TOPOGRAPHICAL AND SEASONAL EFFECTS OF DECOMPOSED CASSAVA PEELS ON BIOREMEDIATION OF HYDROCARBON POLLUTED SOILS IN OBIO/AKPOR LOCAL GOVERNMENT AREA OF RIVERS STATE, NIGERIA

BY

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CERTIFICATION

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ABSTRACT

Oil exploitation in the Niger Delta has resulted in widespread hydrocarbon pollution. Despite vast research on bioremediation using organic amendments for restoring hydrocarbon contaminated land, the potential of decomposed cassava peels has attracted little attention in the literature. This study was therefore designed to examine the seasonal effect of decomposed cassava peels for bioremediation of hydrocarbon polluted soils of different topographical surfaces in Obio/Akpor Local Government Area(LGA), Rivers State, Nigeria.

Ecosystem concept was adopted while experimental research design was used. A well-drained and waterlogged sites were purposively selected for the study. Each site was divided into 18 plots, each measuring 2m by 2m and was contaminated with Bonny light crude oil at three levels of 2.0, 4.0 and 6.0% concentrations. The experiment was undertaken in both dry and wet seasons. The baseline soil without contamination served as control. Decomposed cassava peels were introduced into the soil to a depth of 10cm seven days after contamination. Seventy two soil samples were collected from 0-15cm and 15-30cm depth. Soils in the experimental sites were analysed before and after contamination, and after three months of bioremediation for physical (sand, silt and clay, bulk density, total porosity) and chemical (Total Organic Carbon-TOC, Total Nitrogen-TN, Phosphorus-P, pH, Total Hydrocarbon Content-THC, and Total Petroleum Hydrocarbon-TPH) properties respectively. The properties of polluted soils before and after remediation were compared using descriptive statistics and independent t-test at $p \leq 0.05$.

The TOC, TN, P and pH of soils before and after contamination, and after remediation were: 0.37%, 0.08%, 0.67mg/kg and 6.39; 0.72%, 0.21%, 0.82mg/kg and 6.4; and 0.58%, 0.16%, 0.51mg/kg and 6.22, respectively. These indicated an increase in the parameters after contamination and decrease after remediation. Percentage reduction in TPH was 58.2% in dry season and 24.8% in wet season. The THC in dry seasonbefore contamination were 40.63mg/kg, 32.5mg/kg and 36.67mg/kg in well drained site and 35mg/kg, 30mg/kg and 40mg/kg in waterlogged site for 2.0, 4.0 and 6.0% levels of contamination. After contamination, THC increased to 740.8mg/kg, 755mg/kg and 787mg/kg in well drained site and 882.5mg/kg, 912.5mg/kg and 935mg/kg in waterlogged site. After remediation THC decreased to 339.2mg/kg, 317.5mg/kg and 436.7mg/kg in well drained site and 525.1mg/kg, 462.6mg/kg and 558.2mg/kg respectively in waterlogged site. In the wet season THC results before and after contamination, and after remediation were 85.8mg/kg, 100.8mg/kg and 121.7mg/kg; 470mg/kg, 598.3mg/kg and 827mg/kg; and 238.2mg/kg, 350mg/kg and 486.7mg/kg respectively. The THC was significantly lower in remediated soils $t_{(5)}=15.12$. The TPH reduced from 69.7ppm to 29.1ppm in dry season, while in wet season TPH declined from 58.9ppm to 44.3ppm.

Bioremediation was influenced by seasons and topographical locations in Obio/Akpor Local Government Area, Rivers State. Remediation was more effective in well-drained soil than in waterlogged soil but proceeded faster in the dry season than in the wetseason. Application of decomposed cassava peels for hydrocarbon remediation on well-drained soil in dry season is recommended.

Keywords: Bioremediation of polluted soil, Decomposed cassava peels,Soil chemical properties

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CHAPTER ONE

INTRODUCTION

1.1 Background to the Study

Obio/Akpor Local Government Area in Rivers States, is one of the major areas of oil exploration and production activities in Nigeria. These activities have resulted in oil spill pollution with attendant environmental degradation (Idoniboye 1981, Nwangwu and Okoye, 1981; Odu, 1982; Baker, 1982). This has become a matter of great concern to the people of Obio-Akpor Local Government Area, because their water bodies and terrestrial ecosystems have been affected by oil pollution. Farming, usage of water, fishing and domestic purposes are what most people in Obio/Akpor Local Government Area do which have resulted in environmental pollution from petroleum exploration in the area due to contamination of farmlands, fisheries and water supplies for domestic use. Until about 1970 awareness of the impact of petroleum exploration on soil contamination and health risk by petroleum exploration was significantly limited worldwide.

In developing countries it has been observed that most farmers in areas where oil is produced find it difficult to restore the fertility of contaminated farmlands because of inadequate knowledge of proper remediation methods (Okoh, 2006). This problem could be solved if there is adequate attention given to baseline data to evaluate bioremediation application strategies in various communities, using native microorganisms that are isolates (Ebuehi *et al*., 2005). Government shows little or no concern to the problem of oil pollution and this has affected food safety because long time pollution could lead to the release of pollutants into food and water that can cause harm. Oil spills distort the stability of the ecosystem. The process of exploration, production, distribution and handling of crude petroleum has affected the biophysical environment of the Obio/Akpor wetland. Based on the evaluation of the effect oil spillage in Oshika in 1983 Powell and White

(1985) demonstrated the loss of vegetation and aquatic animals, particularly water lettuce, crabs, fish and birds.

Ndiokwere and Nzehe (1990), provided information on high metals in soil and trees near the refinery in Warri. The natural recovery of hydrocarbon spill from soil is often delayed while communities with such problems are often not allowed to have access to land for the purpose of practicing agricultural activities (Gradi, 1985). The rehabilitation of affected land is usually the only alternative available for the people in Obio/Akpor community to reduce effect that will likely be negative to well-being, physical and environmental degradation.

Microorganism is a factor that is environment sensitive for instance temperature, pH, oxygen that are dissolved, automation, greenhouse reducing conditions, availability of various types of chemicals, and the nature of sources of carbon that may differ at various times of the year (Gilbert *et al.,* 2012). Temperature changes are very important. Depending on the type of microbial communities that come from contaminated areas, the production processes may be different. Temperature and seasonal weather changes affect microbial activity. Generally, decrease in microbial metabolism will occur due to temperature decrease and to alteration in the chemical make up of water. McGill *et al,.* (1981) submitted that the extent of physical movement of petroleum hydrocarbons in the soil profile is based on viscosity of the hydrocarbon, temperature and moisture of the soil, as well as structure and texture of the soil. Biodegradation which is a means of remediation of contaminated site has been accepted widely because it is viable economically and condusive to the environment (Dinkla *et al.*, 2001).

Bioremediation technology uses different options, as a means of cleaning up of oil polluted sites and one of such options is the utilization of wastes derived from agricultural products which has proved to be efficient in controlling pollution (Daane *et al.*, 2001). Bioremediation treatment that explains how the genetic response to environmental degradation continues to be researched around the world (Hammer, 1993). Bioremediation is the use of microorganisms or living plants to reduce and detoxify pollution in the environment. It is a technology used to remove pollutants from the environment and therefore, restores the original natural environment (Sasikuma and Papmazah, 2003). Bioremediation aims at reducing the cost of design and can reduce the

pollutant to a low and reasonable level. In order to achieve this low cost, researchers have started to adopt the application of organic wastes for effective bioremediation.

Nutrients availability, particularly nitrogen and phosphorus, mostly control microbial activities (Margesin and Schinner, 1997) with such nutrients utilized for improving biodegradation of hydrocarbon contamination (Choi *et al.,* 2002). Biostimulation is an effective strategy which enhances crude oil biodegradation. There has not been any harmful effects from nutrient enrichment following full scale field operation (Purseglove, 1985, Odokuma and Ibor, 2002). Many researchers such as Odokuma and Dickson, (2003), Xu and Johnson, (1997), Offor and Akonye, (2006), Olar and Molna, (1995), Akonye and Onwudiwe (2004), Tanee and Kinako (2008) showed biostimulation on soil contaminated due to oil spill using organic manure. They also reported improved cassava yield in a crude oil polluted phytoremediated soil.

The toxic impact of crude oil on microflora ecosystem was observed in the analysis of Amadi *et al*., (1996) using the Niger Delta rain forest as study site; the impact of hydrocarbon on the germination, nutrient uptake and yield of maize was investigated by Udo and Fayemi (1975). Etuk (2008), presented bioremediation of crude petroleum using enhanced attenuation process in the Niger Delta. Findings from the literature indicate that several studies on bioremediation of hydrocarbon contaminated soils using different organic wastes such as dung from cow, poultry dropping, spent mushroom, sawdust and abattoir wastewater have been documented. However, only few studies on the potentials of decomposed cassava peels have been reported and this is why this present study has been proposed.

One staple crop cultivated in most African countries is cassava (John *et al.,* 2006), and Nigeria where it has become a major source of income and export. Babawale (2001) explained that cassava flour are major staple food product from cassava, with over 80% of Nigerians consuming it. The processing of cassava into garri includes peeling, grating, drying to remove water, sieving and frying. The peels are made up of rough brownish outer skin removed with part of the fleshly whitish or yellowish cassava because they are generally regarded as wastes that should be disposed or allowed to rot or in some instances fed to livestock. Micro-organisms usually colonize the cassava peels because of

its chemical composition (Uzochukwu *et al*., 2001) while the waste peels are decomposed by the microorganisms enzymatic activities.

The implication is that the cassava peels could be a good source of microbial enzymes (Okafor, 1998). The addition of soil amendments, such as decomposed cassava peels to the soil will increase microorganisms activities in the soil significantly. The organisms, while growing on the cassava peels substrate produce enzymes that are used in metabolizing the hydrocarbons in the polluted soils. Adding decomposed cassava peels to the soil has been found to improve the soil and can reduce the hydrocarbon pollution of biodegradable systems to a safe level of health, well-being and the environment. Treatment refers to both controlling and spreading of decomposed cassava peels on the surface as well as the introduction of this organic waste into the soil surface.

1.2 Statement of the Problem

The main source of foreign exchange in Nigeria is crude oil and natural gas which contributes as high as 95 % to Nigeria annual expenditures (Owugah, 2001). Despite this contribution, Obio/Akpor local government area which is a major oil producing area in Rivers State has suffered severe deterioration in the quality of its environment because of the activities associated with oil exploration. The oil industry in the area has many producing wells, gas plants, a network of thousands of kilometres of pipelines which criss-cross the area and carry crude oil to the flow stations, terminals and refineries.

One major challenge confronted by oil producing areas today is environmental degradation. It is evident that the environment of Obio/Akpor has been greatly polluted and this has affected the economy of the people (Babatunde, 2010). Soil degradation in the area which is on a continuous basis has serious health, social and economic implications. Crude oil spillage has environmental impacts on both coastal and terrestrial environment in Obio/Akpor Local Government Area. Human beings, flora and fauna in the area are affected by the obnoxious spills. The impacts of the toxicity of the oil spill goes beyond the immediate vicinity of production and exploration as a result of storage, disposal, transportation and other handling activities, which result in the pollution of farmlands, water resources, destruction of aquatic life and vegetal cover. Most oil components are harmful to humans and wildlife since they are not difficult to incorporate

in the food chain. This increased the interest of scientists in assessing the distribution, condition and characteristics of crude oil and its derivatives as it affects the environment in the community. Oil spills can result in immediate and long-term deterioration to water body, soil, health of plant and man and natural resources, because most hydrocarbon compounds are harmful and continuous in acquatic and soil environments. In Obio/Akpor local government area like other parts of the Niger Delta, the people attach importance to the quality of the environment because their economy, wellbeing and development depend on it. Over 60 percent of the people in the area depend on the natural environment for their livelihood (UNDP, 2006). They use the environment for agriculture, fishing and collection of forest products. Pollution has therefore destroyed the environment which is their means of survival.

Bomu field (Bomu II) in Gokana Local Government Area of Rivers State operated for a period of nine years after which it blew off on 19th July, 1970 and the oil spilled on the land before it was stemmed. About 607 hectares (1510 acres) of land was impacted. Much damage was done to crops and the area contaminated could not be put to agricultural use for about three years. The less impacted area was farmed after one and half years (Odogwu, 1981). Most part of the land was barren due to the oil spill.

Although Obio/Akpor local government area has a perculiar environment rich in aquatic and terrestrial flora and fauna, the ecological damage caused by oil spill has destroyed both marine and terrestrial ecosystems. Soils, plants, animals and water resources in the area are severely affected, by the toxicity of oil. A large portion of mangrove and freshwater swamps have been contaminated and severely affecting aquatic and terrestrial species. The environmental resource base on which the community survives is destroyed by oil operations. Communities in the area therefore become prone to food shortages, health hazards and water pollution due to oil spills. Different components of the environment have been contaminated by the wide use of petroleum products and bioremediation of hydrocarbon through the use of microorganisms has been reported to be the main technology that can be used in cleaning the hydrocarbon polluted environments (Challain *et al*., 2004). In Obio/Akpor Local Government Area, oil exploration and production activities and the discharge of hydrocarbon-derived chemical wastes have polluted the soils, groundwater and led to ecosystem degradation. Soil

fertility has greatly reduced which results in low agricultural produce and this affects the people's meaningful living.

The effect of oil spills on the biophysical attributes of the environment should be assessed to determine the risk which the fragile ecosystem of Obio/Akpor Local Government Area faces. This is due to the fact that the biophysical environment is the receptor in which the crude oil spilled resides. Therefore, it is crucial to assess its impact on the ecological and physical attributes of the naturally stable environment, in which the activities of man specifically of oil, is carried out. A number of studies on bioremediation of hydrocarbon contaminated soils have been undertaken by different scholars in different parts of Nigeria and the world using different agro wastes. However, no study on topographical and seasonal effects of decomposed cassava peels on bioremediation of hydrocarbon polluted soils has been conducted in Obio/Akpor local government area of Rivers State. This is the gap which this study hopes to fill. Decomposed cassava peels as organic waste is used in this study as natural attenuation agent for petroleum contaminated soil. The choice of this organic waste is informed by the fact that it is very common in the immediate vicinity of the study sites and the local wastes are readily available in the community for farmers to use as remediating agent.

It is necessary to restore soil contaminated with oil from the Obio/Akpor environment to its original state before oil spills. Various remediation strategies have been suggested to minimize= the harmful impact of soil hydrocarbon pollution at various costs that discourage many polluters from carrying out effective remediation. Therefore, it is necessary to carefully examine the technology that would significantly reduce soil hydrocarbon pollution in the Obio/Akpor local government area. In view of the foregoing, this research seeks to provide answers to the following research questions:

1.3 Research Questions

1. What are the effects of decomposed cassava peels on the degradation of oil in soils polluted with oil?
2. Are there changes in the number of microbial population in soils undergoing bioremediation?
3. What is the level of heavy metals in the soils after remediation?

4. Is there any variation in the rate of bioremediation in the dry and wet seasons?
5. Is there any difference in the rate of bioremediation in well drained and waterlogged soils?

1.4 Aim and Objectives of Study

The aim of the study is to examine the effects of topography and seasons on decomposed cassava peels as a natural attenuation agent in bioremediation of hydrocarbon polluted soils. The objectives of the study are to:

1. Investigate the effects of decomposed cassava peels on the degradation of crude oil in soils polluted with oil.
2. Investigate the soil microbial population dynamics undergoing bioremediation.
3. Assess the level of heavy metals concentration in the soil after remediation.
4. Determine seasonal variations in the rate of bioremediation.
5. Compare the rates of bioremediation in well drained and waterlogged soils.

1.5 Research Hypotheses

This research is based on the following hypotheses:

1. There is a significant difference in hydrocarbon levels of the polluted and remediated soils.
2. There is a significant difference between the physicochemical properties of soil before and after soil remediation.
3. There is a significant reduction in the levels of heavy metals concentration after remediation of hydrocarbon polluted soils.
4. There is a significant variation in the rate of bioremediation in the dry season and in the wet season.
5. The rate of remediation is faster in well drained soil than in the waterlogged soil.

1.6 Justification of Study

So much has been documented about soil degradation, oil spills and their impact on the environment. In the past, a number of remedial measures have been adopted, ranging from mechanical, physical and chemical strategies for the remediation of oil-contaminated environments. However, most of these methods have some disadvantages because

hydrocarbon contaminated soil is not completely remediated. These methods also proved to be costly and results in more damage to the ecosystem. Bioremediation through the use of organic waste offers a good environmentally friendly method for remediating hydrocarbon and heavy metal contaminated soil. It is a great strategy to make biodegradation of oil cheaper, more environmentally friendly and easier. The method also make the soil fertile.

The results obtained from this study will provide insight into what can be done to improve soil fertility while effort continues to be made to effectively reduce soil pollution due to oil spill in Nigeria, particularly in Obio/Akpor Local Government Area in Rivers State. This research would be of benefit to residents of the city. It will help stakeholders to understand issues relating to soil pollution and the need to prevent it within the study area and also follow-up will be included in this study, which will help policymakers in planning.

It would also serve as a reference material that is crucial in providing inspiration to future researchers to adopt the use of cassava peel as natural agents of attenuation in the remediation of soil polluted with crude oil.

CHAPTER TWO

CONCEPTUAL FRAMEWORK AND LITERATURE REVIEW

2.1 Conceptual Framework

In order to adequately capture the aim and objectives of the study, the study is hinged on some conceptual frameworks which provide clear guidance and proper background for addressing the study. These are the ecosystem concept, concept of pollution, soil pollution, hydrocarbon pollution, hydrocarbon degradation and factors influencing petroleum hydrocarbon degradation.

2.1.1 The Ecosystem Concept

The term ecosystem was coined in 1935 by the British ecologist Arthur Tansley to encompass the interactions among biotic and abiotic components of the environment at a given site. The living and non-living components of an ecosystem are known as biotic and abiotic components, respectively. Ecosystem is defined as a community, including all the organisms in a given area interacting with the physical environment so that a flow of energy leads to a clearly defined trophic structure, biotic diversity and material cycles i.e, exchange of materials between living and non-living, within the system. The two components of an ecosystem are in constant interaction with each other.

Biotic Components of Ecosystem

The living components of an ecosystem are called the biotic components. These include plants, animals and micro organisms (bacteria and fungi). These biotic components can further be classified, based on the energy requirement source.

(a). Producers are plant in the ecosystem which can manufacture their own food through photosynthesis in the presence of sunlight and cholorophyll. All other living beings are dependent on plants for their energy requirement of food as well as oxygen.

(b). Consumers include herbivores, carnivores and omnivores. The herbivores are the living organisms that feed on plants. Carnivores eat other living organisms. Omnivores are animals that can eat both plant and animal tissues, example, man .

(c). Decomposers are the bacteria and fungi, which are the saprophytes. They feed on the decaying organic matter and convert this matter into nitrogen and carbon dioxide. The saprophytes play a vital role in recycling the nutrients so that the producers i.e. plants can use them again.

Abiotic Components of Ecosystem

Abiotic components are the physical and / or the chemical factors that act on the living organisms at any part of their life. These are also called the ecological factors. The physical and chemical factors are characteristics of the environment. Light, air, soil, water, and nutrients, etc form the abiotic components of an ecosystem. In an aquatic ecosystem the abiotic factors include water pH, sunlight, turbidity, water depth, salinity, available nutrients and dissolved oxygen. Similarly, abiotic in terrestrial ecosystem include soil, soil types, temperature, rain, altitude, wind, nutrients, sunlight, etc.

Ecosystem have a complex set of interactions that occur between the biotic and abiotic components. The components of an ecosystem are linked to each other through the energy flows and nutrient cycles. Although ecosystems do not have well defined boundaries, interactions between them are affected when one factors is changed or removed. This has the capacity to affect the entire ecosystem.

2.1.2 The Concept of Pollution

A major environmental challenge confronting human activities and development is environmental pollution. This occurs as a result of environmental change that will have adverse impact on quality of life, including man, animals, plants and microorganisms as well as the soil ecosystem (Marinescu *et al.,* 2010). Any alteration in the characteristics of air, water or soil physically, chemically or biologically that may undesirablely have impact on well-being, survival or activities of man or other life forms is referred to as pollution. Pollution occurs when the concentration of contaminants reaches a level that is not pleasant (Freeze and Cherry, 1979), or a conditon where the substance concentration is higher than expected but at the same time cause some sort of damage. It is polluted by a

chemical or other agent which results in the community becoming uninhabitated or usable for all animal and soil requirements to support life in all its natural forms. The soil, water and air are damaged as a result of pollution of the environment with substance that negatively impact on human quality of life and functioning of the ecosystem naturally.

The level of contamination is determined by three variables which are the nature, persistent and concentration of chemical. The ecosystem and environmental balance is affected by pollution. Pollution has peaked as a result of modernization and development which has led to global warming and increase health hazard to both man and animal. All types of pollution has two sources of incident, the point and the non-point source.

Emission that is directly from an identifiable discharge point is known as point source like land fill or spillage. In Urban areas point sources of pollution in the submission of Lacatusu (1998) includes direct discharges from industry and municipalities into streams and rivers, in addition to chemical leakage releases and storage tanks leaking underground. For instance, non-sources include agricultural, urban storm run off, construction sites and automobile emissions. Non-point sources can contribute significant pollutant load from runoff and atmospheric deposition into the river (Lacatusu, 1998). Point sources are not difficult to recognise, monitor and control, while the control of non-point sources is difficult. Pollution occurs in different forms and affects many different aspects of the environment.

2.1.3 Soil Pollution

Soil is a complex biological system consisting of vegetation and inorganic organisms, including water and gas in various proportions. This is a crucial part of the biosphere and is also dynamic because man and animal depend on it as source of food and shelter. Soil pollution is described as the appearance in soils of toxic compounds, chemicals, salts, radioactive materials, or disease causing agents which have adverse effects on the growth of plants and animal health (Pepper, 1996). Pollution comes from the activity of man and nature which can be life-threatening. A major source of environmental contamination is anthropogenic waste (Lu and Zhu, 2009). Biomass of fossil fuels is a form of organic pollutants in the soil. Soil contamination is different from water or air pollution because the pollution remains in contact for a while with the soil, thus altering the biological and

chemical properties of soil. Increased in soil pollution based on the submission of Lacatusu (1998) will probably result in the soil inability to bind chemical substances through the phenomena of adsorption and complexity, as well as the potential for inducing negative functions, thus the pollution phenomenon starts off.

Human food chain can be contaminanted by hazardous chemical that enters it through the soil or acquatic plants. Therefore, soil pollution is causing great concern due to impact it directly has on public health. Some chemical contaminants that commonly cause health hazard are pesticides, hydrocarbon products, inorganic materials (heavy metals and micronutrients) and solvent. Contamination of the soil may be as a result of industrial pollution, waste not properly disposed, radioactive waste and acidic rain while evacuation of industrial waste is a source of environmental contamination. Waste products that pollute the environment are discharged from different industries which contaminate and change soil characteristics both chemically and physically. Therefore, toxic chemicals can enter the soil or seawater, prevent biological processes and eventually release toxic wastes that will significantly affect natural resources. There are various types of wastes including waste in urban city and personal waste. Urban wastes comprise of both commercial and domestic wastes. These wastes are often referred to as trash which is made up of plastic, glass, glass cups, cables, debris, waste from the street, oil spills, paper, utensils, abandoned vehicles and other manufactured goods. Urban waste is also segregated into industrial waste. However, because they are easily degraded they can still be harmful.

Specific amount of waste is produced by each person through urine and faeces. Although most of the water is absorbed into the canal, large amounts are immediately disposed into the diaper form. The sewage disposal system stops at the sewage, while the pollutants pollute the soil and water. The soil is polluted through most modern agricultural practices due to the adoption of advanced agro-technologies, large amounts of fertilizers, herbicides and pesticides applied to the soil for the purpose of increasing crop yields. These chemicals are not produced by nature and cannot be easily destroyed. As a result, they get into the water and mix with water and slowly reduce soil fertility. Soil composition are demaged by other chemicals which results in water and air eroding the soil. Most of the pesticides are adsorbed by plants while soil plant will cause soil pollution when decomposed since they become part of the soil.

Oil spillage is a threat to the environment and has become a regular phenomenon specifically in the region where oil exploration is done. These occurrences result from leaks from underground storage tanks, oil-well blow outs, oil tanker accidents, spills from production sites, and in many cases, sabotage and vandalization (Jidere and Akamigbo, 2009). These pollutants contaminate soil and lead to the alteration of the soil physicochemical constituent, thus affecting the agricultural use of land. Soil quality reduces due to chemicals present in hydrocarbon making such soil unsuitable for cultivation. Such chemical can enter groundwater through soil and make it unsuitable for consumption. Radioactive substances which result from explosions of nuclear testing laboratories and industries give rise to nuclear dust. The accumulation of radioactive wastes that enter the soil will lead to land/soil pollution while the rain will mix with the pollutant present in the air to form acid. Soil structure can change significantly by the polluted water.

2.1.4 Hydrocarbon Pollution

The pollution of soil caused by oil spill, is an environmental challenge in any community where the oil exploration is being carried out. The level of damage depends on the size and extent of the pollution. Soil pollution from fossil fuels is becoming a global phenomenon due to the dependence on protroleum products as source of energy worldwide, rapid industrialization, increased population and environmental hazard. Pollution due to hydrocarbon causes disruptions of ecosystems, biodiversity and environment. Hydrocarbon sources according to Das and Chandran (2010) belong to families of carcinogens and oxygen pollutants. Environmental pollution by crude oil products and hydrocarbon is a source of inconvenience to the environment arising from the nature of the oil and possibility of spreading into ground and surface water.

Contamination as a result of oil spillage poses environmental risk and safety of human (Balasubramaniam *et al.,* 2007). Exploration, production and transportation of oil can have an impact on the community. The most observable sources of environmental pollutation are release from factories and facilities for refining, spill from oil tanker, underground storage tank leaks, and oil transportation accidents. Soils contaminated by oil pose serious risks to quality of health and result in organic contamination of groundwater

that reduces the availability of the water and in turn lead to economic losses, problems in the environment and decrease production when such soil are used for agricultural purposes (Wang et al., 2008). Basically, such concerns are connected with health risks, contact with polluted soil, vapors and contamination from secondary source either soil or underground water supplies.

It is well established that there is harmful effect of crude oil on microorganisms, soils, plants, animals and humans (Bijay *et al*., 20l2). Crude oil have significant impact on the soil by increasing metals that are toxic to human health while nutrient content and penetration of water into the soil is reduced due to its hydrophobic properties. Plants can also be affected through the seed germination retardation, stunted growth, reduced stem density or complete total mortality.

Crude oil spill in the soil creates conditions that lead to decrease in available basic nutrients, such as nitrogen, and some toxins like arsenic and plant based lead (Akamigbo and Jidere, 2002; Gill *et al.,* 2003) . Ekpo and Nwankpa (2006) found that crude oil has a negative influence on the soil. According to Manahan (1994), it weakens soil microbes by inhibiting their activity. Oil waste also affects plant growth (Ekpo, 2002), drinking water by seeds (Atuanya, 1987), biotoxicity (Atuanya, 1987), soil structure and water scarcity (Odjegba and Sadiq, 2002, Gill *et al.,* 2003) and reduced crop productivity (Gaskin et al., 2007). Metals related to fossil fuels are generally found in the soil while it is crucial because the impact of metal load is understood as a consequence of direct effects on population and human ecosystem (Agbozu *et al.,* 2007). . .

2.1.5 Hydrocarbon Degradation

Biodegradation is the ability of micro-organisms to alter organic pollutants into substance that is not harmful and hazardous that can be incorporated into biochemical cycles naturally. A crucial role is played by the environment in the transportation of contaminant while the impact of contaminants on the environment depends on contaminant chemical structure that are largely different (Brady and Weil, 2002). Most microorganisms can easily use hydrocarbons as the major source of carbon and energy and the distribution of such microorganisms in nature is very wide while the utilization of hydrocarbon by the microbial organisms depend on chemical properties and environmental contaminant

(Atlas, 1981). Biodegradation using microorganisms in the submission of Ulrici (2000) is a critical approach for the removing of hydrocarbon and other contaminants in the soil as a result of oil spill and is not as expensive as other technology adopted for environmental restoration (Leahy and Colwell, 1990).

The process of petroleum biodegradation is complex depending on hydrocarbon nature and quantity present. Environmental degradation of hydrocarbon is limited because oil pollutants do not get to microorganisms. The level of change of organic pollutants in the soil in the assertion of Vezzulli et al. (2004) and Gallizia *et al.,* (2005) depend on chemicals available to microorganisms, population and level of activity of microorganisms. As a result, characteristics of soil and properties of pollutant can reveal how the available treatment methods can be used for a specific pollution event. An important condition for successful degradation of waste is the ability of microorganisms to metabolized organic wastes. Due to variation on the structure of chemical and molecular weights, the sensitivity of oil hydrocarbons to microbial attack varies. The rates at which micro-organisms can degrade hydrocarbon usually ranked as follows : n-alkanes>branched alkanes>low molecular weights aromatics> cyclic alkanes (Perry, 1984; Leahy and Cowell, 1990).

Biodegradation levels are higher for light aromatics, followed by aromatics and polar compounds of high molecular weight, making biodegradation extremely difficult (Leahy and Colwell 1990, Obuekwe *et al.,* 2001). Some types of microorganisms can break down hydrocarbons so that they are used as carbon and energy source. Some bacteria will detect the contaminant and move towards it using a chemotactic response, while fungi microbes will grow filamentously near the contaminant (Rosenberg and Ron, 1996). Bioremediation may either be natural or promoted by adding microbes and fertilizers. The addition of biological surfactants will increase solubility, eliminate contaminants and improves the biodegradation rates of the oil. The volatility and susceptibility to biodegradation of the constituents of the oil differ greatly. Some compounds degrade readily, others are resistant to degradation and others are not biodegradable (Mukred, *et al.,* 2008). Enzymes are produced by microorganisms using carbon sources responsible for attacking the molecules of hydrocarbon. In the degradation of hydrocarbon various

enzymes and metabolic pathways are involved while the absence of required enzymes will serve as barrier to the attack to complete hydrocarbon degradation.

Bacteria, fungi and yeast are responsible for the breaking down of hydrocarbons. The most active factor in breaking down carbon in crude oil is the presence of bacteria (Rahman et al., 2003; Brooijmans *et al.,* 2009) which are widespread in marine, freshwater and soil environments. In addition, there are several reports on the specific number of hydrocarbon based materials due to methodological differences used to calculate the fuel species.

Good research and understanding of microbiological processes that occur in soil that is contaminated may reveal method for bioremediation that will efficiently reduce the concentration of pollutant below the levels of toxicity because the proportion of hydrocarbon consuming substances involved in the degradation of hydrocarbon naturally is too low in the environment either in soil and water (Amund and Igiri 1990; Adebusoye *et al.,* 2007). Oil pollution can persist for many years in the environment without degradation (Atlas 1992; Solano-Serena *et al.,* 2000). Therefore, the use of agricultural waste for bioremediation as supplement for nutrient to those naturally present can increase the level of remediation of contaminanted environments.

2.1.6 Factors Influencing Petroleum Hydrocarbon Degradation

Removal of crude oil impurities from the environment can be done naturally using microorganism a process known as biodegradation. Certain factors limit the biodegradation of hydrocarbons in crude oil. An important factor in hydrocarbon contamination is the component and level of biodegradation when considering how a corrective approach is assessed. Of the physical factors, an important part is played by temperature in controlling the properties and level of microbiological metabolism of hydrocarbons, which is very special in soil bioremediation.

Temperature and Chemical Composition of the Crude Oil

Temperature is a factor that is important in the biodegradation of hydrocarbons product. Atlas (1993) indicates that the impact of temperature will combine with the properties of hydrocarbon and the composition of microbial activity in the environment. The ambient

temperature will affect both the nature of the oil spill and microorganism activities and population (Venosa and Zhu, 2003). Lower temperature in the submission of Atlas (1981) will result in viscosity of oil increasing while a reduction in molecular weight of volatility, which slows down the onset of biodegradation. Biodegradation of hydrocarbons occurs in various temperature ranges. In general, biodegradation of hydrocarbons increases with temperature and reaches peaks around 30-40 ° C in soil environments, 20-30 ° C in some freshwater environments and 15-20 ° C in marine environments (Bossert and Bartha 1984; Cooney, 1984).

Increased temperature will result in reduction in viscosity, which affects the level of distribution. The temperature influences the rate at which hydrocarbon is broken down through controlling reactions of enzymes present in microbial activity. Essentially, increase in temperature will result in reaction of enzymes doubling in the cell (Nester *et al.,* 2001), but the microorganisms will not withstand temperature that is too high. They are usually found in hot springs and mounds of compost. They occur locally in cold soil and can be activated to degrade hydrocarbons when the temperature reaches 60 ° C. These results suggest a natural suppression potential in cold soils due to thermally enhanced bioremediation strategies" (Perfumo et al. al., 2007). The chemical component of oil is another parameter that affects the process of bioremediation.

Nutrients of Nitrogen and Phosphorus

Nutrients are crucial components for effective hydrocarbon pollutants biodegradation, particularly nitrogen, phosphorus and, in some cases, iron. Materials utilized by microorganisms to build components of a new cell are nutrients. Microorganisms require that nitrogen and phosphorus be included in the biomass. Nitrogen is the main component of nucleic acids. Gaudy and Gaudy (1988) state that nucleic acid is responsible for the ability of each organism to reproduce. In addition Boyd (1984) noted that other forms of nitrogen must be converted to ammonia before they can be absorbed by the microorganisms. It has been revealed that cell growth can increased when soil contaminated with nitrogen oil is treated while microbial delay phase is reduced because the population of microbial organisms is maintained at high levels of activity, and level of hydrocarbon degradation is increased "(Walworth *et al.,* 2005). However, excessive soil

fertilization can reduce microbial activity (Braddock *et al.,* 1997). Phosphorus is necessary for the production of cellular material because it is crucial element in nucleic acids, required on the ground. The addition of phosphorus has the same advantages as nitrogen but the same limitation will be observed when excessively applied (Mississippi State, Department of Environmental Quality, 1998). Based on the attributes of the affected environment, most nutrients available may be limited because of biodegradation. Shailubhai (1986), Atlas and Bartha (1993) have observed that all soils except soils with high level of acid contain organisms capable of degrading petroleum derivatives, and that the challenge was to provide the necessary nutrients. The availability of nitrogen and phosphorus, which leads to an increase in the population of micro-organisms that degrade hydrocarbons, is a factor that is crucial in bioremediation.

Moisture and Surface Area

Moisture is very important in life processes, but excess of it interferes with the availability of oxygen. According to Atlas (1998), the moisture content of a soil is expressed in terms of its water holding capacity. Moisture content, in which water no longer flows from the soil under gravity, is referred to as field capacity. Moisture content in the soil is between 45 and 85% of ground water (about 12 to 30% by weight)" is ideal for the degradation of hydrocarbons (US EPA, 2006). Very low moisture content can reduce the rate of bioremediation as observed by (Dupont, 1993) while very high moisture contents limit the oxygen distribution thus restricting diffusion of oxygen through the water phase (Baker and Herson, 1994). All soil microorganisms require moisture for cell growth and function. Water availability impacts water and nutrients diffusion of water and nutrients that are soluble through the cells of microorganism. However, excessive moisture in soil that is saturated is not desirable because the amount of oxygen available for aerobic respiration reduces. The predominant process is anaerobic respiration, which generates low energy for microorganism (rather than aerobic respiration) and slows down the rate of biogas degradation.

Water in soil is required for successful bioremediation and is essential for microbial growth. Travis (1999) established that microorganisms need water for diffusion of oxygen into the environment to assimilate nutrients and carry many of the soluble nutrients

necessary for microbial growth. Surface area is a factor responsible for effective bioremediation. Growth of petroleum microorganisms takes place in the presence of water and hydrocarbon which implies that there will be increase in the number and growth of microbes where oil and water is available.

Oxygen Requirement

Aerobic microorganisms need oxygen for metabolism. The oxygen available in the soils depends on the type of soil. The energy released when a microorganism uses oxygen as the terminal electron acceptor is twice when compared to nitrate and order of magnitude higher than sulphate and carbondioxide (Dupont, 1993). Huesman and Truex (1996) and Heuckeroth *et al*., (1995) have found that for soil respirometry experiments involving hydrocarbon contamination, the oxygen consumption rate remained constant as long as the concentration of oxygen was above approximately 5%. Odu (1981) declared that most fungi and bacteria that breakdown hydrocarbons in petroleum product need oxygen that is free or dissolved (Odu, 1981).

Soil type is another crucial factor that should be considered in sound bioremediation technology in a specific situation. In situ bioremediation refers to the treatment of soil in a place. Contaminants can adsorb to soil particles and render some contaminants unavailable to microorganisms for biodegradation. Hydrophobic contaminants, like petroleum hydrocarbons have low solubility in water and tends to adsorb strongly in soil with high organic contents. In such cases, surfactants are used as part of the bioremediation process to increase solubility and mobility of these contaminants (State of Mississippi, Department of Environmental Quality, 1998). Therefore, in most circumstances, the bioavailability of contaminants depends not only on the nature of pollutant but also on soil type. In addition research result revealed that thermophilic bacteria in the cold soil is an indication that high temperatures increases the level of biodegradation by increasing pollutants availability. Pollutants adsorbed to soil particles i are mobilized and their solubility increased by high temperatures (Perfumo *et al.,* 2007).

Table 2.1: Microorganisms Capable of Degrading Petroleum Hydrocarbon in Soil

Bacteria	Yeast/Fungi
Achromobacter	Aspergillus
Acinetobater	Candida
Arthrobacter	Cladosporium
Bacillus	Penicillium
Flavobacterium	Rhodotorula
Nocarolia	Sporobolomyces
Pseudomonas	Trichoderma
Vibrio	
Brevibacterium	
Corny bacterium	
Alcaligences	

Source: (Atlas, 1984, Focht and Westake , 1987)

2.1.7 Soil Texture and Ground Water Drainage

Draining of ground water is known as the removal of excess water from the surface or below the surface of the land so that soil condition that is favourable for plant growth is created. Soil texture and structure influence the moisture characteristics (soil moisture relationships) a specific soil will possess. The particle size distribution is referred to as soil texture, and soil particles are the core component of sand, silt and clay, from the largest to the lowest mineral fraction. The size and percentage of soil particle determines the size composition. Most soil types are affected by grain size distribution and storage, stress, history, density and other soil characteristics (Obioha, 2001). Soil structure affects the capability of the soil to provide good air and water diffusion. Proper drainage channel of excess water should be provided regularly while the appropriate amount of water should be held in the soil.

The physical properties of the soil are influenced by the amount of total sand and of the different sand fractions present in the soil. Sand particles, due to their size, have a direct effect on soil porosity. Pore space in soil provides for oxygen to be supplied to the micro-organisms and to the root system of plants. As a general rule, the larger the size of soil particle, the better the drainage. Fine structured soils have small particles, but in reality they have a large surface around them. The soil surface retains moisture in the soil but more water retained by smaller soil particles. When the soil particles are very small (clay), the water can become very firm against the surface around each clay particle. Clay soils when compared to sandy soil have a higher water holding capacity.The characteristics of soil are specifically critical for successful biodegradation of hydrocarbon. Factors that are crucial in causing limitation are texture of the soil, soil permeability, pH and amount of water held by the soil.

The texture of the soil is influenced by bulk density, permeability and humidity of the soil. Soils with high clay content or with dominant micropores between the particles, enabling the movement of water or air, have generally low permeability. This is a challenge for the bioremediation process while soil bioremediation can be allowed by mixing it with soil amendments as the bioremediation process is based on the activity of micro-organisms,

water, high temperature and pH to promote cell growth and maintain biodegradation (Alexander 1995; Jain *et al.,* 2011).

The size of soil particles is very important because it affects the proportion of air, the amount of water retained in the soil, and the rate the water drains from the soil. It also affects the ease with which the soil is cultivated. Furthermore, soil drainage, aeration and nutrient levels to a large extent depends on soil texture. Soil that is well-drained have good aeration, which implies that such soil is the atmosphere that promotes microorganisms and growth of root. Soils also vary in susceptibility to erosion depending on soil texture. Soil with a high proportion of silt and clay particles is more prone to erosion when compare to sandy soil. Variations in the structure of soil also affect levels of organic matter. Organic matter biodegradation is faster in sandy soils in comparison with waterlogged soils, under the same environmental conditions, cultivation and fertility management, because of the large amount of oxygen available for degradation in the sandy soils. There is an increase in the cation exchange capacity of the soil with the percentage of clay and organic matter, and the soil load capacity at pH depends on the clay and organic matter content.

2.1.8 Effects of Seasons on Bioremediation

The success of biorestoration depends to a large extent on the predominant variables in the environment and therefore requires a good understanding of its impact on the fate of pollution under specific site conditions. Most bioremediation sites are characterized by environmental parameters such as temperature variations, high / low pH, the dynamics of groundwater, and fluctuations of soil moisture. The most crucial role in the process of bioremediation is played by temperature of soil water (Sims *et al.,* 1993). Decrease in temperatures will lead to BTEX volatilisation and flow fluctuations are often reduced, which delay the onset of the biodegradation process (Margesin and Schinner 2001). In addition, the solubility and therefore bioavailability of BTEX complexes increases at high temperatures. JRB (1984) found that increasing the temperature also reduced the adsorption of solids into the soil, allowing more organic matter to degrade microorganisms. He added that temperature plays an important role in managing the type and amount of microbial population responsible for hydrocarbon degradation. Corseuil

and Weber (1994) note that the production of microorganisms in general is associated with increasing soil temperature to the optimal values for high growth. However, when the soil temperature drops in the winter, the flow and strength of the cell membrane decreases, which prevents the absorption of nutrients and contaminants. Although most soil bacteria work best within 20 to 40 ° C (Chapelle, 2001), many hydrocarbons have been shown to be biodegradable under (low or high) temperature conditions (Muller et al.,1998; Margesin and Schinner, 2003). 1999). Microorganism in the soil depending on temperature are subdivided into three groups: (1) Psychrophiles, (2) Mesophiles, and (3) Thermophiles (Chablain et al., 1997; Margesin and Schinner, 2001). Temperature in the assertion of Stetter (1998) will support the growth of psychrophiles when below 20 ^{0}C, while at 20 ^{0}C and 44 ^{0}C mesophiles grow and thermophiles require above 45 ^{0}C. Most degradable hydrocarbons are mesophiles which metabolize optimally in the range of 20-35 ^{0} C (Chambers *et al.,* 1991). Generally, increased temperatures during dry season are connected with higher enzyme activity and faster conversion rates to a better degree of species specificity. At this rate, the degradation rates of hydrocarbons can be doubled or tripled as a result of temperature of 10 ^{0}C (Corseuil and Weber, 1994). When the temperature rises above the optimal value, proteins, enzymes and cell membranes become trapped and unstable, leading to biodegradation stoppage. Moreover, reducing the temperature during the cold season can reduce the rate of breakdown, but will not prevent it.

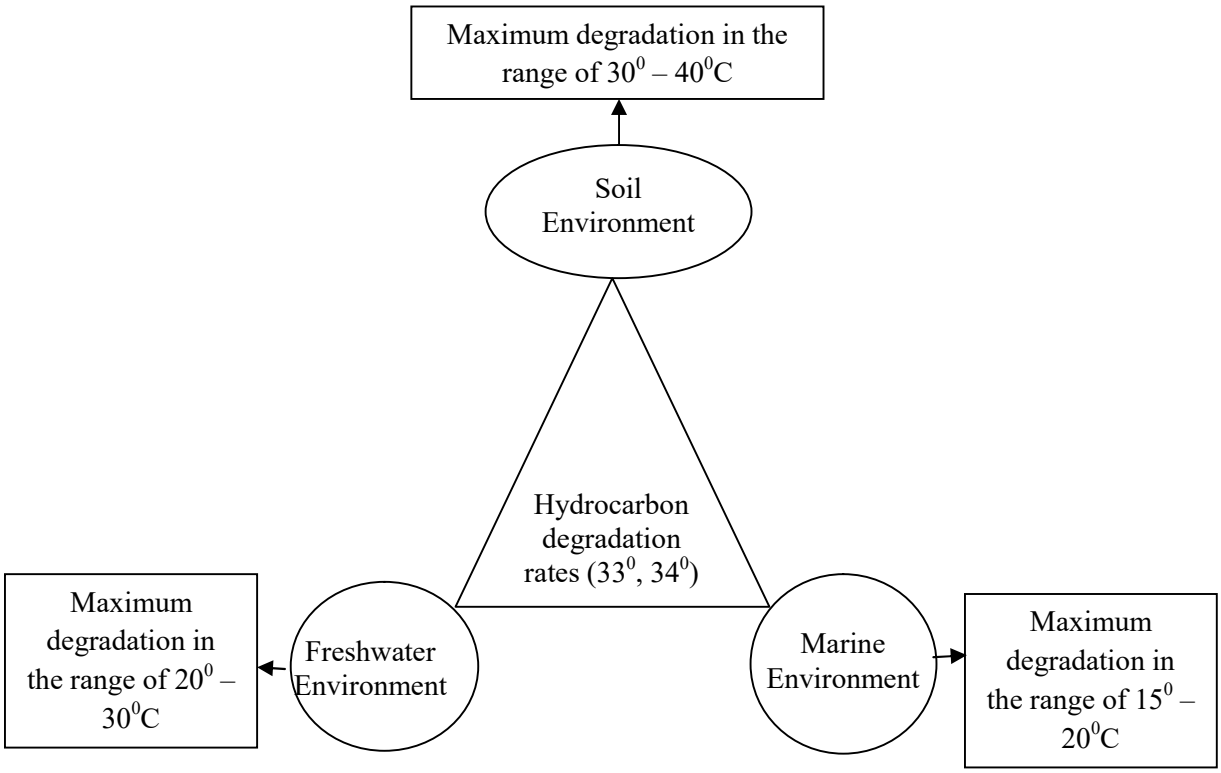


Figure 2.1: Hydrocarbon Degradation Rates in Soil, Fresh Water, and Marine Environment

Source: Nilanjana and Preethy (2010)

2.1.9 Remediation Technologies

Remediation is the process of cleaning up hydrocarbon from the environment and techniques used for reducing or eliminating pollutants from the soil, surface or groundwater. Environmental restoration involves removal of pollutants from the environment. In order to solve the problem associated with contamination of the environment, most technologies for remediation have been designed for treating soil, leachate, sewage and wastewater through a variety of contaminants, including insulation and pre-existing methods (Riser-Roberts, 1998). The computational technologies are numerous and can be categorized into pre-existing and internal methods. The route involves movement of the pollutants to a place for final treatment. In situ systems cure the pollutants at the same spot without the soil being removed.

Restoration technologies can be classified based on the processes which are physical, chemical and biological processes. They can be used together to reduce pollution to a level that is safe or acceptable (Reddy *et al.,* 1999, RAAG, 2000). Chemical restoration involves the use of chemicals to remove pollutants from contaminated media. The purpose of chemical methods is to degrade the accumulated pollutants in the soil or to modify their physicochemical properties in such a way as to reduce the ecological risks. Most methods of chemical remediation are available for utilization. Among the advantages of the chemical techniques are the wide range of applications, the efficiency and the specificity of application. Disadvantages include the production of waste in large quantity, including harmful waste, and process control problems, particularly in in-situ techniques situation. Physical restoration includes the elimination of danger by physical methods which are divided into: (a) ex situ techniques that require transport of contaminated soils to the cleaning site. This includes mechanical separation, extraction and storage. (b) in situ techniques that can be utilized on site without removing soil from the contaminated site. It includes electrokinetic cleaning strategies, cofferdam system, BAG removal. Physical restoration methods also include combustion, soil washing, soil vapor extraction, thermal desorption, stabilization, solidification, etc. The benefits of physical strategies are the ability to disposed or remove a wide spectrum of contaminants and various practical use (usually on a small local scale). The benefit is that they generate a significant amount of

waste that requires future management or disposal, and that they have a relatively high cost for large-scale applications.

Biological remediation is the latest method of soil restoration, which has gained wide acceptance. The methods depends on the biological activity of microorganisms and higher plants that have the capacity to degrade contaminants accumulated in the soil, including the mineralization, prevention and disposal. This technique is based on microbial enzymatic activity to transform or degrade environmental pollutants (Philip *et al.,* 2005). There are two types of biological remediation. These include:

1. Bioremediation that involves micro-organisms activity are usually utilized to remediate soils contaminated with organic compounds. However, recent studies have been conducted on the use of micro-organisms for the detoxification and purification of soils contaminated with inorganic substances (eg heavy metals).
2. Phytoremediation: It is bioremediation method that uses green plants for removal of pollutants from contaminated soils which is generally adopted for treating heavy metals. Moreover, it can be used for the removal of organic pollutants for example PAHs and hydrocarbons products that are toxic. The effectiveness of the strategy depends on contaminant level, pollutant bioavailability, plant used and nature of the soil (USEPA, 2012). The best way of making it work is when contaminants are in the root area of the soil. The most frequently utilized methods are phytoextraction, phytostabilization and phytotransformation.

i. Phytoextraction is a method by which plants extract contaminants from the soil by collecting them in the roots and sprout so that the plants can be harvested and burnt. It is mainly used to disinfect heavy metals in the soil.

ii. Phytostabilization: In this method, the mobility and bioavailability of contaminants in plants is reduced in the soil through the absorption of contaminants in their structure. The leachable components are connected to the structure of the installation so that they no longer enter the environment.

iii. Phytotransformation: This is where impurities are broken down by compounds produced or secreted by plants. It can be utilized to remedy contaminated soil with polar organic pollutants like atrazine and contaminated with nonpolar organic pollutants for example phenanthrene.

The benefits of biological remediation methods include a wide range of applications. This is not an expensive sanitation technique compared to other methods of remediation because the process is natural which does not generally produce byproducts that is toxic. In addition Perelo (2010) submitted that sustainable solution is provided resulting from the total mineralization of pollution in the environment. It is recognized widely by the general public as a safe way to treat polluted soils and does not require techniques that are sophisticated for its management. The bioremediation by-products are generally CO_2, water, and cellular biomass, which are not harmful and can be used for growth by plant. Despite the advantages, bioremediation has its disadvantages that involves the dependence of process efficacy on the bioavailability and content of pollutant removal. However Ghosh and Singh (2005), emphasized that this applies to the utilization of microorganisms because many plant species have been successfully used to purify these organisms. The strength of the method depends on the weather and climatic conditions (low temperatures and humidity reduce the effectiveness of methods).

Although most technologies are available for treating polluted environment, the selection is based on site species and characteristics, methodological requirements, and cost and constraints due to timing (Riser-Roberts, 1998; Reddy et al., 1999).) Because most pollution technologies are site specific, choosing the right technologies is often difficult, but it is a very important step in the successful remediation of a polluted site. Therefore, effective treatment of polluted sites depends on appropriate selection, design and restoration of biological functions based on soil properties and systemic performance (Faisal et al. 2004).

2.2 Literature Review

2.2.1 Studies on Oil Pollution and Remediation in the Niger Delta

Several workers have described the application of microorganisms in the bioremediation of oil pollution with encouraging results (Odu, 1978; Ijah, 1998, 2002, 2003; Okpokwasili, 1988; Barnhart, 1989; Pritchard, 1991). Akpe *et al*., (2015) worked on the efficiency of plantain peels and guinea corn shaft in the bioremediation of crude oil polluted soil. Their findings showed that the use of agro wastes such as plantain peels and guinea corn shaft improved hydrocarbon degradation in crude oil polluted soil.

Ibiene *et al*., (2011), worked on the effect of organic fertilizers on the bioremediation of hydrocarbon contaminated soil. They supplemented the hydrocarbon polluted soil with different organic fertilizers which include cow dung, poultry droppings and spent mushroom. Their findings showed that the organic fertilizers were effective nutrient sources for bioremediation.

Ebere *et al*., (2011), undertook remediation of hydrocarbon polluted soil using NPK, sawdust and poultry manure as remediation agents. They observed that a combination of amendments in the right proportion was effective in restoring crude oil polluted soil.

Tanee and Albert (2011) assessed the biostimulation potential of sawdust on soil parameters and cassava yield (Manihot esculenta) in oil-contaminated soil. They found that adding sawdust increased soil nutrition and cassava yield, which explains why sawdust can be used to biostimulate crude oil polluted soil for cultivation of cassava.

Ayotamuno *et al*., (2009), employed the use of biostimulation supplemented with phytoremediation to evaluate their effect on the reclamation of a petroleum contaminated soil. They simulated petroleum contaminated soil and added NPK fertilizer for biostimulation of indigenous microbes. Their findings revealed that there was a marked reduction in total hydrocarbon content after applying the different treatments. They also observed a similar reduction in total hydrocarbon content with the growth of the elephant grass. They were able to establish the fact that supplementing biostimulation with phytoremediation lead to attenuation in total hydrocarbon content.

Similarly Njoku *et al*., (2009), worked on phytoremediation of crude oil contaminated soil. They assessed the effect of the growth of Glycine max on the physico-chemistry and crude oil content of soil contamination with different concentrations of crude oil. Their findings showed that the growth of Glycine max reduced toxicity of crude oil in soil and restored polluted soils.

Ogbonna *et al*., (2013), worked on the use of biological agents on the biodegradation of polycyclic aromatic hydrocarbons. They were able to isolate bacteria and fungi from soil and waste water from four abattoirs for the treatment of polycyclic aromatic hydrocarbons (PAHs). The results showed that the pace of recovery for the impacted soil was slow and

the biological agents were not very effective in the recovery of impacted soil with high molecular weight components.

Ayolagha *et al*., (2013), evaluated the efficacy of organic and inorganic fertilizers as remediation materials in crude oil polluted inceptisols using maize as a test crop. Results of their investigation showed that plots treated with poultry manure had the best performance and was more efficacious than cow dung in restoring crude oil polluted soil.

Oku (2014), worked on bioremediation using attenuation processes with Hibiscus Cannabis and inorganic fertilizer (NPK 15:15:15). His findings revealed that although there was bioremediation efficiency with each of the processes, it was best with the combined trio of NPK 15:15:15, hibiscus cannabis and attenuation.

Udo and Fayemi (1975), studied not only bioremediation but also assessed impacted soils in respect of germination, growth and nutrient uptake of corn. Their findings revealed, among other things, that poor and stunted growth of corn were observed in areas where the total petroleum hydrocarbon (TPH) was above the 50 mg/kg limits for remediated soils set by the Department of Petroleum Resources (DPR). Good growth was observed in corn where the requisite soils have total petroleum hydrocarbon (TPH) below the approved limits for efficient agricultural productivity. Thus, nutrient uptake improves under such conditions.

Wegwu *et al*., (2010), employed the technique of land farming or natural attenuation process to monitor the recovery of crude oil impacted agricultural land. The study confirmed the efficacy of land farming or enhanced natural attenuation process in the remediation of impacted farm lands. Andrade *et al*., (2004), in a study on the impact of high quality oil on marsh lands off the coast of Galicia (Northern Spain) showed that oil contamination changes the physical and chemical characteristics of soil, and increased resistance to penetration and hydrophobicity. Production of oil affects the physical, chemical and soil properties of the soil, resulting in poor food production, reducing the availability of nutrients in the soil by increasing soil infertility and toxicity. Experiments with the practice of poultry manure on maize planted in oil-contaminated soils have shown that as the plant is contaminated, the growth is reduced (Ogboghodo, 2004).

It should be noted however that the process of bioremediation of oil spillage has attracted both global and local attention because of its impact on agriculture, tourism and other economic values of the landscape including the contamination of fisheries and sources of portable water. It is worthy of note that similar environmental degradation problems exist globally despite climatic and topographic challenges. The ecosystems are affected adversely due to changing soil chemistry resulting from natural and anthropogenic factors. This has led to the contamination of the soil ecosystem.

Different bioremediation techniques have been employed but no consensus has been reached regarding which technique is the best in the remediation of petroleum impacted soil locally or globally. No specific timeline has also been articulated by various studies on soil remediation process as well as which of these treatments work better under which condition in the impacted soil recovery processes.

2.2.2 Environmental Impact of Oil Spills in the Niger Delta

Ninety percent of oil is produced in the Niger Delta region where Obio/Akpor is located. It is estimated that the Federal Republic of Nigeria has earned over $ 300 billion from oil sales over the past 40 years (Awosika, 2008). Given the accumulation of this large capital, oil producing communities in its lands are expected to be more economically advanced.

Unfortunately, it is the opposite. Obi (2002) observed that, "despite the significant contribution of the Niger Delta oil minority to federal income, they have not been able to have direct access to revenue made from oil except for federal and ethnic charity." The region as a result until the 1990s, was one of the underdeveloped and poorest in the Nigerian field (Ikelegbe, 2005). World Bank (1995) reported that lumps from oil spillage are observed directly and oil films cover the water surface in oil producing areas. Spills of oil or leaks during processing can cause serious surface water, soil and groundwater contamination. Oil spills are very dangerous form of hydrocarbon pollution because it is very catastrophic and it has the most noticeable effects. Many“blow-outs”which occur at oil prospecting sites and spillage resulting from destruction of pipelines have been observed in various community where oil is produced in Nigeria (Bayode *et al*., 2011). Statistics show that between 1967 and 1980 most of the oil spills occurred in mangroves in remote areas of the local government area of Obio/Akpor. It is noted that within six

months, mangrove trees begins to die in polluted water. Crabs, molluscs and periwinkles die while fire is spread over 25 hectares of land. As the oil drains, the oil spreads across the ground and pollute the environment. The oil spill has destroyed much of the mangroves which are important trees for indigenous peoples. Oil spillage will likely lead to the relocation of some cities and land for agricultural purposes. Despite the environmental impact of crude oil spills, ingestion, skin contact and inhalation of spilled petroleum components are associated with some chronic and long-term health effects related to the consumption of plants and aquatic organisms contaminated, endemic state in the region.

Abii and Nwosu (2009), investigated the effects of the oil spill on Eleme soil in two communities (Ogale and Agbonnchia) in River States, Nigeria, while the control sites was Aleto. The results showed that oil spills had a negative impact on the nutrient content and soil fertility at Eleme. Idodo Umeh and Ogbeibu (2010) studied the values of total oil hydrocarbons (TPH) and heavy metals in cashews, bananas and tubers harvested from oil and non-oil contaminated areas, Delta State, Nigeria. The results showed that heavy metal values were higher in cassava, epicap and mescocaps tubers and from fruits harvested in oil-polluted soils compared to non-oil-polluted soils. Minai-Tehrani et al. (2007) observed the effect of various hydrocarbon concentrations on the germinantion and growth of Festuca aroundicea (tall fescue) and the results showed that the plant oil and seed yield decreased by increasing the fuel oil content in the soil. Leaf size was reduced at higher oil pollution compared to control.

Ojimba (2011), examined socio-economic factors related to poverty in crop varieties contaminanted by crude oil in Rivers State. Primary data was utilized in the study (questionnaires) and tobit censored regression found that extent of income diversification reduced poverty significantly by 9.8 times in crude oil polluted farm-households and 12.7 times in non-polluted farm-households. Other variables identified in reducing poverty in crude oil polluted farms include ownership of land through inheritance, years of farming experience, access to extension services and farm labour. The implication of crude oil on human health in the Niger Delta was investigated (Best and Seiyefa,2013). The findings revealed that oil spill polluted ground water, soil moisture, surrounding air and fruits. It is again bioaccumulative in some plants. Spill crude oil will affect fertility of soil negatively

(Osuji and Nwoye, 2007). Economic trees and food crops are also smothered, destroying or reducing yields (Edema *et al*., 2009), and could lead to reduction in food security to about 60% of the households (Ordinioha and Sawyer,2008), with the ability to reduce vegetables ascorbic acid content by about 36% (Nwaoguikpe,2011) while cassava crude protein content is reduced by 40% (Osam *et al*., 2011). These factors can lead to a 24% increase in children's malnutrition in affected communities (Ordinioha and Sawyer, 2008). Animal studies have shown that contact with oils in Nigeria can be haematoxic and hepatotoxic and cause infertility and cancer. Oil has created conditions that make nutrients, such as nitrogen, essential for cultivation unavailable but do not reduce toxic substances. Therefore, if soil is contaminated by oil, the results may be long-term based on this contamination.

CHAPTER THREE

METHODOLOGY

3.1 Introduction

The materials and methods of data collection and analysis for this study are as presented in the following subtopics, which comprise sources of data collected, types of data collected, experimental design, soil treatment, post treatment sampling, procedures for data collection, laboratory analysis of data collected and method of statistical analysis of data.

3.2 Sources of Data

The data required for this study were obtained from two main sources. The primary data include direct field work and laboratory analysis of soil samples from experimental plots and information acquired from field measurements, and through direct observations.

The secondary data were obtained from library search, review of related and relevant literature. They also comprised data on geological maps, soil and vegetation maps. Some of these were sourced from the Ministry of Agriculture, Rivers State, Rivers State University of Science and Technology, Port Harcourt, Geology, and Geography and Environmental Management Departments of the University of Port Harcourt and other relevant agencies.

3.3 Experimental Design

The study used experimental research design. The experimental plots were located on two topographic surfaces in Rumuagholu and Rumekini in Obio/Akpor Local Government Area of Rivers State, Nigeria. The experiment consisted of six treatment plots at each of the three levels of contamination with three replications. These gave a total of eighteen plots in randomized complete block design (Fig. 3.3). The size of each plot was 2 m by 2 m. Eighteen sampling plots were located in Rumuagholu representing well drained soils and eighteen sampling plots were located in Rumuekini behind University of Port

HarcourtTeaching Hospital (UPTH) representing the waterlogged (swamp) area. The experimental setup consisted of plots with three grades of pollution which include 2% (4.8 litres), 4% (9.6 litres) and 6% (14.4 litres) of Bonny light crude oil. 2.4 litres of Bonny light crude oil is equivalent to one percent pollution (Elf, 2000). The plots had a furrow round them to prevent spill over between the plots. The soil samples before contamination served as control.

3.4 Soil Treatment

The experimental plots were contaminated by pouring crude oil (Bonny-light) on them. The sample plots were graded into three levels of contamination with six replicates. Each sampling plot of 2 m by 2 m size was contaminated with different grades of fresh Bonny-light crude oil. The crude oil was measured into watering can and spread on each plot. The objective of applying crude oil on the sampling plots was to simulate conditions of oil spill. The plots were left undisturbed for seven days to allow for infiltration and percolation of the contaminant into the soil. The crude oil was obtained from the Nigerian National Petroleum Corporation (NNPC) Eleme, Rivers State. Cassava peels were obtained from the researcher's community in B.Dere in Gokana Local Government Area of Rivers State. The cassava peels were exposed to heat from sunlight and moisture and allowed to decompose for three weeks. Seven days after crude oil contamination of each plot, remediation materials were carefully introduced into each oil polluted plot. 28kg weight of decomposed cassava peels was introduced on each polluted plot of 2 m by 2 m to a depth of 10cm. The method involves treatment of contaminated plots by incorporating top soil with the decomposed cassava peels.

3.5 Post-Treatment Sampling

Soil samples were collected from both well drained and waterlogged sites in Rumuagholu and Rumekini respectively using soil auger. This instrument was used to collect soil samples at depth of 0-15cm (top soils) and 15-30cm (sub soils). The decomposed cassava peels was introduced into the soil and left for three months before soil sampling after remediation. Soil samples were collected and bulked together from each grade of 2%, 4% and 6% pollution plots. Eighteen sampled plots were augured and bulked together (composite samples) from top soils (0-15cm) and eighteen sample plots

were obtained and bulked together from the sub soil making a total of thirty six soil samples taken from each experimentation sites. In all seventy two soil samples were collected from both sites for analysis. The soil samples were put in polythene bags, labeled accordingly and immediately transferred to the laboratory for analysis. There was periodic monitoring of the sampling sites. Soil samples for analysis were collected before contamination, after contamination and after remediation. Soil samples collected before contamination served as control.

3.6 Methods of Soils Analysis

The parameters that were analyzed include soil physical and chemical properties. a The heavy metals analyzed are lead, Cadmium, Nickel, and Copper. Soil physicochemical parameters such as particle size distribution, bulk density and total porosity, soil pH, moisture content, total hydrocarbon content (THC), total petroleum hydrocarbon (TPH), total nitrogen (T.N.), organic carbon (O.C.) and available phosphorus were analysed before contamination, after contamination and after remediation. Microbiological analysis was carried out to determine Total Heterotrophic Bacteria (THB) and Hydrocarbon Utilizing Bacteria (HUB). Laboratory analysis of samples was done using standard laboratory techniques.

3.6.1 Determination of soil particle size

Particle size analysis was carried out using the hydrometer method (Bouyoucos, 1975).

3.6.2 Bulk Density and Total Porosity

Core samples for bulk density were dried in an oven at 105^0 until constant weight was reached (Obi, 2000). The percentage total pore space was computed from the bulk density, assuming a particle density of 2.65 g/cm^3. The weight of the oven-dry samples was later taken and recorded accordingly. The bulk density and total porosity of the samples were evaluated according to the equation.

$$\text{Bulk density} = \frac{Weight\ \ of\ \ oven\ dry\ sample\ (gm^3)}{Volume\ \ of\ \ Sample\ (m^3)}$$

$$\text{Total porosity} = \left(1\ -\ \frac{bulk\ \ density}{Particle\ \ density}\right) x\ 100$$

3.6.3 Soil pH

5g of the soil sample was weighed into a clean beaker. 2Omls of distilled water was added to it and the sample was stirred with electromagnetic stirrer for l0mins and allowed to stand for 30mins, the mixture was stirred again for 2mins, the pH meter electrode was rinsed with distilled water and dipped into the sample in the beaker and the figures on the pH meter screen was allowed to stabilize before reading was taking.

3.6.4 Moisture Content

1 gram of the sample was weighed into a clean dried porcelain evaporating dish. This was placed in an oven to maintain a temperature of 105 for six hours. The evaporating dish was cooled in desiccators to room temperature then it was re-weighed and recorded.

