DECEMBER 2019 Ph.D. in Civil Engineering FERZAND KAMAL AHMED MEDHAT


**HASAN KALYONCU UNIVERSITY**

**GRADUATE SCHOOL OF**

**NATURAL & APPLIED SCIENCES**


# GEOTECHNICAL AND ENVIRONMENTAL EFFECTS OF OILY WASTEWATER ON ERBIL SOILS

**Ph.D. THESIS**

**IN**

**CIVIL ENGINEERING**


**BY**

**FERZAND KAMAL AHMED MEDHAT**


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# Geotechnical and Environmental Effects of Oily Wastewater on Erbil Soils

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**IN**

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**FERZAND KAMAL AHMED MEDHAT**

## ABSTRACT

### GEOTECHNICAL AND ENVIRONMENTAL EFFECT OF OILY WASTEWATER ON ERBIL SOILS

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This study investigates the effect of the excess of oily wastewater generated from the outlet of the refineries before remediating by the wastewater treatment plant on its impact on the environment and geotechnical properties of contaminated soils. The study area was the Kawergosek refinery (southwest of Erbil city).

Environmental investigations have been included in this study. The results of the questionnaire showed that the majority of the citizens lived near oil fields and refineries should care about the air and soil pollution problems Figure (5-5), the air was also polluted by harmful gases such as Co and $H_2S$, the surrounding agricultural lands were also polluted and caused a bad effect on the life of the citizens. The environmental pollution map of the southwest of Erbil city has also been designed where most of the oil fields and refineries exist, Figure (5-4). It has been shown that the emission rate of $H_2S$ in oil fields is much higher than those of refineries, Figure (5-2).

Laboratory investigations have been carried out on soil samples with various percentages of contamination with oily wastewater. The results showed a considerable effect on the chemical soil characteristics, also on the physical and mechanical properties of Kawergosek refinery plant soils.

Field investigations have also been conducted through examining the contaminated soil with oily wastewater in the model pit site in Cihan university/college of engineering, and in the Kawergosek refinery, lagoon site. The results showed that the examined soil was highly affected by the effect of oily wastewater on its chemical and engineering properties for both sites. Further study conducted regarding the effect of heads of spilled oily wastewater on the diffusion rates inside the three pits model, it has been shown a positive influence on the rate of diffusion, Figure (5-22) and a small effect on C and Φ values of Direct shear tests, Table(5-30).


**Keywords:** Oil Fields, Refineries, Oily wastewater, Geotechnical properties, Environment.

# ÖZET

## PETROL İÇEREN ATIKSULARIN ERBIL TOPRAKLARI ÜZERİNE JEOTEKNIK VE ÇEVRESEL ETKILERI

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Bu çalışma, rafinerilerin çıkışından kaynaklanan ve arıtma işlemi uygulanmaksızın deşarj edilen petrol içeren atıksu tarafından kirlenmiş toprakların çevre ve jeoteknik özelliklerini araştırmaktadır. Çalışma alanı ise Erbil şehrinin güneydoğusunda yer alan Kawergosek rafinerisidir.

Çevresel araştırmalar da bu çalışmaya dahil edilmiş olup, anket sonuçları petrol sahalarının ve rafinerilerin yakınında yaşayan vatandaşların çoğunun hava ve toprak kirliliği sorunlarını önemsemesi gerektiğini göstermiştir (Şekil 5.5). Aynı zamanda şehir havası da CO ve $H_2S$ gibi zararlı gazlar tarafından kirlenmiş olup, çevredeki tarım arazileri de kirlenmiş ve vatandaşların hayatı üzerinde kötü bir etkiye neden olmaktadır. Erbil şehrinin güneybatısındaki çevre kirliliği haritası, petrol sahalarının ve rafinerilerin çoğunun bulunduğu yerleri de kapsayacak şekilde bu çalışmada tasarlanmıştır (Şekil 5.4). Yapılan çalışma, petrol sahalarındaki $H_2S$ emisyon oranının rafinerilerden çok daha yüksek olduğunu göstermiştir (Şekil 5.2).

Aynı zamanda çalışmada, petrol içeren atık su ile çeşitli kirlenme yüzdelerine sahip toprak numuneleri üzerinde laboratuvar araştırmaları yapılmıştır. Sonuçlar, petrol içeren atıksuyun, toprağın kimyasal özellikleri üzerinde ve ayrıca Kawergosek rafineri tesisinin toprağının fiziksel ve kimyasal özellikleri üzerinde önemli bir etkiye sahip olduğunu göstermiştir.

Bununla birlikte, çalışmada petrol içeren atıksu ile kirlenmiş zemin için model çukur oluşturularak saha incelemeleri de yapılmıştır. Yapılan saha incelemeleri Cihan üniversitesi/Mühendislik Fakültesi arazisinde ve Kawergosek rafineri sahası içerisinde bulunan lagün kenarında yapılmıştır. Elde edilen sonuçlar incelenen toprağın kimyasal ve mühendislik özelliklerinin petrol içeren atıksu ile kirlenmesi neticesinde oldukça etkilendiğini göstermiştir. Bir diğer çalışmada ise, petrol içeren atıksuyun toprak içerisindeki yayılımı üzerine yükseklik farkının etkisi incelenmiştir. Bu amaçla farklı yüksekliklerde üç adet model çukur oluşturulmuş olup, yükseklik arttıkça difüzyon hızının da arttığı ve direk kesme testleri ile C ve Φ üzerinde küçük bir etksinin olduğu tespit edilmiştir.

**Anahtar Kelimeler:** Petrol alanları, Rafineriler, petrol içeren atıksu, Geoteknik özellikler, Çevre

*To Soul of my parents*

*My Wife and All my Children*

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## LIST OF SYMBOLS/ABBREVIATIONS

| | |
|---|---|
| Gs | Specific Gravity |
| γs | Dry Unit Weight |
| L.L | Liquid Limit |
| P.L | Plastic Limit |
| P.I | Plasticity Index |
| σ | Stress |
| Є | Strain |
| W | Moisture Content |
| Cv | Coeffecient of Consolidation |
| Cc | Compression Index |
| Cr | Swelling Index |
| K | Coeffecient in Permeability |
| C | Cohesion |
| Ø | Friction Angle |
| P | Applied Load |
| E | Void Ration |
| EPA | Environmental Protection Agency |
| O.W.W | Oily wastewater |
| MBP | Mass balance principle |

# CHAPTER 1

# INTRODUCTION

## 1.1 General overview

Environment science is the branch of science concerned with the physical, chemical and biological conditions in the environment. Recent years have witnessed significant development in the field of environmental sciences and the influencing factors; this is due to polluted impact by humans, intentionally or unintentionally, for their short-term benefits. Therefore, it is necessary to study and investigate more and more in order to obtain a clean and hazardless atmosphere for the human being. The experienced experts will develop the right scope to investigate the existing environment (Ruth 2003).

## 1.2 Environmental pollution

Pollution refers to the very bad condition of the environment quantitively and qualititively; there are many types of pollution such as:

1- Air pollution
2- Water pollution
3- Noise pollution
4- Land pollution
5- Radioactive pollution

Because of the rapid development of industrialization and urbanization generally in Iraq and the city of Erbil in particular, the effects of the pollution mentioned above started at a definite stage and caused a reduction in the level of the ideal environment.

The major sources of pollution in Erbil city are emissions of oil production industries, automobiles, domestic fuels which they affect human health, animal and plants. These wastes are not polluted the air or water only also the soil is being polluted.

The sources of contaminants are the oil fields, refineries, and thermal power plants. The contaminants have resulted accidentally from the spill of oil during the transportation as leakage from the pipelines and storage tanks or during oil drilling processes, and in the refineries, which results in a large quantity of oily wastewater.

The oil refineries are industrial process plants where crude oil is processed and refined into many products. Large volumes of water are employed in refining processes, especially for cooling systems, distillation, hydro-treating, and desalting. Tank drains, equipment flushing, surface water runoff (Abdulkarim and Embaby 2006). This process makes refineries to generate a significant amount of oily wastewater that has been in contact with hydrocarbons. Oily wastewater can also include water rejected from boiler feed water pretreatment processes (or generated during regenerations). Oily wastewater can also refer to cooling tower blow downstream or even once-through cooling water that leaves the refinery.

The treatment of the oily wastewater is a complex manner and sometimes maybe cost. In exceptional circumstances, such as the need for a large amount of oil products, the refiners may accumulate its oily wastewater at specified lagoons as shown in Figure 1.1. Then recycled again in the refinery or treated by wastewater treatment plant so that would have less effect on the environment.

Another pollution source of refineries is air pollution. Figure 1.2 shows views of Erbil city (southwest) in which the air pollution in the atmosphere is seen, especially near oilfields and refineries.

**Figure 1.1** Lagoon for the wastewater near the refinery.

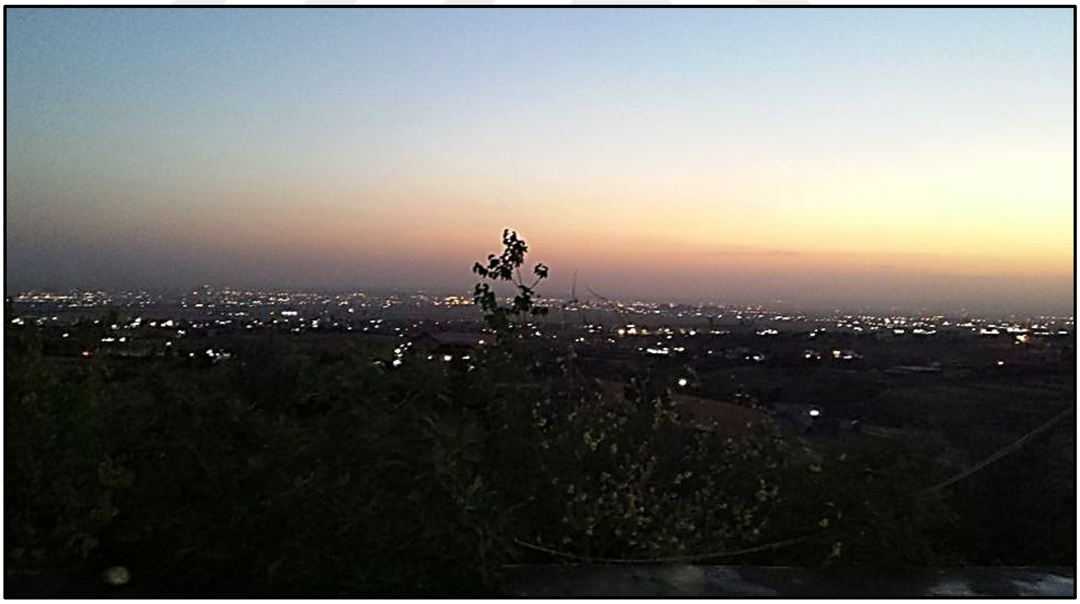


**Figure 1.2** View of the southwest-polluted area in Erbil .

The source of refineries oily wastewater (contains small quantities of hydrocarbon) are water rejected from boiler feed water treatment processes from cooling water below downstream (IPIECA). The reduction and prevention of pollution in refineries are implemented in three ways;

1- Reducing waste generation

2- Recycling waste from other purposes

3- Using the wastewater treatment plant

Figure 1.3 shows a typical refinery of wastewater treatment plant. (IPIECA).

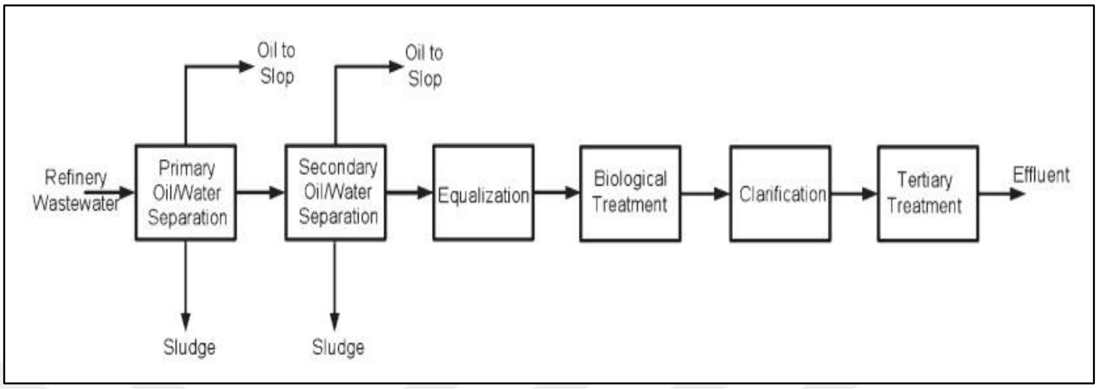



**Figure 1.3** Typical refinery wastewater treatment.

In general, oily water and solid wastes emanating from refineries have a damaging effect on public health and the environment when pollution parameters are above the set standards. In Erbil city, the main source of oil pollution problems resulted from the major refinery called Kawergosk, (20 km west of the city), and from many other in secured and developed small refineries located on the southwest of the city, which they used old types of equipment and unscientific production process.

In Kawergosk refinery, the oily wastewater resulted from all utility units through refining oily water sewer system were sent to Wastewater treatment plant for remediation purposes, the outlet of the wastewater treatment plant were discharged to the river in which it has no effect on the environmental pollution. Details of Kawergosk oil refinery are shown in the appendix 1.1; Figure 1.4 clarifies the remediation steps of oily wastewater, which comes from the outlet of the refinery.

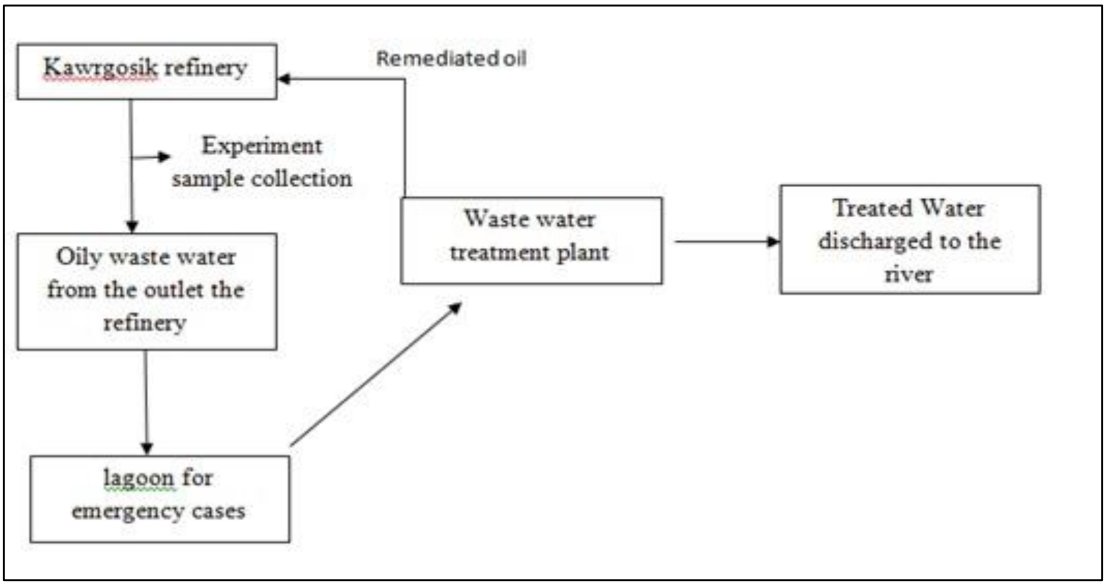



**Figure 1.4** Oily wastewater remediation diagram.

## 1.3 Aim of the study

The reason behind conducting this study is to investigate the effect of oily wastewater resulting from the outlet of the Kawergosek refinery on the environment (air and soil pollution). Field and laboratory tests have been conducted, then comparing the results regarding their effect on the engineering and geotechnical characteristicss of soils. Figure 1.5 shows the process diagram of the study.

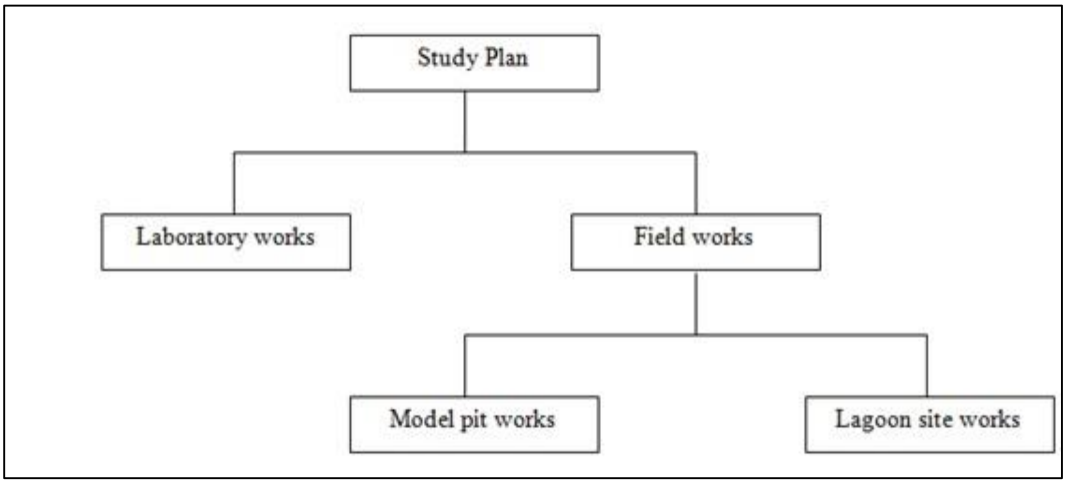



**Figure 1.5** Study plan diagram.

Various techniques have been used in this investigation regarding environmental pollution, such as;

- Direct measuring of the harmful gases especially (CO and $H_2S$) in most of the affected areas.

- Conducting a survey questionnaire in the surrounding towns.

-Measuring the degree of soil contamination especially hydrocarbon gas in the Kawergosk refinery.

## 1.4 Theses layout

Chapter 1 – Introduction: Includes a brief identification of air pollution and soil contaminations caused by oily wastewater resulted from refineries. The objective of the study is to investigate the effect of air pollution and soil contaminations on the environment and on the geotechnical properties of soils.

