecting a two months clean-up than males. The model also indicated that individuals who lived longer in their communities (above ten years) were more likely to expect a shorter clean-up duration. Individuals from the Cape Three Point community were the most likely to expect a clean-up exercise to last more than two months, compared to individuals from Akwidaa (Table 7.3.7). Persons from Dixcove and Cape Three Points generally had expectations of a clean-up taking more than two months to complete, contributing as much as 86.7% of all respondents with this expectation (Table 7.3.7).

Based on the study, it can be established that older females that lived for more than 10 years in the Akwidaa community are most likely to expect the clean-up of the beach in their community to take less than two months to complete. Generally, people living in these communities expect a clean-up exercise to have short durations because they heavily depend on the beach for their livelihoods and would want access to it as soon as possible.

5.4.6 Community expectation on government funding role

Responding to an oil spill (Tier 3 spill) can be a capital intensive exercise. One way or the other, funds must be sourced from somewhere to cover the cost of a clean-up exercise. For Tier 1 and Tier 2 spills, the responsible party for the spill is required to provide the funds for the clean-up exercise. Tier 3 spills are regarded as a national disaster, hence government

funding is critically needed. This is the protocol stipulated by the National Oil Spill Contingency Plan, however, it was necessary to understand the expectations of individuals living in coastal communities likely to be affected by a Tier 3 spill.

Examining respondents' expectation from the binary logistic model (Table 7.3.4), it is recognised that older individuals above 60 years were approximately twice more likely to expect the government to fund oil spill response measures, with male adults being the most probable in this group to have this expectation. Individuals in the Cape Three Points community are the most likely (among all three communities) to expect the government to fund a spill response measure in their community (Table 7.3.8). The most likely among this group are individuals who have lived in the community for longer periods (10 years and above). Individuals living in Dixcove are the least to expect government funding, as 80% of respondents from the community indicated they did not expect this of government. Among all respondents who did not expect the government to fund an oil clean-up exercise, approximately 76% of them expected a clean-up exercise to last for two months or less (Table 7.3.9).

In essence, the study established that adult males who lived in the Cape Three Points community for more than ten years are most probable to expect the government to provide funding for the clean-up of an oil spill along the beach. This observation may be attributable to the fact that job avenues and economic activities are very limited in Cape Three Points compared to the other surveyed communities. With adult males in Cape Three Points constantly looking for job opportunities to make money, perhaps the clean-up of an oil contaminated beach may be regarded as a viable job opportunity for them. It would

consequently be their expectation that Government will provide the funding for them to undertake the exercise as payable jobs.

5.4.7 Community expectation on government technical support role

The science behind clean-up of an oil spill can be quite complicated, such that highly skilled and experienced persons are required to carry out an effective clean-up exercise. Government agencies like the Environmental Protection Agency, have available, technically skilled individuals with training and experience in oil spill clean-up. In the event of an oil spill, it is expected that these technical persons from various government agencies come together to provide working groups with technical advice on how best to clean up the spilt oil. As regards this, respondents from coastal communities surveyed were questioned on their expectation of government agencies providing technical support to their community in the event of an oil spill.

The binary logistic model further revealed that older individuals above 60 years were five times less likely to expect the government to provide technical support in an oil spill response measure than individuals below 30 years of age (Table 7.3.4). Half of all respondents who expected the government to provide technical support during spill clean-up were young individuals in their twenties (Table 7.3.10). This is because the youth expect job opportunities to be created for them during clean-up, so far as government provided technical support. Females were almost twice more probable not to have this expectation of the government, with approximately 61% of all female respondents not having the expectation (Table 7.3.12). Individuals who lived longer in the communities surveyed were less likely to expect government's technical support (Table 7.4.4). Most people in Dixcove

(60%) expect the government to provide technical support while most in Cape Three Points (68.2%) do not (Table 7.3.11).

This suggests that younger males who have lived in the surveyed communities for a short period of time (less than 5 years) are likely to expect the government to provide technical support during an oil spill response.

Respondents who expected a clean-up exercise to take less than two months were also divided on their expectation of government to provide technical support. For all respondents who expected two months or less clean-up exercise, only 32% expected the government to provide technical support (Table 7.3.13).

5.4.8 Community expectation on government logistical support role

Having the right and necessary logistics available is among the key factors to a successful spill clean-up. Logistics may include vessels (barges, landing craft, skimmers, and boats), personal protective equipment, cleaning materials and chemicals, booms, dispersants, hazardous waste storage containers/bags. Respondents from coastal communities surveyed were questioned on their expectation of government agencies providing logistical support to their community in the event of an oil spill.

It is observed from the binary logistic model that younger individuals below the ages of 30 years were approximately twice likely to expect the government to provide logistical support than individuals above 60 years of age (Table 7.3.4). However, 83% of individuals between the ages of 50 to 59 expect the government to provide logistical support during a clean-up exercise (Table 7.3.14). Additionally, the model predicts that females are twice more likely to expect the government to provide logistical support than

males. A crossbar analysis of the data conversely shows approximately 61% of females did not expect logistical support from the government (Table 7.3.15). This contradiction is expected as the model only explained up to 31.4% of the variation in respondents' expectation.

The longer an individual stayed in a community, the more likely they expect the government to provide logistical support, such that individuals living in the community for more than 10 years are approximately twice more likely than individuals who have lived in a community for less than a year. Individuals living in Dixcove are four times more likely to expect the government to provide logistical support than individuals living in the Cape Three Points community (Table 7.3.4). Respondents living in Cape Three Points were divided on their expectation of government providing logistical support (Table 7.3.16). In essence, younger females who have lived in the Dixcove community for a long period of time (above 10 years) may most likely expect the government to provide logistical support during an oil spill response.

Just about 39% of all respondents have both expectations that a clean-up exercise would last for two months or less, and that government must provide logistical support during a clean-up exercise. On the contrary, about 10% of respondents expect a clean-up exercise to last for more than two months but do not expect the government to provide the logistical support for the clean-up exercise. Roughly 15% of all respondents think that a clean-up exercise would last for more than two months and would require logistical support from government to carry out the exercise (Table 7.3.17).

5.4.9 Community expectation on government oversight role

The Environmental Protection Agency is the body that regulates and permits all activities that have consequences on the state of the environment on behalf of the Government. Its role as oversight agency during a spill clean-up is undoubtedly crucial. In this regard, respondents from coastal communities surveyed were questioned on their expectation of government agencies playing an oversight role in their community in the event of an oil spill.

Approximately 43% of respondents above 30 years old do not expect the government to provide oversight during a spill response, while only 16% do (Table 7.3.18). Individuals above 60 years old are six times likely not to expect the government to provide oversight during spill response than individuals below 30 years of age (Table 7.3.4). Females are most likely to expect the government to play an oversight role than males (47% of respondents who did not expect the government to play an oversight role are males) (Table 7.3.19). Individuals living in the Dixcove and Akwidaa communities are likely to expect the government to play an oversight role, while those living in the Cape Three Community are likely not to (31% of respondents who do not expect government's oversight role are from the Cape Three Points community) (Table 7.3.20). The longer individuals lived in a community, the more likely they expect the government to play an oversight role in oil spill response. Fishermen are among the most likely to expect the government to play this role (Table 7.3.4). This suggests that younger females below 30 years of age that have lived for a long period of time in the Dixcove and Akwidaa communities are the most probable group of individual to expect the government to play an oversight role during an oil spill response measure.

About 31% of all respondents have expectations that a clean-up exercise would last for two months or less, and also that government must provide oversight during a clean-up exercise. Forty-four percent (44%) of respondent indicated that clean-up would take two months or less but don't expect the government to provide oversight during the exercise. About 6% of all respondents think that a clean-up exercise would last for more than two months and would require logistical support from government to carry out the exercise. On the contrary, 18% of respondents expect a clean-up exercise to last for more than two months but do not expect the government to provide the oversight during exercise (Table 7.3.21).

5.5 EPA AND COMMUNITY ENGAGEMENT DURING SPILL RESPONSE

The agency, as a matter of fact, recognizes how the oil and gas industry renders some communities socially, economically and environmentally vulnerable. Though the state of vulnerability of any given community may be a complicated subject matter, due to the many intricate factors that contribute to their vulnerability, the EPA has developed an Environmental Sensitivity Atlas that indicates the most vulnerable communities along the coast of the country. From this Atlas, six coastal districts have been flagged as the most vulnerable along the coast to the oil industry. Among these six coastal districts is the Ahanta West District.

As a means to protect these sensitive coastal districts, the EPA undertakes awareness creation programmes in these districts regarding the oil and gas industry. Also,

scheduled visits to the oil fields are arranged occasionally between EPA and oil field operators to conduct environmental monitoring.

Regarding community responsibility during an oil spill, EPA's only expectation of any community is for them to report the occurrence or sighting of any oil spill to the agency. No technical training of any sort has been provided to coastal communities in anticipation to respond to an oil spill. However, individuals in some selected coastal communities have been trained by oil companies to assist them in the clean-up of an oil spill, per the annual reports submitted to the EPA by oil exploration and production companies. On the other hand, EPA has not conducted independent verifications of these reported training of individuals in coastal communities by the oil production companies.

In the event of an oil spill, the National Oil Spill Contingency Plan stipulates the protocol to be followed in responding to the spill. Per the contingency plan, any spill that occurs is to be reported to the EPA immediately. The agency is then to quickly bring together relevant national and private institutions to address the spill. These institutions include the National Disaster Management Organisation (NADMO), Fire Service, Military, and Ghana Health service. The first response is to ensure that the oil doesn't beach along the coast, but in the instance where beaching of the oil is likely to occur, the oil must be diverted to the least sensitive beach for clean-up. Clean-up response includes the use of dispersants (Corexit), booms and skimmers. In the case of major oil spills (tier 3), EPA is to immediately contact Oil Spill Response Limited (UK) for assistance. The company has been contracted by the EPA as rapid response party to help control and clean-up large spills that would otherwise be considered a national disaster.