Calculation

% Moisture =

$$\frac{Weight\ of\ \ fresh - weight\ of\ dried\ \ sample}{Weight\ of\ \ sample\ \ used} x \frac{100}{1}$$

3.6.5 Determination of Carbon Content of Soil

Organic carbon was determined in accordance with titration method of Walkley and Black (1934). 0.1g of the dried sample was weighed into clean conical flask of 250ml capacity, 5ml of potassium dichromate ($K_2Cr_2O_7$) and 7.5ml concentrated sulphuric acid was added to the mixture and a separate 250mls conical flask containing nothing which serves as blank was also added 5ml of potassium dichromate ($K_2Cr_2O_7$) and 7.5ml concentrated sulphuric acid. The samples were heated on electro-thermal heater for 15mins after which they were allowed to cool to room temperature before diluting to 100mls with distilled water. 10mls diluted digest was measured into a separate 250mls conical flask and 2 drops of phenanthroline monohydrate was added as indicator, the sample were titrated with ferrous ammonium sulphate until color changes to leafy green titre value was recorded.

Calculation

$$\% \text{ organic carbon} = \frac{blank\ titre\ sample\ x\ 0.2\,x\,0.3}{Weight\ of\ sample\ used}$$

3.6.6 Determination of Total Nitrogen in Soil

Stage 1: Digestion

Total nitrogen was determined by the Kjeldahl digestion and distillation method (Black, 1965). Sample was weighed into a clean conical flask 250ml capacity, 3grams of digestion catalyst was added into the flask and 20mls concentrated sulphuric acid was also added and the sample was heated to digest. The content changed from black to sky- blue coloration. The digest was cooled to room temperature and was diluted to 100ml with distilled water.

Stage 2: Distillation

20mls diluted digest was measured into a distillation flask and the flask was held in place on the electro thermal heater or hot plate. The distillation flask was attached to liebig condenser connected to a receiver containing 10mls of 2% boric acid indicator. 40mls of 40% sodium hydroxide was injected into the digest via a syringe attached to the mono-arm steelhead until the digest became strongly alkaline. The mixture was heated to boiling and the distilled ammonia gas through the condenser attached to the receiver beaker. The color of the boric acid changes from purple to greenish as ammonia distillate was introduced into the boric acid.

Stage 3: Titration

The distillate was titrated with standard 0.1N Hydrochloric acid solution back to purple from greenish. The volume of hydrochloric acid added to effect this change was recorded as titre value.

Calculation

$$\% \text{ organic nitrogen} = \frac{titre\ value\ x\ 1.4\ x\ 100\ x100}{1000\ x\ 20\ x\ 1}$$

Where titre value = the volume of HCl used in titrating the ammonium distillate.

1.4 = Nitrogen equivalent to the normality of HCl used in the titration 0.1N.

100 = the total volume of digest dilution

100 = percentage factor

1000 = conversion factor from gram to milligram.

20 = integral volume of digits analyzed or distilled.

1 = the weight of sample in gram digested.

3.6.7 Available Phosphorus

Available phosphorus was determined by the method of Bray and Kurtze (1945). 1g soil sample was extracted with 50ml 2.5% Acetic Acid. The extract was filtered into 250ml capacity conical flask and 0. 8ml of combined reagent was added in the flask. A blank and standard phosphate ion concentration ranging from 0.0001-0.0007 was prepared and 0.8ml combined reagent was added respectively.

Conc. Mg/kg	Stoke volume ml	Total volume ml	Absorbance
0.0001	0.01	5	0.005
0.0002	0.02	5	0.013
0.0003	0.03	5	0.039
0.0004	0.04	5	0.044
0.0005	0.05	5	0.063
0.0006	0.06	5	0.07
0.0007	0.07	5	-

The bluish color developed within 30mins interval was read at 840nm wavelength in thermospectronic spectrophotometer.

The sample extracted volume developed was also read at the same wavelength. The concentration of the phosphate ion in the sample was extrapolated from the standard phosphate graph plotted with the value in the table displayed. A plot of concentration absorbance gave a straight line graph that has a gradient of 10x.

3.6.8 BETEX/TPH/PAH IN SOLID SAMPLES

Extraction:-

2gm of samples were weighed into a clean extraction container.

10ml of extraction solvent (pentane) was added into the samples and mixed thoroughly and allowed to settle.

Solvent rinsed extraction bottle, using filter paper fitted into buchner funnels

The extracts were concentrated to 2ml and then transferred for clean up/separation

Clean up/separation

1cm of moderately packed glass wool was placed at the bottom of 10mm ID x 250mm loup chromatographic column.

8lury of 2g activated silica in 10ml methylene chloride was prepared and placed into the chromatographic column. To the top of the column was added 0.5cm of sodium sulphate. The column was rinsed with additional 10ml of methylene chloride.

The column was pre eluted with 20ml of pentane, this was allowed to flow through the column at a rate of about 2 minutes until the liquid in the column was just above the sulphate layer.

Immediately 1ml of the extracted sample was transferred into the column. The extraction bottle was rinsed with 1ml of pentane and added to the column as well.

The stop-clock of the column was opened and the eluant was collected with a 10ml graduated cylinder. Just prior to exposure of the sodium sulphate layer to air, pentane was added to the column in 1-2ml increments. Accurately measured volume of 8-10ml of the eluant was collected and was labelled aliphatics

3.6.9 Heavy Metals (Extractable Micro-nutrients)

Soil digest 1 gram of soil was digested with mineral acid (Nirtric acid and perchloric acid) in the ratio of 3:1. Digest was dilated to 50ml with distil water. The digest was filtered with what map filter paper 54). The digest was analysed with Atomic Absorption spectrophotometer (AAS) and the results was obtained in ppm. To obtain result in mg/kg, multiply by 50.

3.7.0 Gas Chromatographic Analysis

The concentrated aliphatic fraction were transferred into labelled glass vials with teflon rubber crimp caps for GC analysis.

1ml of the concentrated sample was injected by means of hypodermic syringe through a rubber septum into the column. Separation occur as the vapour constituent partition between the gas and liquid phases. The sample was automatically detected as it emerges from the column (at a constant flow rate) by the FID detector whose response is dependent upon the composition of the vapour.

3.7.1 Enumeration of Total Heterotrophic Bacteria

Medium used = Nutrient Agar

Diluent = physiological saline

Technique or Procedure used = Spread Plate Technique

The medium was prepared as directed by the manufacturers and all the materials used were sterilised using an autoclave. This includes pipettes, petri dishes and physiological saline.

After performing a ten-fold serial dilution, 0.1ml of the desired diluent was transferred to the sterile dry agar plate and spread with a sterile hockey stick (bent glass rod). The inoculation was performed in duplicate plates of any of the desired diluents. These plates were incubated at 37^0C for 24 hours. After the incubation period, the plates were counted and average counts were calculated. Plate counts of less than twenty five and more than 300 colonies were not counted and recorded as too few to count or too numerous to count respectively. From the average counts colony forming units per ml or gram of the (cfu/ml or cfu/g) was calculated.

3.7.2 Enumeration of Hydrocarbon Utilizers

The medium used is mineral salt medium as composed by (Atlas R.,. 1999). This medium in devoid of carbon source which is provided by vapour phase transfer using filter paper deeped in crude oil and placed in the cover of the plates under aseptic condition

The plates can be inoculated by spread plates as described under the total heterotrophic bacteria enumeration. The incubation is within 35^0C and 37^0C for a period of days.

After incubation, the plates are counted as described for THBC.

3.8.0 Method of data analysis

Different statistical tools were employed for data analysis and presentation such as descriptive and inferential statistics. The descriptive statistics used to express the results for the study include range, mean and percentages. The inferential statistics used to test the hypotheses was the independent student's t- test.

3.9.0 Study Area

3.9.1 Location and Extent

The study area for this research is Obio/Akpor Local Government Area. Obio/Akpor Local Government Area is one of the Local Government Areas that make Port Harcourt metropolis and is one of the 23 local government areas in Rivers State. It lies within the Eastern Niger Delta region of Nigeria. It is located approximately between latitudes 4^0 $45^{'}$ and 4^0 $56^{'}$ N and longitudes 6^0 $52^{'}$ and 7^0 6' E. The 1975 Master plan of Port Harcourt City which covered both Port Harcourt Local Government Area and Obio/Akpor shows that Obio/Akpor Local Government has a total of 260km^2 landmass out of which about (17.3km^2) of it is wetland (Visigah, 2017). Obio-Akpor is bounded by Ikwere Local Government Area to the north, as shown in Figure 1. To the south is Port Harcourt Local Government Area, Oyigbo Local Government Area is to the east while Emohua Local Government Area is to the west. Port Harcourt metropolis consist of Obio/Akpor, Port Harcourt and Eleme Local Government Areas which are located on low topography and are 6,000 feet from the Atlantic Ocean (Oyegun and Adeyemo, 1999). It is one of the largest economic centers in Nigeria and an important community in the Niger Delta. It is also the richest municipal government in Rivers State. The local government covered an area of 260 km^2 and the 2006 census revealed that 464,789 people live in the community (NPC, 2006). As a result of rapid urbanization and the increase in industrial and commercial activity in Port Harcourt, there has been a rise in oil prices, thus leading to an

increase in activities of the oil industry. The Obio/Akpor was carved out from the Port Harcourt local government area on 3 May 1989 by President I. B. Babangida who was the President of Nigeria as at the time. Its constituent is Ikwerres while Rumuodomaya is the headquarter of the local government (Mamman et al., 2000).

3.9.2 Climate

Obio/Akpor Local Government Area lies within the tropical climatic belt and so has a humid tropical climate. The occurrence and distribution of rainfall depend on two air masses that prevail over the area like other parts of the country. Their effects are closely related to the ITCZ movement, north and south of the equator. The two air masses are the tropical continental (Tc) and tropical maritime (Tm). Tropical maritime (Tm) air is associated with the extreme southwest moisture winds that blow from the Atlantic Ocean and cause rainfall in Rivers State. It passes through Port Harcourt from March to November. This period is when the area has rainy season. The dry season begins in November and lasts until February, a three-month period when there is little or no rain. This phenomenon is attributed to the tropical continental air, which is characterized by a tropical cyclone and a dusty continental airmass extending south through the Sahara. When ITCZ, which is the meeting point of the two bodies of air, passes south of the equator, the northeast wind dominates the research area and creates a dry climate, while when ITCZ shifts to the northern hemisphere, it produces moisture-laden wind which dominates the region to allow rainfall during the rainy season. Heavy rains decrease from over 4000 mm in the Bonny and Brass basins to 1700 mm in the northern part of the state in Degema. However, rain is enough for planting all year round. The average number of rainy days is 330 days for many parts of Rivers state and 182 for the study area with average rainfall of 250 mm (Mamman *et al.* 2000).

Generally, temperatures in the area are high and relatively uniform all year round. The maximum monthly and minimum temperatures range from 28 ° C to 33 ° C and 17 ° C to 24 ° C, respectively, increasing to the north and west. Temperatures range between 25 ° C and 28 ° C per month. The annual temperature record is 26 ^{0} C with a slight change of 2 ° C (Mamman *et al.,* 2000). The humidity is high because each year the region experiences lot of rain, with a reduction in dry season (Salau, 1993). The location of the

city is such that it receives abundant sunshine. Cloud protection reduces the amount of sunlight reaching the surface. The highest daily average temperature of the year occur in February and April, with precipitation reaching the highest levels in July and September (Oyegun and Adeyemo, 1999).

3.9.3 Vegetation

Obio/Akpor local government area has different vegetation types. The major types of vegetation include mangrove swamp forest, fresh water forest and lowland rain forest. The mangrove swamp forest is located within the belt of salt water swamps, underlain by clay and mud and impregnated with brackish water on which mangrove trees grow. Typical mangrove forests in the study area consist mostly of the red mangrove (Rhizophora mangle) with its characteristics stilt or prop roots. The Delta mangrove swamp spans about 1900 sq km as the largest mangrove swamp in Africa (Awosika, 1995). The fresh water swamp area is beyond the tidal reach. This area is large and contains the major source of timber, forest products and biodiversity. In this area fresh water plants replace mangrove plants, the most common species are the raffia palms and the bamboo. This fresh water swamp area is susceptible to yearly inundation by river floods. The lowland rainforest occupies the non-riverine or upland areas where the ground is better drained than the proceeding zones. As a result of favourable combination of high temperature and heavy rainfall, plants in this area grow very tall. The vegetation that is dominant are palm bush and mosaic crop while large areas are usually left to fallow. The lowland rainforest zone is evergreen and luxuriant throughout the year. However, it is under pressure due to marginal farming of short season crops and wood exploitation.

3.9.4 Soil

Obio/Akpor Local Government Area like the Port Harcourt City Local Government Area consists of deltaic plain soils which are found in wetland and upland areas and is rich in iron but has a low mineral reserve and low fertility (Ofomata, 1975) as cited in Mmom, Ezekwe & Chukwu-Okeah (2017). This condition can be attributed to the latitudinal location of the area and the heavy rainfall in the area which cause soil leaching. The soil of the area according to Oyegun (1999) cited in Visigah (2017), has undergone chemical

weathering due to abundant vegetation which results in the formation of clay minerals and silt particle from the parent materials of the environment.

3.9.5 Relief and Drainage

The Obio/Akpor local government area which is part of Port Harcourt lies within the Niger Delta relief system, which is one of Nigeria's seven relief systems. On the surface, the geographical area of the study is part the of Niger Delta which has coastal plains. The area is 15.24 meters above sea level (Oyegun and Adeyemo, 1999). Generally, Rivers State has a gentle slope to the Northwest (NW) and Southeast (SE). The northern parts have some soft plains, while the southern parts have sand bars, mud, bays and swamp drainage basins. (Oyegun and Adeyemo, 1999). The flood plain of the Niger Delta is susceptible to annual flooding due to heavy rainfall. There are many channels of water in the fresh water zone which have their boarders as natural levees. These are of great topographic and economic importance to the people of the locality. The area is low-lying with seasonal flooding which is a drainage feature of the region. The area drains to the coast southwards. Large quantities of water are discharged through tidal inlets and the rivers have many bends and curves along their courses. Rivers found in the study area have values of 1.5 km and a ratio of 1: 9, indicating that winding channels are turbulent. There is a decrease in the system downstream. There is increase in speed and size in the fresh water area, particularly noticeable in the flood waters of the new Calabar River. The valleys and banks of the rivers are very much eroded (Mamman *et al.,* 2000). Majority of the rivers in the area of study empty into the Atlantic Ocean.

3.9.6 Geology

Rivers State, where Obio/Akpor local government area is found is a coastal plain. There are fluvial and marine sediments on its surface which make up its geology. The fluvial deposits are gradually transported through the River Niger and other rivers such as the New Calabar River, the Bonny River and the Andoni River. The deposits are accumulated regoliths or overburden soil of variable thickness (0 metre- 30 metres thick) and are made up of gravels, sand, silts, peat, and clays. The highest rock type in Rivers State is sandy, while in the state's riparian areas, mud is found in some areas where there are brackish water. In shallow pits and bugs, animals and vegetal remains that are elements of peat can

be found. Pebbles and gravels are found at the bottom of the channel (Oyegun and Adeyemo, 1999).

3.9.7 Socio-Economic Activities

Obio/Akpor Local Government Area is an industrial area. Many international companies and other industries, mainly companies related to the oil industry have offices in the area because it is a major oil refinery location in Nigeria. Rivers State is one of Nigeria's richest states in terms of gross domestic product and foreign exchange earnings from the oil industry. Crude oil is the largest exporting product. Port Harcourt is the heart of the Nigerian oil industry where, until recently, almost all major international oil companies were represented. Obio / Akpor's economic activities include the manufacturing of food products namely processing of food, car assembly, paper products manufacturing, paints, refinery and petroleum product manufacturing, metallurgy and manufacturing. There are also extractive industries such as oil extraction of crude oil, liquefaction of gas and oil. Agro based and agricultural processing industries exist in the city too. Items such as cars, electronics, textiles and processed food are imported. Rice, grain, meat, and other agricultural products are sometimes imported. Many small businesses, such as retail, crafts, and transportation, thrive in the city. Most government agencies, such as the Nigeria Port Authority, NNPC and Customs, operate on a wide range of state and local economic systems.

Obio-Akpor Local Government Area has one of the highest crime rate in Nigeria. The worst case so far has been crimes committed in the name of freedom fighters in the Niger Delta region. There are also political thieves, insurgents and combatants in the region. Congestion is another social problem. The city of Obio/Akpor will be a peaceful city with great social life. There is a lot of fun and relaxation centre. Downtown-Akpor has 5 star hotels, such as Meridian Hotel, Golden Tulip and Presidential Hotel. The newly opened recreation area has cinema, night clubs, bars and restaurants.

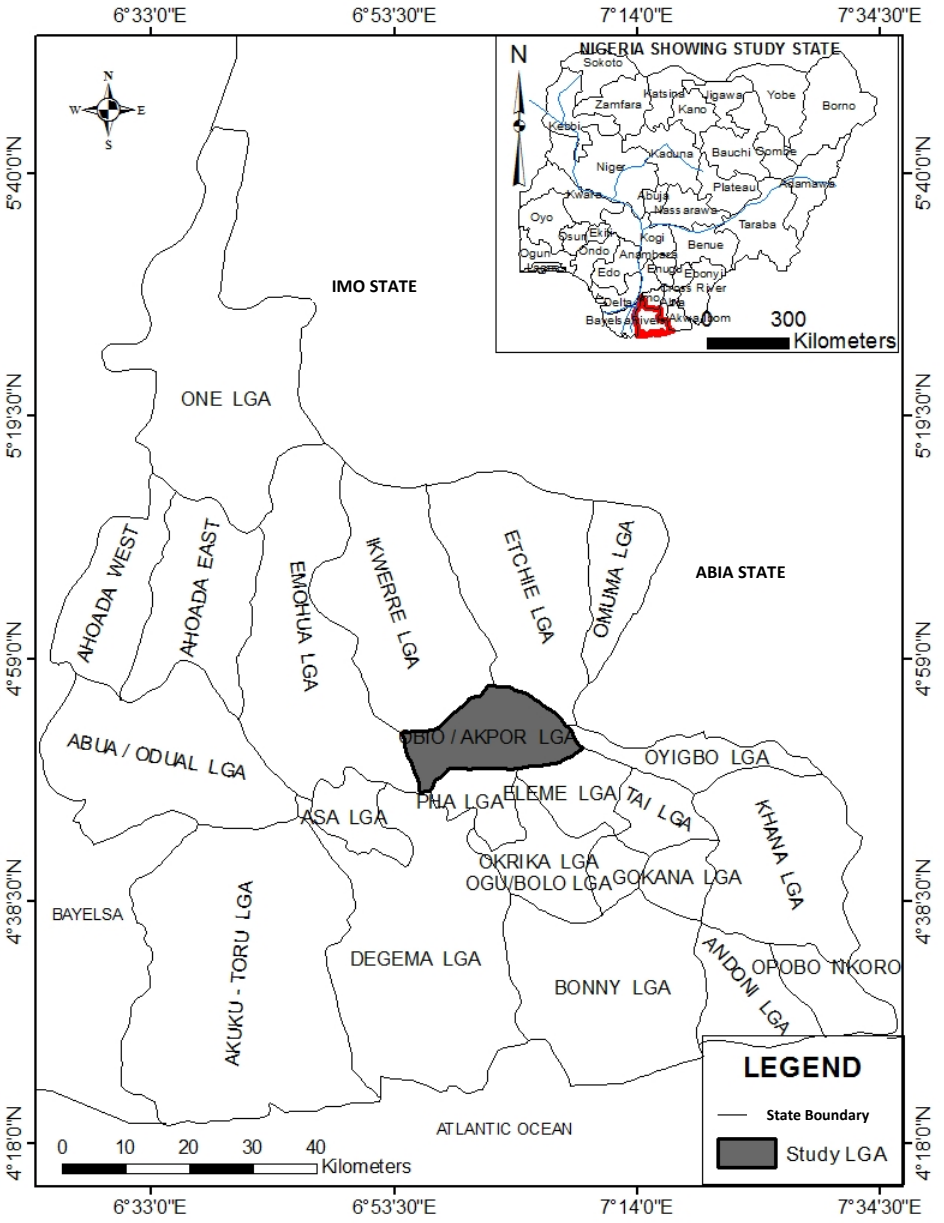


Figure 3.1: Rivers State Showing Obio/Akpor Local Government Area
Source: Department of Geography, Laboratory for Cartography and GIS, University of Port Harcourt, (2017).

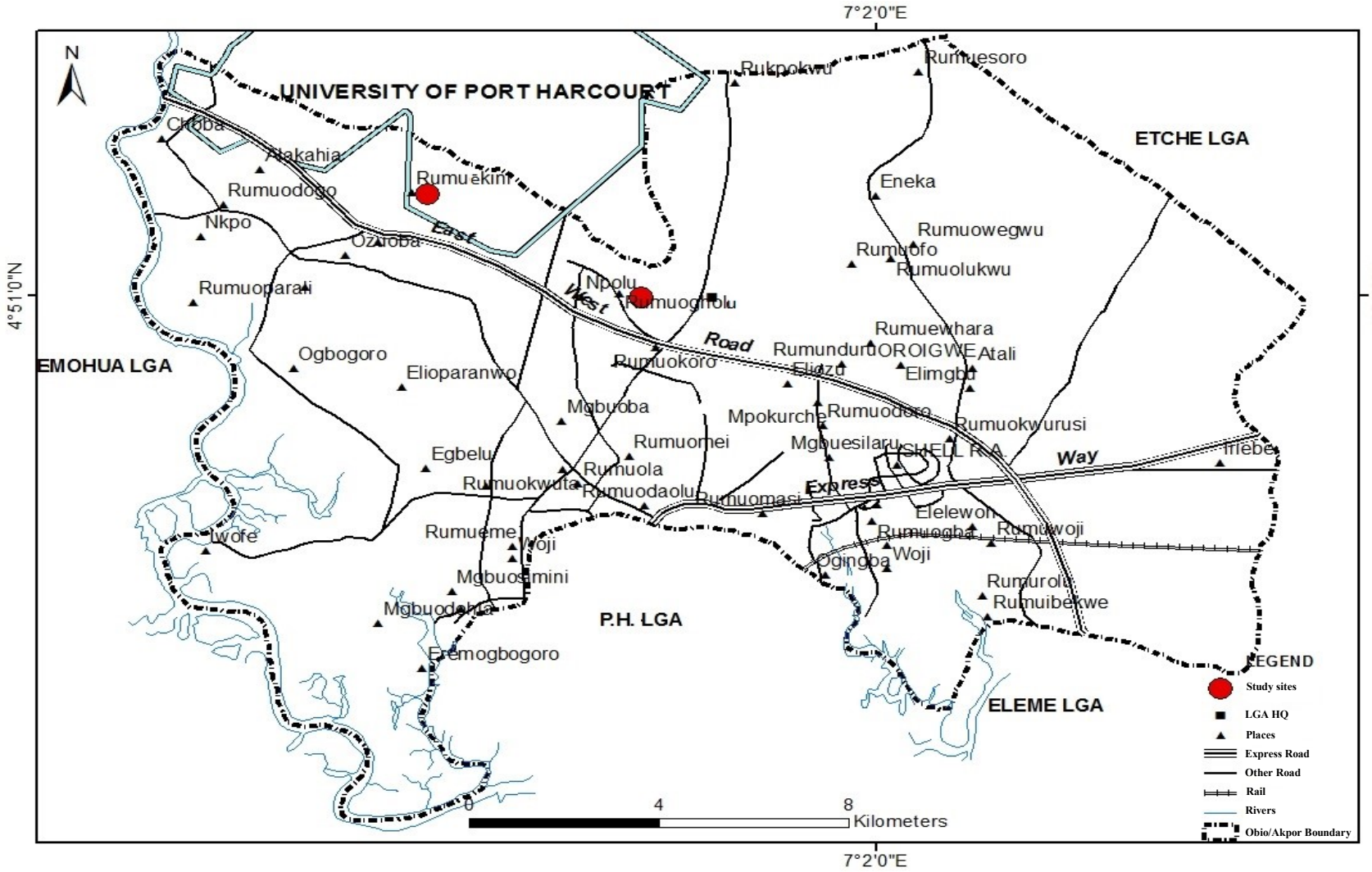
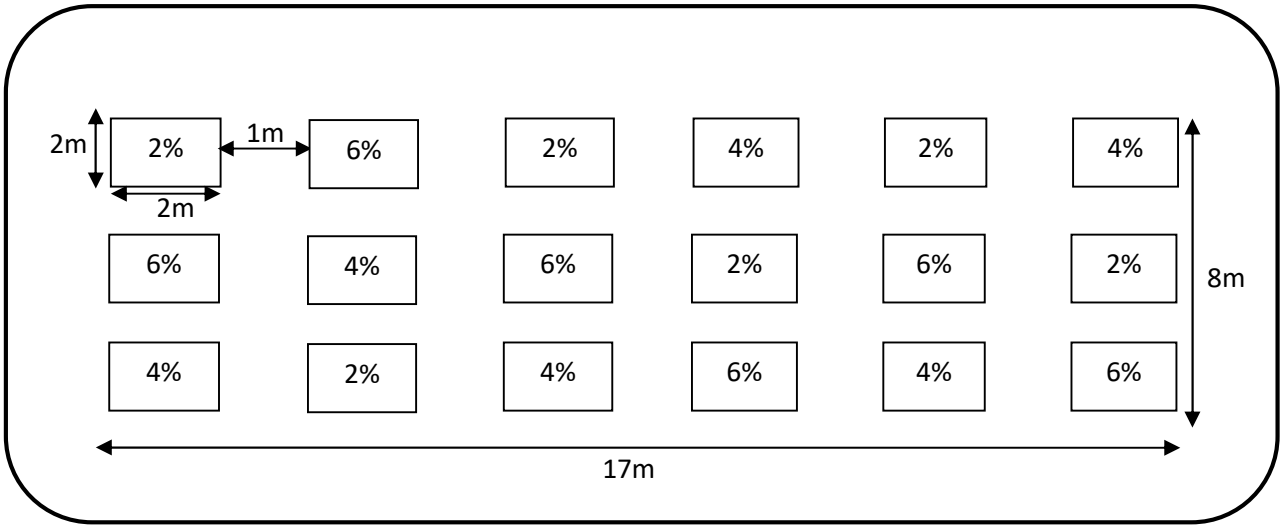
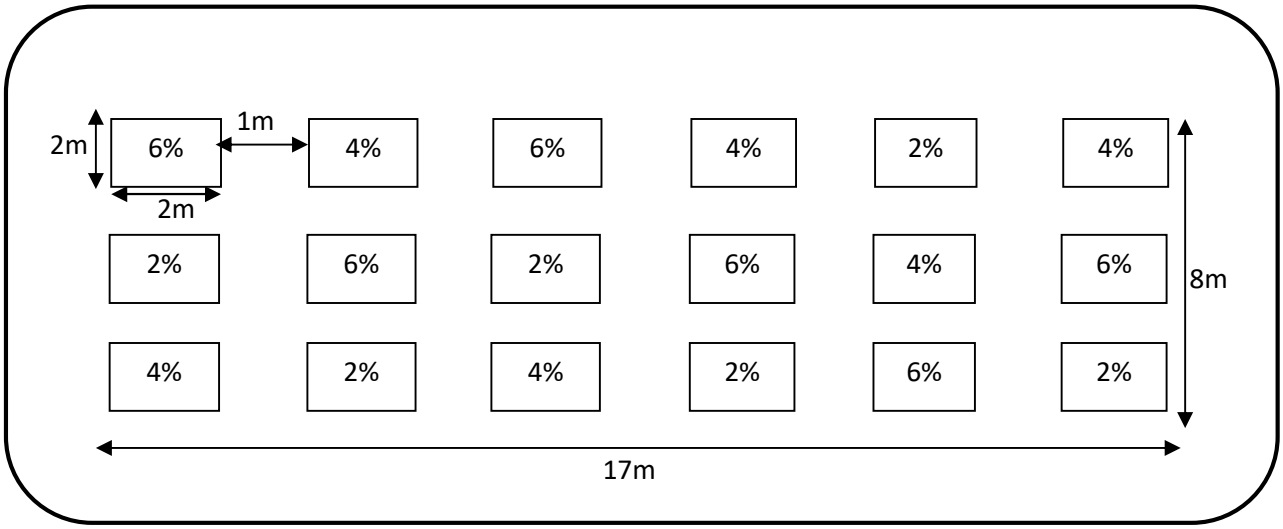


Fig. 3.2: Obio/Akpor Local Government Area Showing Study Sites
Source: Department of Geography, Laboratory for Cartography and GIS, University of Port Harcourt (2017).



Different levels (2% = 4.8 litres) of crude oil contamination in well drained site, Rumuagholu



Different levels (2% = 4.8 litres) of crude oil contamination in waterlogged site, Rumuekini

Fig. 3.3: Schematic Diagram of Experimental layout

CHAPTER FOUR

COMPARISON OF HYDROCARBON POLLUTED SOILS BEFORE AND AFTER REMEDIATION

4.1 Introduction

This chapter is concerned with the presentation of data, analysis and discussion of results collected from the field. The initial conditions of the soil before crude oil contamination will be described. This will be followed by analysis of the effects of crude oil contamination on the soil and thereafter the effects of remediation on the soils of the study area would be discussed. In order to facilitate discussion of data, contaminated and remediated soils were compared under topical sub-headings which include: (i) physical properties of soil (ii) chemical properties of soil, (iii) analysis of total hydrocarbon content (iv) microbial characteristics and,(v) heavy metal concentration in soils. This chapter also presents discussions on seasonal variations in the rate of bioremediation and compares the rate of remediation in well drained and waterlogged soils. The student's t- test was used to test the hypotheses.

4.2 Background condition of the soil before and after contamination

4.2.1 Soil particle size distribution before and after contamination

Table 4.1 shows that sand is the predominant soil fraction in the sampled area. Sand fraction in the well drained site before contamination had mean values of 81.2%, and 81% in surface soils and 80% and 79.8% in subsurface soils in the 2%, 4% and 6% polluted plots while the mean values after contamination were 82%, 82.5% and 82.3% in surface soils and 80.3%, 80.5% and 80.7% in subsurface soils. In the waterlogged site the mean values of sand fraction before conta mination were 59.8% and 60% in surface soils and `58.5% and 58.2% in subsurface so ils in 2%, 4% and 6% polluted plots while the mean

values after contamination were 61%, 61.5% and 60.8% in surface soils and 59%, 58.8% and 59.2% in subsurface soils.

Crude oil contamination did not have significant influence on sand particles as indicated in Tables 4.1 and 4.2. However, the depth of soil sampling influenced sand particles at 15-30cm depth. Sand particles were higher at 0-15cm than at 15-30cm in the 2%, 4% and 6% polluted plots. Sand particles were higher at 0-15cm by 2.07% in the 2% polluted plots, by 2.42% in the 4% polluted plots and by 1.94% in the 6% polluted plots. It was observed from the analysis that sand proportion remained the same for both contaminated and uncontaminated soils indicating that crude oil contamination did not alter sand percentage. The finding is in agreement with Marinescu *et al*., (2011) who reported no significant result in crude oil pollution on granulometric fraction of the soil.

The mean values of silt content in the well drained site before contamination were 14.2% and 14.3% in surface soils and 14.5% and 14.7% in subsurface soils in the 2%, 4% and 6% polluted plots while the mean percentages of silt after contamination were 14%, 13.8% and 13.7% in surface soils and 14.7%, and 14.3% in subsurface soils. In the water logged site the mean percentage of silt content before contamination were 31.2% and 31.3% in surface soils and 32.2%, 32% and 32.3% in subsurface soils in the 2%, 4% and 6% polluted plots while after contamination the mean percentages were 32%, 31.5% and 31.7% in surface soils and 32.7%, 32.5% and 32.2% in subsurface soils. The analysis of the results showed that the proportion of silt in both surface and subsurface layers of the soil is almost the same. However, the silt content is higher in the water logged site than in the well drained site as indicated in Tables 4.1 and 4.2. The presence of crude oil in the soil did not significantly affect silt content of the soil at both 0-15cm and 15-30cm soil depth as shown in Tables 4.1 and 4 .2. A similar result was obtained by Marinescu *et al*., (2011) who observed that granulometric fraction of the soil was not significantly influenced by the presence of crude oil in a crude oil polluted area.

Table 4.1. Percentage of Sand, Silt and Clay content in Top Soil (0-15cm)

Pollution level		Well drained site, Rumuogholu						Waterlogged site, Rumuekini					
		Before Contamination			After contamination			Before Contamination			After contamination		
		Sand(%)	Silt (%)	Clay(%)	Sand(%)	Silt (%)	Clay(%)	Sand(%)	Silt (%)	Clay(%)	Sand(%)	Silt (%)	Clay(%)
Treatment replicate	2% 1	81	15	4	81	15	4	59	32	9	61	32	7
	2	80	15	5	83	14	3	60	31	9	62	34	4
	3	82	14	4	82	14	4	62	31	7	61	32	7
	4	83	13	4	83	14	3	58	32	10	61	30	9
	5	80	14	6	81	13	6	61	30	9	60	33	7
	6	81	14	5	82	14	4	59	31	10	61	31	8
	Range	80-83	13-15	4-6	81-83	13-15	3-6	58-62	30-32	7-10	60-62	30-34	4-9
	Mean	81.2	14.2	4.7	82	14	4	59.8	31.2	9	61	32	7
	S.D	1.07	0.69	0.75	0.82	0.58	1.00	1.35	0.69	1.00	0.58	1.29	1.53
Treatment replicate	4% 1	80	15	5	84	13	3	59	32	9	62	31	7
	2	80	16	4	83	14	3	59	34	7	61	30	9
	3	83	13	4	81	14	5	61	30	9	61	33	6
	4	81	15	4	82	13	5	60	30	10	62	32	6
	5	80	14	6	83	14	3	59	32	9	61	32	7
	6	82	13	5	82	15	3	62	30	8	62	31	7
	Range	80-83	13.16	4-6	81-84	13-15	3-5	59-62	30-34	7-10	61-62	30-33	6-9
	Mean	81	14.3	4.7	82.5	13.8	3.7	60	31.3	8.7	61.5	31.5	7
	S.D	1.15	1.10	0.75	0.96	0.69	0.94	1.15	1.49	0.94	0.5	0.96	1.00
Treatment replicate	6% 1	83	11	6	82	14	4	61	32	7	62	33	5
	2	82	14	4	82	13	5	61	31	8	61	30	9
	3	80	15	5	83	13	4	58	32	10	60	32	8
	4	80	16	4	82	14	4	60	31	9	60	32	8
	5	81	14	5	82	14	4	60	30	10	61	32	7
	6	81	15	4	83	14	3	59	32	9	61	31	8
	Range	80-83	11-16	4-6	82-83	13-14	3-5	58-61	30-32	7-10	60-62	30-33	5-9
	Mean	81.2	14.2	4.7	82.3	13.7	4	59.8	31.3	8.8	60.8	31.7	7.5
	S.D	1.07	0.98	0.75	0.47	0.47	0.58	1.07	0.75	1.07	0.69	0.94	1.26

Source: Author's analysis, 2015

Table 4.2. Percentage of Sand, Silt and Clay content in Sub Soil (15-30cm)

Pollution level		Well drained site Rumuogholu						Waterlogged site Rumuekini					
		Before Contamination			After contamination			Before Contamination			After contamination		
		Sand(%)	Silt (%)	Clay(%)	Sand(%)	Silt (%)	Clay(%)	Sand(%)	Silt (%)	Clay(%)	Sand(%)	Silt (%)	Clay(%)
Treatment replicate	2% 1	81	14	5	82	13	5	60	30	10	58	30	12
	2	81	13	6	80	14	6	56	34	10	60	32	8
	3	79	16	5	81	15	4	60	31	9	57	33	10
	4	80	15	5	79	15	6	58	33	9	60	35	5
	5	79	15	6	80	14	6	58	34	8	61	32	7
	6	80	14	6	80	14	6	59	31	10	58	34	8
	Range	79-81	13-16	5-6	79-82	13-15	4-6	56-60	30-34	8-10	57-61	30-35	5-12
	Mean	80	14.5	5.5	80.3	14.2	5.5	58.5	32.2	9.3	59	32.7	8.3
	S.D	0.82	0.96	0.5	0.94	0.69	0.76	1.38	1.57	0.75	1.41	1.60	2.21
Treatment replicate	4% 1	80	14	6	82	14	4	58	33	9	60	32	8
	2	79	16	5	81	15	4	58	31	11	58	34	8
	3	81	13	6	81	14	5	59	32	9	60	32	8
	4	80	15	5	80	14	6	60	30	10	57	34	9
	5	80	14	6	79	15	6	59	32	9	60	30	10
	6	79	15	6	80	14	6	57	34	9	58	33	9
	Range	79-81	13-16	5-6	80-82	14-15	4-6	57-60	30-34	9-11	57-60	30-34	8-10
	Mean	79.8	14.5	5.7	80.5	14.3	5.2	58.5	32	9.5	58.8	32.5	8.7
	S.D	0.69	0.96	0.47	0.96	0.47	0.90	0.96	1.35	0.76	1.21	1.38	0.75
Treatment replicate	6% 1	79	15	6	81	14	5	60	30	10	60	30	10
	2	80	15	5	82	13	5	57	34	9	58	33	9
	3	80	14	6	80	15	5	55	34	11	58	32	10
	4	81	13	6	81	14	5	58	32	10	60	33	7
	5	79	16	5	80	15	5	60	31	9	59	33	8
	6	80	15	5	80	14	6	59	33	8	60	32	8
	Range	79-81	13-16	5-6	80-82	13-15	5-6	55-60	30-34	8-11	58-60	30-33	7-10
	Mean	79.8	14.7	5.5	80.7	14.2	5.2	58.2	32.3	9.5	59.2	32.2	8.7
	S.D	0.69	0.94	0.5	0.75	0.69	0.37	1.27	1.49	0.96	0.90	1.07	1.11

Source: Author's Analysis, 2015

Clay content in the well drained site before contamination had mean values of 4.7% in surface soils and 9.3% and 9.5% in subsurface soils while the mean values after contamination were 4% and 3.7% in surface soils and 5.5% and 5.2% in subsurface soils. In the waterlogged site the mean values of clay content before contamination were 9%, 8.7% and 8.8% in surface soils and 9.3% and 9.5% in subsurface soils in the 2%, 4% and 6% polluted plots while the mean values after contamination were 7% and 7.5% in surface soils and 8.3% and 8.7% in subsurface soils. The clay content in surface and subsurface soils in the study area is small as shown in Tables 4.1 and 4.2. However, the clay content is relatively higher in the waterlogged site than in the well drained site. The fineness of the soil in the waterlogged site reduces the rate of percolation of liquid and gaseous substances within the soil leading to waterlogging. Crude oil contamination did not significantly influence clay size particles as shown in Tables 4.1 and 4.2. However, depth of soil sampling influenced clay particles. Clay particles were lower at 0-15cm than 15-30cm depth by 27.27% in the well drained site and 15.66% in the waterlogged site in the 2% polluted plots. This may be due to the movement of clay particles from 0-15cm which are later deposited at 15-30cm soil depth. Akpoveta *et al.,* (2011) observed that there was no effect on soil texture after petroleum hydrocarbon contamination. The results of the analysis revealed that the soils are not texturally similar in both experimentation sites. While the soil texture is sandy loam in the well drained site, it is sandy clay in the waterlogged site.

4.2.2 Bulk density and total porosity before and after contamination

4.2.2.1 Bulk density

Bulk density is one of the physical properties of the soil which is greatly modified by the presence of plants. Soil bulk density tends to increase during cropping due to the impact of rain drops that breaks down soil aggregates. The finer soil fragments are washed down to seal soil pores and therefore make the soil more compact. The mean bulk density values in the well drained site before contamination were 1.23 g/cm^3 and 1.22 g/cm^3 in surface soils and 1.30 g/cm^3 and 1.31 g/cm^3 in subsurface soils while the mean values after contamination were 1.25 g/cm^3 and 1.26 g/cm^3 in surface soils and 1.40 g/cm^3 and 1.41 g/cm^3 in subsurface soils. The mean bulk density values before contamination were 1.19 g/cm^3 and 1.20 g/cm^3 in surface soils and 1.25 g/cm^3 and 1.26 g/cm^3 in subsurface soils

while the mean values after contamination were 1.20 g/cm^3, 1.34 g/cm^3 and 1.32 g/cm^3 in subsurface soils in the 2%, 4% and 6% polluted plots.

It was observed from the data in Tables 4.3 and 4.4 that mean bulk density values for the subsurface soils were higher than the surface soils. The implication is an increase in bulk density with soil depth due to reduction in subsurface layers resulting in lower organic matter, aggregation and root penetration when compare to surface layers. Subsurface layers are also subject to the compacting weight of the soil above them. The data obtained in Tables 4.3 and 4.4 showed that crude oil contamination has effect on bulk density as the bulk density values of soil samples slightly increased after contamination from 1.23g/cm^3 to 1.25g/cm^3 and 1.22g/cm^3 to 1.26g/cm^3 in surface soils in the well drained site (Tables 4.3). It was observed that bulk density of the subsurface soils increased by 12.14% and 13.48% in the well drained site and 10.53% and 4.29% in the waterlogged site.

4.2.2.2 Total Porosity

The mean total porosity values in the well drained site before contamination were 53.7% and 53.8% in surface soils and 51%, and 50.7% in subsurface soils while the mean values after contamination were 52.7% and 52.5% in surface soils and 47.2%, 46.8% and 47% in subsurface soils in the 2%, 4% and 6% polluted plots. In the waterlogged site total porosity mean values before contamination were 55.2% and 54.5% in surface soils and 53.2%, 52.7% and 52.3% in subsurface soils while the mean values after contamination were 54.7%, 54% and 53.7% in surface soils and 50%, 49.7% and 50.3% in subsurface soils in the 2%, 4% and 6% polluted plots as shown in Tables 4.3 and 4.4. From the results of the analysis the mean values for total porosity decreased after contamination compared to the mean values obtained before contamination. This was due to the oil that blocked the pore spaces of the soil. This condition can harm some vegetation because it can lead to the production of carbon dioxide and or toxins in roots of plants and micro-organisms, which may affect oil biodegradation. However, there was no significant difference between them. It was also observed from the analysis that total porosity values for the subsurface soils were lower when compared to the surface soils. This is probably due to compaction by gravity. Compaction decreases porosity as bulk density increases.

Table 4.3. Bulk Density and Total Porosity values for Top Soils (0-15cm) before and after Contamination

Pollution level		Well drained site				Waterlogged site			
		Before Contamination		After contamination		Before Contamination		After contamination	
		Bulk density (g/cm^3)	Total porosity (%)	Bulk density (g/cm^3)	Total porosity (%)	Bulk density (g/cm^3)	Total porosity (%)	Bulk density (g/cm^3)	Total porosity (%)
Treatment replicates	2% 1	1.26	52	1.22	54	1.18	55	1.19	55
	2	1.22	54	1.25	53	1.21	54	1.19	55
	3	1.24	53	1.24	53	1.17	56	1.20	55
	4	1.20	55	1.26	52	1.17	56	1.22	54
	5	1.23	54	1.27	52	1.19	55	1.20	55
	6	1.21	54	1.26	52	1.20	55	1.22	54
	Range	1.20-1.26	52-55	1.22-1.27	52-54	1.17-1.21	54-56	1.19-1.22	54-55
	Mean	1.23	53.7	1.25	52.7	1.19	55.2	1.20	54.7
	S.D	0.02	0.94	0.02	0.75	0.02	0.69	0.01	0.55
Treatment replicates	4% 1	1.19	55	1.25	53	1.18	55	1.22	54
	2	1.23	54	1.25	53	1.21	54	1.23	54
	3	1.22	54	1.28	52	1.19	55	1.21	54
	4	1.24	53	1326	52	1.22	54	1.22	54
	5	1.21	54	1.25	53	1.20	55	1.21	54
	6	1.25	53	1.27	52	1.21	54	1.23	54
	Range	1.21-1.25	53-55	1.25-1.28	52-53	1.18-1.22	54-55	1.21-1.23	-
	Mean	1.22	53.8	1.26	52.5	1.20	54.5	1.22	54
	S.D	0.02	0.75	0.01	0.50	0.01	0.50	0.01	0
treatment replicates	6% 1	1.24	53	1.25	53	1.20	55	1.24	53
	2	1.22	54	1.24	53	1.23	54	1.23	54
	3	1.25	53	1.27	52	1.21	54	1.22	54
	4	1.21	54	1.26	52	1.21	54	1.23	54
	5	1.20	55	1.25	53	1.18	55	1.22	54
	6	1.22	54	1.26	52	1.19	55	1.24	53
	Range	1.20-1.25	53-55	1.24-1.27	52-53	1.20-1.23	54-55	1.22-1.24	53-54
	Mean	1.22	53.8	1.26	52.5	1.20	54.5	1.23	53.7
	S.D	0.02	0.75	0.01	0.50	0.02	0.50	0.01	0.47

Source: Author's Analysis, 2015

Table 4.4. Bulk Density and Total Porosity values for Sub Soils (15-30cm) before and after Contamination

Pollution level		Well drained site				Waterlogged site			
		Before Contamination		After contamination		Before Contamination		After contamination	
		Bulk density (g/cm^3)	Total porosity (%)	Bulk density (g/cm^3)	Total porosity (%)	Bulk density (g/cm^3)	Total porosity (%)	Bulk density (g/cm^3)	Total porosity (%)
Treatment replicates	2% 1	1.30	51	1.41	47	1.23	54	1.32	50
	2	1.32	50	1.40	47	1.24	53	1.31	51
	3	1.28	52	1.42	46	1.22	54	1.33	50
	4	1.30	51	1.39	48	1.25	53	1.35	50
	5	1.29	51	1.41	47	1.28	52	1.33	50
	6	1.31	51	1.38	48	1.25	53	1.34	49
	Range	1.28-1.32	50-52	1.38-1.42	46-48	1.22-1.28	52-54	1.31-1.35	49-51
	Mean	1.30	51	1.40	47.2	1.25	53.2	1.33	50
	S.D	0.01	0.58	0.01	0.69	0.02	0.69	0.01	0.58
Treatment replicates	4% 1	1.31	51	1.40	47	1.26	52	1.33	50
	2	1.29	51	1.39	48	1.25	53	1.34	49
	3	1.30	51	1.42	46	1.27	52	1.32	50
	4	1.32	50	1.41	47	1.24	53	1.35	50
	5	1.29	51	1.40	47	1.26	52	1.33	50
	6	1.33	50	1.42	46	1.22	54	1.34	49
	Range	1.29-1.33	50-51	1.39-1.42	46-48	1.22-1.27	52-54	1.32-1.35	49-50
	Mean	1.31	50.7	1.41	46.8	1.25	52.7	1.34	49.7
	S.D	0.02	0.47	0.01	0.69	0.02	0.75	0.01	0.47
Treatment replicates	6% 1	1.29	51	1.41	47	1.28	52	1.31	51
	2	1.34	49	1.40	47	1.29	51	1.33	50
	3	1.32	50	1.39	48	1.21	54	1.32	50
	4	1.30	51	1.41	47	1.26	52	1.31	51
	5	1.28	52	1.40	47	1.27	52	1.32	50
	6	1.31	51	1.43	46	1.24	53	1.33	50
	Range	1.28-1.34	49-52	1.39-1.43	46-48	1.21-1.29	51-54	1.31-1.33	50-51
	Mean	1.31	50.7	1.41	47	1.26	52.3	1.32	50.3
	S.D	0.02	1.14	0.01	0.58	0.03	0.94	0.01	0.47

Source: Author's Analysis, 2015

4.2.2.3 Moisture Content

The moisture content of surface soils in the well drained site before contamination had mean values of 8.33%, 8.36% and 8.23% while the mean values after contamination were 7.10%, 7.02% and 7.01% in the 2%, 4% and 6% polluted plots. In the waterlogged site the mean values before contamination were 9.0%, 9.24% and 8.99% while the values after contamination were 7.30%, 7.02% and 7.08% respectively in the 2%, 4% and 6% polluted plots. The moisture content mean values of subsurface soils in the well drained site before contamination were 9.02%, 9.06% and 9.17% while the mean values after contamination were 7.50%, 7.64% and 7.68% in the 2%, 4% and 6% polluted plots. In the waterlogged site the mean moisture content values before contamination were 9.31%, 9.30% and 9.53% while the mean values after contamination were 7.55%, 7.64% and 7.67% respectively in the 2%, 4% and 6% polluted plots. A significant moisture reduction ($p = 0.01$) in the contaminated soil compared to the pre-contaminated (control) soil was observed. The moisture content in soils contaminated with oil was lower when compared to pre-contaminated soils, and statistical analysis revealed a difference that is significant between them. Pollution by crude oil has reduced the availability of soil moisture. Low soil water content in oil-contaminated soil may be due to a decrease in soil moisture top-up due to the hydrophobic nature of the oil-contaminated soil (Baruah, 1994, 2007). This can reduce plant growth and yield (GIGR, 1999, Michael, 1978). The hydrophobic characteristics of crude oil will have significant effect on soil water holding capacity and moisture content. Studies have revealed that soils contaminanted with petroleum hydrocarbons have lower water holding capacity, moisture content and hydraulic conductivity when compared with soils that is not polluted (Trofimov and Razanova, 2003; Nwaoguike, 2011).

Table 4.5 : Moisture Content (%) of Top Soil (0-15cm) before and after contamination

Pollution level		Well drained site		Waterlogged site	
		Before Contamination	**After contamination**	**Before Contamination**	**After contamination**
Treatment replicates	2% 1	**11.38**	**7.14**	**8.74**	**8.78**
	2	8.26	7.25	8.70	7.45
	3	8.34	8.32	9.72	8.30
	4	7.50	6.00	8.60	6.48
	5	7.26	7.24	10.13	6.50
	6	7.22	6.71	8.11	6.30
	Range	7.22-11.38	6.00-8.32	8.11-10.13	6.30-8.78
	Mean	8.33	7.10	9.00	7.30
	S.D	1.44	0.69	0.70	0.96
Treatment replicates	4% 1	7.70	6.21	10.10	7.05
	2	7.72	7.65	9.78	6.60
	3	10.76	7.00	8.60	7.20
	4	8.56	6.45	9.70	6.54
	5	7.30	8.15	8.70	6.43
	6	8.21	6.67	8.56	8.29
	Range	7.30-10.70	6.21-8.15	8.60-10.10	6.43-8.29
	Mean	8.36	7.02	9.24	7.02
	S.D	1.15	0.68	0.63	0.63
Treatment replicates	6% 1	7.66	6.57	8.68	6.80
	2	10.04	6.50	9.12	8.15
	3	8.96	7.10	8.16	7.22
	4	7.32	8.30	9.22	6.44
	5	8.16	6.68	10.10	6.32
	6	7.24	6.90	8.64	7.53
	Range	7.24-10.04	6.50-8.30	8.16-10.10	6.34-8.15
	Mean	8.23	7.01	8.99	7.08
	S.D	0.10	0.61	0.61	0.64

Source: Author's Analysis, 2015

Table 4.6 : Moisture Content (%) of Sub Soil (15-30cm) before and after contamination

Pollution level		Well drained site		Waterlogged site	
		Before Contamination	**After contamination**	**Before Contamination**	**After contamination**
Treatment replicates	2% 1	**10.80**	**8.41**	**9.72**	**8.72**
	2	9.76	7.36	11.36	7.36
	3	7.20	7.20	8.69	7.19
	4	8.26	8.26	9.76	7.55
	5	8.50	6.50	8.12	6.85
	6	9.60	7.48	8.24	7.60
	Range	7.20-10.80	6.50-8.41	8.12-11.36	6.85-8.72
	Mean	9.02	7.50	9.31	7.55
	S.D	1.17	0.65	1.12	0.58
Treatment replicates	4% 1	10.26	8.26	10.69	7.62
	2	8.34	7.34	9.18	8.78
	3	8.56	6.56	8.38	7.38
	4	9.70	7.34	9.32	6.55
	5	9.28	7.70	10.02	7.84
	6	8.24	7.62	8.22	7.65
	Range	8.24-10.26	7.34-8.26	8.22-10.69	6.55-8.78
	Mean	9.06	7.64	9.30	7.64
	S.D	0.75	0.60	0.86	0.66
Treatment replicates	6% 1	8.94	7.94	11.06	7.66
	2	11.30	7.30	9.12	8.42
	3	8.70	6.70	8.42	8.31
	4	9.85	8.94	8.86	7.58
	5	7.50	7.66	10.94	6.74
	6	8.75	7.53	8.76	7.32
	Range	7.50-11.30	7.30-8.94	8.42-11.06	7.32-8.42
	Mean	9.17	7.68	9.53	7.67
	S.D	1.17	0.68	1.06	0.57

Source: Author's Analysis, 2015

4.2.3 Soil Chemical Properties before and after contamination

4.2.3.1 Total Organic Carbon

Organic carbon contents of top soils in the well drained site had mean values of 0.34%, 0.38% and 0.40% before contamination while the mean values were 0.70%, 0.71% and 0.74% after contamination in the 2%, 4% and 6% polluted plots. In the waterlogged site total organic carbon values of top soils had means of 0.47%, 0.45% and 0.43% before contamination while after contamination the mean values were 0.80%, 0.81% and 0.90% in the 2%, 4% and 6% polluted plots. The mean values of organic carbon for sub soils in the well drained site were 0.37%, 0.35% and 0.38% before contamination while the values obtained after contamination were 0.71%, 0.73% and 0.74% in the 2%, 4% and 6% polluted plots. In the waterlogged site total organic carbon in sub soils had mean values of 0.42%, 0.43% and 0.45% before contamination while after contamination the mean values were 0.80%, 0.82% and 0.84% respectively in the 2%, 4% and 6% polluted plots.

The percentage organic carbon was observed to increase after crude oil contamination in both surface and subsurface soils when compared to the pre-contaminated (control) soil as shown in Tables 4.5 and 4.6. Statistical analysis showed a significant difference between TOC in the soil samples before and after contamination. The mean values of organic carbon contents for the samples after contamination in surface soils were obtained as 0.70%, 0.71% and 0.74% in the well drained site and 0.80%, 0.81% and 0.90% in the waterlogged site in the 2%, 4% and 6% polluted plots. These values were significant increase from the values obtained before contamination which were (0.34%, 0.38% and 0.40%) in well drained site and (0.47%, 0.45% and 0.43) in waterlogged site as shown in Table 4.5. The organic carbon increased can be due to the addition of carbon in the hydrocarbon to the carbon present already in the soil. These conditions, according to Odjuvwuederhie *et al*., (2006) are known to affect crop yield.

Table 4.7. Chemical Properties of Top Soil (0-15cm) before and after Contamination

Pollution level		Well drained site								Water logged site							
		Before Contamination				After contamination				Before Contamination				After contamination			
treatment		TOC	TN	Av.P	Soil	TOC	TN	Av.P	Soil	TOC	TN	Av.P	Soil	TOC	TN	Av.P	Soil
		(%)	(%)	(mg/kg)	pH	(%)	(%)	(mg/kg)	pH	(%)	(%)	(mg/kg)	pH	(%)	(%)	(mg/kg)	pH
	2% 1	0.28	0.07	0.42	6.21	0.62	0.18	0.80	6.70	0.46	0.07	0.35	6.50	0.75	1.09	0.80	6.96
	2	0.22	0.08	0.55	6.33	0.74	0.15	0.84	6.71	0.57	0.10	0.50	6.30	0.63	0.31	0.55	6.84
	3	0.36	0.08	0.35	6.14	0.67	0.13	0.78	6.84	0.41	0.12	0.50	6.20	0.72	0.25	0.80	6.74
	4	0.31	0.09	0.65	6.30	0.81	0.21	0.65	6.59	0.40	0.20	0.76	6.24	0.93	0.67	1.12	7.16
	5	0.38	0.07	1.10	6.72	0.70	0.17	1.11	6.86	0.36	0.10	0.50	6.42	0.86	0.84	0.58	6.95
	6	0.46	0.08	0.60	6.40	0.68	0.22	0.76	6.45	0.61	0.18	0.75	6.30	0.91	0.76	0.85	6.58
	Range	0.22-0.46	0.07-0.09	0.35-1.10	6.21-6.72	0.62-0.81	0.15-0.22	0.65-1.11	6.45-6.86	0.36-0.61	0.70-0.20	0.35-0.75	6.20-6.50	0.63-0.93	0.25-1.09	0.55-1.12	6.58-7.16
	Mean	0.34	0.08	0.61	6.35	0.70	0.18	0.82	6.69	0.47	0.13	0.56	6.33	0.80	0.65	0.78	6.87
	S.D		0.01		0.19		0.03		0.14		0.05		0.10	0.11	0.29		0.18
Treatment replicates	4% 1	0.29	0.10	0.65	6.72	0.59	0.10	0.65	6.72	0.40	0.19	0.75	6.54	0.96	0.18	1.10	6.98
	2	0.37	0.08	1.10	6.21	0.71	0.14	0.79	6.31	0.46	0.20	0.50	6.43	0.96	1.12	1.10	6.90
	3	0.41	0.07	0.35	6.42	0.66	0.32	0.85	6.68	0.39	0.14	0.70	6.29	0.69	0.35	0.55	6.78
	4	0.48	0.07	0.95	6.32	0.84	0.26	0.67	6.43	0.45	0.12	0.65	6.28	0.75	0.92	0.85	6.55
	5	0.36	0.09	0.55	6.15	0.69	0.19	0.78	0.58	0.50	0.06	0.50	6.24	0.64	0.75	0.65	6.42
	6	0.34	0.10	0.42	6.10	0.77	0.21	1.10	6.81	0.52	0.10	0.40	6.27	0.87	0.81	0.55	6.54
	Range	0.24-0.48	0.07-0.10	0.35-1.10	6.10-6.72	0.59-0.84	0.10-0.32	0.65-1.10	6.31-6.81	0.39-0.52	0.06-0.20	0.40-0.75	6.24-6.54	0.64-0.96	0.18-1.12	0.55-1.10	6.42-6.98
	Mean	0.38	0.09	0.67	6.32	0.71	0.20	0.81	6.59	0.45	0.14	0.58	6.34	0.81	0.66	0.80	6.70
	S.D		0.01		0.21		0.07		0.17		0.05		1.10	0.13	0.31		0.20
Treatment Replicates	6% 1	0.45	0.08	1.20	6.74	0.84	0.22	1.10	6.74	0.38	0.07	0.35	6.44	0.87	0.92	1.20	7.03
	2	0.38	0.07	0.45	6.78	0.84	0.16	0.55	6.73	0.43	0.11	0.75	6.28	0.99	0.90	0.55	6.55
	3	0.34	0.08	1.10	6.40	0.75	0.30	1.10	6.87	0.54	0.13	0.50	6.30	0.67	0.87	0.65	6.92
	4	0.43	0.06	0.55	6.21	0.63	0.15	0.75	6.63	0.41	0.21	0.60	6.52	1.08	0.35	0.75	6.52
	5	0.37	0.08	0.35	6.55	0.70	0.28	0.65	6.36	0.45	0.15	0.50	6.32	0.88	0.93	0.65	6.85
	6	0.40	0.07	0.80	6.20	0.68	0.43	0.80	6.47	0.35	0.14	0.70	6.34	0.91	0.77	0.55	6.53
	Range	0.34-0.45	0.06-0.08	0.35-1.10	6.20-6.78	0.63-0.84	0.15-0.43	0.55-1.10	6.36-6.87	0.35-0.54	0.07-0.21	0.35-0.75	0.28-6.44	0.67-1.08	0.35-0.92	0.55-1.2	6.50-7.03
	Mean	0.40	0.07	0.74	6.48	0.74	0.26	0.83	6.63	0.43	0.14	0.57	6.37	0.90	0.79	0.73	6.73
	S.D		0.01		0.23		0.10		0.17		0.04		0.09	0.13	0.20		0.17

Source: Author's analysis, 2015

Table 4.8. Chemical Properties of Sub Soil (15-30cm) before and after Contamination

Pollution level		Well drained site								Water logged site							
		Before Contamination				After contamination				Before Contamination				After contamination			
		TOC	TN	Av.P	Soil	TOC	TN	Av.P	Soil	TOC	TN	Av.P	Soil	TOC	TN	Av.P	Soil
		(%)	(%)	(mg/kg)	pH	(%)	(%)	(mg/kg)	pH	(%)	(%)	(mg/kg)	pH	(%)	(%)	(mg/kg)	pH
Treatment replicates	2% 1	0.30	0.08	0.40	6.10	0.65	0.17	0.55	6.86	0.37	0.07	0.35	6.43	1.08	1.08	0.40	7.04
	2	0.35	0.04	0.90	6.55	0.76	0.15	0.60	6.71	0.50	0.10	0.65	6.36	0.87	0.87	0.65	6.22
	3	0.40	0.05	0.65	6.30	0.68	0.14	0.65	6.95	0.43	0.09	0.50	6.24	0.25	0.25	0.80	6.80
	4	0.30	0.07	0.30	6.33	0.70	0.18	1.35	6.54	0.42	0.05	0.55	6.84	0.39	0.39	0.55	6.36
	5	0.45	0.06	0.55	6.18	0.80	0.24	0.75	6.18	0.40	0.12	0.75	6.48	0.52	0.52	0.80	7.25
	6	0.40	0.07	1.10	6.21	0.69	0.20	0.45	6.65	0.39	0.06	0.60	6.85	0.68	0.68	0.70	6.61
	Range	0.30-0.45	0.04-0.08	0.30-1.10	6.10-6.55	0.65-0.76	0.14-0.24	0.45-1.35	6.54-6.95	0.37-0.50	0.05-0.12	0.35-0.75	6.24-6.85	0.25-1.08	0.25-1.08	0.40-0.80	6.22-8.36
	Mean	0.37	0.06	0.65	6.28	0.71	0.18	0.73	6.74	0.42	0.08	0.57	6.53	0.63	0.63	0.65	6.71
	S.D		0.01	0.28	0.14		0.03		0.13		0.02		0.23	0.28	0.28		0.36
Treatment replicates	4% 1	0.29	0.06	0.55	6.40	0.66	0.15	0.64	6.48	0.35	0.06	0.45	6.29	0.69	0.77	0.55	6.78
	2	0.36	0.08	0.45	6.40	0.58	0.13	0.95	6.81	0.46	0.11	0.30	6.42	0.90	0.35	0.60	7.00
	3	0.31	0.06	0.60	6.32	0.75	0.18	0.73	6.96	0.40	0.07	0.55	6.40	0.60	0.36	0.70	6.86
	4	0.43	0.02	1.10	6.28	0.84	0.14	0.65	6.46	0.39	0.10	0.35	6.52	0.96	0.64	0.60	6.28
	5	0.41	0.09	0.55	6.43	0.78	0.36	0.75	6.74	0.55	0.08	1.10	6.28	0.75	0.79	0.40	6.75
	6	0.32	0.07	0.65	6.46	0.79	0.28	0.80	6.86	0.43	0.10	0.50	6.90	0.99	0.83	1.10	6.56
	Range	0.29-0.43	0.02-0.09	0.45-1.10	6.28-6.46	0.58-0.84	0.13-0.36	0.69-0.94	6.46-6.96	0.35-0.55	0.06-0.10	0.30-1.10	6.28-6.90	0.60-0.99	0.35-0.79	0.40-1.10	6.29-7.00
	Mean	0.35	0.06	0.65	6.38	0.73	0.21	0.75	6.72	0.43	0.09	0.54	6.47	0.82	0.62	0.66	6.71
	S.D			0.28	0.06		0.08		0.19		0.02		0.21	0.14	0.20		0.23
Treatment replicates	6% 1	0.31	0.07	0.95	6.78	0.81	0.76	1.10	6.78	0.53	0.06	0.50	6.52	1.23	0.20	0.65	7.06
	2	0.32	0.02	0.50	6.37	1.08	1.00	0.60	6.62	0.40	0.05	0.55	6.32	0.72	0.93	0.50	6.97
	3	0.40	0.05	0.65	6.21	0.63	0.35	0.65	6.48	0.45	0.08	0.60	6.51	0.87	0.82	0.70	6.74
	4	0.36	0.08	0.50	6.29	0.48	0.55	0.75	6.78	0.48	0.11	0.65	6.53	0.82	0.37	1.10	6.56
	5	0.47	0.04	0.75	6.36	0.84	0.30	0.80	6.80	0.32	0.13	0.80	6.44	0.64	0.70	0.60	6.39
	6	0.42	0.07	0.60	6.47	0.60	0.42	0.70	6.83	0.54	0.18	0.35	6.77	0.95	0.81	0.50	6.64
	Range	0.31-0.47	0.02-0.08	0.50-0.75	6.21-6.78	0.48-1.08	0.30-1.00	0.60-1.10	6.48-6.83	0.32-0.54	0.05-0.18	0.35-0.80	6.32-6.77	0.64-1.23	0.20-0.93	0.50-1.10	6.39-7.06
	Mean	0.38	0.06	0.66	6.41	0.74	0.56	0.77	6.72	0.45	0.10	0.58	6.52	0.84	0.64	0.68	6.73
	S.D		0.02		0.18	0.20	0.26		0.12		0.04		0.13	0.19	0.26		0.23

Source: Author's analysis, 2015

4.2.3.2 Total Nitrogen

The mean values of total nitrogen of surface soils in the well drained site before contamination were 0.08%, 0.09% and 0.07% while the mean values after contamination were 0.18%, 0.20% and 0.26% in the 2%, 4% and 6% polluted plots. In the waterlogged site, mean values of surface soils before contamination were 0.13% and 0.14% while the mean values after contamination increased to 0.65%, 0.66% and 0.79% respectively in the 2%, 4% and 6% polluted plots. In the subsurface soils nitrogen content mean value in the well drained site before contamination was 0.06% while the values after contamination were 0.18%, 0.21% and 0.56% in the 2%, 4% and 6% polluted plots. In the waterlogged site the mean values of total nitrogen before contamination were 0.08%, 0.09% and 0.10% while after contamination the mean values increased to 0.63%, 0.62% and 0.64%.

It was observed that there were significant differences in nitrogen levels between soil samples before and after contamination. When compared to the nitrogen content recorded in soil samples before contamination, the values obtained in the contaminated soils were higher in both well drained and waterlogged sites as indicated in Tables 4.5 and 4.6. While the mean values of nitrogen in crude oil pre-contaminated surface soils were 0.08%, 0.09% and 0.07% in the well drained site and 0.13%, 0.14% and 0.14% in the waterlogged site, the mean values for contaminated soils were 0.18%, 0.20% and 0.26% in the well drained site and 0.65%, 0.66% and 0.79% in the waterlogged site indicating the presence of more nitrogen in the contaminated soils than the pre-contaminated (control) soils. The values were significantly different ($p = 0.05$). The increase in nitrogen might be attributed to the fact that crude oil contains some amount of nitrogen.