Chapter 2 – Literature review: This chapter relates to previous studies conducted on-site investigations regarding contaminated air and soil with waste oil that comes from oil fields and refineries and its effect on the environment and geotechnical properties of the soils.

Chapter 3 – Study area: The background and the effect of waste oil in the oil fields and refineries on the environment and geotechnical properties of the soil in the study area (southwest of Erbil city) are presented.

Chapter 4 – Methodology: This chapter illustrates the field and laboratory tests on the contaminated clayey soil with oily wastewater resulted from the Kawergosek refinery. Environmental site investigation procedures are also included in this chapter.

Chapter 5 – Results and Discussions: This chapter presents the classification tests of examined soil and experimental program regarding chemical, physical and mechanical tests for contaminated soil samples with oily wastewater in the field and laboratory. It also presents the environmental pollutions of the surrounding areas. The outcome results of the tests and comparing with the previous works in the case of there is a comparison showed up, have also been presented.

Chapter 6 – Conclusions: Overall conclusions and recommendations of the site investigation are summarized in this chapter.

# CHAPTER 2

# LITERATURE REVIEW

## 2.1 Introduction

Ecologically, environment is the living or operating conditions (physical, chemical and biological) areas for humans, therefore a clean environment becomes necessary to avoid environmental pollution risks on a local, regional and global scale. Air pollution in oil fields and refineries became a major risk toward the workers or even to the inhabitants in the surrounding areas. Taking scientifically necessary precautions towards these risks become an urgent issue and should be study carefully.

Soil contamination is defined as the change in physical, chemical and biological conditions of the soil through man's intervention resulting in the degradation in quality and productivity of the soil.

Soil contamination problems increased recently due to the increase of industrial wastes such as petroleum hydrocarbon, organic solvents, heavy metals and wide-range use of agricultural fertilizer. Its effect on geotechnical properties of soils has been widely observed nowadays.

The environment can contaminate soil, air and, water by three mechanisms;

a. Rainfall (acid rain) falling onto sanitary landfill

b. Human activities

c. Physiochemical alterations

All types of pollution have direct or indirect effects on soil properties. However waste in interaction can affect almost the physical and engineering properties of soil such as index limits, compressibility, shear strength, permeability and, consolidation.

The deterioration of soil properties can lead to various geotechnical problems such as Landslides, Settlement, Erosion, Underground structural stability and Foundation durability. It's necessary to apply a correct method for safe disposal of wastes, this becomes a challenging task for geotechnical engineering in general and environmental engineering in particular.

The presents of the oil industry in the Iraqi Kurdistan region became active since 2000, so it's important to study the polluted areas and take necessary actions to overcome unexpected environmental and geotechnical problems.

Soil contamination became a major studying goal in many countries; this problem arises from the impact of past and current industrial activity and due to improper disposal of waste caused by society.

The major source of soil contamination is due to waste oil from oil fields and refineries. This oil contamination is due to accidental spillage or leakage brings damage to the environment. It percolates with time to the subsurface and contaminates the soil especially the hydrocarbon that is a major part of waste oil; this will also alter the physical properties of oil-contaminated soil.

Attempts to understand the soil responds to various pollutants have been widely studied by researchers and investigators in order to find scientific solutions for minimizing the unexpected various environmental problems.

## 2.2 Oil pollution

The main source of oil pollution is from the oil spill leakage in the oil fields and during transportation through damaged and old pipelines in the refinery. The oil pollution source is somehow difference if it comes from the transportation of oil products by trucks during accidents and leaks from the truck itself as this traditional way is widely used to reach the end-users. On the other hand, the riskiest source of oil pollution in the refineries is in the untreated wastewater (oily wastewater), that throws from some refineries to the nearby area; this type of pollution has been widely observed in this investigation. Before this study, the effect of Kawergosek refinery wastewater on surrounding water resources have been studied. Shuokr et al.2016, they have seen that high pollutants in wastewater refinery and the major pollutant occurred in a mixing point with the greater Zab river while, slight effect on the ground water has been observed. This study concentrated on the air and soil pollution inside the refinery and in the surrounding areas.

## 2.3 Effect of oil pollution on engineering properties of soils

### 2.3.1 Effect of oil pollution on engineering properties of cohesive soils

Khamehchiyan et al. (2007) examined the effect of crude oil contamination on geotechnical properties of clayey and sandy soils through extensive laboratory testing program on various contaminated samples. It has been shown that there is a decrease in strength, permeability maximum dry density, optimum moisture content and Atterberg limits for contaminated samples. Figures 2.1, 2.2, and 2.3(a and b) shows the outcomes of their work.

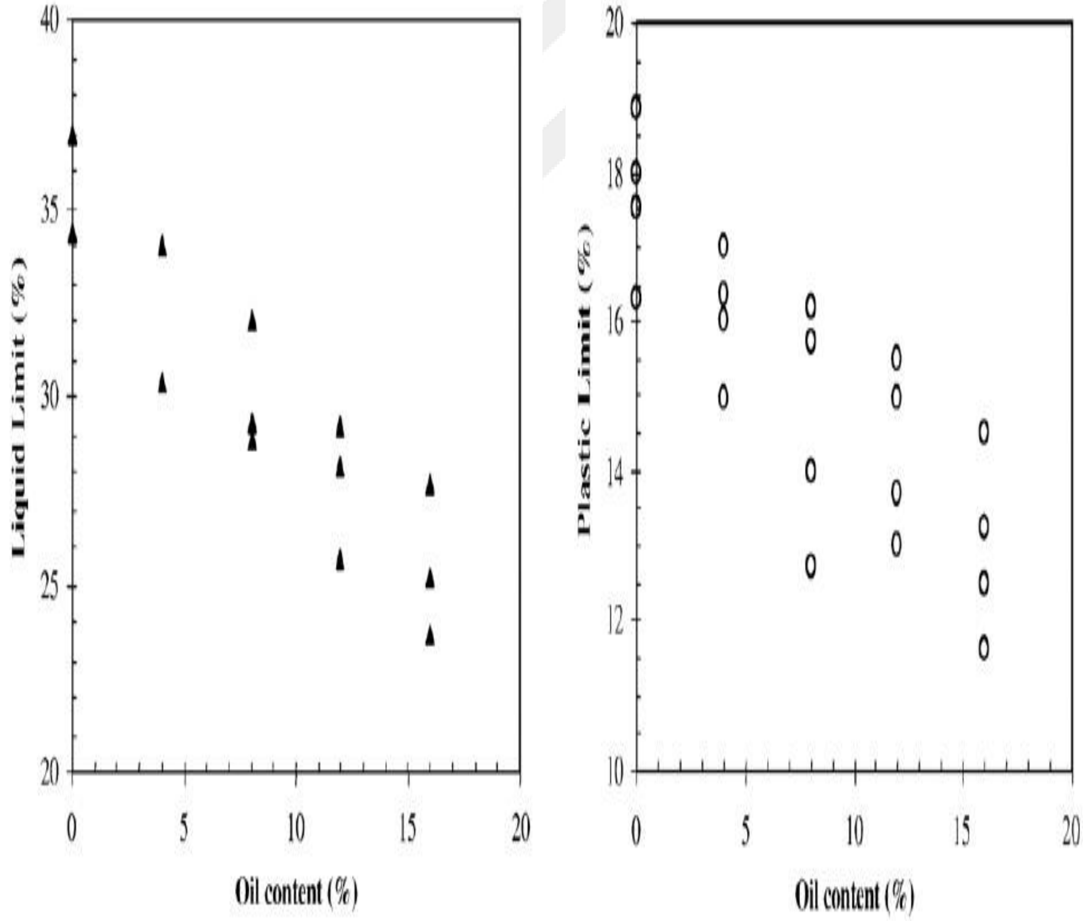



**Figure 2.1** Influence of oil content on Atterberg limits for CL clay (after Mashalah et al., 2007).

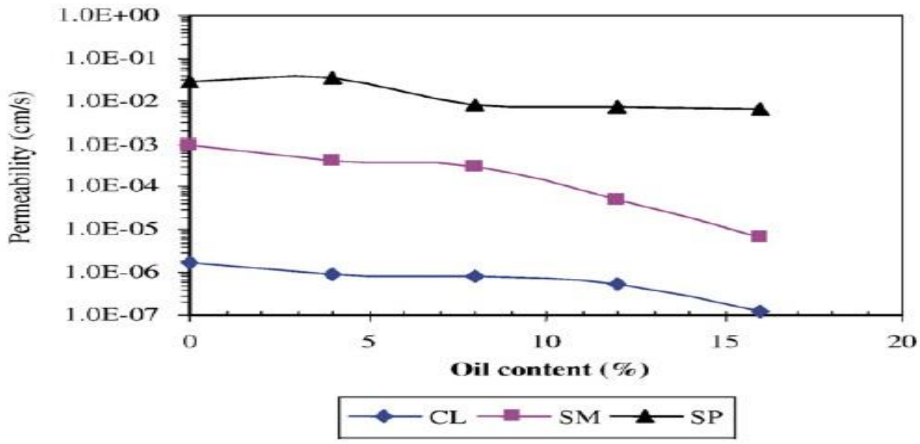
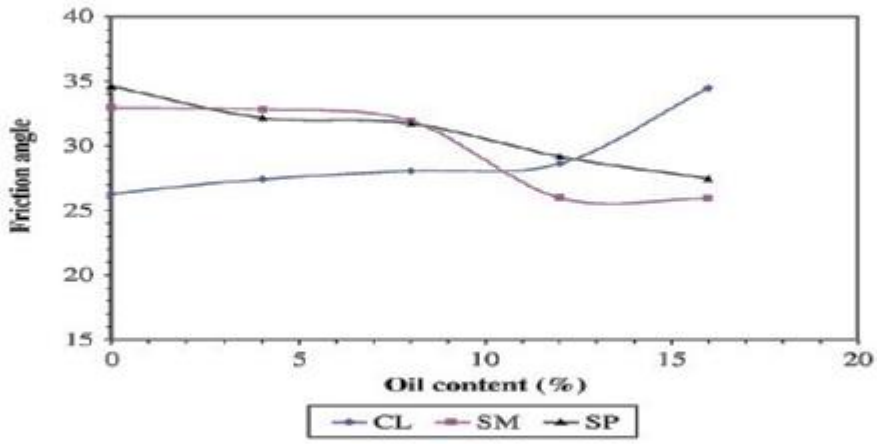
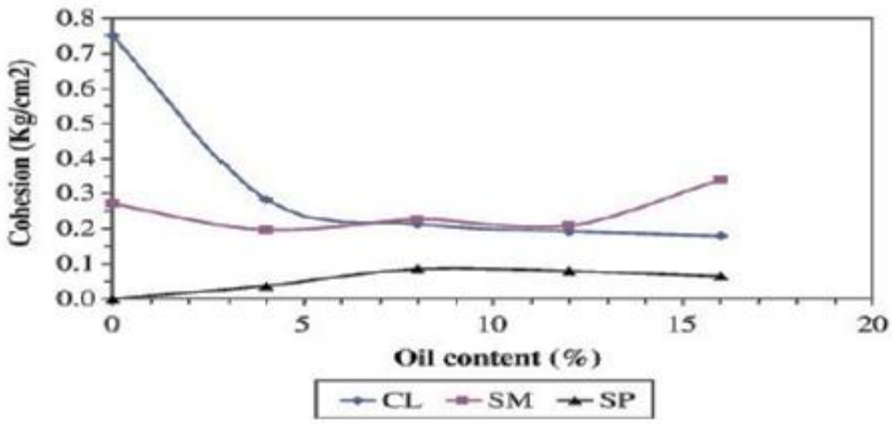



**Figure 2.2** Influence of oil content on permeability (after Khamehchiyanet al., 2007)




(a)




(b)

**Figure 2.3** Shear shtrength parameters of oil content for soil samples, a) Friction angle, b) Cohesion. (after Khamehchiyan et al., 2007).

Ur-Rehman et al. (2007) used crude oil for examining highly expensive soil and studied its behavior. They showed that there would be a significant change in engineering behavior and plasticity of the contaminated clay, also a reduction in swelling pressure was observed. Figure 2.4 shows a part of their work which is a comparison of percentage swelling for uncontaminated and contaminated clay also moisture content and dry density relationship.

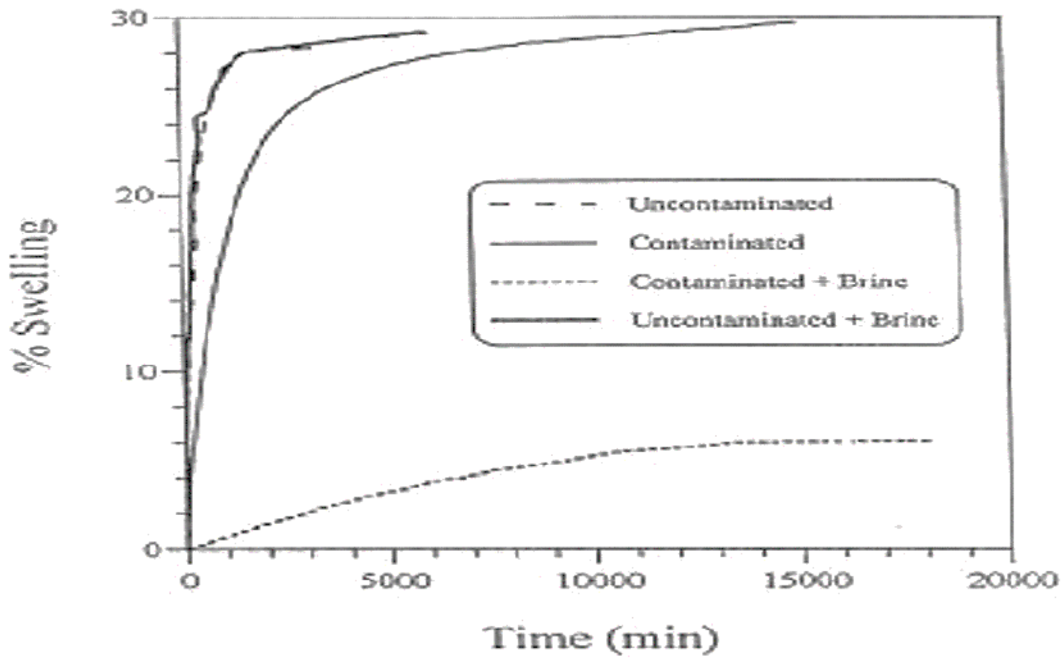



**Figure 2.4** comparison of percentage swelling for uncontaminated and contaminated clay (after Ur-Rehman et. al. 2007)

Gupta et al. (2009) studied physical and engineering behaviors of fine-grained alluvial soil (high and low compressibility properties) by contaminating with lubricant oil. They showed that both hydraulic conductivity and compressibility index values increased with increase in contamination. Also, the permeability values of both soils were increased with an increasing the degree of contamination, this behavior is due to flocculated structured of oil-contaminated soils leads to an increase in void ratio. They have concluded that the engineering properties of high compressibility soil were much more affected than the second type of examined soil of low compressibility properties, Table 2.1.

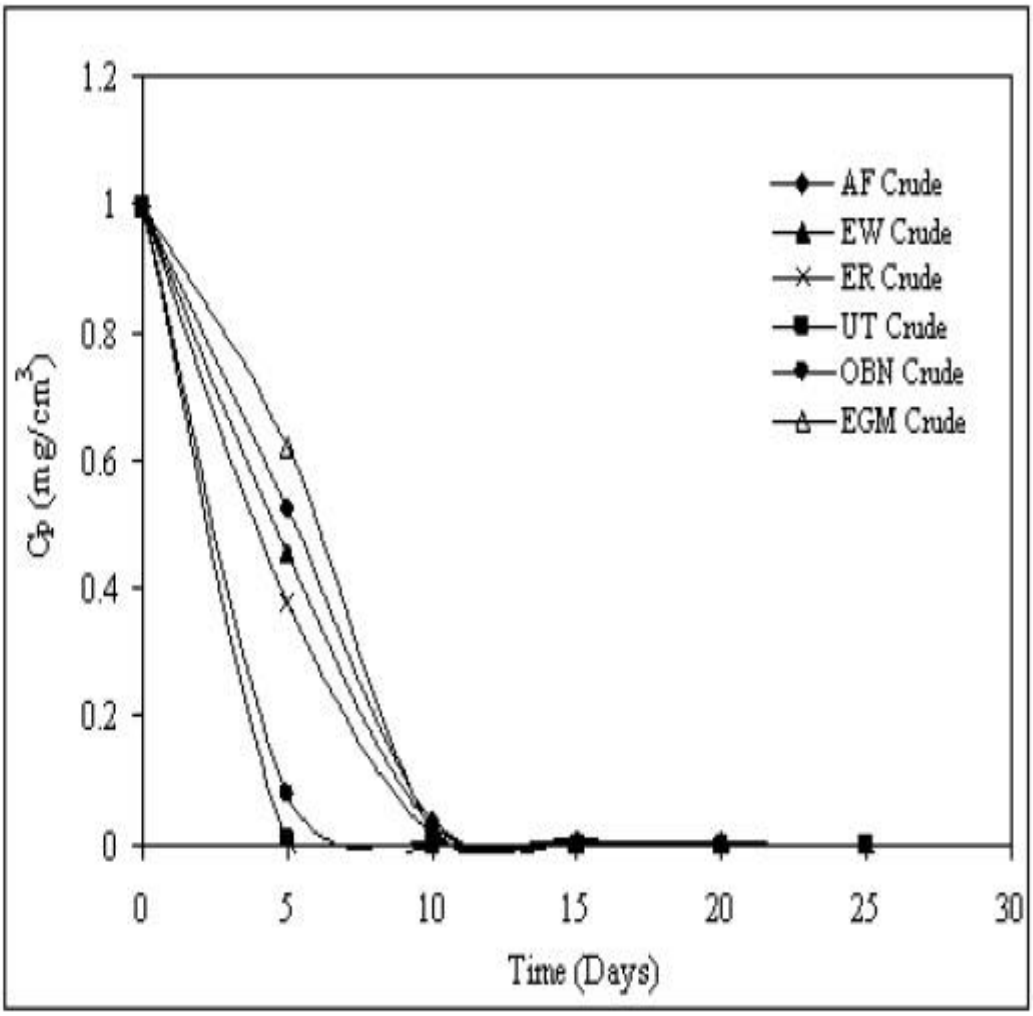
**Table 2.1** Compaction Characteristics of Virgin and Soil-Contaminant Mixes (After Gupta et.al 2009)

| Soil-1 | | | Soil-2 | | |
|---|---|---|---|---|---|
| Mix Label | OMC (%) | MDD (kN /m3) | Mix Label | OMC (%) | MDD (kN/m3) |
| CL-0 | 15.7 | 17.4 | CH-0 | 20.5 | 14.7 |
| CL-1 | 14.9 | 17.7 | CH-1 | 19.1 | 14.9 |
| CL-2 | 12.9 | 18 | CH-2 | 16.4 | 15.2 |
| CL-3 | 11.8 | 17.6 | CH-3 | 15 | 14.8 |
| CL-4 | 11.2 | 17 | CH-4 | 13.9 | 14.3 |