CHAPTER SIX

6.1 CONCLUSIONS

Treating petroleum contaminated soil with hydrogen peroxide results in various beneficial but potentially harmful physical responses. These physical responses include the displacement of the oil from the soil matrix by the peroxide (oil can be easily collected from the soil surface), vigorous bubbling that occurs as the hydrogen peroxide percolates the soil matrix (frees and breaks up the soil matrix to allow for oxygen to mix up and enrich the soil), and an exothermic reaction that allows for the lighter constituents of the crude oil to be volatilised and evaporated out of the soil matrix. These physical responses could possibly enhance the treatment of hydrocarbon contaminated soil, however, the heat generated from the reaction alone can cause severe burns to persons handling the treatment if proper care is not taken, while the gaseous emissions could contain harmful volatile constituents of the crude oil which when inhaled could potentially result in respiratory and other serious health problems. Higher concentrations of hydrogen peroxide will result in an increase in these physical responses and an increased potential for health risks.

In evaluating the level of efficiency of each treatment method adopted comparing the degree to which polycyclic aromatic hydrocarbons were degraded in the contaminated soil, it can be concluded that a combined approach of 60% hydrogen peroxide and biostimulation with chemical fertilizer is the most efficient way to treat crude contaminated soil. Biostimulating a chemically treated soil improves the efficiency of treatment of the contaminated soil. However, soils treated with high concentration of hydrogen peroxide (30% and 60%) can only have their treatment efficiency slightly improved (less than 5%),

while those treated with low concentrations of hydrogen peroxide can be considerably improved by as much as 35%.

Though a combined method of 60% hydrogen peroxide and biostimulation was capable of degrading higher volumes of petroleum hydrocarbons and polycyclic aromatic hydrocarbons in the soil, it was also the least cost-effective approach to treating the contaminated soil. It is also concluded based on this study that biostimulating a chemically oxidised crude contaminated soil generally decreases the cost-effectiveness of treating the soil. Most especially contaminated soil which has been chemically pre-treated with a high concentration of hydrogen peroxide (30% or 60%).

In the three surveyed communities of Dixcove, Akwidaa and Cape Three Points where fishing remains the primary occupation of the population, no oil spill has been witnessed along the beach before. This coupled with inadequate engagement by the government and oil-producing companies with the communities regarding how to respond to oil spills, has resulted in the communities embracing a relaxed attitude towards adopting any local early response measures in the case where a major oil spill occurs. Proper government/oil industry engagement with the surveyed communities on matters concerning community involvement during an oil spill response have not been carried out, and EPA currently has no plans of undertaking any exercise of such nature.

Critical gaps exist in the community's knowledge and understanding of the duration for oil spill clean-up, most especially among elderly females close to 60 years. Older females that lived for more than 10 years in the Akwidaa community were most likely to expect the clean-up of the beach in their community to take less than two months to complete. This gap in knowledge on the appropriate clean-up duration could be a potential

source of conflict during a spill response in the future. This conflict is likely to result from a perception of the communities that, clean-up efforts are not been taking seriously by government/oil industry, in the case where considerable time is required to effectively clean an oil spill.

The various expectations of the communities on government's role in oil spill clean-up have not been influenced by factors such as age, gender, residing community, resident time in a community, and occupation. Other factors not considered in this study may account for their expectations of government. However, members of the communities are greatly divided on the roles that the government must play in responding to an oil spill along the beach in the communities. At most 56% of the surveyed population expressed an expectation of government providing logistical support during spill response, with a mindset that the spill response exercise will provide jobs for the youth in the communities, as the government provides the logistics required.

6.2 RECOMMENDATIONS

The following recommendations are made from this study:

- I. Coastal communities in the Ahanta West District should be educated and trained, by responsible government agencies such as EPA, or by Oil & Gas exploration and production companies, in early response measures to protect sensitive areas along the coast in the instance where a major oil spill occurs. This could be through the conduct of drill exercises involving local inhabitants, on how to deploy booms around sensitive areas such as turtle nesting grounds along the beach in Akwidaa, or canoe landing sites along the beach in Dixcove.

- II. Further studies should be conducted to investigate and understand other factors that may influence the expectations that coastal communities in the Ahanta West District may have of government in the case of an oil spill. This in-depth probe will ensure that conflicts that may arise out of misunderstood expectations of the local communities are avoided during spill clean-up.
- III. It is recommended that for a timely clean-up of an oil spill along the beach where booms and dispersants will not be employed, higher concentration (30% - 60% concentration) of hydrogen peroxide equal to the volume of oil that has contaminated the soil (1:1 ratio H₂O₂/crude oil) should be used.
- IV. In the absence or lack of higher concentrations (30%, 60%) of hydrogen peroxide, biostimulation of the soil should be employed after pre-treating the soil with lower concentrations (6%) of hydrogen peroxide.
- V. Further studies need to be conducted to identify which specific oil degrading soil microbes present in coastal soil from the Ahanta West District are capable of surviving oxidation from high concentrations (30%, 60%) of hydrogen peroxide, and can thus be biostimulated to finish cleaning up the contaminated soil post chemical treatment.

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APPENDICES

7.1 Appendix A

A: Questionnaire

UNIVERSITY OF GHANA, LEGON.

ENVIRONMENTAL SCIENCE PROGRAMME

QUESTIONNAIRE ON OIL CONTAMINATION AND CLEAN-UP ALONG THE COAST OF THE AHANTA WEST DISTRICT OF THE WESTERN REGION OF GHANA.

Dear respondent,

Thank you for agreeing to take part in this survey which forms part of a project work being carried out by an MPhil. Student of the University of Ghana, Legon. The project involves cleaning up soil from a beach that is contaminated with oil (petroleum). This 4-5 minutes questionnaire is to collect information from your community on your observations, expectations, understanding and acceptability of oil contamination at the beach and its clean-up. Answers provided in this questionnaire shall be treated with complete confidentiality, and will serve the purpose of this research only.

1. **Age of respondent.**

15-19 20-29 30-39 40-49 50-59 60>

2. **Residing community of respondent.**

Dixcove Akwidaa Princes Town Miemia

Achenim

Other.....

3. **How long have you stayed in the community?**

Less than a year 1-6 years 6-10 years 10 years >

4. **What is your occupation?**

Fisher folk Farmer White-collar Blue-collar

Pink-collar

Student Trader Unemployed

Other.....

5. **For what purposes do you use the beach in your community?**

Source of livelihood Recreation Source of food Tourism

No use Other.....

6. **How often in a week do you use the beach for any of the purposes stated above?**

Everyday 6 days 5 days 4 days 3 days 2

days 1 day Occasional Never

7. **Have you ever witnessed oil contamination along the beach in the area?**

Yes No

If yes proceed to question 8

If no proceed to question 13

8. **Where was the oil contamination witnessed?**

On/in beach sand On seawater surface Coastal vegetation

Mangrove

Please explain further:

9. **Where do you believe the oil contamination came from?**

.....
.....

10. **How many times have you witnessed this sort of oil contamination in the area?**

Once Twice thrice more than thrice

11. **How did the oil contamination affect you on a personal level?**

Economically Socially Occupationally

Please explain further:

.....
.....

12. **How often in a week did you use the beach after you noticed any oil contamination?**

Everyday 1 day 6 days 5 days 4 days 3 days
 2 days Occasional Never

13. **Are there any traditional/indigenous ways you are aware of that the community handles oil contaminations when they occur along the beach?**

Yes No

14. **Briefly, explain how local community members have cleaned oil contamination along the beach.**

Phytoremediation Bioremediation Chemical dispersant Not
sure No treatment

15. **Have you observed or heard of any Government or NGO undertaking an oil contamination clean-up exercise along the beach in the area?**

Yes No

Please provide more details:

16. How was the Government/NGO clean-up undertaken?

In-situ Ex-situ

17. How many days out of a week did you use the beach after the oil clean-up exercise was undertaken?

Everyday 6 days 5 days 4 days 3 days 2 days

1 day Occasional Never

18. How did the oil clean-up exercise affect your personal use of the beach?

Economically Socially occupationally

Please explain further:

.....
.....

19. How quickly do you think a complete clean-up exercise should take?

Less than a week Less than a month 4 months 6 months

12 months more than a year

Other.....

20. Did any Government agency, Oil Company or NGO engage the community after oil contamination was observed along the beach in the area? What sort of engagement took place if any?

Yes No

Please explain further:

.....
.....

21. **What role do you think government and its relevant agencies like the EPA should play in an oil contamination clean-up exercise?**

- Funding Technical support Logistical support
- Oversight Legislative framework

Please explain your choice further:

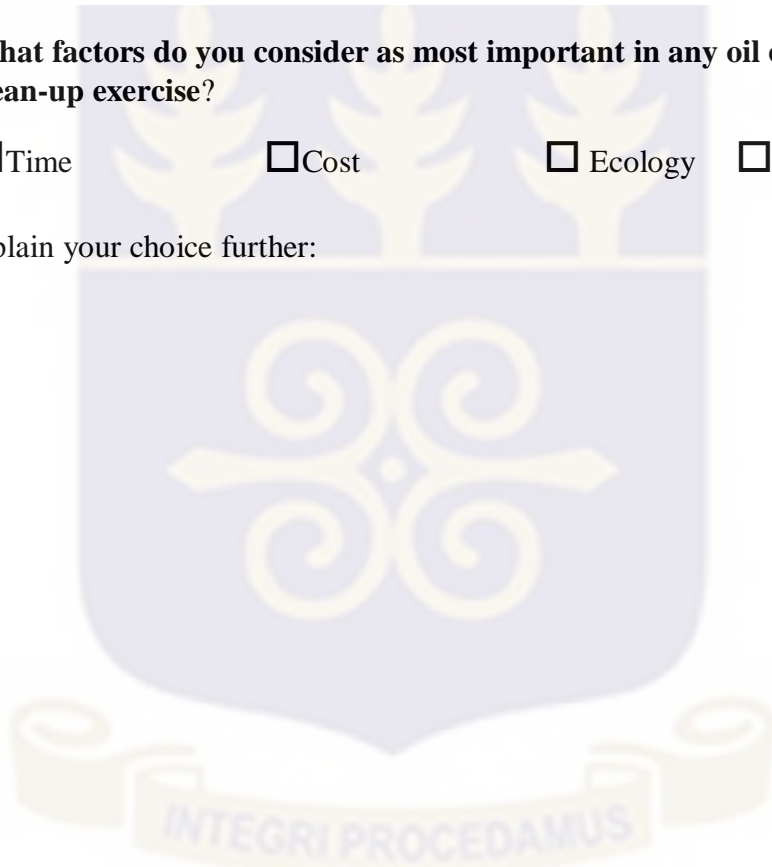
.....