4.2.3.3 Available Phosphorus

Available phosphorus mean values for surface soils in the well drained site before contamination were 0.61mg/kg, 0.67mg/kg and 0.74mg/kg while the mean values after contamination were 0.82mg/kg, 0.81mg/kg and 0.83mg/kg in the 2%, 4% and 6% polluted plots. In the waterlogged site the mean values of available phosphorus in the surface soils before contamination were 0.56mg/kg, 0.58mg/kg and 0.57mg/kg while the mean values after contamination were 0.78mg/kg, 0.80mg/kg and 0.73mg/kg respectively in the 2%, 4% and 6% polluted plots. The mean values of available phosphorus of the subsurface

soils in the well drained site before contamination were 0.65mg/kg and 0.66mg/kg while the mean values after contamination were 0.73mg/kg, 0.75mg/kg and 0.77mg/kg in 2%, 4% and 6% polluted plots. In the waterlogged site available phosphorus mean values before contamination were 0.57mg/kg, 0.54mg/kg and 0.58mg/kg while the mean values after contamination were 0.65mg/kg, 0.66mg/kg and 0.68mg/kg in the 2%, 4% and 6% polluted plots.

It was observed that the amount of available phosphorus increased after crude oil contamination in surface and subsurface soils in both well drained and waterlogged sites and the differences were also significant, ($p = 0.05$). The percentage phosphorus content results obtained after contamination indicate a significant increase over the initial results before contamination as indicated in Tables 4.5 and 4.6. Both total nitrogen and available phosphorus levels were higher in soil polluted by crude oil when compare to pre-contaminated (control) soils. This is in line with the findings of Odu (1972), who highlighted the increase in soil nitrogen and phosphorus in polluted soil. The reason may be due to the high levels of particulate organic matter in contaminanted soil.

4.2.3.4 Soil pH

From the results shown in Tables 4.5 and 4.6, the average pH values in soil samples analyzed in the well drained site of the study area were 6.35, 6.32 and 6.48 (surface soils) and 6.28, 6.38 and 6.41 (subsurface soils). These values indicate that the soils in the study area are slightly acidic. The average pH values obtained in waterlogged site were 6.33, 6.34 and 6.37 (surface soils) and 6.53, 6.47 and 6.52 (subsurface soils) showing that the soils in the waterlogged site are also slightly acidic. For most plant to grow a pH value between 6.5 and 7.5 is considered appropriate.

The mean pH values of surface soils in the well drained site before contamination were 6.35, 6.32 and 6.48 while the mean values after contamination were 6.69, 6.59 and 6.63 in the 2%, 4% and 6% polluted plots. In the waterlogged site the mean pH values before contamination were 6.33, 6.34 and 6.37 whereas the values after contamination were 6.87, 6.70 and 6.73 respectively in the 2%, 4% and 6% polluted plots. In the subsurface soils, the mean pH values in the well drained site before contamination were 6.28, 6.38 and 6.41 while the mean values after contamination were 6.74 and 6.72 in the 2%, 4% and 6%

polluted plots. In the waterlogged site the mean values of soil pH before contamination were 6.53, 6.47 and 6.52 while the mean pH values after contamination were 6.71 and 6.73 respectively in the 2%, 4% and 6% polluted plots as shown in Tables 4.5 and 4.6.

Tables 4.5 and 4.6 revealed that contaminated soils compared to pre-contaminated soils had higher pH values. Statistical analysis showed that difference between the two soil samples was significant. The increase in soil pH caused by crude oil contamination is in line with the submissions of Andrade *et al*., (2004), and Ayotamuno *et al*., (2004), who noted increase in the soil pH due to crude oil contamination. However, an increase in soil pH was observed when organic carbon and soil organic matter increased in hydrocarbon-contaminated soils (Osuji and Nwoye 2007, Marinescu et al., 2011, Nwaoguikpe 2011). Oil spill does not generally result in impact that is significant on soil properties (Osuji and Nwoye 2007). For example, when Marinescu *et al.,* (2011) noted an increase in total nitrogen in hydrocarbon contaminated soils. Similarly, Akpoveta *et al.* (2011) observed a decrease in phosphorus content in a contaminated hydrocarbon site, Marinescu et al. (2011) observed an increase in the same element in similar soil. These differences are due to the nature of the pollutant and the original properties of the soil (McGill *et al.,* 1981, Alexander 1999, Semple *et al.,*2001)

4.2.4 Total hydrocarbon content (mg/kg) of soils before and after contamination during the dry season

The mean values of total hydrocarbon content of surface soils in the well drained site before contamination during the dry season were 40.83 mg/kg, 32.5 mg/kg and 36.67 mg/kg while the mean values after contamination increased to 740.83 mg/kg, 755 mg/kg and 787.5 mg/kg in the 2%, 4% and 6% polluted plots. In the waterlogged site the mean values of total hydrocarbon content before contamination were 35 mg/kg, 30 mg/kg and 40 mg/kg while after contamination the mean values increased to 882.5 mg/kg, 912.5 mg/kg and 935 mg/kg in the 2%, 4% and 6% polluted plots respectively. In the subsurface soils the average total hydrocarbon content values in the well drained site before contamination were 85mg/kg, 60.83 mg/kg and 74.17 mg/kg while the average values after contamination increased to 611.67 mg/kg, 615 mg/kg and 762.5 mg/kg in the 2%, 4% and 6% polluted plots. In the waterlogged site the mean values of total hydrocarbon content before contamination were 115 mg/kg, 71.67 mg/kg and 85 mg/kg whereas the mean values after contamination increased to 428.33 mg/kg, 431.67 mg/kg and 675 mg/kg respectively in the 2%, 4% and 6% polluted plots. High levels of hydrocarbon were observed from both surface and subsurface soils after contamination when compared to the pre-contaminated hydrocarbon levels as shown in Figures 4.1 to 4.2. The difference in the total hydrocarbon levels between the contaminated and pre-contaminated soils was statistically significant ($p=0.05$).

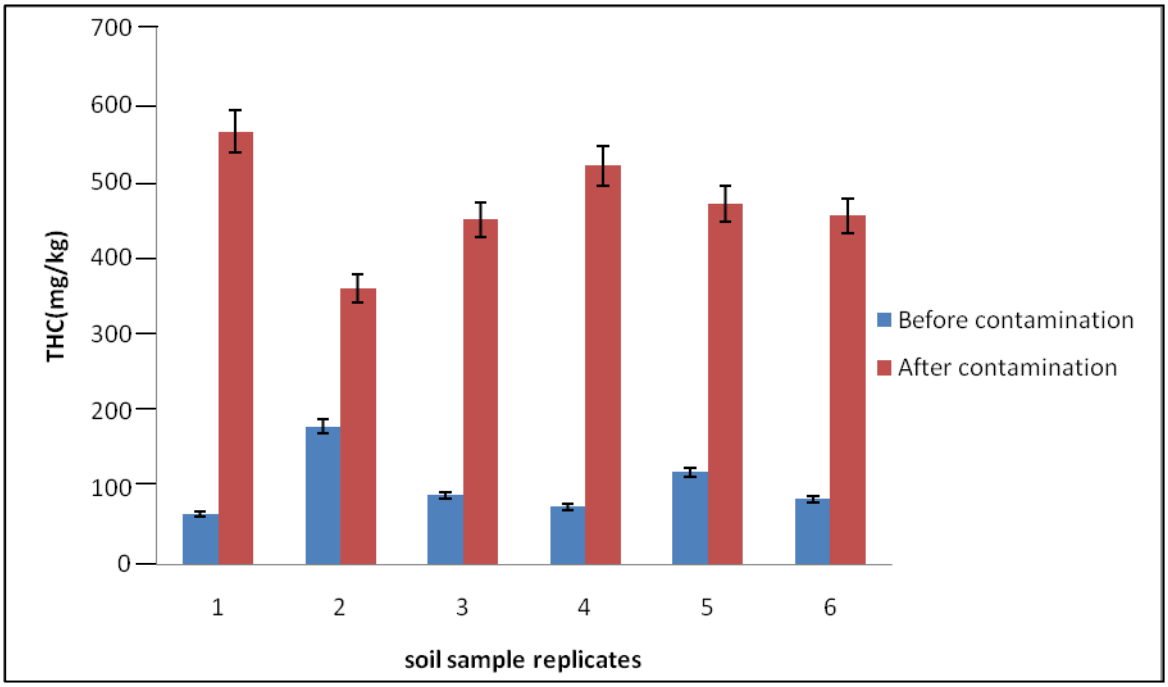


Fig. 4.1: Total hydrocarbon content of top soils of 2% polluted well drained site in dry season.

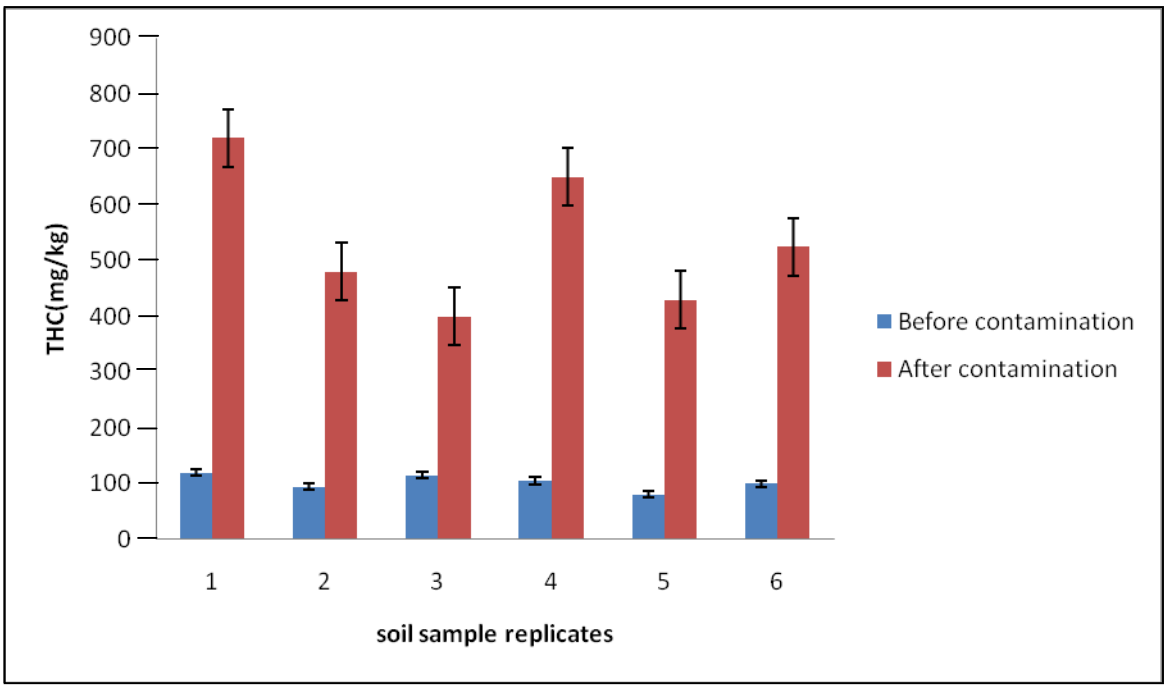


Fig. 4.2: Total hydrocarbon content of top soils of 2% polluted waterlogged site in dry season.

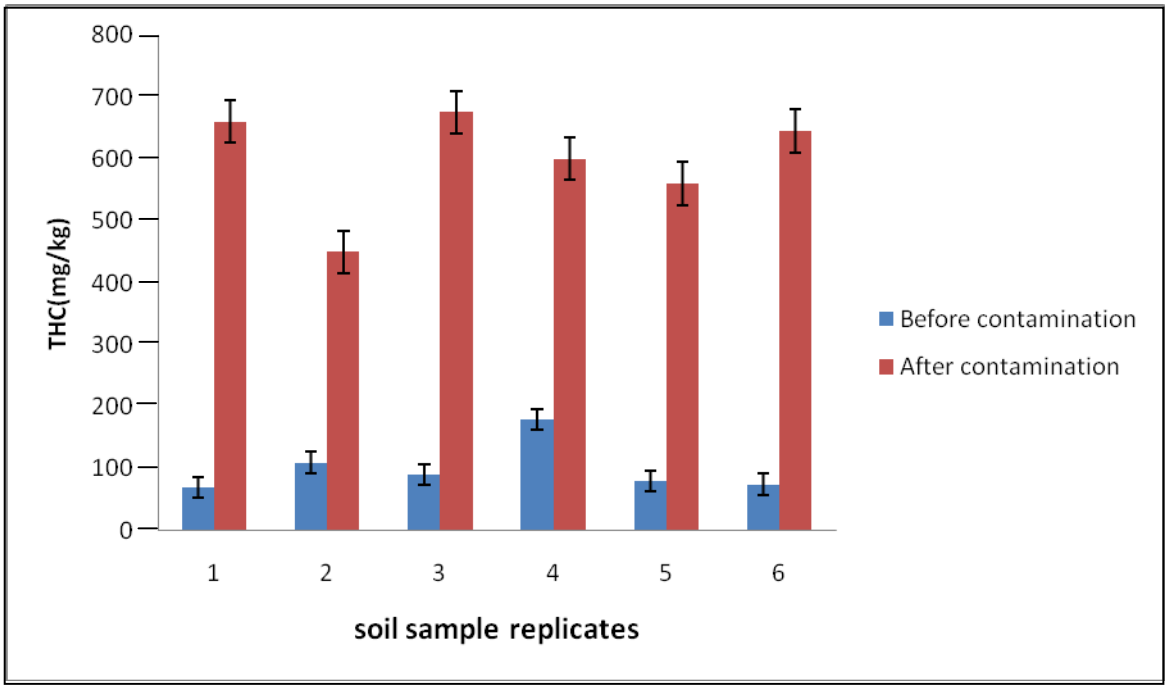


Fig. 4.3: Total hydrocarbon content of top soils of 4% polluted well drained site in dry season

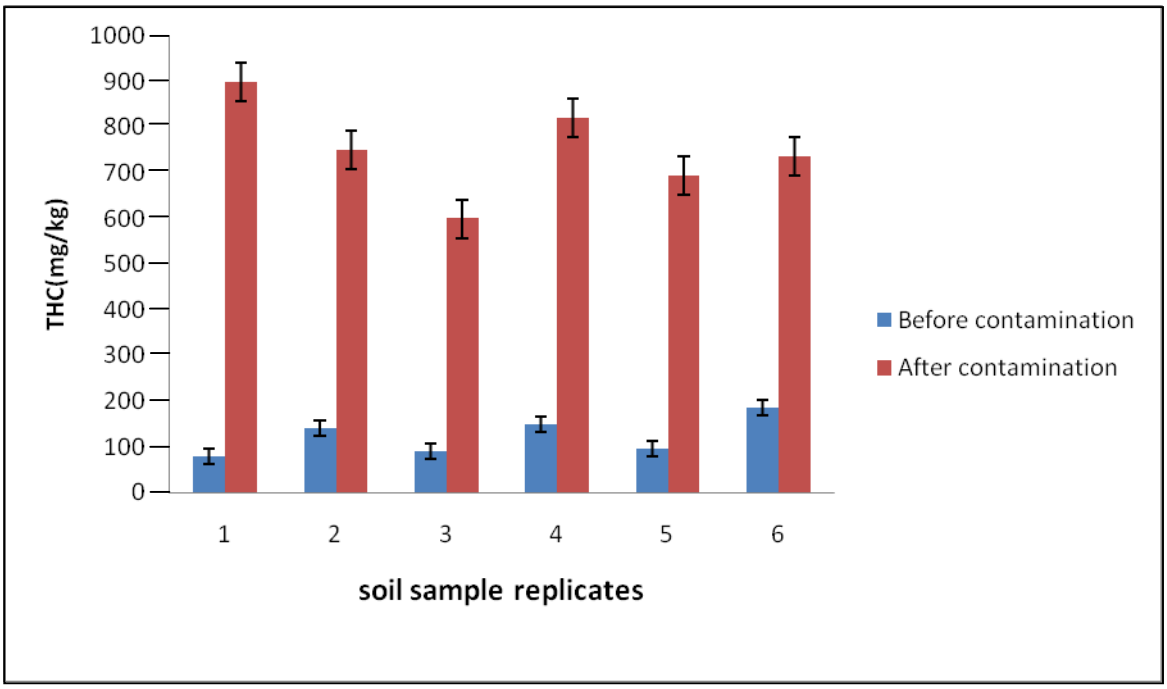


Fig. 4.4: Total hydrocarbon content of top soils of 4% polluted waterlogged site in dry season

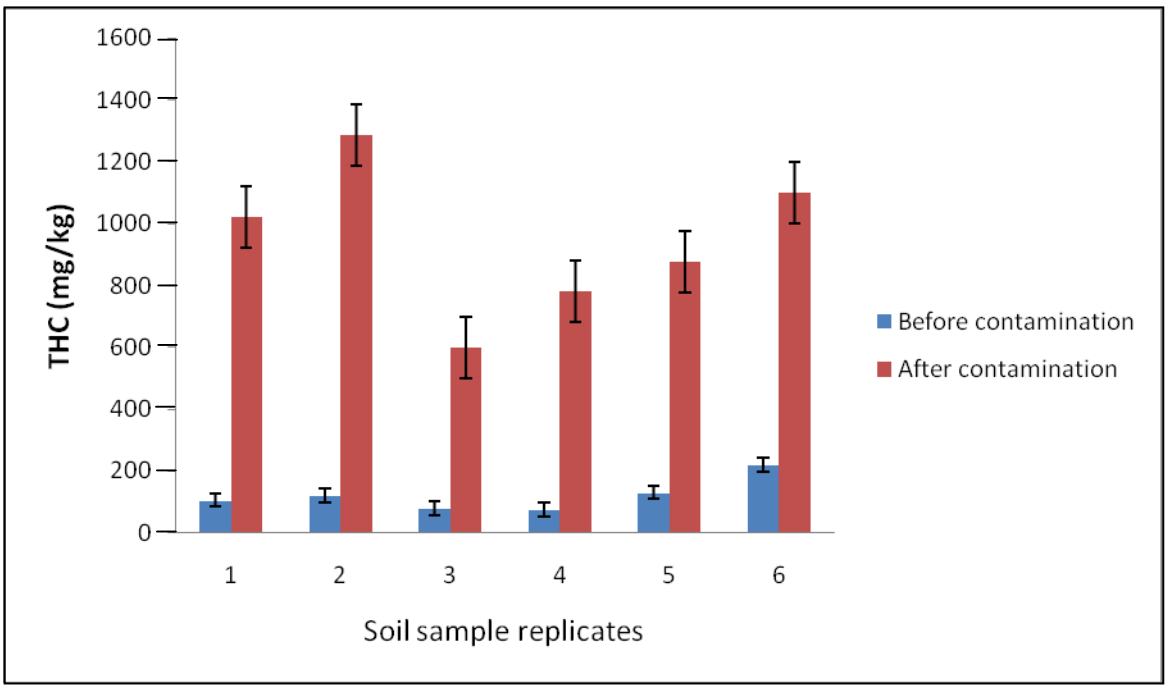


Fig. 4.5: Total hydrocarbon content of top soils of 6% polluted well drained site in dry season

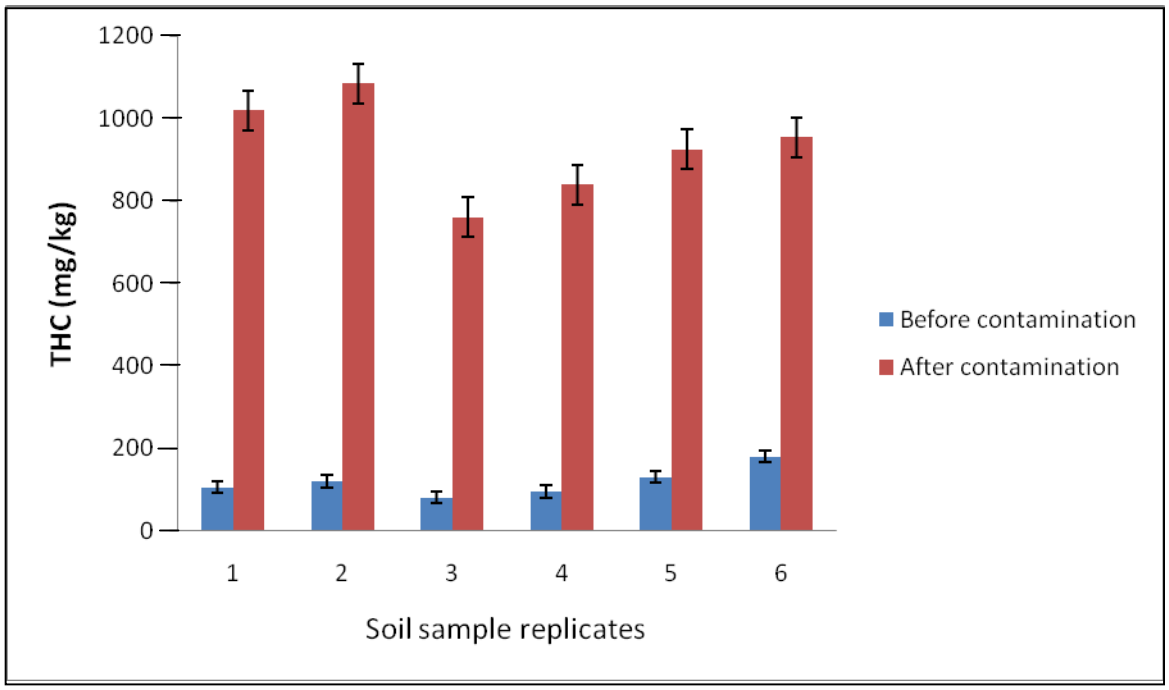


Fig. 4.6: Total hydrocarbon content of top soils of 6% polluted waterlogged site in dry season

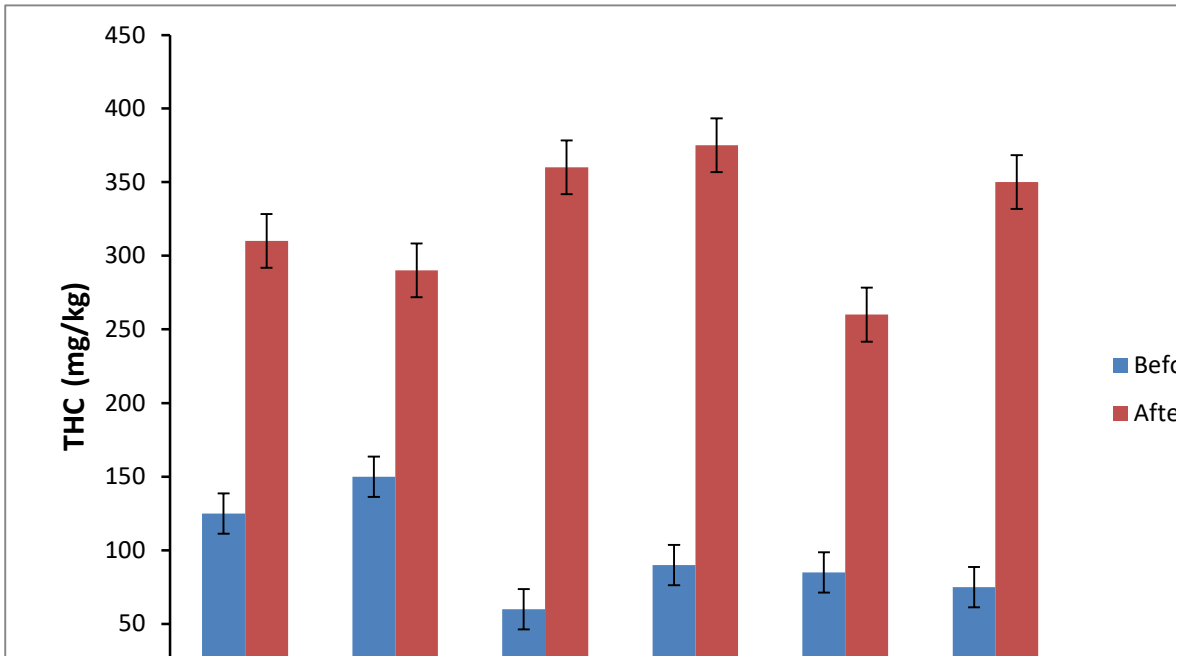


Fig. 4.7: Total hydrocarbon content of sub soils of 2% polluted well drained site in dry season

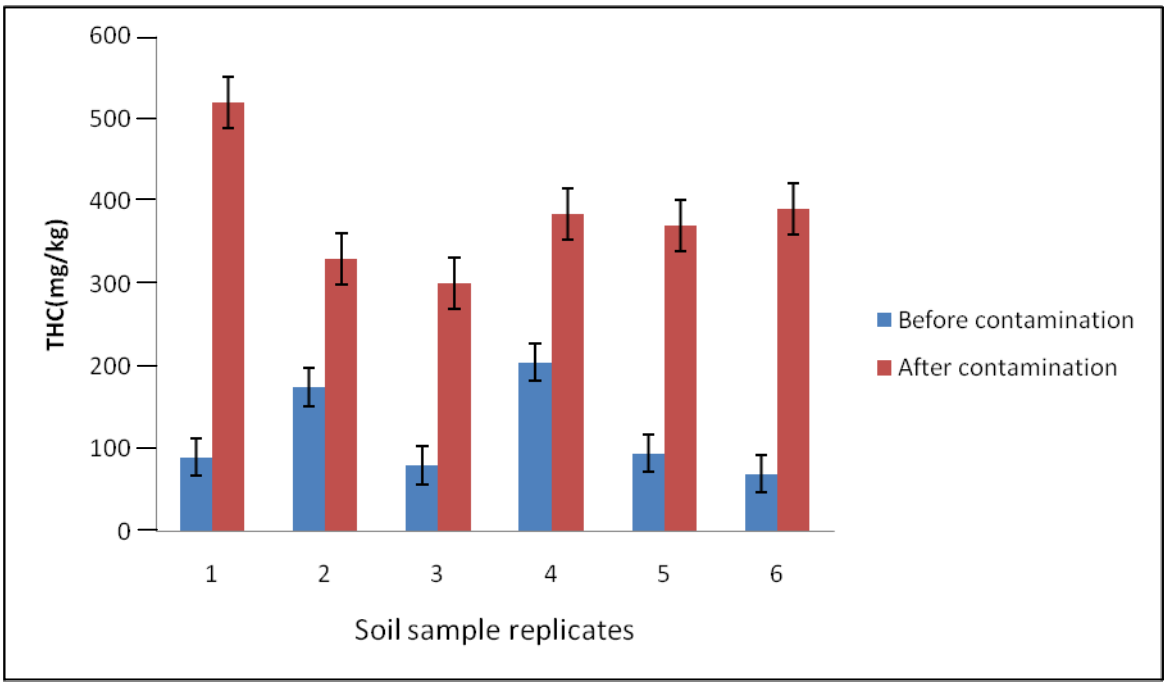


Fig. 4.8: Total hydrocarbon content of sub soils of 2% polluted waterlogged site in dry season

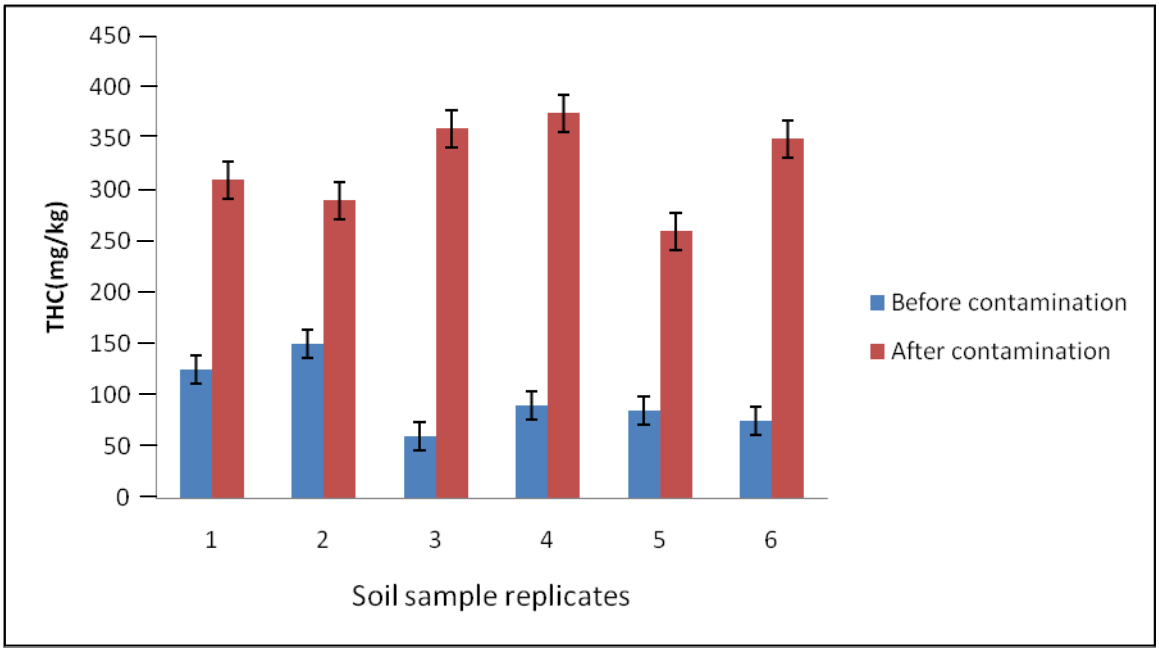


Fig. 4.9: Total hydrocarbon content of sub soils of 4% polluted well drained site in dry season

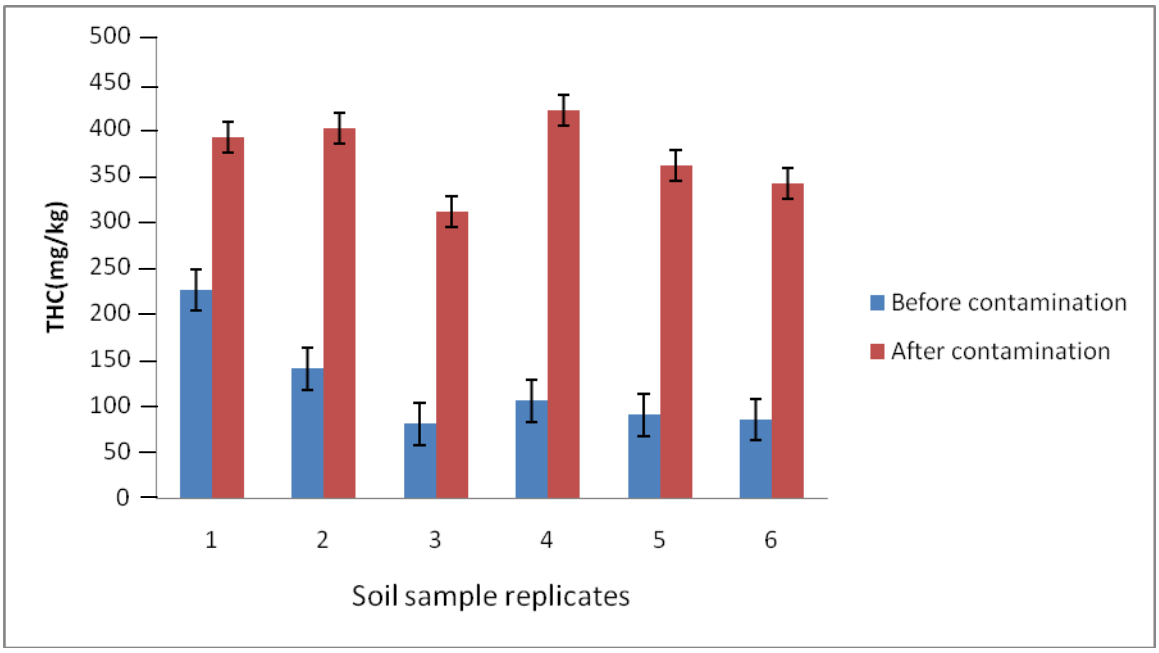


Fig. 4.10: Total hydrocarbon content of sub soils of 4% polluted waterlogged site in dry season

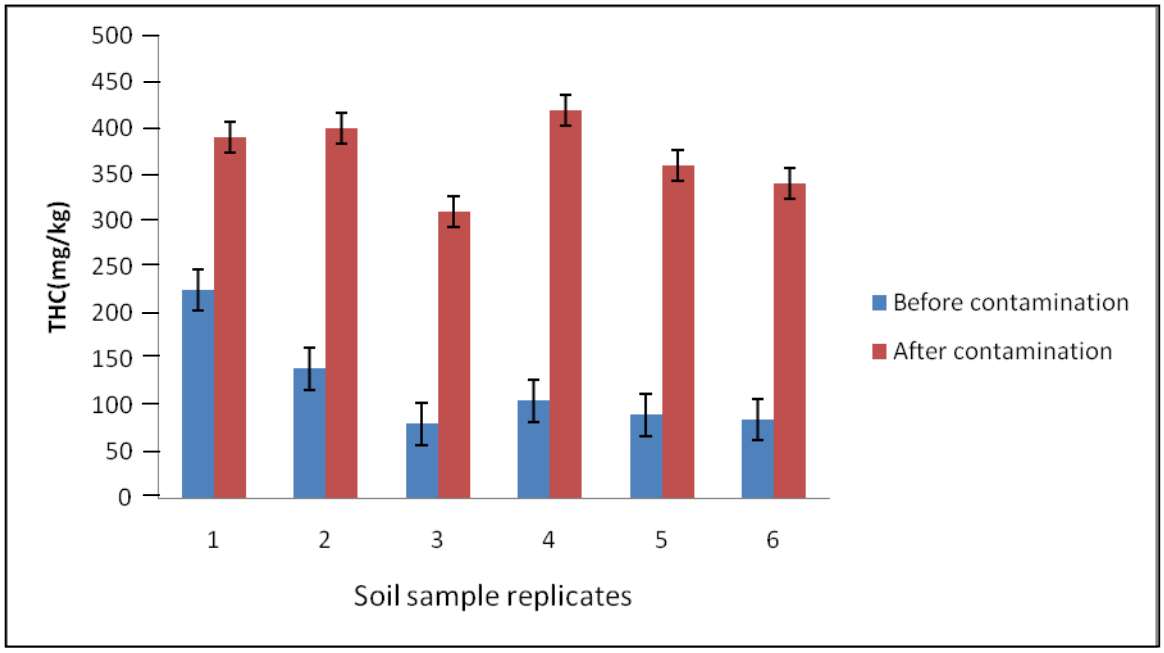


Fig. 4.11: Total hydrocarbon content of sub soils of 6% polluted well drained site in dry season

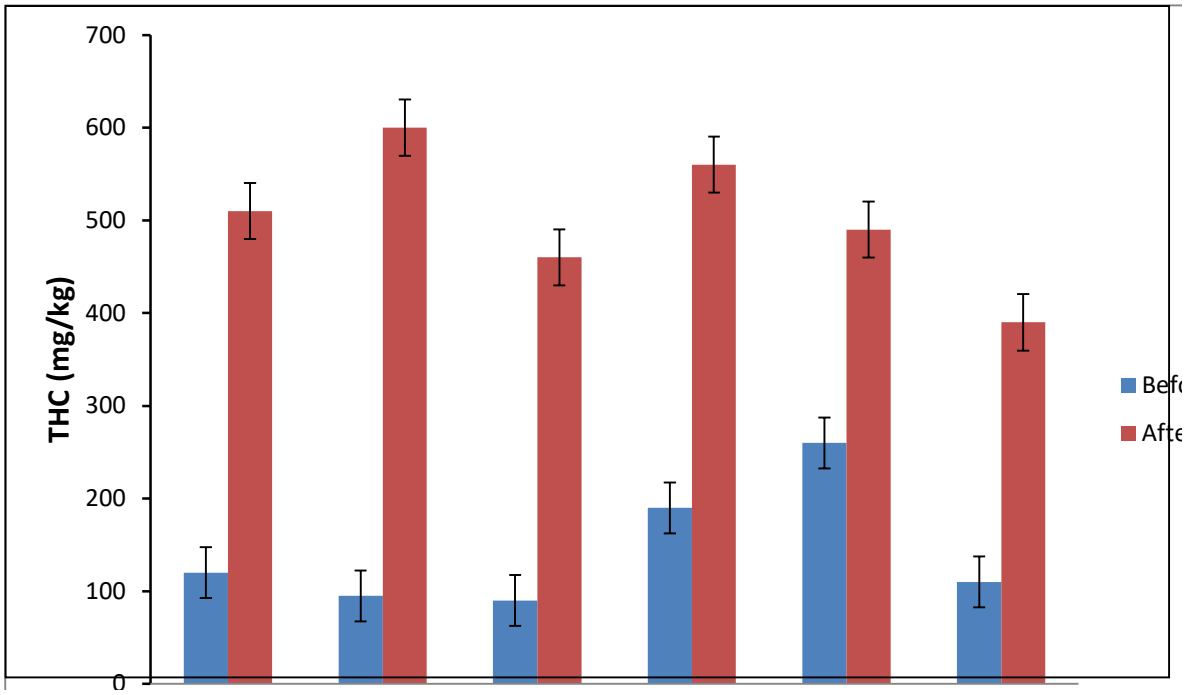


Fig. 4.12: Total hydrocarbon content of sub soils of 6% polluted waterlogged site in dry season

4.2.5 Total hydrocarbon content (mg/kg) of soils before and after contamination during the wet season.

Total hydrocarbon content also increased after contamination during the wet season as indicated in Figures 4.13 to 4.24. The mean values of total hydrocarbon content in surface soils before contamination in the well drained site during the wet season were 85.83 mg/kg, 100.83 mg/kg and 121.67 mg/kg while the mean values after contamination increased to 470 mg/kg, 598.33 mg/kg and 1043.33 mg/kg in the 2%, 4% and 6% polluted plots. In the waterlogged site the average hydrocarbon content values before contamination were 102.5mg/kg, 123.33 mg/kg and 118.33 mg/kg while the mean values after contamination increased to 534.17 mg/kg, 750 mg/kg and 580 mg/kg respectively in the 2%, 4% and 6% polluted plots. In the subsurface soils the mean values of total hydrocarbon content in the well drained site before contamination were 97.5 mg/kg, 105 mg/kg and 128.33 mg/kg while the mean values after contamination increased to 324.17 mg/kg, 365 mg/kg and 436.67 mg/kg respectively in the 2%, 4% and 6% polluted plots. In the waterlogged site the average values of total hydrocarbon content before contamination were 119.17 mg/kg, 120.83 mg/kg and 144.17 mg/kg while the mean values after contamination increased to 382.5mg/kg, 368.33mg/kg and 390mg/kg in the 2%, 4% and 6% polluted plots. A significant difference between the levels of total hydrocarbon content of soil samples before and after contamination was also observed during the wet season. The difference in the THC level between both soil samples was significant ($p = 0.05$).

It was evident from the results of the analysis that total hydrocarbon content increased after crude oil contamination at both project sites during the dry and wet seasons.

The background level of total hydrocarbon content before contamination in both project sites was low as there has not been any historical oil spill incident in the project sites. However, contamination of the soils with crude oil in the study area has produced high levels of hydrocarbon as observed in this study. Excess of hydrocarbon in the soil will prevent the growth of plants which in turn will have negative impact on availability of food and shelter for animals depending on such plants (Osuji, 2001). Also crops like yam, cocoyams and vegetables do not thrive well in hydrocarbon contaminated soil

because air is dislaced in the soil leading to poor aeration in the pores between the particles of the soil by hydrocarbon that has significant impact on the growth of plants, this can cause seeds sown on contaminated soil not to germinate even after 30 days (Ekweozor, 1998).

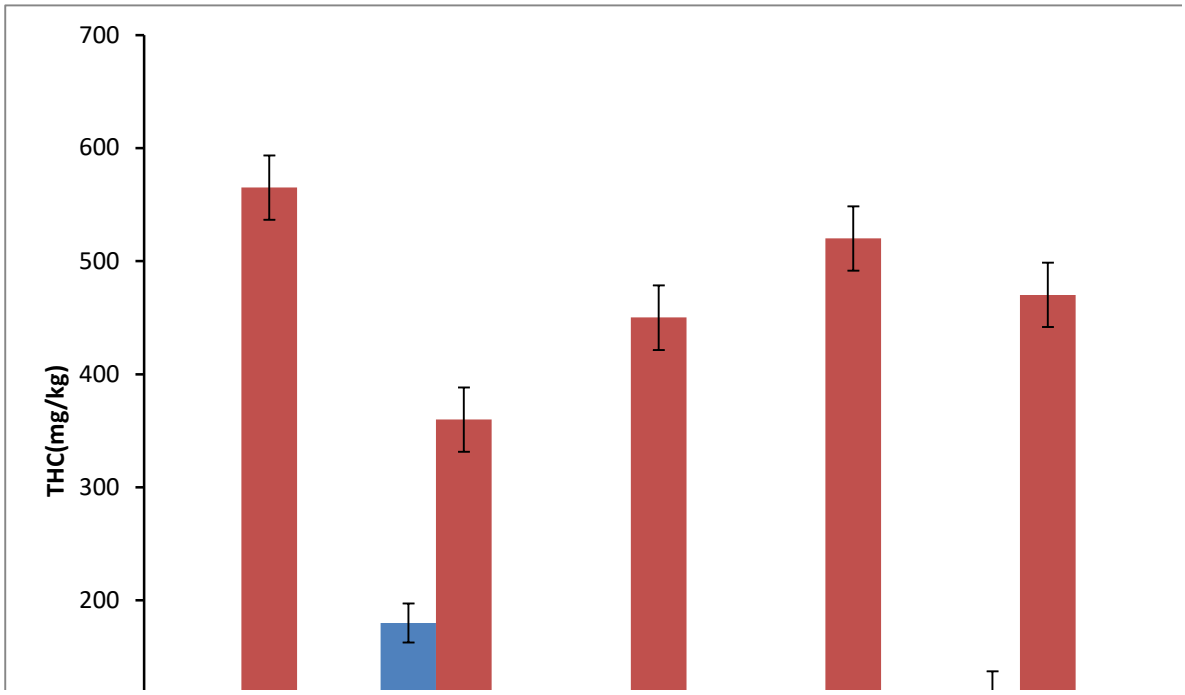


Fig. 4.13: Total hydrocarbon content of top soils of 2% polluted well drained site in wet season

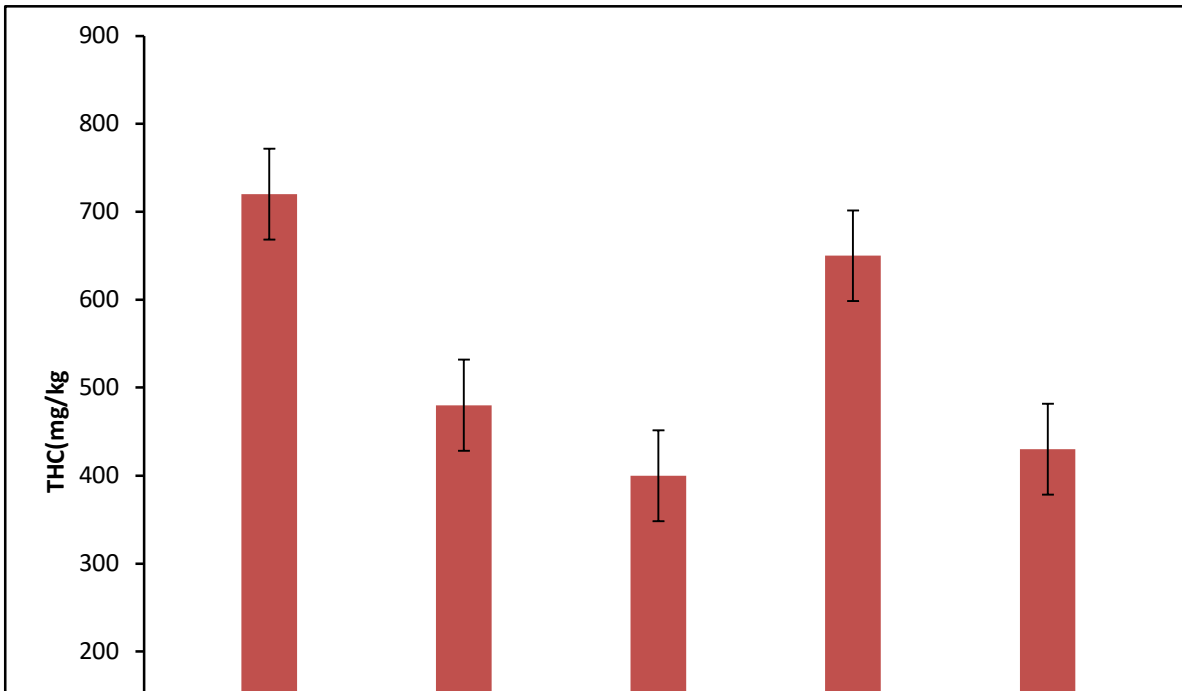


Fig. 4.14: Total hydrocarbon content of top soils of 2% polluted waterlogged site in wet season

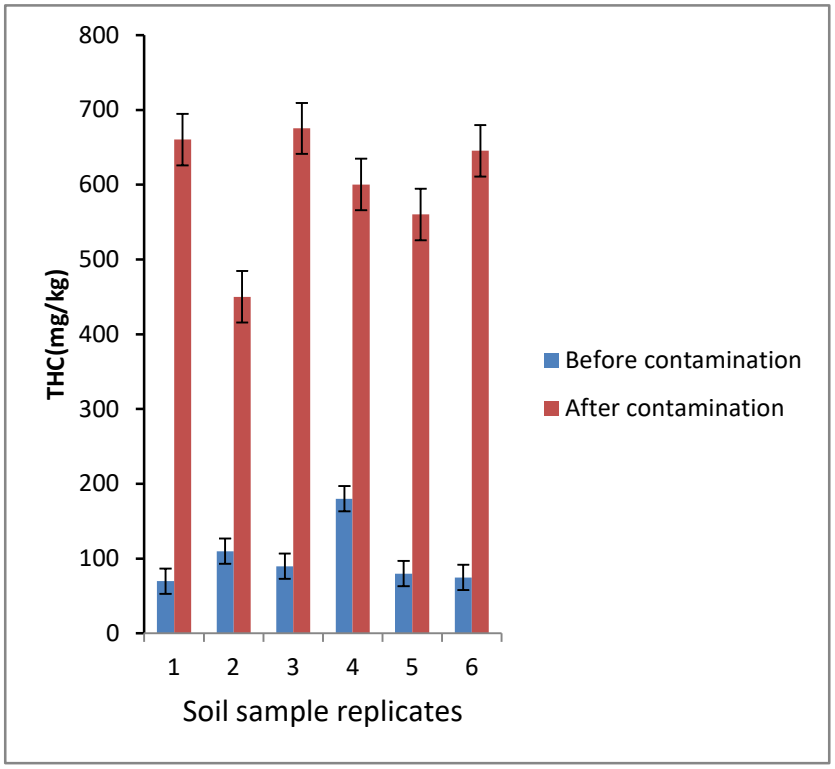


Fig. 4.15: Total hydrocarbon content of top soils of 4% polluted well drained site in wet season

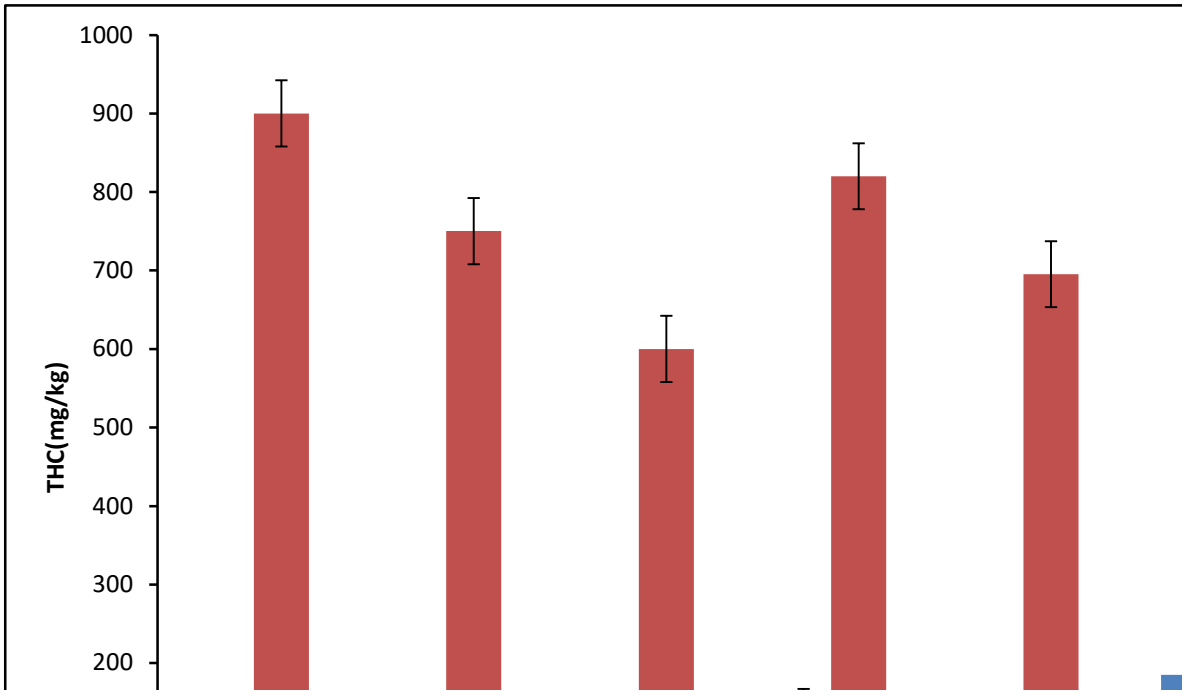


Fig. 4.16: Total hydrocarbon content of top soils of 4% polluted waterlogged site in wet season

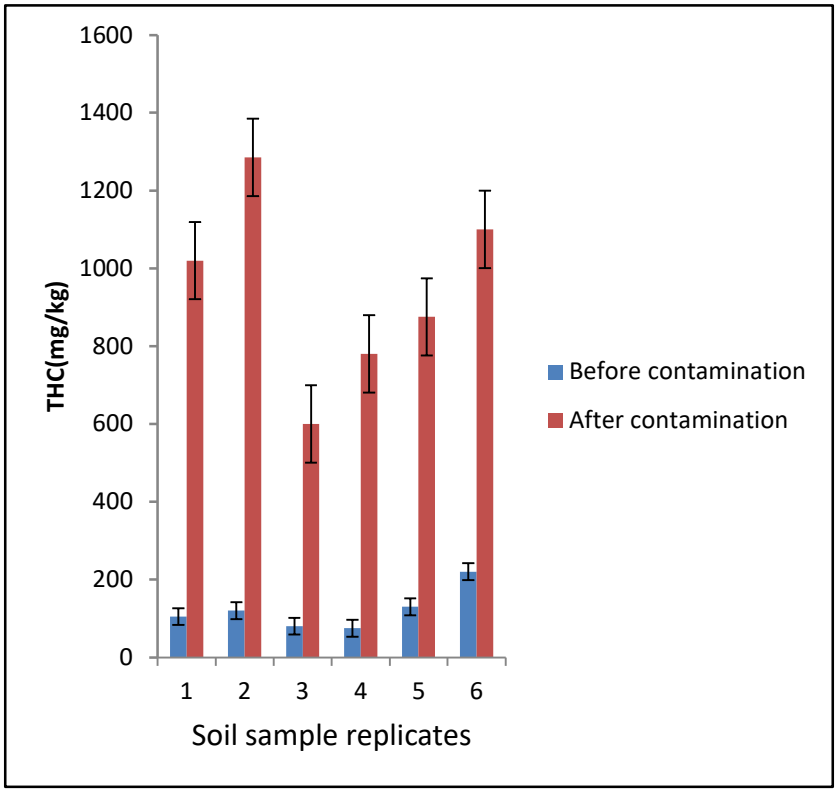


Fig. 4.17: Total hydrocarbon content of top soils of 6% polluted well drained site in wet season

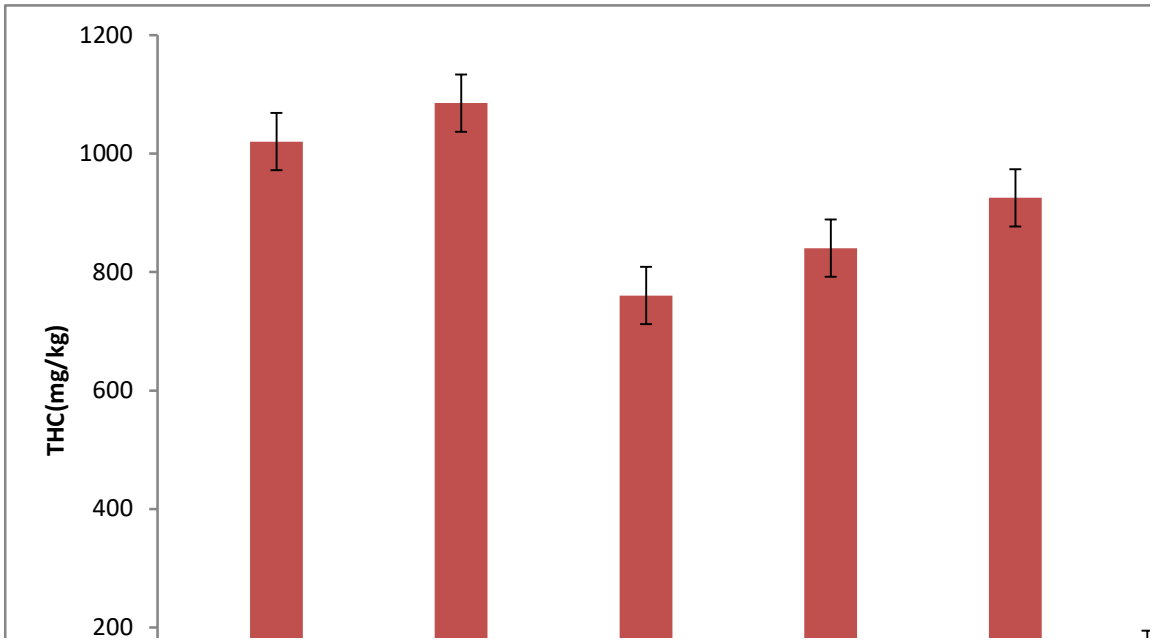


Fig. 4.18: Total hydrocarbon content of top soils of 6% polluted waterlogged site in wet season

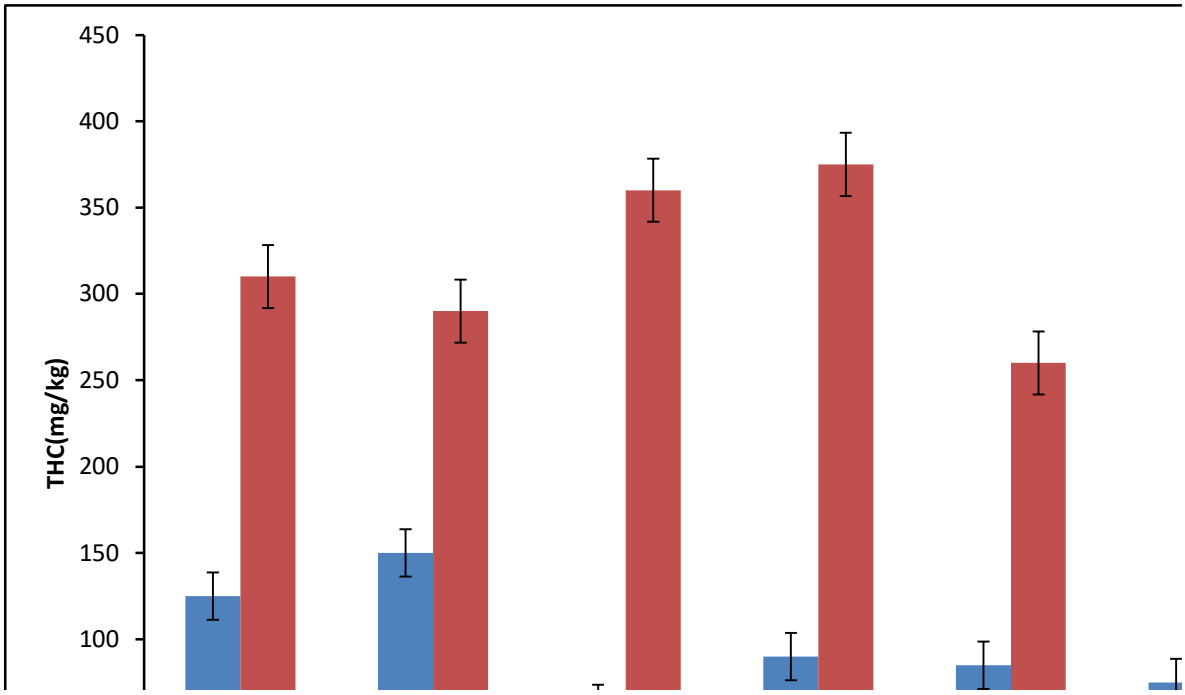


Fig. 4.19: Total hydrocarbon content of sub soils of 2% polluted well drained site in wet season

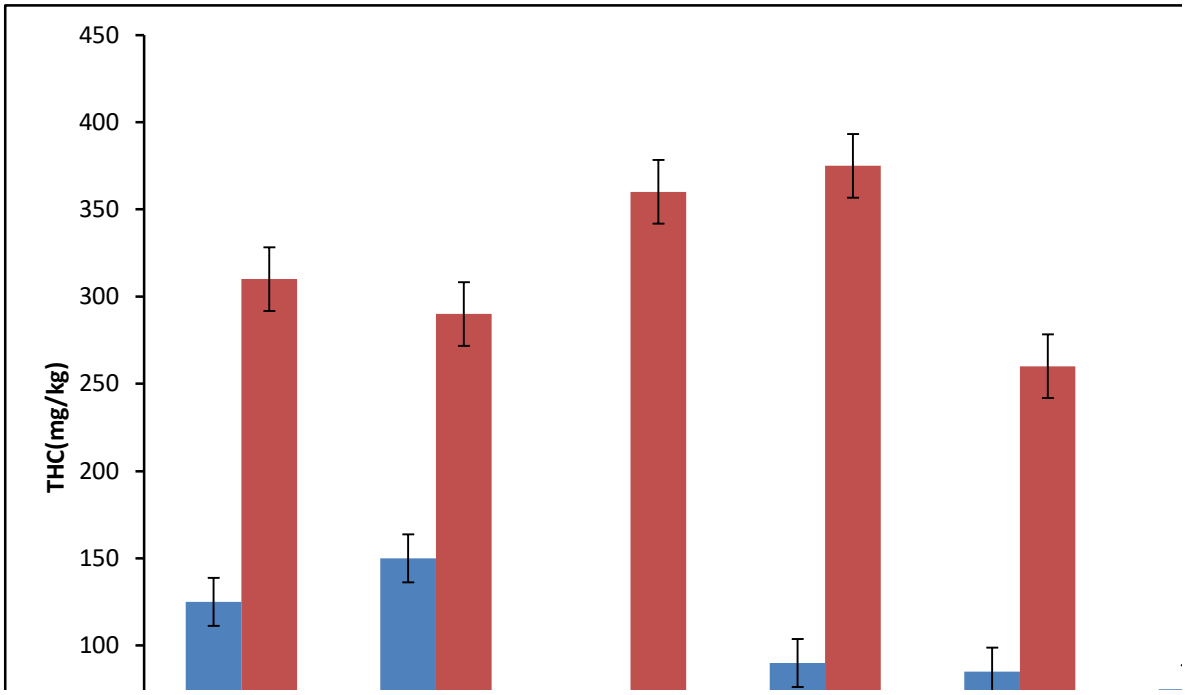


Fig. 4.20: Total hydrocarbon content of sub soils of 2% polluted waterlogged site in wet season

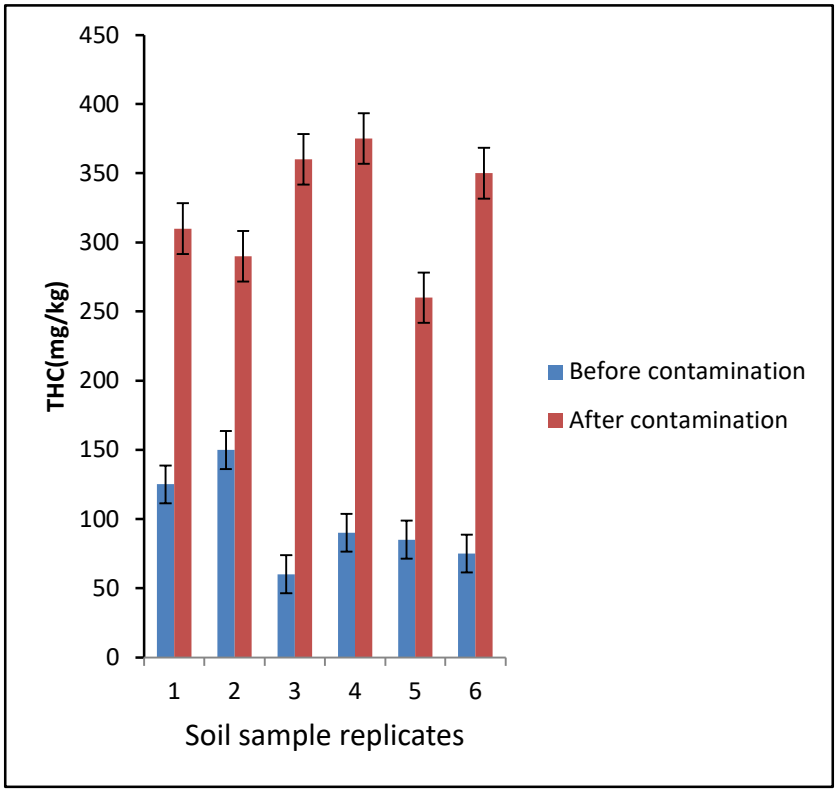


Fig. 4.21: Total hydrocarbon content of sub soils of 4% polluted well drained site in wet season

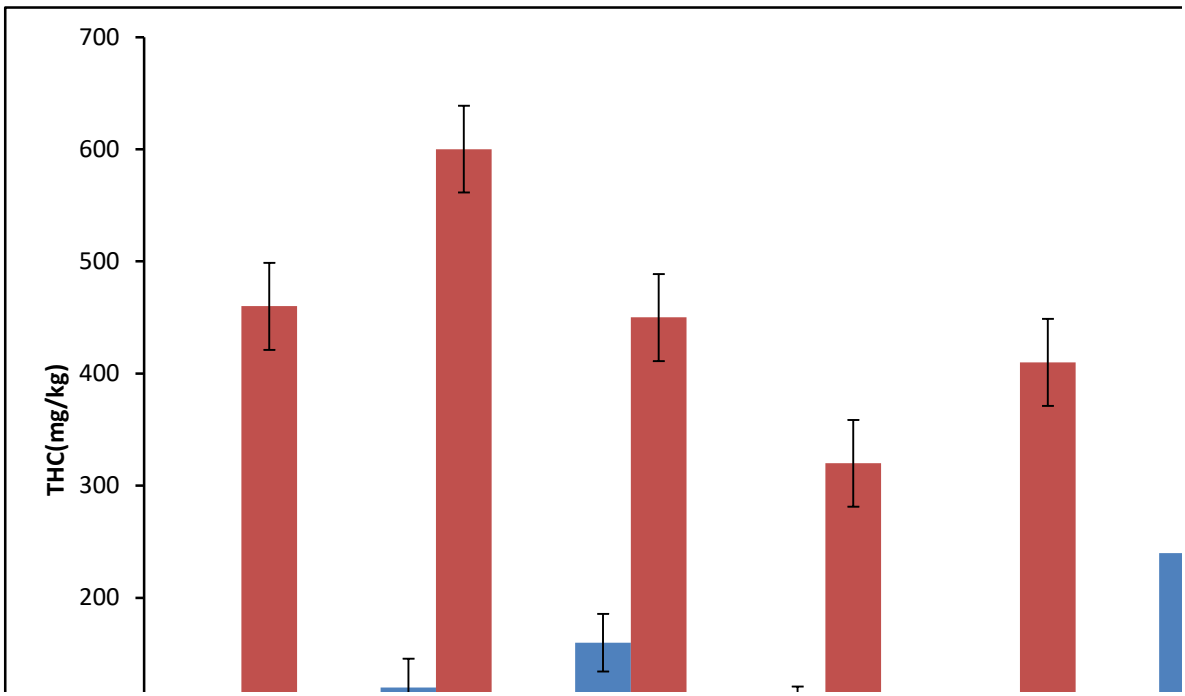


Fig. 4.22: Total hydrocarbon content of sub soils of 4% polluted waterlogged site in wet season

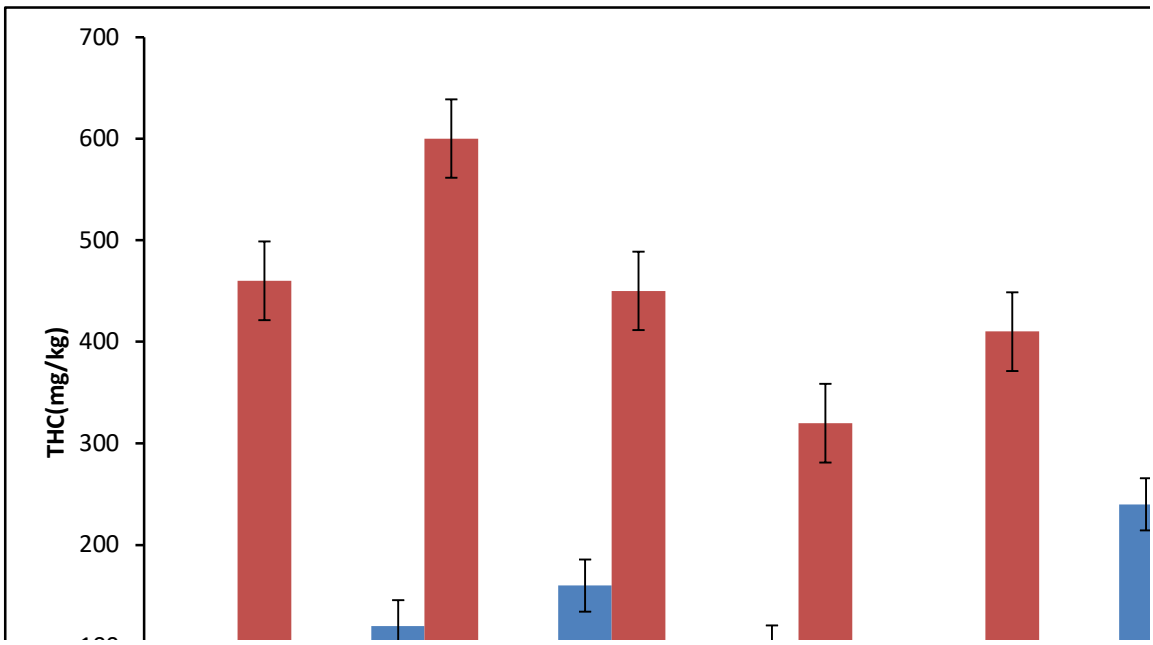


Fig. 4.23: Total hydrocarbon content of sub soils of 6% polluted well drained site in wet season

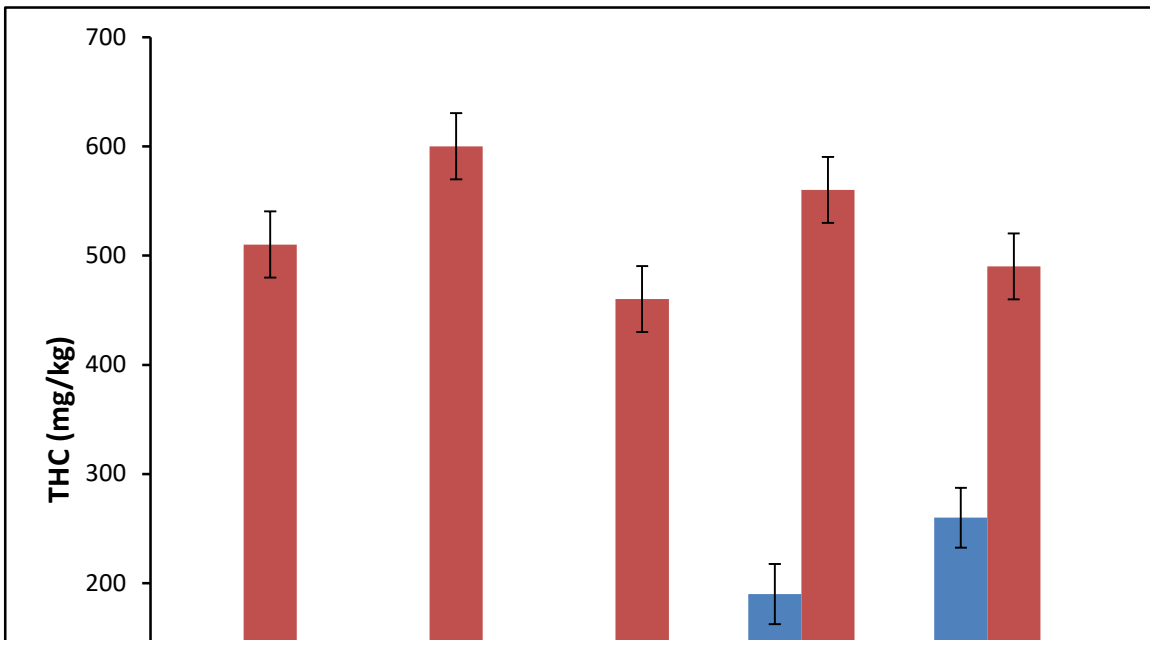


Fig. 4.24: Total hydrocarbon content of sub soils of 6% polluted waterlogged site in wet season

4.2.6 Enumeration of Total Heterotrophic Bacteria (THB) and Hydrocarbon Utilizing Bacteria (HUB) before and after contamination

Soils polluted by crude oil differ from unpolluted soils as a result of change in the biological and physicochemical characteristics (Robertson *et al.,* 2006). When the soil is contaminanted with hydrocarbons, the microorganism observed in the soil will initially reduced (particularly in soils not contaminanted before). Hofman *et al*., (2004) reported that although the number of organisms in the soil increase in soils polluted with hydrocarbon but over time a decline in species richness is observed.