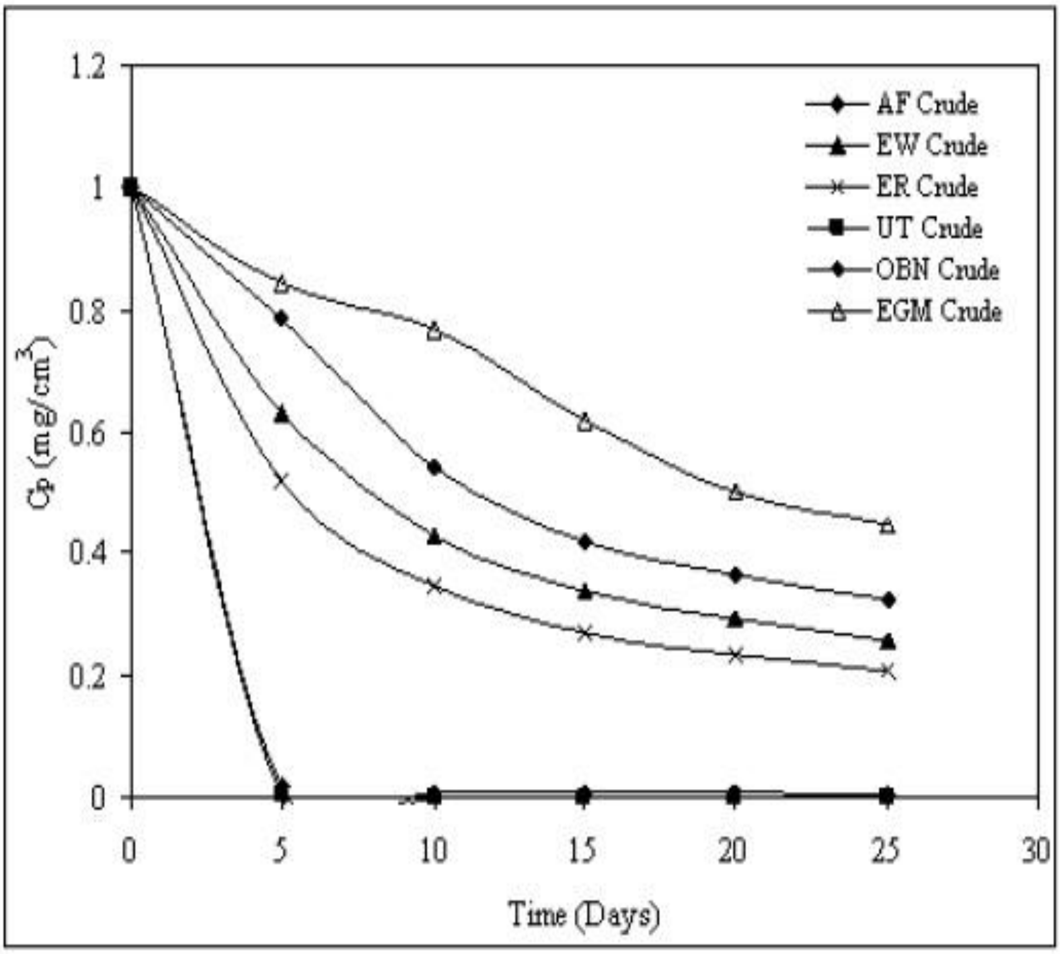
A serial of engineering and mechanical tests have been conducted on clayey contaminated soils by Rana A. J. Al-Adhami et al. in 2018 to examine the characteristics of the contaminated soil. Their results showed a significant increase in the values of index tests with an increase of oil content, while the compressive index increased. They have also observed that shear strength, maximum dry density and, coefficient of consolidation Cv of the examined soil have also been affected by crude oil.

Ewetola (2013) has investigated some soil physical properties. The study showed that soil pore spaces have been affected by crude Oil, this Leeds to decrease the infiltration rate of water into the soil. This investigation has also shown, Bulk density, Hydraulic conductivity also been affected by crude oil.

Oghenejoboh and Puyate (2010) have studied the longitudinal and vertical diffusion of the crude oil rate kinematic viscosity (dynamic viscosity/density) to the soil by using various types of crude oil. The results showed that kinematic viscosity of crude oil has a direct effect on the rate of diffusion to the soil, lowest kinematic viscosity gives highest results of diffusion rate to the soil, while for other samples of crude oil with highest kinematic viscosity exhibits lowest diffusion rate. Longitudinal and vertical diffusion rate to the soil were examined, the results showed that vertical diffusion rate of all tested sample of crude oil was significant as a result of advective flow in addition to diffusive flow, while for longitudinal diffusion rate was almost negligible as it's controlled purely by molecular diffusion; their results are shown in the Figures 2.5(a and b).




(a)




(b)

**Figure 2.5** Six crude oil samples in loamy sand soil, a) Longitudinal diffusion rate, b) Vertical diffusion rate (after Oghenejoboh and Puyate 2010)

Investigations regarding the impact of diesel oil contamination of soil permeability have been conducted by Ayininuola and Kawashima (2015), the results showed the coefficient of permeability for examined two soil samples in which they were varied between low for soils not exposed to the atmosphere and high for those exposed to the atmosphere. To improve the permeability of the contaminated sample with diesel oil, they have recommended that the soil have to be aerated and subjected to sunlight. Applying these two methods to the contaminated soils will lead to improving its infiltration capacity; Figures 2.6 and 2.7 show their results.

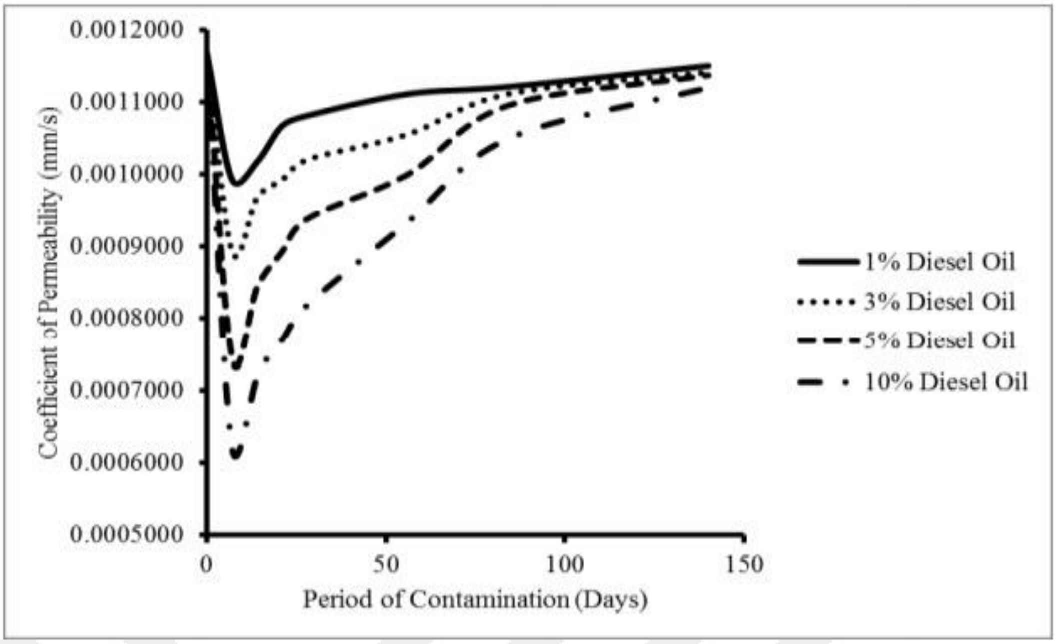



**Figure 2.6** Coefficient of permeability of exposed contaminated soil sample a with time (after Ayininuola and Kawashima 2015)

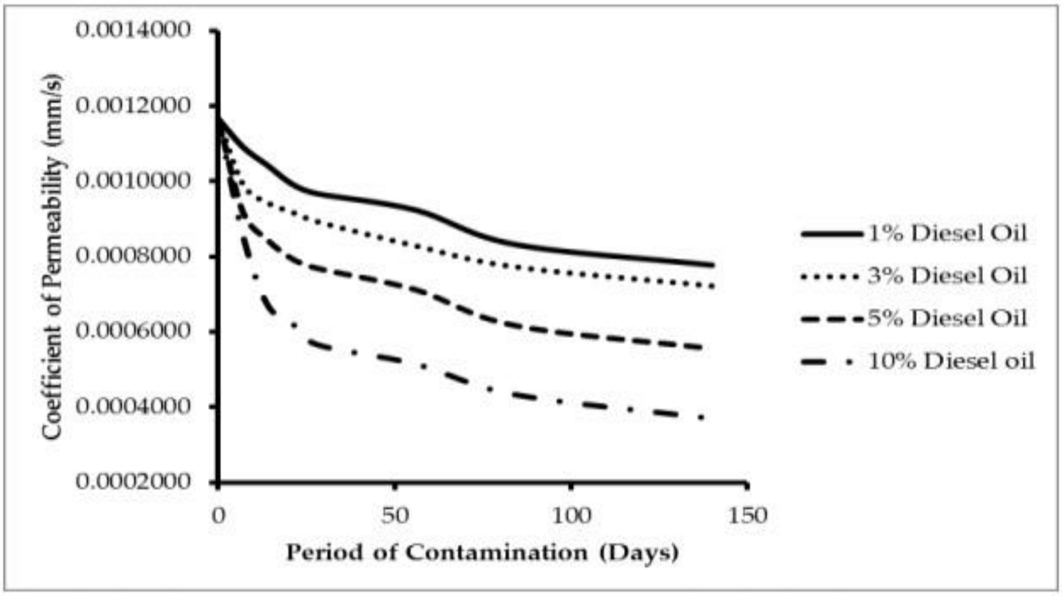



**Figure 2.7** Coefficient of permeability of unexposed contaminated soil sample a with time (after Ayininuola and Kawashima 2015)

In his research, Thaer (2011) conducted an extensive laboratory testing on fine-grain soils from the south area of Iraq, the results showed that a decrease in the values of Atterberg limits maximum dry density and optimum moisture content for samples contaminated with crude oil, as shown in Figure 2.8 while a reduction in permeability was also observed, Figure 2.9. The cohesion was clearly affected by the increase of crude oil content while the internal friction angle values increased. The compression index was found to be higher for contaminated soils. As shown in Figures 2.10 and 2.11 respectively.

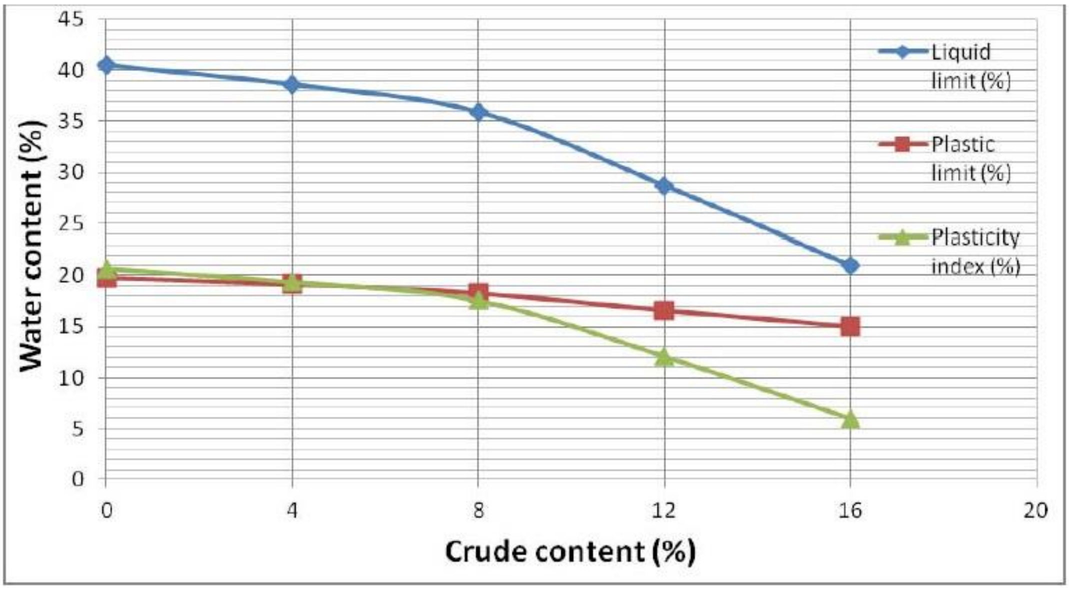



**Figure 2.8** Effect of crude content on consistency limit (after Thaer 2011)

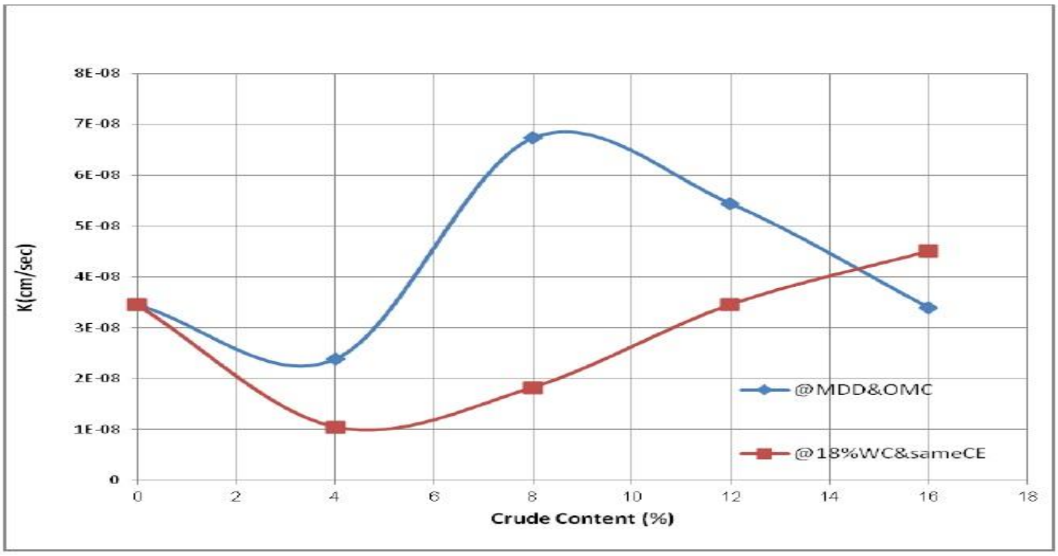



**Figure 2.9** Effect of crude oil content on permeability using consolidation Odometer cell (indirect method) (after Thaer 2011)

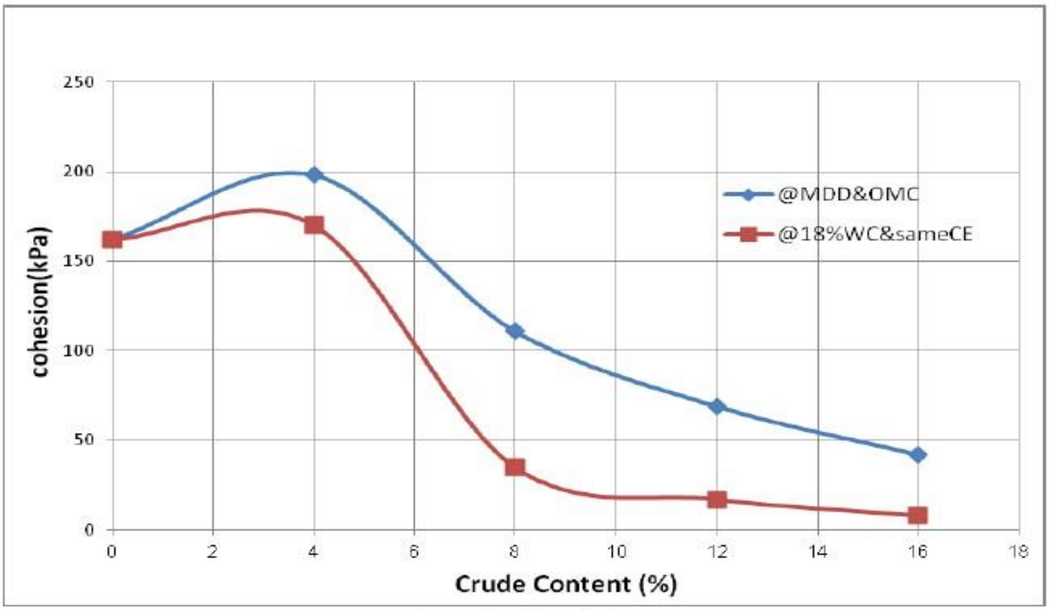



**Figure 2.10** (Cohesion - C) Effect of crude oil content on shear strength parameters (Direct shear) (after Thaer 2011).