.....

22. **What factors do you consider as most important in any oil contamination clean-up exercise?**

- Time Cost Ecology Methodology

Please explain your choice further:



7.2 Appendix B

EPA interview

The following are notes from the interview conducted with resource person from the Environmental Protection Agency:

- The EPA regulates and grants an environmental permit to all industry players in the upstream, midstream and downstream of the petroleum sector. This includes the granting of permits for seismic acquisition, exploration, appraisal, drilling, and production activities. The agency has been playing this role as far back as when it was established (over forty years ago), mainly for the salt pond basin oil production. As regards the Jubilee field, EPA's role became more prominent after 2004.
- The issue of community vulnerability is quite complicated in the sense that certain factors may either increase or decrease the probability of spilt oil beaching along the shore of any community. These factors include the time of the oil spill and the direction of the ocean current. These factors tend to determine if the spilt oil will travel eastward or westwards towards the beach, or travel further away from the beach.
- The EPA has prepared an Environmental Sensitivity Atlas, which identifies and grades areas along the entire coast of the country into different levels of sensitivity to an oil spill, based on environmental resources available, socio-economic activity, and tourism potential of each area. Six coastal districts have been identified by the EPA as most sensitive, of which includes the Ahanta West District. Awareness creation programmes are carried out by the EPA in these districts to educate the communities on the oil and gas industry, as well as the community's role in an oil spill response.
- The only expectation of the EPA for any community is for them to report the occurrence or sighting of any oil spill. The EPA has not engaged any community on how they should on their own, respond to an oil spill. In other words, the agency has not provided any technical training to coastal communities in anticipation to respond to an oil spill. Few individuals in some selected coastal communities have been trained by oil companies to assist them in the clean-up of an oil spill. The EPA has not conducted independent verifications of these reported training of individuals in coastal communities by the oil production companies.
- Scheduled field visits are arranged occasionally between EPA and oil field operators to conduct environmental monitoring. This is to ensure that things are being done properly and safely for the good of the environment.
- In the case of a major oil spill, the position of the Agency is to quickly clean-up the beach to avoid incurring unnecessary environmental and economic costs, and also to minimise any inconveniences caused to the residents of the potentially affected communities. In instances of very serious spills, arrangements will be made for

fishermen to land their boats in areas away from the spill site till clean-up is completed.

- Per the records of the agency, no major oil spill has been recorded offshore in exception of drilling mud Cosmos spilt during oil exploration in 2010. The quantity was not much to have caused any major concerns.
- After an oil spill is reported to the EPA, the agency quickly will bring together relevant national and private institutions to address the spill. All relevant institutions including the National Disaster Management Organisation (NADMO), Fire Service, Military, and Ghana Health service, have been stipulated by the national oil spill contingency plan to play a role in responding to a major oil spill.
- The first response is to ensure that the oil doesn't beach, however, there may be instances where the best strategic approach would be to divert the spilt oil to a less sensitive beach to be cleaned up. This is to ensure the oil doesn't beach at a more sensitive beach.
- EPA annually contracts Oil Spill Response Limited (UK), through an annual subscription fee. This is to ensure that Oil Spill Response Limited will come to the aid of the country in the case of a major oil spill. The EPA in collaboration with major oil companies in the country is making arrangements to establish an oil spill fund, part of which would be used for the annual subscription with Oil Spill Response Limited (UK).
- Clean-up response includes the use of dispersants, booms and skimmers. Dispersants that have been stocked in the country for use during a spill include Corexit. The cost of acquiring these chemicals can however not be disclosed. All oil producing companies in the country have taken steps to stockpile some of these dispersants offshore and onshore for their use during tier one and two spills.
- However, tier one spills may be allowed to disperse naturally by environmental factors.

7.3 Appendix C

Table 7.3.1: Correlation between age of respondents and the number of times they used the beach in a week

Correlations			
		Age of respondent	Number of times in a week beach is used for purpose
Age of respondent	Pearson Correlation	1	0.073
	Sig. (2-tailed)		0.574
	N	61	61

Table 7.3.2: Correlation between sex of respondents and number of times they used the beach in a week

Correlations			
		Number of times in a week beach is used for purpose	Sex of respondent
Number of times in a week beach is used for purpose	Pearson Correlation	1	-0.401**
	Sig. (2-tailed)		0.001
	N	61	61
**. Correlation is significant at the 0.01 level (2-tailed).			

Table 7.3.3: Observed variation in respondents' expectations base on Cox & Snell R Square and Nagelkerke R Square

Binary logistic determinant factor	-2 Log likelihood	Cox & Snell R Square	Nagelkerke R Square
Expectation to clean up the beach in two months or less	57.253 ^a	.162	.241
Expectation of Government and its agencies to play Funding role	59.469 ^a	.306	.415
Expectation of Government and its agencies to play Technical support role	59.649 ^a	.321	.431
Expectation of Government and its agencies to play Logistical Support role	67.802 ^a	.235	.314
Expectation of Government and its agencies to play Oversight role	57.284 ^a	.320	.436
a. Estimation terminated at iteration number 20 because maximum iterations have been reached. The final solution cannot be found.			

Table 7.3.4: Results of binary logistic model for various determinant factors

Binary logistic determinant factor	Predictor factor	B	Sig	Exp(B)	95% C.I.for EXP(B)	
					Lower	Upper
EXPECTATION TO CLEAN UP THE BEACH IN TWO MONTHS OR LESS	Age	-.059	.849	.943	.514	1.728
	Sex	-.244	.880	.784	.033	18.781
	Community		.538			
	Dixcove	19.618	.999	331129554.752	.000	
	Akwidaa	18.906	.999	162415415.955	.000	
	Cape Three Points	20.349	.999	687482331.112	.000	
	Resident Time	-.198	.749	.820	.243	2.763
	Occupation		.922			
	Fisherman	-.475	.779	.622	.022	17.202
	Farmer	1.133	.625	3.106	.033	290.856
	Constant	-	.999	.000		
	19.547					
SHOULD GOVERNMENT AND ITS AGENCIES PLAY FUNDING ROLE?	Age	-.223	.457	.800	.445	1.440
	Sex	22.173	.999	4262570519.148	.000	
	Community		.183			
	Dixcove	-	.999	.000	.000	
		18.678				
	Akwidaa	-	.999	.000	.000	
		20.834				
	Cape Three Points	-	.999	.000	.000	
		21.226				
	Resident Time	-1.256	.204	.285	.041	1.974
Fisherman	24.411	.999	39959197284.634	.000		
Farmer	24.312	.999	36178333989.062	.000		
Constant	-	1.000	.000			
	19.762					
SHOULD GOVERNMENT AND ITS AGENCIES PLAY TECHNICAL SUPPORT ROLE?	Age	.622	.051	1.862	.998	3.474
	Sex	.498	.754	1.646	.073	37.365
	Community		.250			
	Dixcove	-	.999	.000	.000	
	22.726					

	Akwidaa	- 22.339	.999	.000	.000	
	Cape Three Points	- 20.742	.999	.000	.000	
	ResdTime	1.107	.119	3.026	.752	12.177
	Occupation		.490			
	Fisherman	-1.953	.257	.142	.005	4.150
	Farmer	19.209	.999	219950531.021	.000	
	Constant	16.949	.999	22944342.762		
SHOULD GOVERNMENT AND ITS AGENCIES PLAY LOGISTICAL SUPPORT ROLE?	Age	-.039	.886	.962	.569	1.627
	Sex	.672	.639	1.959	.118	32.653
	Community		.466			
	Dixcove	19.639	.999	338032274.978	.000	
	Akwidaa	20.876	.999	1164977686.199	.000	
	Cape Three Points	21.173	.999	1567946277.972	.000	
	Resident Time	-.627	.267	.534	.176	1.617
	Occupation		.806			
	Fisherman	-1.380	.347	.252	.014	4.477
	Farmer	- 22.390	.999	.000	.000	
	Constant	- 17.891	.999	.000		
SHOULD GOVERNMENT AND ITS AGENCIES PLAY OVERSIGHT ROLE?	Age	.499	.094	1.647	.918	2.957
	Sex	- 19.557	.999	.000	.000	
	Community		.013			
	Dixcove	-1.536	.389	.215	.007	7.086
	Akwidaa	-1.181	.485	.307	.011	8.423
	Cape Three Points	1.774	.281	5.895	.234	148.277
	Resident Time	-.615	.305	.541	.167	1.752
	Occupation		.987			
	Fisherman	- 21.276	.999	.000	.000	

	Farmer	- 21.822	.999	.000	.000	
	Constant	42.044	.999			

Table 7.3.5: Prediction accuracy of binary logistic model

OBSERVED		PREDICTED			
		Expectation to clean up the beach in two months or less			Percentage Correct
		Yes	No		
Expectation to clean up the beach in two months or less	Yes	45	1	97.8	
	No	13	2	13.3	
Overall Percentage					77.0
		Should Government and its agencies play Funding role?			Percentage Correct
		Yes	No		
Should Government and its agencies play Funding role?	Yes	15	9	62.5	
	No	9	28	75.7	
Overall Percentage					70.5
		Should Government and its agencies play Technical support role?			Percentage Correct
		Yes	No		
Should Government and its agencies play Technical support role?	Yes	16	10	61.5	
	No	5	30	85.7	
Overall Percentage					75.4
		Should Government and its agencies play Logistical Support role?			Percentage Correct
		Yes	No		
Should Government and its agencies play Logistical Support role?	Yes	28	5	84.8	
	No	15	13	46.4	