From the data obtained in Tables 4.7 and 4.8, analysis of soil microbial pre-contaminated and contaminated with hydrocarbon revealed that higher population of heterotrophic bacteria (THB) was recorded in the pre-contaminated soils samples with mean counts of 4.11 x 10^7cfu/g, 4.10 x 10^7cfu/g and 4.15 x 10 cfu/g in well drained site and 4.07 x 10 cfu/g, 4.02 x 10^7cfu/g and 4.05 x 10^7 cfu/g in the waterlogged site for surface soils and mean counts of 4.98 x 10^7 cfu/g, 4.78 x 10^7 cfu/g and 4.73 x 10^7 cfu/g in the well drained site and 4.28 x 10 ^{7}cfu/g, 4.3 x 10^7 cfu/g and 4.42 x 10^7 cfu/g in the waterlogged site for subsurface soils than the contaminated soils. Hydrocarbon utilizing bacterial counts were less when compared to heterotrophic bacterial counts before contamination (Table 4.7). This could be as a result of nutrient limitation for crude oil utilizers. The total heterotrophic bacteria (THB) was observed to be low after crude oil contamination especially in the waterlogged site with mean counts of 3.21 x 10^6 cfu/g, 3.47 x 10^6 cfu/g and 3.06 x 10^6 cfu/g in surface soils and 2.79 x 10^6 cfu/g, 2.8 x 10^6 cfu/g and 2.76 x 10^6 cfu/g in subsurface soils (Table 4.8). The mean counts after contamination in the well drained site were 4.15 x 10^7 cfu/g, 4.25 x 10^5 cfu/g and 3.91 x 10^6 cfu/g in surface soils and 2.92 x 10^6 cfu/g, 2.95 x 10^6 cfu/g and 2.83 x 10^6 cfu/g in subsurface soils. Generally, the THB counts were higher in crude oil pre-contaminated soils than in crude oil contaminated soils. However, statistical analysis revealed that the difference in counts between the two soil samples was not significant.

There were higher counts of hydrocarbon utilizing bacteria (HUB) in crude oil contaminated soil than in pre-contaminated (control) soil with mean counts of 4.5 x 10^5 cfu/g, 4.6 x 10^5 cfu/g and 4.62 x 10^5cfu/g in surface soils and 4.3 x 10^5 cfu/g, 4.4 x 10^5

cfu/g and 4.47 x 10^5 cfu/g in subsurface soils in the well drained site. In the waterlogged site the mean HUB values after contamination were 4.22 x 10^5 cfu/g, 4.28 x 10^5 cfu/g and 4.56 x 10^5cfu/g in surface soils and 4.5 x 10^5 cfu/g, 4.43 x 10 ^{5}cfu/g and 4.60 x 10^5 cfu/g in subsurface soils in the 2%, 4% and 6% polluted plot (Tables 4.7 and 4.8). This is as a result of crude oil utilized as a food source for HUB. This indicated that the presence of oil attracted organisms that degrade hydrocarbon or served as a substrate for the proliferation of native hydrocarbon degrading microorganisms. The presence of crude oil in the soil significantly increased the population of bacteria and metabolic activity. Compared to pre-soil samples, the bacteria (HUB) levels in oil-contaminated soil were higher with the two soil samples having significant difference ($p = 0.05$). The HUB population grows with the infection. Studies have revealed that an increase in hydrocarbon users is correlated positively with the concentrations of hydrocarbon (Margesin *et al.,* 2000 and Alamri, 2006).

Table 4.9. Total heterotrophic bacteria and hydrocarbon utilizing bacteria (cfu/g) of top soils (0-15cm) before and after contamination in the dry season.

Pollution level		Well drained site				Water logged site			
		Before Contamination		After contamination		Before Contamination		After contamination	
		THB	HUB	THB	HUB	THB	HUB	THB	HUB
Treatment replicat	2% 1	9.6×10^7	8.0×10^2	6.4×10^6	1.6×10^5	2.5×10^7	2.0×10^2	6.1×10^6	2.4×10^5
	2	1.27×10^7	2.2×10^3	3.4×10^6	3.2×10^5	3.1×10^6	2.2×10^3	5.4×10^6	4.4×10^4
	3	2.8×10^6	1.2×10^3	4.3×10^6	6.3×10^5	4.3×10^7	2.1×10^2	1.17×10^5	3.8×10^5
	4	4.1×10^6	2.8×10^2	2.94×10^7	3.5×10^5	2.6×10^6	1.4×10^2	2.3×10^5	3.4×10^4
	5	3.6×10^7	1.7×10^3	4.2×10^6	4.3×10^6	6.7×10^7	2.9×10^3	2.5×10^6	6.7×10^5
	6	3.3×10^7	2.1×10^3	3.67×10^6	8.1×10^5	5.2×10^7	2.7×10^3	1.8×10^6	4.6×10^5
	Range	1.27×10^7-9.6×10^7	1.2×10^3-8.0×10^2	3.4×10^6-6.4×10^6	1.6×10^5-8.1×10^5	2.5×10^7-6.7×10^7	1.4×10^2-2.9×10^3	1.17×10^5-6.1×10^6	2.4×10^5-6.7×10^5
	Mean	4.11×10^7	2.77×10^3	4.15×10^6	4.5×10^5	4.07×10^7	2.27×10^3	3.21×10^6	4.22×10^5
Treatment replicate	4% 1	1.8×10^7	1.2×10^3	7.9×10^6	1.8×10^5	4.4×10^7	3.0×10^2	1.7×10^5	7.3×10^4
	2	2.9×10^6	2.0×10^3	4.9×10^6	9.4×10^5	2.9×10^6	1.0×10^3	6.0×10^5	3.9×10^5
	3	5.4×10^6	1.3×10^2	3.1×10^5	6.2×10^5	3.6×10^6	2.3×10^2	2.9×10^6	6.1×10^4
	4	4.2×10^6	2.7×10^3	3.3×10^6	3.4×10^6	7.2×10^7	2.5×10^2	1.8×10^6	2.8×10^5
	5	8.0×10^6	6.5×10^2	1.7×10^6	3.8×10^5	4.0×10^6	2.1×10^3	5.3×10^6	2.4×10^5
	6	2.3×10^7	1.0×10^3	4.6×10^6	3.0×10^5	2.0×10^7	2.8×10^3	3.1×10^6	3.2×10^5
	Range	1.8×10^7-8.0×10^6	1.0×10^3-6.5×10^2	1.7×10^6-7.9×10^6	1.8×10^5-9.4×10^5	2.9×10^6-7.2×10^7	1.0×10^3-2.3×10^2	1.7×10^5-6.0×10^6	2.4×10^5-7.3×10^5
	Mean	4.1×10^7	2.45×10^6	4.25×10^6	4.6×10^5	4.02×10^7	2.28×10^3	3.47×10^6	4.28×10^5
gokeTreatment replicate	6% 1	4.3×10^7	1.0×10^3	2.73×10^6	1.73×10^6	6.4×10^7	2.0×10^2	2.9×10^6	3.6×10^4
	2	4.2×10^6	7.0×10^2	9.4×10^5	9.4×10^5	4.2×10^6	4.0×10^2	2.73×10^5	2.1×10^5
	3	4.4×10^6	2.0×10^3	1.4×10^5	6.5×10^5	5.0×10^7	2.2×10^3	3.5×10^5	4.8×10^5
	4	3.7×10^7	1.1×10^3	2.6×10^6	3.5×10^6	4.3×10^7	2.4×10^3	2.8×10^6	8.6×10^4
	5	3.2×10^6	1.0×10^3	3.8×10^6	2.7×10^5	2.4×10^6	1.2×10^2	3.7×10^6	3.1×10^5
	6	5.1×10^7	2.3×10^3	3.5×10^6	3.9×10^5	2.0×10^7	1.8×10^3	3.3×10^6	5.1×10^5
	Range	3.2×10^6-5.1×10^7	1.0×10^3-7.0×10^2	1.4×10^5-9.4×10^5	1.73×10^6-9.4×10^5	2.0×10^7-6.4×10^7	1.2×10^2-4.0×10^2	2.73×10^5-3.7×10^6	1.16×10^5-8.6×10^4
	Mean	4.15×10^7	2.4×10^3	3.9×10^6	4.62×10^5	4.05×10^7	2.27×10^3	3.06×10^6	4.5×10^5

Source: Author's Analysis, 2015

Table 4.10. Total heterotrophic bacteria and hydrocarbon utilizing bacteria (cfu/g) of sub soils (15-30cm) before and after contamination in the dry season.

Pollution level		Well drained site				Water logged site			
		Before Contamination		After contamination		Before Contamination		After contamination	
		THB	HUB	THB	HUB	THB	HUB	THB	HUB
Treatment replicate	2% 1	8.5×10^7	7.0×10^2	1.8×10^6	5.9×10^5	5.9×10^7	4.0×10^2	1.5×10^6	6.5×10^5
	2	3.3×10^6	1.2×10^3	1.8×10^6	1.6×10^5	3.3×10^6	1.2×10^3	6.5×10^5	3.6×10^5
	3	4.1×10^7	1.3×10^3	2.4×10^6	4.2×10^5	4.1×10^6	2.0×10^2	2.13×10^6	2.5×10^5
	4	6.2×10^7	1.0×10^2	3.8×10^5	3.2×10^5	4.5×10^7	1.0×10^2	1.4×10^6	7.2×10^5
	5	4.3×10^6	1.1×10^3	2.7×10^6	6.2×10^5	3.9×10^7	1.3×10^3	3.0×10^5	2.4×10^4
	6	3.5×10^7	2.0×10^3	5.0×10^5	4.7×10^5	4.0×10^7	3.0×10^2	2.2×10^6	4.8×10^5
	Range	3.3×10^6-8.5×10^7	1.0×10^2-7.0×10^2	1.8×10^6-5.0×10^5	1.6×10^5-6.2×10^5	3.3×10^6-5.9×10^7	1.0×10^2-4.0×10^2	1.4×10^6-6.5×10^5	2.4×10^4-7.2×10^5
	Mean	4.98×10^7	2.27×10^3	2.92×10^6	4.3×10^5	4.28×10^7	2.08×10^3	2.79×10^6	4.5×10^5
Treatment replicate	4% 1	8.2×10^7	2.1×10^7	2.8×10^6	2.5×10^5	3.8×10^7	1.0×10^2	1.6×10^6	1.3×10^5
	2	4.2×10^6	1.0×10^3	9.0×10^5	2.8×10^5	7.2×10^6	1.0×10^3	4.7×10^6	9.0×10^4
	3	4.0×10^7	1.2×10^2	1.6×10^5	6.4×10^5	4.0×10^6	2.2×10^2	1.7×10^5	5.6×10^5
	4	3.1×10^6	2.4×10^3	1.2×10^6	1.8×10^5	3.4×10^7	2.4×10^3	3.3×10^5	3.6×10^5
	5	3.2×10^7	3.7×10^2	1.8×10^6	4.4×10^5	4.6×10^7	2.9×10^2	3.0×10^6	2.9×10^4
	6	6.0×10^7	2.2×10^3	1.3×10^6	8.3×10^5	3.0×10^7	2.7×10^3	2.5×10^6	4.2×10^5
	Range	3.1×10^6-8.2×10^7	1.0×10^3-3.7×10^2	1.2×10^6-9.0×10^5	1.8×10^5-6.4×10^5	3.0×10^7-7.2×10^6	1.0×10^2-2.9×10^2	1.6×10^6-4.7×10^6	1.3×10^5-9.0×10^4
	Mean	4.78×10^7	2.1×10^3	2.95×10^6	4.4×10^5	4.3×10^7	2.07×10^3	2.8×10^6	4.43×10^5
Treatment replicate	6% 1	5.1×10^7	2.0×10^2	1.7×10^5	1.9×10^5	3.6×10^7	3.0×10^2	3.1×10^6	3.6×10^5
	2	3.6×10^6	1.0×10^3	3.6×10^5	9.4×10^5	3.8×10^6	1.0×10^3	2.13×10^7	4.4×10^4
	3	6.0×10^6	1.3×10^3	1.5×10^6	2.5×10^5	3.2×10^7	2.2×10^2	1.6×10^6	6.1×10^5
	4	5.4×10^7	2.1×10^3	2.8×10^6	4.0×10^6	5.1×10^6	2.4×10^2	2.8×10^5	9.2×10^4
	5	4.2×10^7	3.3×10^2	4.3×10^6	3.2×10^5	4.3×10^7	1.5×10^3	2.7×10^6	2.5×10^5
	6	4.1×10^7	3.0×10^2	3.1×10^6	5.8×10^5	6.5×10^7	2.7×10^3	4.2×10^6	1.8×10^5
	Range	3.6×10^6-5.4×10^7	1.0×10^3-3.3×10^2	1.5×10^6-4.3×10^6	1.9×10^5-9.4×10^5	3.2×10^7-6.5×10^7	1.0×10^3-3.0×10^2	1.6×10^6-4.2×10^6	1.8×10^5-9.2×10^4
	Mean	4.73×10^7	2.1×10^3	2.83×10^6	4.47×10^5	4.42×10^7	2.13×10^3	2.76×10^5	4.6×10^5

Source: Author's Analysis, 2015

4.2.7 Heavy metals concentration in soils before and after contamination

Heavy metals are generally referred to as those metals which possess a specific density of more than 5g/cm^3 and adversely affect the environment and living organisms (Jarup, 2003). These metals can maintain various biochemical and physiological functions in living organisms when in very low concentrations. However, they become toxic when they exceed certain threshold levels. Heavy metals have adverse health effects and last for a long period of time. Heavy metals exposure continues and is increasing in many parts of the world. They are environmental pollutants and their toxicity is a problem of increasing significance for ecological, evolutionary, nutritional and environmental reasons (Jaishaukar *et al*., 2013; Nagajyoti *et al*., 2010). The most commonly found heavy metals in waste water include arsenic, cadmium, chromium, copper, lead, nickel and zinc, all of which cause risks to human health and the environment (Lambert *et al*., 2000). Heavy metals enter the surroundings by natural means and through human activities. Various sources of heavy metals include soil erosion, natural weathering of the earth's crust, mining, industrial effluents, urban runoff, sewage discharge, insect or disease control agents applied to crops, and many others (Morais *et al*., 2012).

The concentration levels of heavy metals before and after contamination are shown in Figures 4.25 to 4.48. The concentration level of the heavy metals increased after contamination in both surface and subsurface soils compared to the pre-contaminated (control) soils. The mean concentration in mg/kg level of lead in the well drained site were 7.09, 7.06 and 9.52 in surface soils and 9.20, 8.93 and 9.52 in subsurface soils also in mg/kg before contamination while the mean values increased after contamination to 10.78, 11.53 and 11.18 all in mg/kg in surface soils and 13.54, 13.61 and 13.15 in mg/kg respectively in subsurface soils in the 2%, 4% and 6% polluted plots. In the waterlogged site the mean values of lead in mg/kg before contamination were 6.18, 6.11 and 6.10 in surface soils and 5.56, 5.68 and 5.53 in subsurface soils in mg/kg while the mean values in mg/kg after contamination increased to 6.82, 7.89 and 6.82 (surface soils) and 6.40, 6.62 and 6.42 in mg/kg (subsurface soils) in the 2%, 4% and 6% polluted plots. The mean values of lead in contaminated soils were slightly higher than the pre-contaminated soils and there was no statistically significant difference in the two soil samples analysed.

The concentration level of cadmium in the well drained site before contamination in mg/kg were 0.2, 0.22 and 0.25 in surface soils and 0.29, 0.30 and 0.26 in subsurface soils while the mean values in mg/kg increased after contamination to 0.52, 0.53 and 0.50 (surface soils) in 2%, 4% and 6% polluted plots. In the waterlogged site the mean values of cadmium before contamination were 0.39, 0.38 and 0.40 in surface soils and 0.40, 0.39 and 0.41 in subsurface soils in mg/kg while the mean values after contamination increased to 4.25, 4.52 and 3.30 (surface soils) and 2.26, 2.28 and 2.10 (subsurface soils) all in mg/kg in the 2%, 4% and 6% polluted plots. It was observed that the mean values of cadmium in contaminated soils were higher than in pre-contaminated soils but the difference between the two soil samples was not statistically significant.

The mean concentration level of nickel in the well drained site in mg/kg before contamination were 35.78, 35.62 and 35.65 in surface soils and 34.60, 34.50 and 34.48 in subsurface soils while the mean values in mg/kg after contamination increased to 43.06, 40.83 and 41.75 (surface soils) and 47.73, 46.34 and 42.05 (subsurface soils) in the 2%, 4% and 6% polluted plots. In the waterlogged site the mean values of nickel before contamination were 35.49, 35.37 and 35.48 in surface soils and 49.03, 49.18 and 47.53 in subsurface soils all in mg/kg while the mean values increased after contamination to 49.73, 44.80 and 47.00 (surface soils) and 54.12, 50.97 and 55.12 (subsurface soils) measure in mg/kg in 2%, 4% and 6% polluted plots. The mean values of nickel before and after contamination were significantly different ($p = 0.05$).

The mean values of copper in the well drained site before contamination were 6.19, 6.18 and 6.13 mg/kg in surface soils and 7.22, 7.24 and 7.25 mg/kg in subsurface soils while the mean values increased after contamination to 7.2, 7.11 and 7.03 (surface soils) and 7.82, 8.03 and 8.20 (subsurface soils) mg/kg. In the waterlogged site the mean concentrations of copper in mg/kg before contamination were 5.08, 5.14 and 5.15 in surface soils and 5.19 and 5.16 in subsurface soils while the mean values in mg/kg increased after contamination to 5.87, 6.15 and 6.47 (surface soils) and 6.56, 7.18 and 7.02 (subsurface soils) in the 2%, 4% and 6% polluted plots. Statistical analysis revealed that difference between before and after contamination in mean values of copper were significant. The overall increase in heavy metal content in soil after oil contamination is

consistent with the findings of Anolifo and Vwioko (1995), who concluded that the overall increase in heavy metal content in soil was largely due to oil spill. Heavy metal contamination is due to the presence of different metals in the soils, specifically copper, nickel, cadmium, zinc, chromium and lead (Honosa *et al.,* 2004). The general observation is that heavy metal contamination not only have significant impact on different parameters related to the quality and productivity of plants, but also result in changes in size, composition and microbial activity (Yao and Huang, 2003).

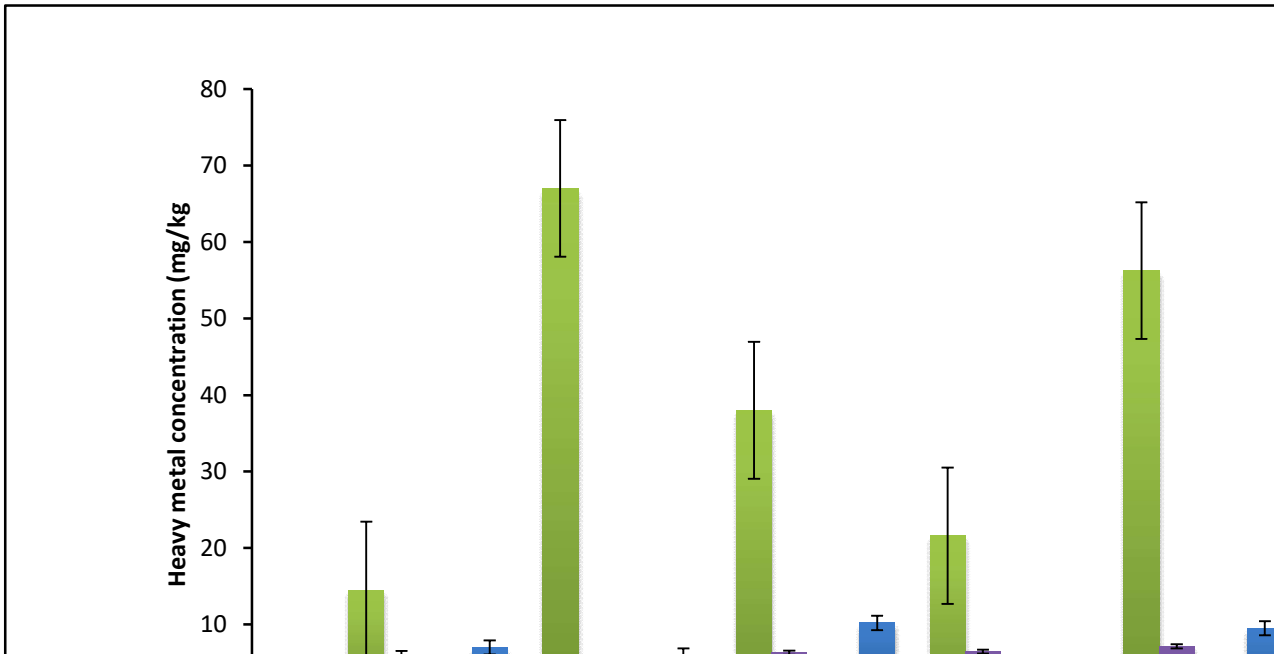


Fig. 4.25: Heavy metal concentration (mg/kg) in top soil (0-15cm) before crude oil (2%) contamination in well drained site.

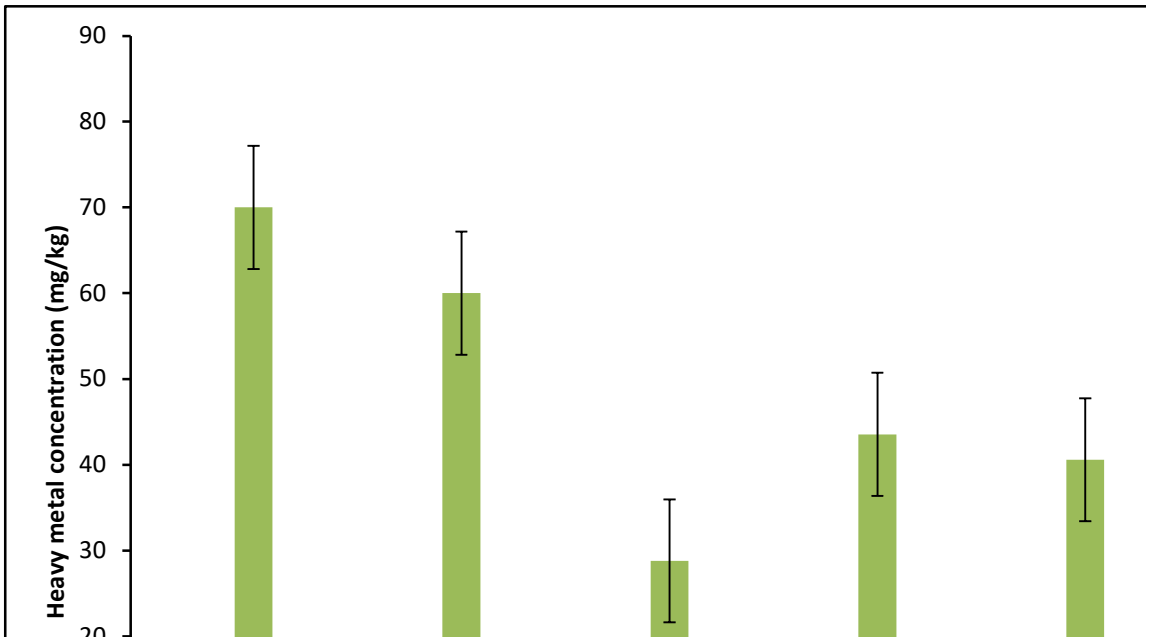


Fig. 4.26: Heavy metal concentration (mg/kg) in top soil (0-15cm) after crude oil (2%) contamination in well drained site

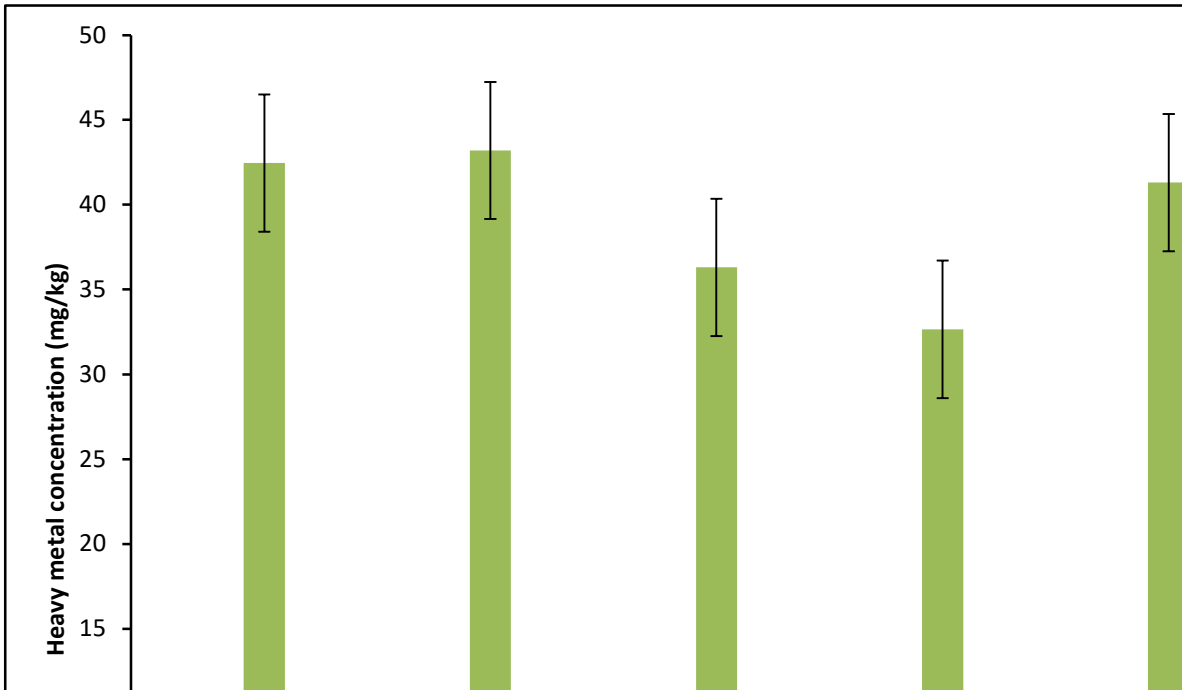


Fig. 4.27: Heavy metal concentration (mg/kg) in top soil (0-15cm) before crude oil (2%) contamination in waterlogged site

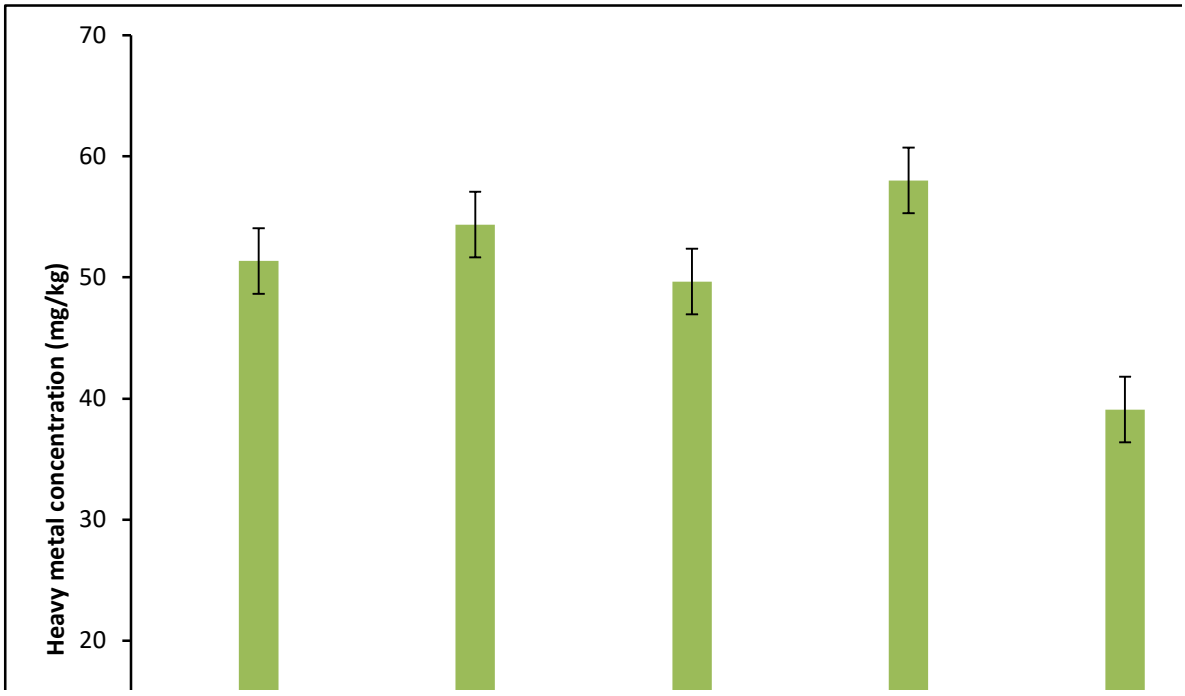


Fig. 4.28: Heavy metal concentration (mg/kg) in top soil (0-15cm) after crude oil (2%) contamination in waterlogged site

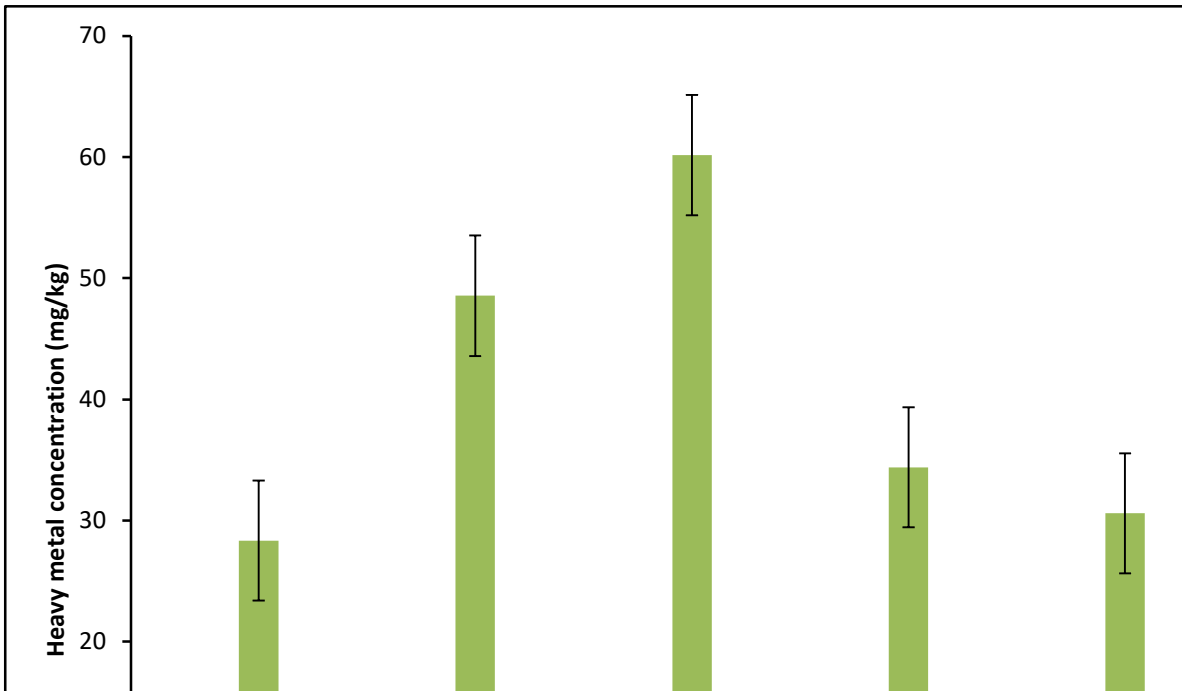


Fig. 4.29: Heavy metal concentration (mg/kg) in top soil (0-15cm) before crude oil (4%) contamination in well drained site

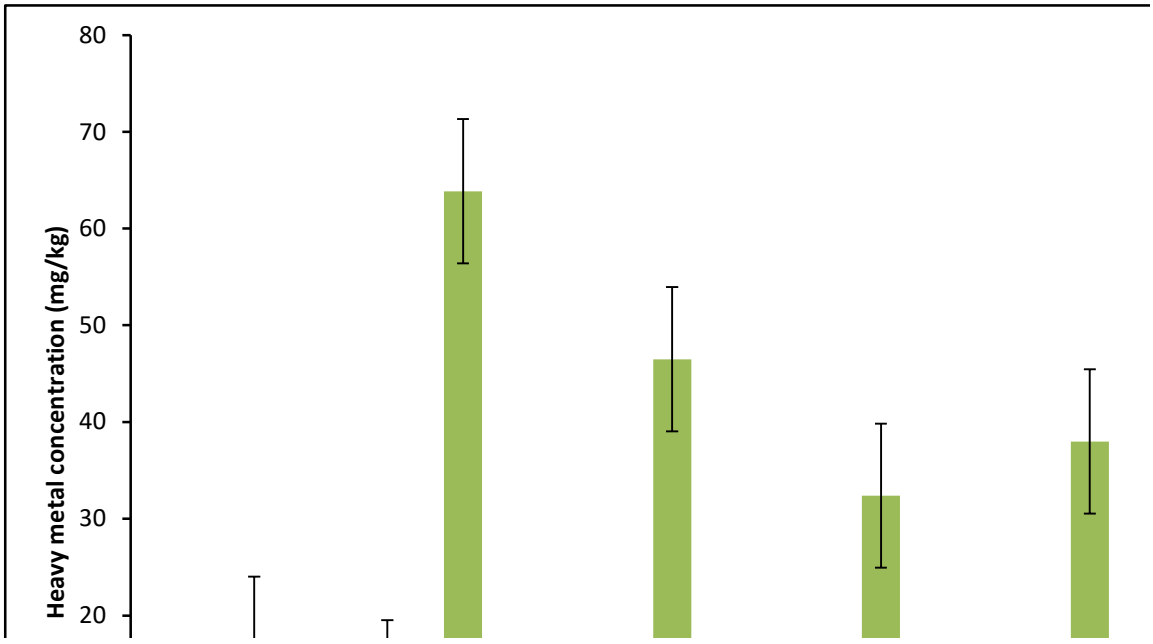


Fig. 4.30: Heavy metal concentration (mg/kg) in top soil (0-15cm) after crude oil (4%) contamination in well drained site

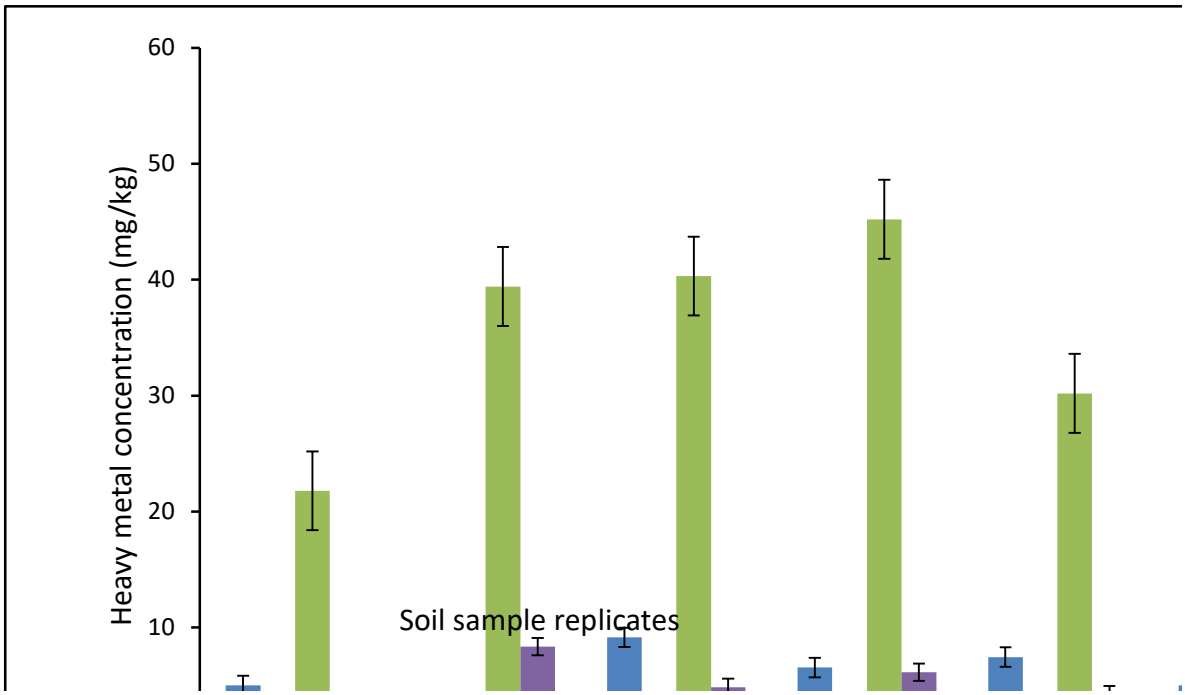


Fig. 4.31: Heavy metal concentration (mg/kg) in top soil (0-15cm) before crude oil (4%) contamination in waterlogged site

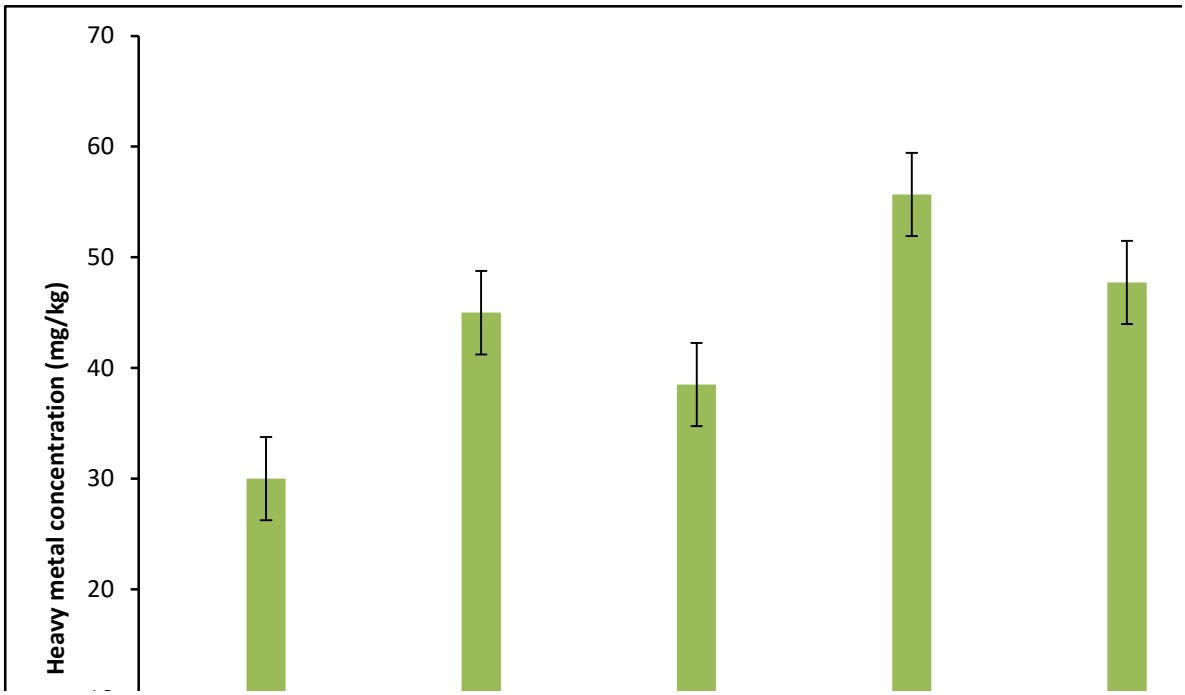


Fig. 4.32: Heavy metal concentration (mg/kg) in top soil (0-15cm) after crude oil (4%) contamination in waterlogged site

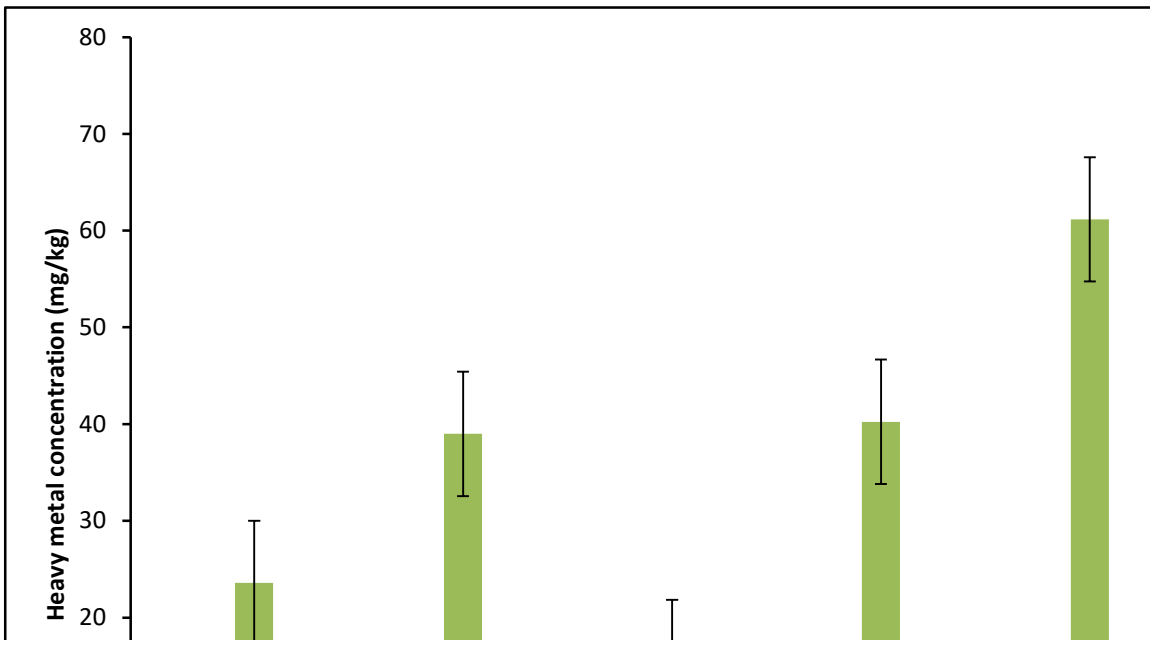


Fig. 4.33: Heavy metal concentration (mg/kg) in top soil (0-15cm) before crude oil (2%) contamination in well drained site

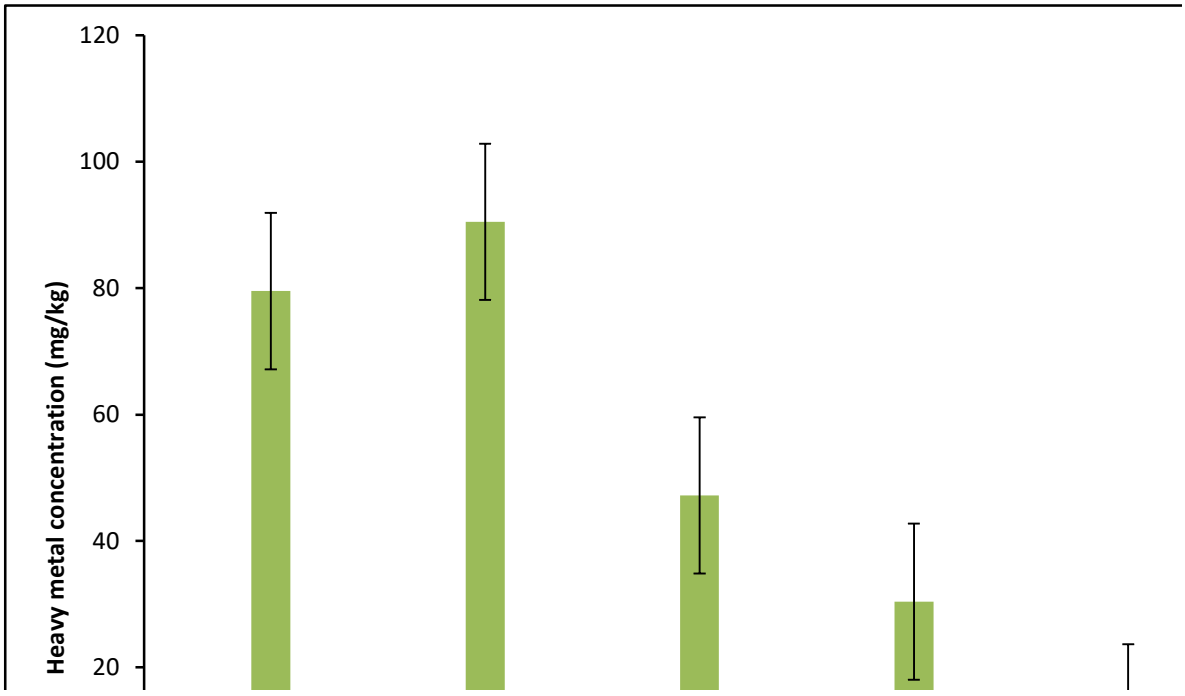


Fig. 4.34: Heavy metal concentration (mg/kg) in top soil (0-15cm) after crude oil (2%) contamination in well drained site

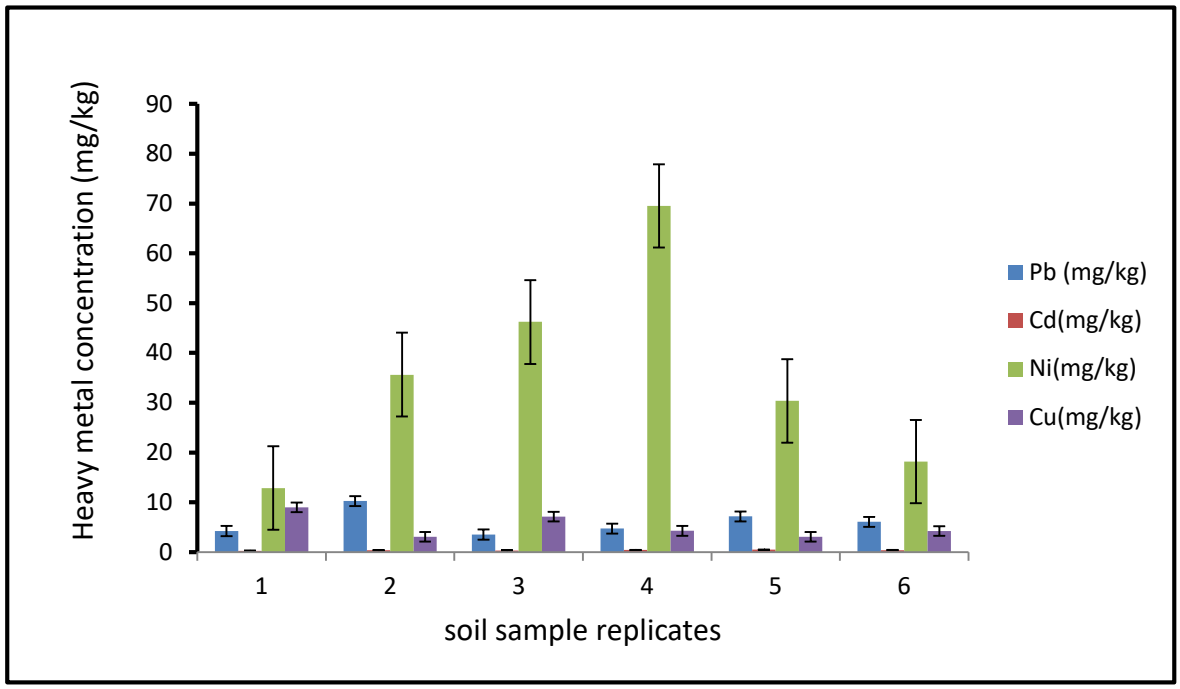


Fig. 4.35: Heavy metal concentration (mg/kg) in top soil (0-15cm) before crude oil (2%) contamination in waterlogged site

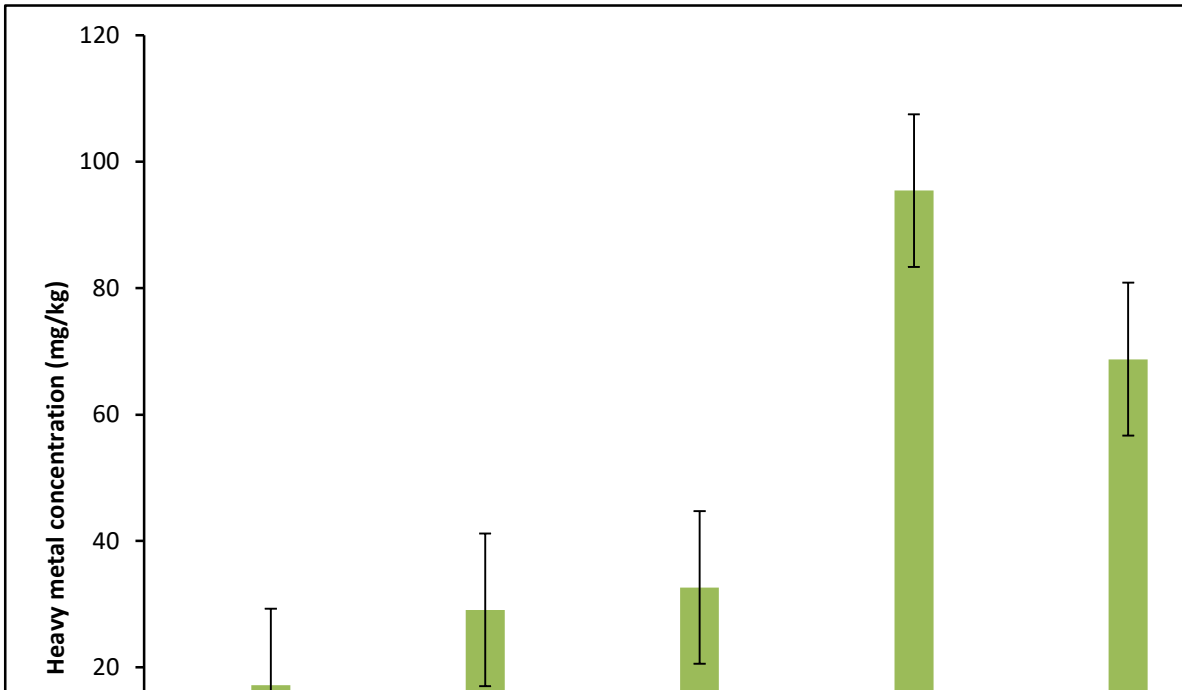


Fig. 4.36: Heavy metal concentration (mg/kg) in top soil (0-15cm) after crude oil (6%) contamination in waterlogged site

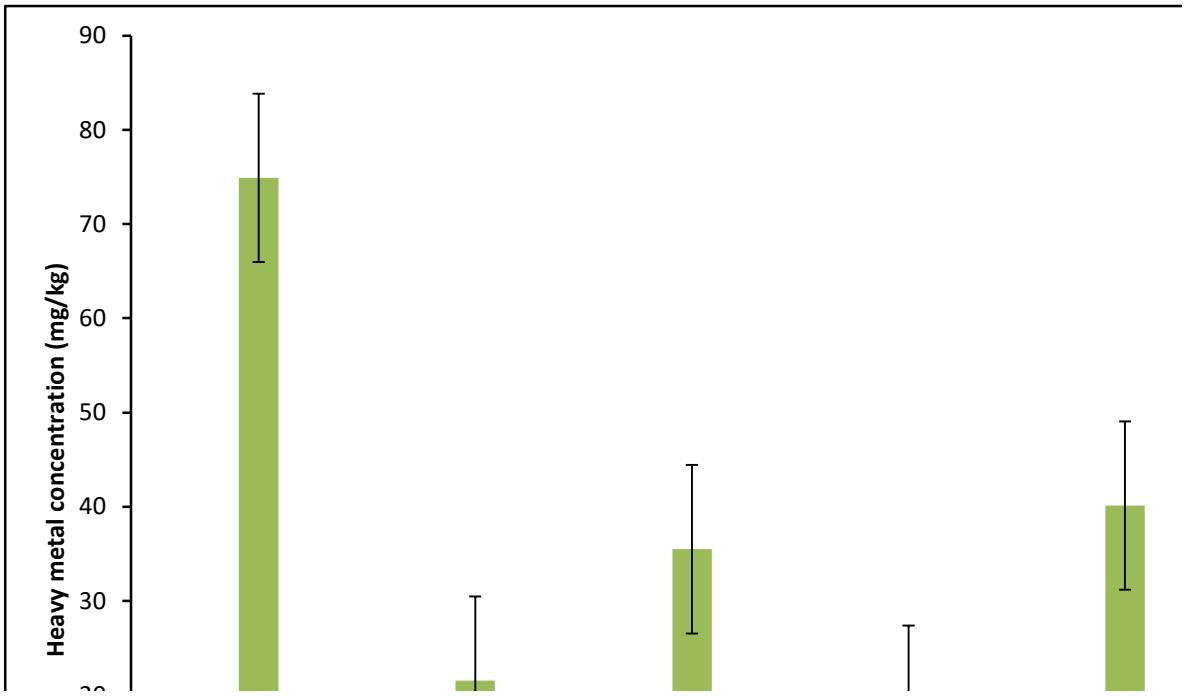


Fig. 4.37: Heavy metal concentration (mg/kg) in sub soil (15-30cm) before crude oil (2%) contamination in well drained site

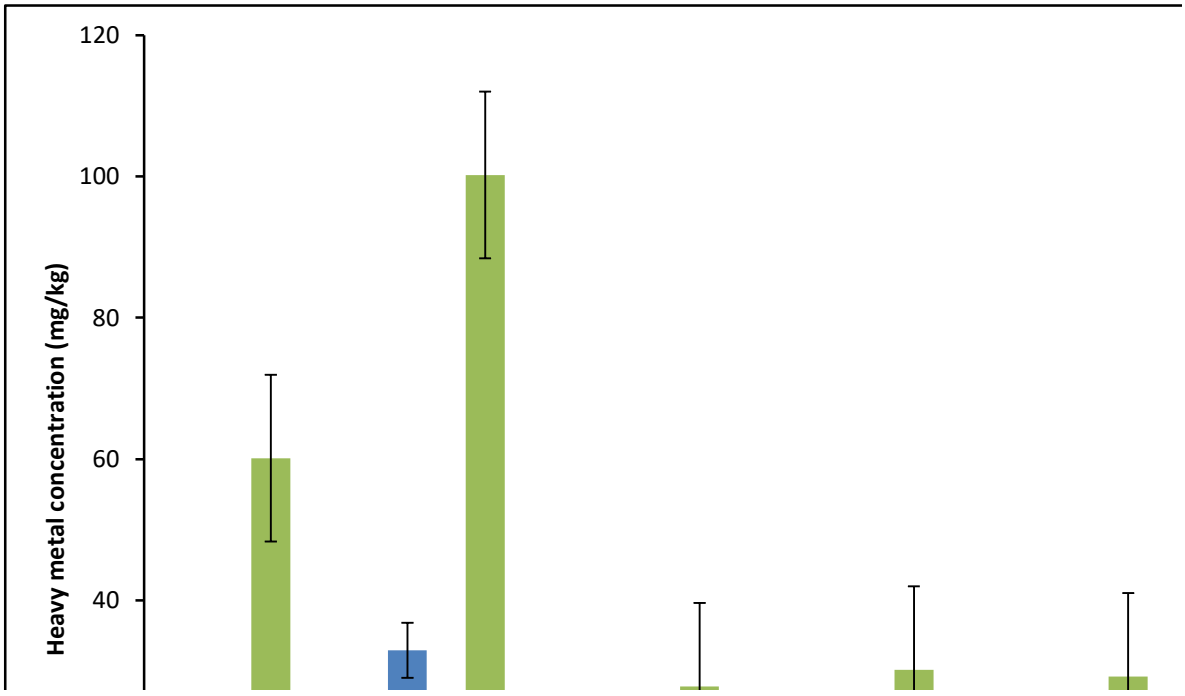


Fig. 4.38: Heavy metal concentration (mg/kg) in sub soil (15-30cm) after crude oil (2%) contamination in well drained site

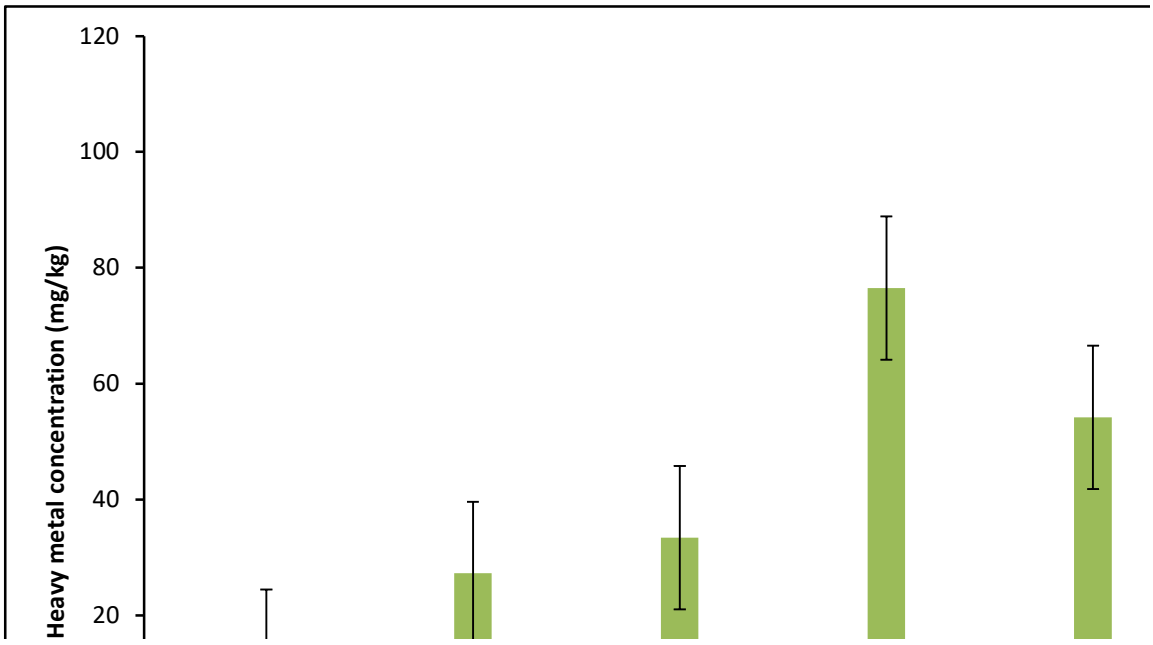


Fig. 4.39: Heavy metal concentration (mg/kg) in sub soil (15-30cm) before crude oil (2%) contamination in waterlogged site

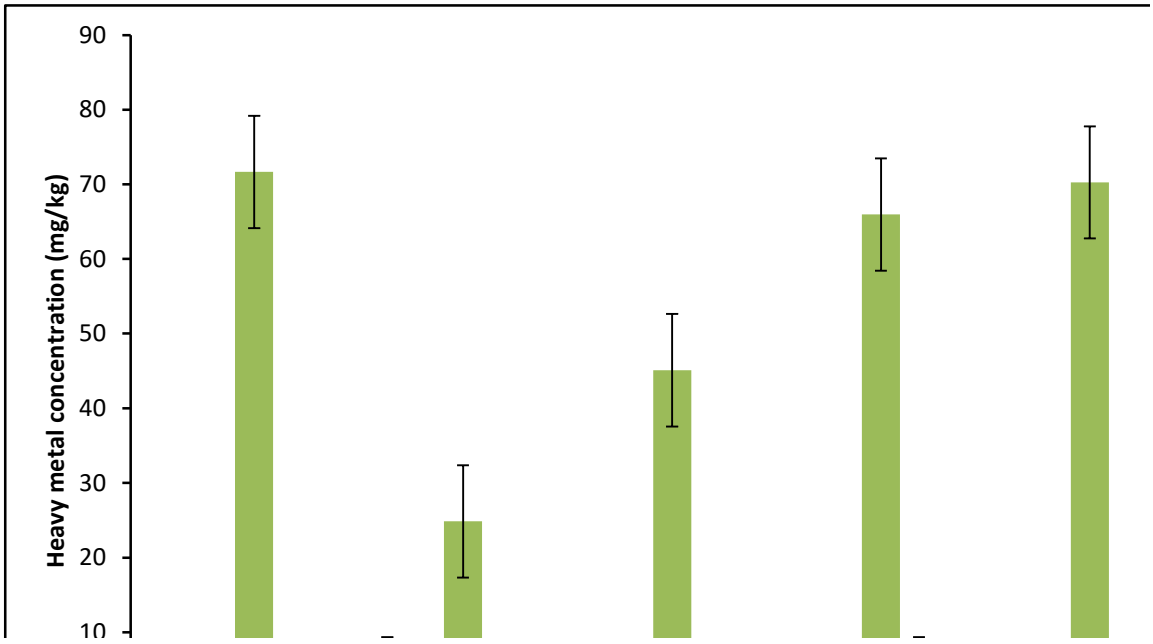


Fig. 4.40: Heavy metal concentration (mg/kg) in sub soil (15-30cm) after crude oil (2%) contamination in waterlogged site