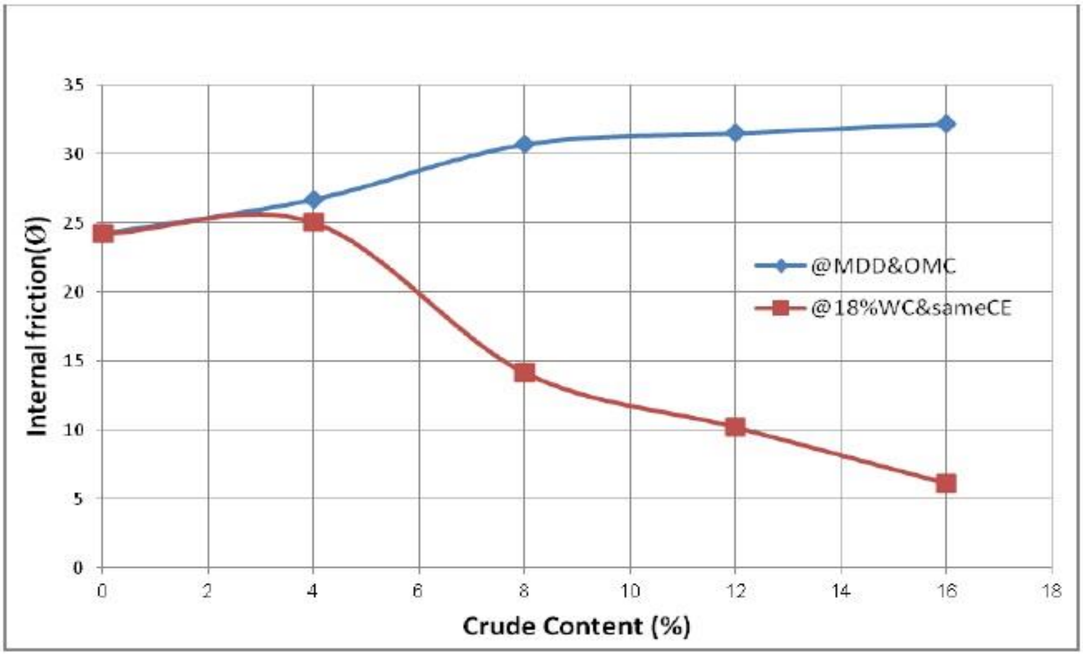



**Figure 2.11** (Internal friction - ø) Effect of crude oil content on shear strength parameters (Direct shear) (after Thaer 2011)

Nazar (2011) examined the effect of motor oil contamination on geotechnical properties over consolidated clay. It has been shown that a significant decrease in Atterberg Limits and Unconfined compressive strength, also increase in the coefficient of permeability, Swelling Index is noted.

From the results of direct shear tests on clayey contaminated soils with oil content found by, Khamehchigan et al (2007), a direct interrelation between oil content and friction angle, cohesion were found, increasing oil content resulted in excessive decrement in cohesion values.

Gonzalez – Corrochano et.al (2012) examined the recycle highly polluted mine oil and fly ash in order to obtain a usable material such as light wet aggregates (LWA). They showed that leaching, recycling of contaminated mine soil and fly ash for the manufacture of (LWA) is visible.

Elisha (2012) presented the effect of crude oil contamination on the geotechnical properties of soft clay of the Niger Delta region of Nigeria. The laboratory investigations of this work showed that a remarkable effect of oil contamination on soft clay by crude oil caused 17.9% increase in liquid limit, 6.9% increase in plastic limit and 37.5% increase in plasticity index, also showed a corresponding increase in Bulk Density, with an increase in sorption time. Porosity and swelling pressure of contaminated clay decrease with an increase in both sorption time and crude oil content, while undrain shear strength fluctuates. Table 2.2 and Figure 2.12 illustrate his works.

**Table 2.2** Summary of selected properties of uncontaminated and contaminated clays

| Property | Uncontaminated Soft clay | Contaminated Soft Clay |
|---|---|---|
| Liquid Limit (%) | 67 | 79 |
| Plastic Limit (%) | 43 | 46 |
| Plasticity Index (%) | 24 | 33 |
| Shrinkage Limit (%) | 18 | 21 |
| Compression Index (%) | 0.312 | 0.851 |
| Swell Percentage (%) | 27.7 | 28.3 |
| Swelling Pressure (kPa) | 594 | 182 |
| Max. Dry Density (kN/m$^3$) | 14.1 | 16.7 |
| Opt. Moisture Content (%) | 22.8 | 8.3 |

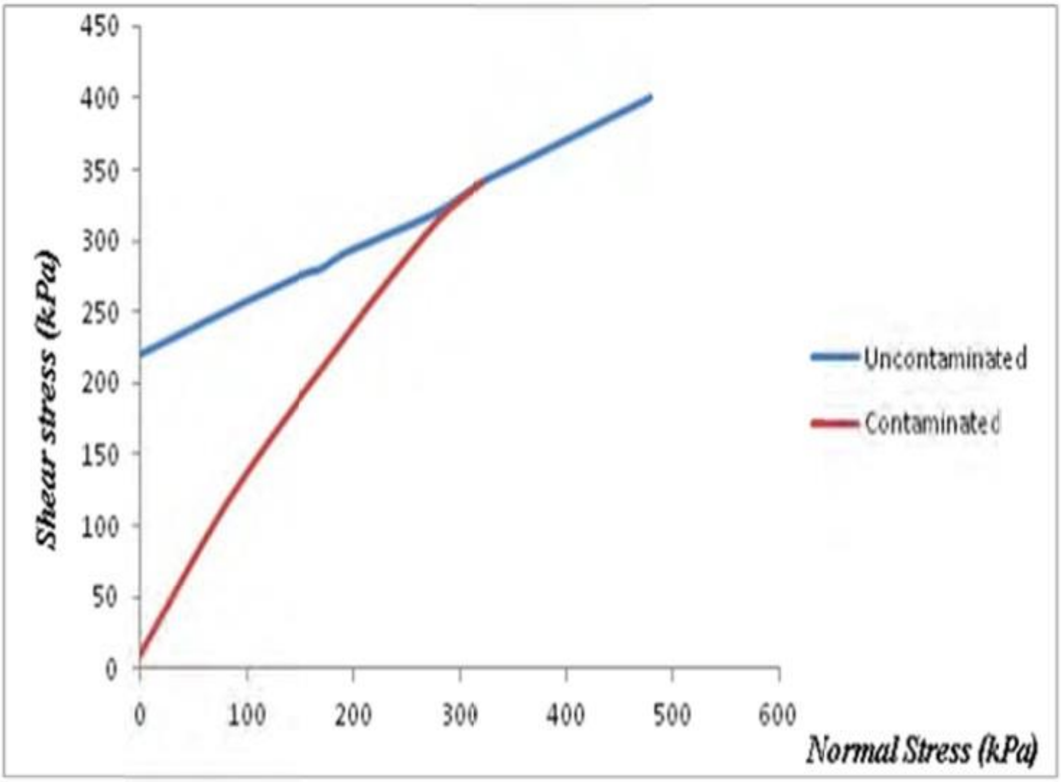



**Figure 2.12** Mohr-Coulomb envelops for uncontaminated and contaminated soft clay (after Elisha 2012).

Akinwumi et al. (2014) examined the contamination of Lateritic clay with crude oil and, their effect on plasticity, strength and permeability of the soil. They found that the Atterberg limits were increased in contaminated soil samples, specific gravity, optimum moisture content, max day unit weight, CBR and permeability decreased as its crude oil content increased. They concluded that soil requires stabilization or remediation before using it as a construction material. Figure 2.13 shows crude oil content percentage versus Atterberg limits.

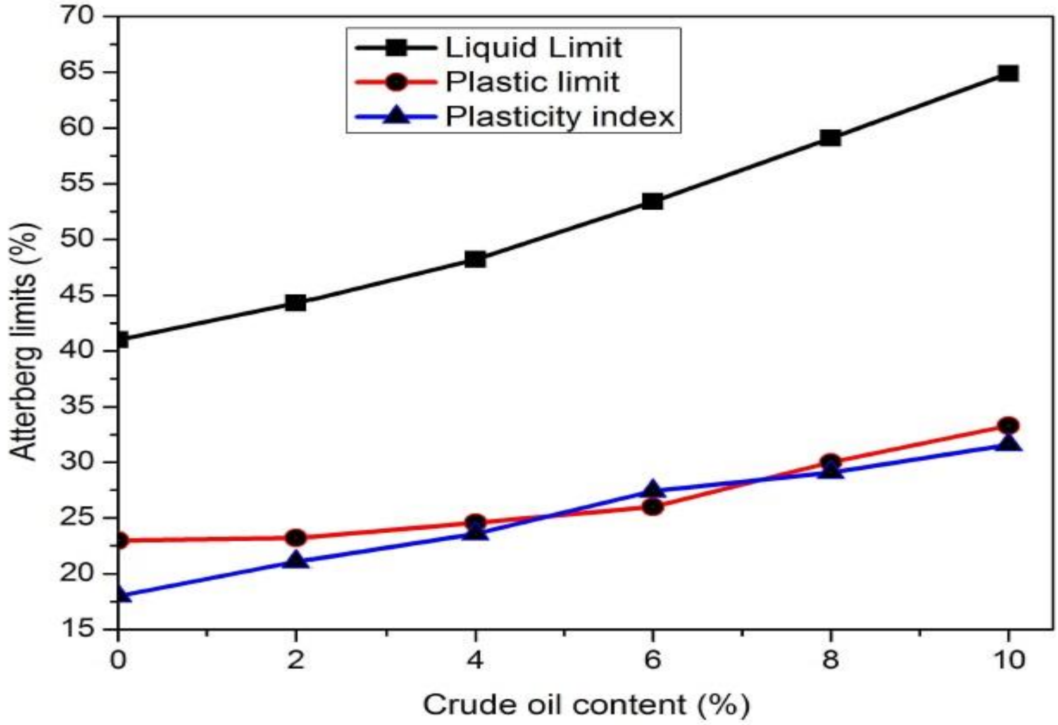



**Figure 2.13** Variation of Atterberg limits with oil content (after Akinwumi et al. 2014)**.**

Abousnina et al. (2015) tested oil-contaminated sand as an emerging and sustainable construction material. It has been found that the cohesion increased significantly by increased oil contamination. Permeability, friction angle, optimum moisture content and, Atterberg Limits generally decreased.

Oghenejoboh et al. (2015) investigated the concentration distribution of spilled crude petroleum in different soil and its effect on volume of oil on diffusion rate, they showed that the diffusion rate of spilled petroleum in both longitudinal and vertical directions increases as the volume of spill increases, there are differences in the vertical and longitudinal diffusion of oil and the percentage of oil diffusion depends directly on the volume of petroleum spilled, finally, they have found that the rate of diffusion in sandy soil is faster followed by topsoil and the smallest one found in loamy soil (2009). The Figures 2.14 (a and b) shows a comparison of the diffusion rate of spilled petroleum for all samples.

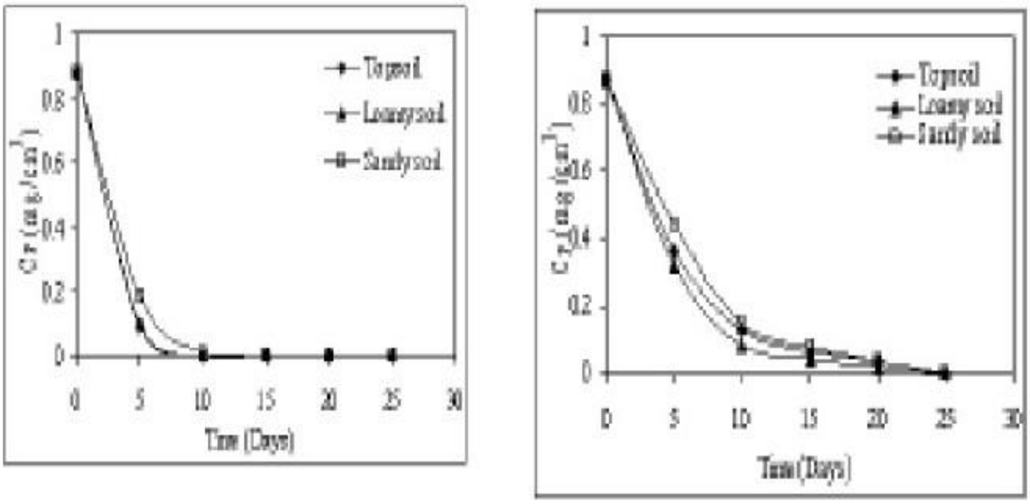


**Figure 2.14** Comparison of diffusion rate of spilled petroleum in soils at spilled volume of 200 cm3 (a) longitudinal direction (b) vertical direction (after Oghenejoboh et. al. 2015)

Pourakbar et al. (2015) investigated the possible use of palm oil fuel ash (POFA) and cement on several basic characteristics of clayey soil behavior. The results showed a slight increase in the unconfined compressive strength of the samples in the same curing time and decreased the soil plasticity index.

Daka (2015) studied the effect of oil contamination with bentonite-kaolinites-sand mixtures on Atterberg limits, compaction, and hydraulic conductivity using different oil percentages. The study shows that oil contamination generally increased the Atterberg limit values, also the hydraulic conductivity decreases with the increase of oil contamination.Arashk and Hafshejani (2016) reviewed several investigations, about some changes on the plasticity characteristics and Atterberg Limits of different soil samples contaminated with hydrocarbon of crude oil with hydrocarbon. The results show that a decrease on Atterberg Limit values after contaminating samples the reasons behind was due to some factors such soil type, different chemical and physical properties of soils, types of contamination, and different environmental conditions. Finally, they concluded that the Atterberg Limit values of contaminated soils are far less than the un-contaminated samples.

In their study which is on the effect of contamination of soil properties using remote sensing, (Karkush et al., 2014) showed that this technique is very useful and powerful for the estimation of contaminant types in the surface layer of soil, the comparison of results showed a good correlation between the spectral reflectance from field measurements and the spectral reflectance obtained from analyzing the satellite imagery. The effect of soil pollutant interaction on geotechnical properties has been clarified. It has been shown their influence on index properties, volume change behavior, shear strength and, permeability.

Okop and Ekpo (2012) investigated the effect of crude oil penetration in the soil through conducting many experimental tests in various depths. The results found that a variety of hydrocarbon concentrations, the higher values were found in the middle soil level while the smallest concentrations were found in the deepest level of soils measured.

### 2.3.2 Effect of oil pollution on engineering properties of cohesive less soils

Regarding cohesive less oil contaminated soils, this becomes the interest of many researchers, and some of them are reviewed and shown below;

Hassan et.al (2008) presented the results of investigating the permeability and leaching of asphalt concrete mixes contaminating oil-contaminated soils (OCS) they indicated their effect on blocking the interconnected voids also permeability will decrease by increasing percentages of (OCS).

Chew and Lee (2010) examined the simple shear behavior of palm biodiesel contaminated soil results showed that shear strength may be reduced when the soil is contaminated, the K values decrease with an increase of plum biodiesel content, also cohesion and friction angle decreased.

Rahman et al. (2010) Influence of Oil contaminated on Geotechnical properties of Basaltic Residual Soil American Journal of Applied Science, this study presents the geotechnical properties of oil contaminated as well as uncontaminated soils for comparison. The results showed that the oil-contaminated on the soil system has influenced the geotechnical properties of the examined soil. The /results obtained support the decision-makers in revising of contaminated soils or recycling, Figure 2.15 shows Atterberg limit values for soil contaminated with various oil percentages.

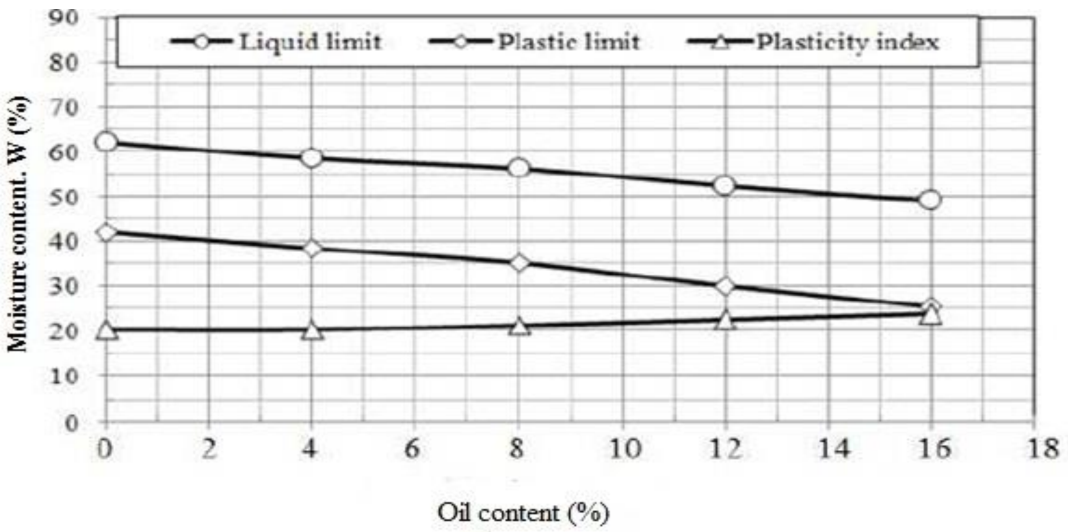



**Figure 2.15** The results of Atterberg limit values for soil contaminated with various oil percentages (after Rahman et. al. 2010)

Nasehi et al., (2016) examined the influence of Gas oil contamination on geotechnical properties of fine and course-grained soils. They have concluded that a decrease in ϕ and increase C for soils with the increase of Gas oil content, also reduction of dry density and optimum moisture content observed during compaction test. Finally, increase of Atterberg limits value exists and the increase of Gas oil content percentage reversely affects the UCS of silt soil.

Yu et al. (2016) worked on stabilization/solidification (S/S) of nitrobenzene-contaminated soil based on hydrophobized CaO. The result indicated significantly strengthens the fixation of nitrobenzene in SIS remediation of contaminated soil. hydrophobized CaO can be used in emergency cases for SIS of high concentration of toxic organic pollutants contaminated soil.