Overall Percentage				67.2
		Should Government and its agencies play Oversight role?		Percentage Correct
		Yes	No	
Should Government and its agencies play Oversight role?	Yes	15	8	65.2
	No	7	31	81.6
Overall Percentage				75.4

Table 7.3.6: Cross tabulation of Age of respondents' against their expectation of beach clean-up duration

Age of respondent * Expectation to clean up the beach in two months or less Cross tabulation					
		Expectation to clean up the beach in two months or less			Total
		Yes	No		
Age of respondent	15-19 years old	Count	3	2	5
		% within Age of respondent	60.0%	40.0%	100.0%
		% within Expectation to clean up the beach in two months or less	6.5%	13.3%	8.2%
		% of Total	4.9%	3.3%	8.2%
	20-29 years old	Count	17	3	20
		% within Age of respondent	85.0%	15.0%	100.0%
		% within Expectation to clean up the beach in two months or less	37.0%	20.0%	32.8%
		% of Total	27.9%	4.9%	32.8%
	30-39 years old	Count	8	5	13
		% within Age of respondent	61.5%	38.5%	100.0%
		% within Expectation to clean up the beach in two months or less	17.4%	33.3%	21.3%
		% of Total	13.1%	8.2%	21.3%
40-49 years old	Count	11	3	14	
	% within Age of respondent	78.6%	21.4%	100.0%	
	% within Expectation to clean up the beach in two months or less	23.9%	20.0%	23.0%	
	% of Total	18.0%	4.9%	23.0%	

	50-59 years old	Count	4	2	6
		% within Age of respondent	66.7%	33.3%	100.0%
		% within Expectation to clean up the beach in two months or less	8.7%	13.3%	9.8%
		% of Total	6.6%	3.3%	9.8%
	Above 60 years old	Count	3	0	3
		% within Age of respondent	100.0%	0.0%	100.0%
		% within Expectation to clean up the beach in two months or less	6.5%	0.0%	4.9%
		% of Total	4.9%	0.0%	4.9%
Total	Count	46	15	61	
	% within Age of respondent	75.4%	24.6%	100.0%	
	% within Expectation to clean up the beach in two months or less	100.0%	100.0%	100.0%	
	% of Total	75.4%	24.6%	100.0%	

Table 7.3.7: Cross tabulation of residing community of respondents' against their expectation of beach clean-up duration

Residing community of respondent * Expectation to clean up the beach in two months or less Cross tabulation					
			Expectation to clean up the beach in two months or less		Total
			Yes	No	
Residing community of respondent	Dixcove	Count	14	6	20
		% within Residing community of respondent	70.0%	30.0%	100.0%
		% within Expectation to clean up the beach in two months or less	30.4%	40.0%	32.8%
		% of Total	23.0%	9.8%	32.8%
	Akwidaa	Count	15	2	17
		% within Residing community of respondent	88.2%	11.8%	100.0%
		% within Expectation to clean up the beach in two months or less	32.6%	13.3%	27.9%
		% of Total	24.6%	3.3%	27.9%
	Cape Three Points	Count	15	7	22
		% within Residing community of respondent	68.2%	31.8%	100.0%
		% within Expectation to clean up the beach in two months or less	32.6%	46.7%	36.1%

		% of Total	24.6%	11.5%	36.1%
	Axim	Count	2	0	2
		% within Residing community of respondent	100.0%	0.0%	100.0%
		% within Expectation to clean up the beach in two months or less	4.3%	0.0%	3.3%
		% of Total	3.3%	0.0%	3.3%
Total		Count	46	15	61
		% within Residing community of respondent	75.4%	24.6%	100.0%
		% within Expectation to clean up the beach in two months or less	100.0%	100.0%	100.0%
		% of Total	75.4%	24.6%	100.0%

Table 7.3.8: Cross tabulation of residing community of respondents' against their expectation of the government playing a funding role during oil spill clean-up

Residing community of respondent * Should Government and its agencies play Funding role? Cross tabulation					
			Should Government and its agencies play Funding role?		Total
			Yes	No	
Residing community of respondent	Dixcove	Count	4	16	20
		% within Residing community of respondent	20.0%	80.0%	100.0%
		% within Should Government and its agencies play Funding role?	16.7%	43.2%	32.8%
		% of Total	6.6%	26.2%	32.8%
	Akwidaa	Count	9	8	17
		% within Residing community of respondent	52.9%	47.1%	100.0%
		% within Should Government and its agencies play Funding role?	37.5%	21.6%	27.9%
		% of Total	14.8%	13.1%	27.9%
	Cape Three Points	Count	11	11	22
		% within Residing community of respondent	50.0%	50.0%	100.0%
		% within Should Government and its agencies play Funding role?	45.8%	29.7%	36.1%
		% of Total	18.0%	18.0%	36.1%

	Axim	Count	0	2	2
		% within Residing community of respondent	0.0%	100.0%	100.0%
		% within Should Government and its agencies play Funding role?	0.0%	5.4%	3.3%
		% of Total	0.0%	3.3%	3.3%
Total		Count	24	37	61
		% within Residing community of respondent	39.3%	60.7%	100.0%
		% within Should Government and its agencies play Funding role?	100.0%	100.0%	100.0%
		% of Total	39.3%	60.7%	100.0%

Table 7.3.9: Cross tabulation of respondents' expectation of a clean-up duration of two months or less against their expectation of the government playing a funding role during oil spill clean-up

Expectation to clean up the beach in two months or less * Should Government and its agencies play Funding role? Cross tabulation					
			Should Government and its agencies play Funding role?		Total
			Yes	No	
Expectation to clean up the beach in two months or less	Yes	Count	18	28	46
		% within Expectation to clean up the beach in two months or less	39.1%	60.9%	100.0%
		% within Should Government and its agencies play Funding role?	75.0%	75.7%	75.4%
		% of Total	29.5%	45.9%	75.4%
	No	Count	6	9	15
		% within Expectation to clean up the beach in two months or less	40.0%	60.0%	100.0%
		% within Should Government and its agencies play Funding role?	25.0%	24.3%	24.6%
		% of Total	9.8%	14.8%	24.6%
Total		Count	24	37	61
		% within Expectation to clean up the beach in two months or less	39.3%	60.7%	100.0%
		% within Should Government and its agencies play Funding role?	100.0%	100.0%	100.0%
		% of Total	39.3%	60.7%	100.0%

Table 7.3.10: Cross tabulation of age of respondents' against their expectation of the government playing a technical support role during oil spill clean-up

Age of respondent * Should Government and its agencies play Technical support role? Cross tabulation					
			Should Government and its agencies play Technical support role?		Total
			Yes	No	
Age of respondent	15-19 years old	Count	2	3	5
		% within Age of respondent	40.0%	60.0%	100.0%
		% within Should Government and its agencies play Technical support role?	7.7%	8.6%	8.2%
		% of Total	3.3%	4.9%	8.2%
	20-29 years old	Count	13	7	20
		% within Age of respondent	65.0%	35.0%	100.0%
		% within Should Government and its agencies play Technical support role?	50.0%	20.0%	32.8%
		% of Total	21.3%	11.5%	32.8%
	30-39 years old	Count	4	9	13
		% within Age of respondent	30.8%	69.2%	100.0%
		% within Should Government and its agencies play Technical support role?	15.4%	25.7%	21.3%
		% of Total	6.6%	14.8%	21.3%
	40-49 years old	Count	3	11	14
		% within Age of respondent	21.4%	78.6%	100.0%
		% within Should Government and its agencies play Technical support role?	11.5%	31.4%	23.0%
		% of Total	4.9%	18.0%	23.0%
	50-59 years old	Count	2	4	6
		% within Age of respondent	33.3%	66.7%	100.0%
		% within Should Government and its agencies play Technical support role?	7.7%	11.4%	9.8%
		% of Total	3.3%	6.6%	9.8%
Above 60 years old	Count	2	1	3	
	% within Age of respondent	66.7%	33.3%	100.0%	
	% within Should Government and its agencies play Technical support role?	7.7%	2.9%	4.9%	
	% of Total	3.3%	1.6%	4.9%	
Total		Count	26	35	61
		% within Age of respondent	42.6%	57.4%	100.0%

	% within Should Government and its agencies play Technical support role?	100.0%	100.0%	100.0%
	% of Total	42.6%	57.4%	100.0%

Table 7.3.11: Cross tabulation of residing community of respondents' against their expectation of the government playing a technical support role during oil spill clean-up

Residing community of respondent * Should Government and its agencies play Technical support role?					
Cross tabulation					
			Should Government and its agencies play Technical support role?		Total
			Yes	No	
Residing community of respondent	Dixcove	Count	12	8	20
		% within Residing community of respondent	60.0%	40.0%	100.0%
		% within Should Government and its agencies play Technical support role?	46.2%	22.9%	32.8%
		% of Total	19.7%	13.1%	32.8%
	Akwidaa	Count	7	10	17
		% within Residing community of respondent	41.2%	58.8%	100.0%
		% within Should Government and its agencies play Technical support role?	26.9%	28.6%	27.9%
		% of Total	11.5%	16.4%	27.9%
	Cape Three Points	Count	7	15	22
		% within Residing community of respondent	31.8%	68.2%	100.0%
		% within Should Government and its agencies play Technical support role?	26.9%	42.9%	36.1%
		% of Total	11.5%	24.6%	36.1%
	Axim	Count	0	2	2
		% within Residing community of respondent	0.0%	100.0%	100.0%
		% within Should Government and its agencies play Technical support role?	0.0%	5.7%	3.3%
		% of Total	0.0%	3.3%	3.3%

