Developing a treatment method for oil contaminated mining sites

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Mini-dissertation accepted in partial fulfilment of the requirements for the degree *Master in Business Administration* at the North-West University

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Graduation: June 2021
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DECLARATION

I, Mactavish Butholezwe Ncube, hereby declare that this mini-dissertation, submitted in partial fulfillment of the requirements for the degree Master of Business Administration in the faculty of Economics and Management Science at the North-West University, is my original work and has not been submitted to any institution of Higher Education. All the sources used for this study are cited and referenced in the reference list.

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ABSTRACT

The purpose of this study is to develop a cheap method that can be utilised by Metal Companies at its Site XY to decontaminate oil-contaminated soils. Oil spillages are a serious environmental threat since oil takes a long time to decompose in the soil. The heavy industry, more especially the mining sector, generates many spillages from its operations which can lead to a deviation from the environmental regulations such as the National Environmental Management Standards Act 107 of 1998. The Act gives the Ministry of Mineral Resources and Environmental Affairs the power to suspend mining activities and mining rights if there is a contravention of the constitutional directive to guard the environment by the respective prospecting or mining organisation (Vinti, 2018). Many mines prefer to seek third-party organisations' services to treat the contaminated soil, which comes at a higher cost. Metal Companies is one such organisation that still relies on procured services to treat oil-contaminated soil. In this study, samples from Site XY of Metal Companies were treated using some of the common methods that have been applied in other places as reported in the literature studies. A sample weighing 36 kg was collected from Site XY after which it was split into eight samples each weighing 4.13 kg. These samples were used to test eight different bioremediation methods over three months. The results from the eight treatment approaches were used to measure the depletion of oil and determine if the improvements were helping in making Site XY comply with the environmental regulations.

The statistical evaluation methods used to analyse the results proved that organic reagents were more effective at decontaminating the soil, making the process cost-effective if in-house treatment is to be considered. The study was conducted in winter, and a drop in the rate of oil-depletion was observed in the fourth week from the two of the most effective methods. Recommendations were made to review the reagents and preferred treatment seasons at that stage. The costing methods for projecting future decontamination costs were developed to allow the mining sites to utilise internal resources for cleaning the oil rather than outsourcing the clean-up services. It was also recommended that the cost sensitivity analysis be conducted at all stages of the projects to identify activities and methods that lead to a waste of resources.

ACKNOWLEDGEMENTS

I would like to take this opportunity to praise the Almighty God for guiding me through this MBA journey as well as helping me complete this dissertation on time. Secondly, I wish to express my gratitude to the following individuals who have contributed to this success story:

- To my supervisor Dr Johan Jordaan, thank you for the guidance and support throughout this learning expedition, you have always shown confidence in me from the first day that I started my MBA studies.
- Prof Wim Roestenburg: Thank you for the additional support and encouragement; your contribution in shaping this document is highly appreciated.
- To my two children, Nompilo and Mziwandile Elisha, thank you for being present in my life. This work was completed when you were still toddlers but you have been the primary source of my motivation. I have subjected myself to immense pressure, always hoping that the outcome will be your happiness.
- To my beautiful wife Bridgette, thank you for affording me all the support that I needed the most. From the encouragement to start the MBA studies, booking and managing my trips to school and holding the fort constantly while I was spending so much time studying. I am very privileged to have you in my life.
- To my mother and my late father, thank you for raising me, an MBA degree wouldn’t have been possible to achieve without the foundation that you have laid down in my Career.
- To Dr Innocent Shuro, thank you for the discussions that we have had during the course of doing this research. You have spared me sometime out of your hectic schedule just to help review my work.
- To all the other individuals I did not mention by names who have contributed to this research, thank you and may God the Almighty bless you in great abundance.
- Lastly, I would like to thank the Academic Staff from the North-West University’s Business School for imparting the valuable skills and granting me an opportunity to do my MBA in this prestigious institution. This has been such a rewarding and enlightening experience.

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LIST OF ABBREVIATIONS

List of Abbreviations	Meaning
CBA	Cost Benefit Analysis
CSA	Cost Sensitivity Analysis
NEMA	National Environmental Management Act
NPV	Net Present Value
TPH	Total Petroleum Hydrocarbon

DEFINITION OF KEY TERMS

- **Auger sampler:** A hollow sampling pipe used to collect samples from thick beds of material.
- **Bioremediation:** This is a technique used to clean oil-contaminated soil or water which utilises bacteria or microbes that releases enzymes into the hydrocarbon. The released enzymes are able to break down the oil into environmentally friendly products.
- **Cost-benefit analysis (CBA):** This is a method of comparing the benefits and costs between different projects in an organisation that helps decide which project to undertake.
- **Cost sensitivity analysis (CSA):** A simulation model that compares the relationship of different cost parameters that are the subject of the study under a specified environment. The CSA gives a good indication of how alternative decisions selected will affect one or more factors in a project.
- **Gy's formula**: An expression used to predict errors from a sampling method.
- **Net present value (NPV): T**his is the measure of the difference between the ***value*** of cash coming into the project and the ***value*** of cash outflows over a period of time.
- **Non-developed supplier market:** A market in which it is impossible to find suppliers with developed production systems.
- **Outsourcing:** A process of delegating specific tasks in the business to capable institutions or individuals to successfully execute them. This helps in freeing some of the internal resources for other useful responsibilities.
- **Phytoremediation:** A technique that uses plants to absorb the soil's oil and metal pollutants by break it down through metabolism.

CHAPTER ONE – INTRODUCTION

1.1 Introduction

It is vital to minimise contamination in the topsoil when conducting mining activities since the top soil contains all the ecosystem's nutrients and life-supporting components. Petrochemical contaminants have some of the gravest threats to the pristine soil environment, which makes it necessary that the remediation as well as spillage mitigation plans are put in place in order to reduce the extent of oil spillages to the ground surface in the mining industry (Ashmole & Motloung, 2008).

Metal Companies is a pseudo-name for a group of international mining organisations with operations worldwide, some of which are in South Africa. Some of the activities at Metal Companies generate oil spillages which mix with ground soil, thereby leading to a non-compliance condition according to the National Environmental Management Standards Act 107 of 1998. The Act gives the Ministry of Mineral Resources and Environmental Affairs the power to suspend mining activities and mining rights if there is a contravention of the constitutional directive to guard the environment by the respective prospecting or mining organisation (Vinti, 2018).

Oil spillages pose severe threats to water bodies since the spillages can spread in vast areas of water-covered land. The oil spillage from the Deepwater Horizon disaster which occurred in 2010 resulted in 636 million litres of oil spilling to the ocean floor, which covered 17.725 km^2 ,*i.e*. 36 ℓ/m^2 of oil (Incardona et al., 2014). The environmental impacts from service garage activities such as oil servicing sometimes go unnoticed, and on average, a single vehicle can yield 5 litres of oil per service activity. A litre of oil can amass in the soil and pollute as much as a million litres of water (Singh, Srivastava, & John, 2009). The presence of oil in the ground increases the soil bulk density, which results in the reduction of soil porosity for the circulation of air and thereby reducing the water holding capacity of the soil in the process. Mining activities can easily wipe microorganisms that live in the soil by introducing oil into the soil (Abosede, 2013). The Waste Management Act 59 of 2008 stipulates that remediation plans and the site assessment report for the contaminated land should be in place. If not present, this may result in fines from the Ministry of Environmental Affairs, which will penalise the respective company for the breach of the waste management systems (Zhakata, Gundani, Chauke, & Odeku, 2016).

Metal Companies have closure plans in place that were drafted with the help of consultants' in order to evaluate the risks in shutting down the operations. Alternative plans that have to be undertaken for the best practice to address the requirements of the environmental standards were also included in this closure plan. The gaps in the process were identified together with the closure work's monitoring processes.

The treatment process of the oil-contaminated soils is an outsourced activity at Site XY of Metal Companies which comes at a very high cost of R12 500 for a cubic meter of oil-contaminated soil treated excluding logistics costs. The collected oil-contaminated soil is rehabilitated in a different site location, bringing additional transportation costs. More than four consultants have recently been afforded an opportunity to test their techniques in treating the contaminated soil at Site XY. However, the value of the activities and processes through which the consultants achieve these results has never been evaluated (Kim & Ballard, 2001).

1.2 Problem statement

Metal Companies spend more than R200,000 monthly in service fees to rehabilitate oil-contaminated soil through several subcontracted outside companies. The oil-contaminated soil is collected in drums and then transported to one of the big cities in South Africa where it is cleaned and transported back to the site for restoration. The methods used by the outside contractors to rehabilitate the contaminated soils have not been disclosed, which leaves Metal Companies dependent on these companies. An unsuccessful attempt to degrade the hydrocarbon contaminated soils has been done on-site using several methods.

Metal Companies has not explored all the available methods to rehabilitate oil-contaminated soil successfully. An in-depth understanding of the techniques chosen for rehabilitating oil-contaminated soils is of great importance. Different ways of cleaning oil-contaminated soil are available, such as phytoremediation, bioremediation methods and soil washing methods.

1.2.1 Environmental standards

Minister Bomo Edith Molelwa gave guidelines that must be adhered to regarding standards for the remediation of contaminated land and soil quality as per Act 59 of 2008 in Notice 467 of 2013. According to these norms, the soil screening values for land use have the stipulated total petroleum hydrocarbon (TPH) limits shown in Table 1 below (Molelwa, 2013).

Table 1: Soil screening values for organics (Molelwa, 2013)

Type of Hydrocarbon	Units	All land-Uses protective of the water Resources	Standard Residential
C10-C14	mg/kg	440	500
C15-C36	mg/kg	45000	91000

The samples at Site XY of Metal Companies contain less long-chain hydrocarbon (C15-C36) than the allowable limits and more lower-chain hydrocarbons (C10-C14) in comparison to these limits. The sampled soil for this study measured as follows:

Table 2: A comparison of Site XY's organics analysis against the national standards

Type of Hydrocarbon	Units	Site XY	All Land Use Standards (Upper Limits)
C10-C14	mg/kg	25000	440
C15-C36	mg/kg	43000	45000

1.2.2 Project objectives

The research is based on an actual project that has the objectives listed in this chapter of the dissertation. Several methods could possibly reach these objectives which makes the purpose of this research to be the selection of the best technique.

- The project's primary objective is to develop a treatment method for rehabilitating oil-contaminated soils at Site XY of Metal Companies.

- The study's second objective is to reduce the C10-C14 hydrocarbon from 25,000 mg/kg to less than 440 mg/kg.
- The third objective is to apply cost forecasting techniques to reduce the expenses incurred in the rehabilitation of oil-contaminated soil at Site XY.

1.2.3 Primary research questions

- Can a method be developed to successfully decontaminate the oil-contaminated soil found at Site XY of Metal Companies?

1.2.4 Secondary research questions

- How can we best apply cost forecasting models, such as labour planning, and make a projection of the treatment outcome to reduce the expenses incurred in rehabilitating oil-contaminated soil at Site XY?
- To find the most cost-efficient way to reduce the C10-C14 hydrocarbon oils' oil-contamination levels from 25,000 mg/kg to less than 440 mg/kg at Site XY of Metal Companies.

1.2.5 Proposed data collection plan

The data collection plan shown in Figure 1 below will be used in this project. The available information at Site XY, which is stored at the Company's archives, will help understand the previous project plans and trials. Access to vast sources of research articles will be gained through the internet. The discovered information will be shared with the organisation, as this will also form part of the proposal for the implementation of a better technique for cleaning the oil-contaminated soil.

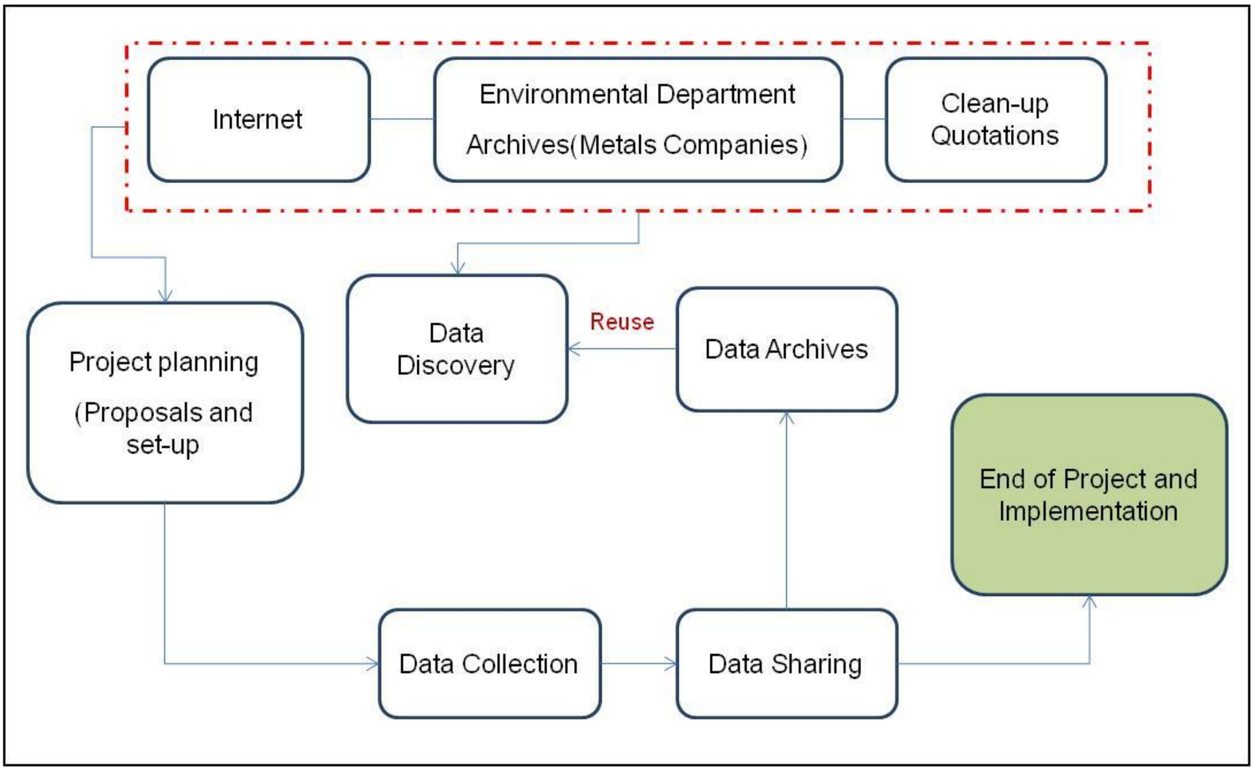

Figure 1: Data collection flow diagram

1.2.6 Expected managerial implications of the research

Some people may consider mining activities to be contributing economically to the communities whereas a different group of people view this process as detrimental to the environment. Rehabilitation of the mining sites will help create a good perception of the organisation to the community and the government. In a paper published by Tuija and Rauno, an investigation on some of the practices necessary for mines to gain social acceptance was done. Fears of emissions from the mine operations led to community protests in 2013, after which the mine had to set up an enrichment plant some 45 km away from the site where mining activities were done. This shows how sensitive the community and Governing bodies can be when it comes to environmental contamination in the mines (Mononen & Sairinen, 2020). The loss of operating permits due to such challenges, as reported by Tuija, can be very costly in that the penalties will come with their own costs, and community unrests lead to low productivity.