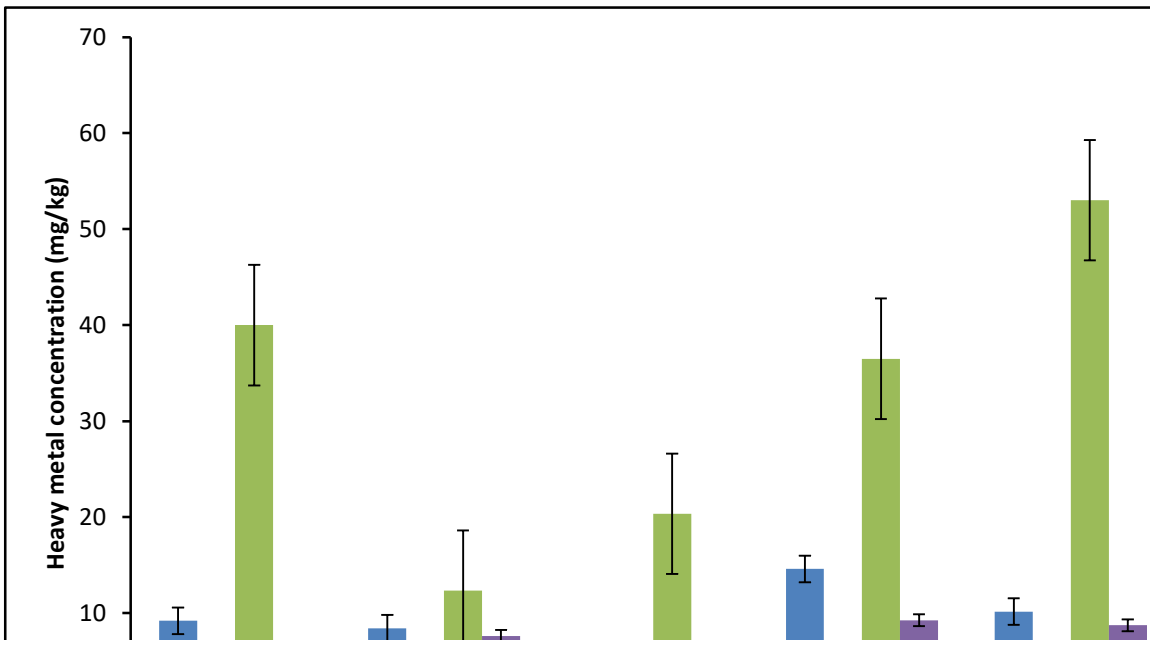


Fig. 4.41: Heavy metal concentration (mg/kg) in sub soil (15-30cm) before crude oil (2%) contamination in well drained site

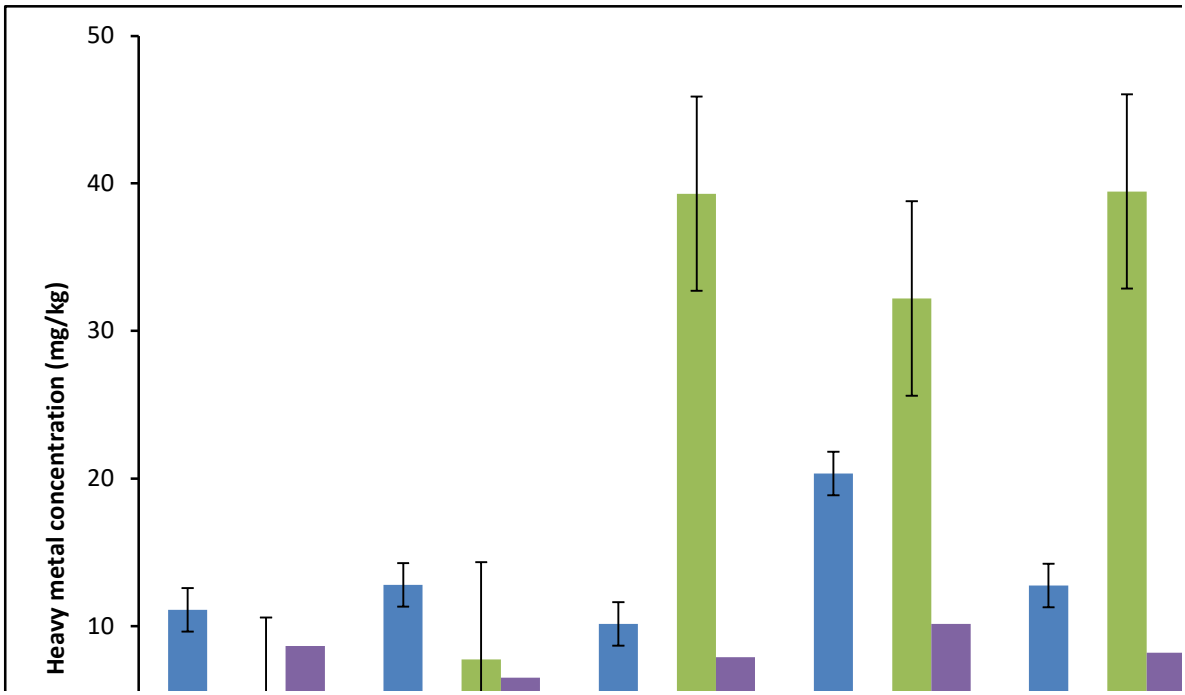


Fig. 4.42: Heavy metal concentration (mg/kg) in sub soil (15-30cm) after crude oil (2%) contamination in well drained site

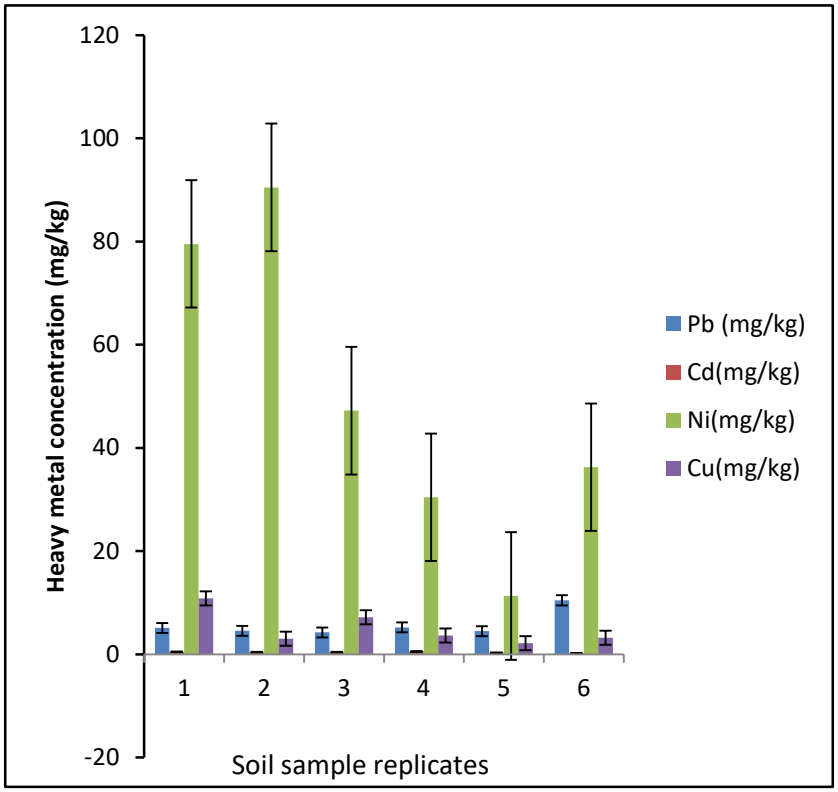


Fig. 4.43: Heavy metal concentration (mg/kg) in sub soil (15-30cm) before crude oil (4%) contamination in waterlogged site

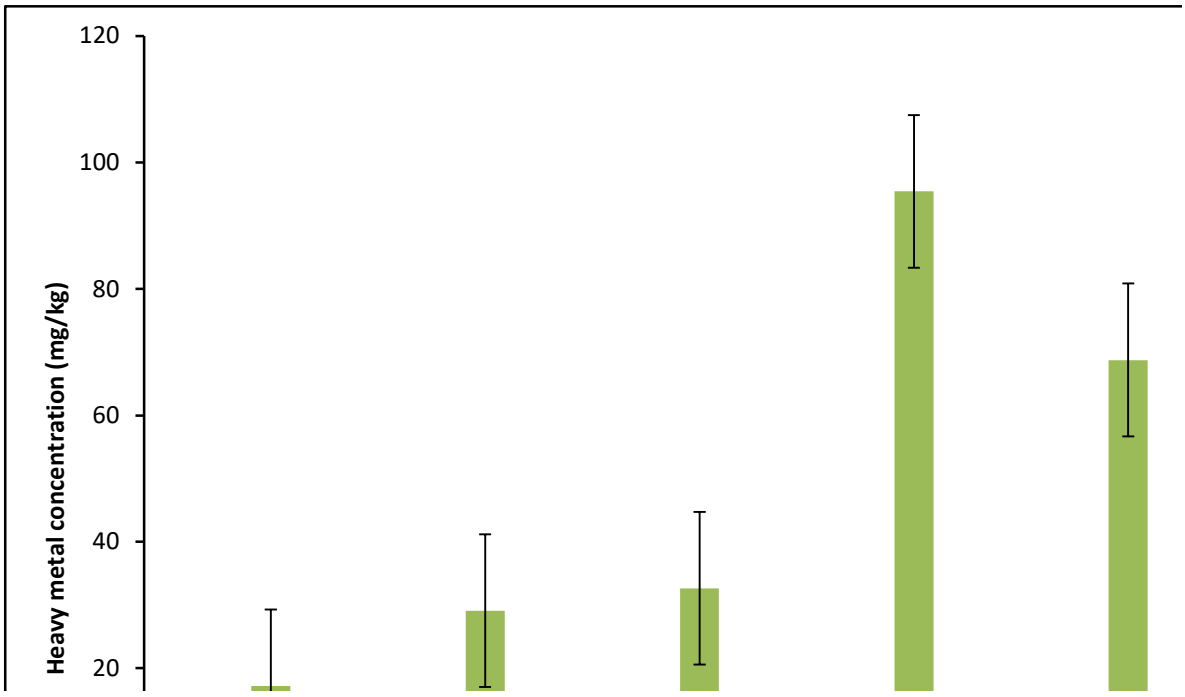


Fig. 4.44: Heavy metal concentration (mg/kg) in sub soil (15-30cm) after crude oil (4%) contamination in waterlogged site

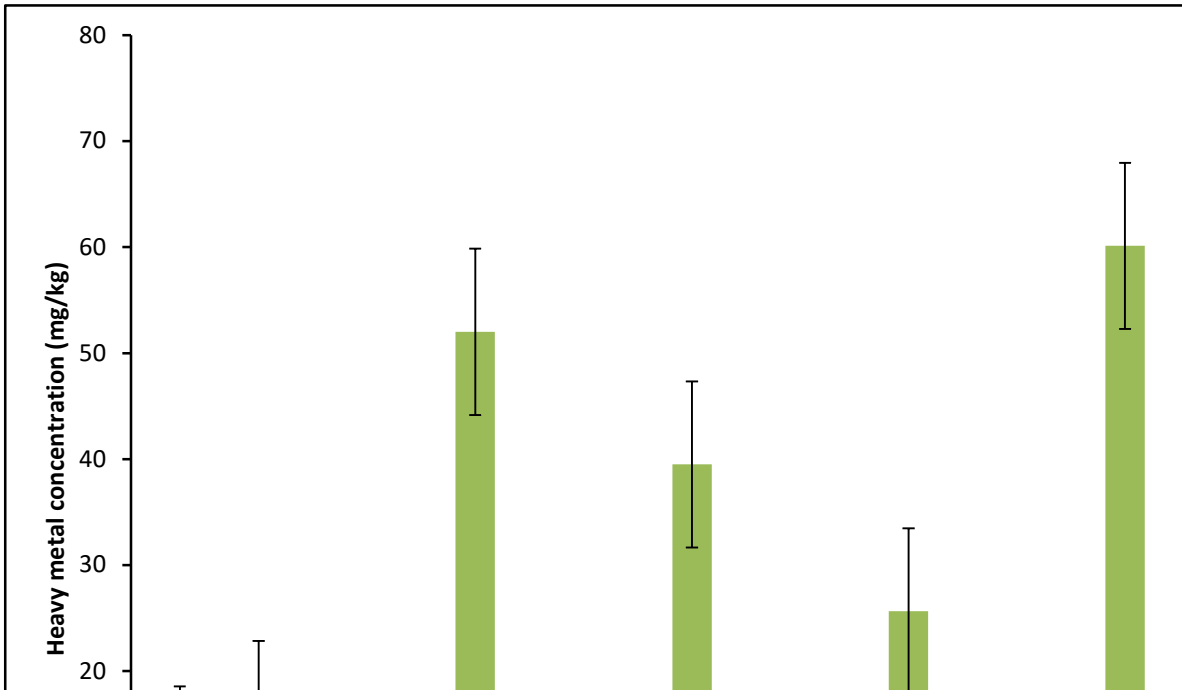


Fig. 4.45: Heavy metal concentration (mg/kg) in soil (15-30cm) before crude oil (6%) contamination in well drained site

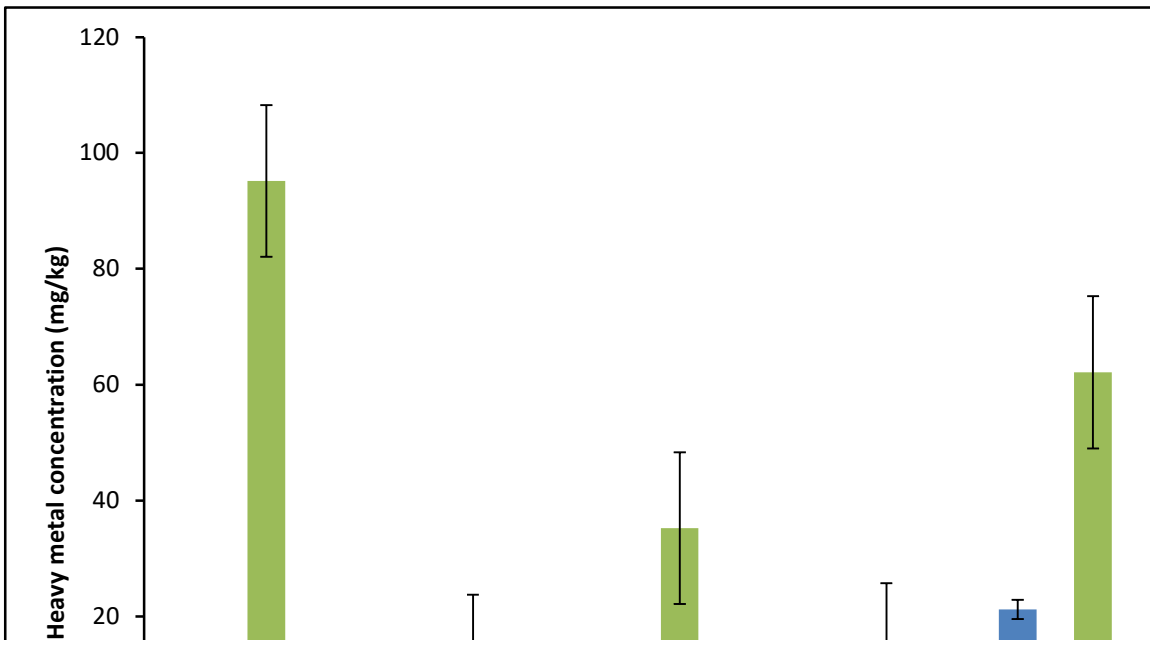


Fig. 4.46: Heavy metal concentration (mg/kg) in sub soil (15-30cm) after crude oil (6%) contamination in well drained site

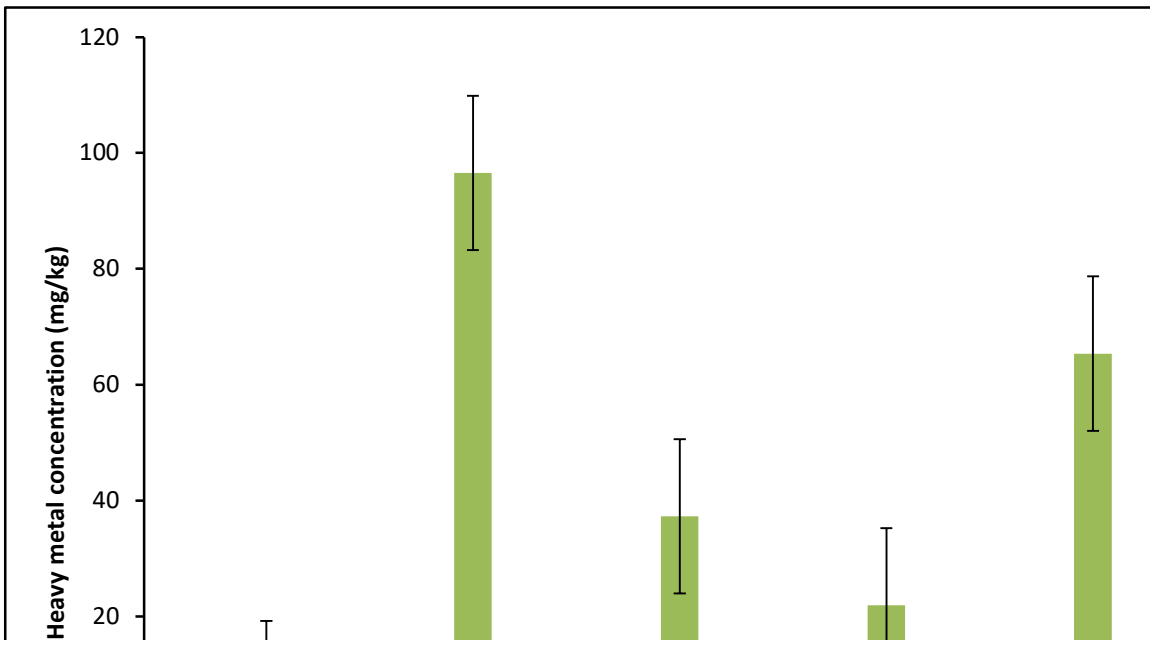


Fig. 4.47: Heavy metal concentration (mg/kg) in sub soil (15-30cm) before crude oil (6%) contamination in waterlogged site

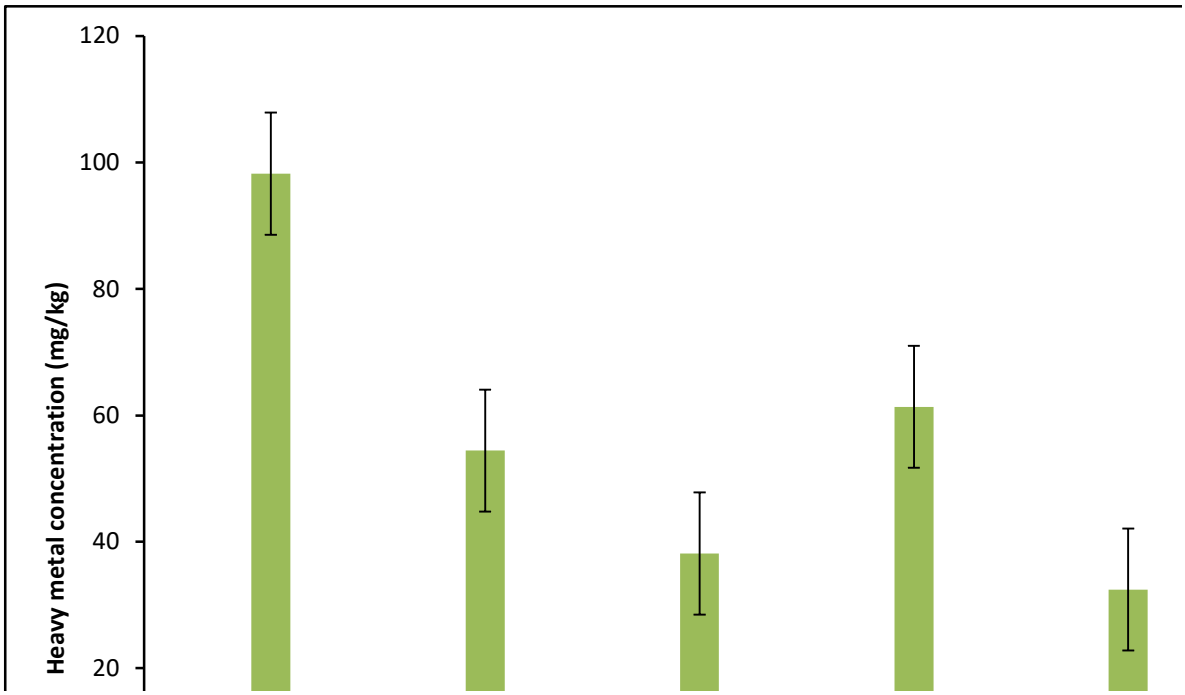


Fig. 4.48: Heavy concentration (mg/kg) in sub soil (15-30cm) after crude oil (6%) contamination in waterlogged site

Effects of Heavy Metals on Humans

Heavy metals are commonly found in the environment and diet. They are required in small amounts for maintaining good health, but in large amounts they can become toxic or dangerous. Heavy metal toxicity can reduce energy levels and damage the functioning of the brain, lungs, kindney, liver, blood composition and other important organs. Long-term exposure to heavy metals can lead to physical, muscular and neurological degenerative processes that cause diseases. Arsenic is highly carcinogenic and can cause cancer of lungs, liver, bladder and skin. Human activities such as mining, manufacturing, and fossil fuel burning have resulted in the accumulation of lead and its compounds in the environment, including air, water and soil. The main sources of lead exposure are lead based paints, gasoline, cosmetics, toys, household dust, contaminated soil, industrial emissions (Gerharhsson *et al*.,2002). Lead is highly toxic. Lead has major effects on different parts of the body. Acute exposure to lead can cause loss of appetite, headache, hypertension, abdominal pain, renal dysfunction, fatigue, sleeplessness, arthritis, hallucinations and vertigo. Mercury has the ability to combine with other elements and form organic and inorganic mercury. The nervous system is very sensitive to all types of mercury. Increased exposure to mercury can alter brain functions and lead to shyness, tremors, memory problems, irritability, and changes in vision or hearing. Exposure to metallic mercury vapors at higher levels for shorter periods of time can lead to lung damage, vomiting, diarrhea, nausea, skin rashes, increased heart rate or blood pressure.

Human are exposed to these heavy metals by means of air, food and water. In marine foods, mercury is often seen at higher levels. It is present in higher concentrations in most species of fatty fish and in the liver of lean fish (Reily, 2007). Thorough knowledge of heavy metals is therefore important to provide defensive measures against their excessive contact (Ferner, 2001).

4.3.0 Physical properties of contaminated and remediated soils.

4.3.1 Soil particle size distribution after contamination and after remediation

The results of particle size distribution of soils after contamination and after remediation are presented in Tables 4.9 and 4.10. From the data in Tables 4.9 and 4.10 sand is still the predominant soil fraction in both contaminated and remediated soils. The mean percentages of sand fraction in the well drained site after contamination were 82%, 82.5% and 82.3% in surface soils and 80.3%, 80.5% and 80.7% in subsurface soils in the 2%, 4% and 6% polluted plots while the mean percentages after remediation were 81.7%, 81.5% and 81.3% (surface soils) and 80.3%, 80.2% and 80% (subsurface soils). In the waterlogged site the sand fraction after contamination had mean percentages of 61%, 61.5% and 60.8% in surface soils and 59%, 58.8% and 59.2% in subsurface soils in the 2%, 4% and 6% polluted plots while the mean percentages after remediation were 60.8%, 60.3% and 60.5% (surface soils) and 59%, 58.8% and 58.7% (subsurface soils). There was no significant difference between the contaminated and remediated soils as indicated in Tables 4.9 and 4.10. The depth of soil sampling was still observed to influence sand particle distribution at 0-15cm depth more than at 15-30cm. The percentage of sand in the surface soils were slightly higher than in the subsurface soils. It was also observed that the well drained site has higher sand content which result in having higher rapid water and hydrocarbon infiltration and lower water and hydrocarbon holding capacity.

The mean percentages of silt in the well drained site after contamination were 14%, 13.8% and 13.7% in surface soils and 14.2%, 14.3% and14.2% in subsurface soils in the 2%, 4% and 6% polluted plots while the mean percentages after remediation were 14%, 14.2 and 14.2% (surface soils) and 14.3%, 14.2% and 14.2% (subsurface soils). In the waterlogged site the mean percentages of silt after contamination were 32%, 31.5% and 31.7% in surface soils and 32.7%, 32.5% and 32.2% in subsurface soils while the mean percentages after remediation were 31.2%, 31% and 31.3% (surface soils) and 33%, 32.5% and 32.7% (subsurface soils). It was noted that the proportion of silt did not change significantly after remediation as indicated in Tables 4.9 and 4.10. The waterlogged area has silt content that is high that may lead to slower intake of hydrocarbon and water but water holding capacity will be higher.

Table 4.11: Percentage of Sand, Silt and Clay Content in Top Soils (0-15cm) after Contamination and after Remediation.

Pollution level		Well drained site						Waterlogged site					
		After Contamination			After Remediation			After Contamination			After Remediation		
		Sand (%)	Silt (%)	Clay(%)	Sand(%)	Silt (%)	Clay(%)	Sand (%)	Silt (%)	Clay(%)	Sand (%)	Silt (%)	Clay (%)
Treatment replicates	2% 1	81	15	4	81	15	4	61	32	7	61	31	8
	2	83	15	3	81	14	5	62	34	4	62	30	8
	3	82	14	4	82	13	5	61	32	7	60	33	7
	4	83	14	3	81	15	4	61	30	9	59	32	9
	5	81	13	6	83	13	4	60	33	7	61	30	9
	6	82	14	4	82	14	4	61	31	8	62	31	7
	Range	81-83	13-15	3-6	81-83	13-15	4-5	60-62	30-34	4-9	59-62	30-33	7-9
	Mean	82	14	4	81.7	14	4.3	61	32	7	60.8	31.2	8
	S.D	0.82	0.58	1.00	0.75	0.82	0.47	0.58	1.29	1.53	1.07	1.07	0.82
Treatment replicates	4% 1	84	13	3	81	14	5	62	31	7	60	31	9
	2	83	14	3	80	15	5	61	30	9	61	30	9
	3	81	14	5	82	14	4	61	33	6	62	31	7
	4	82	13	5	83	13	4	62	32	6	59	32	9
	5	83	14	3	81	15	4	61	32	7	60	30	10
	6	82	15	3	82	14	4	62	31	7	60	32	8
	Range	81-84	13-15	3-5	80-83	14-15	4-5	61-67	30-33	6-9	59-61	30-32	7-10
	Mean	82.5	13.8	3.7	81.5	14.2	4.3	61.5	31.5	7	60.3	31	8.7
	S.D	0.96	0.69	0.94	0.96	0.69	0.47	0.5	0.96	1.00	0.94	2.65	0.94
Treatment replicates	6% 1	82	14	4	82	13	5	62	33	5	60	32	8
	2	82	13	5	81	14	5	61	30	9	59	33	8
	3	83	13	4	80	15	5	60	32	8	61	30	9
	4	82	14	4	81	14	5	60	32	8	62	32	6
	5	82	14	4	82	15	3	61	32	7	60	30	10
	6	83	14	3	82	14	4	61	31	8	61	31	8
	Range	82-83	13-14	3-5	80-82	13-15	3-5	60-62	30-33	5-9	59-61	30-33	6-10
	Mean	82.3	13.7	4	81.3	14.2	4.5	60.8	31.7	7.5	60.5	31.3	8.2
	S.D	0.47	0.47	0.58	0.74	0.09	0.76	0.69	0.94	1.26	0.96	1.14	1.21

Source: Author's analysis, 2015

Table 4.12: Percentage of Sand, Silt and Clay Content in Sub Soils (15-30cm) after Contamination and after Remediation.

Pollution level		Well drained site						Waterlogged site					
		Before Contamination			After contamination			Before Contamination			After contamination		
		Sand (%)	Silt (%)	Clay (%)	Sand (%)	Silt (%)	Clay (%)	Sand (%)	Silt (%)	Clay (%)	Sand (%)	Silt (%)	Clay(%)
Treatment replicates	2% 1	82	13	5	80	14	6	58	30	12	59	32	9
	2	80	14	6	82	14	4	60	32	8	60	33	7
	3	81	15	4	80	14	6	57	33	10	58	345	8
	4	79	15	6	81	14	5	60	35	5	57	32	11
	5	80	14	6	79	15	6	61	32	7	60	33	7
	6	80	14	6	80	15	5	58	34	8	60	34	6
	Range	79-82	13-15	4-6	79-82	14-15	4-6	57-61	30-35	5-12	57-60	32-34	6-11
	Mean	80.3	14.2	5.5	80.3	14.3	5.3	59	32.7	8.3	59	33	8
	S.D	0.94	0.69	0.76	0.94	0.47	0.75	1.41	1.60	2.21	1.15	0.82	1.63
Treatment replicates	4% 1	82	14	4	80	13	7	60	32	8	58	31	11
	2	81	15	4	81	14	5	58	34	8	57	32	11
	3	81	14	5	80	15	5	60	32	8	60	33	7
	4	80	14	6	79	15	6	57	34	9	61	32	7
	5	79	15	6	81	14	5	60	30	10	58	34	8
	6	80	14	6	80	14	6	58	33	9	59	33	8
	Range	80-82	14-15	4-6	79-81	13-15	5-7	57-60	30-34	8-10	57-61	31-34	7-11
	Mean	80.5	14.3	5.2	80.2	14.2	5.7	58.8	32.5	8.7	58.8	32.5	8.7
	S.D	0.96	0.47	0.90	0.69	0.69	0.81	1.21	1.38	0.75	1.34	0.96	1.7
Treatment replicates	6% 1	81	14	5	80	14	6	60	30	10	59	32	9
	2	82	13	5	79	13	8	58	33	9	57	33	10
	3	80	15	5	81	14	5	58	32	10	60	32	8
	4	81	14	5	81	15	4	60	33	7	58	34	8
	5	80	15	5	79	15	6	59	33	8	60	32	8
	6	80	14	6	80	14	6	60	32	8	58	33	9
	Range	80-82	13-15	5-6	79-81	13-15	4-6	58-60	30-33	7-10	57-60	32-34	8-10
	Mean	80-7	14.2	5.2	80	14.2	5.8	59.2	32.2	8.7	58.7	32.7	8.7
	S.D	0.74	0.69	0.37	0.82	0.69	1.21	0.90	1.07	1.11	1.11	0.75	0.75

Source: Author's analysis, 2015

The mean percentages of clay in the well drained site after contamination were 4%, 3.7% and 4% in surface soils and 5.5%, 5.2% and 5.2% in subsurface soils in the 2%, 4% and 6% polluted plots while the mean percentages after remediation were 4.3%, 4.5% and 4.5% (surface soils) and 5.3%, 5.7% and 5.8% (subsurface soils). In the waterlogged site the mean percentages of clay after contamination were 7%, 7% and 7.5% in surface soils and 8.3%, 8.7% and 8.7 in subsurface soils in 2%, 4% and 6% polluted plots while after remediation the mean percentages were 8%, 8.7% and 8.2% (surface soils) and 8%, 8.7% and 8.7% (subsurface soils). The percentage of clay did not change significantly after remediation as shown in Tables 4.9 and 4.10. The values of clay particles were observed to increase with depth.

4.3.2 Bulk density and total porosity after contamination and after remediation

4.3.2.1 Bulk density

The results of soil analysis after contamination and after remediation in Tables 4.11 and 4.12 showed that bulk density reduced after remediation with the application of the decomposed cassava peels compared to the contaminated soils. The mean bulk density values in the well drained site after contamination were 1.25 g/cm^3, 1.26g/cm and 1.26 g/cm^3 in surface soils and 1.40 g/cm^3 , 1.41g/cm and 1.41 g/cm^3 in subsurface soils in the 2%, 4% and 6% polluted plots while the mean values after remediation were 1.19 g/cm^3, 1.20 g/cm^3 and 1.18 g/cm^3 in surface soils and 1.32 g/cm^3, 1.34 g/cm^3 and 1.33 g/cm^3 in subsurface soils. In the waterlogged site the mean values of bulk density after contamination were 1.20 g/cm^3, 1.22 g/cm^3 and 1.23 g/cm^3 in surface soils in 2%, 4% and 6% polluted plots while the mean values after remediation were 1.17 g/cm^3, 1.18 g/cm^3 and 1.21 g/cm^3 in subsurface soils. The mean values of bulk density obtained after remediation in the well drained and waterlogged sites indicated that soils in the area can actually support plant growth.

In terms of the effectiveness of organic restoration as a bioremediation tool, cassava peels that are decomposed slightly reduced the bulk density of the soil, which was increased by oil pollution. It was observed that the mean bulk density values recorded after remediation were lower than the mean values after contamination. However, the difference between them was not statistically significant. The critical value of apparent density to limit root

growth varies depending on soil type (Hunt and Gikes, 1992), but global densities greater than 1.6 g / cm tend to limit root growth (McKenzie *et al.,* 2004).). Generally, sandy soils have higher bulk density (1.3 to 1.7 g / cm) when compare to fine and loose clays (1.1 to 1.6 g / cm), due to larger pores though fewer.

4.3.2.2 Total porosity

The mean values for total porosity in the well drained site after contamination were 52.7% and 52.5% in surface soils and 47.2%, 46.8% and 47% in subsurface soils in the 2%, 4% and 6% polluted plots while the mean values after remediation were 55.2%, 54.7% and 55.3% in surface soils and 50.2%, 49.3% and 49.7% in subsurface soils. In the waterlogged site the mean values for total porosity after contamination were 54.7%, 54% and 53.7% in surface soils and 49.8%, 49.5% and 50.3% in subsurface soils in the 2%, 4% and 6% polluted plots while the mean values after remediation were 55.7%, 55.3% and 56.3% in surface soils and 54.5%, 54% and 54.3% in subsurface soils as shown in Tables 4.11 and 4.12. It was observed that total porosity increased after remediation when compared to the contaminated soil but the values were not significantly different. Total porosity increases with time as organic amendments decomposed and mineralized, and oil that clogged porous spaces was gradually consumed by the degrading population of bacteria.

The crude oil pollutant which blocked the pore spaces within the soil during contamination may have been removed in the process of remediation. The pore spaces is occupied by soil water while the conduits for the exchange of air and water is provided by the pore system. Bulk density and porosity of soil is an indication of size, shape and particles arrangement and voids which shows suitability of the soil for root growth, permeability and appropriateness of soil-plant-atmosphere (Cresswell and Hamilton, 2002; Mc Kenzie *et al*., 2004). Generally, it is preferable to plant in low bulk density soil (< 1.5 g/cm) (Hunt and Gikes,1992) for air and water to move optimumly through the soil.

Table 4.13: Bulk Density and Total Porosity Values for Top Soils (0-15cm) after Contamination and after, Remediation.

Pollution level		Well drained site				Water logged site			
		Before Contamination		After contamination		Before Contamination		After contamination	
		Bulk density (g/cm^3)	Total porosity (%)	Bulk density (g/cm^3)	Total porosity (%)	Bulk density (g/cm^3)	Total porosity (%)	Bulk density (g/cm^3)	Total porosity (%)
Treatment replicates	2% 1	1.22	54	1.18	55	1.19	55	1.18	
	2	1.25	53	1.17	56	1.19	55	1.16	55
	3	1.24	53	1.19	55	1.20	55	1.18	56
	4	1.26	52	1.20	55	1.22	54	1.17	55
	5	1.27	52	1.19	55	1.20	55	1.16	56
	6	1.26	52	1.20	55	1.22	54	1.17	56
	Range	1.22-1.27	52-54	1.17-1.20	55-56	1.19-1.22	54-55	1.16-1.18	55-56
	Mean	1.25	52.7	1.19	55.2	1.20	54.7	1.17	55.7
	S.D	0.02	0.75	0.01	0.37	0.01	0.47	0.01	0.47
Treatment replicates	4% 1	1.25	53	1.21	54	1.22	54	1.19	55
	2	1.25	53	1.18	55	1.23	54	1.18	55
	3	1.28	52	1.20	55	1.21	54	1.16	56
	4	1.26	52	1.22	54	1.22	54	1.20	55
	5	1.25	53	1.19	55	1.21	54	1.18	55
	6	1.27	52	1.20	55	1.23	54	1.17	56
	Range	1.25-1.28	52-53	1.18-1.22	54-55	1.21-1.23	54	1.16-1.20	55-56
	Mean	1.26	52.5	1.20	54.7	1.22	54	1.18	55.3
	S.D	0.01	0.50	0.01	0.47	0.01	0	0.01	0.47
Treatment replicates	6% 1	1.25	53	1.18	55	1.24	53	1.15	57
	2	1.24	53	1.17	56	1.23	54	1.17	56
	3	1.27	52	1.17	56	1.22	54	1.16	56
	4	1.26	52	1.19	55	1.23	54	1.17	56
	5	1.25	53	1.18	55	1.22	54	1.15	57
	6	1.26	52	1.19	55	1.24	53	1.16	56
	Range	1.24-1.27	52-53	1.17-1.19	55-56	1.22-1.20	53-54	1.15-1.17	56-57
	Mean	1.26	52.5	1.18	55.3	1.23	53.7	1.16	56.3
	S.D	0.01	0.50	0.01	0.47	0.01	0.47	0.01	0.47

Source: Author's analysis 2015

Table 4.14: Bulk Density and Total Porosity values for Top Soils (15-30cm) after Contamination and after, Remediation.

Pollution level		Well drained site				Waterlogged site			
		Before Contamination		After contamination		Before Contamination		After contamination	
		Bulk density (g/cm^3)	Total porosity (%)	Bulk density (g/cm^3)	Total porosity (%)	Bulk density (g/cm^3)	Total porosity (%)	Bulk density (g/cm^3)	Total porosity (%)
Treatment replicates	2% 1	1.41	47	1.33	50	1.32	50	1.21	54
	2	1.40	47	1.31	51	1.31	51	1.19	55
	3	1.42	46	1.29	51	1.33	50	1.18	55
	4	1.39	48	1.32	50	1.35	49	1.21	54
	5	1.41	47	1.33	50	1.33	50	1.19	55
	6	1.38	48	1.34	49	1.34	49	1.22	54
	Range	1.38-1.42	46-48	1.29-1.34	49-51	1.31-1.35	49-51	1.18-1.22	54-55
	Mean	1.40	47.2	1.32	50.2	1.33	49.8	1.20	54.5
	S.D	0.01	0.69	0.02	0.69	0.01	0.69	0.1	0.50
Treatment replicates	4% 1	1.40	47	1.34	49	1.33	50	1.23	54
	2	1.39	48	1.32	50	1.34	49	1.21	54
	3	1.42	46	1.35	49	1.32	50	1.22	54
	4	1.41	47	1.33	50	1.35	49	1.21	54
	5	1.40	47	1.34	49	1.33	50	1.23	54
	6	1.42	46	1.36	49	1.34	49	1.22	54
	Range	1.39-1.42	46-48	1.32-1.36	49-50	1.32-1.35	49-50	1.21-1.23	54
	Mean	1.41	46.8	1.34	49.3	1.34	49.5	1.22	54
	S.D	0.01	0.69	0.01	0.47	0.01	0.50	0.01	0
Treatment replicates	6% 1	1.41	47	1.32	50	1.31	51	1.22	54
	2	1.40	47	1.34	49	1.33	50	1.20	55
	3	1.39	48	1.33	50	1.32	50	1.21	54
	4	1.41	47	1.32	50	1.31	51	1.22	54
	5	1.40	47	1.34	49	1.32	50	1.20	5
	6	1.43	46	1.33	50	1.33	50	1.21	54
	Range	1.39-1.43	46-48	1.32-1.34	49-50	1.31-1.33	50-51	1.20-1.22	54-55
	Mean	1.41	47	1.33	49.7	1.32	50.3	1.21	54.3
	S.D	0.01	0.58	0.01	0.47	0.01	0.47	0.01	0.47

Source: Author's analysis 2015

4.3.2.3 Moisture content

The mean moisture content of soils in the well drained site after contamination were 7.10%, 7.02% and 7.01% in surface soils and 7.50%, 7.64% and 7.68% in subsurface soils in 2%, 4% and 6% polluted plots while the mean values after remediation were 11.70%, 11.23% and 11.12% in surface soils and 10.42%, 10.45% and 10.40% in subsurface soils. In the waterlogged site the mean values of moisture content after contamination were 7.30%, 7.02% and 7.08 in surface soils and 7.50% 7.64% and 7.67% in subsurface soils in the 2%, 4% and 6% polluted plots while the mean values after remediation were 13.25%, 13.37% and 13.42% (surface soils) and 11.55%, 11.49% and 11.47% (subsurface soils). The mean values of moisture content of soils contaminated with crude oil were lower when compared to remediated soils and statistical analysis revealed that the difference in the two samples were significant. This is expected because in polluted soil due to the adherence of water particles sticking to hydrophobic layer which prevent water getting to inner part of soil aggregate. The same assertion was made by Ayotamuno *et al*.,(2006). Further decrease in moisture content was observed throughout the remediation process. This could be as a result of the metabolic activities of the microbes utilizing the crude oil causing a decrease in total hydrocarbon content and a decrease in moisture content. The increase in moisture content in surface and subsurface soils after remediation could also be attributed to heavy rainfall during the period of sampling.

Table 4.15.Moisture Content (%) of Top Soil (0-15cm) after contamination and after remediation

Pollution level		Well drained site		Waterlogged site	
		After Contamination	**After Remediation**	**After Contamination**	**After Remediation**
Treatment replicates	2% 1	**7.14**	**12.70**	**8.78**	**14.12**
	2	7.25	11.86	7.45	11.58
	3	8.32	11.76	8.30	9.64
	4	6.00	10.20	6.48	16.48
	5	7.24	12.10	6.50	14.76
	6	6.71	11.60	6.30	12.90
	Range	6.00-8.32	10.20-12.70	6.30-8.78	11.58-16.48
	Mean	7.10	11.70	7.30	13.25
	S.D	0.69		0.96	2.21
Treatment replicates	4% 1	6.21	10.42	7.05	16.56
	2	7.65	13.10	6.60	14.76
	3	7.00	12.20	7.20	9.18
	4	6.45	9.78	6.54	13.18
	5	8.15	10.67	6.43	14.32
	6	6.67	11.22	8.29	12.22
	Range	6.21-8.15	9.78-13.10	6.43-8.29	9.18-16.56
	Mean	7.02	11.23	7.02	13.37
	S.D	0.68		0.63	2.31
Treatment replicates	6% 1	6.57	9.70	6.80	20.76
	2	6.50	11.36	8.15	14.20
	3	7.10	10.84	7.22	11.40
	4	8.30	12.31	6.44	13.25
	5	6.68	10.40	6.32	11.14
	6	6.90	12.10	7.53	9.77
	Range	6.50-8.30	9.70-12.31	6.32-8.15	9.77-20.76
	Mean	7.01	11.12	7.08	13.42
	S.D	0.61		0.64	3.59

Source: Author's Analysis, 2015

Table 4.16.Moisture Content (%) of Sub Soil (15-30cm) after contamination and after remediation

Pollution level		Well drained site		Waterlogged site	
		After Contamination	**After Remediation**	**After Contamination**	**After Remediation**
Treatment replicates	2% 1	**8.41**	**12.20**	**8.72**	**12.20**
	2	7.36	11.04	7.36	12.71
	3	7.20	9.46	7.19	10.71
	4	8.26	10.20	7.55	13.10
	5	6.50	11.20	6.85	9.72
	6	7.48	8.42	7.60	11.41
	Range	6.50-8.41	8.42-12.20	6.85-8.72	9.72-12.71
	Mean	7.50	10.42	7.55	11.55
	S.D	0.65	1.24	0.58	1.27
Treatment replicates	4% 1	8.26	12.00	7.62	10.60
	2	7.34	12.56	8.78	11.10
	3	6.56	10.34	7.38	10.56
	4	7.34	9.18	6.55	13.00
	5	7.70	7.34	7.84	11.40
	6	7.62	11.28	7.65	12.30
	Range	7.34-8.26	7.34-12.56	6.55-8.78	10.56-13.00
	Mean	7.64	10.45	7.84	11.49
	S.D	0.60	1.77	0.66	
Treatment replicates	6% 1	7.94	6.30	7.66	13.12
	2	7.30	12.38	8.42	14.12
	3	6.70	8.13	8.31	10.36
	4	8.94	11.28	7.58	11.20
	5	7.66	11.86	6.74	9.82
	6	7.53	12.48	7.32	10.20
	Range	7.30-8.94	6.30-12.38	7.32-8.42	9.82-14.12
	Mean	7.68	10.40	7.67	11.47
	S.D	0.68	2.34	0.57	1.60

Source: Author's Analysis, 2015

4.3.3 Chemical properties of contaminated and remediated soils

4.3.3.1 Organic carbon

The mean organic carbon content of soils in the well drained site after contamination were 0.70%, 0.71% and 0.74% in surface soils and 0.71%, 0.73% and 0.74% in subsurface soils in the 2%, 4% and 6% polluted plots while the mean values after remediation reduced to 0.59%, 0.57% and 0.58% (surface soils) and 0.60%, 0.61% and 0.63% (subsurface soils). In the waterlogged site mean organic carbon values after contamination were 0.80%, 0.81% and 0.90% in surface soils and 0.80%, 0.82% and 0.84% in subsurface soils in 2%, 4% and 6% polluted plots. While the mean values after remediation reduced to 0.74%, 0.72% and 0.73% (surface soils) and 0.72%, 0.71% and 0.73% (subsurface soils) as indicated in Tables 4.13 and 4.14. It was observed that the percentage organic carbon reduced after remediation in both surface and subsurface soils when compared to the contaminated soils (Tables 4.13 and 4.14). After contamination, organic carbon increased and decreased as remediation progressed. A similar observation was made by Ayotamuno, Kogbara and Agunwamba (2006). This indicated that the microbes utilized the nutrients in order to increase their population.

4.3.3.2 Total nitrogen

Nitrogen content in the well drained site after contamination had mean values of 0.18%, 0.20% and 0.26% in surface soils and 0.18%, 0.21% and 0.56% in subsurface soils in the 2%, 4% and 6% polluted plots while the mean values after remediation were 0.16%, 0.15% and 0.17% (surface soils) and 0.15%, 0.17% and 0.16% (subsurface soils). In the waterlogged site the mean values of nitrogen after contamination were 0.65%, 0.66% and 0.79% in surface soils and 0.63%, 0.62% and 0.64% in subsurface soils while the mean values after remediation reduced to 0.18%, 0.20% and 0.21% (surface soils) and 0.14%, 0.17% and 0.18%(subsurface soils). The results showed that the mean values of nitrogen were higher in contaminated soils but decreased after remediation for all the soil samples. In the report of Ayotamuno and Kogbara (2006) during biodegradation one can experience a huge loss of nitrogen as a result of series of widely occurring biochemical reduction reactions caused by denitrifying bacteria. This showed that the nitrogen was

Table 4.17: Chemical Properties of Top Soils (0-15cm) after Contamination and after Remediation.

Pollution level		Well drained site										Water logged site									
		After Contamination					After Remediation					After Contamination					After Remediation				
		TOC (%)	TN (%)	Av.P (mg/kg)	Moisture Content (%)	Soil pH	TOC (%)	TN (%)	Av.P (mg/kg)	Moisture Content	Soil pH	TOC (%)	TN (%)	Av.P (mg/kg)	Moisture Content	Soil pH	TOC (%)	TN (%)	Av.P (mg/kg)	Moisture Content	Soil pH
Treatment replicates	2% 1	0.62	0.18	0.80	7.14	6.70	0.56	0.07	0.35	12.70	5.60	0.75	1.09	0.80	8.78	6.96	0.96	0.11	0.43	14.12	4.90
	2	0.74	0.15	0.84	7.25	6.71	0.58	0.08	0.54	11.86	4.30	0.63	0.31	0.55	7.45	6.84	0.90	0.08	0.83	11.58	4.90
	3	0.67	0.13	0.78	8.32	6.84	0.57	0.13	0.75	11.76	4.50	0.72	0.25	0.80	8.30	6.74	0.69	0.21	0.74	9.64	4.20
	4	0.81	0.21	0.65	6.00	6.59	0.65	0.29	0.48	10.20	4.50	0.93	0.67	1.12	6.48	7.16	0.55	0.23	0.55	16.48	5.40
	5	0.70	0.17	1.11	7.24	6.86	0.55	0.17	0.43	12.10	4.40	0.86	0.84	0.58	6.50	6.95	0.60	0.19	0.75	14.76	4.80
	6	0.68	0.22	0.76	6.71	6.45	0.63	0.22	0.56	11.60	4.70	0.19	0.76	0.85	6.30	6.58	0.74	0.26	0.36	12.90	4.60
	Range	0.62-0.81	0.15-0.22	0.65-1.11	6.00-8.32	6.45-6.86	0.55-0.65	0.09-0.29	0.35-0.75	10.20-12.70	4.30-5.60	0.63-0.93	0.25-1.09	0.55-1.12	6.30-8.78	6.58-7.16	0.55-0.96	0.08-0.20	0.36-0.83	11.58-16.48	4.20-5.40
	Mean	0.70	0.18	0.82	7.10	6.69	0.59	0.16	0.52	11.70	4.67	0.80	0.65	0.78	7.30	6.87	0.74	0.18	0.61	13.25	4.80
	S.D		0.03		0.69	0.14	0.04	0.08	0.12			0.11	0.29		0.96	0.18	0.15	0.60	0.17	2.21	0.04
Treatment replicates	4% 1	0.59	0.10	065	6.21	6.72	0.45	0.10	0.73	10.42	4.60	0.96	0.18	1.10	7.05	6.98	0.77	0.17	0.38	16.56	4.90
	2	0.71	0.14	0.79	7.65	6.31	0.56	0.18	0.38	13.10	4.10	0.96	1.12	1.10	6.60	6.90	0.60	0.16	0.78	14.76	5.10
	3	0.66	0.32	0.85	7.00	6.68	0.60	0.19	0.30	12.20	5.20	0.69	0.35	0.55	7.20	6.78	0.53	0.19	0.24	9.18	4.30
	4	0.84	0.26	0.67	6.45	6.43	0.58	0.13	0.33	9.78	4.80	0.75	0.92	0.85	6.54	6.55	0.72	0.19	0.58	13.18	4.98
	5	0.69	0.19	0.78	8.15	6.58	0.59	0.14	0.72	10.67	4.70	0.64	0.75	0.65	6.43	6.42	0.90	0.25	0.77	14.32	4.87
	6	0.77	0.21	1.10	6.67	6.81	0.64	0.16	0.54	11.22	4.20	0.87	0.81	0.55	8.29	6.54	0.80	0.24	0.85	12.22	4.77
	Range	0.59-0.84	0.10-0.32	0.65-1.10	6.21-8.15	6.31-6.81	0.45-0.04	0.10-0.19	0.30-0.73	9.98-13.10	4.10-5.20	0.64-0.96	0.18-1.12	0.55-1.10	6.43-8.29	6.42-6.98	0.53-0.90	0.16-0.25	0.24-0.85	9.18-16.56	4.30-4.98
	Mean	0.71	0.20	0.81	7.02	6.59	0.57	0.15	0.50	11.23	4.60	0.81	0.66	0.80	7.02	6.70	0.72	0.20	0.60	13.37	4.82
	S.D		0.07		0.68	0.17	0.60	0.03	0.18		0.37	0.13	0.31		0.63	0.20	0.12	0.03	0.22	2.31	0.25
Treatment replicates	6% 1	0.84	0.22	1.10	6.57	6.74	0.61	0.25	0.71	9.70	4.80	0.87	0.92	1.20	6.80	7.03	0.85	0.25	0.71	20.76	5.00
	2	0.84	0.16	0.55	6.50	6.73	0.72	0.17	0.55	11.36	4.80	0.99	0.90	0.55	8.15	6.55	0.74	0.19	0.55	14.20	5.00
	3	0.75	0.30	1.10	7.10	6.87	0.68	0.28	0.39	10.84	4.10	0.67	0.87	0.65	7.22	6.92	0.62	0.27	0.81	11.40	4.90
	4	0.63	0.15	0.75	8.30	6.63	0.47	0.11	0.58	12.31	4.20	1.08	0.35	0.75	6.44	6.52	0.55	0.20	0.51	13.25	4.84
	5	0.70	0.28	0.65	6.68	6.36	0.58	0.09	0.34	10.40	5.40	0.88	0.93	0.65	6.32	6.85	0.70	0.18	0.86	11.14	4.83
	6	0.68	0.43	0.80	6.90	6.47	0.42	0.10	0.49	12.10	4.60	0.91	0.77	0.55	7.53	6.53	0.92	0.17	0.39	9.77	4.29
	Range	0.63-0.84	0.15-0.43	0.55-1.10	6.50-8.30	6.36-6.87	0.42-0.72	0.09-0.28	0.34-0.71	9.70-12.31	4.10-5.40	0.67-1.08	0.35-0.92	0.55-1.20	6.32-8.15	6.52-7.03	0.55-0.92	0.17-0.25	0.39-0.86	9.77-20.76	4.29-5.00
	Mean	0.74	0.26	0.83	7.01	6.63	0.58	0.17	0.51	11.12	4.65	0.90	0.79	0.73	7.08	6.73	0.73	0.21	0.64	13.42	4.81
	S.D		0.10		0.61	0.17	0.11	0.07	0.12		0.43	0.13	0.20		0.64	0.17	0.13	0.04	0.17	3.59	0.24

Source: Author's analysis, 2015

Table 4.18: Chemical Properties of Sub Soils (15-30cm) after Contamination and after Remediation.

Pollution level		Well drained site										Water logged site									
		Before Contamination					After contamination					Before Contamination					After contamination				
		TOC (%)	TN (%)	Av.P (mg/kg)	Moisture Content (%)	Soil pH	TOC (%)	TN (%)	Av.P (mg/kg)	Moisture Content	Soil pH	TOC (%)	TN (%)	Av.P (mg/kg)	Moisture Content	Soil pH	TOC (%)	TN (%)	Av.P (mg/kg)	Moisture Content	Soil pH
Treatment replicates	2% 1	0.65	0.17	0.55	8.41	6.86	0.54	0.10	0.45	12.20	4.40	0.66	1.08	0.40	8.72	7.04	0.80	0.16	0.52	12.20	4.40
	2	0.76	0.15	0.60	7.36	6.71	0.60	0.11	0.30	11.04	4.10	0.90	0.87	0.65	7.36	6.22	0.81	0.05	0.53	12.71	4.80
	3	0.68	0.14	0.65	7.20	6.95	0.61	0.17	0.50	9.46	4.30	0.70	0.25	0.80	7.19	6.80	0.73	0.18	0.30	10.71	4.40
	4	0.70	0.18	1.35	8.26	6.54	0.58	0.22	0.33	10.20	5.20	0.63	0.39	0.55	7.55	6.36	0.63	0.12	0.46	13.10	4.95
	5	0.80	0.24	0.75	6.50	6.78	0.73	0.18	0.52	11.20	4.40	1.38	0.52	0.80	6.85	7.25	0.66	0.16	0.35	9.72	4.74
	6	0.69	0.20	0.45	7.48	6.65	0.54	0.12	0.30	8.42	4.60	0.55	0.68	0.70	7.60	6.61	0.71	0.17	0.36	11.41	4.43
	Range	0.65-0.76	0.14-0.24	0.45-1.35	6.50-8.41	6.54-6.95	0.54-0.73	0.10-0.22	0.30-0.52	8.42-12.20	4.10-5.20	0.66-1.38	0.25-1.08	0.40-0.80	6.85-8.72	6.22-8.36	0.63-0.81	0.05-0.18	0.30-0.52	9.72-12.71	4.40-4.95
	Mean	0.71	0.18	0.73	7.50	6.74	0.60	0.15	0.40	10.42	4.50	0.80	0.63	0.65	7.55	6.71	0.72	0.14	0.42	11.55	4.62
	S.D		0.03		0.65	0.13	0.06	0.04	0.09	1.24	0.30	0.28	0.28		0.58	0.36		0.04	0.09	1.27	0.22
Treatment replicates	4% 1	0.66	0.15	0.64	8.26	6.48	0.55	0.06	0.40	12.00	4.20	0.69	0.77	0.55	7.62	6.78	0.64	0.11	0.36	10.60	4.50
	2	0.58	0.13	0.95	7.34	6.81	0.60	0.25	0.35	12.56	4.00	0.90	0.35	0.60	8.78	7.00	0.65	0.09	0.47	11.10	5.30
	3	0.75	0.18	0.73	6.56	6.96	0.53	0.23	0.55	10.34	4.40	0.60	0.36	0.70	7.38	6.86	0.57	0.22	0.56	10.56	4.60
	4	0.84	0.14	0.65	7.34	6.46	0.74	0.13	0.52	9.18	4.40	0.96	0.64	0.60	6.55	6.28	0.74	0.24	0.35	13.00	4.55
	5	0.78	0.36	0.75	7.70	6.74	0.58	0.15	0.31	7.34	4.20	0.75	0.79	0.40	7.84	6.75	0.80	0.16	0.32	11.40	4.66
	6	0.79	0.28	0.80	7.62	6.86	0.66	0.20	0.45	11.28	4.40	0.99	0.83	1.10	7.65	6.56	0.86	0.20	0.34	12.30	4.23
	Range	0.58-0.84	0.13-0.36	0.64-0.94	7.34-8.26	6.46-6.96	0.53-0.74	0.06-0.25	0.31-0.52	7.34-12.56	4.00-4.60	0.60-0.99	0.35-0.79	0.40-1.10	6.55-8.78	6.29-7.00	0.57-0.86	0.09-0.24	0.32-0.56	10.56-13.00	4.23-4.66
	Mean	0.73	0.21	0.75	7.64	6.72	0.61	0.17	0.43	10.45	4.30	0.82	0.62	0.66	7.84	6.71	0.71	0.17	0.40	11.49	4.64
	S.D		0.08		0.60	0.19	0.07	0.06	0.09	1.77	0.02	0.14	0.20		0.66	0.23	0.10	0.06	0.09		0.32
Treatment replicates	6% 1	0.81	0.76	1.10	7.94	6.78	0.65	0.18	0.45	6.30	5.10	1.23	0.20	0.68	7.66	7.06	0.91	0.07	0.34	13.12	4.80
	2	1.08	1.00	0.60	7.30	6.62	0.75	0.12	0.30	12.38	4.20	0.72	0.93	0.50	8.42	6.97	0.80	0.14	0.29	14.12	4.50
	3	0.63	0.35	0.65	6.70	6.48	0.57	0.14	0.30	8.13	4.60	0.87	0.82	0.70	8.31	6.74	0.56	0.24	0.43	10.36	4.30
	4	0.48	0.55	0.75	8.94	6.78	0.56	0.19	0.55	11.28	4.30	0.82	0.37	1.10	7.58	6.56	0.70	0.18	0.57	11.20	4.38
	5	0.84	0.30	0.80	7.66	6.80	0.62	0.13	0.45	11.86	4.10	0.64	0.70	0.60	6.74	6.39	0.76	0.20	0.36	9.82	5.21
	6	0.60	0.42	0.70	7.53	6.83	0.63	0.20	0.41	12.48	4.20	0.95	0.81	0.50	7.32	6.64	0.65	0.22	0.41	10.20	4.47
	Range	0.48-1.08	0.30-1.00	0.60-1.10	7.30-8.94	6.48-6.83	0.57-0.75	0.12-0.20	0.30-0.55	6.30-12.38	4.10-5.10	0.64-1.23	0.20-0.93	0.50-1.10	7.32-8.42	6.39-7.06	0.56-0.91	0.07-0.24	0.29-0.57	9.82-14.12	4.30-5.21
	Mean	0.74	0.56	0.77	7.68	6.72	0.63	0.16	0.41	10.40	4.42	0.84	0.64	0.68	7.67	6.73	0.73	0.18	0.40	11.47	4.61
	S.D	0.20	0.26		0.68	0.12	0.06	0.03	0.09	2.34	0.34	0.19	0.26		0.57	0.23	0.11	0.06	0.09	1.60	0.31

Source: Author's analysis, 2015.

utilized by the microbes in order to increase in their biomass. However, the mean values of nitrogen between the contaminated and remediated soils were not significantly different.

4.3.3.3 Available phosphorus

The mean values of available phosphorus in the well drained site after contamination were 0.82 mg/kg, 0.81 mg/kg and 0.83 mg/kg in surface soils and 0.73 mg/kg 0.75 mg/kg and 0.77 mg/kg in subsurface soils in the 2%, 4% and 6% polluted plots while the mean values after remediation decreased to 0.52 mg/kg, 0.50 mg/kg and 0.51 mg/kg in surface soils and 0.40 mg/kg, 0.43 mg/kg and 0.41 mg/kg in subsurface soils. In the waterlogged site the mean values of available phosphorus after contamination were 0.78 mg/kg, 0.80 mg/kg and 0.73 mg/kg in surface soils and 0.65 mg/kg, 0.66 mg/kg and 0.68 mg/kg in subsurface soils in the 2%, 4% and 6% polluted plots while the mean values after remediation decreased to 0.61 mg/kg, 0.60 mg/kg and 0.64 mg/kg (surface soils) and 0.42 mg/kg and 0.40 mg/kg (subsurface soils). The amount of available phosphorus decreased after remediation when compared to the values obtained after contamination as indicated in Tables 4.13 and 4.14. The available phosphorus levels in crude oil contaminated soils were higher than those of the remediated soils but the differences were not significant ($p = 0.05$).

4.3.3.4 Soil pH

The mean pH values of soils in the well drained site after contamination were 6.69, 6.59 and 6.63 in surface soils and 6.74 and 6.72 in subsurface soils in the 2%, 4% and 6% polluted plots while the mean values after remediation were 6.09, 6.07 and 6.06 in surface soils and 6.50, 6.30 and 6.42 in subsurface soils. In the waterlogged site the mean values of soil pH after contamination were 6.87, 6.70 and 6.73 in surface soils and 6.71 and 6.73 in subsurface soils in the 2%, 4% and 6% polluted plots while the mean pH values after remediation were 4.80, 4.82 and 4.81 in surface soils and 4.62, 4.64 and 4.61 in subsurface soils. It was observed that soil pH increased in both experimentation sites after contamination with crude oil and decreased after remediation (Tables 4.13 and 4.14). Although the pH values of contaminated soils were higher compared to those of remediated soils, the difference between the two soil samples were not significant

statistically. A fall in pH under similar condition has been reported by Okpokwasili and Okore (1991). This also confirmed Tisdale and Nelson's (1999) observation that decreasing pH during remediation treatment could have been due to the production of acid radicals in the nitrification process of agricultural residues used as fertilizers.

4.3.4 Total hydrocarbon content (mg/kg) of contaminated and remediated soils during the dry season.

Figures 4.49 to 4.60 showed Total hydrocarbon contents of soils after contamination and after remediation in the dry season. High levels of hydrocarbon were observed from surface and subsurface soils in the well drained and waterlogged sites after contamination compared to the values obtained after remediation with the decomposed cassava peels. The mean values of total hydrocarbon content after remediation in the well drained site decreased from 740.83 mg/kg to to 339.17 mg/kg. 615 mg/kg to 317.5 mg/kg and 762.5 mg/kg to 436.67 mg/kg, in surface soils. In the waterlogged site the mean values of total hydrocarbon after remediation decreased from 882.5mg/kg to 525mg/kg, 912.5 mg/kg to 462.5 mg/kg and 413.5 mg/kg to 247.5 mg/kg and 670.5 mg/kg to 406.67 mg/kg in subsurface soils. The observation made was that soil remediation led to significant decrease of hydrocarbon content while the findings indicated that the total value of hydrocarbon level in soil remediated were not as high as that of soils that were contaminated. Statistical analysis showed a difference that is significant ($p=0.05$) when hydrocarbon levels of soils remediated and contaminated were compared. Fertility of soils was affected by oil spill resulting in reduction of the ability of the soil to sustain plant growth and development through the provision of appropriate amount of nutrients, water, oxygen and organisms (Abii and Nwosu, 2009). Increasing the amount of carbon in soil contaminanted with hydrocarbon will increase the growth of microorganisms that use hydrocarbon. Although microorganisms have some benefits of enhancing growth of plant, the situation changes as a result of increase in number which will lead to competition for available nutrients to plants in the soil and indirectly contribute to plant stagnanted growth (Kaye and Hart 1997; Xu and Johnson, 1997; Tiquia *et al.,* 2002; Trofimou and Razanova, 2003).