Total	Count	26	35	61
	% within Residing community of respondent	42.6%	57.4%	100.0%
	% within Should Government and its agencies play Technical support role?	100.0%	100.0%	100.0%
	% of Total	42.6%	57.4%	100.0%

Table 7.3.12: Cross tabulation of sex of respondents' against their expectation of the government playing a technical support role during oil spill clean-up

Sex of respondent * Should Government and its agencies play Technical support role? Cross tabulation					
			Should Government and its agencies play Technical support role?		Total
			Yes	No	
Sex of respondent	Male	Count	21	27	48
		% within Sex of respondent	43.8%	56.2%	100.0%
		% within Should Government and its agencies play Technical support role?	80.8%	77.1%	78.7%
		% of Total	34.4%	44.3%	78.7%
	Female	Count	5	8	13
		% within Sex of respondent	38.5%	61.5%	100.0%
		% within Should Government and its agencies play Technical support role?	19.2%	22.9%	21.3%
		% of Total	8.2%	13.1%	21.3%
Total		Count	26	35	61
		% within Sex of respondent	42.6%	57.4%	100.0%
		% within Should Government and its agencies play Technical support role?	100.0%	100.0%	100.0%
		% of Total	42.6%	57.4%	100.0%

Table 7.3.13: Cross tabulation of respondents expectation of a clean-up duration of two months or less against their expectation of the government playing a technical support role during oil spill clean-up

Expectation to clean up the beach in two months or less * Should Government and its agencies play Technical support role? Cross tabulation					
			Should Government and its agencies play Technical support role?		Total
			Yes	No	
Expectation to clean up the beach in two months or less	Yes	Count	20	26	46
		% within Expectation to clean up the beach in two months or less	43.5%	56.5%	100.0%
		% within Should Government and its agencies play Technical support role?	76.9%	74.3%	75.4%
		% of Total	32.8%	42.6%	75.4%
	No	Count	6	9	15
		% within Expectation to clean up the beach in two months or less	40.0%	60.0%	100.0%
		% within Should Government and its agencies play Technical support role?	23.1%	25.7%	24.6%
		% of Total	9.8%	14.8%	24.6%
Total	Count	26	35	61	
	% within Expectation to clean up the beach in two months or less	42.6%	57.4%	100.0%	
	% within Should Government and its agencies play Technical support role?	100.0%	100.0%	100.0%	
	% of Total	42.6%	57.4%	100.0%	

Table 7.3.14: Cross tabulation of age of respondents' against their expectation of the government playing a Logistical support role during oil spill clean-up

Age of respondent * Should Government and its agencies play Logistical support role? Cross tabulation					
			Should Government and its agencies play Logistical Support role?		Total
			Yes	No	
Age of respondent	15-19 years old	Count	2	3	5
		% within Age of respondent	40.0%	60.0%	100.0%
		% within Should Government and its agencies play Logistical Support role?	6.1%	10.7%	8.2%
		% of Total	3.3%	4.9%	8.2%
	20-29 years old	Count	11	9	20
		% within Age of respondent	55.0%	45.0%	100.0%
		% within Should Government and its agencies play Logistical Support role?	33.3%	32.1%	32.8%
		% of Total	18.0%	14.8%	32.8%
	30-39 years old	Count	7	6	13
		% within Age of respondent	53.8%	46.2%	100.0%
		% within Should Government and its agencies play Logistical Support role?	21.2%	21.4%	21.3%
		% of Total	11.5%	9.8%	21.3%
	40-49 years old	Count	7	7	14
		% within Age of respondent	50.0%	50.0%	100.0%
		% within Should Government and its agencies play Logistical Support role?	21.2%	25.0%	23.0%
		% of Total	11.5%	11.5%	23.0%
	50-59 years old	Count	5	1	6
		% within Age of respondent	83.3%	16.7%	100.0%
		% within Should Government and its agencies play Logistical Support role?	15.2%	3.6%	9.8%
		% of Total	8.2%	1.6%	9.8%
Above 60 years old	Count	1	2	3	
	% within Age of respondent	33.3%	66.7%	100.0%	
	% within Should Government and its agencies play Logistical Support role?	3.0%	7.1%	4.9%	
	% of Total	1.6%	3.3%	4.9%	
Total		Count	33	28	61
		% within Age of respondent	54.1%	45.9%	100.0%

	% within Should Government and its agencies play Logistical Support role?	100.0%	100.0%	100.0%
	% of Total	54.1%	45.9%	100.0%

Table 7.3.15: Cross tabulation of sex of respondents' against their expectation of the government playing a Logistical support role during oil spill clean-up

Sex of respondent * Should Government and its agencies play Logistical support role? Cross tabulation					
			Should Government and its agencies play Logistical Support role?		Total
			Yes	No	
Sex of respondent	Male	Count	28	20	48
		% within Sex of respondent	58.3%	41.7%	100.0%
		% within Should Government and its agencies play Logistical Support role?	84.8%	71.4%	78.7%
		% of Total	45.9%	32.8%	78.7%
	Female	Count	5	8	13
		% within Sex of respondent	38.5%	61.5%	100.0%
		% within Should Government and its agencies play Logistical Support role?	15.2%	28.6%	21.3%
		% of Total	8.2%	13.1%	21.3%
Total	Count	33	28	61	
	% within Sex of respondent	54.1%	45.9%	100.0%	
	% within Should Government and its agencies play Logistical Support role?	100.0%	100.0%	100.0%	
	% of Total	54.1%	45.9%	100.0%	

Table 7.3.16: Cross tabulation of residing community of respondents' against their expectation of the government playing a Logistical support role during oil spill clean-up

Residing community of respondent * Should Government and its agencies play Logistical Support role? Cross tabulation					
			Should Government and its agencies play Logistical Support role?		Total
			Yes	No	
Residing community of respondent	Dixcove	Count	12	8	20
		% within Residing community of respondent	60.0%	40.0%	100.0%
		% within Should Government and its agencies play Logistical Support role?	36.4%	28.6%	32.8%
		% of Total	19.7%	13.1%	32.8%
	Akwidaa	Count	8	9	17
		% within Residing community of respondent	47.1%	52.9%	100.0%
		% within Should Government and its agencies play Logistical Support role?	24.2%	32.1%	27.9%
		% of Total	13.1%	14.8%	27.9%
	Cape Three Points	Count	11	11	22
		% within Residing community of respondent	50.0%	50.0%	100.0%
		% within Should Government and its agencies play Logistical Support role?	33.3%	39.3%	36.1%
		% of Total	18.0%	18.0%	36.1%
	Axim	Count	2	0	2
		% within Residing community of respondent	100.0%	0.0%	100.0%
		% within Should Government and its agencies play Logistical Support role?	6.1%	0.0%	3.3%
		% of Total	3.3%	0.0%	3.3%
Total	Count	33	28	61	
	% within Residing community of respondent	54.1%	45.9%	100.0%	
	% within Should Government and its agencies play Logistical Support role?	100.0%	100.0%	100.0%	
	% of Total	54.1%	45.9%	100.0%	

Table 7.3.17: Cross tabulation of respondents' expectation of clean-up duration taking two months or less against their expectation of the government playing a Logistical support role during oil spill clean-up

Should Government and its agencies play Logistical Support role? * Expectation to clean up the beach in two months or less Cross tabulation					
			Expectation to clean up the beach in two months or less		Total
			Yes	No	
Should Government and its agencies play Logistical Support role?	Yes	Count	24	9	33
		% within Should Government and its agencies play Logistical Support role?	72.7%	27.3%	100.0%
		% within Expectation to clean up the beach in two months or less	52.2%	60.0%	54.1%
		% of Total	39.3%	14.8%	54.1%
	No	Count	22	6	28
		% within Should Government and its agencies play Logistical Support role?	78.6%	21.4%	100.0%
		% within Expectation to clean up the beach in two months or less	47.8%	40.0%	45.9%
		% of Total	36.1%	9.8%	45.9%
Total	Count	46	15	61	
	% within Should Government and its agencies play Logistical Support role?	75.4%	24.6%	100.0%	
	% within Expectation to clean up the beach in two months or less	100.0%	100.0%	100.0%	
	% of Total	75.4%	24.6%	100.0%	

Table 7.3.18: Cross tabulation of age of respondents' against their expectation of the government playing an oversight role during oil spill clean-up

Age of respondent * Should Government and its agencies play oversight role? Cross tabulation					
			Should Government and its agencies play Oversight role?		Total
			Yes	No	
Age of respondent	15-19 years old	Count	3	2	5
		% within Age of respondent	60.0%	40.0%	100.0%
		% within Should Government and its agencies play Oversight role?	13.0%	5.3%	8.2%
		% of Total	4.9%	3.3%	8.2%
	20-29 years old	Count	10	10	20
		% within Age of respondent	50.0%	50.0%	100.0%
		% within Should Government and its agencies play Oversight role?	43.5%	26.3%	32.8%
		% of Total	16.4%	16.4%	32.8%
	30-39 years old	Count	2	11	13
		% within Age of respondent	15.4%	84.6%	100.0%
		% within Should Government and its agencies play Oversight role?	8.7%	28.9%	21.3%
		% of Total	3.3%	18.0%	21.3%
	40-49 years old	Count	5	9	14
		% within Age of respondent	35.7%	64.3%	100.0%
		% within Should Government and its agencies play Oversight role?	21.7%	23.7%	23.0%
		% of Total	8.2%	14.8%	23.0%
	50-59 years old	Count	2	4	6
		% within Age of respondent	33.3%	66.7%	100.0%
		% within Should Government and its agencies play Oversight role?	8.7%	10.5%	9.8%
		% of Total	3.3%	6.6%	9.8%
	Above 60 years old	Count	1	2	3
		% within Age of respondent	33.3%	66.7%	100.0%
		% within Should Government and its agencies play Oversight role?	4.3%	5.3%	4.9%

		% of Total	1.6%	3.3%	4.9%
Total		Count	23	38	61
		% within Age of respondent	37.7%	62.3%	100.0%
		% within Should Government and its agencies play Oversight role?	100.0%	100.0%	100.0%
		% of Total	37.7%	62.3%	100.0%