Understanding the stakeholders' perception and the mining industry's reputation in these communities is critical in drafting a mines' rehabilitation strategy. The mining sector needs to build trust by committing to environmental rehabilitation, thereby minimising its footprint. The rehabilitation of oil-contaminated soil is a project that can help Metal Companies comply with the environmental regulations at a very low cost (Svobodova, Vojar, Yellishetty, & Janeckova Molnarova, 2020).

CHAPTER TWO – LITERATURE REVIEW

2.1 Introduction

This section discusses some of the environmental regulations related to soil contamination in South Africa. The causes of soil contamination, the different types of contaminants, and the various oil contamination sources are also discussed in this chapter. Understanding why a gap exists in internal rehabilitation practices from within mines will help motivate and justify why the study is necessary. There are standard rehabilitation techniques that have proven to be very useful from the literature, forming part of the discussions. The most common methods to treat and restore soil will be discussed, including the advantages and disadvantages of certain aspects to consider with each of the methods. The literature study examined the impacts of soil contamination on the soil conditions, which plays a part in the survival of the naturally occurring microorganisms and the ecosystem. Outsourcing of project work, as seen at Metal Companies, will also be discussed since it has been a common practice at Metal Companies and other mining organisations to rehabilitate the soil.

A discussion of the cost-benefit and cost sensitivity analysis will also form part of this literature study since the approach attempts different techniques out of which the best will be recommended. Some trials have failed on-site before, making it essential to understand these methods' cost-benefits and cost sensitivity. This gives an insight as to what needs to alert the project team earlier as far as the project's success is concerned. With the labour, forecasting projects will also be brought into the picture since this form a vital tool for planning projects. Lastly, case studies of similar work applicable to most of the issues already discussed in the body of the literature are also discussed to show how researchers have used these techniques in other places.

2.2 Environmental compliance

Clear guidelines for the restoration of natural resources within the close vicinity to where an organisation operates need to outline directions on the roles that the shareholders will play in making their investments responsible as per King IV compliance requirements (Esser & Delport, 2018). Mining organisations are stipulated to provide their rehabilitation plans to the Department of Mineral Resources which gets reviewed annually on condition that changes are required to update the existing program and financial provisions for the mine closure.

A continuous rehabilitation programme that is very cost-effective will help any mining company reduce costs incurred when mining activities come to an end. The commitment provides fair competing platforms for the mining company with its peers in the market. Some mining companies are already investing in rehabilitation programmes instead of failing to spare funds for rehabilitation activities (Van Zyl, Bond-Smith, Minter, Botha, & Leiman, 2012). The closure programme for Degroot mine, which was done in 2015, had an estimated cost of R2,148,139. Part of this plan included managing the soil and compliance with the statutory requirements. One of the concluding recommendations from the Degroot mine report was that the rehabilitation processes must be done concurrently with the mining activities to reduce costs when the mine shuts it operations (Wells, 2015).

Mining companies are stipulated to set aside funds for rehabilitation as part of the Mineral and Petroleum Resources Development Act' closure plans. The funds need to be made available via any one of four different ways, namely, trust funds, cash deposit, guarantee and insurance. The mines are asked upon closure to supply the Department of Mineral Resources with all documentation, such as the closure plans, and the environmental risk reports which enforce compliance to the Mineral and Petroleum Resources Development Act (Krause & Synman, 2014).

2.3 Definition of soil contamination

Contamination occurs due to the soil's degradation, which becomes an environmental problem resulting in reduced soil functions, such as a drop in the population of microorganisms living in the ground. Mining companies need to treat soil remediation activities with utmost importance and minimise all forms of land pollution in the sites where their operations are found (Eugenio, McLaughlin, & Pennock, 2018). Some guidelines force companies to comply with environmentally friendly practices when conducting their business in different countries, given the shrinking land resources. Caution needs to be exercised by the mining organisations to demonstrate responsibility in the way they conduct their business (Vacha, 2017).

2.4 Typical soil contaminants

Some researchers classify soil contaminants into different categories depending on the source and state in which they occur. Some of the standard classifications may include the following:

- **Petroleum spills**: These are petroleum products that spill to the soil or water either from filling stations, vehicle garages or oil drills.
- **Landfills or garbage**: The contaminants from waste will depend on the type of chemicals in the material, which can easily seep into the soil depending on the moisture conditions.
- **Pesticides**: These are chemical substances used to kill or control insects or rodents in fields or homes. Pesticides can find their way into the soil or contaminate the air, thereby affecting the area's habitats (Shayler, McBride, & Harrison, 2009).

2.5 Inland sources of oil spillages

- **Pipelines**: The rapture of pipelines that transport oil in plants and refineries can lead to vast amounts of oil spillages, especially if the discovery, response and repairs are delayed. It is sometimes wise to transport oil in batches and containing it in reserve tanks to minimise the risk of uncontrolled spillages in a vast area. The pipeline spillages are occasionally challenging to quantify, especially if the system does not have flow meters and accurate level transmitters to reconcile the oil losses to the spillages efficiently. Buried pipelines have a risk of delayed oil leak detections whenever the oil is not visible on the surface. Site XY uses pipelines to distribute diesel and oil to most of its fuelling and lubrication units. In the past years, the site suffered huge oil losses due to undetected spillages from the buried pipelines, which makes it one of the challenges that still needs to be solved (Michel & Ploen, 2017).

- **Oil tankers**: This spillage is usually refined oil products distributed from the refineries to the end-users. The major causes of spillages from the tankers are either collisions or overfilling the vessels (Michel & Ploen, 2017)
- **Oil exploration sites**: Water flooding can spread the oil spillages to more significant areas around the oil exploration sites. The oil spillage in Colorado, which occurred in 2014, found its way to the nearest rivers from the exploration site after which it affected the vegetation in that area when the oil dried up (Michel & Ploen, 2017).
- **Garages and workshops**: Vehicle maintenance workshops play a crucial role in almost all the world's economies since road transportation is one of the most popular ways of connecting different places. The source of waste from these workshops ranges from oil filters, used oil drained to the soil, and other fluids. A study conducted in Ghana has shown that when it comes to oil spillages in service garages, the environmental consciousness is a factor of the level of education of the mechanics doing the service work (Michael, 2015). Site XY of Metal Companies has many service garages with technicians who specialise in different categories of vehicles and equipment. This group of people needs to be well trained on safe disposal methods and containment of oil spillages that occur within the workshops to minimise the environment's impact.

2.6 Impacts of contamination on the soil ecosystem

The oil that mixes with the soil makes it very difficult for nutrients and other elements such as nitrogen and oxygen to be accessed by the plants and the natural bacteria. The main problem caused by the oil spillages is that it covers the soil from the ingress of air thereby changing the temperature, pH, and soil structure, which deprive soil microorganisms of the air to breathe (Udeh, Nwaogazie, & Momoh, 2013).

Some oil-contaminated soil remediation methods involve removing topsoil and discarding it elsewhere. This only results in transferring the problem to a different area since any mix of water with this topsoil will spread the contaminants to other sites (Oh, Cao, Li, & Cheng, 2014).

2.6.1 Current status of soil rehabilitation research

Little research has been done on mining sites to continuously rehabilitate the oil-contaminated soil as the site's mineral resources are depleted. The problem with conducting the rehabilitation processes at the end of the mine's life is that this period is marked by an operation which has ceased to be economical and thereby generating enough funds for such projects making it very expensive to rehabilitate the soil (Du Plessis & Brent, 2006).

The challenges presented by the oil-contamination of soil are internationally seen as a grave issue, with some governments putting in place laws that aim at minimising the volumes of oil that might mix with the soil should there be a spillage. The underground storage tanks regulation of 2002 is one such measure that was put in place in the USA (Rule, 2007). In his report, Thomas Grigalunas states that it is not easy to estimate the cost of cleaning up oil spillages, mainly when different techniques are applied. Given these challenges, Thomas goes on to qualify the fact that the management of the oil spillage clean-up processes is an area that still requires in-depth research (Grigalunas et al., 1986). In an article by David Oliveria in the engineering news magazine dated on the 21st of March 2014, one consulting company in South Africa has successfully treated oil spills using its mobile facility for some companies in the Limpopo area. Such dependence on external service providers by mining organisations shows that most organisations still leave the rehabilitation process to the consultants' external services (Olivera, 2014).

The outsourcing of projects comes with challenges, such as the Corporate Governance agency problems where the managers try to benefit at the organisation's expense. One of the risks in outsourcing projects is that there will be a conflict of interest from the chain of people involved in the process (Milosevic, Andrei, & Vishny, 2015).

2.7 Common decontamination techniques

Currently, two standard methods are used to decontaminate oil-contaminated soils on a commercial scale, as described below:

2.7.1 Bioremediation

A technique called bioremediation is mostly used for decontaminating oil-polluted soils. This method utilises bacteria or microbes that release enzymes into the hydrocarbon, breaking down the oil in the process after which the bacteria consume the hydrocarbon (Hodges & Simmers, 2006). These microorganisms degrade environmental contaminants into less toxic forms. The microorganisms are sometimes imported to a contaminated site to enhance the degradation of oil, which is also known as bioaugmentation (Kensa, 2011). Metabolism occurs in these microbes via the reaction shown below where $C_6H_{12}O_6$ represents any fossil fuel or organic matter in the soil decomposed by the bacteria.

$$C_6H_{12}O_6 + O_2 = CO_2 + H_2O + Energy$$

Equation 1: The decomposition process of oil with bacteria (Ophardt, 2020)

The bacteria come together to decompose the contaminated soil during the bioremediation treatment process. The main products of this decomposition process which utilises natural bacteria are Carbon dioxide and water. These bacteria communities grow and metabolise by feeding on the oil, which creates a need for a constant supply of oil in the soil for these bacteria communities to survive (Kleindienst, Paul, & Joye, 2015). Some people have used fertilisers to help create favourable conditions that boost the soil's bacteria population, thereby speeding up the bioremediation process (Udeh et al., 2013). The soil pH conditions influence the solubility, mobility and distribution of these bacteria microbes in the contaminated soil with the optimal pH being observed between 6 and 7.5.

The oil-decontamination of soil can also be classed according to the temperature ranges under which the reaction occurs, i.e. mesophilic, which occurs from 10°C to 40°C and thermophilic, which takes place from 45°C to 70°C. Organic waste material such as chicken manure carries lots of nitrogen; hence some studies have applied it to clean oil-contaminated soil (Naowasarn & Leungprasert, 2016).

Genetically modified microbes' strains can be made to consume a specific hydrocarbon type. When this is applied, it is critically important to optimise environmental settings; otherwise, the bioremediation process can fail (Hodges & Simmers, 2006). Some researchers have further classified bioremediation into two techniques: *bioaugmentation*, whereby known oil degraders are added to assist the indigenous and existing microbial community. The second method is called *biostimulation*, whereby ways of enhancing the growth of pre-existing oil-degrading microorganisms are applied, such as the addition of nutrients that boosts their growth (Adeleye et al., 2018). Microbes' ability to modify their genetic makeup, which results in these microbes producing oil-degrading enzymes, is an essential key feature that can be used for breaking vast quantities of oil spillages (Kensa, 2011).

2.7.2 Phytoremediation

The phytoremediation method uses plant species that deplete oil when planted on the contaminated soil. Phytoremediation can be applied in different forms, including the uptake of contaminants by the plants after which they volatilise into the atmosphere. The second technique of applying phytoremediation is through plants collecting these contaminants from the soil after which the plant is plugged out of the soil for disposal (Pivetz, 2001). The *crotalaria pallida legume*, a native plant species in South Africa, maximises light interception by its sun-tracking leaf movements which results in optimal rates of photosynthesis. Research has proven that some of these plants can achieve more than 10^{o} per hour of leaf movements (Schmalstig, 1997). The planting of *crotalaria pallida* in the acidic oil-contaminated soil had a pH increasing effect, and the degradation of the crude oil that was observed was thought to be a result of the generation of organic acids during the tests (Baruah, Deka, & Baruah, 2016).

The process of using a combination of microbes and these plants for the removal of the hydrocarbon pollutants makes it one of the most cost-effective methods; however, the only setback is the long duration of the treatment process. In a case study done by Adegbite in Nigeria, the community had to be involved in the rehabilitation exercise and some of the concerns that were raised such were the fast rate at which oil waste was generated as well as the recontamination processes in the area. The rate at which oil-contaminated soil is produced is one key consideration that needs to be made in choosing the in-situ treatment methods to be adopted at Site XY of Metal Companies (Adesipo, Freese, & Nwadinigwe, 2020).

Completing the remediation processes takes a long time, making this method inefficient due to limitations in the quantities of soil that can be treated at a time. The surface area of the plant roots used in phytoremediation is low, making the total contact with the soil deficient and less effective. This method also relies on the soil's moisture content, meaning that it will be difficult to successfully apply it at Site XY since the region where this company is located is very hot and dry (Oh et al., 2014).

2.7.2.1 Soil rehabilitation methods classifications

The treatment of soil can be classified into two methods in relation to the place of decontamination from where the spillage occurred.

2.7.2.2 In-situ treatment

In-situ treatment involves treating the soil in the area of contamination by applying the treatment methods without moving the soil to a different site. This method has advantages of being cheaper, and unlike the ex-situ method, it does not require the excavation of the contaminated soils to a different site that interrupts the landscape. Bioremediation is one of the best proven in-situ methods in that it does not transfer the source of contamination to other sites (Okoh & Trejo-Hernandez, 2006). Composting of the oil-contaminated soil is achieved through mixing decomposing organic waste with the oil-contaminated soils after which the nitrogen content in the material is boosted to speed up the process. Oil is a hydrophobic substance, and it has been observed that very high concentrations of oil in the soil result in reduced moisture contents, as seen from the bioremediation case study by Gogoi et al. conducted in India. This has negative implications on organisms that live in the soil, leading to a need to compensate for these ideal conditions of optimising the moisture content in the soil (Gogoi, Dutta, Goswami, & Krishna Mohan, 2003). Some view the treatment of oil-contaminated soil in the area of spillage as the safest and most reliable method since handling accidents that arise from material movements from site to site can be minimised. At Site XY, the practice has been to collect the soil in drums and then transport it for treatment elsewhere. However, trials have been ongoing, and a treatment pad has been constructed (Anyadiegwu, Igbojionu, Ohia, & Eluagu, 2019).