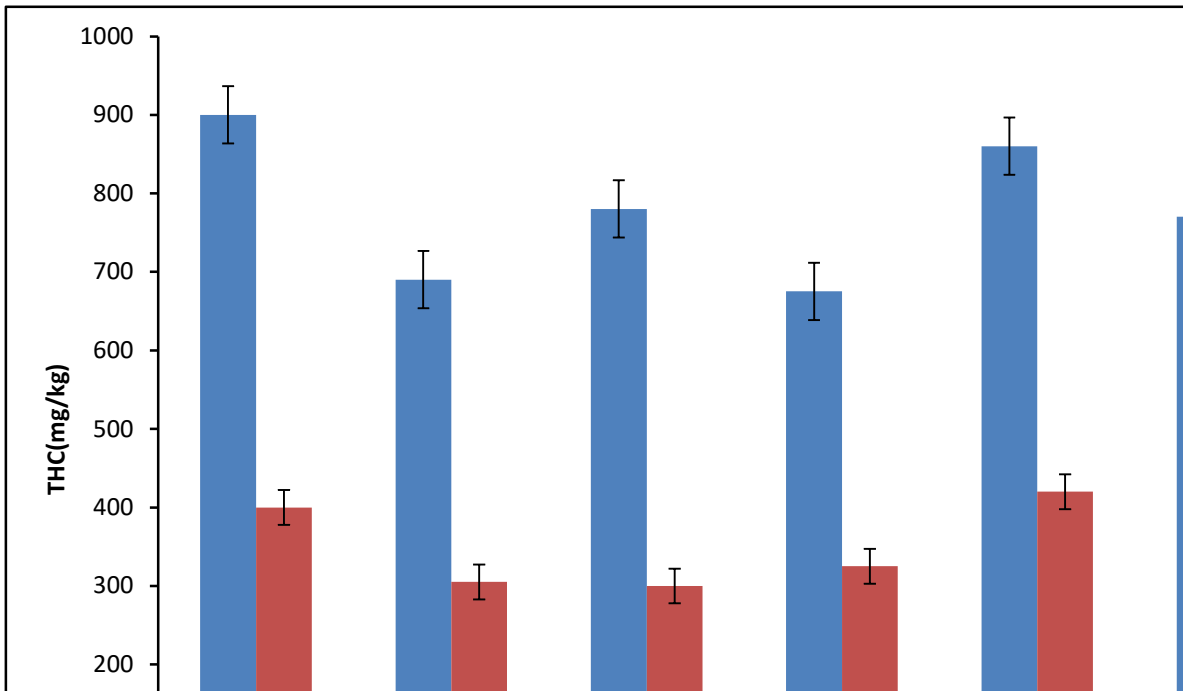


Fig. 4.49: Total hydrocarbon content of top soils of 2% polluted well drained site in dry season

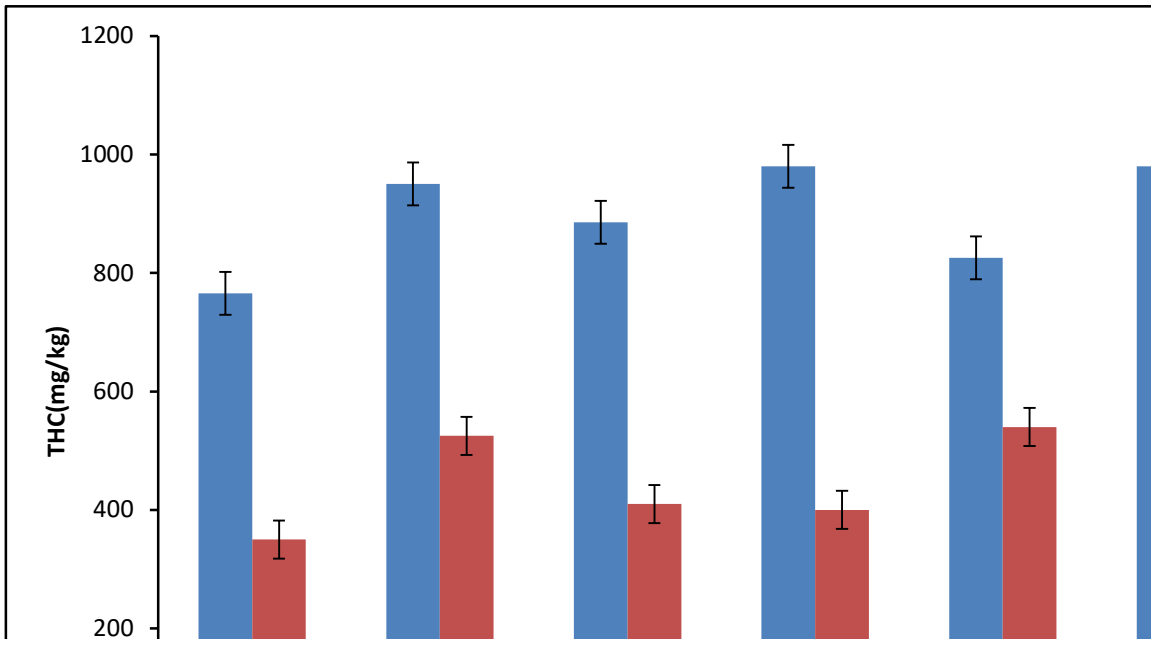


Fig. 4.50: Total hydrocarbon content of top soils of 2% polluted waterlogged site in dry season

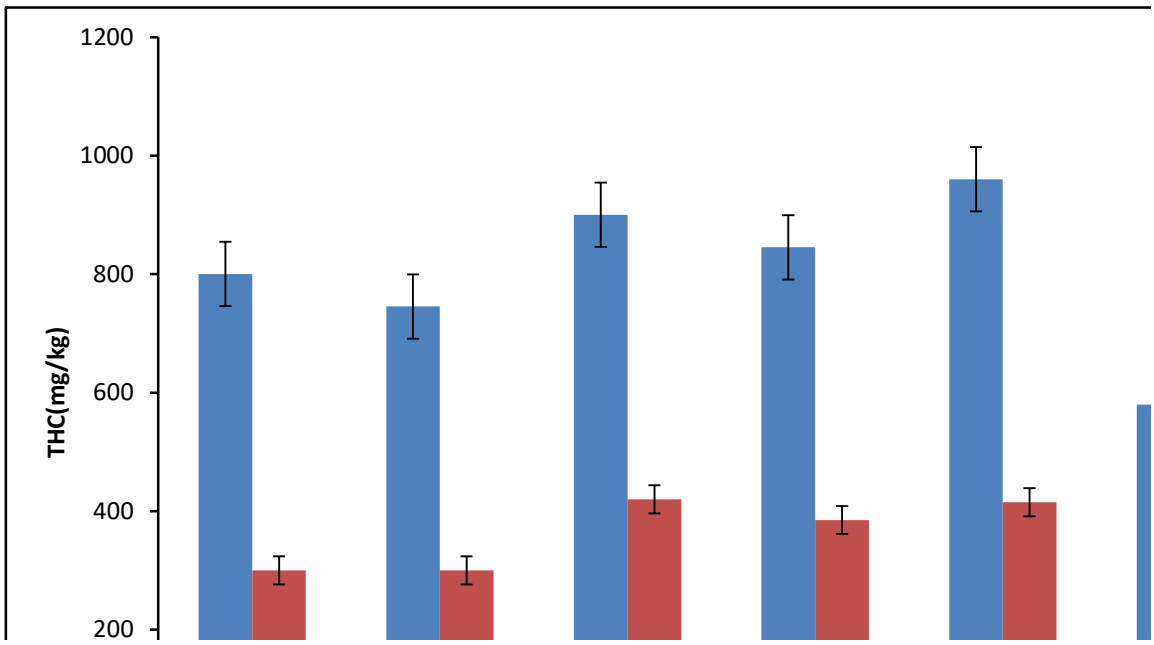


Fig. 4.51: Total hydrocarbon content of top soils of 4% polluted well drained site in dry season

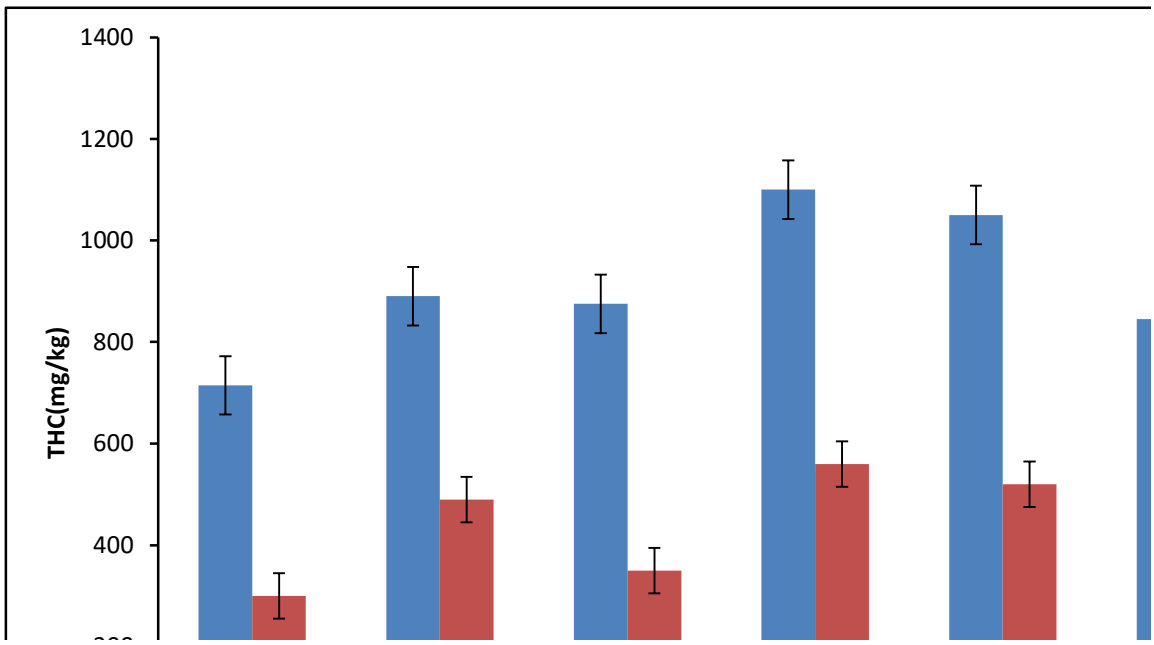


Fig. 4.52: Total hydrocarbon content of top soils of 4% polluted waterlogged site in dry season

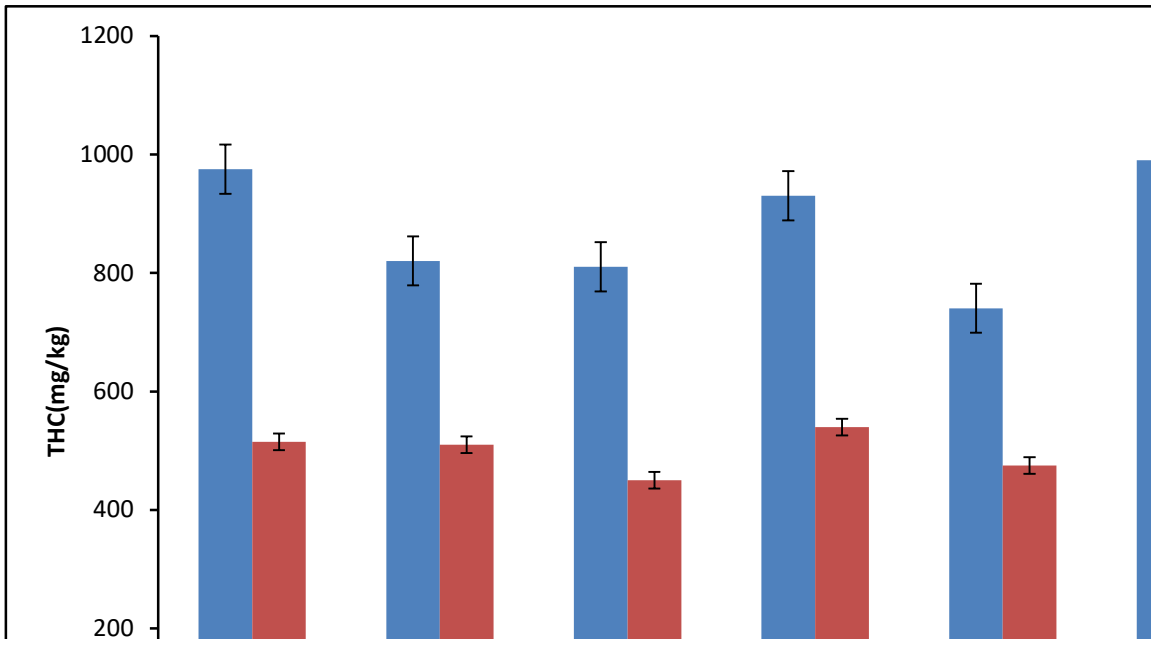


Fig. 4.53: Total hydrocarbon content of top soils of 6% polluted well drained site in dry season

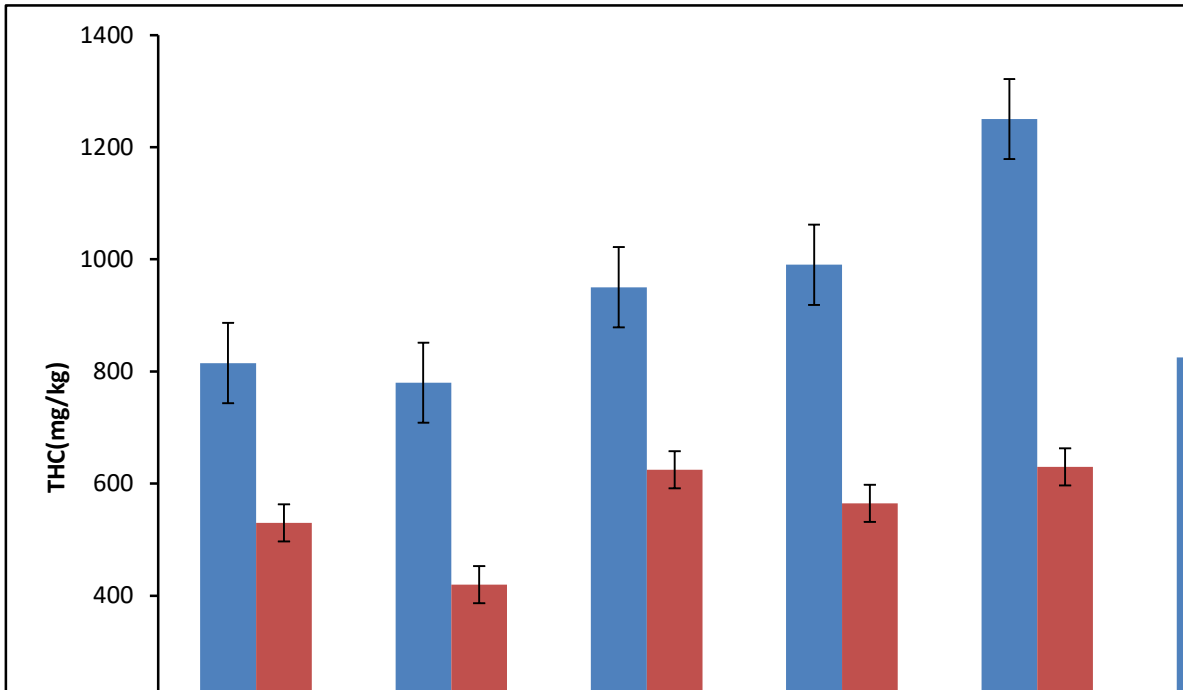


Fig. 4.54: Total hydrocarbon content of top soils of 6% polluted waterlogged site in dry season

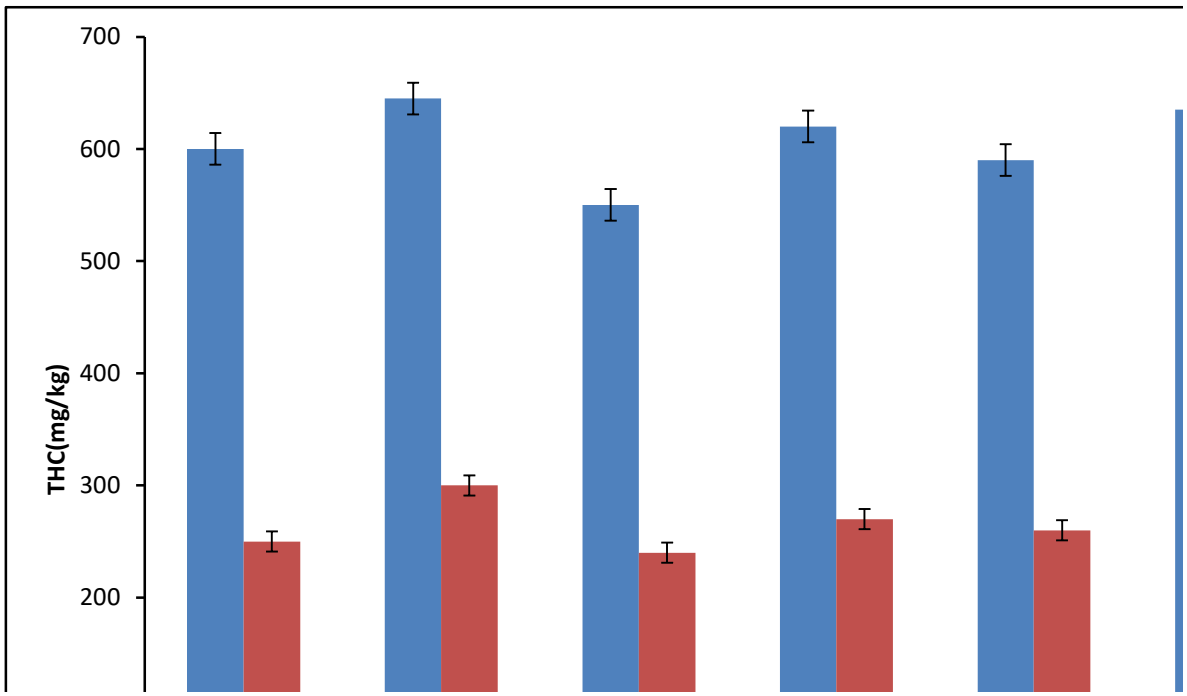


Fig. 4.55: Total hydrocarbon content of sub soils of 2% polluted well drained site in dry season

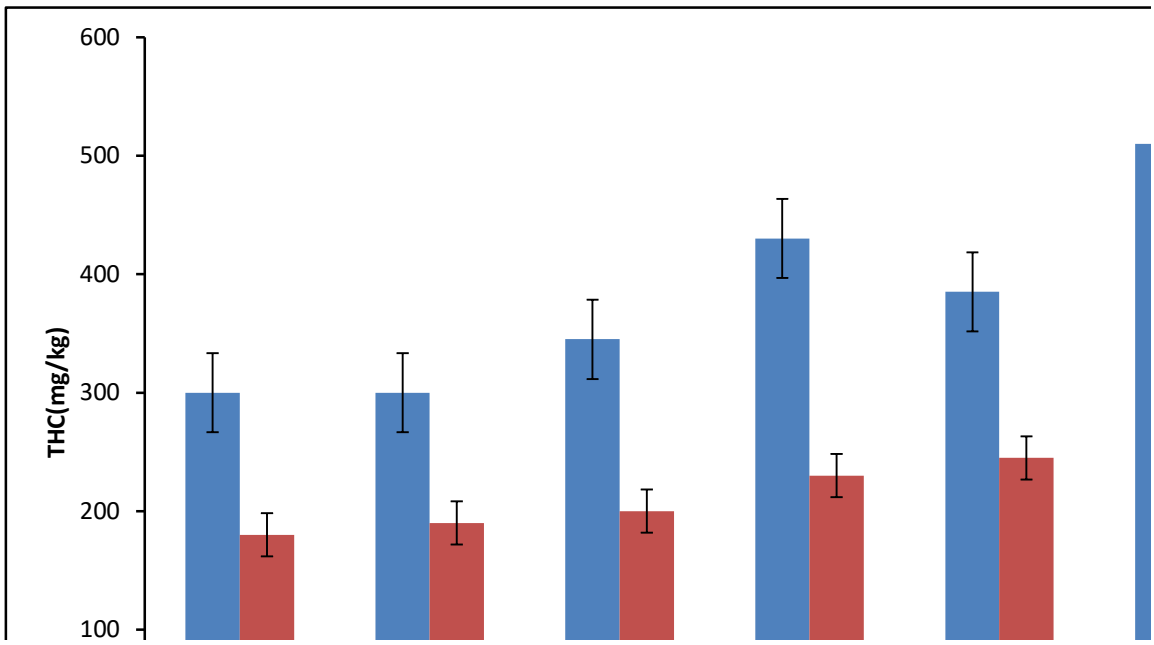


Fig. 4.56: Total hydrocarbon content of sub soils of 2% polluted waterlogged site in dry season

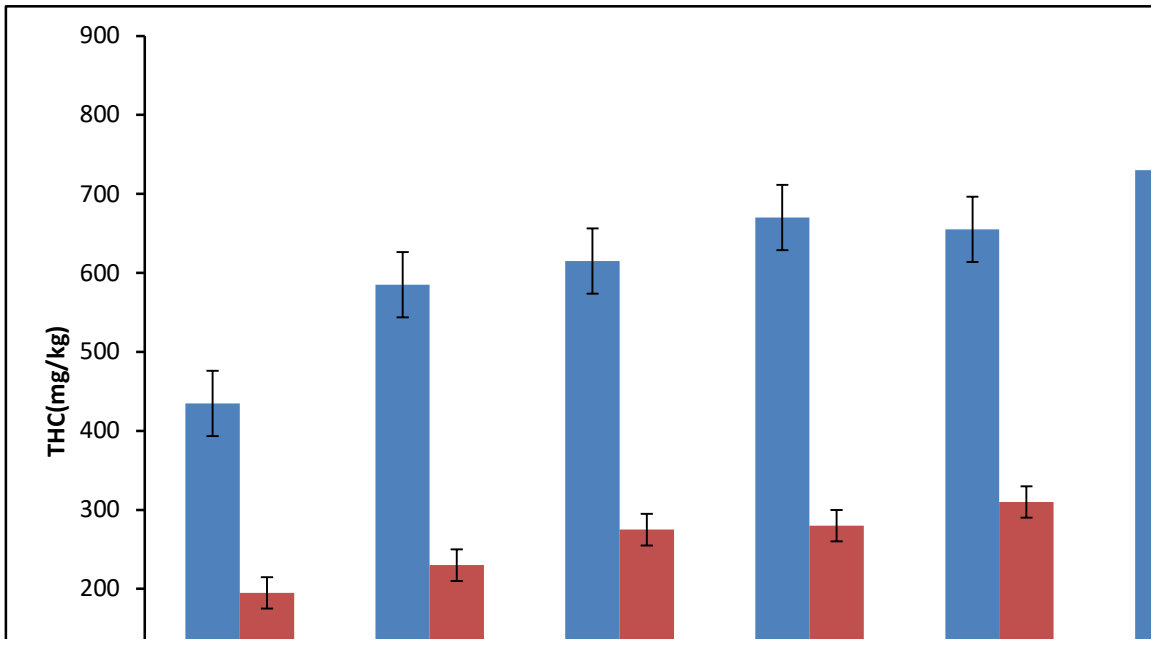


Fig. 4.57: Total hydrocarbon content of sub soils of 4% polluted well drained site in dry season

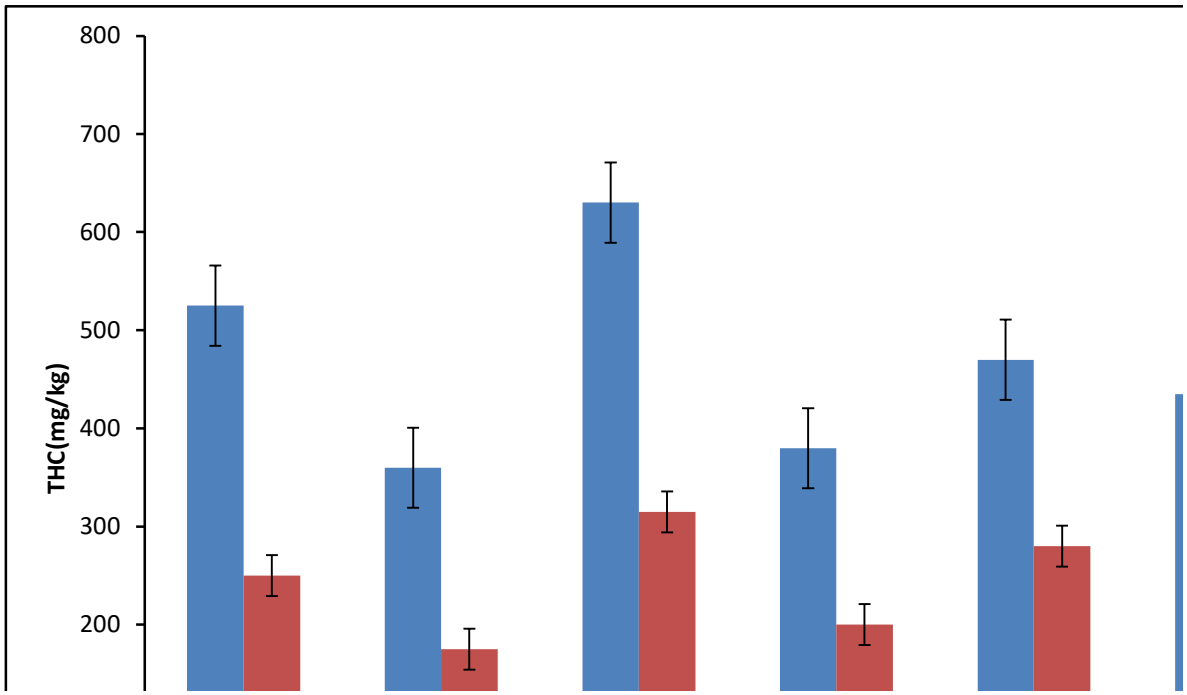


Fig. 4.58: Total hydrocarbon content of sub soils of 4% polluted waterlogged site in dry season

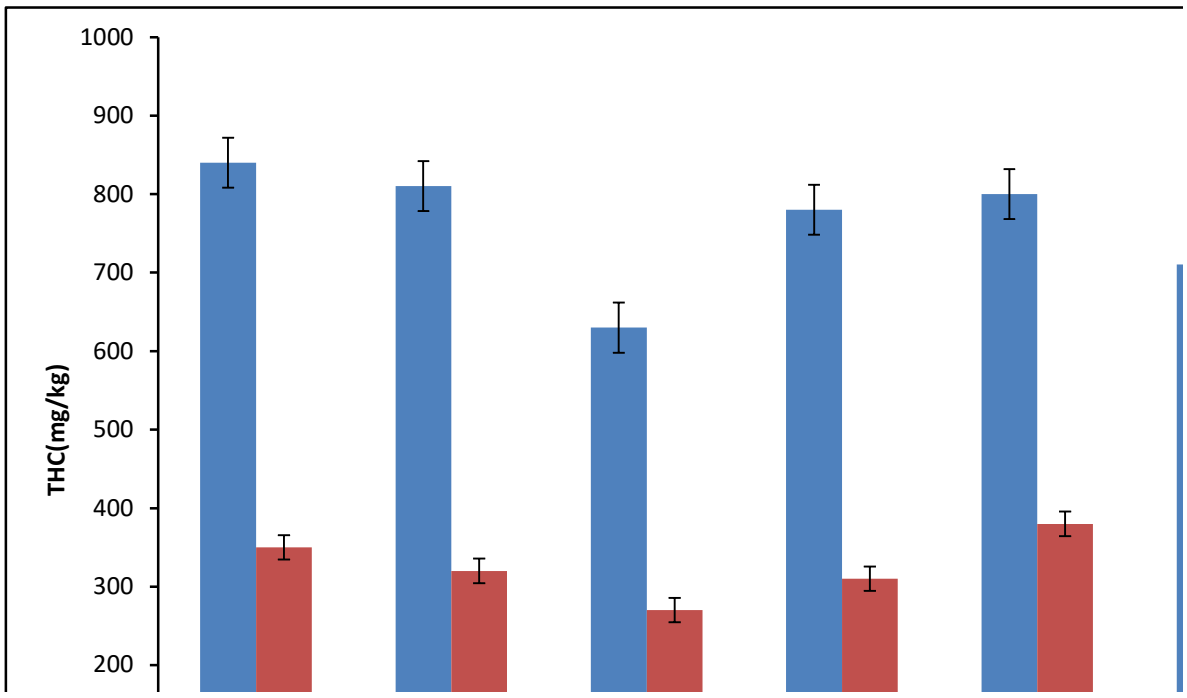


Fig. 4.59: Total hydrocarbon content of sub soils of 6% polluted well drained site in dry season

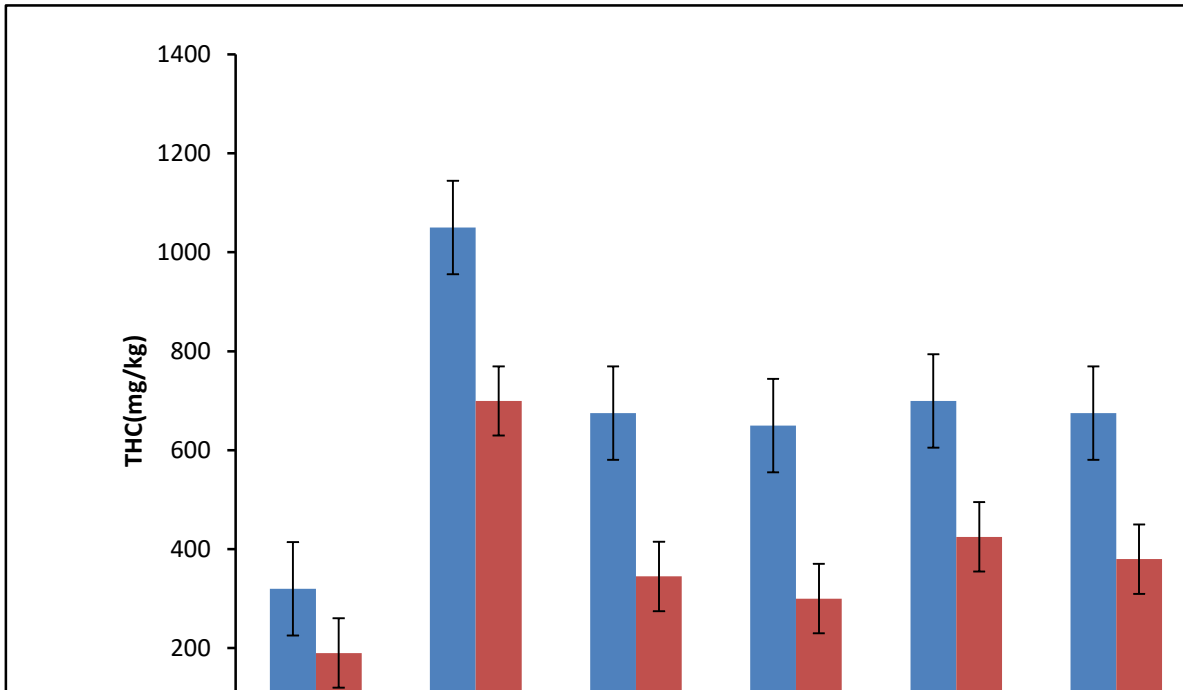


Fig. 4.60: Total hydrocarbon content of sub soils of 6% polluted waterlogged site in dry season

4.3.5: Total hydrocarbon content (mg/kg) of Soils after contamination and after remediation during the wet season

Total hydrocarbon content of soil samples after contamination and after remediation during the wet season are shown in Figures 4.61 to 4.72. It was observed that the values of total hydrocarbon content in surface and subsurface soils in the well drained and waterlogged sites after contamination were higher compared to the values obtained after remediation. The mean values of total hydrocarbon content after remediation decreased from 470 mg/kg to 238.33 mg/kg, 598.33 mg/kg to 350 mg/kg, 827.5 mg/kg to 486.67 mg/kg in surface soils and from 324.17 mg/kg to 200 mg/kg, 365 mg/kg to 214.17 mg/kg and 420.67 mg/kg to 245 mg/kg in subsurface soils in the 2%, 4% and 6% polluted plots. In the waterlogged site, the mean hydrocarbon content values after remediation decreased from 534.17 mg/kg to 300 mg/kg, 750 mg/kg to 435 mg/kg and 880 mg/kg to 520 mg/kg in surface soils and from 365.83 mg/kg to 235 mg/kg, 370 mg/kg to 216.67 mg/kg and 480 mg/kg to 286.67 mg/kg in subsurface soils. It was also observed during the dry season phase of the field work that the values of total hydrocarbon content in crude oil remediated soils decreased when compared to the values obtained after contamination. The decrease in Total Hydrocarbon Content (THC) through biostimulation process increased the population of microbes present in the soil. This is in agreement with the report of Atlas (1984), that addition of nutrients and oil degrading microbes increase the rate of microbial metabolism of hydrocarbon in the soil. Results analysis showed that the total hydrocarbon content values of remediated soils samples were lower than those of contaminated soil samples. Statistical analysis showed a significant difference in hydrocarbon levels between the contaminated and remediated soils.

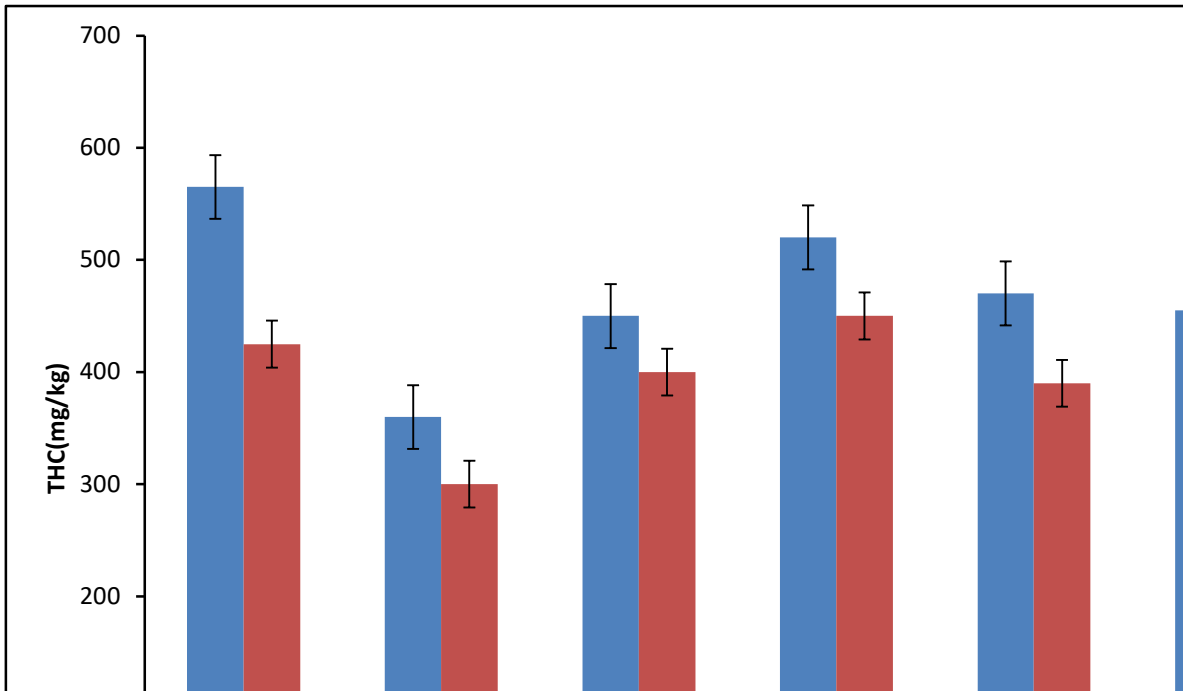


Fig. 4.61: Total hydrocarbon content of top soils of 2% polluted well drained site in wet season

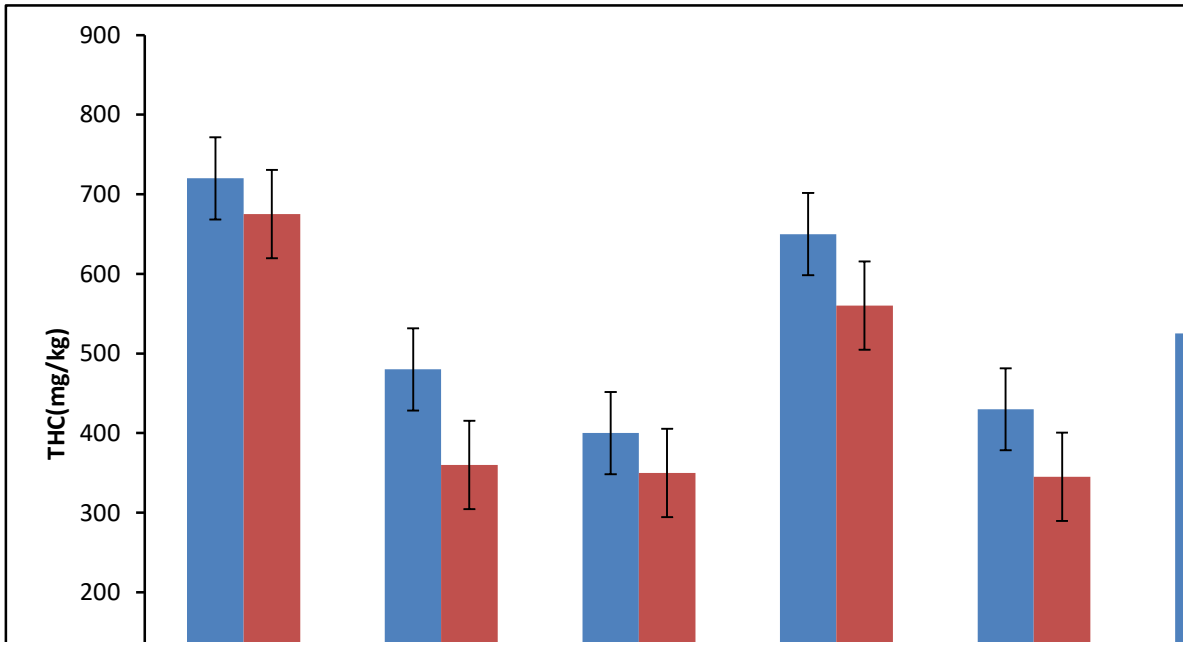


Fig. 4.62: Total hydrocarbon content of top soils of 2% polluted waterlogged site in wet season

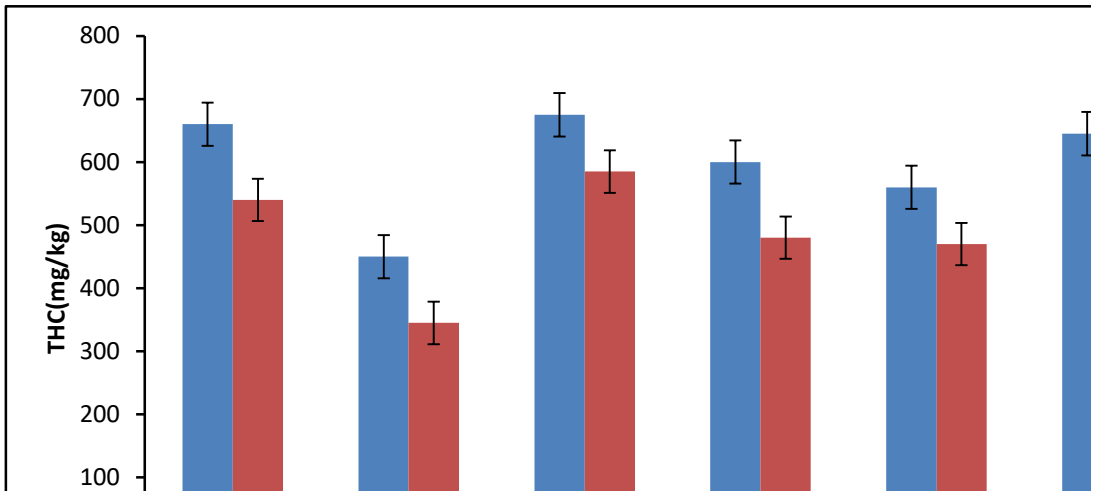


Fig. 4.63: Total hydrocarbon content of top soils of 4% polluted well drained site in wet season

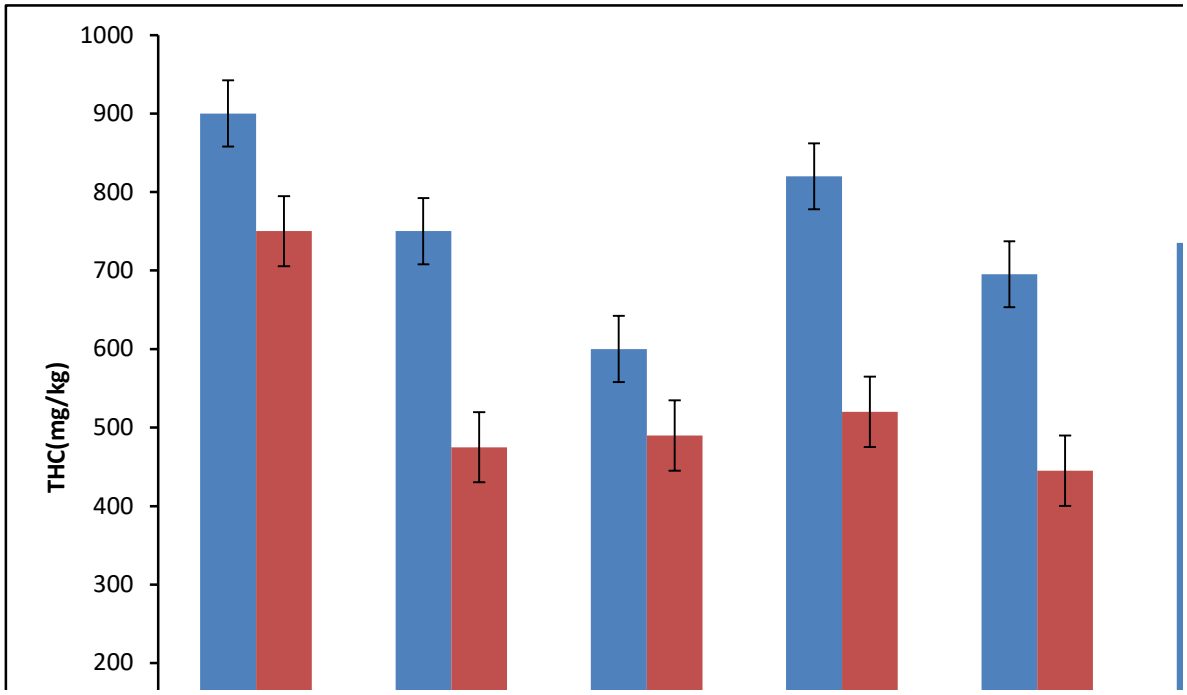


Fig. 4.64: Total hydrocarbon content of top soils of 4% polluted waterlogged in wet season

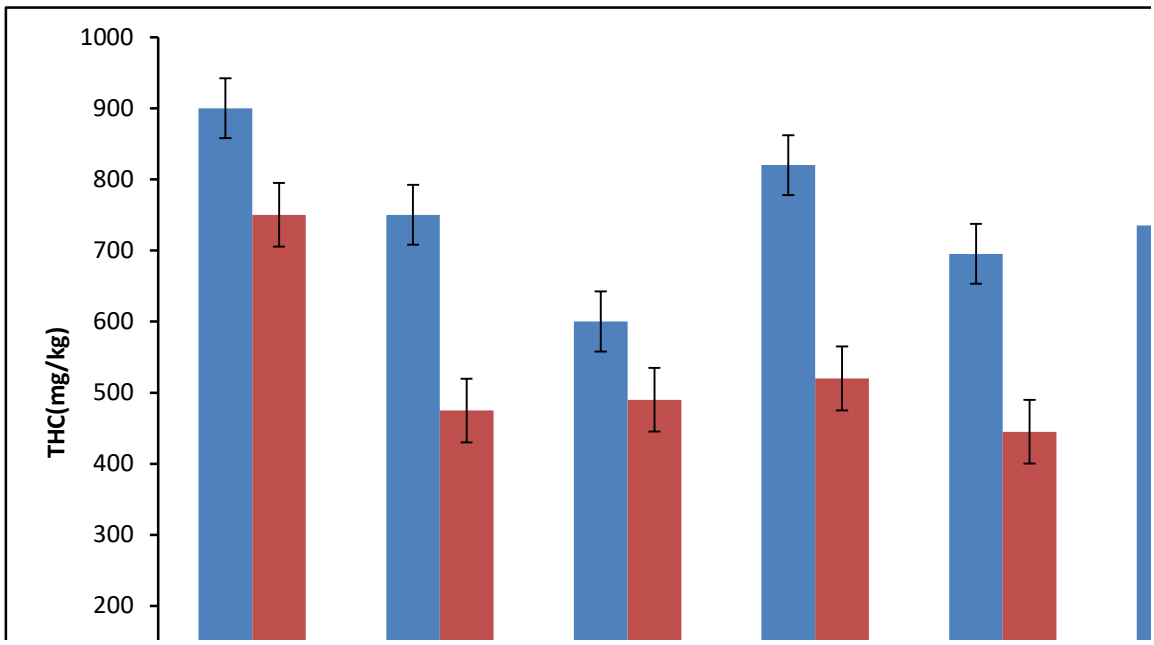


Fig. 4.65: Total hydrocarbon content of top soils of 6% polluted well drained site in wet season

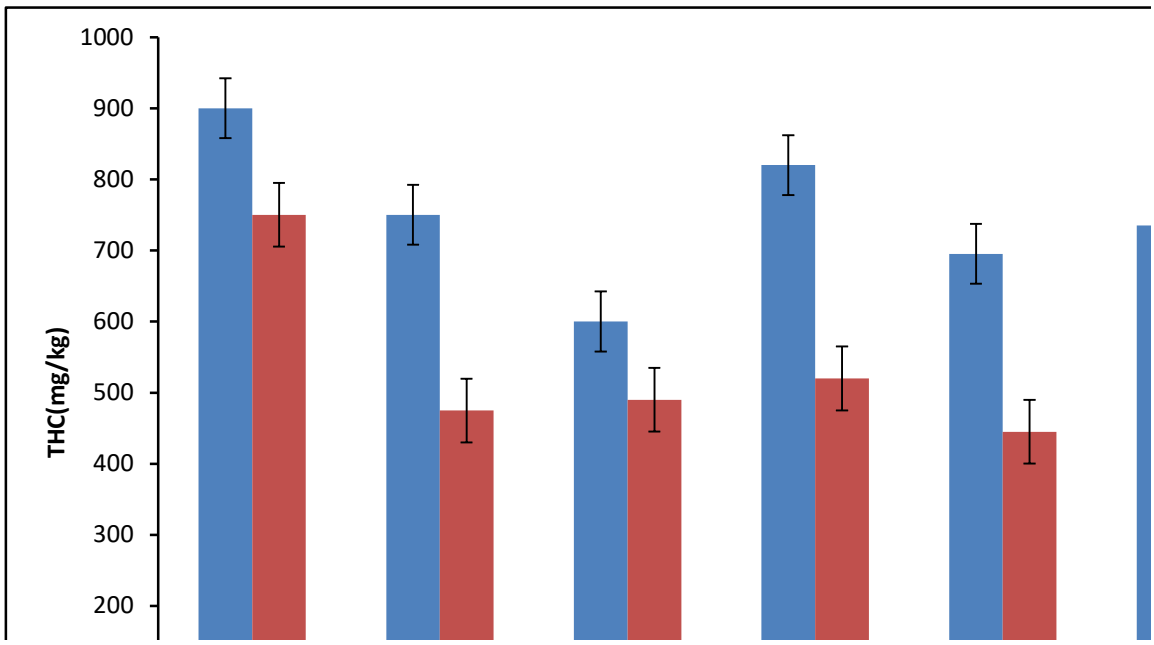


Fig. 4.66: Total hydrocarbon content of top soils of6% polluted waterlogged site in wet season

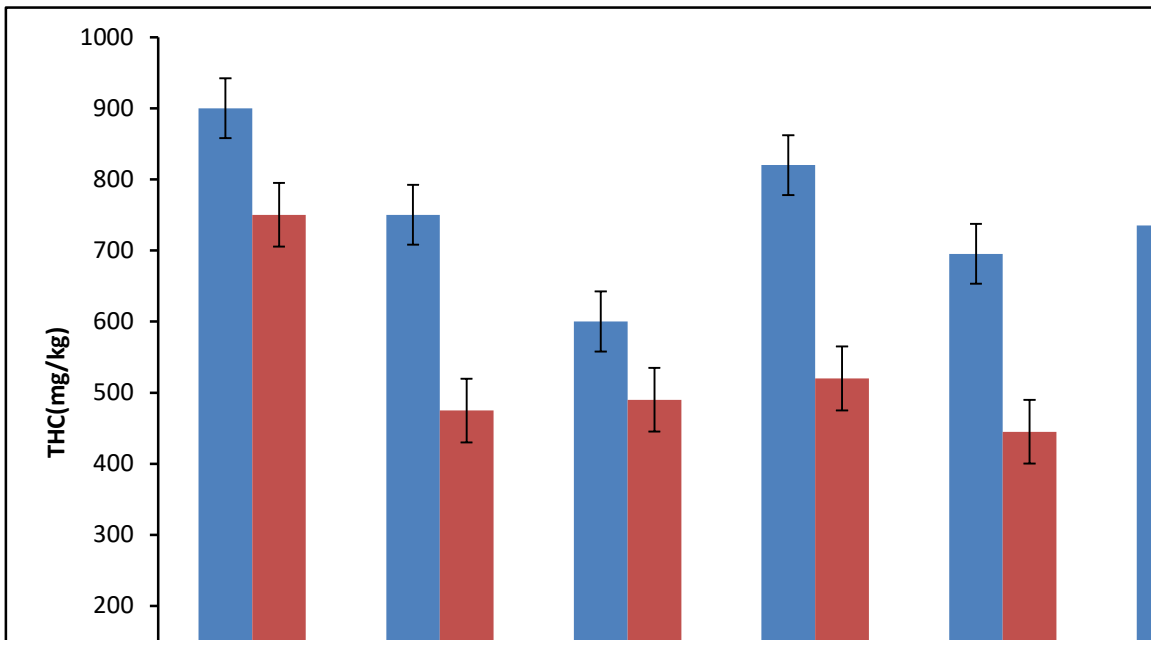


Fig. 4.67: Total hydrocarbon content of sub soils of2% polluted well drained site in wet season

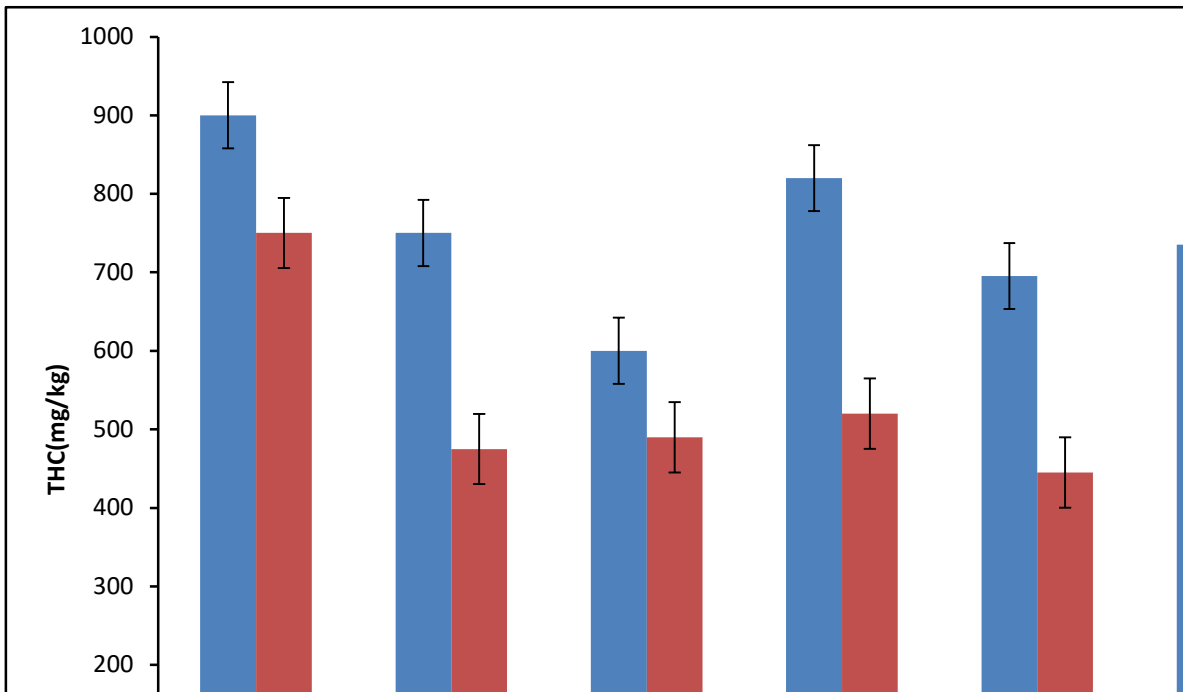


Fig. 4.68: Total hydrocarbon content of sub soils of 2% polluted waterlogged in wet season

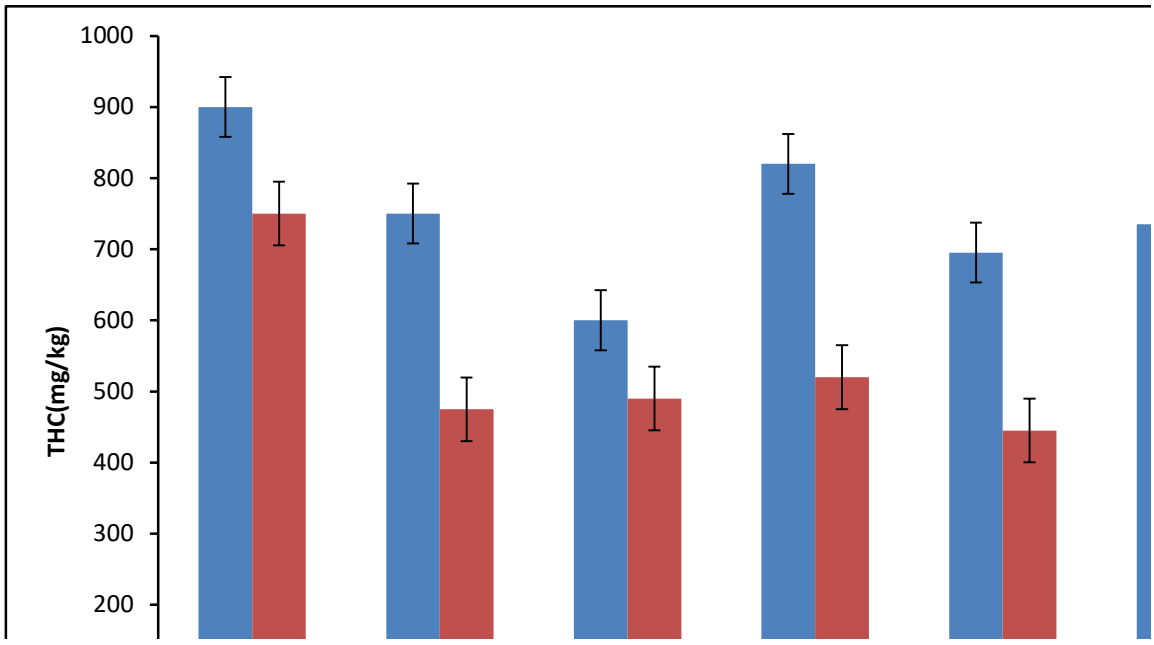


Fig. 4.69: Total hydrocarbon content of sub soils of 4% polluted well drained site in wet season

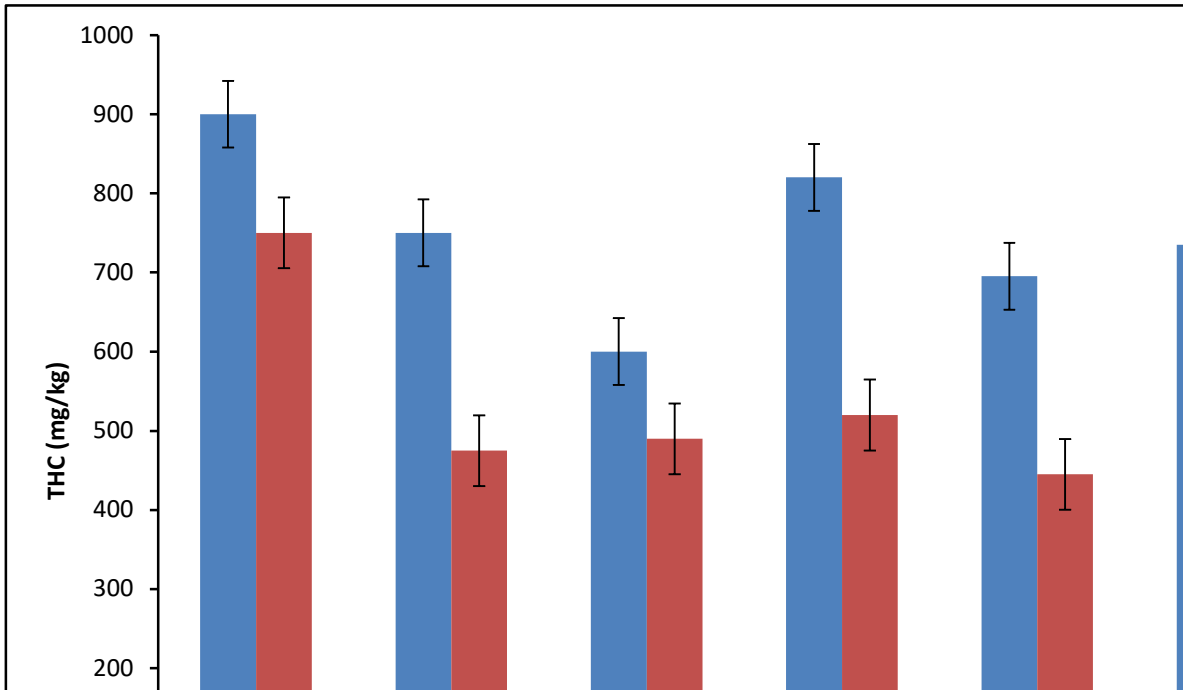


Fig. 4.70: Total hydrocarbon content of sub soils of 4% polluted waterlogged site in wet season

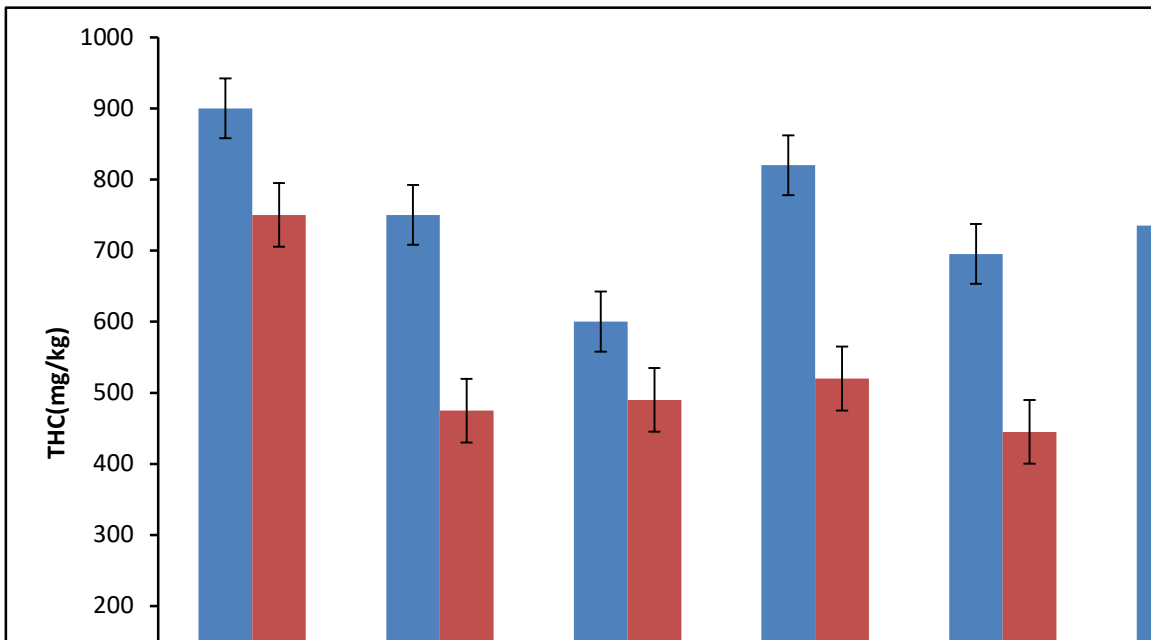


Fig. 4.71: Total hydrocarbon content of sub soils of 6% polluted well drained site in wet season

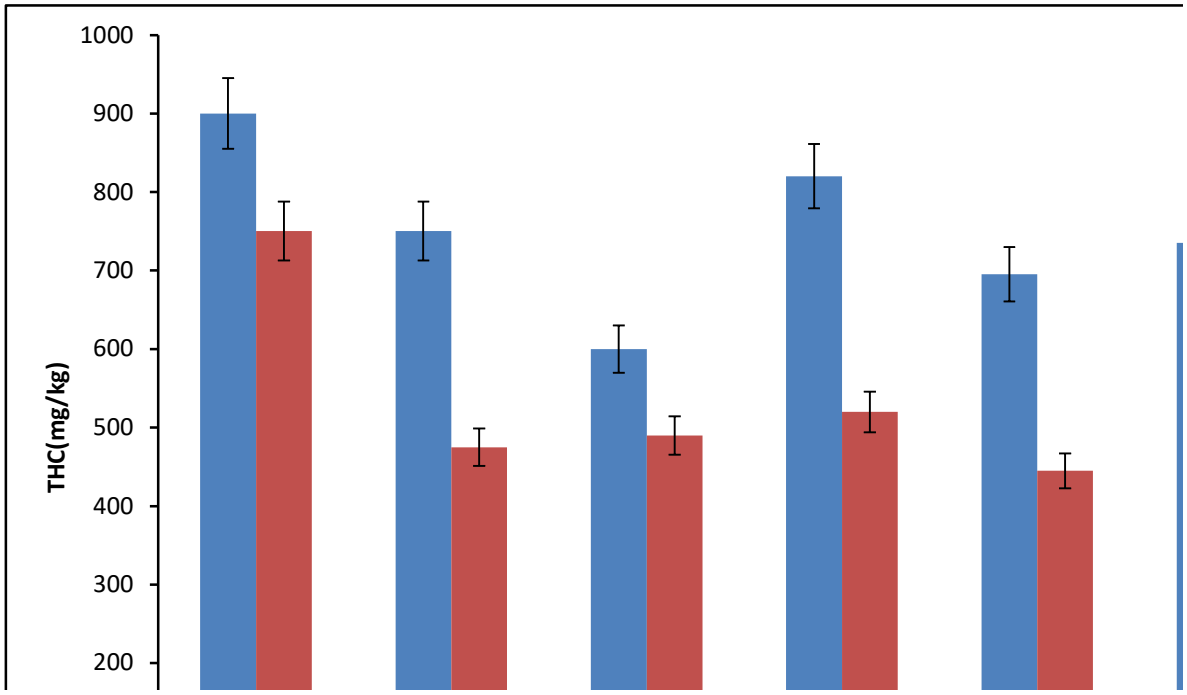


Fig. 4.72: Total hydrocarbon content of sub soils of 6% polluted waterlogged site in wet season

Hypothesis one

Hi: There is significant difference between polluted and remediated soils with respect to hydrocarbon levels.

The data for 2%, 4% and 6% hydrocarbon contaminated and remediated top and sub soils in the well drained site during the dry season are used to validate this hypothesis.

Table 4.19: Student's t-test table for difference in 2% hydrocarbon levels between polluted and remediated top soils

	Polluted soil	**Remediated soil**
Mean	740.83	426.67
Variance	11544.17	5156.67
Observations	6	6
Pearson correlation	0.68	
Hypothesized mean difference	0	
Df	5	
t.stat	9.77	
t. critical two tail	2.57	

Decision: since the calculated t statistic value of 9.77 is greater than the critical value of 2.57, the null hypothesis is rejected and the alternative hypothesis accepted which states that there is a statistically significant difference in hydrocarbon levels in the 2% polluted and remediated top soils.

Table 4.20: Student's t test table for difference in 4% hydrocarbon levels between polluted and remediated top soils.

	Polluted soil	**Remediated soil**
Mean	755	403.33
Variance	6780	3456.67
Observations	6	6
Pearson correlation	0.72	
Hypothesized mean difference	0	
Df	5	
t.stat	15.12	
t. critical two tail	2.57	

Decision: Since the calculated t statistic value of 15.12 is greater than the critical value of 2.57, we reject the null hypothesis and accept the alternative hypothesis which states that there is a statistically significant difference in hydrocarbon levels of the 4% polluted and remediated top soils.

Table 4.21: Student's t-test table for difference in 6% hydrocarbon level between polluted and remediated top soils.

	Polluted soil	**Remediated soil**
Mean	787.5	475
Variance	9837.5	2500
Observations	6	6
Pearson correlation	0.78	
Hypothesized mean difference	0	
Df	5	
t.stat	11.25	
t. critical two tail	2.57	

Decision: Since the calculated t-statistic value of 11.25 is greater than the critical value of 2.57, the null hypothesis is rejected and the alternative hypothesis accepted which states that there is a statistically significant difference in hydrocarbon levels of the 6% polluted and remediated top soils.

Table 4.22: Student's t-test table for difference in 2% hydrocarbon levels between polluted and remediated sub soils

	Polluted soil	**Remediated soil**
Mean	611.67	339.117
Variance	666.67	1504.167
Observations	6	6
Pearson correlation	0.605	
Hypothesized mean difference	0	
Df	5	
t.stat	21.57	
t. critical two tail	2.57	

Decision: Since the calculated t statistic value of 21.57 is greater than the critical value of 2.57, we reject the null hypothesis and accept the alternative hypothesis which states that there is a statistically significant difference in hydrocarbon levels of the 2% polluted and remediated sub soils.

Table 4.23: Student's t-test table for difference in 4% hydrocarbon levels between polluted and remediated sub soils

	Polluted soil	**Remediated soil**
Mean	615	317.5
Variance	10230	4867.5
Observations	6	6
Pearson correlation	0.99	
Hypothesized mean difference	0	
Df	5	
t.stat	22.30	
t. critical two tail	2.57	

Decision: Since the calculated t statistic value of 22.30 is greater than the critical value of 2.57, the null hypothesis is rejected and the alternative hypothesis accepted which states that there is a statistically significant difference in hydrocarbon levels of the 4% polluted and remediated sub soils.

Table 4.24: Student's t-test table for difference in 6% hydrocarbon levels between polluted and remediated sub soils

	Polluted soil	**Remediated soil**
Mean	762.5	436.67
Variance	6097.5	3266.67
Observations	6	
Pearson correlation	0.807	
Hypothesized mean difference	0	
Df	5	
t.stat	17.16	
t. critical two tail	2.57	

Decision: Since the calculated t statistic value of 17.16 is greater than the critical value of 2.57, we reject the null hypothesis of no difference and accept the alternative hypothesis which states that there is a statistically significant difference in hydrocarbon levels of the 6% polluted and remediated sub soils.

Hypothesis two

The second hypothesis states that there is a significant difference between the chemical properties of soils before and after remediation.

The data in Tables 4.13 and 4.14 in the 2% contaminated and remediated soils in the well drained site were used to validate this hypothesis.

Table 4.25: Student's t-test table for difference in organic carbon between 2% contaminated and remediated top soils

	Polluted soil	**Remediated soil**
Mean	0.703	0.59
Variance	0.004	0.002
Observations	6	6
Pearson correlation	0.63	
Hypothesized mean difference	0	
Df	5	
t.stat	5.501	
t. critical two tail	2.57	

Decision: Since the calculated t statistic value of 5.50 is greater than the critical value of 2.57, the null hypothesis is rejected and the alternative hypothesis is accepted which states that there is a statistically significant difference in total organic carbon in the 2% contaminated and remediated top soils.

Table 4.26: Student's t-test table for difference in total organic carbon between 2% contaminated and remediated sub soils

	Polluted soil	**Remediated soil**
Mean	0.713	0.6
Variance	0.003	0.005
Observations	6	6
Pearson correlation	0.83	
Hypothesized mean difference	0	
Df	5	
t.stat	7.25	
t. critical two tail	2.57	

Decision: Since the calculated t statistic value of 7.25 is greater than the critical value of 2.57, the null hypothesis is rejected and the alternative hypothesis is accepted which states that there is a statistically significant difference in total organic carbon in the 2% contaminated and remediated sub soils.