Table 7.3.19: Cross tabulation of sex of respondents' against their expectation of the government playing an oversight role during oil spill clean-up

Sex of respondent * Should Government and its agencies play oversight role? Cross tabulation					
			Should Government and its agencies play Oversight role?		Total
			Yes	No	
Sex of respondent	Male	Count	19	29	48
		% within Sex of respondent	39.6%	60.4%	100.0%
		% within Should Government and its agencies play Oversight role?	82.6%	76.3%	78.7%
		% of Total	31.1%	47.5%	78.7%
	Female	Count	4	9	13
		% within Sex of respondent	30.8%	69.2%	100.0%
		% within Should Government and its agencies play Oversight role?	17.4%	23.7%	21.3%
		% of Total	6.6%	14.8%	21.3%
Total		Count	23	38	61

	% within Sex of respondent	37.7%	62.3%	100.0%
	% within Should Government and its agencies play Oversight role?	100.0%	100.0%	100.0%
	% of Total	37.7%	62.3%	100.0%

Table 7.3.20: Cross tabulation of residing community of respondents' against their expectation of the government playing a oversight role during oil spill clean-up

Residing community of respondent * Should Government and its agencies play oversight role? Cross tabulation					
			Should Government and its agencies play Oversight role?		Total
			Yes	No	
Residing community of respondent	Dixcove	Count	10	10	20
		% within Residing community of respondent	50.0%	50.0%	100.0%
		% within Should Government and its agencies play Oversight role?	43.5%	26.3%	32.8%
		% of Total	16.4%	16.4%	32.8%
	Akwidaa	Count	9	8	17
		% within Residing community of respondent	52.9%	47.1%	100.0%
		% within Should Government and its agencies play Oversight role?	39.1%	21.1%	27.9%
		% of Total	14.8%	13.1%	27.9%
	Cape Three Points	Count	3	19	22
		% within Residing community of respondent	13.6%	86.4%	100.0%
		% within Should Government and its agencies play Oversight role?	13.0%	50.0%	36.1%
		% of Total	4.9%	31.1%	36.1%
	Axim	Count	1	1	2
		% within Residing community of respondent	50.0%	50.0%	100.0%
		% within Should Government and its agencies play Oversight role?	4.3%	2.6%	3.3%
		% of Total	1.6%	1.6%	3.3%

Total	Count	23	38	61
	% within Residing community of respondent	37.7%	62.3%	100.0%
	% within Should Government and its agencies play Oversight role?	100.0%	100.0%	100.0%
	% of Total	37.7%	62.3%	100.0%

Table 7.3.21: Cross tabulation of respondents expectation of a clean-up duration of two months or less against their expectation of the government playing an oversight role during oil spill clean-up

Expectation to clean up the beach in two months or less * Should Government and its agencies play Oversight role? Cross tabulation					
			Should Government and its agencies play Oversight role?		Total
			Yes	No	
Expectation to clean up the beach in two months or less	Yes	Count	19	27	46
		% within Expectation to clean up the beach in two months or less	41.3%	58.7%	100.0%
		% within Should Government and its agencies play Oversight role?	82.6%	71.1%	75.4%
		% of Total	31.1%	44.3%	75.4%
	No	Count	4	11	15
		% within Expectation to clean up the beach in two months or less	26.7%	73.3%	100.0%
		% within Should Government and its agencies play Oversight role?	17.4%	28.9%	24.6%
		% of Total	6.6%	18.0%	24.6%
Total	Count	23	38	61	
	% within Expectation to clean up the beach in two months or less	37.7%	62.3%	100.0%	
	% within Should Government and its agencies play Oversight role?	100.0%	100.0%	100.0%	
	% of Total	37.7%	62.3%	100.0%	

7.4 Appendix D

Table 7.4.1: Composition of chemical fertilizer used for soil treatment

CHEMICAL	Wt/vol
Nitrogen (N)	20%
Phosphorus (P)	20%
Potassium (K)	20%
Magnesium (MgO)	1.5%
Iron EDTA (Fe)	0.15%
Manganese EDTA (Mn)	0.075%
Copper EDTA (Cu)	0.075%
Zinc EDTA (Zn)	0.075%
Boron (B)	0.0315%
Cobalt EDTA (Co)	0.0012%
Molybdenum (Mo)	0.0012%

*pH (10% of solution) = 4.0 – 4.5

*Density = 1.51 SG at 18°C

7.5 Appendix E



Figure 7.4.1: Thorough mixing of contaminated soil prior to it being separated in containers for treatment



Figure 7.5.3: Bubbles emerging out of soil treated with 30% and 60% hydrogen peroxide



Figure 7.5.2: Hydrocarbon contaminated soil reacting to the addition of hydrogen peroxide



Figure 7.5.4: Vapour emanating from hydrocarbon contaminated soil treated with 30% and 60% hydrogen peroxide



Figure 7.5.5: Nature of hydrocarbon contaminated soil 30 mins after addition of hydrogen peroxide (from left 6%, 30%, 60%)



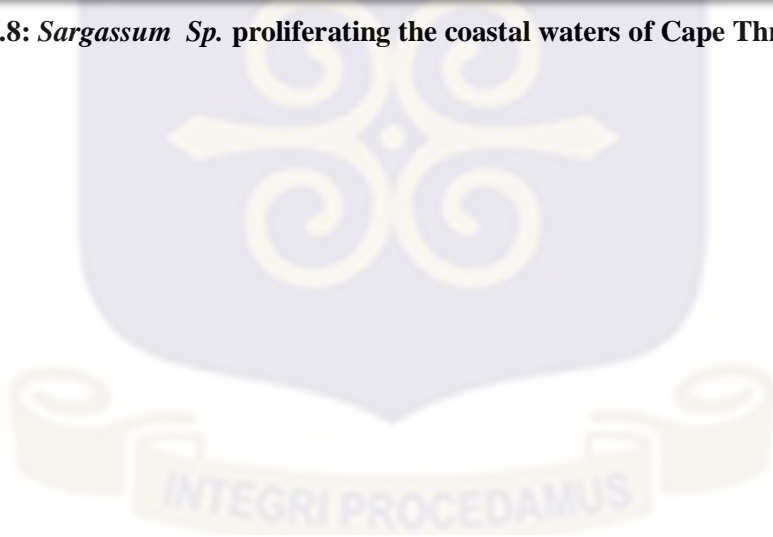
Figure 7.5.6: Nature of hydrocarbon contaminated soil after addition of fertilizer



Figure 7.5.7: Nature of hydrocarbon contaminated soil 48 hours after treating with hydrogen peroxide and fertilizer



Figure 7.5.8: *Sargassum Sp.* proliferating the coastal waters of Cape Three Points



7.6 Appendix F

Table 7.6.1: Initial concentration of polycyclic aromatic hydrocarbons in soil after spill simulation.

PAH	$\mu\text{g/Kg}$
Nephthalene	16636.2
Acenaphthalene	2266
Acenaphthene	425.3
Fluorene	4575.5
Phenanthrene	52635
Anthracene	1969.6
Fluoranthene	43.6
Pyrene	43.2
Benzo(a)anthracene	3594.1
Chrysene	3030.7
Benzo(b)fluoranthene	56.2
Benzo(k)fluoranthene	100.4

Benzo(a)pyrene	72.4
Indeno(1,2,3-c,d)pyrene	27.3
Dibenzo(a,h)anthracene	28.2
Benzo(g,h,i)perylene	24.6



Table 7.6.2: Raw data on polycyclic aromatic hydrocarbon concentration in the different treatment setups over the study period.



DAY OF SAMPLING	PETROLEUM HYDROCARBON TYPE	CONTROL	CHEMICAL FERTILIZER ONLY	6% HYDROGEN PEROXIDE	30% HYDROGEN PEROXIDE	60% HYDROGEN PEROXIDE	6% HYDROGEN PEROXIDE AND CHEMICAL FERTILIZER	30% HYDROGEN PEROXIDE AND CHEMICAL FERTILIZER	60% HYDROGEN PEROXIDE AND CHEMICAL FERTILIZER
Day 1	Nephthalene	14890.9 ± 0.4	9399.3 ± 3.4	10528.5 ± 2.4	12336.6 ± 2.3	10168.7 ± 1.9	10980.4 ± 0.4	10847.2 ± 3.1	10033.3 ± 2.4
	Acenaphthalene	1653.2 ± 1.7	1104.2 ± 0.3	2569.3 ± 2.5	3742.6 ± 3.9	2411.8 ± 2.6	925 ± 1.7	2436.7 ± 2.6	1115.4 ± 1.4
	Acenaphthene	1126.4 ± 3.2	2237.5 ± 1.3	997.1 ± 3.2	1341.7 ± 2.9	2986.6 ± 1.7	3019.6 ± 2.9	1196.2 ± 4	1130.9 ± 2.0
	Fluorene	1122.6 ± 3.5	1975.9 ± 1.9	907.6 ± 2.6	1007.5 ± 1.9	3521.5 ± 2.2	761 ± 1.8	1302.2 ± 2.7	709.3 ± 2.9
	Phenanthrene	51841 ± 3.7	40573 ± 1.7	30766 ± 2.8	36522 ± 1.4	35654 ± 2.9	39548 ± 3.8	33255 ± 1.7	21773 ± 3.7
	Anthracene	1927.8 ± 1.8	11950.9 ± 1.8	153.5 ± 1.3	1507.9 ± 2.5	1580.1 ± 1.8	1234.2 ± 2.4	1352.3 ± 1.81	641.2 ± 1.7
	Fluoranthene	40.1 ± 3.9	18.5 ± 1.6	17.5 ± 0.4	204.7 ± 1.5	59.7 ± 0.5	21.5 ± 0.9	34.1 ± 0.3	29.9 ± 2.9
	Pyrene	39.7 ± 1.7	18.2 ± 2.6	17.3 ± 0.3	203.4 ± 0.8	59.2 ± 1.5	21.2 ± 3.8	33.8 ± 2.9	29.6 ± 1.3
	Benzo(a)anthracene	311 ± 1.6	109.9 ± 2.5	226.1 ± 1.4	2615 ± 2.6	241.5 ± 2.9	902.2 ± 3.4	3301.4 ± 1.5	110.5 ± 3.8
	Chrysene	170.4 ± 3.9	834.9 ± 2.5	166.2 ± 1.9	1200.7 ± 2.4	2796.4 ± 2.94	1537.3 ± 3.1	2593 ± 3.2	1348.8 ± 4.0
	Benzo(b)fluoranthene	99.6 ± 2.7	37.2 ± 3.5	34.9 ± 0.6	48.1 ± 0.5	60.7 ± 3.6	49.2 ± 2.7	61.2 ± 3.5	26.1 ± 2.9
	Benzo(k)fluoranthene	19.7 ± 3.8	40 ± 2.5	39.6 ± 3.9	85.4 ± 2.9	115.2 ± 2.7	53.3 ± 1.9	117.3 ± 3.1	38.7 ± 3.6
Benzo(a)pyrene	129.6 ± 3.2	22.3 ± 0.1	38.4 ± 0.6	64.6 ± 2.1	78.8 ± 2.1	49.4 ± 1.7	90 ± 1.4	37.2 ± 0.7	