2.7.2.3 Ex-situ treatment

When oil-contaminated soils are treated at a place away from the area of contamination, the process is called ex-situ bioremediation treatment.
This method can be categorised into three options: the bioreactor methods where vessels with controlled conditions are utilised, and land farming uses a well-prepared pad for offsite treatment. The third option is the bio-pilling method, whereby the material is aerated to speed up the reaction. Ex-situ methods have advantages such as the increased surface area of the material used for bioremediation due to the soil's natural tilling during transportation. The isolation of the habitats and the environment from the contaminants is another advantage, especially if there are water bodies in the area which in most cases facilitates a spread of the oil (Hartsock, 2016).

On the other hand, some researchers believe that fixed permanent treatment facilities that can be used repeatedly in ex-situ soil treatment minimise the extent of further contaminating the site of spillages. Permanent treatment facilities have been proven to come with many cost savings compared to single-use facilities. Asphalt and clay have been used as a foundation for single-use facilities in other bioremediation projects, introducing set-up and site closure costs. On the other hand, permanent concrete facilities can treat more contaminated material repeatedly in a single year without forking out a penny for the set-up processes (Toffoletto, Deschênes, & Samson, 2005a).

2.7.3 Direct and indirect benefits of soil rehabilitation

Soil remediation projects result in direct and indirect financial benefits which make it very complicated to quantify the benefits yielded from such work; on the other hand, the costs of such undertakings are easy to quantify. Sensitivity tests have shown that direct benefits from rehabilitation can equate to 37.5% improvements in the land's value. In contrast, in a case study conducted in Israel, indirect costs were linked to the property's market value and land within the vicinity of the area of contamination. Indirect benefits were shown to have increased property value in the vicinity of the contaminated area by 14 times due to the rehabilitation work that was successfully carried out on this site. At Metal Companies a different matrix, such as the size and value of land available for indigenous plant and animal species, can be applied as done in Israel by using the equation below (Lavee, Ash, & Baniad, 2012).

$$\text{Total decline in value of land} = \frac{\text{Land value impairment}}{1 + \text{Interest rate (Discount period)}}$$

Equation 2: Decline in the value of land

The cost-effectiveness of project funding was evaluated against the preciseness of applying resources to minimise spillages of the chemicals, thereby leading to a lesser need to rehabilitate the area after the project. The nature of oil spillages at Metal Companies is an area that is worth investigating to minimise the rehabilitation costs (Rolfe, Windle, McCosker, & Northey, 2018).

Different approaches can be used to evaluate the projects applied to rehabilitate land contaminated with various types of toxic chemicals, namely:

- Index approach: This combines all the benefits into a single catalogue to deduce the project cost ratio to the catalogue of benefits (Rolfe et al., 2018).
- Disaggregation approach: A method of dividing the enticement rewarded to full project costs to the separate outputs from the project (Rolfe et al., 2018)

The figure below shows some of the direct and indirect benefits of rehabilitating the land. The oil spills cost can be divided into clean-up, socio-economic losses and environmental costs. Different researchers have used various methods to calculate the cost of oil spillages. The costs can be projected through a modelling process and environmental costs compared against the socio-economic costs or the compensation rewarded to the claimants can be used to estimate the spillage costs (Kontovas, Psaraftis, & Ventikos, 2010).

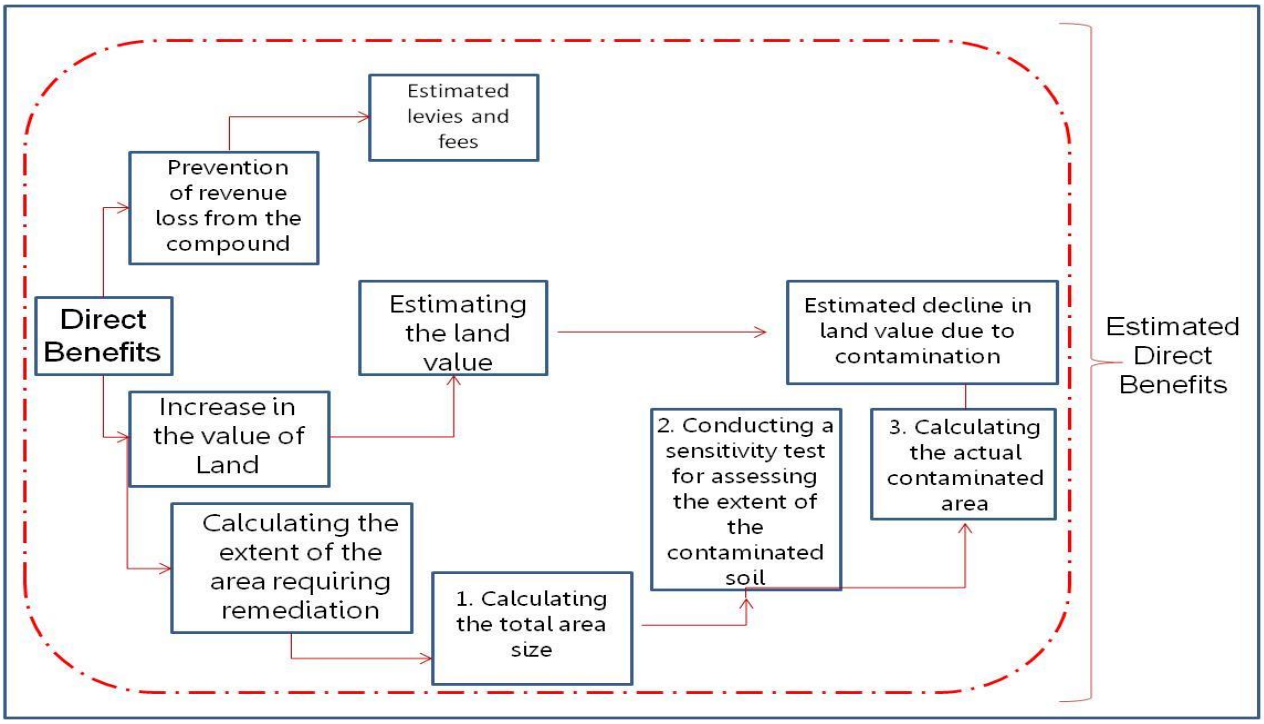

Figure 2: Direct benefits estimation (Lavee et al., 2012)

2.7.4 Outsourcing projects

The word *outsourcing* comes from combining the words outside and resources. This concept has been in use for ages, and its main aim is to delegate specific company tasks to capable institutions so that they successfully execute them. This helps to free some of the internal resources for other useful responsibilities. This process allows the work to be completed efficiently in a cost-effective way, and organisations use it as a strategic tool for better cost savings (Giertl, Potkany, & Gejdos, 2015).

A survey conducted by Amir Reza using a questionnaire shows that outsourcing helps manage the time, inventory and human capital as seen from the positive correlations between these factors from the correspondents' results (Shirzadeh, Heydariyeh, & Hemmati, 2014). This means the quality of the labour is improved tenfold, and the same applies to the inventory management process. This process has its shortcomings in that the project can suffer from quality issues resulting from substandard services that might be offered due to a shortage of critical inventory (Shirzadeh et al., 2014). The project leaders need to regularly monitor and check that all the work requirements are in place.

Activity-based costing breaks down each product and services cost, thereby enabling the organisation to quantify these costs. This requires a lot of planning and resources, which makes it a daunting task, leading to employees losing interest in the approach (Aamer, 2018).

Cost savings by outsourcing certain services in organisations are measured by comparing the costs before and after outsourcing these services. Organisations need to quantify the costs before outsourcing services. The total costs associated with the outsourcing process needs to be considered in the process. The oil rehabilitation project at Metal Companies is a ***non-developed supplier market*** since it has been a challenge to source a service provider capable of rehabilitating oil-contaminated soils (Aamer, 2018).

The processes followed in outsourcing projects at Site XY of Metal Companies are simplified whereby the end-user of the services or product puts together a detailed scope of work for the procurement team to source the right candidates to execute the task. The suppliers' technical capabilities are evaluated using information acquired from the background checks and a set of interviews and certifications. Pricing is considered to be the main driving factor when choosing an incumbent for the project. This approach can sometimes be misleading, considering that the costing is not dissected into the project's activities, and poor quality delivery can result thereof.

2.7.5 Cost-benefit analysis

Cost-benefit analysis (CBA) compares the benefits and costs of different projects in an organisation which also helps to decide which projects to undertake. A reliable method needs to be established for this assessment meaning that the project with the best state of impact on the organisation's economy will be undertaken and modelled to suit its requirements (Drèze & Stern, 1987). The CBA evaluates the total cost of the remediation projects; this is mainly used by environmental economists and considered the fundamental hypothesis of applied welfare economics. The benefits from the cost-benefit analysis can be a better livelihood of the people. On the other hand, the costs will translate to a drop in the people's wellbeing, meaning that remediation projects cost benefits need to surpass the net costs (Atampugre, 2011).

The cost-benefit analysis can evaluate difficult initiatives to quantify precisely how much revenue they will save. As far as environmental conversation is concerned, a survey can gauge how many people are prepared to save to conserve specific environment components. One of the constraints of the cost-benefit analysis method is that it is seen to be optimistic, and the environmental policies are not factored into this method, which then becomes a misleading guideline at times. Another drawback can be illustrated when researchers evaluate the lives of the affected people in a study, and it is impossible to put a value on life (Heinzerling & Ackerman, 2003). The selection of the most viable option for a project depends on several factors such as the environmental impact, the cost-efficiency of the work, operation and the maintenance of the technique, the time frame for achieving the remediation aim, health concerns and the footprint after the clean-up process (Anyadiegwu et al., 2019).

When making decisions, it is very worthwhile to indicate how the alternative selections will affect one or more factors in a project. The information-based approach as applied by the National Centre for Decision Making can be used for key decision-making where the problem is identified after which goals are set, considering the characterisation of economic and environmental settings (Melonee Docherty, 2016).

2.7.6 Cost sensitivity analysis

When making decisions, it is very worthwhile to indicate how the alternative selections will affect one or more factors in a project. A simulation model is usually created with all the particular parameters that form part of the project's work. Each parameter is then varied within the confines under the project environment to check how different project cost aspects responds to such variations (Briš, 2007).

Some people use cost sensitivity analysis to compare different rehabilitation methods from the field experimental data results. This looks at the cost per rand value of the number of contaminated samples remediated against the biological component's performance. The immediate expenses incurred during the field experimentation for the methods under study also referred to as short-term costs, were used as the first economic comparison basis. This method can be adopted in the rehabilitation processes at Site XY of Metal Companies (Saaty & Booth, 1994).

When implementing the cost sensitivity method, the estimated costs of a project's financial requirements are added to the cost-benefit analysis as the economic analysis inputs. These inputs need to be determined to assess the projects' profitability and form part of the reporting channel to the major stakeholders (Laissy, 2008).

The soil textures play an essential role in determining soil remediation exercise costs. The sensitivity of cost as a function of the soil texture was evaluated in a study of cleaning oil-contaminated soil using microwave technology. It was observed that the sandy soils required a maximum of 160 Euros per ton treated, and this number doubled for the same quantity of clayey soil. Moisture contents also contributed to the soil's average cost (Falciglia & Vagliasindi, 2016).

Some researchers have argued that technology comes with a drop in the cost models' overall expenses. However, some believe that technology can be a large investment cost item. The correlation between the costs inputs and the project's anticipated total costs can be measured using the regression analysis expression, which shows the fit's integrity as a gradient taking a value between zero and one. The values closer to one indicate a very strong correlation. Most project trials use different parameters, and it is very wise to check how strong each parameter correlates to the costs incurred in the project.

$$R^2 = 1 - \frac{\sum_{n=1}^{n}(y_i - \dot{y})^2}{\sum_{n=1}^{n}(y_i - \bar{y})^2}$$

Equation 3: Regression analysis expression

Where $\dot{y}$ and $\bar{y}$ are the degrees of freedom, and R^2 is the coefficient of determination (Probst, Nitzl, Kraus, & Förstner, 2020).

2.7.7 Cost forecasting models

According to the Corps' National Economic Development guidance for conducting feasibility studies for several project options, the economic and environmental quality aspects are crucial to inform the decision as to whether a project is worth undertaking. The financial part evaluates the work's cost benefits, whereas the environmental quality only looks at the impact on the natural habitat (Fennell, 2019). Statistics can also be used to determine the cost outcome from a project as previously done in Canada for the healthcare projects where population-based longitudinal micro-simulation models were used to predict healthiness and cost impacts of the populace under study.

The first stage of the modelling process, also referred to as the initialisation stage, involves collecting historical data that is then followed by updates that consider the data trends from the initialisation step. The validation of the data after processing it, using specific statistical algorithms and projection stages is then be implemented, forming the last two phases (Amankwah et al., 2020). When known external factors affect the demand for a service or commodity, machine learning can easily be adapted to forecast how the future direction will look. In Thailand, for example, the demands for electricity are dependent on the seasons, and researchers have quantified this to increase by as much as 15% in certain times of the year. The forecasting models' errors are of a considerable significance in the total value output as seen from the New Zealand power generation that a 1% error can amass to $1.6 million (Jawad et al., 2020).

Temperature conditions determine the bacteria's growth rate required for the bioremediation process. Considerations as to when the rehabilitation work can be conducted need to be done as this will determine the treatment duration and the costs incurred during the process (Zhang, Yuan, Xiong, Wang, & Jiang, 2020).
An in-situ project case study on coral reefs' rehabilitation in Australia quantified labour costs using person-days for each activity, which got them to an average of 170 person-days per activity on a five day week. One major fear by the authors is that if the assumed costs are lower than the actual activity, this becomes a setback for the project. The set-up costs also need to be considered, and in the case of this in-situ project on the coral reefs

case study, prices for all the material required to construct the nursery trays for breeding the raw corals in preparation for the actual work were broken down and quantified. The different methods that form part of the study also need to be compared at the end of the work to determine the most economical ways (Edwards et al., 2010).

2.7.8 Labour costs

A method of evaluating complex related project processes that are dependent on each other which is also referred to as a systems dynamics study, has been used to improve the management of a project by carefully considering the hiring policies and practices. The project's scope is broken down into different loops analysed to see if there is a need for reworks in some stages, which also talks directly to additional labour costs. This process makes it imperative to carefully consider the project labour turnover and hiring skilled people for the specific tasks to minimise these costly reworks as well as improving the quality of the work done in the project. The employees' performance will then improve when they get to familiarise with the task quantified as the employees' performance indicators. Abbaspour and Dabirian made comparisons of the implementation of weekly versus monthly hiring policies. It was observed from their study that monthly hiring had advantages of the fast completion of projects at the expense of cost savings, i.e. this gave a total cost of $297,908 versus $256,839 for a weekly hiring project. In simple terms, the short-term policies allow the project to make the right labour hiring decisions at that particular juncture (Abbaspour & Dabirian, 2019).