Dunya (2007) examined the effect of heavy fuel oil on the engineering and geotechnical properties of both sandy any gypsum soils. The results found that the rate of heavy fuel oil waste penetration depth and settlement decreases with soil density while penetration depth and settlement increases with the increase of the head of the oil. A settlement increases of gypsum content and penetration depths decreases. For sandy soils, internal friction angle decreases with increase of the degree of saturation, while gypsum soils increases.

Penetration of oil in Sandy soils has been studied by Halmemies, et al (2003) using a special column experimental device. The results showed that viscous fuels have lower values of penetration velocity than a lighter, because of horizontal seepage and backpressure caused by saturated zone.

Rasool (1999) studied the effect of the oil contamination on the shear strength parameters of clayey – silt soils using direct shear test method, he found that cohesion values decrease significantly and angle of internal friction increases with increase of oil content, as a result, the behavior of contaminated soils were similar to the behavior of no cohesion soils.

Alhassan and Fagge (2013) used engine oil contamination with clayey and sandy soils, they showed that an increment in the cohesion and angle of internal friction, they concluded the reason behind was the viscous properties of the contaminant.

### 2.3.3 Effect of oil pollution on soil improvements.

It has been approved that some of the oil products have direct effects on soil improvements such as;

In their work, Stabilization of fuel Oil Contaminated Soil, a Case Study, Geotechnical and Geological Engineering by Shah et al., (2003) the stabilization of fuel oil contaminated soil has been studied. The best results were observed when a combination of 10% line 5% of fly ash and 5% cement was added to the contaminated soil. In the process of stabilization, fuel oil might have formed a sTable complex with metals and increase the strength of the soil.

Abousnina et al. (2015) tested oil-contaminated sand as an emerging and sustainable construction material. It has been found that the cohesion increased significantly by increased oil contamination. Permeability, friction angle, optimum moisture content and, Atterberg Limits generally decreased.

Umar et al. (2016) revised the biological process of soil improvement in civil engineering. It has been shown that microbial induced calcium carbonate precipitation (MICP) can be considered as a practical technique that can improve soil supporting new and existing structures and can be used in many geotechnical engineering applications.

### 2.3.4 Effect of other pollution materials (oil products) on the physical, chemical and geotechnical properties of soils.

Some other petroleum products such as plastic industries, petrochemical products, oil-powered industrial machines and, generators, and Textile dyeing industries have also indirect effects on pollution in general. Recent and previous researches on the above pollutants are reviewed below;

Investigations of Kayode et al. (2009) on the effect of lubricating oil pollution on soil showed that a significant effect on physical properties such as bulk density, water porosity and, organic Carbone content, while soil aeration and capillarity have been reduced. They have concluded that it is necessary to increase public awareness to avoid this problem.

Shah and Shroff (1998) studied the effect of Effluents of industrial waste on soil properties. They have concluded that the index properties are increased with the percentage increase of waste except for Shrinkage Limits, Swelling Index is also increased. No significant change in shear strength is observed. Values of sodium, potassium, calcium, ions are increased.

Cetin et al. (2006) in their study geotechnical properties of pure fine and course-grained tire-chips and the in mixtures with cohesive clayey soil has been investigated, in order to be used as a field material. The results were positive regarding the various soil properties, such as Index Compaction Permeability and shearing strength; they should not be used when drainage is needed to prevent the development of poor pressure during loading of fields under saturated conditions. In these cases, they might use by mixing with high permeability material such as sand and gravel.

Lynech et al. (2007) studied the preliminary tests of an electro kinetic barrier to prevent heavy metal pollution of soils. It has been found that an electric field of 125 Vm was sufficient to prevent significant copper incursion from a contaminant flow under a hydraulic gradient of 1.3

Working on the effect of soil pollution on geotechnical behavior of soils, Sivapullaiah (2009) made attempts to understand the soil response to various pollutants (Sulphate). It has been shown that the effects which are different for different types of soil are increased on many geotechnical properties.Rao et al. (2012) studied the characteristics of undrains shear strength of inexpensive soil treated with certain industrial effluence of different poor fluent content ratio. It has been shown that the expansive clay considered in this investigation is sensitive when it's treated with industrial effluent. The undrain shear strength decreases with the increase of effluent added.

Oluremi et al. (2012) worked on the assessment of Cassava wastewater (effluent) on geotechnical properties of lateritic soil; the result showed that contaminations have an early effect on the Atterberg Limits. It has a severe effect on plasticity; it reduces the maximum dry density and increases the optimum moisture content.

Koz et al. (2012) in their study, they have performed a heavy metal analysis on the moss and soil samples around the Murgul Cooper time. This research resulted in critical heavy metal pollution by a comparison value reported in similar studies in the world. As it's shown that the risk abandoned mining areas create a factor of contamination for human health.

Prakash and Arumairaj (2015) studied the effect of acid and base contamination on geotechnical properties of clay. It has been shown that the liquid limit, plasticity index, specific gravity are decreased i soil contaminated samples. The optimum moisture content and maximum dry density decreases with increase in acid content also the same of shearing strength.

Sikora and Ossowski (2013) worked on a geotechnical aspect of Dike (earth dam) construction using soil-ash composites (Coal Combustion Products) the results showed a good mechanical parameter, comparable with mineral soils, example; silt mixing the fly ash with the mineral soil such as dredged sand, fairly improve the parameter of such composite comparing to the constituents. Another benefit of soil-ash composites is their low cost.

In their study which is on the effect of contamination of soil properties using remote sensing, (Karkush et al., 2014) showed that this technic is very useful and powerful for the estimation of contaminant types in the surface layer of soil, the comparison of results showed a good correlation between the spectral reflectance from field measurements and the spectral reflectance obtained from analyzing the satellite imagery. The effect of soil pollutant interaction on geotechnical properties has been clarified. Their influences on index properties, volume change behavior, shear strength and, permeability is very clear.

In his study, Aubaid (2004) worked on the effect of sulphuric acid on the geotechnical properties of clayey silt soil contains calcite. It has been shown a severe reaction to unconfined compression tests. The maximum dry density reduces after adding acids, the value of L.L and P.I also reduced. The chemical and x-ray test for the contaminated soil shows the increasing of gypsum and sulphuric salts.

Karkush et al. (2015) studied the effect of industrial wastewater on the chemical and physical properties of sandy soil. It has been shown that the liquid limit of the contaminated sample was increased in compose with the value of intact soil and slide decrease in the specific gravity, dry density was observed.

In their study, Norhaliza et al. (2016) used a remolded clay sample for the proctor compaction method to make as a comparison for other method that is hand-operated method and miniature mold method. They concluded that remolding clay of hand-operated method and miniature mold method are accepted to perform remolded clay samples, however, the hand-operated method was more suitable for shear strength determination purpose as this method is easy, save time and less energy used in preparing the remolded samples.

### 2.3.5 Concluding remarks

It is clear that many researchers worked on the effect of crude oil on soil pollution and its behavior on environment and geotechnical properties, but no researches found on soil contamination with oily wastewater so far. It is an interesting issue to study this subject especially for oil refineries, as they spill large quantities to the surrounding areas continuously. This idea had been developed in the current investigations to examine its pollution effects on the environment and on the engineering and geotechnical properties of soils in three directions:

1- Studying the geotechnical characteristics of the polluted soils with oily wastewater through conducting various laboratory tests on its effect on index properties, internal friction angle, cohesion, compressibility and, permeability.

2- Studying the field diffusion of oily wastewater and its effect on soil contamination and shearing stress.

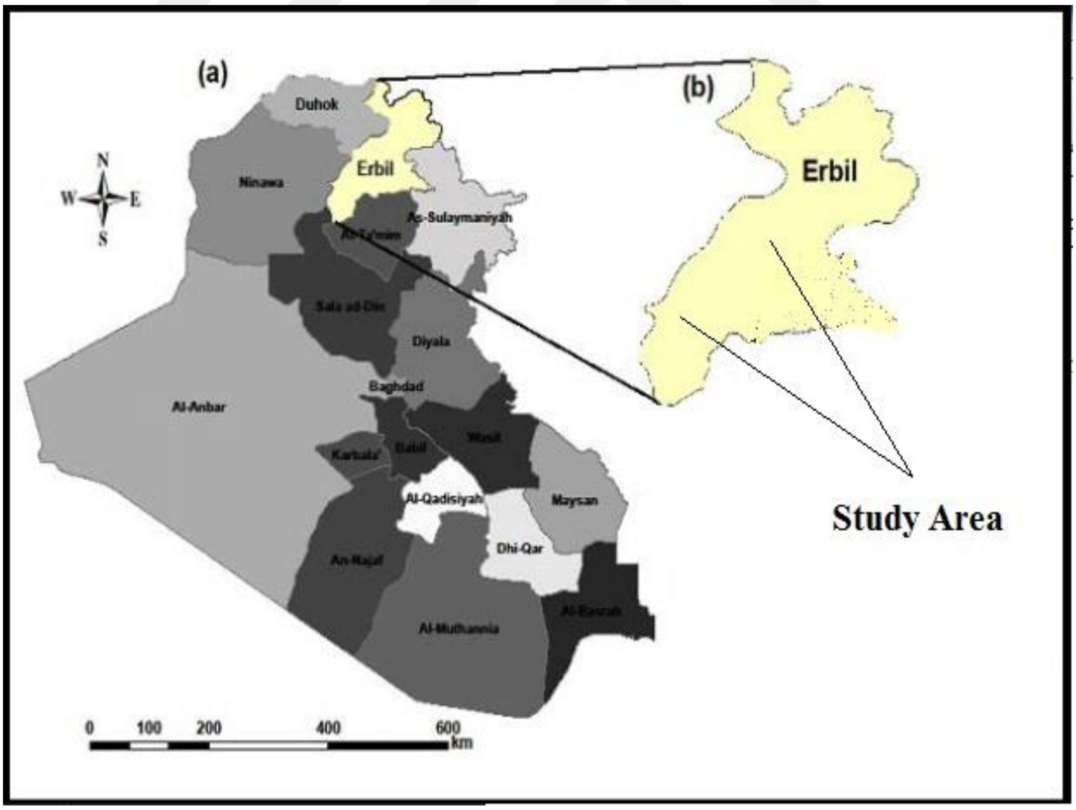
3- Studying the effect of oily wastewater on environmental pollution in the surrounding areas of the refineries.

# CHAPTER 3

# STUDY AREA

## 3.1 Introduction

Erbil is the capital of Kurdistan Region, which is the largest but oldest city in the north of Iraq. It has witnessed a big increase in its population (around 1.5 million), that was accompanied by a huge development in various fields which made many international companies and investors focus on this city and were encouraged to come to Erbil and establish their bases there, something which made Erbil a market and commercial center for the whole of Iraq. Figure 3.1 (a and b) shows the view and the study area on the map of Iraq- Erbil.




(a)

(b)

**Figure 3.1** Erbil city, (a) Study area, (b) Satellite view.

## 3.2 History and geography of erbil

Erbil is one of the oldest and ancient cities in the world; the Citadel of Erbil goes back to 6000 years B.C. Its latitude is 44 degrees north and longitude 36 degrees east. The average altitude of Erbil is around 420 m above the sea level, its area is 40643 km2, and most of the land is flat and useful for various agriculture products, which depends on underground water for irrigation purposes.

Regarding the meteorology of the city, it is very hot in summer and cold in winter, the temperature is between 2-7 degrees centigrade in winter and around 50 degrees centigrade in summer. Annual rainfall is around 400 mm/year. Figure 3.2 shows the view of Erbil city.

**Figure 3.2** Erbil citadel.

## 3.3 Environmental situation

Erbil is facing various environmental problems, such as wastewater treatment, bad sewerage system, land preservation, air pollution, noise pollution, pollution due to the large increase of the number of vehicles. In addition, problems like the big increase in public generators locating in every edge of the city to provide electricity because of the shortage of general electric power, and finally, pollution due to large increase in oilfields and refineries.

The petroleum industry in Erbil is in the early stages of activeness; it has a big impact on the surrounding environment. There could be a release of emissions of toxic and harmful to the atmosphere in consecration that is dangerous to the health of inhabitants.

## 3.4 Environmentally polluted areas

The major environmental polluted areas in Erbil city lies on the southwest (the study area of this investigation), in which the main oil fields and refineries exist. The major oil field called Khormala (its geographical coordinates are latitude 35.975798 and longitude 43.767131), besides more than 150 small size refineries. Kawergosk is the major legal refinery in the same area (its geographical coordinates are latitude 36.324186 and longitude 43.809706), the distance between the oil fields and refineries to the city is around 20-30 km. The main part of this investigation has been conducted in this area. Many crowded villages located in this area beside the main highway road between Erbil and Mosul cities also exist. Figure 3.3 and 3.4 show views of Khormala oil field and Kawergosk refinery.

**Figure 3.3** Khormala oil field.

**Figure 3.4** Kawergosk refinery**.**

The investigation includes various environmental tasks such as a direct measure of the emission gases from surrounding areas, site survey questioners and degree of soil contamination in the major refinery. Laboratory and some of the field tests on the contaminated soils were carried out in the location (Cihan University) which is not far from the main refinery and has similar soil characteristics. A model has been prepared for this reason, which is close to the soil test laboratory in the university. Figure 3.5 shows a view of the model pit (the geographical coordinates are, latitude 36.171855 and Longitude 43.966416).

**Figure 3.5** Model pit in cihan university for conducting field investigation tests**.**

# CHAPTER 4

# METHODOLOGY

The methodology chapter is divided into three parts. 4.1. Environmental site investigations, which focus on the effect of oil fields and refineries on the pollution of the environments. The second part, 4.2. Include conducting laboratory tests on uncontaminated and contaminated soil samples, while the last part 4.3. Illustrates the field investigation tests for the model and refinery sites. The research program flowchart 4.4. Is at the end of the chapter.

## 4.1 Environmental site investigations

### 4.1.1 Introduction

It is obvious that all stages of oil production have negative impacts on the environment, especially on air, water, and soil contaminations. The environmental consequences of oil pollution on the inhabitants exist in all countries producing oil, in particular in the new oil industry countries, in which they have limited knowledge and experience regarding the effect of oil production on the environment especially, air, water, and soil.

Previous studies Bello and Anobeme (2015), clarified the impact of oil exploitation on the environment. The results of some of these investigations showed that oil spills have degraded many agriculture lands, the farmers have been forced to leave their lands and villages and causes to seek non-existent alternative means of livelihood.

There were other impacts of oil pollution on soil, forests, and water (fishing production communities). Therefore it has been the interest of many researchers to investigate this field of study in order to find reasonable solutions for wide crude oil exploitation adverse effect on the environment.

### 4.1.2 Environmental site investigation on Erbil city

Most of the environmental site investigations were carried out in the south-west of the city, in which most major oil fields and refineries are locating in this area.

Erbil city with a population of around 1.5 million is facing many environmental problems, such as;

1. Wastewater treatment& water supply.
2. Land preservation.
3. Air pollution.
4. Noise pollution.
5. Pollution due to the large increase in the number of vehicles.
6. Pollution due to a lack of electric power which is widely replaced by public generators.
7. Emissions come from the main municipal solid waste wild dumping land.
8. Finally pollution due to emissions made by oil fields and refineries, which is one part of our investigations.

### 4.1.3 Environmental problems of the oil fields and refineries in Erbil city

This site investigation, sheds light on various environmental problems in Erbil city, Figure 4.1 shows views of Erbil air and soil contaminations, especially, these problems are causing serious health concerns for the inhabitants, for which, in the worst scenarios, can lead to death, due to lack of the knowledge of authorities to overcome on these issues.

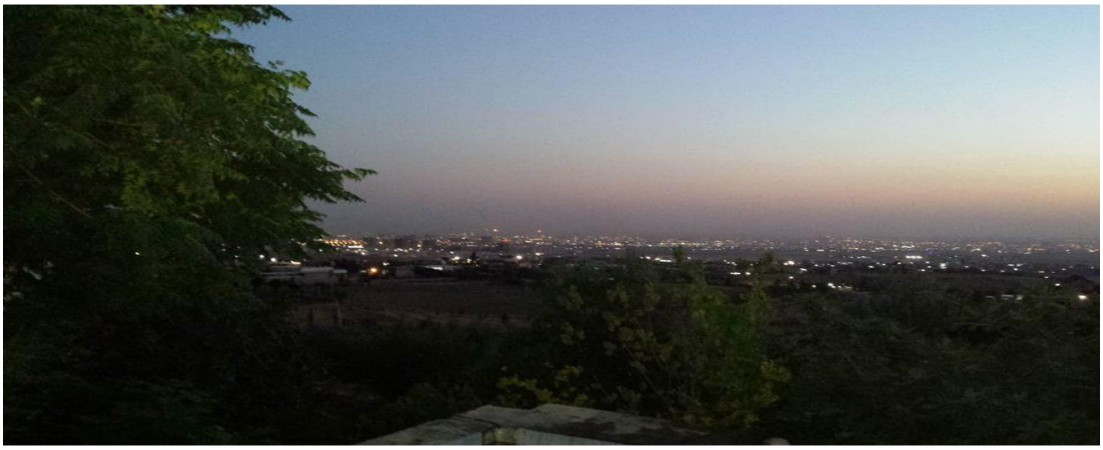


**Figure 4.1** View of southwest polluted area of Erbil city.

### 4.1.4 Oil industry map of Erbil city

The Oil industry map of Erbil city contains the followings;

1- Oil fields, the major one called khormalla (30 km south of the city and its location is, latitude 35.97.57.98 and Longitude 43.76.71.31), which is the main crude oil source for Kawergosk refinery.

2- Main refineries, the major one called Kawergosk. (20 km east of the city and its location, is Latitude 36.32.41.86 and Longitude is 43.80.97.06).

3- Small size refineries; they are around 150, distributed on south-east of Erbil municipal area.

Details of the oil industry map are shown in Figure 4.2.