Day 3	Indeno(1,2,3-c,d)pyrene	118.6 ± 1.2	13 ± 0.4	81 ± 2.5	27.6 ± 1.2	26.2 ± 1.6	74.6 ± 2.7	31.9 ± 1.6	89.7 ± 1.3
	Dibenzo(a,h)anthracene	117.9 ± 2.1	14.1 ± 0.6	80.9 ± 0.9	28.5 ± 1.4	27.1 ± 2.5	74.6 ± 1.7	32.7 ± 1.5	89.5 ± 0.2
	Benzo(g,h,i)perylene	79.9 ± 0.8	6.6 ± 0.2	55.9 ± 0.6	20.3 ± 0.3	25.3 ± 0.5	57.6 ± 1.4	26.7 ± 1.4	53.6 ± 1.3
	Nephthalene	12098 ± 5.7	4853.7 ± 6.5	5866.6 ± 7.4	6601.6 ± 4.8	3514.6 ± 8.3	6606.7 ± 5.5	7261.5 ± 5.6	3135.1 ± 6.3
	Acenaphthalene	1369.7 ± 8.7	204.8 ± 2.1	271.3 ± 1.7	472.3 ± 2.5	2609.3 ± 4.8	507.2 ± 6.8	253.4 ± 3.2	1054.1 ± 11
	Acenaphthene	197.1 ± 1.5	nd	nd	295.1 ± 2.6	968.4 ± 5.3	217.1 ± 2.1	nd	783.1 ± 6.7
	Fluorene	203.6 ± 5.4	137.5 ± 0.3	166.2 ± 0.5	927.1 ± 7.5	96.2 ± 3.7	812.4 ± 4.4	176.4 ± 1.8	173.4 ± 2.1
	Phenanthrene	50237.3 ± 15.1	36920.1 ± 23.2	30230.2 ± 21.8	5010.1 ± 11.6	663.5 ± 8.4	33350.1 ± 17.3	5566.4 ± 9.8	569.5 ± 5.6
	Anthracene	2369.2 ± 7.8	128.1 ± 1.5	126.8 ± 2.6	2917.6 ± 6.3	169.9 ± 0.9	159.4 ± 1.7	252.8 ± 3.2	100.4 ± 2.2
	Fluoranthene	14.8 ± 2.1	19.6 ± 0.3	24.5 ± 0.6	30.7 ± 1.7	34.7 ± 1.5	72.1 ± 2.4	25.2 ± 0.6	89.2 ± 3.3
	Pyrene	15.2 ± 0.1	20 ± 0.7	25.1 ± 2.1	31.4 ± 0.8	34.7 ± 2.1	73.7 ± 2.6	25.8 ± 0.6	89.2 ± 2.4
	Benzo(a)anthracene	46.6 ± 1.4	51.9 ± 2.3	916.8 ± 8.9	74.1 ± 3.1	874.7 ± 2.6	1090.5 ± 15.1	843.9 ± 2.6	724.6 ± 2.1
	Chrysene	83.3 ± 2.7	499.1 ± 3.3	539.5 ± 4.6	788 ± 7.4	785.1 ± 6.8	200.5 ± 2.5	690.9 ± 3.1	609.8 ± 7.4
Benzo(b)fluoranthene	23.4 ± 0.7	20.3 ± 0.4	21.5 ± 0.9	35.9 ± 0.4	19.8 ± 0.6	34.9 ± 1.3	23.7 ± 1.4	17.3 ± 2.1	
Benzo(k)fluoranthene	26.9 ± 0.7	35.2 ± 0.6	25 ± 1.1	55.4 ± 2.1	27 ± 0.8	54 ± 2.1	45.3 ± 2.3	22.3 ± 1.5	
Benzo(a)pyrene	28.4 ± 1.4	37.3 ± 1.6	26.5 ± 0.4	58.6 ± 0.2	26.2 ± 0.7	57.1 ± 0.6	47.9 ± 0.5	21.6 ± 0.9	

	Indeno(1,2,3-c,d)pyrene	56 ± 0.6	42.9 ± 0.8	54.9 ± 2.3	8.2 ± 0.2	146.9 ± 3.2	12.4 ± 1.7	3.6 ± 1.7	123.3 ± 2.9
	Dibenzo(a,h)anthracene	56.7 ± 1.7	43.9 ± 2.8	55.7 ± 2.5	9.7 ± 0.7	154.7 ± 0.6	13.9 ± 0.4	5.3 ± 0.7	129.8 ± 2.1
	Benzo(g,h,i)perylene	42.7 ± 0.9	3.7 ± 0.6	6.9 ± 1.5	5 ± 2.2	81.8 ± 1.6	12 ± 2	10.4 ± 0.6	66.1 ± 1.9
Day 10	Naphthalene	12091.3 ± 11.8	3474.6 ± 8.6	3611.3 ± 8.9	5338.6 ± 10.6	3030.7 ± 20	4186.9 ± 13	8914.2 ± 15.8	7427.1 ± 18.2
	Acenaphthalene	1210.3 ± 16.3	1970.2 ± 14.8	2880.8 ± 7.5	1191.8 ± 8.9	1124.4 ± 9.1	457.9 ± 1.8	1712.9 ± 7.9	2998.9 ± 9.8
	Acenaphthene	712.5 ± 5.6	899.6 ± 8.3	11055.6 ± 15.9	699.7 ± 8.6	763.3 ± 6.4	545.5 ± 4.1	1400.1 ± 8.6	875 ± 5.5
	Fluorene	1782.3 ± 2.7	780.5 ± 8.9	220.2 ± 2.1	1857 ± 6.8	168.7 ± 2.1	323.1 ± 4.2	793.6 ± 8.6	2430 ± 7.9
	Phenanthrene	49854.9 ± 9.6	32200.4 ± 10.4	30111.5 ± 12.6	24094 ± 9.7	532.9 ± 3.9	25632 ± 21.8	26055 ± 48	680 ± 4.8
	Anthracene	88.2 ± 0.8	67.1 ± 2.9	118.9 ± 2.1	777.8 ± 3.6	62.8 ± 1.4	7651.5 ± 12.5	855 ± 4.3	817.5 ± 5.8
	Fluoranthene	64.3 ± 1.7	34.3 ± 0.7	107.2 ± 0.6	36.6 ± 1.4	50.5 ± 1.6	143.8 ± 3.2	59 ± 1.6	20.9 ± 0.4
	Pyrene	64.3 ± 2.8	34.3 ± 1.2	107.2 ± 2.4	36.2 ± 0.6	50.5 ± 0.8	142.8 ± 1.4	58.5 ± 2.6	20.6 ± 1.8
	Benzo(a)anthracene	689.6 ± 5.7	731.3 ± 8.5	866.7 ± 5.7	1533.6 ± 6.3	491.6 ± 3.8	436.3 ± 4.5	135.1 ± 2.2	641.7 ± 4.3
	Chrysene	593.1 ± 4.2	623.2 ± 3.9	702.3 ± 4.8	1179.7 ± 5.5	417.3 ± 5.3	325.1 ± 4.1	829.3 ± 4.7	522.8 ± 5.3
	Benzo(b)fluoranthene	29.3 ± 0.3	17.9 ± 1.4	22 ± 0.8	32.4 ± 1.2	15.2 ± 1.3	36.1 ± 0.9	39.5 ± 1.5	42.5 ± 1.7
	Benzo(k)fluoranthene	147.4 ± 0.3	22.8 ± 2.5	28.3 ± 2.1	31 ± 1.5	17.2 ± 0.2	29.5 ± 0.8	36.9 ± 0.8	37.8 ± 1.8
Benzo(a)pyrene	143.2 ± 1.5	22.1 ± 0.8	27.5 ± 0.7	25.2 ± 0.3	16.8 ± 0.7	30.9 ± 0.1	33.7 ± 0.8	39.4 ± 2.1	