Workforce planning models, which are determined by constraints under considerations, have been recommended by Hargaden and Ryan. These constraints look at the people's utilisations in a project, such as the number of projects that a single individual can be allowed to take part in or the number of people partaking in a single stage of a project. This approach needs to be adopted when outsourcing services from companies that will do certain activities in the project since it ensures that the relevant stakeholders deliver the best quality by prescribing the workforce's expectations in as far as the work is concerned (Hargaden & Ryan, 2015).

2.8 Previous studies

Treatments of oil-contaminated soil have been applied in different places across the world. The case studies below are summaries of the work done by previous researchers from their published articles.

2.8.1 Cost comparisons of different methods by Agunwamba

A study done in Nigeria compared the costs of treating oil-contaminated soil samples by applying different methods. The methods applied included composting, bioremediation, bio-slurry treatment, bio-venting, and phytoremediation techniques. When the total costs for treating each sample were compared to the total volumes treated, bio-slurry was found to be the most cost-effective method per unit volume of the soil treated whereas bio-venting was the fastest method of rehabilitating the samples. The treatment duration for all the tests was plotted against the cost, and there was a weak correlation between the two which gave R^2 value of 0.189 (Agunwamba & Mbogu, 2013).

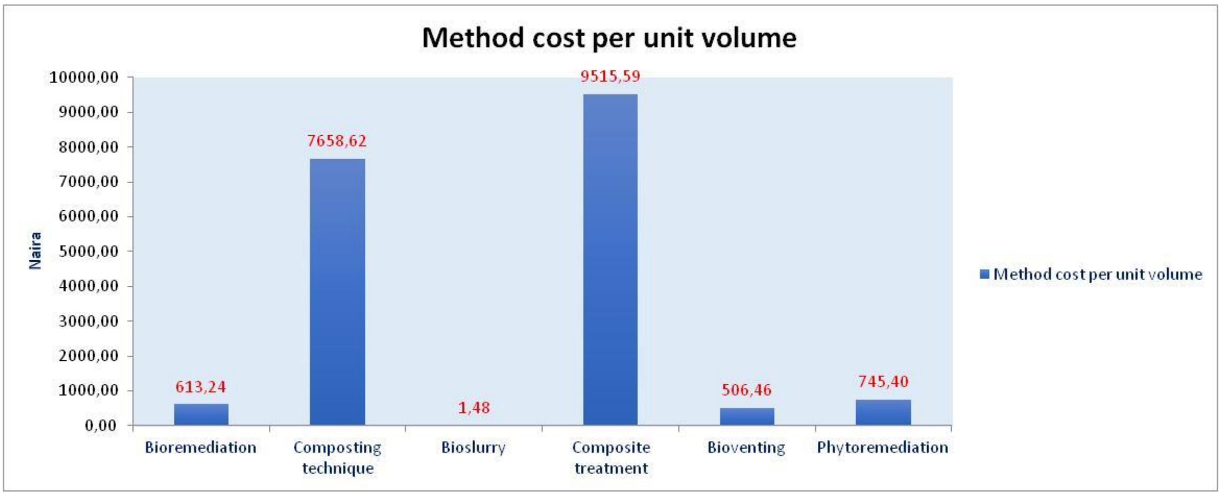

Figure 3: Cost comparisons of different soil rehabilitation methods

2.8.2 Bioremediation of heavy sludge through composting studies by Jose and colleagues

Another study by Jose compared different bioremediation methods where the soil samples were mixed with different materials, such as wooden shavings, pig manure slurry, and the refinery oil sludge as the contaminant. The experiments measured the carbon dioxide released for each experimental set-up to determine the most effective method. It was observed after 12 weeks that wooden shavings and the pig manure slurry, when mixed with the refinery oil, yielded the best results. A graphical plot, which compared the costs against the duration of treatment shows a week correlation as seen below (Marín, Moreno, Hernandez, & García, 2006).

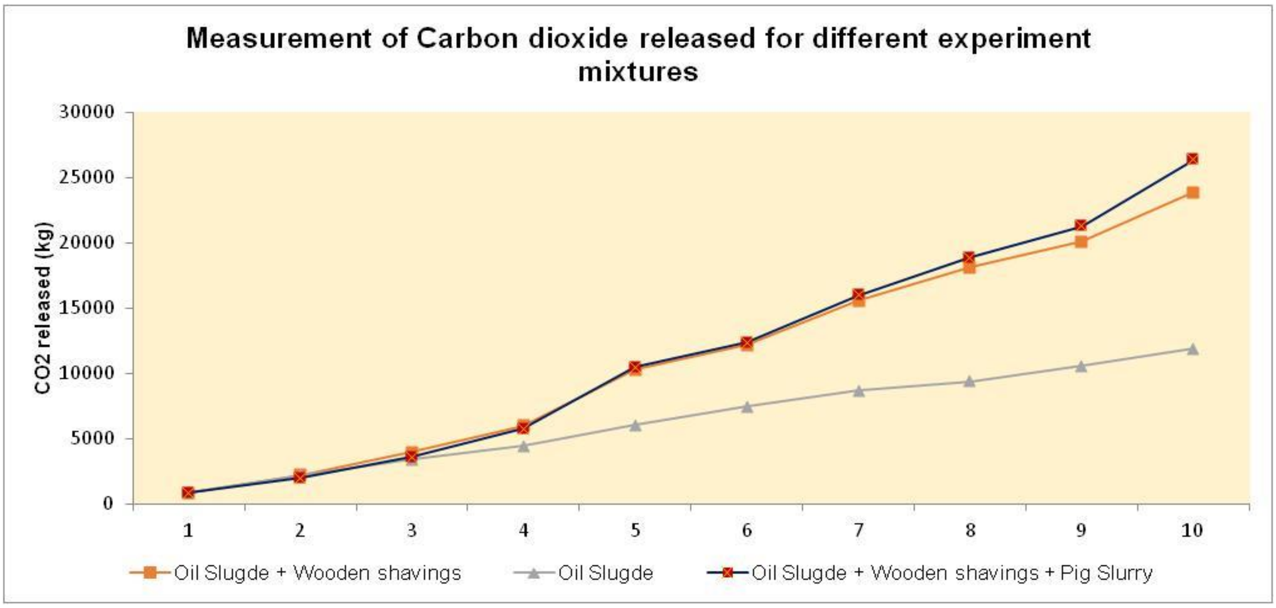

Figure 4: The release of carbon dioxide over 12 weeks

2.8.3 Savannah River bioremediation studies

A cost-efficiency investigation of the utilisation of in-situ bioremediation at Savannah River done in 1995 utilised cost sensitivity by following the costs' adjustment as the input parameters of the work varied. Short-term expenses were contrasted with long-term costs for each stage of the undertaking, which at the end indicated the direction in which the total costs were heading. The short-lived costs framed an early sign of whether the Return on Investment will be ideal as benchmarked from the physical technique of remediating the oil-contaminated soil, which was the common practice. Numerical modelling was also applied to the study, which projected that the remediation process would be 40% more effective than the physical process (Saaty & Booth, 1994).

2.8.4 Economic aspects evaluation of soil remediation by Troquet

Bioremediation will play a vital role in the near future to treat oil-contaminated soil. The economic aspects have been measured by comparing different methods used to treat a drum of oil-contaminated soil based on the quotations received from different service providers. The data compiled below made comparisons of the different available options at the time of the study and the estimated costs incurred with each method of handling one cubic meter (1.8 tons) of oil-contaminated soil (Troquet & Troquet, 2002).

Secondary data from studies of this nature can help select the most viable remediation methods applied at Site XY of Metal Companies after which the cost benefits can be calculated.

Remediation method	Range of Costs(Euro - €)	Increasing expenses factors
Incineration	305	Energy
Chemical Immobilization	28-70	Transportation, monitoring
Soil washing	42	Transportation, solvent disposal
Bioremediation	35-215	Monitoring time course of treatment
Land farming	20.5-205	Monitoring
Composting	542	Excavation, transportation
Phytoremediation	51-203	Monitoring
Slurry phase	185-392	Excavation ,transportation

Table 3: Cost comparisons for bioremediation and classical methods

2.8.5 Bioremediation trials in Canada

A cost-effective bioremediation method was applied in studies conducted in Canada. This method involved creating ideal conditions for microbial activities through a ventilation process of the soil that enables the aerobic microbial processes to occur, resulting in the degradation of the hydrocarbon. The method has been proven to be very simple to set up and operate, taking up to six months to start yielding results (Toffoletto, Deschênes, & Samson, 2005b).

These trials aimed at reducing the hydrocarbon concentration in soil from 6145 mg/kg (C_{10}-C_{50}) to 700 mg/kg (C_{10}-C_{50}) (Toffoletto et al., 2005b). In these trials, life cycle assessment studies in bioremediation treatment processes were carried out. Assessment methods, such as the modelling of each impact and then making comparisons with at least four remediation methods aiming at minimising the risks of the rehabilitation project to the environment as well as the total costs of the project, were done.

2.8.6 British Gas comparative remediation study

A remediation cost comparative study conducted at British Gas suffered additional site set-up costs to what was initially planned as well as the costs incurred on each method used to rehabilitate the contaminated soil. Two of the sites used to remediate the contaminated soils A and B had unforeseen added costs of £1.25 and £9.87 respectively with the £9.87 being attributed to project delays, amongst other issues. The work also suffered indirect costs such as additional studies costs which were excluded initially. Indirect costs are more pronounced with bioremediation and soil washing methods. These costs made land filling a cheaper option; however, landfill taxes makes the option of land filling a less attractive route to adopt (Day, Morse, & Lester, 1997).

2.9 Conclusion

It is evident from the literature that mines can successfully rehabilitate the contaminated soil using internal resources as witnessed by the different case studies discussed in the literature study. The cost incurred in each of the methods needs to be considered in all phases of the project – from planning to the end – to achieve a cheap process. The stringent measures put in place by government through the relevant ministries also calls upon the mines to demonstrate responsibility in their mining activities by looking after the environment in which they operate. The literature also mentioned that there had been a failed attempt to utilise some of the most common remediation methods at Site XY of Metal Companies, and this failure might have been inadequate consultation of the literature studies for the appropriate measures to be taken when conducting such work. The best optimal conditions for each method together with constraints faced were also discussed, and this leaves us with a choice of which methods to try in this dissertation.

CHAPTER THREE – RESEARCH METHODOLOGY

3.1 Introduction

This chapter outlays a set of methods to determine if some of the techniques discussed in the literature can help clean the contaminated soil found at Site XY. Case studies have used different methods to clean the oil-contaminated soil, and a few of these methods were tested on a soil sample from Site XY. The results were then analysed using different statistical tools discussed in the methodology.

This study's sampling process covered a huge fraction of the sampling space showing how the quantified parameters correlate in the process. This process helps increase the test work's statistical power (Dambros, Morais, Vasconcellos, & Franklin, 2020). Sampling protocols were adhered to in order to increase the sampling's confidence levels by reducing errors. Comparative studies of the results from the different experimental trials with secondary data from previous research in soil rehabilitation were applied in the approach. Troquet has applied the same method in his research that was also quantitative study research, as discussed in the literature (Troquet & Troquet, 2002).

3.2 Research philosophy

This study followed the philosophy of positivism since it has already been proven in the case studies that certain conditions can be applied to the oil-contaminated soil to speed up oil decomposition. The natural bacteria that are sometimes found to be living in the soil requires specific nutrients that the previous projects have manipulated to achieve successful oil rehabilitation, as observed in the case studies.

3.3 Research design

This hypothesis testing research study verified whether bioremediation techniques, as explained in the literature, helped in cost-effectively rehabilitating the oil-contaminated soil at Site XY of Metal Companies.

In order to address the second research question, that asked whether it was possible to reduce the hydrocarbon concentration from 25,000 mg/kg to below 440 mg/kg, a bulk sample was collected from the site, and this sample was subjected to some of the bioremediation techniques explained in the literature study (Kothari, 2004). Sampling guidelines were applied to ensure that the quantity of the collected sample was representative as described below:

3.3.1 Source of analysis data

The primary data included the results from the experimental work techniques conducted using samples from Site XY of Metal Companies.
The comparative study population included secondary data from rehabilitation case studies done on oil-contaminated soils worldwide.

3.3.2 Study sample

The sampling process was divided into two parts: the physical soil samples from Site XY (test site), and the secondary data results from internet sources. The methods that were followed for collecting these samples are explained below:

3.3.3 Physical samples

The sample population constituted the mass of the soil (kg) mixed from different spillage sources at Site XY. The extent of contamination in these samples was measured as the total petroleum hydrocarbon (TPH) in the soil (mg/kg).
It was imperative that bias had to be eliminated in the sampling process. As a result of this, the study made use of a stratified random sampling method for the reasons explained below:

- The soil mixture was stored as a thick bed that required an auger sampler for a representative sample to be collected.
- The drums tipped into the compositing pad were weighed to know the tonnage of

contaminated soil before the sampling process was done. The Gy's formula was used to determine the error from the sample size taken from this sampling lot.

- The selection probability was distributed to the entire composite sample mass to correct probabilistic sampling. An assumption was also made that the sample lot was homogenous due to the soil particles. In order to achieve precision in the collected samples, the selection error (SE) from the population had to be made as small as possible by minimising bias in the sampling process (Gy, 1998).
- Points to be sampled can be selected using a Global Positioning System, but in this project, the sampling area was relatively small, i.e. 10x10 m. Since total sampling area was small, a cheaper method was to dissect the pad into squares that measured one meter each after which these squares were then labelled from 1 to 100. A Random numbers table was used to select the squares chosen for soil samples used in test trials (Webster, 2008).

The selection probability was distributed on the entire composite sample mass to correct the probabilistic sampling. An assumption was made that the sample lot was homogenous due to the soil particles. In order to achieve precision in the collected samples, the selection error (SE) from the population was also made as small as possible by minimising bias in the sampling process.

$$\begin{aligned} C &= cflg \\ &= 1x0{,}25x1x1 \\ &= 0{,}25 \end{aligned}$$

Equation 4: Shape factor calculation formula

$$S^2 = \left(\frac{1}{M_S} + \frac{1}{M_L}\right) Cd^3$$

Equation 5: Sampling error formula

Parameter Measured	Value
M_S	36
M_L	500
C	0,25
D	0,08
Sampling error (very small)	$3{,}81x10^{-7}$

Table 4: Calculated errors for the samples to be used in the projects

Where:

- *S^2 is the fundamental sampling error.*
- *M_S is the mass of the sample.*
- *M_L is the mass of the sampling lot.*
- *D is the nominal size of the particles.*

The error calculation results above from the 500 kg of material in the treatment pad at Site XY, was found to be very low and acceptable, i.e. $3.81x10^{-7}$.