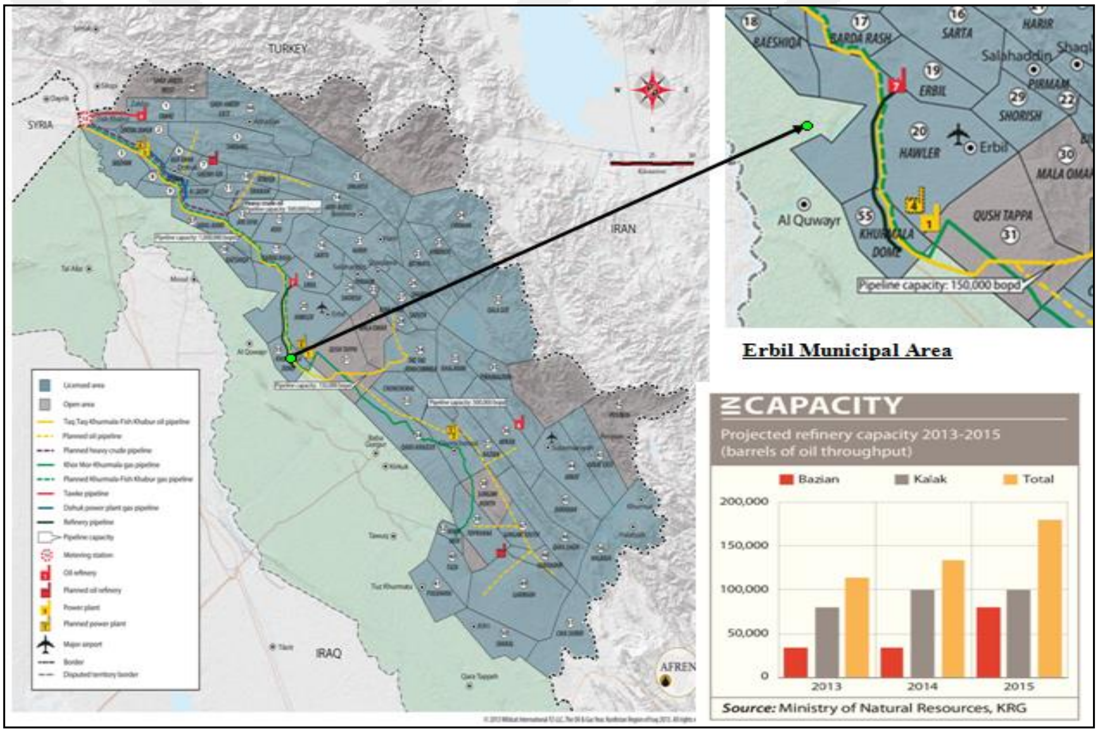



**Figure 4.2** Locations of the oil fields and refineries in north of Iraq (Kurdistan region).

### 4.1.5 Air pollution problems

There is no doubt that air pollution is detrimental to health, especially to the respiratory system. The undesirable system may damage human health, vegetation, human properly or the global environment as well as create aesthetic insults in the form of brown or hazy air or unpleasant smells.

Primary and secondary pollutant are both widely available in the city of Erbil, some of them are toxic air pollutants which cause serious health effects, especially in south-west of the city, in which most of the oil fields and refineries exist, besides the major municipal solid waste wild dumping also located there, (near Kane qrzhala village).

Air pollutions in this area have been investigated as follows;

**First:** By measuring toxic gases (CaO and $H_2S$), using a Drager x-am device which is a malty measurement gas recorder. Drager device has been used to investigate the harmful gases mainly $H_2S$ and Co emitted from the oil fields and refineries and from the other places in the south-west of Erbil city in order to obtain the polluted environmental map. Details of the mentioned distributed gases in various locations are illustrated and discussed in chapter 5.

**Second:** By conducting a site questionnaire to collect data from the citizens living in the polluted area (south-east of Erbil city), this survey includes five points, age, gender, education level and the two necessary, related questions; Do you care about the pollution made by oil fields and refineries? Do you think that the oil fields and refineries affect your life in the following fields, health, weather, agriculture and others if available?

Fifty persons were selected for conducting this questionnaire, having various ages (16 years – above 60 years), 38 male and 12 female. The education level of them was, primary school (10), High school (11), Diploma (9), University degree (16) and postgraduate (4).

**Third:** Soil contamination was investigated in (Kawergosk) refinery; Figure 4.3, this refinery has a modern wastewater treatment plant, Figure 4.4. In past, this refinery was releasing its waste to the surrounding area and caused many environmental problems, especially soil contamination, (this disaster process still occur in most small existing refineries in the south-west of Erbil).

**Figure 4.3** Night view of Kawergosk refinery.

**Figure 4.4** Kawergosk wastewater treatment plant.

Now they established a modern wastewater treatment plant, (normally its cost is nearly 5% of the total cost of the refinery), by this plant they controlled the oily wastewater and minimized its pollution effect. For emergency cases, they constructed large Lagoons, Figure 4.5, and they throw the excess waste in it for the late recycling.


**Figure 4.5** View of a 50m*50m*3m depth, Lagoon with study area.

To examine the degree of soil contamination in the Lagoon site with oily wastewater, five samples were taken in all sides; their chemical contamination percentages have been found.

## 4.2 Geotechnical laboratory studies for site investigation

### 4.2.1 Introduction

Soil contamination is defined as the change in physical, chemical and biological conditions of the soil through man's intervention resulting in the degradation in quality and productivity of the soil.

Soil contamination problems are increased recently due to the increase of industrial wastes such as petroleum hydrocarbon, organic solvents, heavy metals and wide-range use of agricultural fertilizer. Its effect on geotechnical properties of soils has been widely observed nowadays.

All types of pollution have direct or indirect effects on ground soil properties. Soil-waste in interaction can affect almost the properties of soil such as index limits, compressibility, shear strength, permeability and consolidation.

The modification of soil properties can lead to various geotechnical problems such as Land-Slides, Settlement, Erosion, Underground structural stability and Foundation durability.

It's necessary to apply a correct method for safe disposal of wastes, this becomes a challenging task for geotechnical engineering in general and environmental engineering in particular.

Ground monitoring from the begging of the project is necessary instead of waiting for a complete failure of the ground to support human activities and then start remedial actions, therefore contaminated soil becomes a major problem to be studied in Erbil region especially near oil fields and refineries.

The presence of the oil industry in Erbil became active since 2000, so it's important to study the polluted areas and take necessary actions to overcome the various unexpected geo-environmental problems such as decreasing its bearing capacity, leads in increasing settlement of the foundation of structures. In this study, the work has been divided into two main parts, laboratory tests that include physical, chemical and engineering tests and the site test part, which includes developing a model in the site. Details of the testing program are presenting in this chapter.

### 4.2.2 Sampling and soil properties

The soil samples were taken from the Cihan University site, which is near the civil engineering department that has almost similar soil characteristics the same as the soil properties of the Kawergosk refinery site. The excavation of soil has been performed by digging two pits up to 50 cm depth using hand excavation tools. After that, the disturbed samples were taken from various locations of the pits and packed in plastic bags then transported to the soil mechanic laboratory of the civil engineering department.

#### 4.2.2.1 Classification test

##### 4.2.2.1.1 Particle site distribution

Sieve analysis test was used for determining the grain-site distribution of the soil sample according to the ASTM (D 422-O2), the result of the grain-size distribution and hydrometer analysis are shown in Figure 4.6.

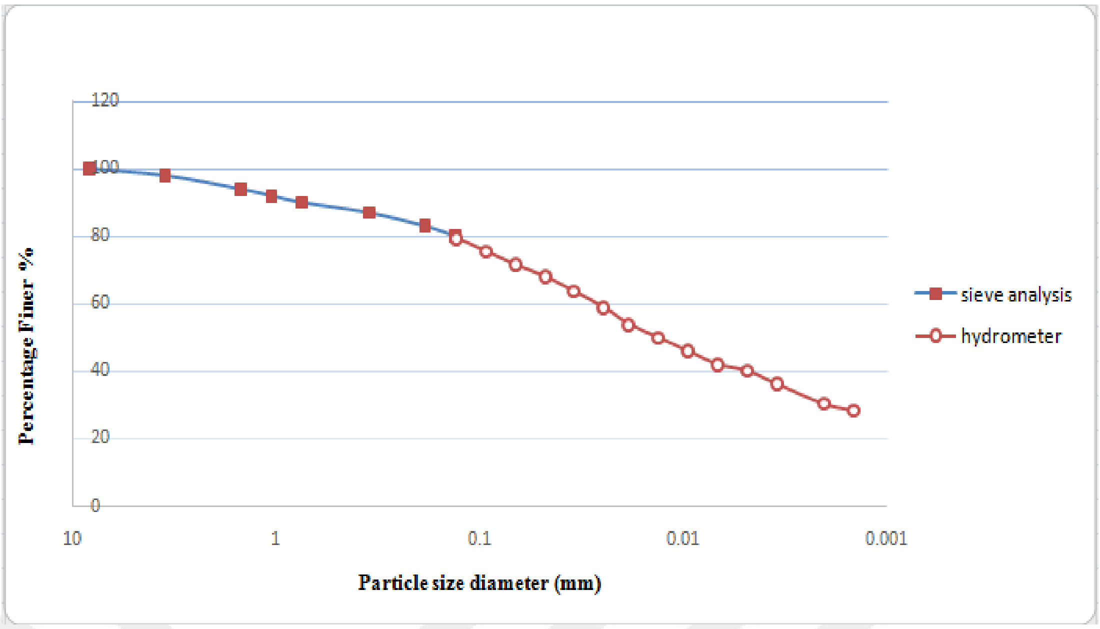



**Figure 4.6** Grain-size distribution curve.

#### 4.2.2.1.2 Specific gravity

ASTM (D 854-O2) specifications have been used for determining the specific gravity of the soil sample; the results are shown in Table 4.1.

#### 4.2.2.1.3 Field dry density

Field dry density was determined at the site by using a sand cone test method; the test was carried out according to the ASTM (D 2167-94), the results are shown in Table 4.1.

#### 4.2.2.1.4 Moisture content

Using ASTM (D 2216-98) has determined the moisture content of the soil sample; the results are shown in Table 4.1.

#### 4.2.2.1.5 Atterberg limits

Atterberg limits (liquid limit and plastic limit) for soil samples through passing sieve number 40 have been determined using ASTM (D 4318) specifications, the results are shown in Table 4.1.

**Table 4.1** Physical properties of soil**.**

| Properties | | Soil Sample |
|---|---|---|
| Moisture Content, (ω) % | | 5.6 |
| Specific Gravity, (Gs) | | 2.7 |
| Atterberg Limits | Liquid Limit (L.L) % | 37.8 |
| | Plastic Limit (P.L) % | 14.7 |
| | Plasticity Index (P.I) % | 23.1 |
| M.I.T classification | Gravel % | 4.0 |
| | Sand % | 26 |
| | Silt% | 24 |
| | Clay% | 46 |
| Coefficient of Uniformity (Cu) | | 24.7 |
| Coefficient of Curvature (Cc) | | 0.16 |
| Unified Soil Classification | | (CL) Lean Clay with Sand |
| Field Unit Weight ($\gamma_t$) gm/cm$^3$ | | 1.40 |

#### 4.2.2.2 Chemical test

Several chemical tests were conducted for uncontaminated soil samples in the Erbil governorate central laboratory; the results are shown in Table 4.2.

**Table 4.2** Chemical tests for uncontaminated soil samples.

| Chemical Parameters | Results |
|---|---|
| Sulphate (%) | 0.067 |
| Chloridate (%)) | 0.039 |
| Total Soluble Salt (TSS) (%)) | 0.021 |
| Carbonates (%)) | 41.2 |
| Gypsum (%) | 0.144 |
| pH | 8.18 |

#### 4.2.2.3 Sample preparation

##### 4.2.2.3.1 Sample preparation for uncontaminated soils

The natural soil samples were prepared for conducting all engineering tests in the laboratory using the same field site and density in order to represent undisturbed sample properties and then used for conducting Atterberg limits, one-dimensional consolidation test and direct shear test to examine.

##### 4.2.2.3.2 Sample preparation for contaminated soils

The dried samples were mixed with oily wastewater which has been brought from the refinery that contains less than %15 oil using different percentages (%5, %10, %15 and %20) in relative with the dry weight of the samples separately and left for four days in air tight plastic bags so as to reach a homogenous and uniform texture as shown in Figure 4.7.

The contaminated samples were used for conducting all engineering tests using the same site field density results to represent as an undisturbed sample. Table 4.3 shows the process of sample preparation for all executed engineering tests. Figure 4.8 shows oily waste water before and after drying in the oven for 24 hours.

**Figure 4.7** Contaminated soil samples.

**Table 4.3** Sample preparation for mechanical tests.

| Permeability Test sample preparation | | | |
|---|---|---|---|
| | gm/cm3 | Volume of Mold cm3 | Weight of dry soil (gm) |
| Gama Dry | 1.4 | 1107 | 1549.80 |
| w.c% | 0.056 | 1549.8 | 86.79 |
| oil % | 0.05 | 1549.8 | 77.49 |
| Total weight | | | 1714.08 |
| Gama Dry | 1.4 | 1107 | 1549.80 |
| w.c% | 0.056 | 1549.8 | 86.79 |
| oil % | 0.1 | 1549.8 | 154.98 |
| Total weight | | | 1791.57 |
| Gama Dry | 1.4 | 1107 | 1549.80 |
| w.c% | 0.056 | 1549.8 | 86.79 |
| oil % | 0.15 | 1549.8 | 232.47 |
| Total weight | | | 1869.06 |
| Gama Dry | 1.4 | 1107 | 1549.80 |
| w.c% | 0.056 | 1549.8 | 86.79 |
| oil % | 0.2 | 1549.8 | 309.96 |
| Total weight | | | 1946.55 |

| Direct Test sample preparation | | | |
|---|---|---|---|
| | gm/ cm3 | Volume of Mold cm3 | Weight of dry soil (gm) |
| Gama Dry | 1.4 | 90 | 126.00 |
| w.c% | 0.056 | 126.00 | 7.06 |
| oil % | 0.05 | 126 | 6.30 |
| Total weight | | | 139.36 |
| Gama Dry | 1.4 | 90 | 126.00 |
| w.c% | 0.056 | 126 | 7.06 |
| oil % | 0.1 | 126 | 12.60 |
| Total weight | | | 145.66 |
| Gama Dry | 1.4 | 90 | 126.00 |
| w.c% | 0.056 | 126 | 7.06 |
| oil % | 0.15 | 126 | 18.90 |
| Total weight | | | 151.96 |
| Gama Dry | 1.4 | 90 | 126.00 |
| w.c% | 0.056 | 126 | 7.06 |
| oil % | 0.2 | 126 | 25.20 |
| Total weight | | | 158.26 |

| Consolidation Test sample preparation | | | |
|---|---|---|---|
| | gm./cm3 | Volume of Mold cm3 | Weight of dry soil (gm) |
| Gama Dry | 1.4 | 62.4 | 87.36 |
| w.c% | 0.056 | 87.36 | 4.89 |
| oil % | 0.05 | 87.36 | 4.37 |
| Total weight | | | 96.62 |
| Gama Dry | 1.4 | 62.4 | 87.36 |
| w.c% | 0.056 | 87.36 | 4.89 |
| oil % | 0.1 | 87.36 | 8.74 |
| Total weight | | | 100.99 |
| Gama Dry | 1.4 | 62.4 | 87.36 |
| w.c% | 0.056 | 87.36 | 4.89 |
| oil % | 0.15 | 87.36 | 13.10 |
| Total weight | | | 105.36 |
| Gama Dry | 1.4 | 62.4 | 87.36 |
| w.c% | 0.056 | 87.36 | 4.89 |
| oil % | 0.2 | 87.36 | 17.47 |
| Total weight | | | 109.72 |

| Triaxial Test sample preparation | | | |
|---|---|---|---|
| | gm/ cm3 | Volume of Mold cm3 | Weight of dry soil (gm) |
| Gama Dry | 1.4 | 86.19 | 120.67 |
| w.c% | 0.056 | 120.67 | 6.76 |
| oil % | 0.05 | 120.6698305 | 6.03 |
| Total weight | | | 133.46 |
| Gama Dry | 1.4 | 86.19 | 120.67 |
| w.c% | 0.056 | 120.6698305 | 6.76 |
| oil % | 0.1 | 120.6698305 | 12.07 |
| Total weight | | | 139.49 |
| Gama Dry | 1.4 | 86.19 | 120.67 |
| w.c% | 0.056 | 120.6698305 | 6.76 |
| oil % | 0.15 | 120.6698305 | 18.10 |
| Total weight | | | 145.53 |
| Gama Dry | 1.4 | 86.19 | 120.67 |
| w.c% | 0.056 | 120.6698305 | 6.76 |
| oil % | 0.2 | 120.6698305 | 24.13 |
| Total weight | | | 151.56 |

**Figure 4.8** Oily wastewater before and after drying in the oven for 24 hours.

Table 4.4 shows the specification of oily wastewater, which has been brought from the inlet of wastewater treatment plant of Kawergosk refinery. From the Table, it can be seen that the oily wastewater contains %15 oil and %85 water, therefore the effect of oil viscosity and density of the fluid have been almost neglected in this investigation. In another hand, it can also be seen from the Table that the oily wastewater is in the moderate interval for irrigation purposes by comparing with FAO 1985 and Turkish standards. Therefore, no need to be diluted by adding drinking water. The major problem is the amount of 15% of oil have to be removed or minimized for irrigation water use, because it contains hydrocarbon which is harmful for agriculture. In order to dilute 15% of oily waste water (OWW) and later on to be used for irrigation, for example, 0.08% of remained oil (after mixing of treated OWW with the greater zab river GZR), which have been reported by Aziz and Fakhrey (2016) and later on could be used for irrigation purposes (Aziz,2007). For determining the impact of OWW on river water, Mass Balance Principle (MBP) can be used (Davis and Cornwell, 2008)

Based on MBP, the following equation were obtained,

1- If drinking water used for dilution of OWW with oil content of 15% to 0.08%

**Drinking water discharge = 10.346 x Oily wastewater discharge**

2- If Greater Zab river used for dilution of OWW with oil content of 15% to 0.08%

**GZR discharge = 186.5 x Oily wastewater discharge**

**Table 4.4** Kawergosk oily wastewater sample properties.

#### 4.2.2.4 Geotechnical tests

| Test | Unit | In-let | FAO 1992standards for irrigation | Turkish standards for irrigation | WHO 2011,standards for drinking water |
|---|---|---|---|---|---|
| ECw | µs/cm | 1745 | 700-3000 | 700-3000 | 1000 |
| TDS | ppm | 872.5 | 450-2000 | 500-2000 | 500 |
| Calcium (Ca) | ppm | 5 | 20 | 20 | 200 |
| Magnesium (Mg) | ppm | 3.13 | 60 | 30 | 30 |
| Sodium (Na) | ppm | 14.11 | 900 | 900 | 200 |
| Chloride (Cl) | ppm | 0.33 | 4-10 | 4-10 | 5 |
| Iron (Fe) | ppm | 2.3 | 5 | 0.1-1.5 | 0.3 |
| Nitrate ($NO_3$) | ppm | 26 | 5-30 | 10-30 | 50 |
| pH | | 9.4 | 6.5-8.4 | 7-8 | 6.5-9.5 |
| Oil | % | 15 | | | |
| Water Content % | % | 85 | | | |

Due to the low values of field density and difficulties of preparing undisturbed samples, the remolded process of preparing samples were selected in the laboratory in order to reach the existing field density for conducting the following tests for both contaminated 5%,10%,15% and 20% of oily wastewater and uncontaminated soil samples. Table 4.5 shows the results of mechanical tests for uncontaminated soil samples.