Table 4.27: Student's t-test table for difference in total nitrogen between 2% contaminated and remediated top soils

	Polluted soil	**Remediated soil**
Mean	0.177	0.11
Variance	0.001	0.001
Observations	6	6
Pearson correlation	0.83	
Hypothesized mean difference	0	
Df	5	
t.stat	6.74	
t. critical two tail	2.57	

Decision: Since the calculated t statistic value of 6.74 is greater than the critical value of 2.57, the null hypothesis is rejected and the alternative hypothesis is accepted which states that there is a statistically significant difference in total nitrogen between the 2% contaminated and remediated top soils.

Table 4.28: Student's t-test table for difference in total nitrogen between 2% contaminated and remediated sub soils

	Polluted soil	**Remediated soil**
Mean	0.18	0.13
Variance	0.001	0.001
Observations	6	6
Pearson correlation	0.938	
Hypothesized mean difference	0	
Df	5	
t.stat	8.37	
t. critical two tail	2.57	

Decision: Since the calculated t statistic value of 8.37 is greater than the critical value of 2.57, the null hypothesis is rejected and the alternative hypothesis is accepted which states that there is a statistically significant difference in total nitrogen between the 2% contaminated and remediated sub soils.

4.3.6 Analysis of Total Petroleum Hydrocarbon

Total petroleum contents in the sample soils were 69.7 ppm and 58.9 ppm during dry and wet seasons respectively after contamination. However, after remediation the values reduced in the dry and wet seasons to 29.1ppm and 44.3 ppm. Results obtained showed that soil samples treated with decomposed cassava peels contained less amount of TPH concentration after remediation compared to contaminated samples without treatment. Gas chromatography (GC) analysis revealed that polluted hydrocarbon consisted mainly of $C_8 - C_{40}$ hydrocarbon fractions. $C_1 - C_7$ were not observed in the soil contaminated with crude oil, which indicated that toxic volatile fractions were not present. As shown in Figures 4.73 and 4.74. The GC revealed pristine and phytane were present in the contaminated samples. The percentage of degradation is an indication of the relationship between hydrocarbons biodegradability to size of molecule (Geller, 2002). It was observed that some middle fractions of $C_{19} - C_{29}$ and the larger molecules > C_{34} were poorly degraded. These molecular compounds with heavier weight are generally tolerant to biodegradation. The n-alkanes fractions ($C_8 - C_{16}$) were mostly degraded. The disappearance of the light n-alkanes with less than C_{12} carbon atoms in the samples is an indication of oil residue after spillage and also suggests that a significant alteration of the chemical components of the aliphatic in the spill oil. The implication is that the evaporation of n-C_8 to n-C_{11} led to the elimination (Connan, 1984).

De Jonge *et al*., (1997) also showed that a decrease in the number of carbon will result in increased biodegradation level of n-alkanes. It was observed that total petroleum hydrocarbon showed a significant decrease after remediation as the TPH values decreased from 69.70 ppm to 29.12 ppm. This could be due to the presence of the organic matter in cassava peels which encouraged microbial population multiplication that resulted in the break down of hydrocarbons. Among the numerous microorganisms present in decomposed cassava peels, bacteria especially pseudomonas are capable of oxidizing hydrocarbons aerobically and utilizing the oxidized products as a source of carbon. The enrichment of microorganisms in decomposed cassava peels might have resulted in decreasing component of oil significantly. These improved soil qualities thus suggest restoration of soil fertility. It was also observed that flourene (C_{13} H_{10}) seemed to

be more degraded than PAHs. Napthalene, flourene and anthracene belong to the low moleculer weight PAHs with two or three rings. Due to this constraint, their degradability was very minimal in this study. Salanitro *et al.,* (1997) indicate that microbes naturally occurring are responsible for breaking down of carbons present in oil in the soils, sludges and sediments. However, the level of bioremediation of hydrocarbons may depend on the soil type and hydrocarbon products, TPH levels and the growth promoters (nutrients) of microorganisms (Akpaetor, 2011).

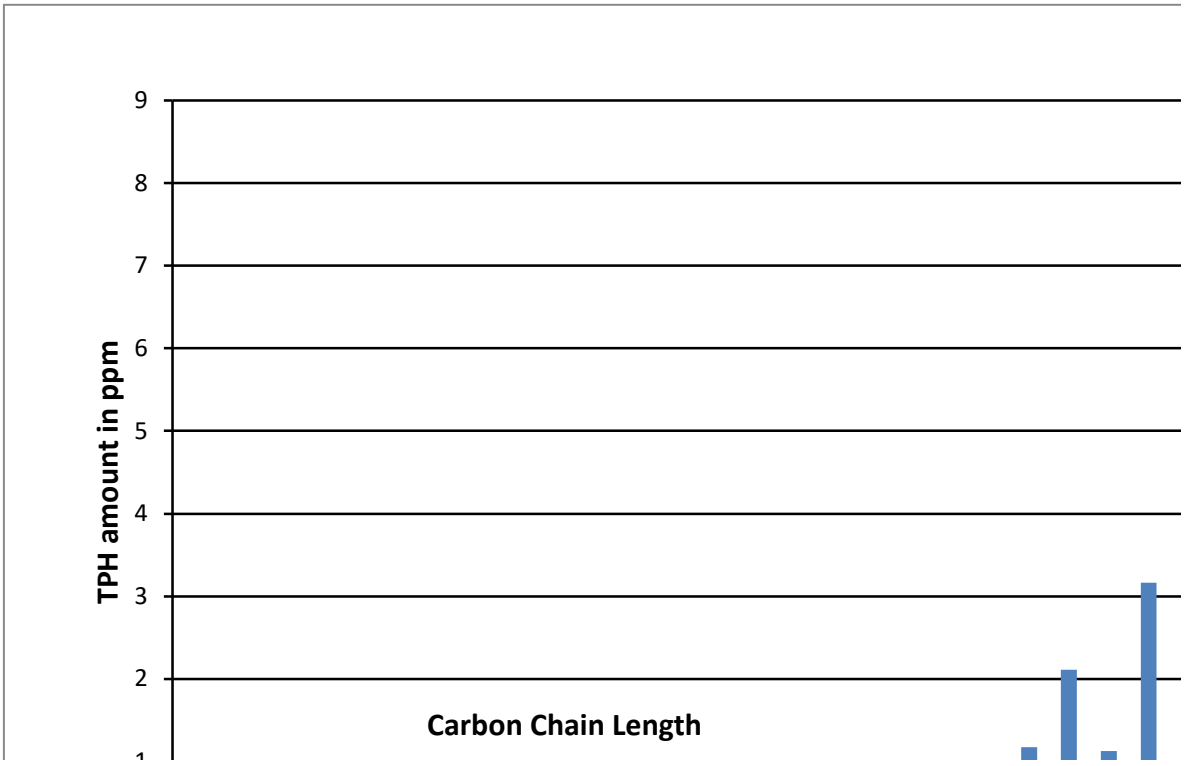


Fig. 4.73: Gas chromatography analysis of total petroleum hydrocarbon after pollution in wet season

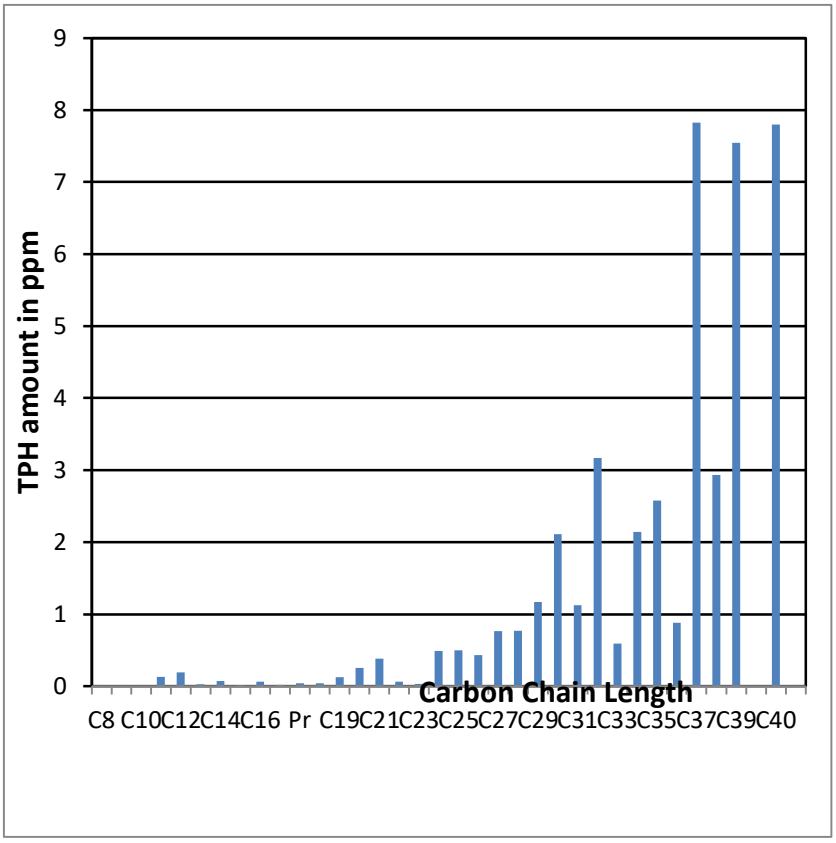


Fig. 4.74: Gas chromatography analysis of total petroleum hydrocarbon after remediation in wet season

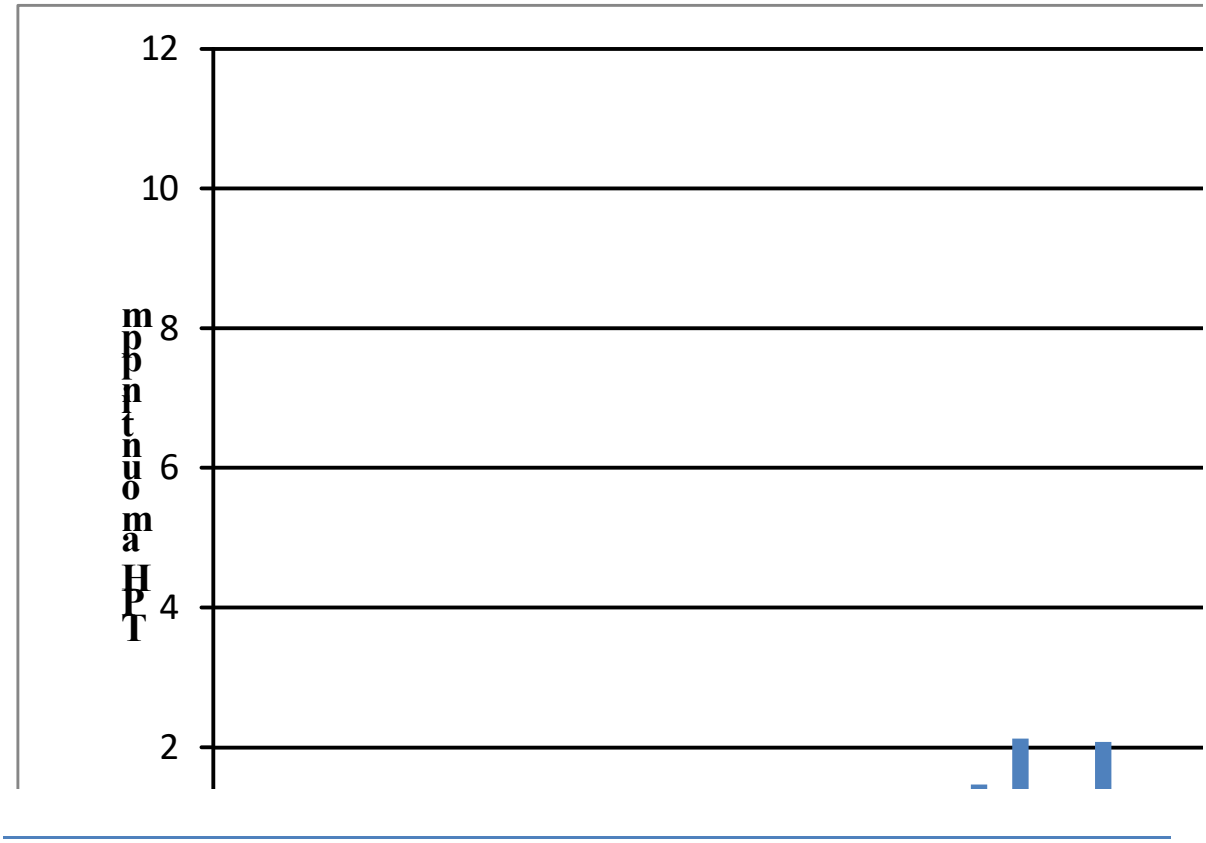


Fig. 4.75: Gas chromatography analysis of total petroleum hydrocarbon after pollution in dry season

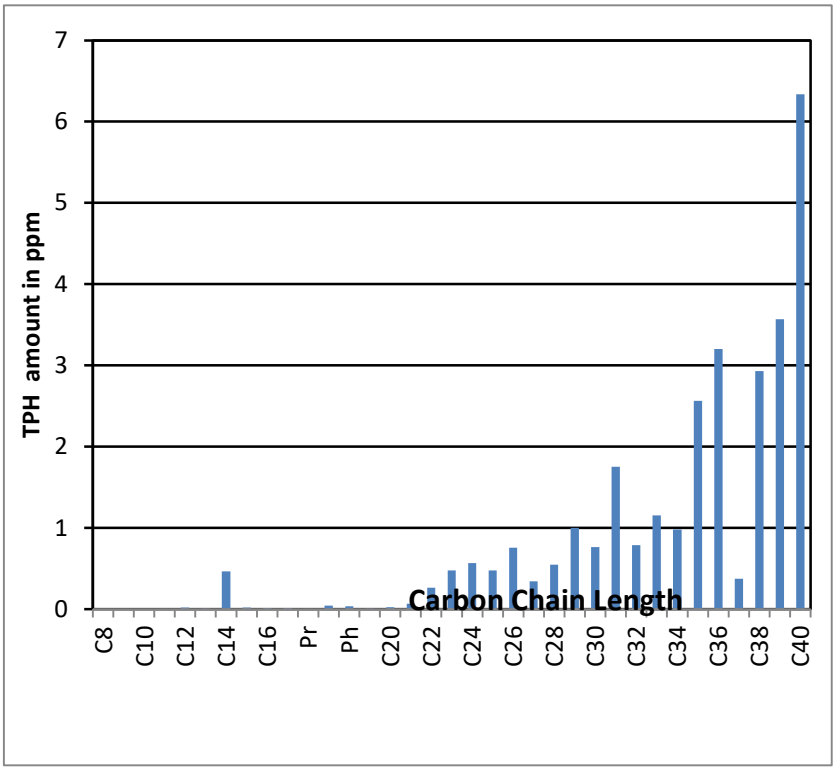


Fig. 4.76: Gas chromatography analysis of total petroleum hydrocarbon after remediation in dry season

4.3.7 Enumeration of Total Heterotrophic Bacteria (THB) and Hydrocarbon Utilizing Bacteria (HUB) of contaminated and remediated Soils

Tables 4.25 and 4.26 provide the results of microbial counts after contamination and after remediation for surface and subsurface soils. The mean count of total heterotrophic bacteria in the well drained site after contamination were 4.15 x 10^6 cfu/g, 4.25 x 10^6 cfu/g and 3.90 x 10^7 cfu/g in surface soils and 2.92 x 10 cfu/g, 2.95 x 10 cfu/g and 2.83 x 10 cfu/g in sub surface soils while the mean counts after remediation were 4.97 x 10^7 cfu/g, 4.98 x 10^7 cfu/g and 4.95 x 10^7 cfu/g (surface soils) and 4.3 x 10 cfu/g, 4.43 x 10 cfu/g and 4.35 cfu/g (subsurface soils). In the waterlogged site total heterotrophic bacterial mean counts after contamination were 3.21 x10^6 cfu/g, 3.47 x 10^6 cfu/g and 3.06 x 10^6 cfu/g in surface soils and 2.79 x 10^6 cfu/g, 2.8x 10^6 cfu/g and 2.76 x 10^5 cfu/g in subsurface soils while after remediation the mean values were 3.75 x 10^7cfu/g, 3.78 x 10^7 cfu/g and 3.75 x 10^7 cfu/g in surface soils and 3.85 x 10^7 cfu/g and 3.87 x 10^7 cfu/g in subsurface soils.

The mean counts of hydrocarbon utilizing bacteria in the well drained site after contamination were 4.5 x 10^5 cfu/g, 4.6 x 10^5 cfu/g, and 4.62 x 10^5 cfu/g, in surface soils and 4.3 x 10^5 cfu/g,, 4.4 x 10^5 cfu/g, and 4.47 x 10^5 cfu/g, in subsurface soils in the 2%, 4% and 6% polluted plots while the mean values after remediation were 4.88 x 10^5 cfu/g,, 4.90 x 10^5 cfu/g and 4.85 x 10^5 cfu/g (surface soils) and 4.43 x 10^5 cfu/g, 4.45 x 10^5 cfu/g and 4.42 x 10^5 cfu/g (subsurface soils). In the waterlogged site hydrocarbon utilizing bacteria mean counts after contamination were 4.22 x 10^5 cfu/g, 4.28 x 10^5 cfu/g and 4.56 x 10^5 cfu/g in surface soils and 4.5 x 10^5 cfu/g, 4.43 x 10^5 cfu/g, and 4.6 x 10^5 cfu/g in subsurface soils in the 2%, 4% and 6% polluted plots while the mean values after remediation were 4.32 x 10^5 cfu/g, 4.35 x 10^5 cfu/g and 4.33 x 10^5 cfu/g in surface soils and 4.40 x 10^5 cfu/g, 4.42 x 10^5 cfu/g and 4.41 x 10^5 cfu/g in subsurface soils.

THB and HUB counts for most soil samples at the beginning of the study. However, when the contaminated plots were subjected to organic amendment using the decomposed cassava peels, it was observed that there was a significant increase in microbial population. Both the THB and HUB increased. The THB had mean counts of 4.97 x 10^7cfu/g, 4.98 x 10^7 cfu/ and 4.95 x 10^7 cfu/g in surface soils in the well drained site after remediation while THB counts were 4.15 x 10^6 cfu/g, 4.25 x 10^6 cfu/g and 3.9 x 10^6 cfu/g in the same site after contamination. In the subsurface soils THB had mean counts of 4.37

x 10^6 cfu/g, 4.38 x 10^6 cfu/g and 4.35 x 10^6 cfu/g after remediation while after contamination THB mean counts were 2.92 x 10^6 cfu/g, 2.95 x 10^6 cfu/g and 2.83 x 10^6 cfu/g. It was observed that viable counts of HUB and THB in the remediated plots population was higher and the yield significant ($p < 0.05$) compared to pre-contaminated (control) soil. Following the three months of soil amendment, the decomposed cassava peels treatment showed a significant count of THB and HUB as indicated in Tables 4.25 and 4.26. This revealed that degradation of organic changes and mineralization provided nutrients that supported the increase of microorganism that degrade hydrocarbon. In a report by Huesemann and Moore (1993) the amount of hydrocarbon decomposers was generally higher when nitrogen and phosphorus was added to the soil, which were also included in the decomposed cassava peels amendment, as indicated in Tables 4.27. Comparing the results in the upper soil (0–15 cm) and the lower soil (15–30 cm), it was reported that THB and HUB levels decreased with increasing depth of soil, as shown in Table 4.26. The findings confirm the reports of Bossert and Compeau (1995), Avidano *et al.,* (2005) and Katsivala *et al.,* (2005), according to which the population of microorganisms reduces with the depth of soil.

Table 4.29: Total Heterotrophic Bacteria and Hydrocarbon Utilizing Bacteria (cfu/g) of Top Soils (0-15cm) after Contamination and after Remediation.

Pollution level		Well drained site				Water logged site			
		After Contamination		After remediation		After Contamination		After remediation	
		THB	HUB	THB	HUB	THB	HUB	THB	HUB
Treatment replicates	2% 1	6.4×10^6	1.6×10^5	9.6×10^7	8.2×10^5	6.1×10^6	2.4×10^5	9.5×10^7	8.8×10^5
	2	3.4×10^6	3.2×10^5	3.2×10^6	6.5×10^5	5.4×10^6	4.4×10^4	3.2×10^7	4.8×10^4
	3	4.3×10^6	6.3×10^5	2.7×10^7	4.8×10^5	1.17×10^5	3.8×10^5	2.7×10^7	2.5×10^4
	4	2.9×10^7	3.5×10^5	4.8×10^7	2.3×10^5	2.3×10^5	3.4×10^4	1.6×10^6	2.0×10^5
	5	4.21×10^6	4.3×10^6	3.9×10^7	3.2×10^5	2.5×10^6	6.7×10^5	2.4×10^7	3.6×10^5
	6	3.67×10^6	8.1×10^5	5.6×10^7	4.3×10^5	1.8×10^6	4.6×10^5	3.0×10^7	4.2×10^5
	Range	3.4×10^6-6.4×10^6	1.6×10^5-8.1×10^5	2.7×10^7-9.6×10^7	2.3×10^5-8.2×10^5	1.17×10^5-6.1×10^6	2.4×10^5-6.7×10^5	1.6×10^6-9.5×10^7	2.0×10^5-8.8×10^5
	Mean	4.15×10^6	4.5×10^5	4.9×10^7	4.88×10^5	3.21×10^6	4.22×10^5	3.75×10^7	4.32×10^5
Treatment replicates	4% 1	7.9×10^6	1.8×10^5	2.4×10^6	7.8×10^5	1.7×10^5	7.3×10^4	2.16×10^8	2.8×10^5
	2	4.9×10^6	9.4×10^5	3.6×10^7	2.0×10^5	6.0×10^5	3.9×10^5	3.7×10^6	4.6×10^5
	3	3.1×10^5	6.2×10^5	7.3×10^6	3.1×10^5	2.9×10^6	6.1×10^4	4.0×10^7	3.6×10^5
	4	3.3×10^6	3.4×10^6	4.7×10^6	4.4×10^5	1.8×10^6	2.8×10^5	3.9×10^7	4.1×10^4
	5	1.7×10^6	3.8×10^5	3.5×10^7	7.1×10^5	5.3×10^6	2.4×10^5	4.3×10^8	7.2×10^5
	6	4.6×10^6	3.0×10^5	8.4×10^6	5.0×10^5	3.1×10^6	3.2×10^5	4.6×10^7	3.8×10^4
	Range	1.7×10^6-1.9×10^6	1.8×10^5-9.4×10^5	2.4×10^6-8.4×10^6	2.0×10^5-7.8×10^5	1.7×10^5- 6.0×10^6	2.4×10^5- 7.3×10^5	2.16×10^8- 4.6×10^7	2.8×10^5- 7.2×10^5
	Mean	4.25×10^6	4.6×10^5	4.98×10^7	4.90×10^5	3.47×10^6	4.28×10^5	3.78×10^7	4.35×10^5
Treatment replicates	6% 1	2.73×10^6	1.73×10^6	3.5×10^7	4.7×10^5	2.9×10^6	3.6×10^4	3.5×10^8	7.7×10^5
	2	9.4×10^5	9.4×10^5	8.6×10^7	4.2×10^5	2.73×10^5	2.16×10^5	2.12×10^5	4.3×10^5
	3	1.4×10^5	6.5×10^5	4.6×10^6	3.4×10^5	3.5×10^5	4.8×10^5	4.1×10^7	2.7×10^5
	4	2.6×10^6	3.5×10^6	3.9×10^6	4.3×10^5	2.8×10^6	8.6×10^5	3.4×10^6	4.6×10^4
	5	3.8×10^6	2.7×10^5	4.7×10^7	7.7×10^5	3.7×10^6	3.1×10^5	4.3×10^7	3.8×10^5
	6	3.5×10^6	3.9×10^5	4.4×10^7	4.8×10^5	3.3×10^6	5.1×10^5	5.1×10^7	2.9×10^5
	Range	1.4×10^5- 9.4×10^5	1.73×10^6- 9.6×10^5	3.5×10^7- 8.6×10^7	3.4×10^5- 7.7×10^5	2.73×10^5- 3.7×10^6	1.16×10^5- 8.6×10^4	2.12×10^8-5.1×10^7	2.7×10^5- 7.7×10^5
	Mean	3.9×10^6	4.62×10^5	4.95×10^7	4.85×10^5	3.06×10^6	4.56×10^5	3.75×10^7	4.33×10^5

Source: Author's Analysis, 2015

Table 4.30: Total Heterotrophic Bacteria and Hydrocarbon Utilizing Bacteria (cfu/g) of Sub Soil (15-30cm) after Contamination and after Remediation.

Pollution level		**Well drained site**				**Water logged site**			
		After Contamination		**After remediation**		**After Contamination**		**After remediation**	
		THB	HUB	THB	HUB	THB	HUB	THB	HUB
Treatment replicates	2% 1	1.8×10^6	5.9×10^5	3.2×10^6	1.05×10^5	1.5×10^6	6.5×10^5	1.5×10^8	4.5×10^5
	2	1.8×10^6	1.6×10^5	9.5×10^7	3.5×10^5	6.5×10^5	3.6×10^5	2.3×10^7	4.3×10^4
	3	2.4×10^6	4.2×10^5	1.3×10^6	5.7×10^5	2.13×10^6	2.5×10^5	7.4×10^7	4.1×10^5
	4	3.8×10^5	3.2×10^5	3.7×10^6	5.3×10^5	1.4×10^6	7.2×10^5	4.3×10^8	6.4×10^4
	5	2.7×10^6	6.2×10^5	4.6×10^7	7.4×10^4	3.0×10^5	2.4×10^4	3.9×10^7	3.8×10^5
	6	5.0×10^5	4.7×10^5	3.9×10^6	3.6×10^4	2.2×10^6	4.8×10^5	3.7×10^7	3.3×10^5
	Range	1.8×10^6-5.0×10^5	1.6×10^5-6.2×10^5	1.3×10^6-9.5×10^7	1.05×10^5-7.4×10^5	1.4×10^6-6.5×10^6	2.4×10^4-7.2×10^5	1.5×10^8-7.4×10^7	3.3×10^5-6.4×10^5
	Mean	2.92×10^6	4.3×10^5	4.3×10^6	4.43×10^5	2.79×10^6	4.5×10^5	3.85×10^7	4.40×10^5
Treatment replicates	4% 1	2.8×10^6	2.5×10^5	4.1×10^6	9.8×10^4	1.6×10^6	1.3×10^5	6.8×10^8	5.1×10^5
	2	9.0×10^5	2.8×10^5	6.9×10^6	7.2×10^4	4.7×10^6	9.0×10^4	3.9×10^7	7.0×10^4
	3	1.6×10^5	6.4×10^5	2.9×10^6	2.8×10^5	1.7×10^5	5.6×10^5	2.7×10^8	8.2×10^5
	4	1.2×10^6	1.8×10^5	2.4×10^7	2.6×10^5	3.3×10^5	3.6×10^5	3.6×10^7	1.0×10^5
	5	1.8×10^6	4.4×10^5	4.0×10^6	2.4×10^5	3.0×10^6	2.9×10^4	3.4×10^7	2.7×10^4
	6	1.3×10^6	8.3×10^5	6.0×10^6	1.9×10^5	2.5×10^6	4.2×10^5	2.8×10^7	2.5×10^4
	Range	1.2×10^6- 9.0×10^5	1.8×10^5- 6.4×10^5	2.4×10^7- 6.9×10^6	1.9×10^5- 9.8×10^4	1.6×10^6- 4.7×10^6	1.3×10^5- 9.0×10^4	2.7×10^8- 6.8×10^8	1.0×10^5- 8.2×10^5
	Mean	2.95×10^6	4.4×10^5	4.38×10^6	4.45×10^5	2.8×10^6	4.43×10^5	3.87×10^7	4.42×10^5
Treatment replicates	6% 1	1.7×10^5	1.9×10^5	7.0×10^7	5.4×10^5	3.1×10^6	3.6×10^5	5.3×10^7	2.10×10^6
	2	3.6×10^5	9.4×10^5	4.3×10^6	5.6×10^5	2.13×10^7	4.4×10^4	2.8×10^8	3.45×10^5
	3	1.5×10^6	2.5×10^5	2.4×10^6	3.8×10^4	1.6×10^6	6.1×10^5	3.5×10^7	4.7×10^6
	4	2.8×10^6	4.0×10^6	3.6×10^7	4.2×10^4	2.8×10^5	9.2×10^4	3.9×10^8	5.5×10^4
	5	4.3×10^6	3.2×10^5	4.5×10^6	3.5×10^5	2.7×10^6	2.5×10^5	4.8×10^7	6.8×10^5
	6	3.1×10^6	5.8×10^5	4.3×10^6	4.0×10^5	4.2×10^6	1.8×10^5	2.9×10^7	3.9×10^5
	Range	1.5×10^6- 4.3×10^6	1.9×10^5- 9.4×10^5	2.4×10^6- 7.0×10^7	3.5×10^5- 5.6×10^5	1.6×10^6- 4.2×10^6	1.8×10^5- 9.2×10^4	2.8×10^8- 5.3×10^7	2.10×10^6- 6.8×10^5
	Mean	2.83×10^6	4.47×10^5	4.35×10^6	4.42×10^5	2.76×10^5	4.6×10^5	3.87×10^7	4.41×10^5

Source: Author's Analysis, 2015

Plate 1: Undecomposed Cassava Peels used for remediation

Plate 2: Decomposed Cassava Peels used for bioremediation

Table 4.31 Nutrient contents of the cassava peels

Element	Percentage
Nitrogen	0.63
Phosphorus	0.40
Potassium	1.00
Calcium	0.37
Magnesium	0.10

Source: Authors Analysis, 2015

4.3.8 Heavy Metals Concentration of Contaminated and Remediated Soils

The results of heavy metal contents in top soils and sub soils of contaminated and remediated soils are presented in Figures 4.77 to 4.100. The results showed lower concentration of heavy metals in the remediated soils compared to the contaminated soils. The mean concentration levels of lead in the well drained site after remediation reduced in surface soils from 10.78 to 7.60; 11.53 to 7.62 and 11.18 mg/kg to 7.01 mg/kg respectively while in subsurface soil the decline was from 13.54, 13.61 and 13.5 to 7.18, 7.16 and 7.16 mg/kg. In the same manner, the mean value for waterlogged site after remediation reduced from 6.82, 7.89 and 6.82 to 3.68, 3.67 and 3.65 mg/kg and 6.40 to 3.05 mg/kg, 6.62 to 3.10 mg/kg and 6.42 to 3.10 mg/kg in subsurface soils. The values of lead in contaminated soils were higher than the remediated soils and there was statistically significant difference between the two soil samples.

The mean concentration levels of cadmium in the well drained site after contamination in surface and subsurface soil were 0.52, 0.53 and 0.50 mg/kg and 0.49, 0.51 and 0.48 mg/kg respectively in the 2%, 4% and 6% polluted plots. In the waterlogged site the mean values in surface soil in mg/kg were 4.2, 4.52 and 3.30 while in subsurface soils the values in mg/kg were 2.26, 2.28 and 2.10 after contamination. The observation was that that the values of cadmium reduced after remediation as the mean values in the well drained site decline in mg/kg from 0.52 to 0.31, 0.53 to 0.32 and 0.50 to 0.30 in surface soils and in subsurface soils also in mg.kg reduced from 0.49, 0.51 and 0.48 to 0.28, 0.27 and 0.25 respectively. Similar reduction was observed in the waterlogged site as the mean values of cadmium after remediation reduced in mg/kg from 4.25, 4.52 and 3.30 to 2.35, 2.46 and 1.93 in surface soils respectively and in subsurface soils from 2.26, 2.28 and

2.10 to 1.31, 1.25 and 1.10 all in mg/kg. The values of cadmium in contaminated soils were higher when compared with the remediated soils. However, the difference between samples of soil was not significant.

The Nickel concentration in the well drained site after contamination had mean values for surface were 44.62, 40.35 and 41.75 while subsurface soil were 46.70, 46.01 and 42.05 respectively all in mg/kg. In the waterlogged site the mean values in mg/kg for surface soil were 49.73, 44.80 and 47.00 and subsurface soils 54.12, 50.97 and 55.12. However, the values of Nickel reduced after remediation as the mean values in the well drained site after remediation reduced in mg/kg from 44.62, 40.35 and 41.75 to 40.53, 37.64 and 38.33 respectively in surface soils and from 46.70, 46.01 and 42.05 to 41.87, 41.76 and 40.08 in subsurface soils respectively. The mean values of Nickel also reduced after remediation in the waterlogged site in mg/kg from 49.73 to 26.63, 44.80 to 26.61 and 47.00 to 26.62 in surface soils and from 54.12 to 31.35, 50.97 to 30.63 and 55.12 to 31.10 in subsurface soils. The values of Nickel in contaminated soils were higher than the values obtained after remediation and the difference were significant, ($p = 0.05$).

The mean copper concentration levels in the well drained site after contamination in mg/kg were 7.25, 7.11 and 7.03 in surface soils and 7.82, 8.03 and 8.20 in subsurface soils in the 2, 4 and 6 percents in polluted plots respectively. In the waterlogged site the mean values after contamination in mg/kg were 5.87, 6.15 and 6.47 in surface soils and 6.56, 7.18 and 7.02 in subsurface soils. The values of copper were also observed to reduce after remediation as the mean values in the well drained site reduced in mg/kg from 7.25 to 6.03, 7.11 to 5.72 and 7.03 to 5.99 in surface soils and from 7.82 to 5.68, 8.03 to 5.48 and 8.20 to 5.21 in subsurface soils. In the waterlogged site the mean values of copper also reduced in mg/kg after remediation from 5.87 to 3.53, 6.15 to 3.92 and from 6.47 to 3.61 in surface soils and from 6.56 to 3.03, 7.18 to 3.02 and 7.02 to 3.02 in subsurface soils. Although the values of copper in contaminated soils were higher when compared with the remediated soils, there was no statistically significant difference between them.

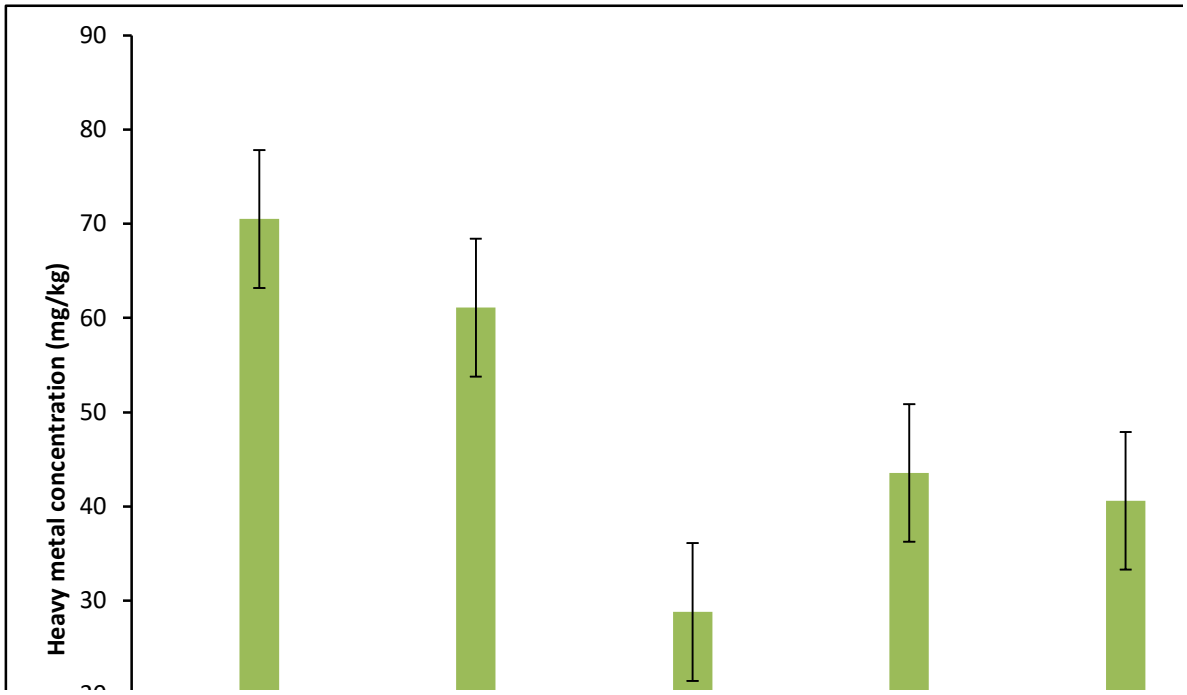


Fig 4.77: Heavy metal concentration (mg/kg) in top soil after crude oil (2%) contamination in well drained site

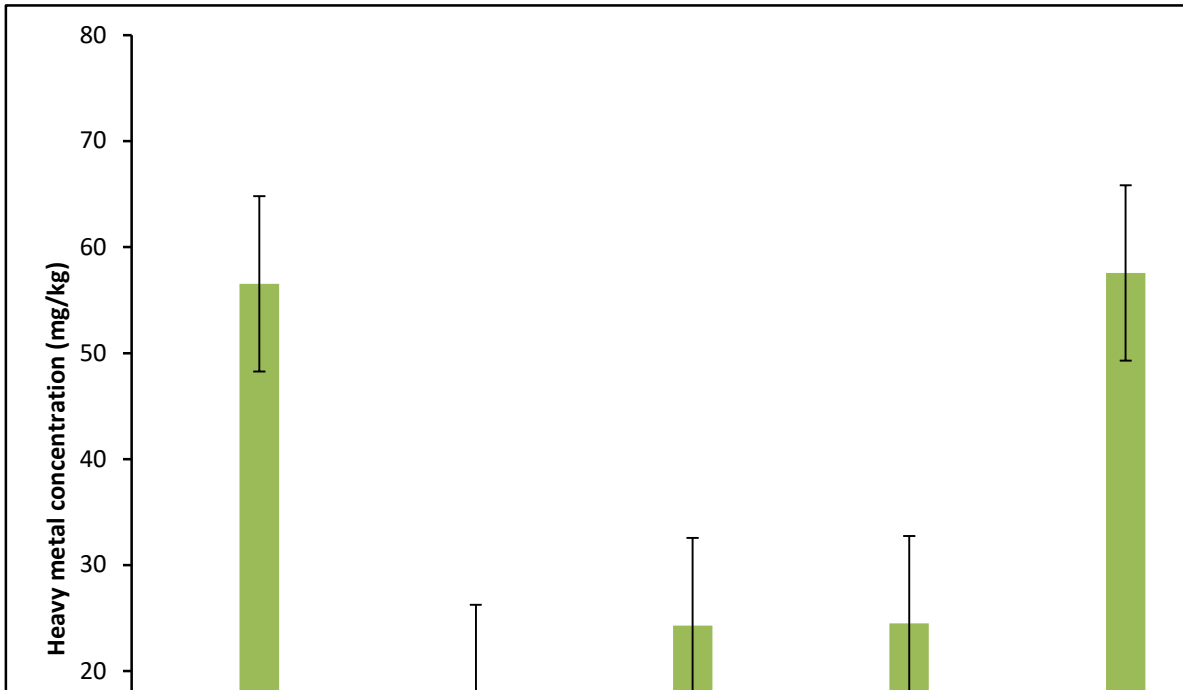


Fig. 4.78: Heavy metal concentration (mg/kg) in top soil (0-15cm) after crude oil (2%) remediation in well drained site

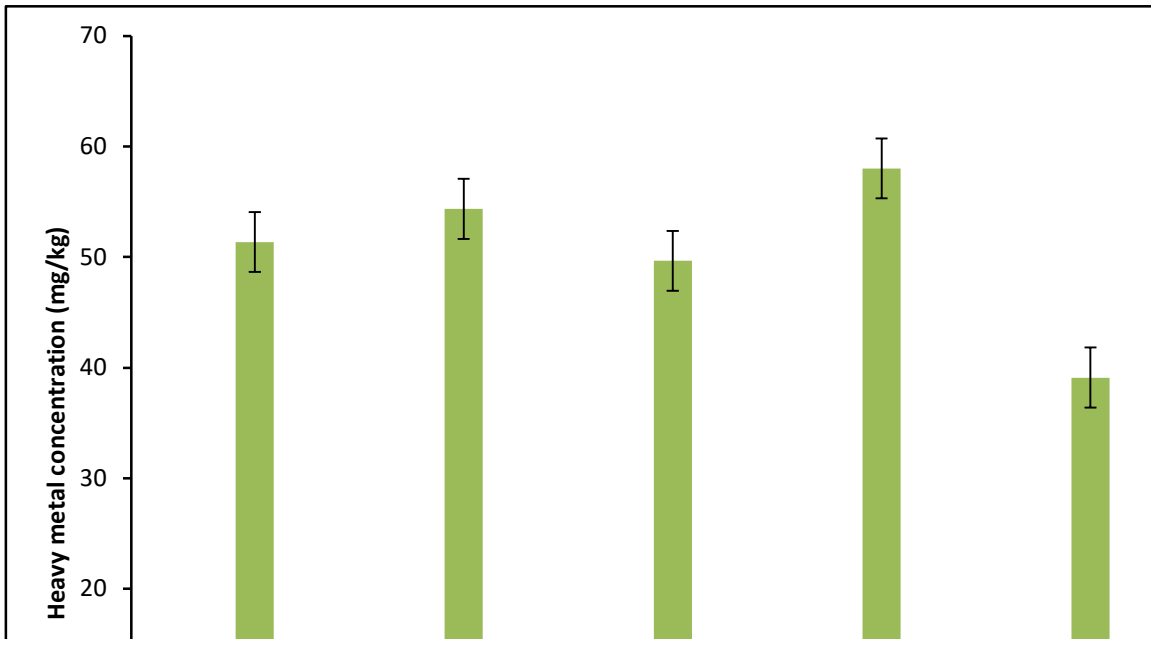


Fig. 4.79: Heavy metal concentration (mg/kg) in top soil (0-15cm) after crude oil (2%) contamination in waterlogged site

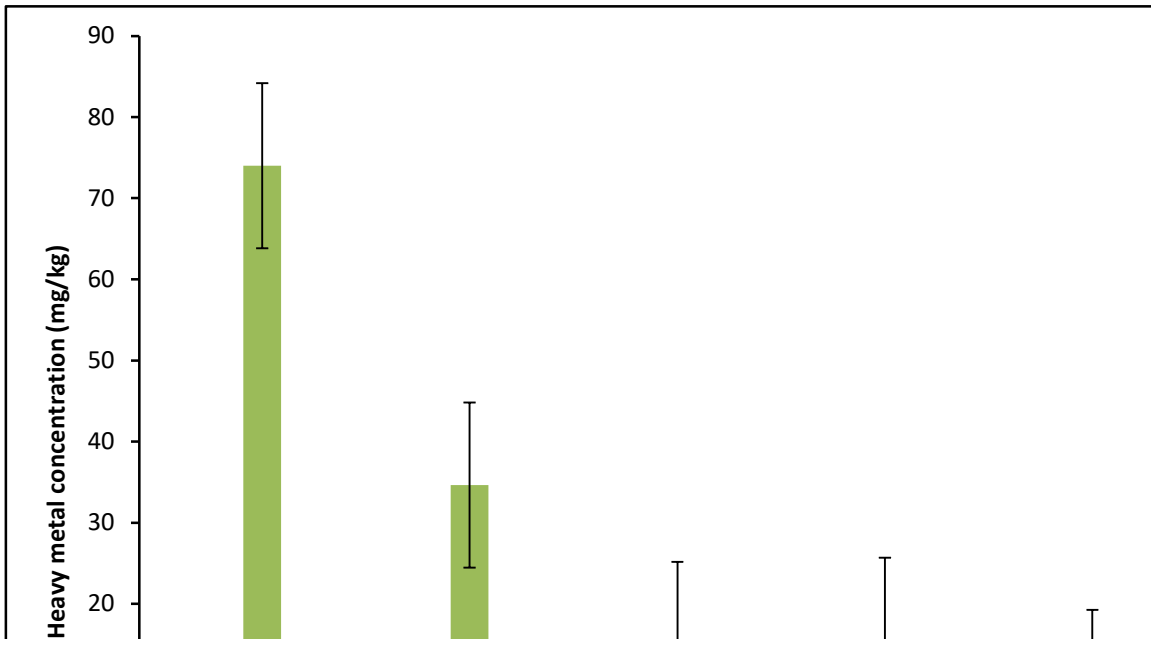


Fig. 4.80: Heavy metal concentration (mg/kg) in top soil (0-15cm) after crude oil (2%) remediation in waterlogged site

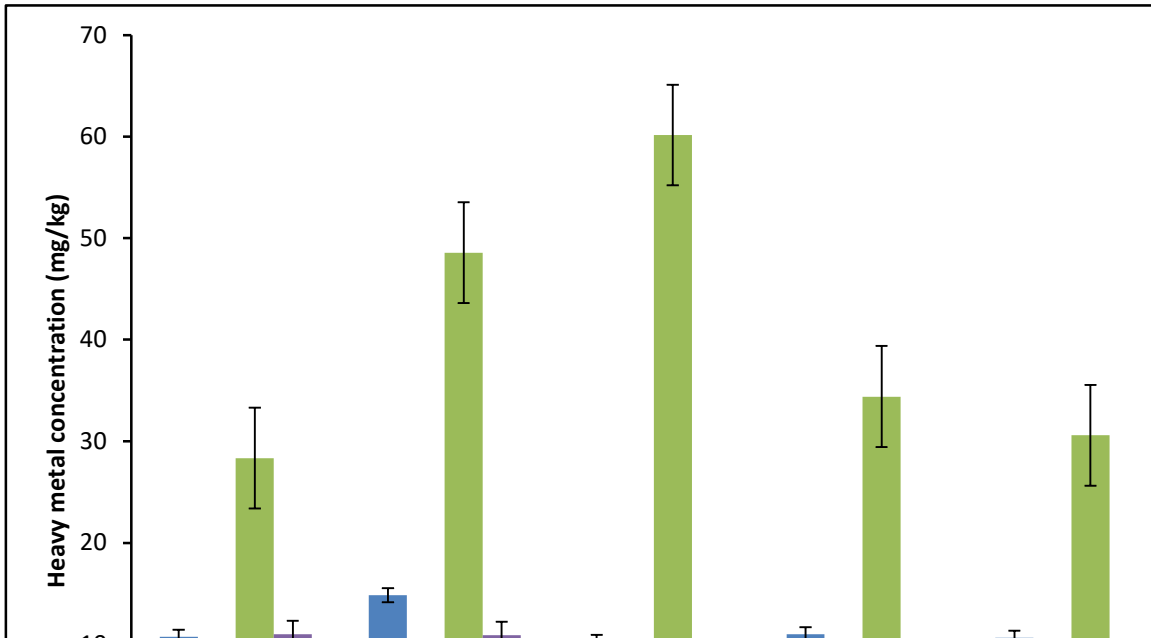


Fig. 4.81: Heavy metal concentration (mg/kg) in top soil (0-15cm) after crude oil (4%) contamination in well drained site

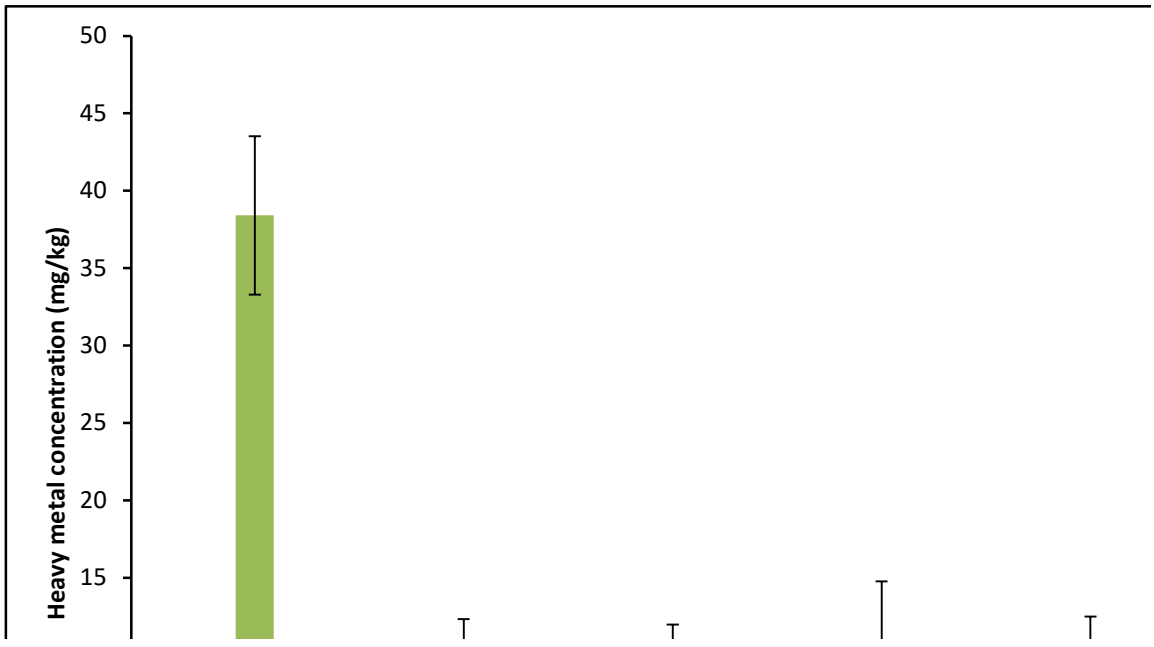


Fig. 4.82: Heavy metal concentration (mg/kg) in top soil (0-15cm) after crude oil (4%) remediation in well drained site

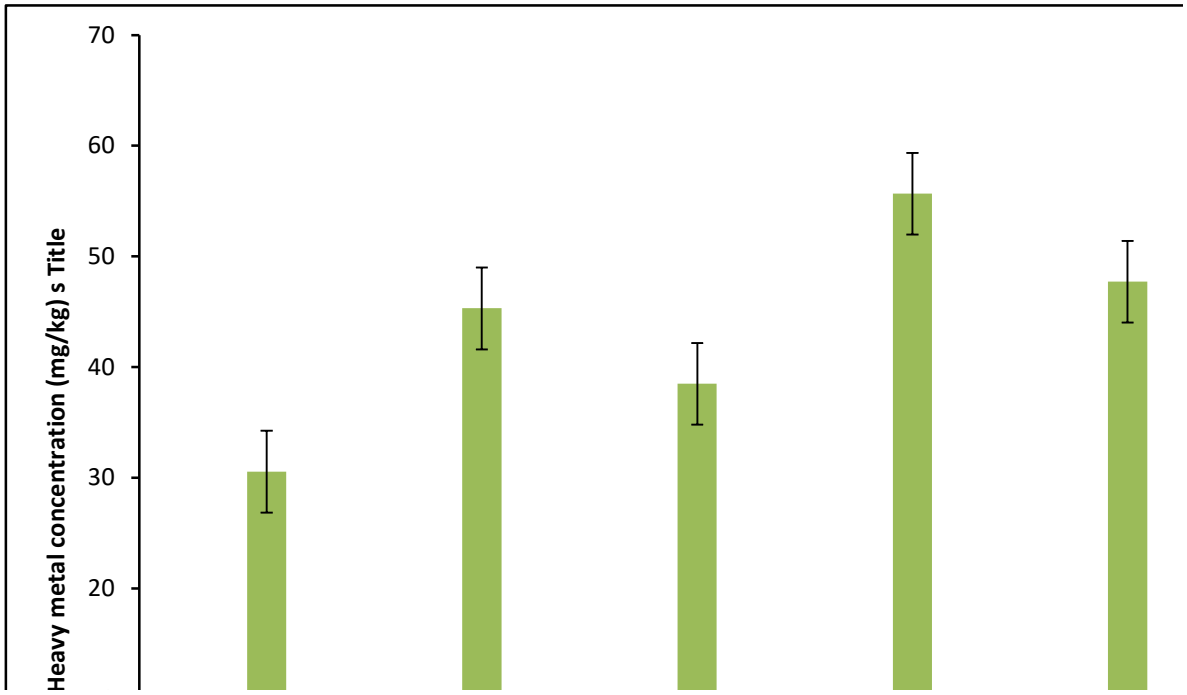


Fig. 4.83: Heavy metal concentration (mg/kg) in top soil (0-15cm) after crude oil (4%) contamination in waterlogged site

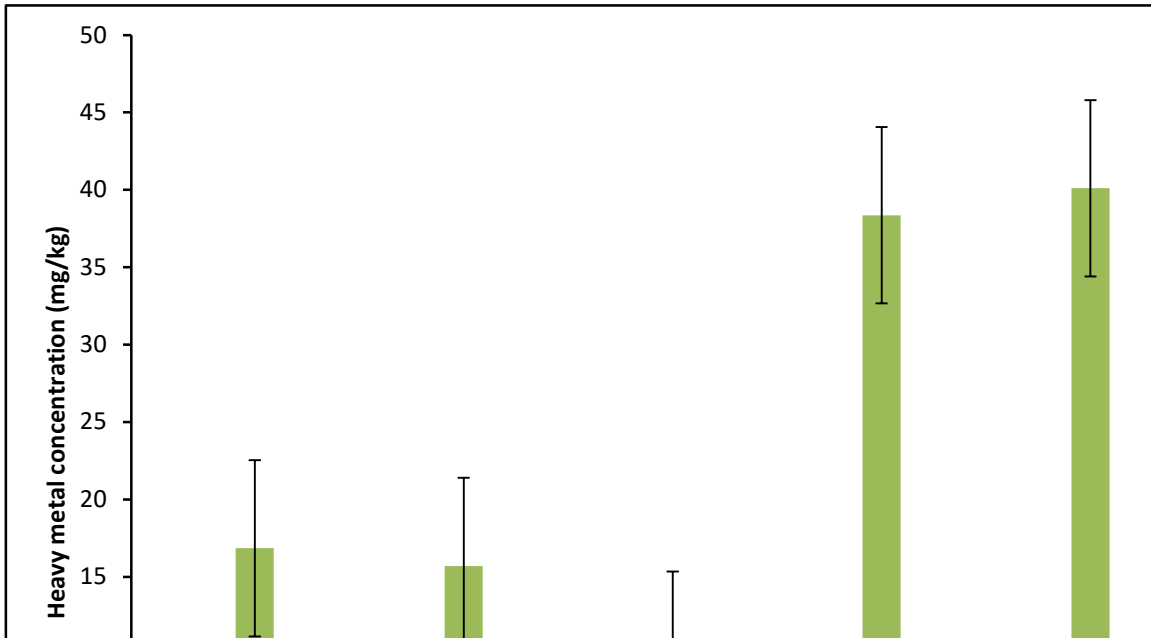


Fig. 4.84: Heavy metal concentration (mg/kg) in top soil (0-15cm) after crude oil (4%) remediation in waterlogged site

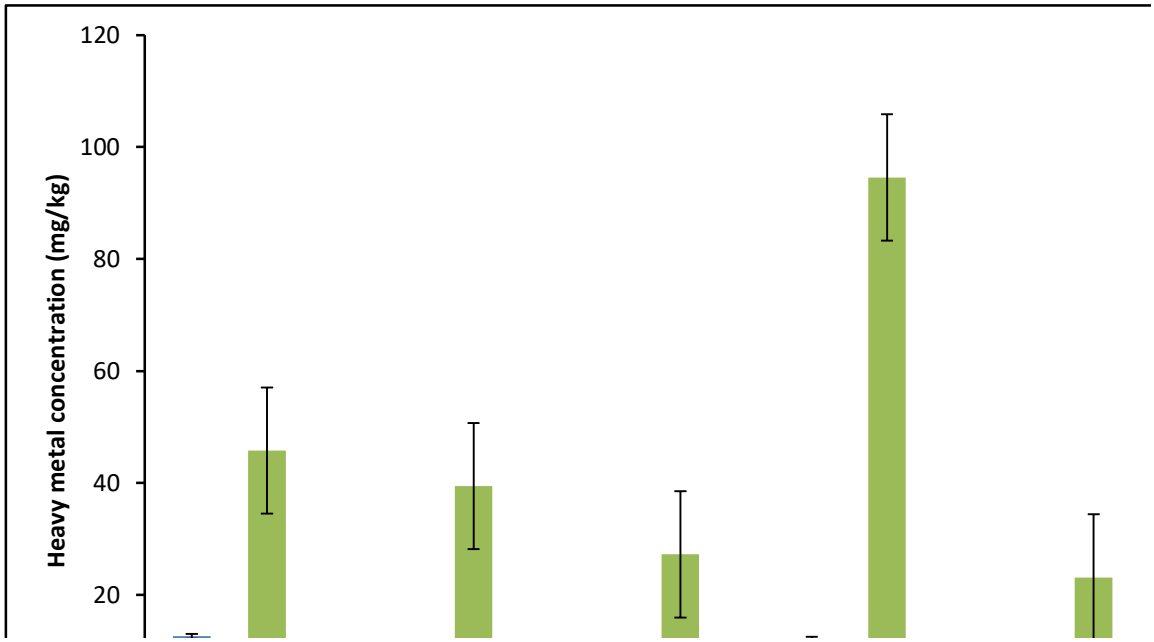


Fig. 4.85: Heavy metal concentration (mg/kg) in top soil (0-15cm) after crude oil (6%) contamination in well drained site

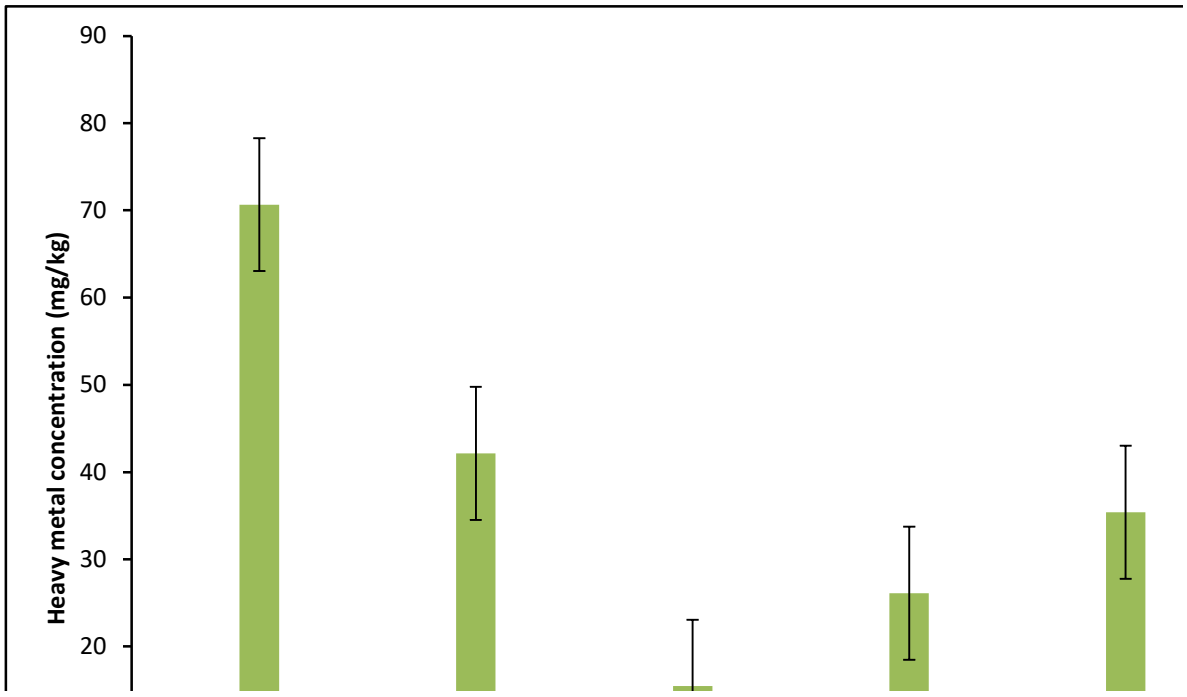


Fig. 4.86: Heavy metal concentration (mg/kg) in top soil (0-15cm) after crude oil (6%) remediation in well drained site

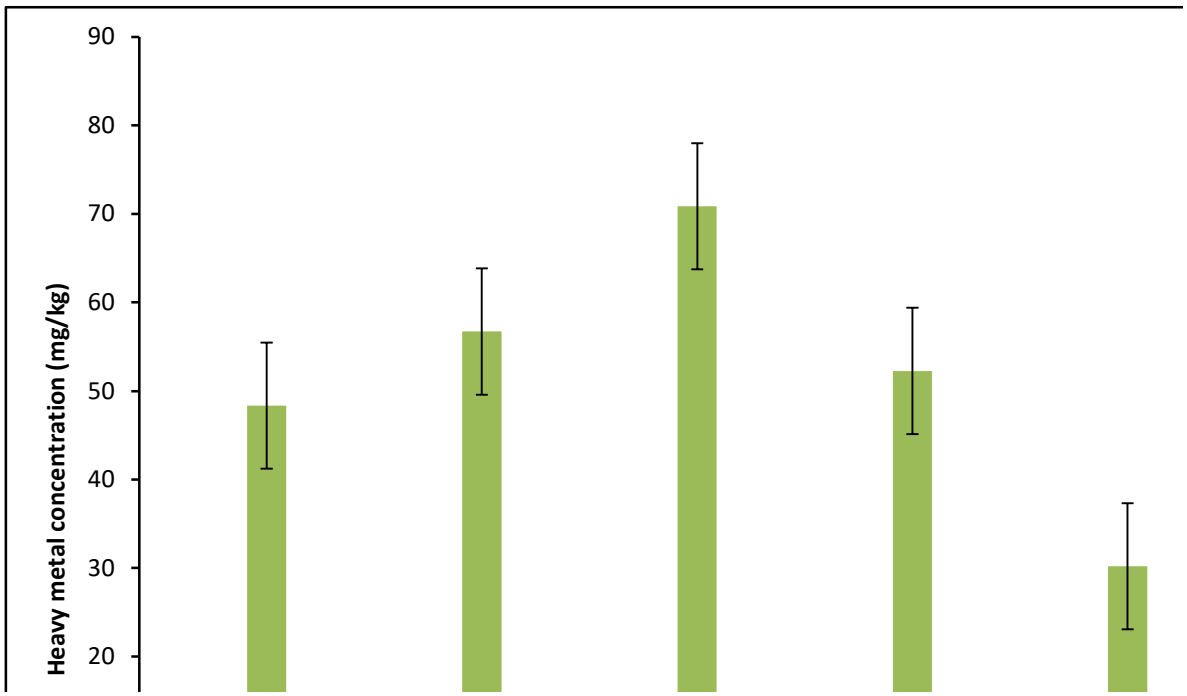


Fig. 4.87: Heavy metal concentration (mg/kg) in top soil (0-15cm) after crude oil (6%) contamination in waterlogged site

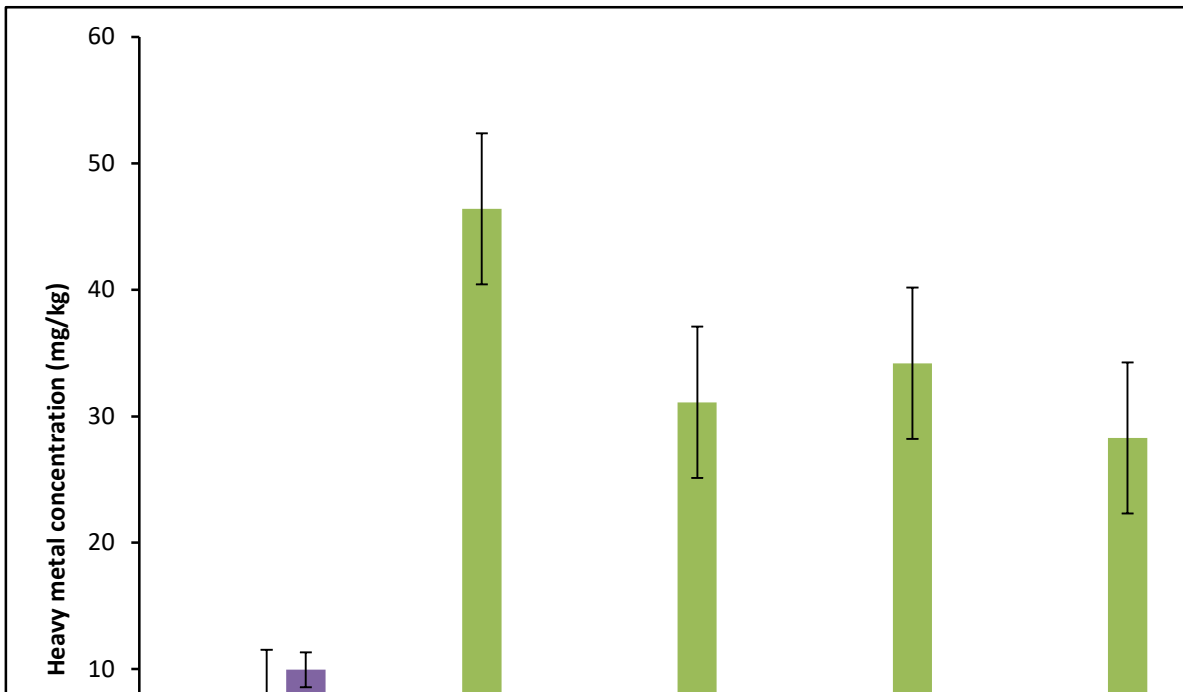


Fig. 4.88: Heavy metal concentration (mg/kg) in top soil (0-15cm) after crude oil (6%) remediation in waterlogged site