A sample weighing 36 kg was then sampled from the 500 kg sampling lot with little concerns of getting errors. This 36 kg was then split into small containers where certain treatment conditions from the secondary data were applied:

1. Liberation factor: A factor of 1 was chosen since this value is recommended for environmental applications.
2. Shape factor f: An assumption was made that the particle shapes did not vary and a value of 1 was used in this case.
3. The granulometric factor (g): Work done by Munnick in the same area has shown that the soil in this area holds a value of g = 0.25. In his study, Munnick has proven that 95% of the top size particles are four times greater than the 5% lower size; that is (D95/D05) was greater than 4 for all these soil categories (Munnik, Verster, & Van Rooyen, 1996).
4. Mineralogical factor (c): This was assumed to be 1 since the research targeted oil spreading across the sample lot instead of a specific mineral (Gerassimidou, Velis,

& Komilis, 2020).

5. Table 6 shows the 30 squares from the dissected sampling lot chosen out of which a sample of 1,200 g from each box was collected to make a composite sample of 36 kg.
6. The highlighted boxes in Table 6 (sampling lot) were generated by the random numbers generator to make 30 samples. Sample 53 appeared twice, which led to two samples being collected from this box.

Sampling lot									
1	2	3	4	5	6	7	8	9	10
11	12	13	14	15	16	17	18	19	20
21	22	23	24	25	26	27	28	29	30
31	32	33	34	35	36	37	38	39	40
41	42	43	44	45	46	47	48	49	50
51	52	53	54	55	56	57	58	59	60
61	62	63	64	65	66	67	68	69	70
71	72	73	74	75	76	77	78	79	80
81	82	83	84	85	86	87	88	89	90
91	92	93	94	95	96	97	98	99	100

Table 5: The dissected sampling lot with selected random samples

3.3.4 Sampling frame

The sampling frame constituted of the following:

- The duration of the rehabilitation process
- The costing results of rehabilitating given oil-contaminated soil case studies
- Methods of contaminated soil rehabilitation from treatment case studies

This study was a longitudinal study since the change in the variables was measured over the number of days, such as the depletion rates of the soil's oil contaminants over a specified period. Clinical research done by Irena Cenzer and others used secondary data for comparing the research at hand with studies that have already been conducted, and they stated in their report that it could have been impossible to achieve this using only the primary data for that type of a longitudinal study (Cenzer, Berger, Rodriguez, Ostermann, & Covinsky, 2020).

Mixes of soil with different materials known to favour conditions for the breakdown of oil in the soil was done in different experimental pots (JC & Mbogu, 2013). This 36 kg bulk sample collected from Site XY was split into nine samples, each weighing 4.150 g. One of these samples was used as a control sample to benchmark the treatment progress for each method applied.

A bacteria powder sample was added to each of the first eight samples. The bacteria were varied in quantities to determine how sensitive the concentration of bacteria was when measured against the rate of depleting the total hydrocarbon. Note that the bacteria names were kept secret due to confidentiality agreements with the suppliers, and as a result, this study referred to these microbes' strands as Bacteria Z. Bacteria Z was applied in powder form in small sachets each of which weighs 50 mg.

3.3.5 Experimental procedure adopted and setup

The contaminated hydrocarbon samples were composted in treatment pots, with some of these samples being inoculated with chicken manure. The chicken manure also acted as a bulking agent since it contained some chippings and feathers collected from the chicken fowl run. The samples of 4.150 g were quenched with one litre of water once a week to maintain good slurry mix (20% water mix).

The composted samples were also tilled once a week and samples were collected for laboratory analysis to determine the decomposition process' progress.

The literature study has proven that nitrogen helps boost the conditions that encourage the growth and effectiveness of the bacteria that feed on oil in the soil (Gogoi et al., 2003). Ammonium phosphate fertiliser was also added to the first six samples at varying quantities, as shown in Table 6 below. The quantities were varied to determine how best the rate of cleaning the hydrocarbon can be optimised, how sensitive the rate of reaction was going to look like. Superphosphate fertiliser manufactured in Botswana and Namibia was the selected fertiliser used as this type of fertiliser was said to enhance the soil's conditions and all living organisms.

The different experimental set-ups were done, as shown in the table below:

	Size (g)	Fertiliser (g)	Bacteria (g)	Chicken Manure (g)	Water (ml/Week)	Tilling / week
Method 1	4150	547,5	120	70	1500	Once
Method 2	4150	547,5	30	70	1500	Once
Method 3	4150	365	90	70	1500	Once
Method 4	4150	365	30	70	1500	Once
Method 5	4150	182,5	90	70	1500	Once
Method 6	4150	182,5	30	70	1500	Once
Method 7	4150	0	120	105	1500	Once
Method 8	4150	0	90	70	1500	Once
Control Sample	3000	0	0	0	1500	Once

Table 6: The differential experimental trials setup

- Each trial's cost sensitivity analysis was evaluated by comparing each test work results with varying quantities of reagents.
- The cost sensitivity analysis was conducted by comparing the secondary data experimental results to the test trials.
- Similar measurements in the secondary data case studies were compared with the similar outcomes from the experimental work results. The costs incurred for the case study and the primary data methods were also compared.

3.3.6 Data collection and data analysis

The data was found in the following sources:

- On the Internet, similar practices were scrutinised to benchmark and measure the extent to which other companies were contaminating the soil.
- The secondary data collection method using the DigitizeIt software: The secondary data from reports sometimes carries hidden graphs that presented challenges in accessing such information. Software such as DigitizeIt, metaDigitize and others helped solve this problem since they contain tools for extracting data points from a graph. In this study, the DigitizeIt software was used to extract values from the relevant graphs of interest in the secondary data reports including the case studies discussed earlier in the literature study (Price, Pick, Nakagawa, & Noble, 2019).

- Experimental tests were conducted and each step of the experiment recorded. The samples were sent out for analysis, and the results were used to evaluate if it was feasible to clean the contaminated soil at Site XY successfully.

3.3.7 Data analysis

The results were analysed using the following statistical tools that have been used in similar studies before:

3.3.7.1 Box plots

Box plots and whiskers were used to show the maximum and mean costs for each test trial conducted in the experiments (JC & Mbogu, 2013). The box plots also helped provide access to the individual data from the experimental studies and costs since it also depicted the following: the mean, lower and upper quartiles and the maximum and minimum for each of the trials in the project. In this way, the test works' multilevel structures were built-in, thereby creating fully informative graphs (Pallmann & Hothorn, 2016).

3.3.7.2 Kruskal-Wallis tests

The statistical significance of the results was verified using the Kruskal-Wallis tests. A probability value of less than 0.05 indicated statistical significance in the data. This work's results were not expected to follow a normal distribution, meaning that the Kruskal-Wallis test was a preferred method to the One Way Anova tests (McKight & Najab, 2010).

3.3.7.3 Parameters estimations

Different parameters in the test work were measured, and the following methods helped in reaching conclusive results:

- The estimating of parameters using regression was applied to the data set achieved from the trial results as this helped determine the response of individual variables in the treatment process from the given level of treatment.

- The response rate of particular parameters with increased or decreased treatment (Barker, Carter, & Sasser, 1985).

3.4 Assessing the quality and rigour of research design

The following techniques and calculations were used to assess the quality of the data:

3.4.1 X-bar and range charts

The X-bar and range charts were used to analyse from the samples collected on a weekly if the methods lowered the total hydrocarbon in the soil. Each method's results were divided into two group sets in the graphical plot using a statistical tool called sigma excel. The differences in the mean and variances of these groups were compared to evaluate if the process would operate optimally in different soil treatment stages at Site XY of Metal Companies once implemented (NCSS, 2020).

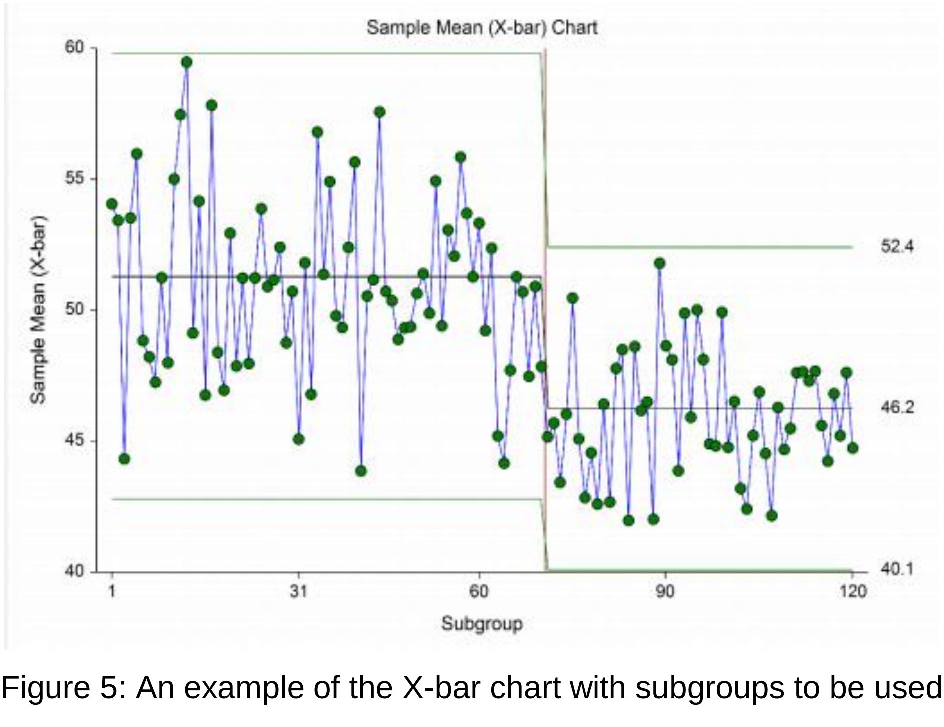

Figure 5: An example of the X-bar chart with subgroups to be used in the study

CHAPTER FOUR – RESULTS AND DISCUSSIONS

4.1 Introduction

This section of the Dissertation reports and discusses the method results from the experiments conducted at Site XY. Comparisons are made between these results and the secondary data results from other studies that closely resemble the approach done at Site XY. The different methods were compared using box plots to determine the approach that eliminated most of the oil by comparing the 25th and 75th quartiles. The most cost-effective method was also determined by looking into the rates of depletion of oil in different methods over time. Fixed and variable costs were used to estimate the method duration's impact on the technique's total cost.

4.1.1 Comparisons of TPH depletion in methods used

The table below shows the total materials added to each of the eight samples prepared from the 36 kg sample collected at Site XY. The cost of materials used during the experimental tests is also included in the table to evaluate the cost of using each of the eight methods over time. A control sample was left untreated to form a basis for measuring each method's total oil reduction over time.

	Site XY Sample (g)	Fertiliser (g)	Bacteria Powder (g)	Chicken Manure (g)	Water (ml)
Method 1	4150	547,5	120	70	1500
Method 2	4150	547,5	30	70	1500
Method 3	4150	365	90	70	1500
Method 4	4150	365	30	70	1500
Method 5	4150	182,5	90	70	1500
Method 6	4150	182,5	30	70	1500
Method 7	4150	0	120	105	1500
Method 8	4150	0	90	70	1500
Control Sample	3000	0	0	0	0
Material Prices	R 0,00	R20,7 /kg	R180 /kg	R 1 /kg	R 0,127 /ltr

Table 7: Materials used for the treatment of oil samples from Site XY

The results from the entire 11 weeks of the treatment period were reported for each method, as shown in the line graphs. The analysis of the lower chain hydrocarbons (C10-C14) was used to measure the success of the decontamination process for each method since the concentration of these hydrocarbon chains was above the limits of the environmental standards, i.e. 25,000 against 440 mg/kg as stipulated by the environmental regulations (Molelwa, 2013).

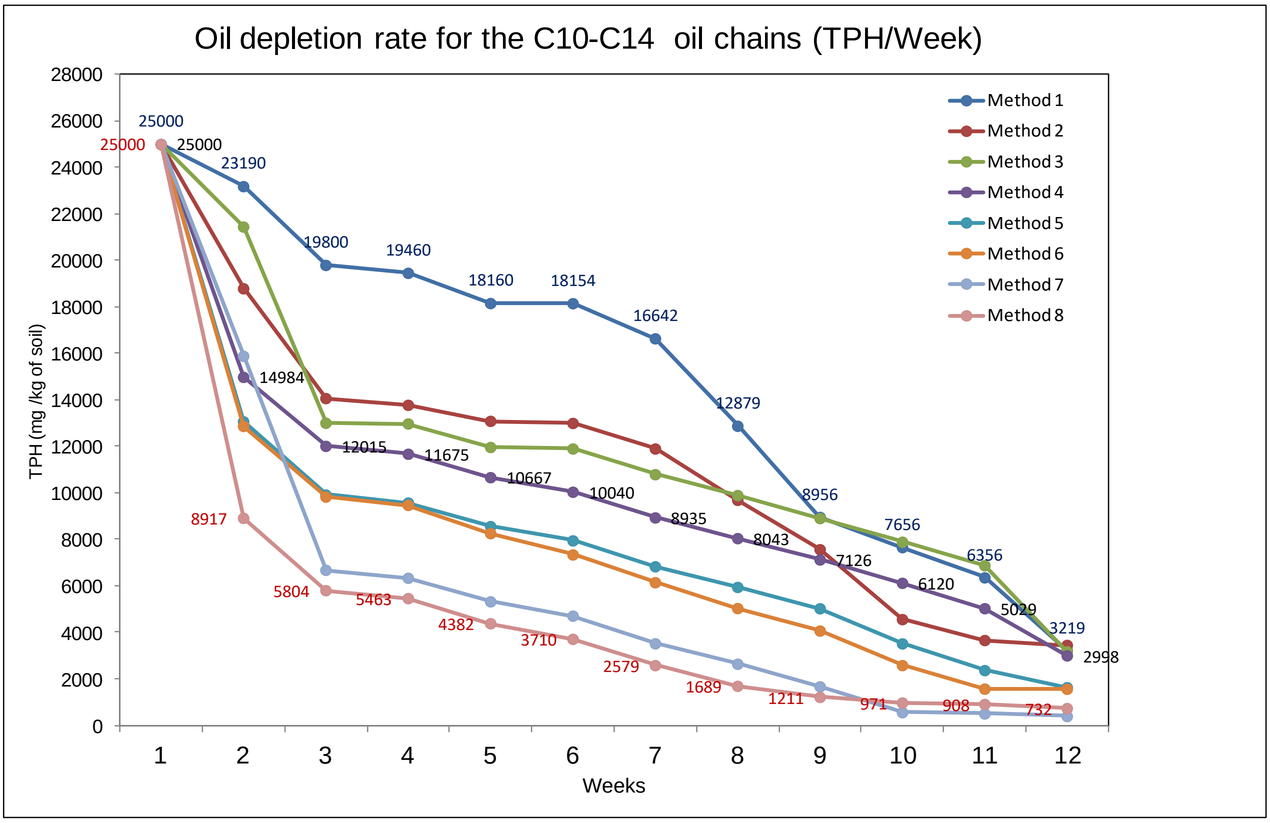

Figure 6: The weekly sample results for total petroleum hydrocarbons

The cost of treatment per week was calculated as a function of each method's total cost to reach the sample results measured in the 11th week. The oil depletion rate in the soil was also measured over this 11-week treatment period by calculating the total petroleum hydrocarbons (TPH) eliminated in the samples on a weekly sampling interval from the start of the treatment until the 11th week. Equation 6 below shows the method used to calculate the rate of the cost per week for each method.

$$Weekely\ Cost\ (R/ton) = \frac{((\text{Week(A)} - \text{Week(A + 1)})\text{mg/kg} * \text{Cost of Materials/ton}}{Control\ Sample\ Concentration\ \ (\frac{mg}{kg})}$$

Equation 6: The weekly treatment cost calculations for oil depletion

The cost breakdown for each method was determined by calculating the material costs for treating 4.150 g of each sample after which the costs were equated to the cost of material required to treat a ton of soil from Site XY. Table 8 below shows the costs incurred in applying each method to decontaminate the soil.