**Table 4.5** Mechanical test results for uncontaminated soil samples**.**

| Mechanical Test | Results | |
|---|---|---|
| Direct Shear | Cohesion (C) | Angle of Internal Friction ($\Phi^o$) |

<table>
<tr><td></td><td colspan="2">20</td><td colspan="2">25</td></tr>
<tr><td rowspan="8">1D Consolidation</td><td colspan="2">Cv m2/year</td><td>Cc</td><td>Cr</td></tr>
<tr><td>Stress (kPa)</td><td>Results</td><td rowspan="7">0.2533</td><td rowspan="7">0.0412</td></tr>
<tr><td>25</td><td>2.007</td></tr>
<tr><td>48</td><td>1.934</td></tr>
<tr><td>96</td><td>1.810</td></tr>
<tr><td>190</td><td>1.620</td></tr>
<tr><td>379</td><td>1.640</td></tr>
<tr><td>756</td><td>1.610</td></tr>
<tr><td rowspan="7">Permeability</td><td>Stress (kPa)</td><td colspan="3">m/year</td></tr>
<tr><td>25</td><td colspan="3">0.00525</td></tr>
<tr><td>48</td><td colspan="3">0.0050</td></tr>
<tr><td>96</td><td colspan="3">0.0048</td></tr>
<tr><td>190</td><td colspan="3">0.0045</td></tr>
<tr><td>379</td><td colspan="3">0.0040</td></tr>
<tr><td>756</td><td colspan="3">0.0035</td></tr>
</table>

#### 4.2.2.4.1 Direct shear test according to ASTM (D 3080-72)

The direct shear test has chosen for conducting several tests on both uncontaminated and contaminated soil samples with 5%.10%.15% and 20% oily wastewater, in order to investigate its effect on the values of Cohesion (C) and angle of internal friction $\phi$. The results of uncontaminated soil samples are shown in Table 4.5.

#### 4.2.2.4.2 D Consolidation test according to ASTM (D 2435)

One dimensional consolidation tests were carried out on the soil samples to investigate its compressibility, coefficient of consolidation, rate of swelling, and coefficient of permeability K, then making a comparison between the results obtained from testing both uncontaminated and contaminated soil samples. The results of uncontaminated soil samples are shown in Table 4.5.

#### 4.2.2.4.3. Permeability (falling head method) test according to ASTM (D 5084)

A series of permeability tests (Falling head method) have been conducted on both uncontaminated and contaminated soil samples with the same percentages of oily wastewater, to examine its behavior and determining their K values and then comparing the site and laboratory test results obtained from consolidation tests. The results of uncontaminated soil samples are shown in Table 4.5.

The results of all mechanical tests are illustrated in chapter 5 for a comprehensive discussion.

## 4.3 Field investigation tests

### 4.3.1 Introduction

Field investigation test regarding soil contaminations inside the pit model was the final stage of this study to examine the effect of oily wastewater on soil contamination and comparing the results with those obtained from the laboratory.

### 4.3.2 Field site preparation

A trial pit model was prepared in the site of Cihan University, near the soil laboratory for;

- Selecting soil samples for the lab test.
- Conducting field tests.
- Investigating field oil penetration (diffusion) rates.

The pit was excavated using a mechanical shovel and covered by a nylon selling to protect the pit from the weather. Figure 4.9, shows the dimension of the pit model.

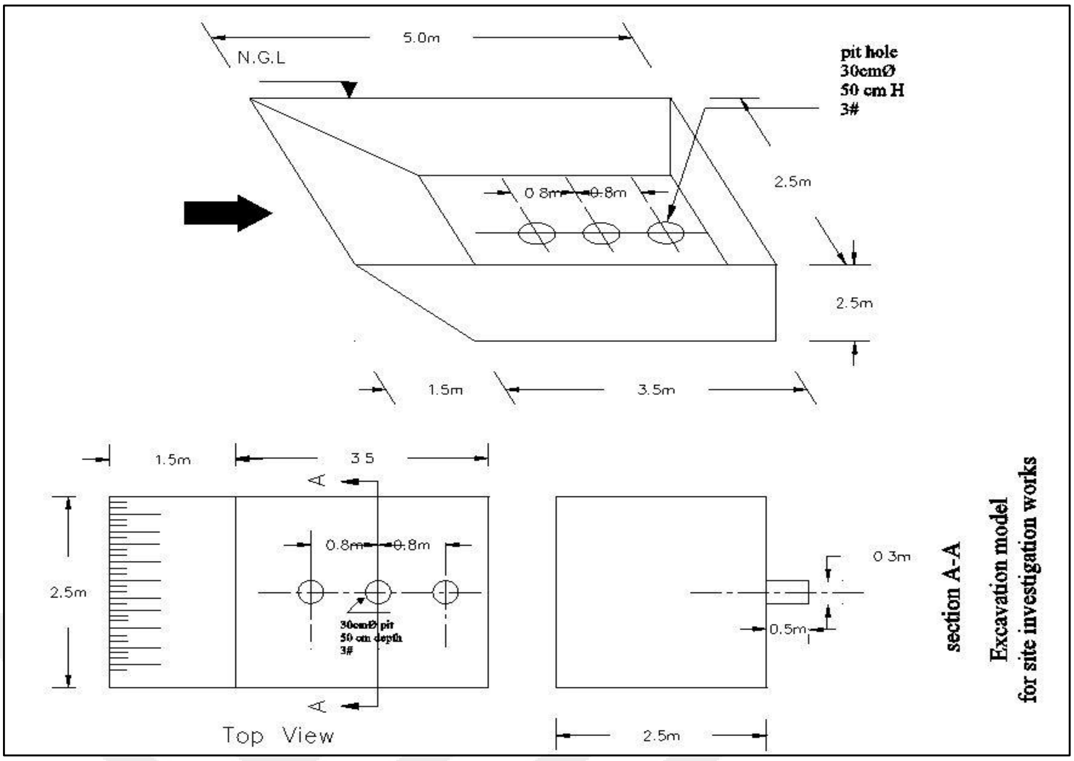



**Figure 4.9** Model pit diagram.

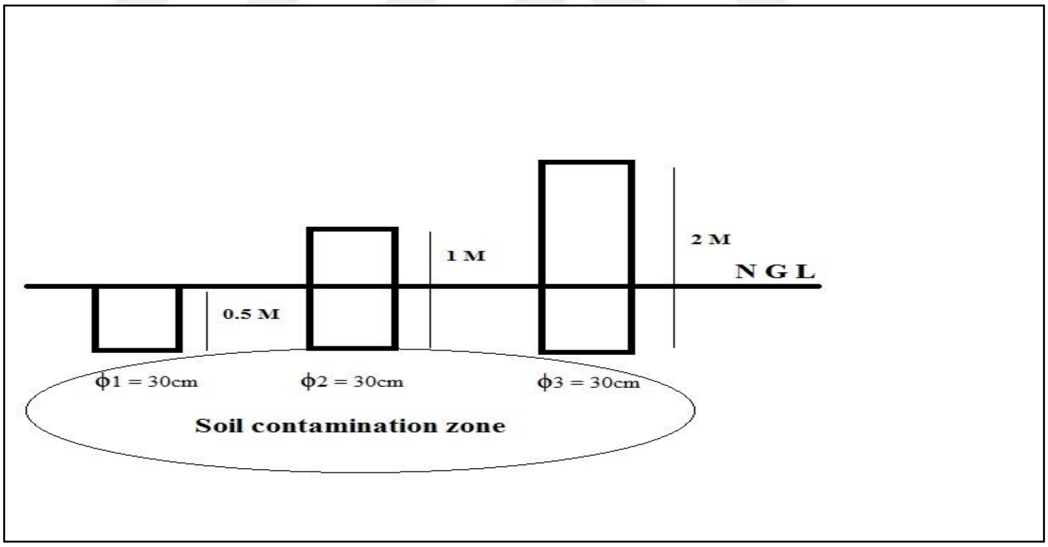



**Figure 4.10** Front view of the examined pits**.**

**NGL**: Normal Ground Level

Inside the model, it was possible to dig three holes (pits) with dimensions 30cm diameter and 50cm depth for each. Then three plastic pipes (30cm diameter) fixed inside the holes having the length of 50cm, 150cm, 200cm as shown in Figure 4.10 and 4.11.

**Figure 4.11** Views of the examined pit.

### 4.3.3 Procedure of the work

The procedure of the work started by filling the first hole (0.5m head), with oily wastewater until the surface, the oily wastewater seeps into the soil both horizontally and vertically, time versus oily wastewater percolation were recorded until the oily wastewater disappeared inside the pipe, then the percolation with time recorded. The same procedure repeated for the other two holes, (1m head and 2m head) in different interval times in order to control the process properly. Details of the diffusion rate results for all three pressure heads and a comparison between chemical components for all three tests have been comprehensively discussed in chapter 5.

## 4.4. Research program flowchart

The diagram of the work program are shown in Figure 4.12.

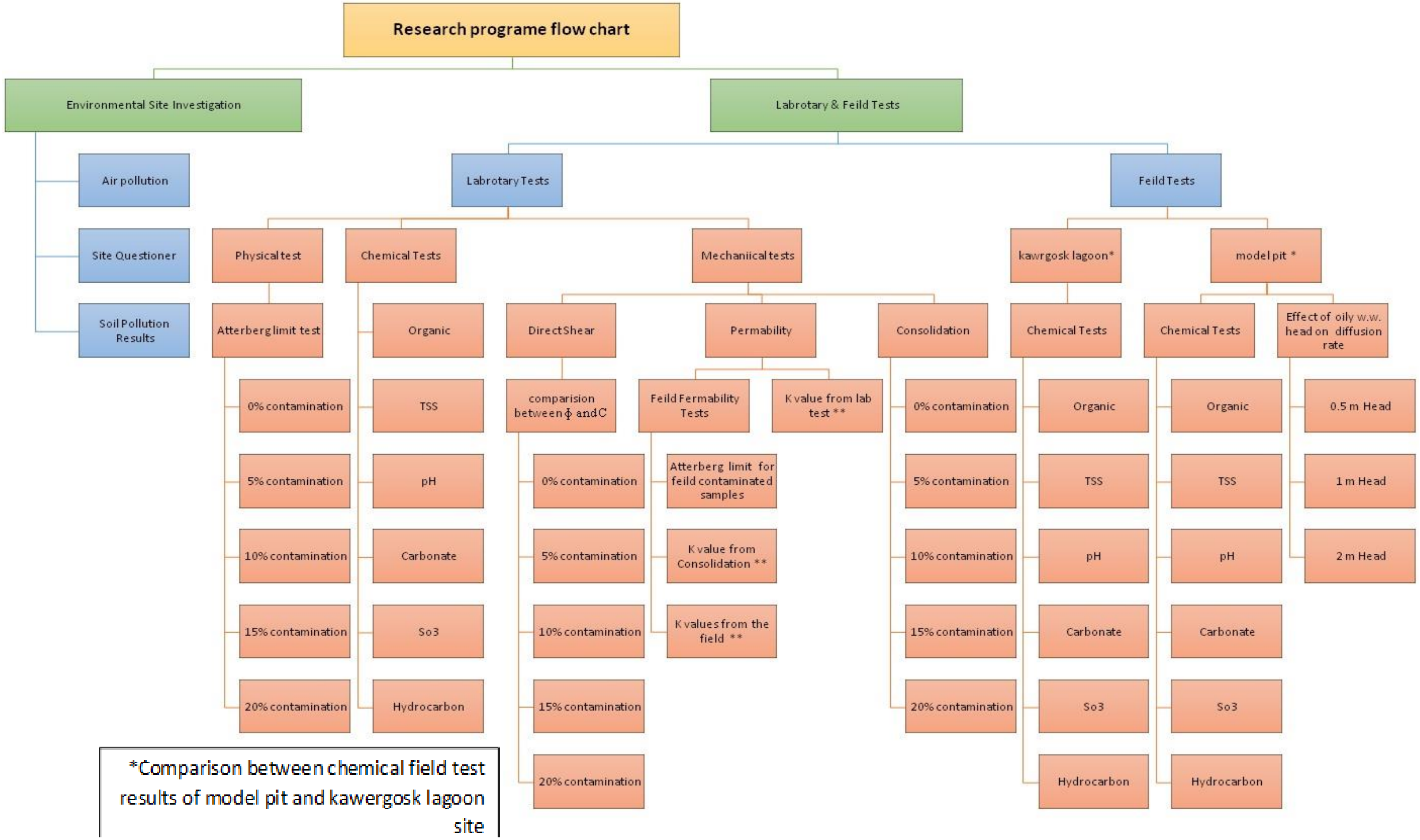



**Figure 4.12** Laboratory and field tests flow chart.

# CHAPTER 5

# RESULTS AND DISCUSSIONS

## 5.1 Environmental site investigation

Environmental site investigation stage of this work is covered the polluted area of the south west of Erbil city (from the main oil field, Khormala in the south up to the main refinery Kawergosk in the west).

### 5.1.1 Discussion of air pollution results

Air pollution results have been shown for various locations in the southwest of the city. From Table 5.1, CO has been observed in most of the recorded places. The range of CO was from 0 ppm in Mastawa village, Tobzawa village up to 8 ppm in Kani Qrzhala (the main Erbil municipal solid waste dump located in Kani Qrzhala), which is harmful, colorless, odorless gas and harmful for the human. This type of gas is mainly emissions from the various factories and small size refineries distributed along the wide area. In the same Table, $H_2S$ was seen in the main oil field called Khormala. The range of $H_2S$ gas in the Khormala oil field was from 5.2 up to 10.4 ppm, Table 5.1. This type of gas is also dangerous for the human and should be controlled regularly on an hourly basis. If the amount of emissions is above the international standards, the production should be stopped for a while until it returns to the standard level. The record of CO is widely seen in most of the refinery sections, the range is from 0 to 91.5 ppm in the Area 1000. Emission of $H_2S$ was limited in the refinery, which is a desirable indication for the refinery environment, and surrounding areas, which is among the standards of EPA (Environmental Protection Agency) for which ambient air standards have been set to protect human health and welfare.