Day 17	Indeno(1,2,3-c,d)pyrene	171.9 ± 2.1	127.6 ± 1.7	161.5 ± 1.2	78.3 ± 0.9	120.9 ± 0.7	21.8 ± 0.3	15.6 ± 1.8	91.9 ± 1.7
	Dibenzo(a,h)anthracene	181 ± 2.7	134.3 ± 1.4	170 ± 0.6	78.3 ± 0.8	127.2 ± 0.6	22.8 ± 1.7	16.6 ± 1.4	91.7 ± 1.8
	Benzo(g,h,i)perylene	83.2 ± 0.7	66.4 ± 1.4	17 ± 1.9	41.8 ± 2.1	60.1 ± 3.2	15.1 ± 0.3	12.5 ± 1.6	48.5 ± 2.3
	Nephthalene	11202.1 ± 5.3	3596.9 ± 7.4	2861.8 ± 8.2	3429.1 ± 5.6	3212.1 ± 7.3	3286.2 ± 4.8	51117.1 ± 7.3	3268.9 ± 11.6
	Acenaphthalene	1196.4 ± 9.3	5476.8 ± 8.3	6715 ± 6.7	2119.3 ± 10.4	1952.8 ± 9.5	1926 ± 4.2	3455.7 ± 5.2	3162.7 ± 6.2
	Acenaphthene	1373.9 ± 7.4	2390.5 ± 6.4	757.5 ± 9.5	848 ± 7.9	733.1 ± 8.4	374 ± 7.1	478.2 ± 8.4	876.7 ± 7.5
	Fluorene	1457.7 ± 8.6	805.9 ± 2.4	56.2 ± 1.2	163.8 ± 3.2	791.5 ± 7.7	409.2 ± 4.3	885.9 ± 6.4	918.3 ± 5.3
	Phenanthrene	49347.92 ± 9.7	30603.1 ± 8.5	30091 ± 5.8	614.5 ± 7.3	579.7 ± 5.7	2246.4 ± 9.6	840.1 ± 4.1	473.2 ± 7.3
	Anthracene	1841.4 ± 1.9	1168.5 ± 2.7	75.5 ± 3.2	127.7 ± 5.2	79.3 ± 2.4	665.9 ± 4.8	148 ± 3.4	103.1 ± 2.1
	Fluoranthene	47.6 ± 0.2	44.1 ± 3.7	28.1 ± 0.8	52 ± 0.6	20.1 ± 0.9	19.8 ± 0.3	41.1 ± 0.2	32.6 ± 0.6
	Pyrene	47.6 ± 0.7	44.1 ± 1.1	28.1 ± 0.1	52 ± 2.2	20.1 ± 1.5	19.8 ± 2.9	41.1 ± 2.1	32.6 ± 0.3
	Benzo(a)anthracene	1271.1 ± 4.6	595.5 ± 3.4	578.6 ± 2.4	620.3 ± 3.7	394.7 ± 2.1	232.9 ± 4.5	986.5 ± 2.1	730.3 ± 7.6
	Chrysene	1194.9 ± 0.3	521.9 ± 0.7	521 ± 0.4	560.2 ± 0.3	584.5 ± 0.8	318.8 ± 0.5	728.7 ± 0.5	452.1 ± 0.7
Benzo(b)fluoranthene	35.1 ± 0.1	18.3 ± 2.6	16.5 ± 1.5	16.3 ± 0.8	17.9 ± 3.8	15.2 ± 2.1	42.2 ± 0.4	23.5 ± 2.5	
Benzo(k)fluoranthene	33.5 ± 2.5	24.2 ± 2.1	18.7 ± 0.2	19.6 ± 0.2	22.4 ± 0.4	16.7 ± 0.8	45.1 ± 3.2	29.4 ± 2.1	
Benzo(a)pyrene	32.5 ± 2.6	23.5 ± 3.9	18.2 ± 2.1	19.1 ± 0.9	21.8 ± 2.7	16.2 ± 2.1	43.9 ± 0.4	28.6 ± 1.6	

	Indeno(1,2,3-c,d)pyrene	192.3 ± 0.3	95.1 ± 2.4	139.9 ± 1.2	128.9 ± 0.6	117.5 ± 0.7	19.8 ± 0.8	9.3 ± 0.1	125.5 ± 2.5
	Dibenzo(a,h)anthracene	202.5 ± 1.4	100.1 ± 2.6	147.3 ± 3.1	135.7 ± 1.2	123.7 ± 2.3	20.8 ± 0.3	9.8 ± 0.4	132.1 ± 1.5
	Benzo(g,h,i)perylene	120.3 ± 0.2	42.3 ± 2.1	67.8 ± 3.2	5.6 ± 0.4	51.8 ± 0.2	16.2 ± 2.9	5.4 ± 1.4	66.7 ± 2.8
Day 24	Naphthalene	11043.3 ± 0.1	3456.9 ± 2.6	1998.8 ± 3.2	2145.5 ± 2.5	1826.83 ± 0.8	537 ± 1.31	1730.8 ± 2.6	1127.8 ± 4.2
	Acenaphthalene	1028.8 ± 2.3	271.1 ± 1.8	816.6 ± 2.9	150.2 ± 0.2	269.5 ± 0.1	219.7 ± 0.6	184.9 ± 0.9	422.9 ± 2.1
	Acenaphthene	1022.5 ± 3.2	1041.1 ± 2.2	214.5 ± 1.9	685.6 ± 2.9	729 ± 2.9	236.7 ± 3.1	198.2 ± 2.8	285.1 ± 3.2
	Fluorene	822.2 ± 0.2	263.7 ± 0.1	372.9 ± 0.1	133.2 ± 1.4	148 ± 2.7	24.1 ± 3.9	242.5 ± 0.7	128.4 ± 0.3
	Phenanthrene	44660.9 ± 0.2	30411.2 ± 4.8	28672 ± 1.9	2746 ± 2.8	2723.9 ± 0.5	20236.9 ± 0.1	562.6 ± 3.5	123.8 ± 0.1
	Anthracene	162.5 ± 2.7	264.5 ± 3.9	13.4 ± 1.6	109.3 ± 2.3	93 ± 0.2	353.9 ± 4.6	143.9 ± 3.2	143.9 ± 2.1
	Fluoranthene	32.2 ± 1.8	20.8 ± 3.7	14.9 ± 2.7	13.2 ± 0.8	10.1 ± 0.9	14.2 ± 0.5	28.2 ± 1.5	8.2 ± 0.3
	Pyrene	33.1 ± 0.5	21.2 ± 0.8	15.2 ± 3.4	13.5 ± 2.1	10.4 ± 2.4	14.5 ± 0.3	28.8 ± 1.7	8.4 ± 0.1
	Benzo(a)anthracene	259 ± 2.6	435 ± 3.2	43.3 ± 0.9	23.1 ± 0.7	45.8 ± 0.5	220.8 ± 0.3	53.8 ± 0.5	162.4 ± 2.4
	Chrysene	161.9 ± 2.9	472.2 ± 4.5	179.9 ± 0.8	66.6 ± 3.9	395.1 ± 0.7	60.4 ± 0.3	118.7 ± 0.4	174.9 ± 3.5
	Benzo(b)fluoranthene	50.2 ± 0.6	29.5 ± 0.3	23.8 ± 2.1	17.5 ± 2.4	21.3 ± 1.5	21.6 ± 2.9	21.9 ± 0.7	17.2 ± 0.3
	Benzo(k)fluoranthene	51.9 ± 3.1	55 ± 3.8	19.8 ± 0.6	12.7 ± 0.6	26.4 ± 0.5	21.7 ± 0.6	45.2 ± 2.5	23.9 ± 3.8
Benzo(a)pyrene	54.9 ± 2.2	58.2 ± 3.1	21 ± 1.6	13.5 ± 3.7	27.9 ± 1.3	23 ± 1.6	47.9 ± 0.2	25.3 ± 0.4	

Indeno(1,2,3-c,d)pyrene	33.4 ± 1.7	2.5 ± 0.9	5.1 ± 0.2	57.8 ± 0.3	6.8 ± 0.9	1.8 ± 0.4	9.4 ± 0.7	2.9 ± 0.3
Dibenzo(a,h)anthracene	34.5 ± 2.7	4.2 ± 0.1	6.7 ± 0.1	58.5 ± 0.2	8.4 ± 0.5	3.5 ± 1.9	11 ± 0.4	4.5 ± 0.2
Benzo(g,h,i)perylene	31.1 ± 0.9	1.6 ± 1.4	4.1 ± 2.1	13.6 ± 0.2	5.6 ± 0.2	0.6 ± 3.1	7 ± 2.3	6.1 ± 1.8

± Represent Standard Error or deviations from mean values for all replicate sets of data. nd = below detection limit of 0.10 µg/Kg.

Table 7.6.3: Raw data on Total Petroleum Hydrocarbon concentration in the different treatment setups over the study period.

	CONTROL (mg/kg)	FERTILIZER (mg/kg)	6% H ₂ O ₂ (H1) (mg/kg)	30% H ₂ O ₂ (H2) (mg/kg)	60% H ₂ O ₂ (H3) (mg/kg)	H1 + FERTILIZER (mg/kg)	H2 + FERTILIZER (mg/kg)	H3 + FERTILIZER (mg/kg)
Initial concentration	30.8 ± 0.13	30.8 ± 0.22	30.8 ± 2.11	30.8 ± 0.21	30.8 ± 1.36	30.8 ± 0.23	30.8 ± 2.3	30.8 ± 1.03
Day 1	21.3 ± 0.21	37.6 ± 0.24	34.5 ± 0.18	29.5 ± 1.97	25.8 ± 2.17	30.3 ± 2.83	28 ± 0.62	27.7 ± 0.27
Day 3	57.7 ± 0.31	56.2 ± 0.62	66.2 ± 0.92	22.9 ± 2.45	59.7 ± 3.42	67.2 ± 0.41	56.6 ± 0.19	57 ± 0.52
Day 10	39.8 ± 1.1	36.2 ± 0.47	41.2 ± 0.63	27.6 ± 0.23	41.1 ± 1.24	36.4 ± 0.37	24.3 ± 2.01	22.6 ± 0.83
Day 17	40.8 ± 0.15	57.9 ± 1.35	46.6 ± 2.43	50.6 ± 0.29	44.6 ± 1.95	40.2 ± 0.18	47.1 ± 0.29	27.7 ± 3.93
Day 24	50.7 ± 0.63	65.7 ± 0.81	63 ± 1.07	38.4 ± 0.11	55.9 ± 2.32	37.5 ± 1.09	72.4 ± 0.16	58.6 ± 2.31

± Represent Standard Error or deviations from mean values for all replicate sets of data