	Soil Sample (R/ton)	Fertiliser (R /ton of soil)	Bacteria (R/ton of soil)	Chicken Manure (R/ton of soil)	Water (R/ton of soil)	Total Cost (R/ton of soil treated)
Method 1	0	2730,9	5207,7	16,9	45,9	8001,4
Method 2	0	2730,9	1301,9	16,9	45,9	4095,6
Method 3	0	1820,6	3905,8	16,9	45,9	5789,2
Method 4	0	1820,6	1301,9	16,9	45,9	3185,3
Method 5	0	910,3	3905,8	16,9	45,9	4878,9
Method 6	0	910,3	1301,9	16,9	45,9	2275,0
Method 7	0	0,0	5207,7	25,3	45,9	5278,9
Method 8	0	0,0	3905,8	16,9	45,9	3968,6

Table 8: Costs of material required to treat one ton of contaminated soil from Site XY

The graph below represents the weekly costs for each method calculated using Equation 6 above. The graph shows that most of the methods were expensive in treating the contaminated soil at the start of the treatment process, and they became cost-effective in the third week. Methods 1 and 3 both showed a similar trend of costs per ton of treatment, these two methods were very cheap at the start of the treatment, and they got expensive on the final week of treatment. The cost of treatment per ton of material for these two methods at the start of the treatment was R982 /ton (Method 1) and R3,645 /ton (Method 3). The treatment cost for Method 1 increased to R1,344.24 /ton, whereas Method 3 treatment costs were at R1,204 /ton, respectively, at the end of the 11th week. These two methods had high bacteria, and ammonium phosphate fertiliser added. The tests were conducted during a cold winter season with temperatures averaging 20°C, which might explain the effects of low temperatures on the bacteria’s activity rates. A study done by Delille and his colleagues has shown that low temperatures have an adverse action on the bioremediation process and some researchers have even gone to the extent of covering the soil with plastics to preserve heat (Delille, Coulon, & Pelletier, 2004).

4.1.1.2 Methods 7 and 8 TPH depletion results

On the other hand, similar trends occurred between Methods 7 and 8. Method 8 was the most economical and cheaper method per ton of material treated. In the first three weeks, i.e. each of these methods had an initial cost of R3,645.30 /ton and R2,584.60 /ton respectively and they both reduced to a treatment cost of less than R40 /ton in the third week. Ammonium phosphate was excluded in both of these methods, and the treatment was purely organic since only chicken manure and bacteria were added to the contaminated soil. Method 7 managed to reduce the soil’s oil concentration to 387 mg/kg (TPH), below the targeted concentration of 440 mg/kg (TPH) in soil.

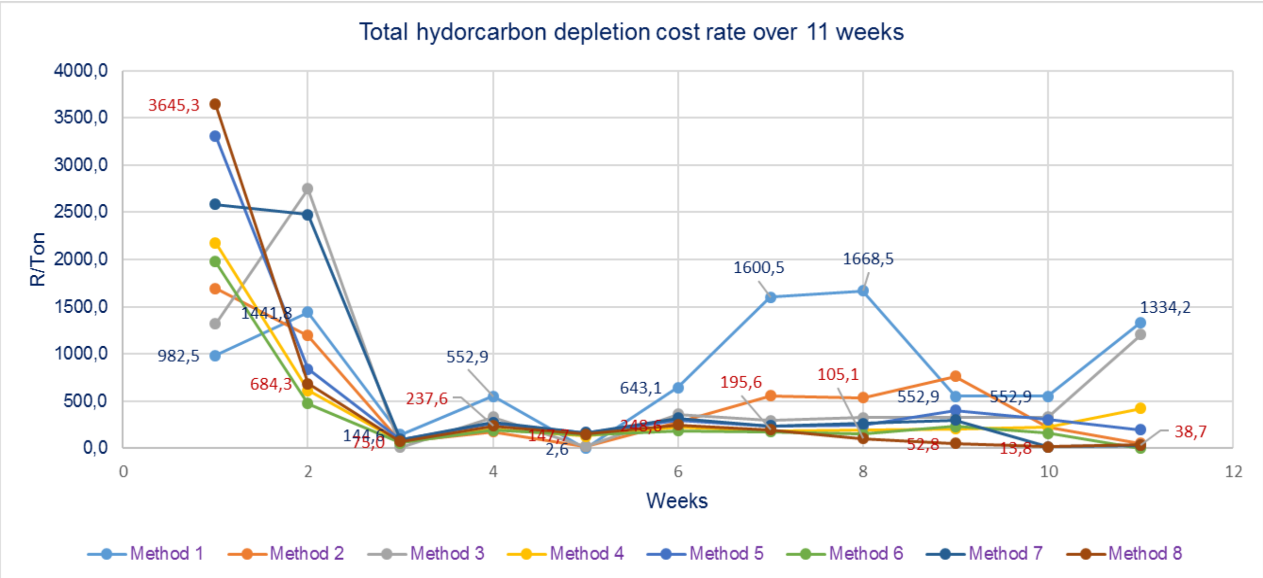

Figure 7: Weekly cost of depleting oil for the different methods

Fertiliser grains were observed to take longer to dissolve and hence the methods that had fertiliser added in the experimental mix were a bit expensive at the end, except for Method 5 that had relatively lower amounts of ammonium phosphate, i.e. 182 g compared to

Methods 1 and 2 that had each 547.5 g of fertiliser. The treatment cost for Method 5 was R195.20 /ton on the final week of treatment.

Below are some of the containers that were used for the treatment processes:

Figure 8: Picture showing the fertiliser grains used in some of the methods

4.1.1.3 Kruskal-Wallis tests

The one-way ANOVA on ranks (Kruskal-Wallis tests) results for the different methods show the probability value (p-value) measured is 0.0005, which is below 0.05, which indicates the statistical significance of the results from this study. Figure 9 below shows a report of the Kruskal-Wallis tests.

Kruskal-Wallis equality-of-populations rank test

Method	Obs	Rank Sum
1	12	827.50
2	12	720.00
3	12	743.00
4	12	659.50
5	12	533.50
6	12	496.50
7	12	365.50
8	12	310.50

chi-squared = **25.933** with **7** d.f.
probability = **0.0005**

chi-squared with ties = **25.948** with **7** d.f.
probability = **0.0005**

Figure 9: Kruskal-Wallis test results

4.1.2 Box plots comparisons for the period of three weeks

4.1.2.1 Three weeks treatment

The box plot below shows that the difference between the 75th and the 25th quartile for Method 8 was higher than all the other methods for reducing the reduction rates in three weeks. On the other hand, Method 1 had the lowest difference, which shows that the total petroleum hydrocarbon concentrations did not change much. Method 1 had the highest amount of ammonium phosphate fertiliser as seen from the picture in Figure 9 above. The fertiliser pellets took more than three weeks to dissolve in the soil mixture with some methods showing the un-reacted fertiliser grains at the end of the experimental trials.

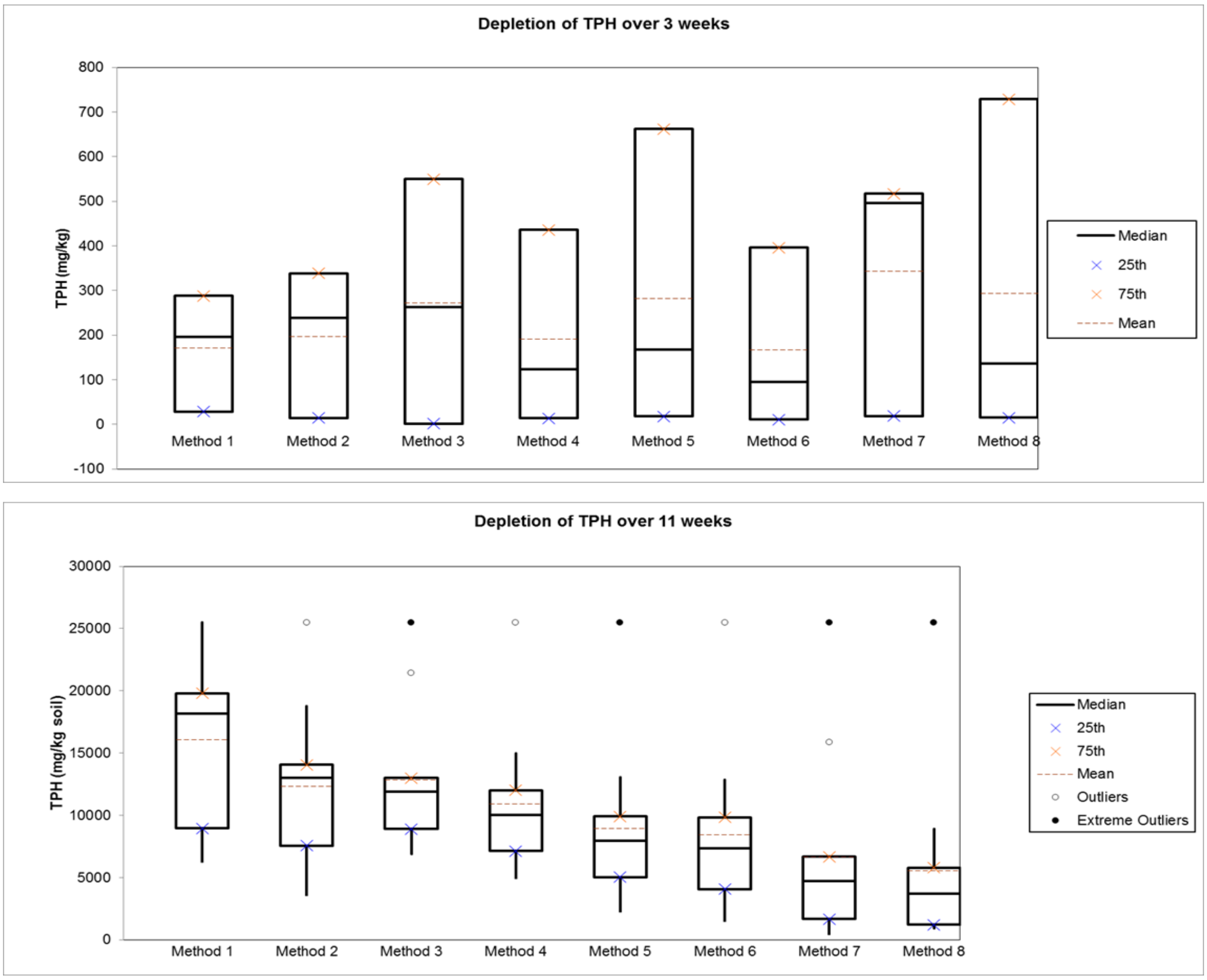

Figure 10: Box plots comparing oil depletion rates over three and 11 weeks

4.1.2.2 11-week treatment

The 11-week box plot analysis shows that Method 1 had the most considerable difference between the 75th and the 25th quartiles. On the other hand, Methods 8 and 7 had lower differences with extreme outliers. The extreme outliers in Methods 8 and 7 indicate a very high rate of oil reduction at the start of the experimental trials that we have already witnessed in the first three weeks. The median of Method 8 is also lower than all the other medians for the 11-week treatment period followed by Method 7's median.

4.1.3 Mean X-bar treatment comparisons

Mean bar charts were constructed to check the percentage fractions of the oil depleted on a weekly basis for some of the sample method results from the experimental trials. The points that fell above and within these control parameters were compared, with the control limit of 75% chosen and an upper control limit of 100% and the lower control limit of 50%. Method 1 operated for seven weeks below the 50% treatment success mark, whereas Method 8 managed to achieve its entire treatment period above the 50% mark. Method 1 also eliminated only 87.4% of the C14-C24 hydrocarbon chains in the sample treated, whereas Method 8 eliminated 97.1% of the hydrocarbons.