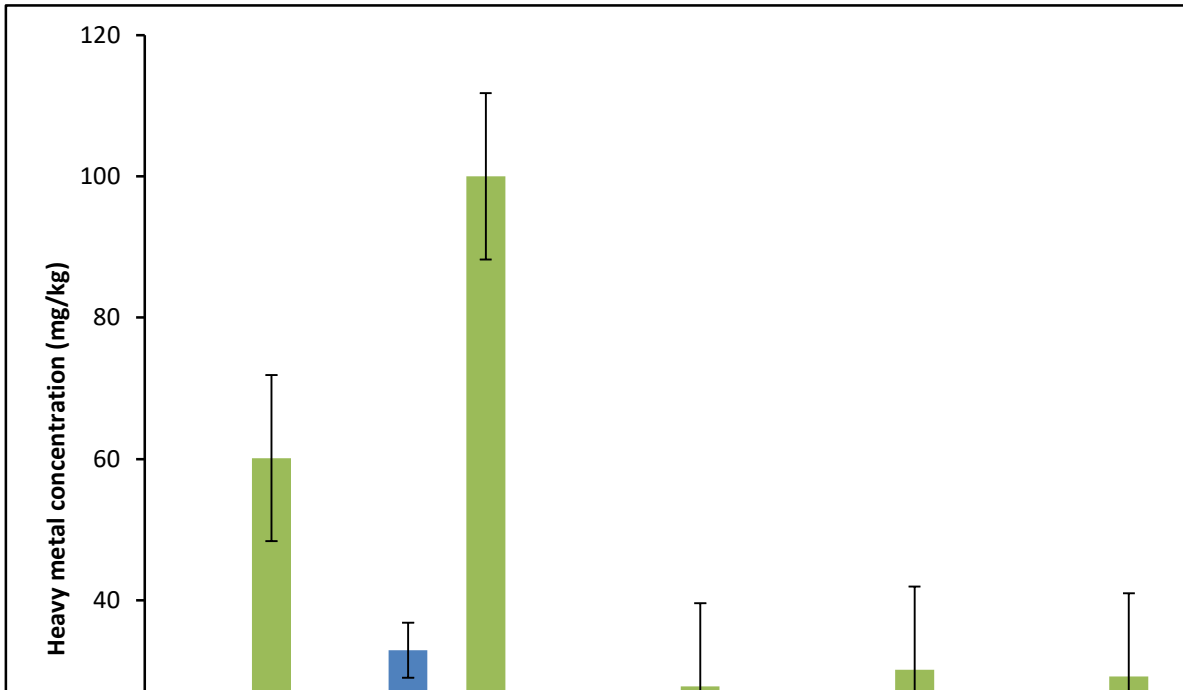


Fig.4.89: Heavy metal concentration (mg/kg) in sub soil (15-30cm) after crude oil (2%) contamination in well drained site

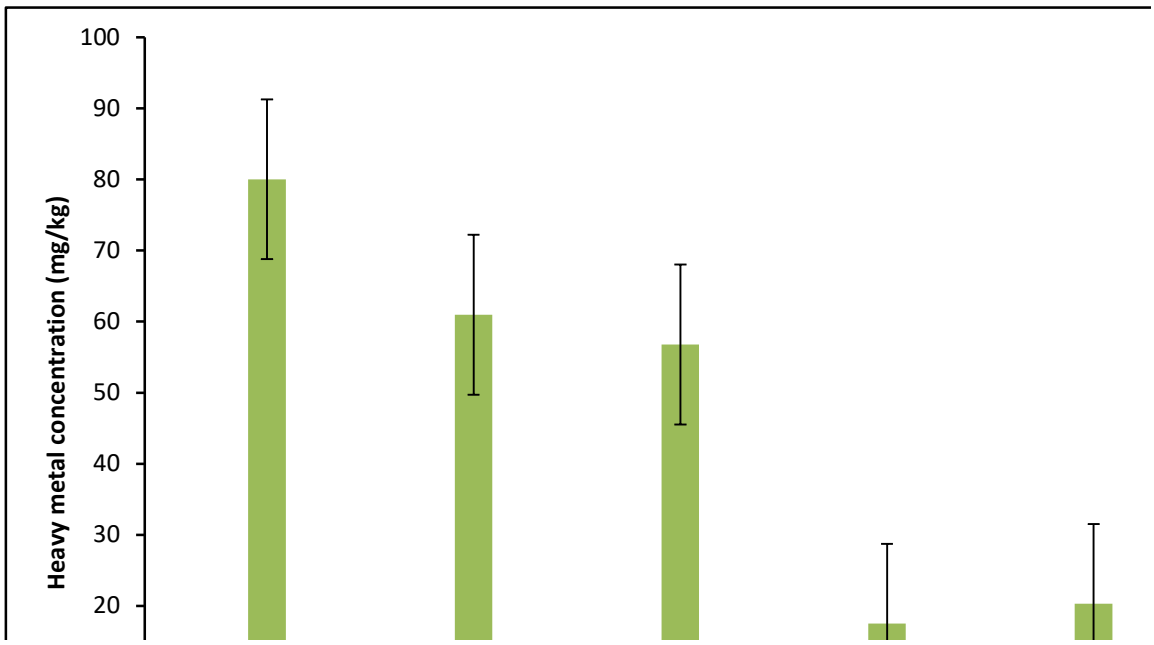


Fig. 4.90: Heavy concentration (mg/kg) in sub soil (15-30cm) after crude oil (2%) remediation in well drained site

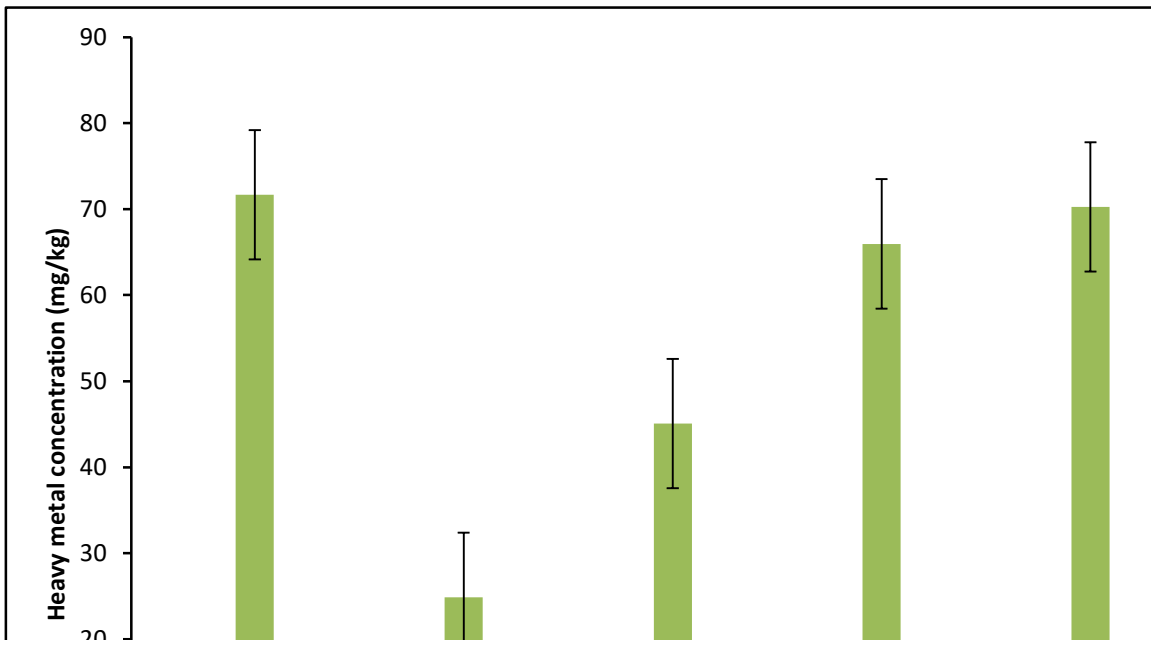


Fig. 4.91: Heavy concentration (mg/kg) in sub soil (15-30cm) after crude oil (2%) contamination in waterlogged site

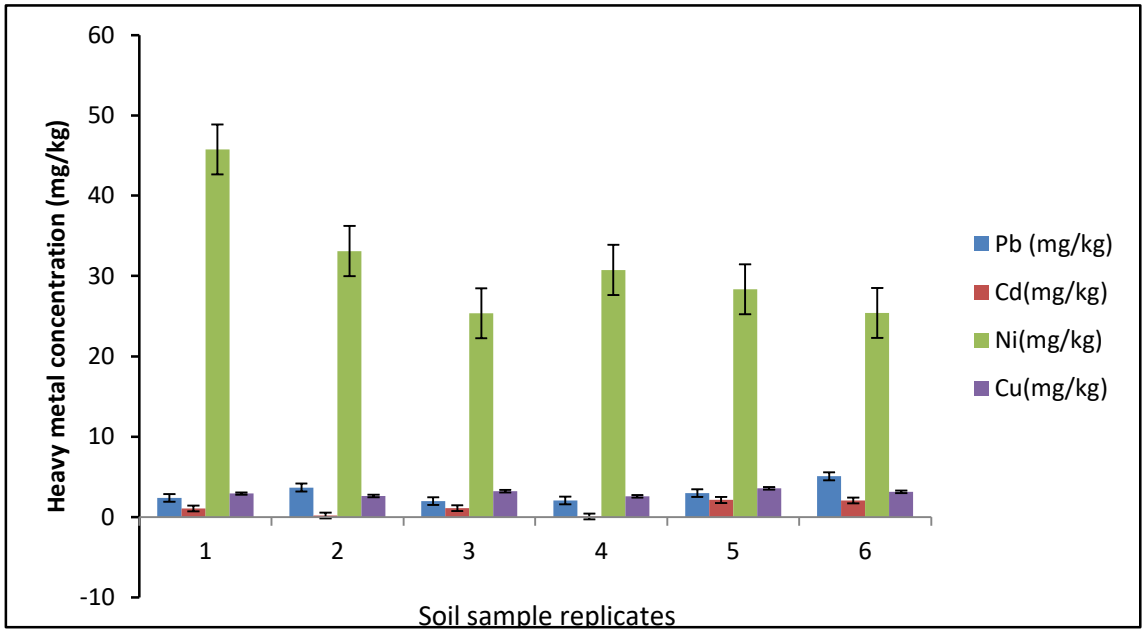


Fig. 4.92: Heavy concentration (mg/kg) in sub soil (15-30cm) after crude oil (2%) remediation in waterlogged site

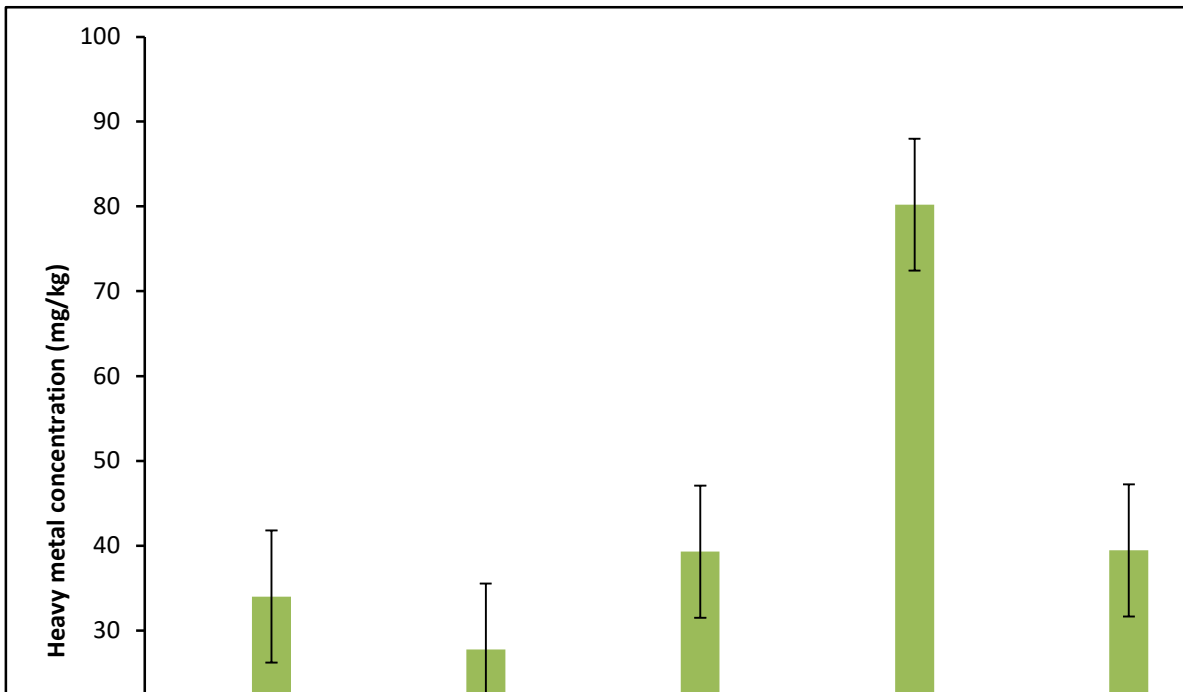


Fig. 4.93: Heavy concentration (mg/kg) in sub soil (15-30cm) after crude oil (4%) contamination in well drained site

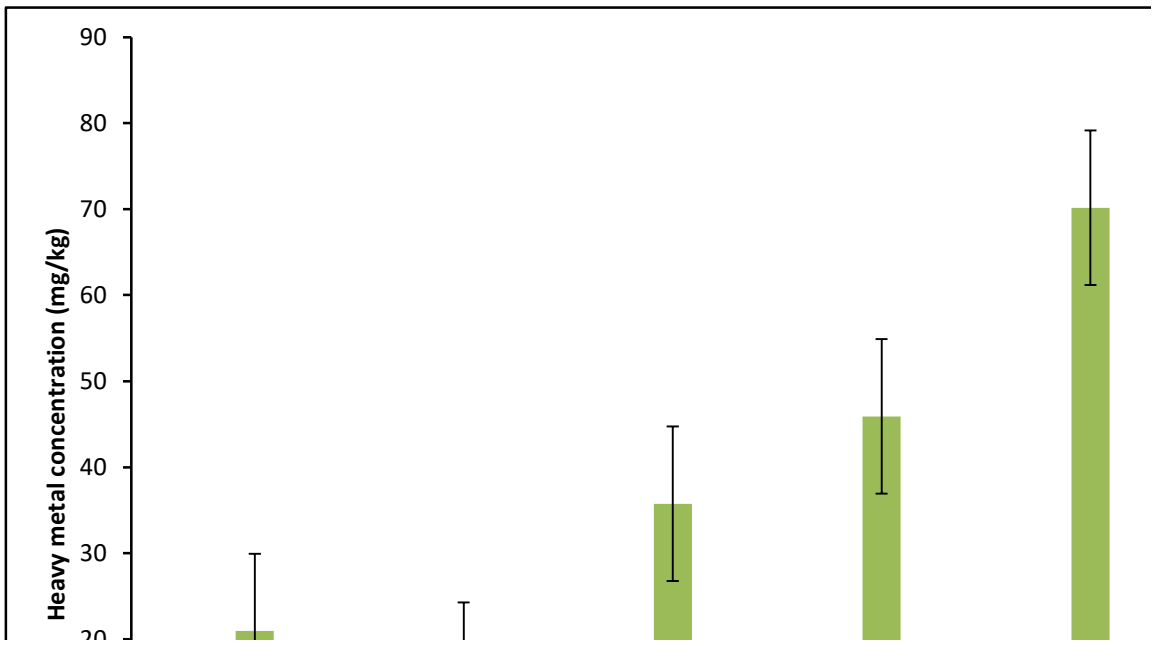


Fig. 4.94: Heavy metal concentration (mg/kg) in sub soil (15-30cm) after crude oil (4%) remediation in well drained site

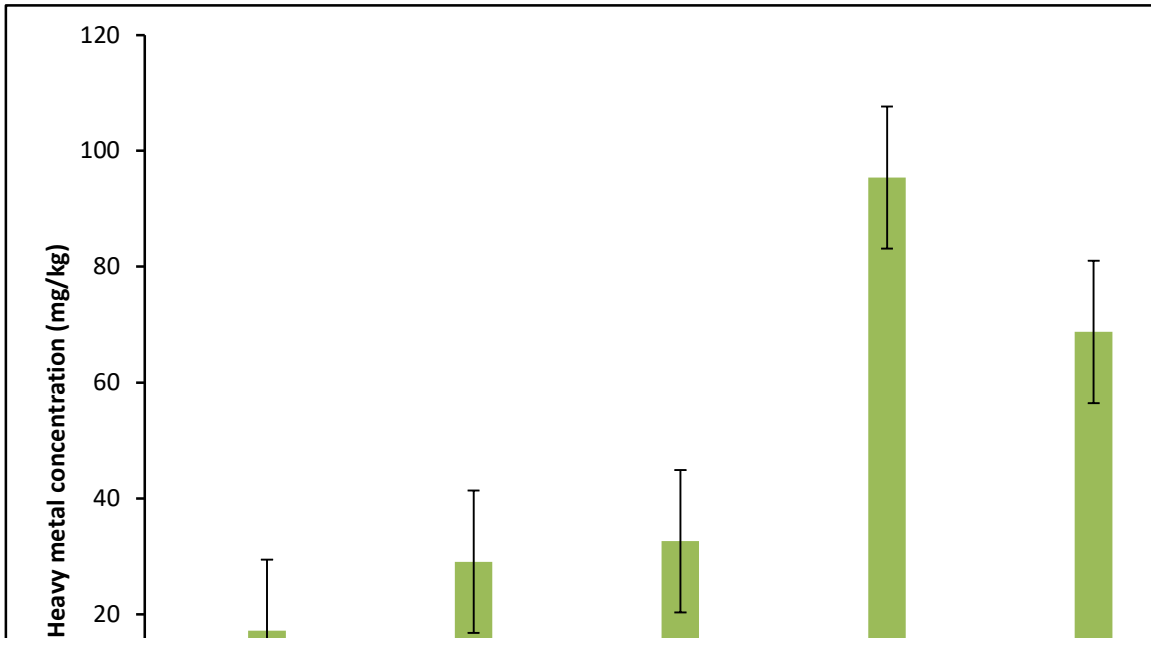


Fig. 4.95: Heavy metal concentration (mg/kg) in sub soil (15-30cm) after crude oil (4%) contamination in waterlogged site

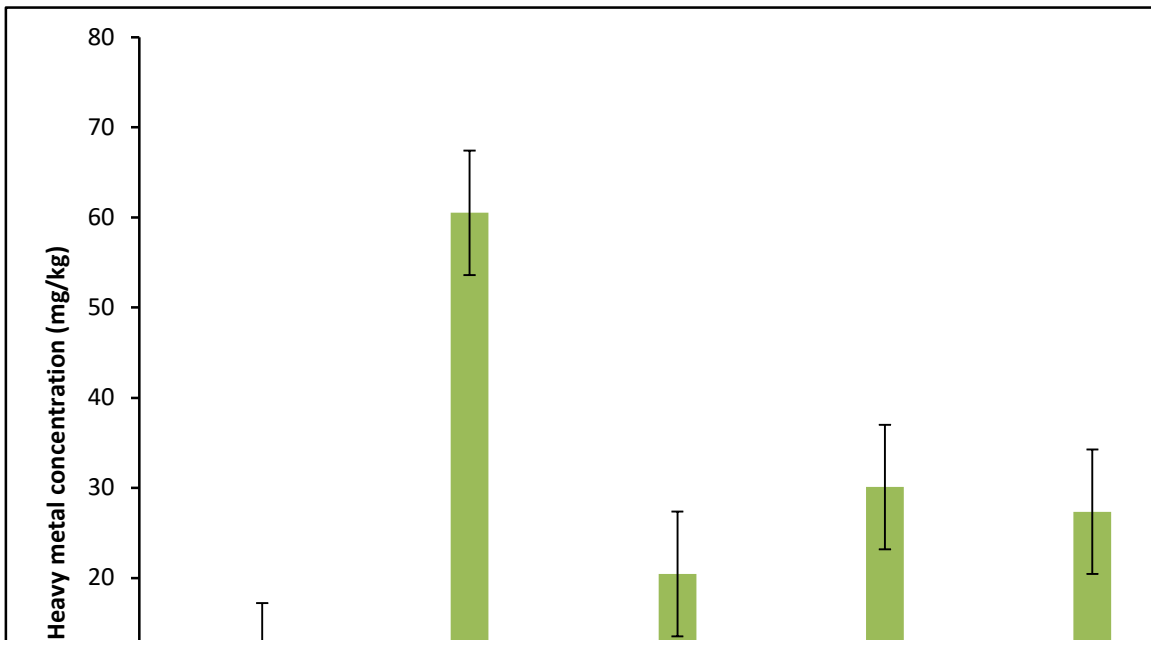


Fig. 4.96: Heavy metal concentration (mg/kg) in sub soil (15-30cm) after crude oil (4%) remediation in waterlogged site

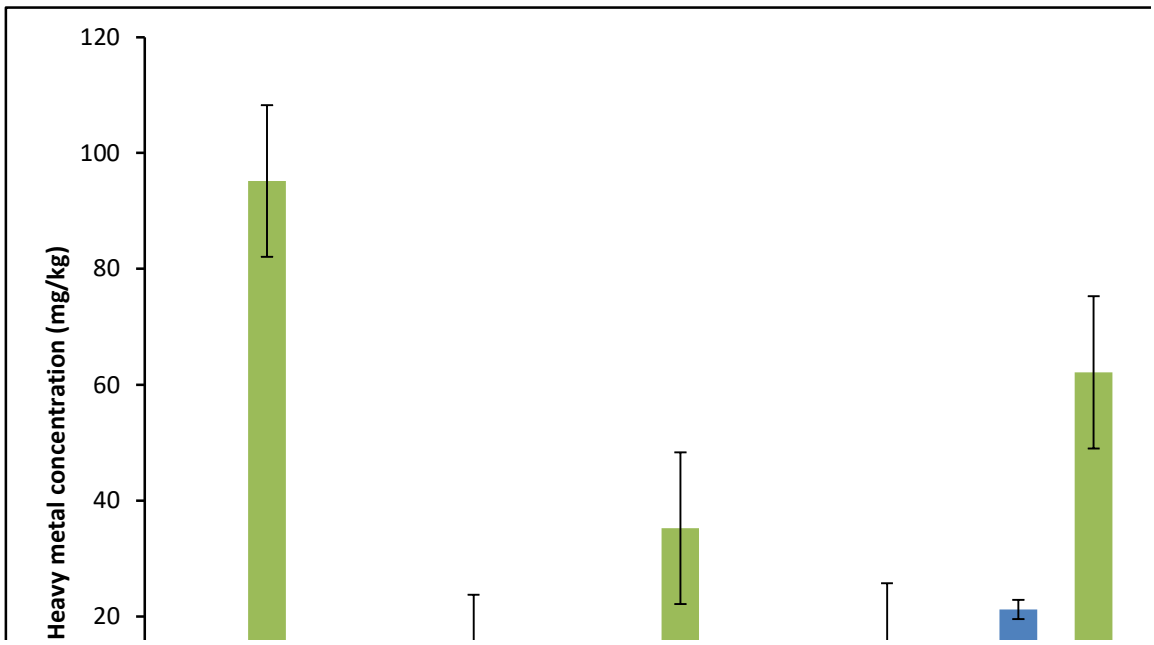


Fig. 4.97 : Heavy metal concentration ((mg/kg) in sub soil (15-30cm) after crude oil (6%) contamination in well drained e

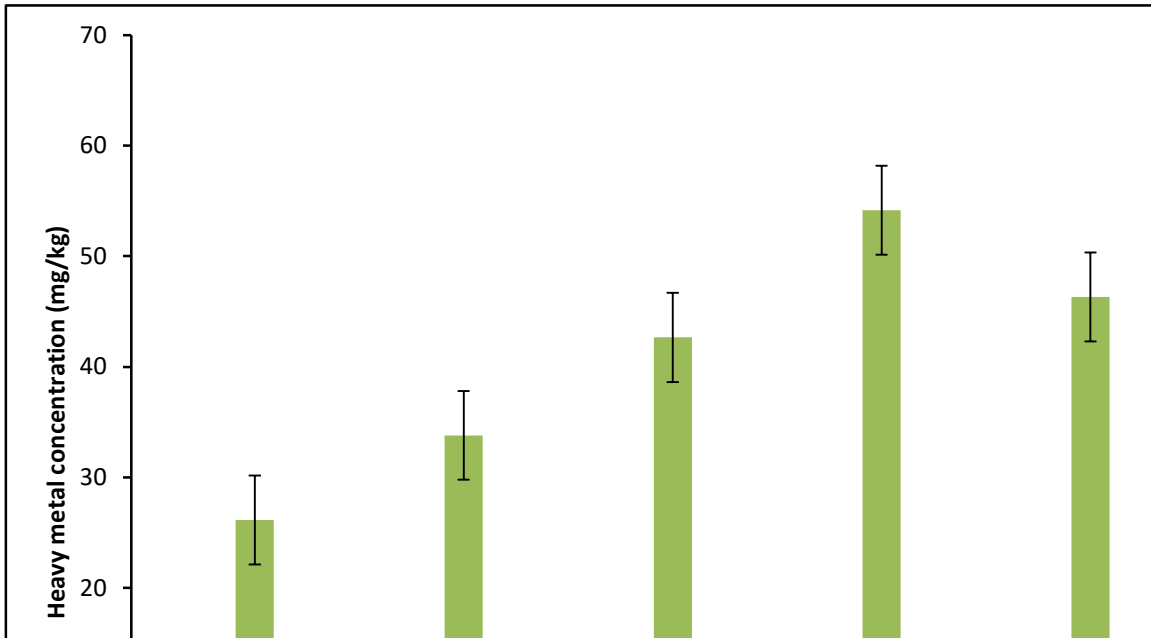


Fig. 4.98: Heavy metal concentration (mg/kg) in sub soil (15-30cm) after crude oil (6%) remediation in well drained site

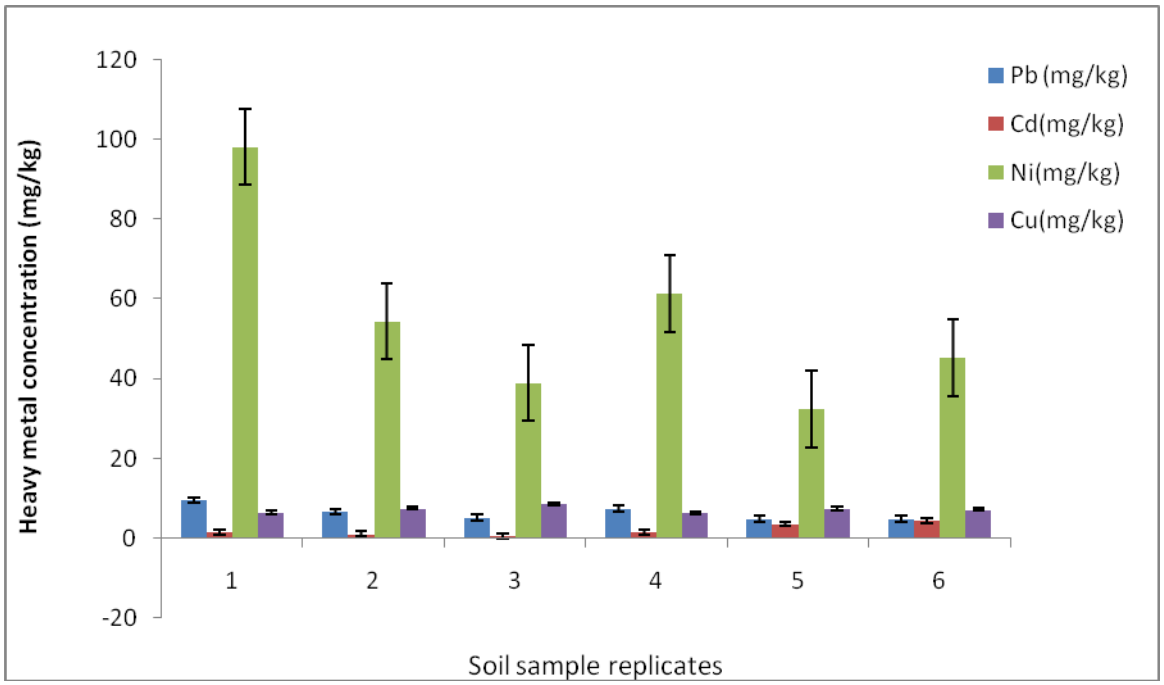


Fig.4.99: Heavy metal concentration (mg/kg) in sub soil (15-30cm) after crude oil (6%) contamination in waterlogged

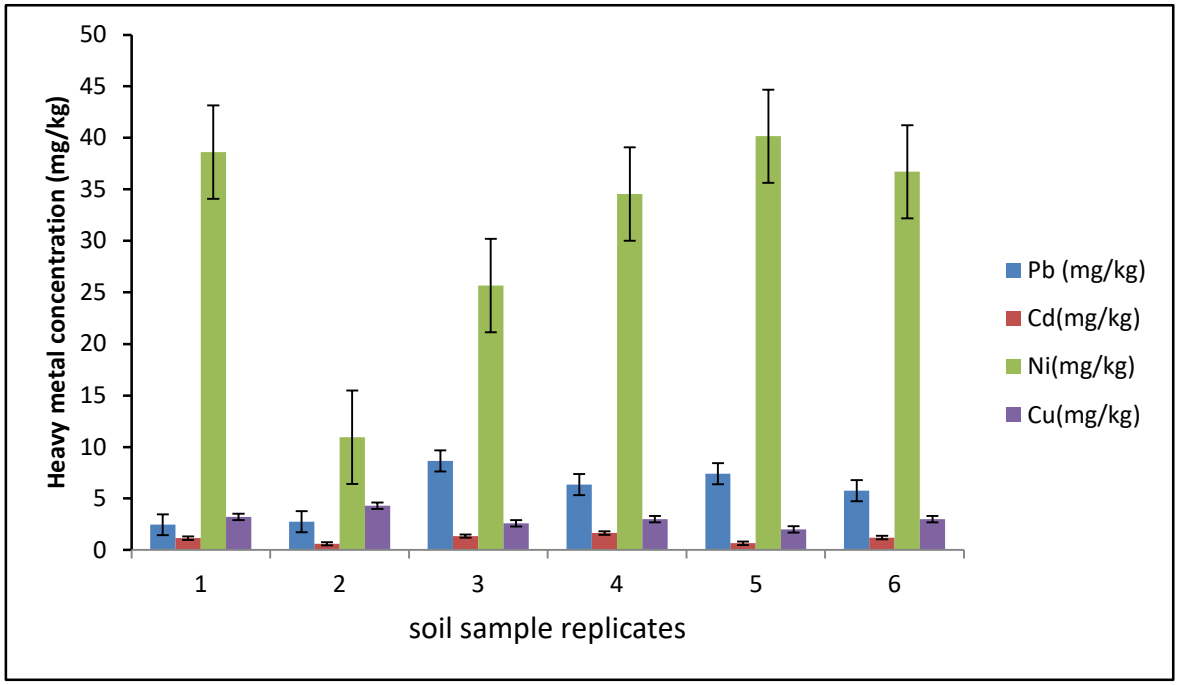


Fig. 4.100: Heavy metal concentration (mg/kg) in sub soil (15-30cm) after crude oil (6%) remediation in waterlogged site

Hypothesis three

The third hypothesis states that there is a significant reduction in the level of heavy metal concentration after remediation of hydrocarbon contaminated soil.

Table 4.32: Student's t-test table for reduction in lead concentration between 2% contaminated and remediated top soils

	Polluted soil	**Remediated soil**
Mean	10.78	7.6
Variance	1.22	1.45
Observations	6	6
Pearson correlation	0.42	
Hypothesized mean difference	0	
Df	5	
t.stat	6.24	
t. critical two tail	2.57	

Decision: Since the calculated t statistic value of 6.24 is greater than the critical value of 2.57, the null hypothesis is rejected and the alternative hypothesis is accepted which states that there is a significant reduction in the level of lead concentration after remediation of hydrocarbon contaminated top soils.

Table 4.33: Student's t-test table for reduction in lead concentration between 2% contaminated and remediated sub soils

	Polluted soil	**Remediated soil**
Mean	14.38	5.5
Variance	83.51	2.56
Observations	6	6
Pearson correlation	0.98	
Hypothesized mean difference	0	
Df	5	
t.stat	2.87	
t. critical two tail	2.57	

***Decision:** Since the calculated t statistic value of 2.87 is greater than the critical value of 2.57, the null hypothesis is rejected and the alternative hypothesis is accepted which states that there is a significant reduction in the level of lead concentration after remediation of hydrocarbon contaminated soils.

4.4.0 Seasonal Variation in the rate of Bioremediation

The data in Tables 4.30 and 4.31 showed total hydrocarbon content of top soils and sub soils after remediation in dry and wet seasons. It was observed that the values of total hydrocarbon content were lower after remediation in both surface and subsurface soils in the dry season when compared to the values obtained after remediation in the wet season. The mean values of THC were 341.67 mg/kg, 355 mg/kg and 503.33 mg/kg in surface soils and 267.50 mg/kg, 269.17 mg/kg and 322.5mg/kg in subsurface soils in the well drained site after remediation during the dry season while the mean values of total hydrocarbon content were 391.67 mg/kg, 490 mg/kg and 670mg/kg in surface soils and 271.67 mg/kg, 297.5 mg/kg and 362.5 mg/kg in subsurface soils in the same site in the wet season after remediation. Similar observation was made in the waterlogged site. While the mean values of total hydrocarbon content were 434.17mg/kg, 426.67 mg/kg and 543.33 mg/kg in surface soils and 224.17 mg/kg, 243.33 mg/kg and 390 mg/kg in subsurface soils in the dry season after remediation, the mean values were 463.33mg/kg, 535 mg/kg and 742.5 mg/kg in surface soils and 275mg/kg, 294.83 mg/kg and 410.83 mg/kg in subsurface soils in the wet season after remediation. Generally, the mean values of total hydrocarbon content after remediation in dry season were lower compared to the mean values after remediation in the wet season.

Table 4.34: Total Hydrocarbon Content (mg/kg) of Top Soils (0-15cm) of Remediated Soils during the dry and wet seasons.

Polluted level		Well drained site		Water logged site	
		THC after remediation in dry season	**THC after remediation in wet season**	**THC after remediation in dry season**	**THC after remediation in wet season**
Treatment replicates	2% 1	400	425	350	675
	2	305	300	525	360
	3	300	400	410	350
	4	325	450	400	560
	5	420	390	540	345
	6	300	385	380	490
	Range	300-420	300-450	350-540	345-675
	Mean	341.67	391.67	434.17	463.33
Treatment replicates	2% 1	300	540	300	750
	2	300	345	490	475
	3	420	585	350	490
	4	385	480	560	520
	5	415	470	520	445
	6	310	520	340	530
	Range	300-415	345-585	300-560	445-750
	Mean	355	490	426.67	535
Treatment replicates	2% 1	515	825	530	800
	2	510	960	420	870
	3	450	360	625	595
	4	540	450	565	670
	5	475	485	630	700
	6	530	940	490	820
	Range	450-540	360-960	490-630	595-870
	Mean	503.33	670	543.33	742.5

Source: Author's Analysis, 2015

Table 4.35: Total Hydrocarbon Content (mg/kg) of Sub Soils (15-30cm) of Remediated Soils during the dry and wet seasons.
Source: Author's Analysis, 2015

Polluted level		Well drained site		Water logged site	
		THC of remediated soil in dry season	**THC of remediated soil in wet season**	**THC of remediated soil in dry season**	**THC of remediated soil in wet season**
Treatment replicates	2% 1	250	260	180	500
	2	300	245	190	250
	3	240	300	200	220
	4	270	320	230	240
	5	260	195	245	210
	6	285	310	300	230
	Range	240-300	195-320	180-300	210-500
	Mean	267.50	271.67	224.17	275
Treatment replicates	4% 1	195	300	250	300
	2	230	240	175	310
	3	275	340	315	205
	4	280	290	200	374
	5	310	320	280	300
	6	325	265	240	280
	Range	195-325	240-340	175-315	205-374
	Mean	269.17	297.50	243.33	294.83
Treatment replicates	6% 1	350	435	190	430
	2	230	490	700	485
	3	270	360	345	390
	4	310	280	300	470
	5	380	330	425	395
	6	305	280	380	295
	Range	270-380	280-490	190-700	295-485
	Mean	322.5	362.5	390	410.83

Source: Author's Analysis, 2015

4.4.1 Percentage reduction in Total Hydrocarbon Content (mg/kg) of soils after remediation during the dry and wet seasons

The percentage reductions in total hydrocarbon content in surface and subsurface soils during the dry and wet seasons were compared in Tables 4.32 and 4.33. Percentage reduction in THC after remediation in dry season were higher compared to the values of percentage reduction obtained after remediation in the wet season. Statistical test of significance showed that percentage reductions in THC in the dry season were higher ($P < 0.05$) than in the wet season. The values were significantly different. This means that the rate of crude oil biodegradation was more rapid in the dry season than in the wet season.

The metabolism modes for biodegradation of hydrocarbon molecules include aerobic and anaerobic conditions. Aerobic condition results in a higher biodegradation rate (Suthersan, 1999). From the results of the analysis in Tables 4.32 and 4.33, it was evident that the bioremediation conducted during the dry season proceeded at a higher rate under more aerobic conditions compared to the wet season. Hydrocarbons are readily degraded under aerobic conditions where oxygen is transferred into the lower layers of soil by diffusion. This creates an ideal growing environment for the microbes together with the proper amount of water, pH, nutrients and the proper range of temperature to accelerate the natural bioremediation process. Some bacteria grow and reproduce only when oxygen is present. They use the oxygen for the process of aerobic biodegradation. While the hydrocarbon loses electrons and is reduce, oxygen gains electrons and is oxidizd and this results in formation of carbon dioxide and water (Nester *et al*.,2001).

Rainfall affects the amount of soil moisture. During the rainy season, the high amount of water reduces the oxygen in the soil and so decreases the biodegradation rate. The wet season phase of the study started in April and continued to July during which there was heavy rainfall. This resulted in significant increase in moisture content of the soil. Too much water in the soil leads to anaerobic condition as the pore spaces within the soils are covered with water causing lack of oxygen. Decreased soils oxygen level results in reduced biodegradation efficiency and rate (Johnson *et al*., 1999; Yang *et al*., 2009). Moisture content that is high can decrease microbial activity, indirectly hindering air supply, which will reduce oxygen delivery to plants. The combination of possible degradable hydrocarbons induces aerobic and anaerobic metabolic development.

However, as oxygen becomes more and more constrained due to the high moisture content, the use of alternate electron acceptors reduces the surface area and decreases the rate of bioremediation during the rainy season. When the oil enters the soil, it removes air and water. This can play an important role in promoting anaerobic soil conditions (Iwegbue *et al.,* 2007). Anaerobic respiration gives little energy for the microorganism (instead of aerobic respiration) and can reduce the rate of hydrocarbon destruction.

Table 4.36: Percentage Reduction in Total Hydrocarbon Content (mg/kg) of Top Soils (0-15cm) afterRemediation during the Dry and Wet Seasons

Polluted level		Well drained site		Water logged site	
		% reduction in THC in dry season	**% reduction in THC in wet season**	**% reduction in THC in dry season**	**% reduction in THC in wet season**
Treatment replicates	2% 1	55.56	24.78	54.25	6.25
	2	55.80	21.67	44.74	25.00
	3	61.64	18.39	53.67	12.50
	4	51.85	17.65	52.94	13.85
	5	51.16	19.59	44.90	19.77
	6	61.04	20.32	53.94	6.67
	Mean	56.16	20.40	50.74	14.01
Treatment Replicates	4% 1	62.50	23.18	42.04	10.67
	2	59.73	24.33	38.94	26.67
	3	53.33	20.33	50.00	08.33
	4	54.44	22.00	40.09	22.59
	5	56.77	19.07	39.48	25.97
	6	46.55	25.38	51.76	17.89
	Mean	55.55	22.38	43.72	18.69
Treatment Replicates	6% 1	47.18	19.12	34.97	21.57
	2	37.80	25.29	46.15	19.82
	3	44.44	23.33	34.21	21.71
	4	41.94	29.49	42.93	20.24
	5	35.81	33.14	49.60	24.14
	6	46.46	14.55	40.61	14.14
	Mean	42.27	24.15	41.41	20.30

Source: Author's Analysis, 2015

Table 4.37: Percentage Reduction in Total Hydrocarbon Content (mg/kg) Sub Soils (15-30cm) after Remediation during the Dry and Wet Seasons

Polluted level		Well drained site		Water logged site	
		% reduction in THC in dry season	**% reduction in THC in wet season**	**% reduction THC in dry season**	**% reduction in THC in wet season**
Treatment replicates	2% 1	58.33	16.30	40.00	3.85
	2	53.49	15.52	36.67	33.33
	3	58.62	16.67	42.03	26.67
	4	56.45	14.67	46.51	37.66
	5	55.93	25.00	36.36	43.24
	6	55.12	11.43	41.18	41.03
	Mean	56.32	16.57	40.46	30.96
Treatment replicates	4% 1	55.17	26.67	52.38	23.08
	2	60.68	20.00	51.39	22.50
	3	55.28	4.23	50.00	33.87
	4	58.21	19.44	47.37	10.95
	5	52.67	20.00	40.43	16.67
	6	55.48	18.46	44.83	17.65
	Mean	56.25	18.13	47.73	20.79
Treatment replicates	6% 1	58.33	5.43	50.00	15.69
	2	53.33	18.33	33.33	19.17
	3	57.14	20.00	48.89	15.22
	4	60.51	12.50	53.85	16.07
	5	52.50	19.51	39.29	19.39
	6	57.04	26.34	43.70	24.36
	Mean	56.48	17.02	44.84	18.32

Source: Author's Analysis, 2015

Hypothesis four

The fourth hypothesis states that there is a significant variation in the rate of bioremediation in the dry season and in the wet season.

The percentage reduction in total hydrocarbon content of top soils after remediation during the dry and wet seasons was used to validate this hypothesis (Table 4.32).

Table 4.38: Student's t-test for difference in percentage reduction in the 2% contaminated and remediated top soils

	Polluted soil	**Remediated soil**
Mean	56.16	16.40
Variance	19.36	21.67
Observations	6	6
Pearson correlation	-0.28	
Hypothesized mean difference	0	
Df	5	
t.stat	13.42	
t. critical two tail	2.57	

Decision: Since the calculated t statistic value of 13.42 is greater than the critical value of 2.57, the null hypothesis is rejected and the alternative hypothesis is accepted which states that there is a significant variation in the rate of bioremediation in the dry season and in the wet season.

Table 4.39: Student's t-test for difference in percentage reduction in the 2% contaminated and remediated sub soils

	Polluted soil	**Remediated soil**
Mean	56.78	16.60
Variance	3.78	20.46
Observations	6	6
Pearson correlation	0.12	
Hypothesized mean difference	0	
Df	5	
t.stat	20.69	
t. critical two tail	2.57	

Decision: Since the calculated t statistic value of 20.69 is greater than the critical value of 2.57, the null hypothesis is rejected and the alternative hypothesis is accepted which states that there is a significant variation in the rate of bioremediation in the dry season and in the wet season.

4.5 Comparison of rates of bioremediation in well drained and waterlogged soils

Different soil types and their potentials for contaminant degradation differ significantly. Particle size distribution parameters have influence on bioremediation. From the results of analysis of soil particle size distribution in Tables 4.36 and 4.37 it was found out that sand was the predominant soil fraction in the well drained site accounting for 80% by weight of the mineral fragments in the soil. Silt content was higher in the waterlogged site than in the well drained site and clay was slightly higher in waterlogged site than in the well drained site. These soil characteristics have influence on remediation of hydrocarbon contaminated soil. The data in Tables 4.32 and 4.33 indicated that the rate of remediation depended on the type of the soil as it was much higher in the well drained site where the soil was sandy loam dominated by sand particles than the waterlogged site where the soil was sand clay dominated by silt and clay particles. There was a difference between the total hydrocarbon content in the well drained and waterlogged sites after remediation in both dry and wet seasons. The mean value of the total hydrocarbon content in the well drained site when compare to waterlogged site was lower. This variation can be explained using soil structure that is loose particularly in sandy soil of the well drained site and much higher stickiness and plasticity of clay in the waterlogged site. At the microscopic level, clay is composed of fine particles (< 0.002 mm in size), and adhere easily to one another (kujawski *et al*., 2009). The biodegradation rates are affected by the fineness of the soil. Gawel (2003) found out that the rate of remediation in loamy soil will be faster when compare to heavy clay soil. In the well drained upland area the soil texture was loamy sand, with a little fraction of clay. Hence remediation was faster because the soil is better drained with good pore spaces. The soil microorganisms require air and water, both of which are necessary for aerobic biodegradation to occur.

Table 4.40: Percentage of Sand, Silt and Clay content in Top Soils (0-15cm)

Sampling point		Well drained site			Waterlogged site		
		Sand (%)	Silt (%)	Clay (%)	Sand (%)	Silt (%)	Clay (%)
Treatment replicates	2% 1	81	15	4	59	32	9
	2	80	15	5	60	31	9
	3	82	14	4	62	31	7
	4	83	13	4	58	32	10
	5	80	14	6	61	30	9
	6	81	14	5	59	31	10
	Range	80-83	13-15	4-5	58-62	30-32	1-7-10
	Mean	81.2	14.2	4.7	59.8	31.2	9
	S.D	1.07	0.69	0.75	1.35	0.69	1.00
Treatment replicates	4% 1	80	15	5	59	32	9
	2	80	16	4	59	34	7
	3	83	13	4	61	30	9
	4	81	15	4	60	30	10
	5	80	14	6	59	32	9
	6	82	13	5	62	30	8
	Range	80-83	13-16	4-6	59-62	30-34	7-10
	Mean	81	14.3	4.7	60	31.3	8.7
	S.D	1.15	1.10	0.75	1.15	1.49	0.94
Treatment replicates	6% 1	83	11	6	61	32	7
	2	82	14	4	61	31	8
	3	80	5	5	58	32	10
	4	80	16	4	60	31	9
	5	81	14	5	60	30	10
	6	81	15	4	59	32	9
	Range	80-83	11-16	4-6	58-61	30-32	7-10
	Mean	81.2	14.2	4.7	59.8	31.3	8.8
	S.D	1.07	0.98	0.75	1.07	0.75	1.07

Source: Author's Analysis, 2015

Table 4.41: Percentage of Sand, Silt and Clay content in Sub Soils (15-30cm)

Sampling point		Well drained site			Waterlogged site		
		Sand (%)	Silt (%)	Clay (%)	Sand (%)	Silt (%)	Clay (%)
Treatment replicates	2% 1	81	14	5	60	30	10
	2	81	13	6	56	34	10
	3	79	16	5	60	31	9
	4	80	15	5	58	33	9
	5	79	15	6	58	34	8
	6	80	14	6	59	31	10
	Range	79-80	13-16	5-6	56-60	30-34	8-10
	Mean	80	14.5	5.5	58.5	32.2	9.3
	S.D	0.82	0.96	0.5	1.38	1.57	0.75
Treatment replicates	4% 1	80	14	6	58	33	9
	2	79	16	5	58	31	11
	3	81	13	6	59	32	9
	4	80	15	5	60	30	10
	5	80	14	6	59	32	9
	6	79	15	6	57	34	9
	Range	79-81	13-16	5-6	57-60	30-34	9-11
	Mean	79.8	14.5	5.7	58.5	32	9.5
	S.D	0.69	0.96	0.47	0.96	1.35	0.76
Treatment replicates	6% 1	79	15	6	60	30	10
	2	80	15	5	57	34	9
	3	80	14	6	55	34	11
	4	81	13	6	58	32	10
	5	79	16	5	60	31	9
	6	80	15	5	59	33	8
	Range	79-81	13-16	5-6	55-60	30-34	8-11
	Mean	79.8	14.7	5.5	58.2	32.3	9.5
	S.D	0.69	0.94	0.5	1.27	1.49	0.96

Source: Author's Analysis, 2015

Hypothesis five

Hypothesis five states that the rate of remediation is faster in the well drained soils than in the waterlogged soils.

The well drained site has higher sand content while the waterlogged site is dominated by more silt content. The results of percentage of sand and silt contents of top and sub soils in Tables 4.36 and 4.37 are used to validate this hypothesis.

Table 4.42: Student's t-test table for difference in percentage of sand and silt contents of top soil in well drained and waterlogged soils

	Polluted soil	**Remediated soil**
Mean	81.17	31.17
Variance	1.37	0.57
Observations	6	6
Pearson correlation	0.64	
Hypothesized mean difference	0	
Df	5	
t.stat	136.93	
t. critical two tail	2.57	

Decision: Since the calculated t statistic value of 136.93 is greater than the critical value of 2.57, The implication is that the alternative hypothesis was accepted which states that the rate of bioremediation is higher in the dry season than in the wet season.

Table 4.43: Student's t-test table for difference in percentage of sand and silt contents of sub soil in well drained and waterlogged soils

	Polluted soil	**Remediated soil**
Mean	80	32.17
Variance	0.8	2.97
Observations	6	6
Pearson correlation	-0.13	
Hypothesized mean difference	0	
Df	5	
t.stat	57.4	
t. critical two tail	2.57	

Decision: Since the calculated t statistic value of 57.4 is greater when compare to the critical value of 2.57, the alternative hypothesis was not rejected which states that the rate of bioremediation is higher in the dry season than in the wet season.

Table 4.44: Soil Parameters Variation at different Pollution levels between contaminated and remediated soils.

Soil parameter	Level of pollution	t-value	p-value	Level of significance
Total hydrocarbon	2%	9.77	0.000	*
Content (THC)	4%	15.12	0.000	*
	6%	11.25	0.000	*
Organic carbon (O.C)	2%	5.50	0.003	*
	4%	5.10	0.004	*
	6%	5.41	0.003	*
Lead (Pb)	2%	6.25	0.002	*
	4%	5.99	0.002	*
	6%	9.34	0.000	*
Rate of remediation in dry and	2%	13.34	0.000	*
Wet seasons	4%	15.19	0.000	*
	6%	4.05	0.001	*
Rate of remediation in well drained and	2%	24.19	0.000	*
Waterlogged soils	4%	81.33	0.000	*
	6%	64.00	0.000	*

Significant at $p<0.05$

***Significant**

N.S. Not Significant

4.6 DISCUSSION

The results of physical properties of contaminated and remediated soils showed that there was no effect of hydrocarbon pollution on sand particles. It was observed from the analysis that sand proportion remained the same for both contaminated and remediated soils which showed that crude oil did not alter sand particles. This finding is in agreement with Marinescu et al., (2011) who reported no significant effect in crude oil pollution on

soil particle size composition. The presence of crude oil in soil did not also significantly affect silt and clay content of the soil as shown in Tables 4.1 and 4.2. The results of soil analysis showed that mean bulk density values after remediation were lower than the mean values after contamination in (Tables 4.11 and 4.12). The mean bulk density values after contamination in the well-drained site were 1.25g/cm^3 and 1.26g/cm^3 while the mean values after remediation were 1.19g/cm^3 and 1.20g/cm^3. The critical bulk density value which limits root growth varies depending on soil type (Hunt and Gikes, 1992). However, global bulk densities greater than 1.6g/cm^3 tend to limit root growth in the assertion of McKenzie et al., (2004). Sandy soils generally have higher bulk densities (1.3 to 1.7g/cm) when compared to fine and loose clays (1.1 to 1.6g/cm^3), due to larger pore spaces though fewer. Hunt and Gikes (1992) found out that bulk density value between 1.1 to 1.5g/cm is adequate for plant growth. Total porosity decreased from 47.2% and 46.8% after contamination and increased after remediation to 55.2% and 55.3%. Crude oil pollutant which blocked the pore spaces of the soil during contamination may have been removed in the process of remediation. Porosity of sandy-loam is measured to be 40% which is lower than sandy clay. This finding has important implications as the pore size is a function of soil structure, a 3-dimensional arrangement of solid particles and voids in which microbial communities reside. Therefore any slight difference in the texture could affect the volume of voids and the microbial activities taking place within the voids.

Results of chemical properties of contaminated and remediated soils showed that the percentage organic carbon increased after contamination and decreased as remediation progressed (Table 4.13 and 4.14). This corroborates the findings of Ayotamuno, et al., (2006). This indicates that the microbes utilized the nutrients in order to increase their population. The mean values of nitrogen were higher in contaminated soils but decreased after remediation in all soil samples. In the report of Ayotamuno and Kogbara (2006) during biodegradation one can experience a huge loss of nitrogen as a result of series of widely occurring biochemical reduction reactions caused by denitrifying bacteria. The amount of available phosphorus in crude oil contaminated were higher than those of the remediated soils, though the differences were not significant. The mean values of moisture content of contaminated soils were lower when compared to remediated soils and there was significant difference between the two soil samples. This is so because in

polluted soil due to the adherence of water particles sticking to hydrophobic layer which prevent water from getting to inner part of soil aggregate. The same assertion was made by Ayotamuno et al., (2006). It was observed from the study that after contamination Organic Carbon (OC), Total Nitrogen (TN), Available Phosphorus and moisture content increased. However, after remediation, the values of these chemical properties decreased. This finding is in agreement with Kim et al., (2005) who noted that the microorganisms make use of the nitrate and phosphate in the degradation of the crude oil, but the nutrients may have been used up or depleted by the microbes therein. Soil pH was observed to increase after contamination with crude oil and decreased after remediation (Table 4.13 and 4.14). A fall in pH under similar condition has been reported by Okpokwasili and Okore (1991). This was also confirmed Tisdale and Nelson's (1999) observation that decreasing pH during remediation treatment could have been due to the production of acid radicals in the nitrification process of agricultural residues used as fertilizers. Both well drained and waterlogged sites were found to be slightly acidic. The pH for optimal hydrocarbon bioremediation in soils for biological processes have been under reported in the literature. However, highest microbial population was reported more likely to be at pH of 7.0-7.5 and the same study showed reduced biodegradation at pH below 6.5 compared to a pH range of 7.0-8.0 (Khorasanizadeh, 2014). The levels of hydrocarbons content in well-drained and waterlogged soils were high after contamination while the values decreased after remediation with the decomposed cassava peels organic wastes Fig 4.49 . Ibiene et al., (2011) have also demonstrated the positive effect of other organic wastes (spent mushroom, cowdung and poultry droppings) on the bioremediation of hydrocarbon contaminated soil on a 28days study period. Researchers seek the combination of organic wastes that will increase the rate of crude oil biodegradation within a short period (Yakubu, 2007, Agary et al., 2010; Solomon et al., 2017). Hydrocarbon loss due to natural attenuation processes of chemical and photo-oxidation, evaporation, dispersion, sorption, transformation, biodegradation, dilution, spreading and volatilization at various time intervals have been reported (Venosa et al., 1996; Alkorta and Garbisu, 2001; Ibiene et al., 2011).

The results of the study showed that total petroleum hydrocarbon in crude oil polluted soil was 69.7pm in dry season and 58.9ppm in wet season after contamination. However, the

TPH amount reduced after remediation to 29.1ppm in dry season and 44.3ppm in wet season. There was a significant percentage reduction of 58.2% in dry season. The percentage reduction in wet seasion was 24.8%. Gas chromatographic result indicated high degradation efficiency in the decomposed cassava peels treatment especially with hydrocarbons with low carbon chain length. Natural attenuation produced good results throughout the entire process with decontamination in both dry and wet seasons. Following the three months of soil amendment, the decomposed cassava peels treatment showed significant count of THB and HUB as seen in Tables 4.25 and 4.26. The present study revealed that degradation of organic wastes changes and mineralization provided nutrients that supported the increase of microorganisms that degrade hydrocarbon. In a report by Huesemann and Moore (1993) the amount of hydrocarbon decomposers was generally higher when nitrogen and phosphorus was added to the soil. Several studies have indicated that crude oil polluted soils contained oil degrading microorganisms (Bento et al., 2005; Lynch et al., 2004; Abu and Dike, 2008; Chikere et al., 2009) including bacteria and fungi capable of utilizing oil as their source of carbon and energy. It was observed from the study that THB and HUB levels decreased with increasing depth of soil. This findings confirmed the reports of Bossert and Compeau (1995), Avidano et al., (2005) and Katsivata et al, 2005, according to which the population of microbial organisms reduces with soil depth.

The levels of heavy metals were lower in the remediated soils compared to the contaminated soils. The values of lead in contaminated soils were higher than the remediated soils. So were the values of cadmium, Nickel and Copper concentration. There were statistical difference in the mean values of lead and Nickel obtained after remediation ($p=0.05$). It was observed that bioremediation rate was faster in the dry season than in the wet season. Seasonal variations in the rate of bio-remediation were in accordance with changes of soil moisture and temperatue. The results from this study show that seasonal variations have important impacts on soil microbial communities and enzyme activities. In the dry season, the soil moisture content in Obio/Akpor, like every other place in the Niger Delta is enough for the growth of soil micro-organisms under aerobic condition resulting in higher hydrocarbon remediation. Slow microbial growth under anaerobic condition in the wet season produced low remediation rate because soil

enzyme activities decrease during this period. However, some studies have different opinions on the effect of seasonal shifts. Some researchers reported that seasonal shifts have no or little impact on soil microbial properties in different regions. These studies suggest there is no clear seasonal pattern on soil microbial properties in forest ecosystems. The seasonal variation of soil microbial properties may be closely related to biotic and abiotic factors in specific region, such as vegetation type, growth, soil nutritional conditions, temperature, water availability, proton concentration, and oxygen supply. Therefore, specific environmental conditions, especially climate conditions and habitat should be considered in bioremediation .

CHAPTER FIVE

SUMMARY, CONCLUSION AND RECOMMENDATION

5.1 Summary of Findings

This study was undertaken to examine the topographical and seasonal effects of decomposed cassava peels on bioremediation of hydrocarbon polluted soils in Obio/Akpor local government area of Rivers State, Nigeria due to exploration of oil and production activities that have led to different cases of oil spills in the affected communities which have caused extensive contamination of the environment. This contamination has affected farmlands, fisheries and potable water in the area. Farmers in the area like other oil producing areas do not know how to restore the fertility of their polluted farmlands using appropriate remediation technique due to limited knowledge and information. Hence, the application of bioremediation technology using decomposed cassava peels which is inexpensive, environmentally friendly, and simple was evaluated in this study. The study major objectives were to investigate the impact of decomposed cassava peels on degradation of hydrocarbon in soil polluted and to assess the level of concentration of heavy metals in the soil after remediation and to determine seasonal variations in the rate of bioremediation and to compare variations in the rate of bioremediation in well drained and waterlogged soils.

Literature review using the conceptual and theoretical framework was presented in chapter two. It gave the concept of pollution and an overview of hydrocarbon pollution as an explanatory framework for the study. It also evaluated hydrocarbon degradation to give insight into the process of bioremediation. The research works of prominent scholars in different parts of Nigeria and abroad were reviewed. Chapter three was concerned with methodology. The study made use of experimental research design. Soil samples from

contaminated and remediated plots in dry and wet seasons were obtained and subjected to laboratory analysis.

The experimentation plots were located on two different topographic surfaces, one was well drained and the other waterlogged soils. In each site there were eighteen sampling plots each measuring 2 m by 2 m and consisted of three grades of pollution which include 2%, 4% and 6%. A sample frame of 36 sampling points were developed from both top soils and sub soils in each experimentation site. In all, 72 samples were collected and analysed. Samples were taken before contamination, after contamination and after remediation. Soil samples collected before contamination served as control. The study revealed that crude oil contamination altered the soil chemistry, and thus led to adverse effects on soil properties both physical and chemical. From the result of the laboratory and statistical analysis it was observed that hydrocarbon decreased in the soil remediated when compare to polluted soil. The results also showed that the bioremediation agents, i.e., the decomposed cassava peels have some limitations with regards to hydrocarbon type as the high molecular weight polyaromatic compounds with more than three rings have very low degradation rates and therefore could not be degraded within a short time. Microbial analysis of contaminated hydrocarbon and soils remediated indicated that the population of hydrocarbon utilizing bacteria (HUB) were higher in soil polluted with crude oil products and both the number of heterotrophic bacteria and hydrocarbon utilizing bacteria increased in remediated soils. Based on the study, it was observed that the heavy metals analysed had lower concentration after remediation. All other heavy metals analyzed were also found to be within normal range. It was discovered that there was variation in the rate of bioremediation in dry and wet seasons as bioremediation conducted during the dry season proceeded at a higher rate because it was done under more aerobic conditions compared to the wet season. The study also revealed that bioremediation was more effective in the well drained soils than in the waterlogged soils.

5.2 Conclusion

Organic wastes utilization is currently receiving great research attention world-wide and the findings in this research work demonstrated the application of an organic waste, decomposed cassava peels in bioremediation of crude oil polluted soil in Obio/Akpor

Local Government Area, Rivers State. The study revealed that cassava peels (agro waste) improved the degradation of hydrocarbon in contaminated soils. The findings also showed that both soil and cassava peels contained bateria which break down hydrocarbons. The cassava peels supplied both nutrients and hydrocarbon degrading bacteria to the contaminated environment and therefore can enhance biological breakdown of hydrocarbon products in polluted soils. The study also showed that contamination as a result of oil spill will lead to rapid development of micro-organisms that break down hydrocarbon which utilize carbon in petroleum product as source of food. The study discovered that the effectiveness of bioremediation depends on soil properties and the season in which it is carried out, but the technique is economical for contaminated soil. The study revealed that bioremediation is more efficacious in well drained soils than in waterlogged or swampy soils and it proceeds at a higher rate in dry season than in wet season.

It was observed that adopting bioremediation technique may be limited due to the soils retension of moisture specifically where the soil has recalcitrant hydrocarbon compounds. However, the study has shown that bioremediation using decomposed cassava peels as a remediation material can be applied to well drained soil in order to remediate hydrocarbon during the dry season.

5.3 Recommendations

Following the determination of the various objectives of this study and subsequent findings, the following recommendations are made with regard to the use of organic waste in remediating hydrocarbon polluted soils in Obio/Akpor local government area. Cassava peels should not be disposed of as a waste which constitute nuisance to the environment, but it should be harnessed and used as a bioremediation agent in recovering hydrocarbon impacted soils.

Farmers should apply the right and sufficient quantity of agro-wastes that can be restored to the required optimum which in turn will stimulate and sustain the activities of microbes.

Remediation and clean up measures should be adopted and periodically carried out on soils contaminated by hydrocarbon pollution in order to prevent associated health hazards.

Besides, remediation of these soils from pollutants would maximize the land resources for agricultural operations and ultimately guarantee food safety in Obio-Akpor local government area.

Seminars and workshop should be organized regularly for the purpose of providing information on the negative impact of oil spill on soil structure and texture which in turn will affect production as it relates to crop yield. The host communities should effectively guard oil installations within their area.

An agency that will be charged with the responsibility of managing clean up in oil communities through policies formulation should be established by the government so that the concept of sustainable development can be operational in Nigeria fully.

Multinational and indigenous oil companies should adopt technological measures that are environmentally friendly to minimize the impacts of oil spill on the soil. Oil facilities should be constantly inspected and where necessary maintenance carried out to prevent oil spillage.

Government should enforce strict environmental laws and regulations that will ensure oil companies are held accountable for their negligence. All companies operating in the oil industries should be compelled by government to constantly retrain their staff on the importance of proactive measure in avoiding oil spillage in the environment.

There is need for government to establish protection unit for the coastal and estuarine area charged with responsibility of monitoring drilling and discharging of waste into water bodies. Government should also enforce strict remediation programs to ensure that international best practices are put in place for site biodiversity production.

5.4 Contribution to Knowledge

- The study was able to establish that cheap and local organic wastes such as decomposed cassava peels can be harnessed and used as bioremediation agents. When decomposed cassava peels are added to the soil, it improves the soil nutrient status and make the soil fertile for cultivation while reducing the hydrocarbon pollution in the soil. Decomposed cassava peel as organic waste is therefore a

natural attenuation agent for petroleum contaminated soil. This organic waste is common in the rural areas and are available to farmers to use as remediating agent.

- The research confirms that decomposed cassava peels contain hydrocarbon degrading bacteria that can enhance biodegradation of crude oil in polluted soils. Okafor (1998) stated that cassava peel is a good source of microbial enzymes. Microorganisms are encouraged to work when they are supplied with optimum levels of nutrients and other chemicals essential for their metabolism. When decomposed cassava peels is added to the soil as soil amendments, it supplies nutrients to the microorganisms and significantly increases the activities of micro-organisms in the soil. As the miro-organisms grow on the cassava peels substrate, they produce enzymes which are used in breaking down hydrocarbons in the polluted soil and so leads to biodegradiation.
- The research has been able to show that soil type is very important in bioremediation process as bioremediation is more effective in well drained soils than in waterlogged soils. Pore space in soil allow oxygen to be supplied to the micro-organisms and to the root system of plants. The texture of the soil is affected by bulk density, permeability and humidity of the soil. The size of soil particles also affects the proportion of air, the amount of water retention in the soil and the rate at which water drains from the soil. Therefore, it affects the ease with which the soil is cultivated. Soil drainage, aeration, and nutrient levels depend to some extent on soil texture. Biological degradation is carried out in aerobic and anaerobic condition because oxygen is a gaseous requirement for micro organisms. According to Macaulay (2015), the presence of oxygen enhances hydrocarbon metabolism. Well drained soils have good aeration which implies that such soil promotes the growth of micro-organisms which result in effective bioremediation.
- The research also shows that bioremediation usually proceeds at a higher rate in dry season than in wet season. In the wet season there is much moisture in the soil leading to anaerobic respiration which is not conducive to the micro-organisms and this reduces bioremediation. The implication of this is that bioremediation is faster in dry season than in wet season and so decomposed cassava peels should be applied in the dry sea

5.5 Suggestions for Further Research

This study focused on topographical and seasonal effects of decomposed cassava peels in remediating hydrocarbon polluted soils in Obio/Akpor local government area of Rivers State. The findings of this research work indicated the usefulness of this agro waste (decomposed cassava peels) in bioremediation of crude oil contaminated soils. It is important to state here that further research studies should be conducted along the lines of investigating the potential of using other agro wastes as natural attenuation agent in hydrocarbon contaminated soils. Also further research study similar to the present work reported in this study should be carried out on different topographic surfaces and in different seasons using other methods or the method used in this study. This will provide a framework for more understanding of the findings in the study particularly on seasonal variation in the rate of bioremediation. It is also essential to suggest that further research should be conducted to evaluate the effect of agro-waste on the hydrocarbon degrading bacteria physiological activities. Further studies should also be carried out to examine the importance of the behaviour of microbial population based on interaction with different toxic contaminants. This will enhance understanding the mechanisms of interaction between the microorganisms, contaminants and the soil in the remediation process.

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