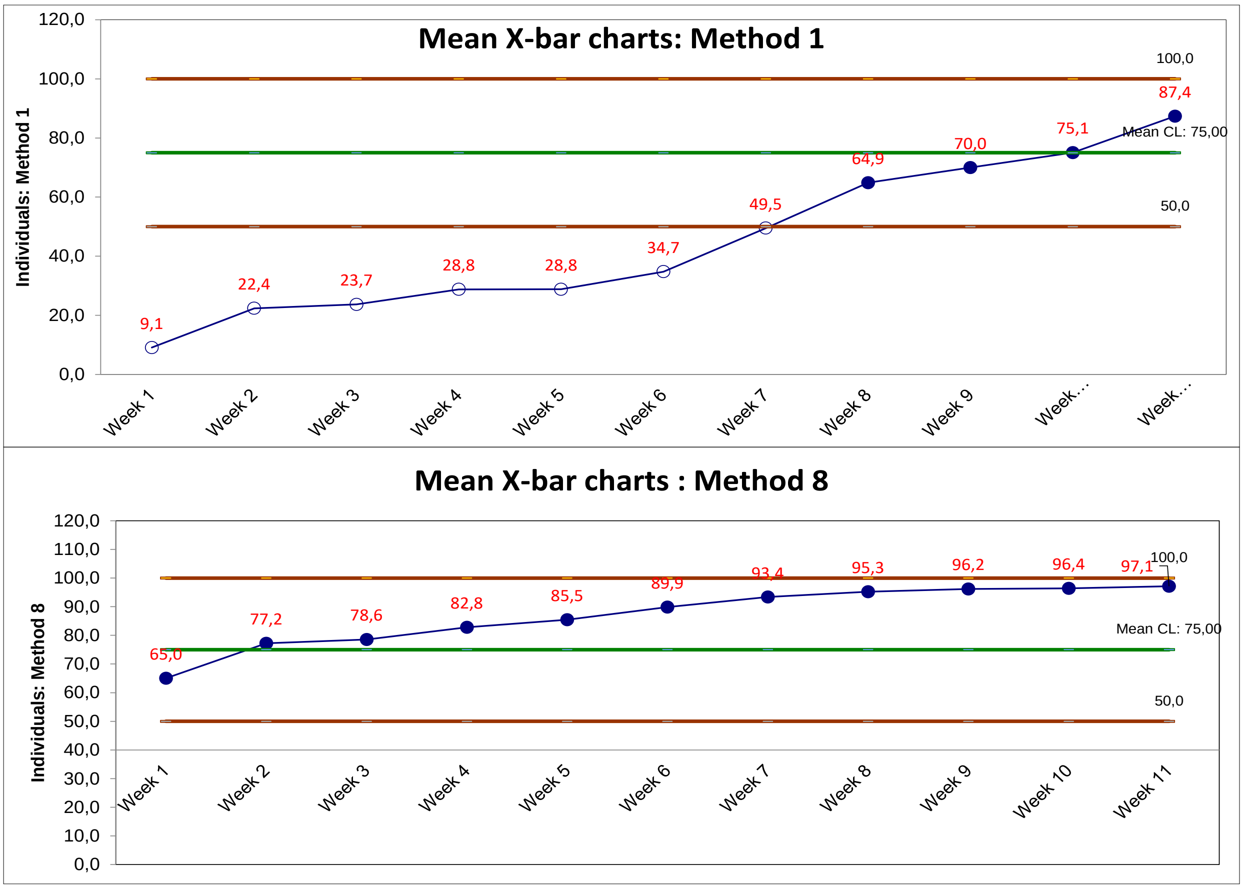

Figure 11: Mean X-bar charts for Methods 1 and 8

Method 7 had only one point that fell out of the control window, and it managed to eliminate 98.5% of the hydrocarbon. On the other hand, Method 5 also had one point out of the limits control, and it gave the best results for the methods that had fertiliser added to the reaction mix. Method 5 managed to eliminate 93.5% of the soil's low chain hydrocarbons.

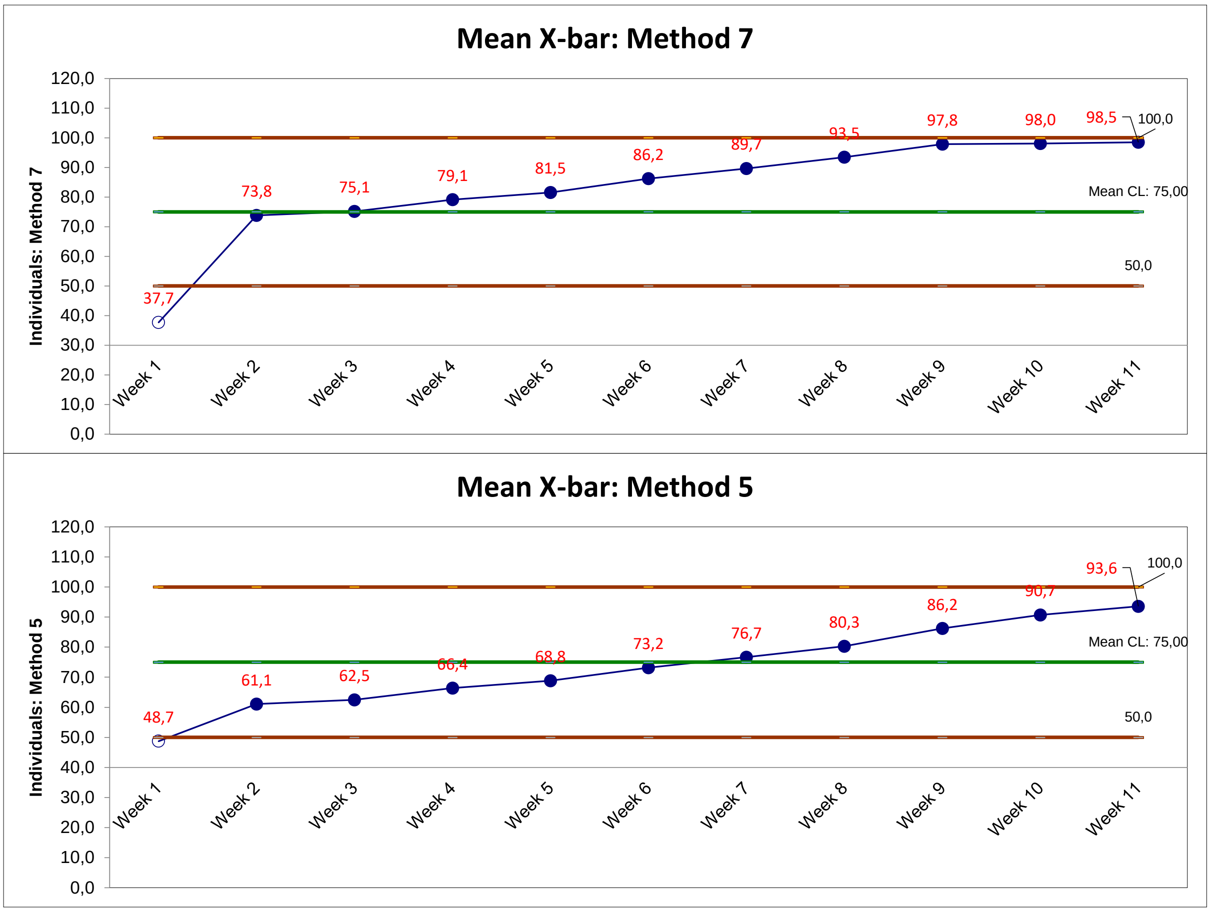

Figure 12: Mean X-bar charts for Methods 1 and 8

4.1.4 Comparison of the results with bioremediation tests by Oellermann

Oellermann and Garber did some bioremediation work reported in 1995 using the same techniques applied in this research. This study by Oellermann has been chosen for making comparisons in this research due to several similarities in the results and methods. Monthly sample results were considered for Site XY for the first three months since the monthly sampling intervals were used in work done by Oellermann.

Two gridlines that had contamination levels in the same range as Site XY samples were selected for comparisons, i.e. Gridline C and F. It is observed in the table below that the three months' results from Site XY show a total reduction of petroleum hydrocarbons that were greater than 85%. In contrast, the gridline results from Oellermann's reported a reduction that was less than 80% for both gridlines. The average degradation rates were also better for Site XY methods' results. The reason behind this is the weather conditions at the time when the bioremediation of the gridlines was done in Oellermann's study. The report also stated that the weather conditions were unfavourable when the gridlines were treated during the dry season. The samples from Site XY were treated under experimental conditions, and we would expect better results than from work done on the field (Pearce, Snyman, Heerden, Greben & Oellermann, 1995). The implementation of this work needs to consider that the province where Site XY is located is very hot, and such factors need to be considered during the treatment process.

	Start Sample	Month 1	Month 2	Month 3	Total oil depleted(%)	Average degradation
Method 1	25500	19460	12879	3219	87,4	7427,0
Method 2	25500	13781	9692	3450	86,5	7350,0
Method 3	25500	12978	9898	3176	87,5	7441,3
Method 4	25500	11675	8043	2998	88,2	7500,7
Method 5	25500	9575	5944	1631	93,6	7956,3
Method 6	25500	9474	5034	1562	93,9	7979,3
Method 7	25500	6338	2639	387	98,5	8371,0
Method 8	25500	5463	1689	732	97,1	8256,0
Gridline C	20720	19575	18460	5250	74,7	5156,7
Gridline F	22990	21350	20215	4915	78,6	6025,0

Table 9: Comparison between the results of Site XY treatment methods and Oellermann's work

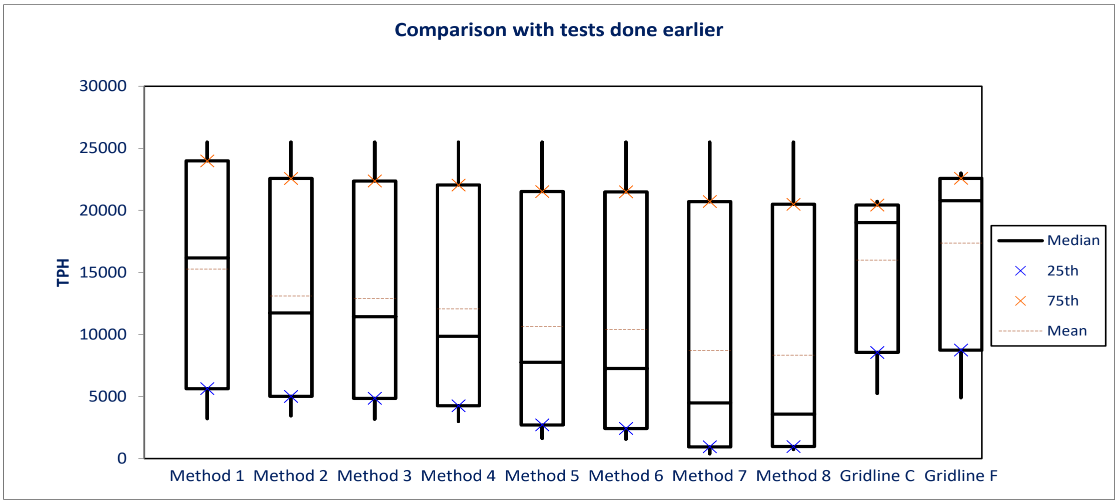

Figure 13: Box plots comparisons of Site XY methods and the gridline results

4.1.5 Cost forecasting for Site XY

Method 8 was the most economical method for the first three weeks of the bioremediation treatment. During the implementation of this method, the fixed costs such as the materials added to the soil and variable costs such as labour need to be considered. Water must be excluded from the fixed cost since water is dosed progressively to compensate for evaporation during the treatment period, unlike the other materials added at the start of the process. The forecasting approach must be used to check the impact of reducing the treatment duration on the total costs when treating different soil quantities, i.e. treating the soil in three weeks instead of 11 weeks.

Two operators paid at R22,000 per month each will be required for the operations. The table below shows the respective costs for each month after factoring water out of the fixed costs:

		Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7	Week 8	Week 9	Week 10	Week 11
Fixed costs	Materials	7725	7725	7725	7725	7725	7725	7725	7725	7725	7725	7725
Var Costs	Water (R/week)	4,2	4,2	4,2	4,2	4,2	4,2	4,2	4,2	4,2	4,2	4,2
	Labour (R/week)	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000
Total Costs (R/week)		9730	2004	2004	2004	2004	2004	2004	2004	2004	2004	2004
Cumulative Costs (R/week)		9730	11734	13738	15742	17746	19751	21755	23759	25763	27767	29772

Table 10: The fixed and variable costs for Method 8 treatment technique per ton of soil

The fixed cost of treatment starts to increase from week four due to the depletion rate's flattening, as seen in Table 10 above. In week 11, the total cost of treatment almost doubles the three-week treatment costs.

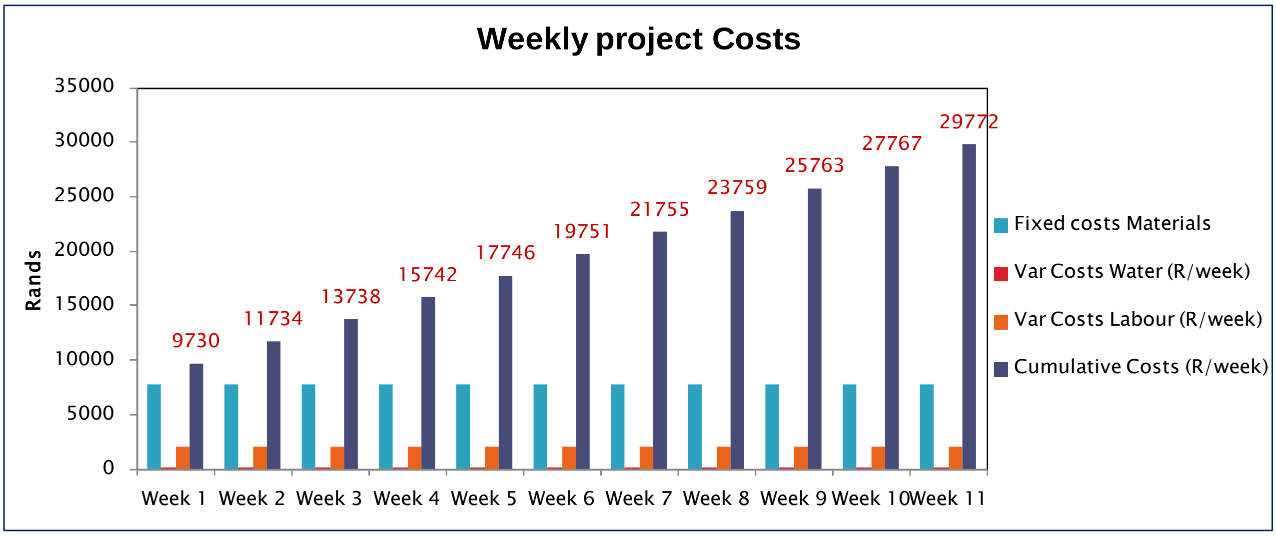

Figure 14: Total treatment costs on a weekly basis

4.2 Sensitivity costs analysis

4.2.1 Chicken manure versus ammonium phosphate fertiliser

The methods that excluded ammonia phosphate and only used chicken manure were more effective at decomposing oil in the soil. On the other hand, fertiliser took long to dissolve and hence the oil depletion rate was slow in the first three weeks. Table 10 below compares and contrasts Method 1 to Methods 7 and 8. It is observed that the oil depletion rate in the samples is higher for Method 8 and 7, which made use of organic material:

	Fertiliser (g)	Manure (g)	Bacteria (g)	Oil after 3 weeks(TPH) mg/kg
Method 1	547	70	120	19800
Method 7	0	105	120	6681
Method 8	0	70	90	5804

Table 11: Three-week treatment cost comparisons for Methods 1, 7 and 8

4.2.2 Multiple regression model

The multiple regression expression results show that Bacteria Z is sensitive to the amount of fertiliser and chicken manure additions. The expression and the table below were determined by analysing the results in a statistical software called Six Sigma excel. The ammonia phosphate dropped these bacteria's effectiveness, as seen in the three-week reaction results. The measure of the impact of the different inputs on the total cost of bioremediation was done using the multiple regression models below:

$$Total\ cost\ per\ kg\ of\ soil\ treated = 1{,}524 + (4.988) * Mass\ of\ fertiliser\ (kg) + (0.241) * (Mass\ of\ chicken\ manure)(kg) + (43.373 * Mass\ of\ bacteria\ (kg)$$

Equation 7: The multiple regression expression for the components used

Parameter Estimates:						
Predictor Term	**Coefficient**	**SE Coefficient**	**T**	**P**	**VIF**	**Tolerance**
Constant	1524,0	1,84359E-10	8,266E+12	0,0000		
Chicken Manure (kg)	0,240964	2,37635E-12	1,014E+11	0,0000	1,589	0,629344
Bacteria (kg)	43,373	6,70892E-13	6,465E+13	0,0000	1,276	0,783654
Mass of Fertiliser (kg)	4,988	1,24246E-13	4,015E+13	0,0000	1,350	0,740909

Table 12: Coefficients of the experimental components

Bacteria is the critical component in the depletion process, as seen from the high coefficient of 0,0434. Small quantities of bacteria were added for each trial. According to the literature, this bacterium multiplies as it feeds on oil, making its contribution more felt than the other materials added to the tests.

It was recommended that Site XY use the organic processes to boost the treatment of the oil-contaminated soil since this will be cheaper as the organic conditions boosting the growth of bacteria. The approach will also support the local communities involved in poultry farming.

4.2.3 Temperature conditions

The tests were conducted during the cold months with maximum temperatures of 20°C, as shown in the graph. The secondary study referenced in the results section has proven that the season in which the soil is treated can significantly impact the bioremediation process's progress.

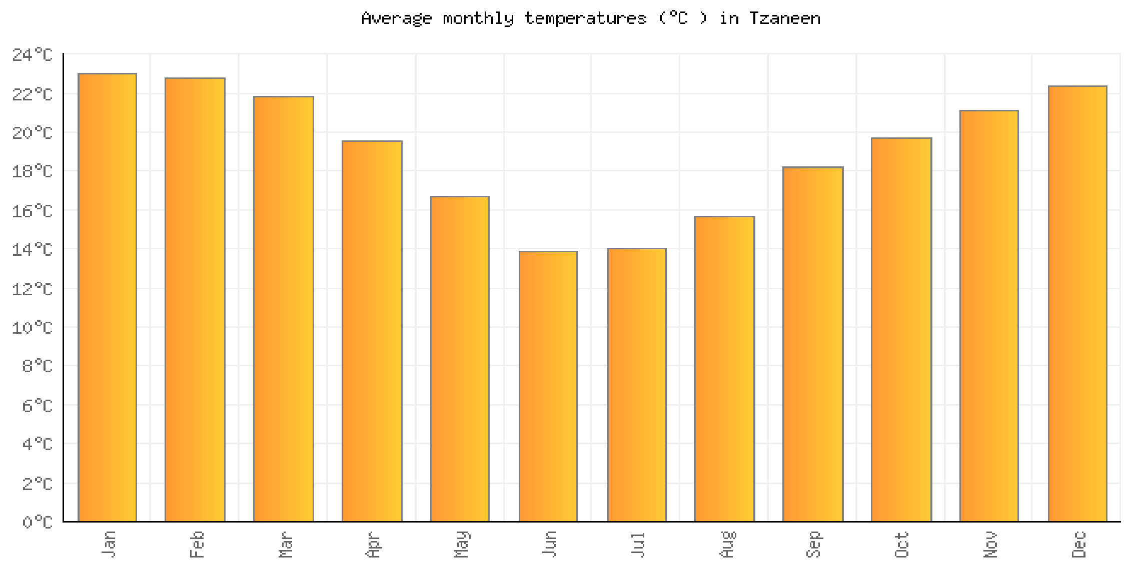

Figure 15: The temperature conditions during the trial period

Research done has shown that the depletion of oil is higher under warm temperature conditions, as shown in the graphs below from research by Delille conducted over two years ago. It will be recommended that the treatment process must be conducted during the summer period when temperatures are above 30°C. The material can be collected during wintertime and stored in the containment area for treatment during summer (Delille et al., 2004).

Jose A Marín reported that oxygen is very important for the aerobiosis process during composting. The samples were agitated once a week; together with the low temperatures, this might have led to slow progress in the treatment process. Bulking agents such as grass or wood shavings need to be added to create oxygen movement during Site XY's treatment process (Marín et al., 2006).

Since several trials have been done on-site without any success, Site XY needs to evaluate each material's added impact on future project trials. The cost of treatment will determine the impact of each material on the soil's cost of treatment, as calculated in the results chapter.

4.2.4 Labour requirements

If the trials are to be conducted on-site, the variable costs need to be well managed by shortening the project duration to use fewer labour hours for the process. As seen above, if the process can be done in three to four weeks, this translates to R14,030 savings. The environmental department team in charge of the rehabilitation process does not have a dedicated team of operators to treat the soil. Since the ideal treatment season is during summer, the project team needs to be assembled and trained whilst there is enough time to understand the task. Contingent workers need to be brought on board since these individuals are highly skilled, and they are available only when required (Pahlanie, Ghazali, & Daryanto)

The table below shows that a minimum of R3,828 will be saved by applying Method 8 to treat the contaminated soil at Site XY. If the depletion rate can be speeded up by operating at higher temperatures and boosting the soil's nitrogen conditions to improve the bacteria's population growth rate, then the savings from treating the soil in four weeks will be R17,858 per ton of soil treated.

	Current Practice	**Method 8 (11 weeks)**	**Method 8 (4 weeks)**
Cost rate	R 2000/ drum	R 29772/ ton	R 15742/ ton
Handling Costs	R 32000/ ton	R 0/ ton	R 0/ ton
Cost rate (R/ ton)	R 33 600	R 29 772	R 15 742
Duration	4-6 months	3 months	1 month
Cost Savings (R/ ton)	R 0	R 3 828	R 17 858

Table 13: Cost comparisons with the current treatment practice at Site XY

4.2.5 Conclusion

In conclusion, Method 7 managed to reduce the contamination to below the targeted contamination levels, making it the best method for decontaminating the oil-contaminated soil at Site XY of Metal Companies. When considering the quickest treatment from the day of implementation of the project, it is observed that Method 8 managed to reduce the total hydrocarbon by more than 50% in the first three weeks of treatment. The company needs to support poultry farming activities in the surrounding communities by buying chicken manure, making it part of its social responsibility program. The depletion rate was observed to be fastest in the first three weeks of the experimental trials of which the same trends were observed with the treatment costs. Variable costs such as labour hours and water costs played a considerable role in the total costs as time progressed, making it critical for the company to optimise conditions such as temperatures and mixing rates in the treatment process during the first three weeks.

CHAPTER FIVE – CONCLUSIONS AND RECOMMENDATIONS

5.1 Introduction

This chapter presents the conclusions of this study's findings and their relationship with regards to the cost implications incurred at Site XY if the best approach is to be adopted. Correlation coefficients for the different components are determined, and this information is used to predict the impact of each of these materials on the rate effectiveness and cost of treatment of the oil-contaminated soil. Recommendations on the optimal conditions under which the treatment process must be done will also be discussed.

5.2 Conclusions

5.2.1 Primary research objective outcomes

Primary research objectives	Comments and observations
The project's primary objective is to develop a treatment method for rehabilitating oil-contaminated soil at Site XY of Metal Companies.	A bioremediation technique that used chicken manure and Bacteria Z to boost the soil conditions was used to reduce the soil's bacteria to 387 mg/kg. The method can easily be implemented at Site XY since it is also cheaper by R3,828 for every ton of soil treated.

Table 14: Primary research objectives

5.2.2 Secondary research objectives outcomes

Secondary research question	Comments and observations
The second objective is to apply cost forecasting techniques to reduce the expenses incurred in the rehabilitation of oil-contaminated soil at Site XY.	A forecasting method was achieved by calculating the costs of the materials used for the best treatment method that was tested. The cost of treating a ton of material was then calculated with the labour requirements throughout the entire treatment process. The cost sensitivity of the treatment was found to affect the project costs. In conclusion, the forecasting revealed that the treatment process is susceptible to treatment duration, using organic materials instead of manufactured chemical fertilisers, and the weather conditions.
The study's final objective is to reduce the C10-C14 hydrocarbon from 25,000 mg/kg to less than 440 mg/kg.	Reduction of total hydrocarbon was observed in all eight research methods. Method 8 was the only method that reduced the total hydrocarbon content in the soil to below 440 mg/kg. In conclusion, bioremediation can decontaminate the soil samples from Site XY.

Table 15: Secondary research objectives

5.3 Implementation of the rehabilitation work at Site XY

The steps in the Gantt chart below will be used to implement the rehabilitation project at Site XY of Metal Companies.

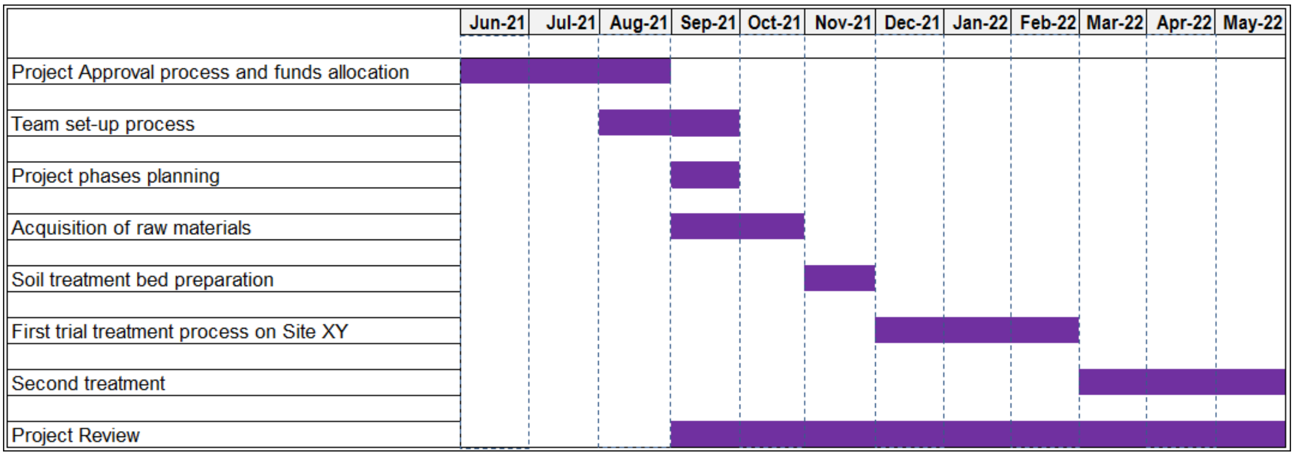

Table 16: Gantt chart for the implementation of the remediation at Site XY

The steps below will be followed during the implementation stage as indicated in the Gantt chart above:

- In June 2021, the proposal will be presented to the Leadership of Metal Companies who is in charge of rehabilitation and environmental compliance at Metal Companies.

- A project team will be formed from the environmental department's personnel to get early buy-in from all the essential stakeholders.

- A project plan will then be formulated in September 2021 to focus on allocating the resources and identifying cost-saving approaches that will help improve some of the methods outlined in this dissertation.

- The site will be prepared in November 2021, the second month of the summer season, to optimise the treatment process as already supported by this study's results.

- The first trial will commence in December 2021 for three months. Project reviews will be conducted throughout all the project phases, which will allow the team to be proactive for any cost-sensitive events that may arise throughout the project.

5.4 List of recommendations

- Every rehabilitation project at Site XY needs to commence by testing all the applicable methods at an experimental scale, like what has been done in this research. The projected costs will then need to be calculated for treating a ton of soil with the same contamination levels. The methods must be tested under different conditions such as the types of reagents and quantities used and different physical conditions under which the experimental tests are conducted, such as temperatures. The extent at which the soil is decontaminated can then be used to measure the cost sensitivity of the method approach to the different variable inputs of the project.
- Site XY of Metal Companies needs to continuously adopt this rehabilitation plan in order for it to comply with the environmental regulations throughout the mine's entire life.
- Poultry farmers need to be integrated into the rehabilitation plans since buying raw materials such as chicken manure and pig manure from the community will inject capital into their businesses. Thus, the company will support local communities as part of their social responsibility plan.
- Bacteria Z are produced in a controlled environment in laboratories from where Metal Companies buys them. Metal Companies needs to invest in research by sponsoring projects in local universities which will also broaden their social responsibility scope. Metal Companies forms part of the Top Employees Institutes, which ranks the companies at the end of each year. Anglo-American is an example of companies that claimed the top companies' awards for 2020 and some of the positive points highlighted about Anglo-American is that they look after their people and the environment (Mogaki, 2015).
- To improve the most viable method from this research, the bioremediation trial conditions at Site XY need to be closely monitored and controlled. The chicken manure created a compost mix just like the wood chippings from the earlier studies.

It will be recommended that organic materials such as leaves and grass be added together with the manure to help loosen the material for the movement of water and nutrients through the bed of soil. The amount of moisture needs to be closely regulated as done in this study, and adequate mixing must help speed up the process. The decomposition process generates a lot of odour, requiring the treatment to be done in an area farther away from populated sites.

5.4.1 Study limitations

This study was limited by the following list of factors:

1. The limited time under which the MBA dissertation was completed made it impossible to explore other techniques for treating the polluted soil at Metal Companies. The treatment time was also reduced to twelve weeks.
2. A limited budget made it impossible to submit more samples to the laboratory for analysis.

5.4.2 Future areas of Research

1. There is a need to investigate the feasibility of replanting trees after cleaning up the soil in mining sites.
2. The perception of the employees and the communities living in the vicinity of the mining sites towards the rehabilitation practices needs to be investigated.

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ADDENDUMS

Addendum A: Ethical clearance certificate

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Economic and Management Sciences Research
Ethics Committee (EMS-REC)

19 June 2020

Dr Johannes Jordaan
Per e-mail
Dear Dr Jordaan,

EMS-REC FEEDBACK: 19062020
Student: Ncube, M (33454892)(NWU-00749-20-A4)
Applicant: Dr J Jordaan - MBA

Your ethics application on, *Developing a costing model for decontamination of mining sites,* which served on the EMS-REC meeting of 19 June 2020, refers.

Outcome:

Approved as a minimal risk study. A number NWU-00749-20-A4 is given for one year of ethics clearance.

Due to the Covid-19 lock down ethics clearance for applications that involve data collection or any form of contact with participants are subject to the restrictions imposed by the South African government.

Kind regards,

Mark
Rathbon
e

Prof Mark Rathbone
Chairperson: Economic and Management Sciences Research Ethics Committee (EMS-REC)

Addendum B: Certificate of language editing

Doretha Rost

LANGUAGE PRACTITIONER

8 December 2020

To whom it may concern:

Dear Mr / Ms

Re: Language editing of dissertation: Developing a treatment method for oil-contaminated mining sites.

I hereby declare that I language edited the above-mentioned dissertation by Mr MB Ncube (student number: 33454892).

Please feel free to contact me should you have any enquiries.

Kind regards,
Doretha Rost

Doretha Rost

Language editing and translation
Cell: 082 875 8295 / Email: doretha.rost@gmail.com