**Table 5.1** Distribution of (CO and $H_2S$) in various locations of south west of Erbil in July 2018.

| Date Readings | Darin Steel Co. | Coca Cola Co. | Bedyoul Co. | Khabt Po.St.Co. | Iraq Oil Co. | Khabat Co. | Tobzawa Co. | Kaniqrzhala Co. | Bnberz Village Co. | Mastawa Village Co. | Helawa Village Co. | Khurmal Oil Field (H2S) | USPA NAOO Standards |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 4 | 2 | 3 | 2 | 4 | 6 | 0 | 4 | 2 | 2 | 3 | 10.4 | 35 ppm in one hour |
| 2 | 4 | 2 | 4 | 2 | 3 | 5 | 0 | 3 | 2 | 2 | 4 | 11.8 | |
| 3 | 2 | 2 | 2 | 2 | 2 | 5 | 2 | 6 | 2 | 2 | 3 | 8.7 | |
| 4 | - | - | - | - | - | - | - | 8 | - | - | - | 9.6 | |
| 5 | 2 | 2 | 3 | 2 | 3 | 4 | 2 | 4 | 2 | 2 | 3 | 7.2 | |
| 6 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 4 | 2 | 0 | 2 | 5.2 | |

**Table 5.2** $H_2S$ distribution in Kawergosk refinery for July 2018/ Units in (ppm).

| Location | reformer | Heaters | A200 | Battery limit | K300 | System gas | Merox area | Palnt C | Blant B | Crude reciver | Area 1000 | USEPA NAAO |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 9:00 | 0.2 | 0 | 5.2 | 0.7 | 2.8 | 0.1 | 0 | 0.1 | 0.3 | 0.5 | 80 | 5 ppm |
| 11:00 | 3 | 0 | 10.4 | 7.8 | 5 | 0 | 0 | 0.3 | 0.8 | 0 | 49 | |
| 13:00 | 3.1 | 0 | 11.1 | 0 | 1.7 | 0.3 | 0.2 | 0.5 | 0.5 | 0 | 85 | |
| 15:00 | 2.8 | 0.2 | 9.6 | 0.1 | 1.5 | 0.1 | 0.1 | 0.2 | 0.1 | 0 | 65 | |
| 17:00 | 3 | 0.1 | 10.1 | 0.2 | 1.6 | 0.2 | 0 | 0 | 0.4 | 0 | 58 | |
| 20:00 | 1 | 0 | 0 | 0 | 1.7 | 0.1 | 0 | 0.5 | 0.7 | 6.2 | 91.5 | |
| 22:00 | 0.8 | 0 | 0.9 | 0 | 2.1 | 0 | 0 | 0.1 | 0.2 | 5.1 | 75.5 | |
| 24:00 | 0.2 | 0 | 0.7 | 0 | 3.5 | 0 | 0.2 | 0.2 | 0.1 | 20.2 | 66.2 | |
| 2:00 AM | 0 | 0 | 0.5 | 0 | 4.5 | 0 | 0 | 0.1 | 0 | 19.1 | 70.5 | |
| Average | 1.56 | 0.03 | 5.38 | 0.97 | 2.71 | 0.08 | 0.05 | 0.22 | 0.34 | 5.67 | 71.18 | |

The distribution of $H_2S$ in the Kawergosk refinery units for a day in July 2018 are shown in Figure 5.1, where the maximum results are observed in area 1000 unit

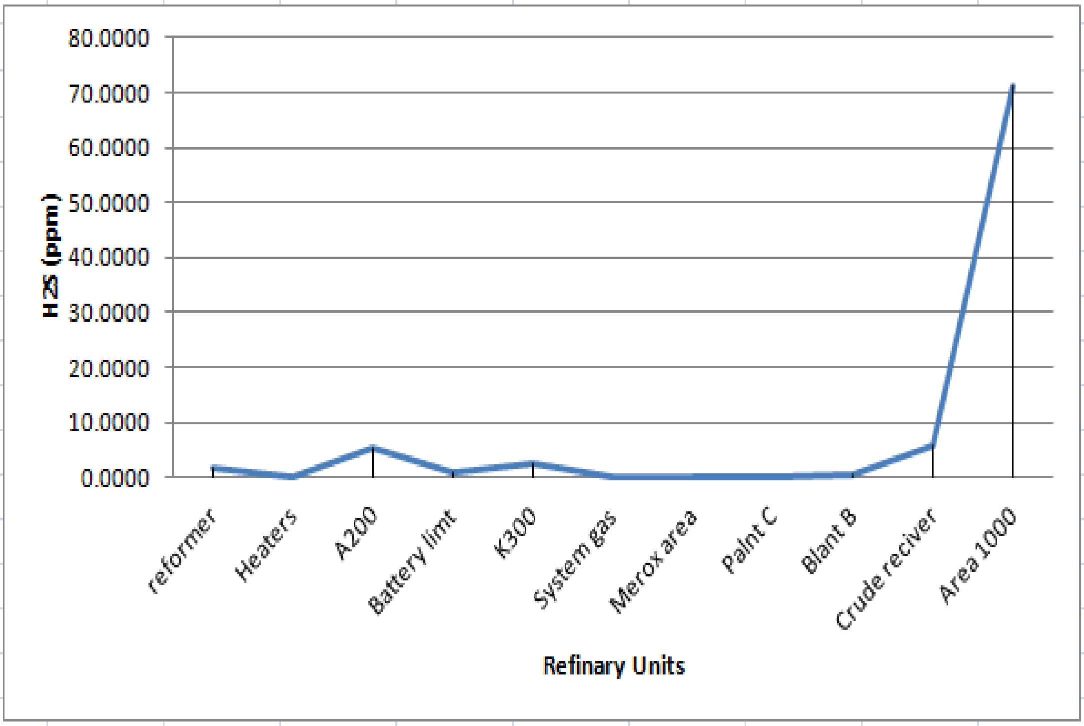



**Figure 5.1** Distribution of $H_2S$ in the refinery units.

A comparison between the results of $H_2S$ in both the Kawergosk refinery and Khurmala oil field is shown in Figure 5.2, from the Figure can be noted that the values of $H_2S$ in Khurmala oil field are much higher than those in Kawergosk refinery.

Comparing the results with those fixed by both United States Environmental Protection Agency (USEPA) and National Ambient Air Quality Organization (NAAO), which is 5 ppm it can be observed that in Kawergosk refinery the average record for one day in July 2018 was 10 ppm which almost exceeds the standard line. High results were recorded in area 1000 units, while zero-result noticed in many other areas of the refinery.

Regarding the Khurmala oil field, the maximum record was 10.4 ppm and the lowest record was 5.2 ppm for one day in July 2018, the average record was 8.8 ppm in which a slight exceed is noticed from the standard.

In conclusion, the results of $H_2S$ in Khurmala oil field records higher than in Kawergosk refinery (except the record of area 1000).

Comparing the results of CO in different locations in Southwest of Erbil Table 5.1 and Figure 5.3, with those fixed by USEPA and NAAO, which is 35 ppm in one hour, it can be noted that they are below the standards, therefore, the pollution is not exposed to excessive level of CO during the recorded period, although the rate of Co value could become higher in future.

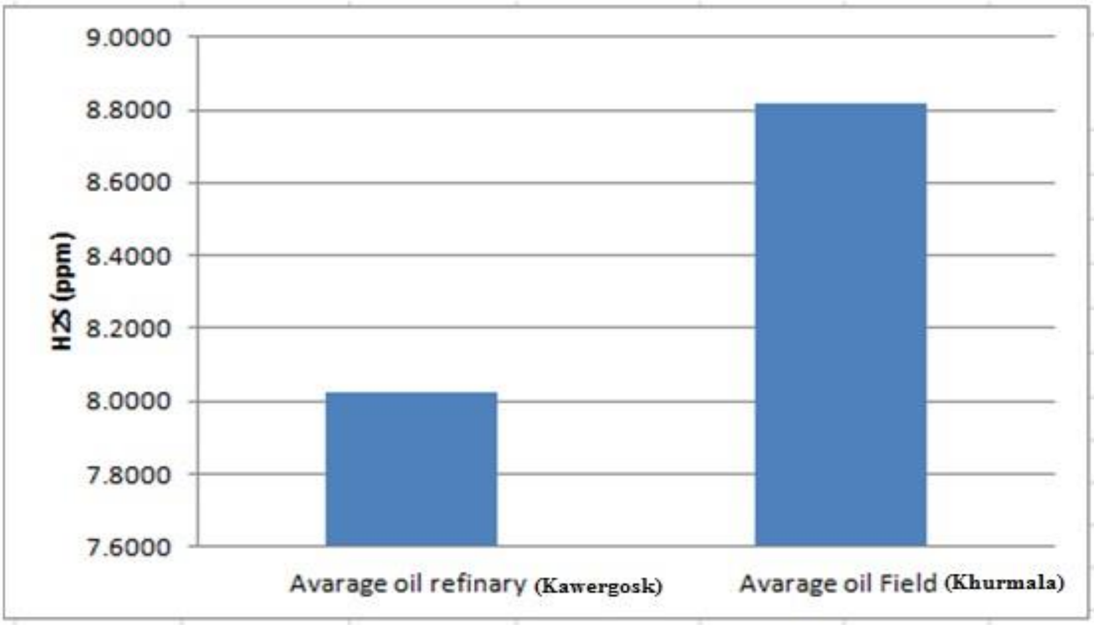
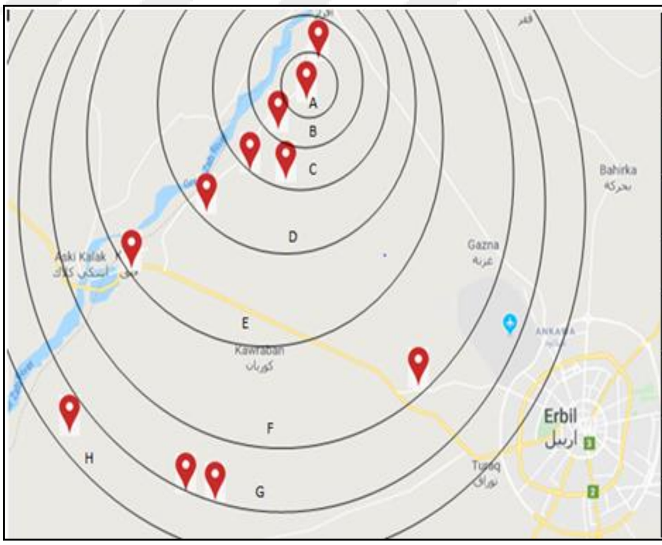



**Figure 5.2** Comparison results of $H_2S$ between Khurmala oil field and Kawergosk refinery.




| Locations | Zone | CO (Avg) ppm |
|---|---|---|
| Kawrgosk | A | Refinery center |
| Darinsteel, Iraq oil | **B** | 2.3 , 2.3 |
| Tobzawa. , Cocoa Cola | C | 1, 1.6 |
| Bedyoil st | D | 2.3 |
| Khabat , khabat st. | E | 3.6, 1.6 |
| Kaniqirzhal | F | 4.8 |
| Helawa | G | 2.5 |
| Mastawa | H | 1.3 |

**Figure 5.3** Distribution of CO in various locations in south west Erbil July 2018**.**

The results of the measurements gases in most of the affected areas in the south west of Erbil city are shown in the map of the city, Figure 5.4.

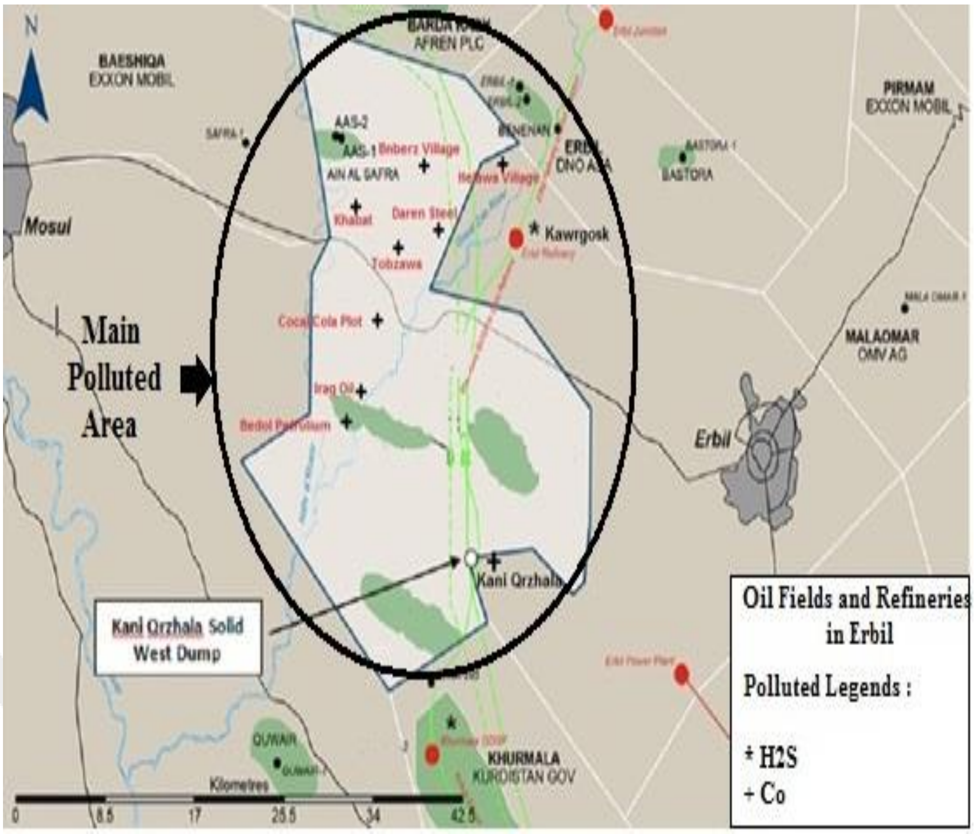



**Figure 5.4** Pollution map of Erbil city.

### 5.1.2 Site questionnaire discussion of the results

A site questionnaire survey was covered in most of the polluted area between the oil fields and, refineries. Three categories were chosen, age, gender, educational level and, two main necessary related questions;

1- Do you care about pollution situations?
2- Did the situation affect your life in the fields of health, weather and, agriculture?

The results of the 50% having the education level from primary school up to post-graduation degree, which has been shown in the Figure 5.5, concluded that the majority would care about the pollutions made by the existing oil fields and refineries. Moreover, more than 50% of them thought that the oil fields and refineries have affected their health and the remaining of them thought that agriculture production was also affected.

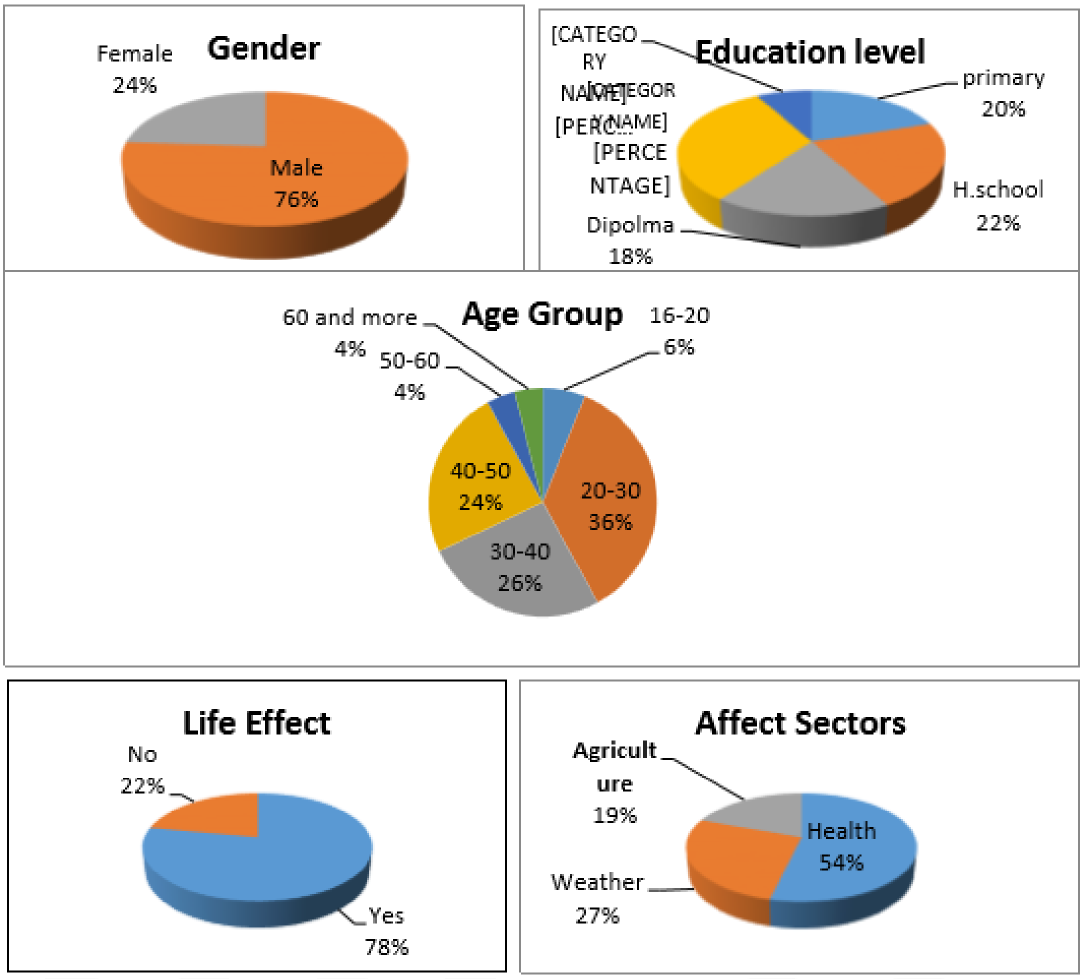



**Figure 5.5** Questionnaire results. Pie charts.

### 5.1.3 Kawergosk Refinery Soil Contamination Discussion of the Results

Five samples around the main Lagoon have been taken to the laboratory for examining the hydrocarbon content. Results of the test in Table 5.3, shows that the percentage of hydrocarbon contamination in soil sample varied from zero to 4 percent. The average value of all samples was 1.5 %. The results of the $H_2S$ were negative. Table 5.4 shows the chemical parameters contamination for four samples in the side of the lagoon for the depths from 1.5m-3m and inside distance 1.5 m – 4 m. the results of organic, pH, $SO_3$ and hydrocarbon were increased with the increase of the depth, while TSS and pH decreased. Therefore, the outside soil, either to be removed or remediated for agricultural and urban development uses in the future.

**Table 5.3** a) Soil contaminated results with oily wastewater in the inside refinery Lagoons.

| **Sample location** | **Sample 1 Dark color** | **Sample 2 Dark color** | **Sample 3 Dark color** | **Sample4 Dark color** | **Sample 5 Light color** | **Average** |
|---|---|---|---|---|---|---|
| Volume% of Hydrocarbon | 2.0% | 4.0% | 1.0% | 0.5% | 0.0 % | 1.5% |
| $H_2S$ | negative | negative | negative | negative | negative | negative |

**Table 5.4** Soil contamination with oily wastewater for the outside of the Kawergosk refinery Lagoon.

| **Sample Location** | **Organic %** | **TSS %** | **PH %** | **Carbonate %** | **SO3 %** | **Hydrocarbon %** |
|---|---|---|---|---|---|---|
| **S1 (3 m depth, 4 m far from the base)** | **5.85** | **0.02** | **0.52** | **2** | **0.009** | **3** |
| **S2 (2.5 m depth, 3m far from the base)** | **4.64** | **0.07** | **0.51** | **3** | **0.001** | **2** |
| **S3 (1.5 m depth, 2m far from the base)** | **0.46** | **0.08** | **0.37** | **3.2** | **0.006** | **1** |
| **S4 (1.5 m depth, 1.5m far from the base)** | **1.1** | **0.07** | **0.56** | **12.6** | **0** | **0.5** |

From the soil pollution results of the Lagoon site of the refinery, one can imagine that huge lands would be polluted regularly, especially in small refinery zones which they have no oily wastewater treatment plant.

Governmental authorities have recently decided to take necessary actions to accelerate control of the pollution problems in the region, especially in Erbil municipal area, also taking necessary procedures to protect the environment and health of citizens in order to distinguish between people’s live, environment and the provision of fuel.

Finally, standards should be set up by the authorities about air pollution emissions and wastewater released by all industries especially for oil and gas refineries take benefits from international standards like EU and EPA, also precautions have to be taken into consideration for future urban development in the southwest of Erbil region regarding polluted air and soil.

## 5.2 Geotechnical test results and Discussions

### 5.2.1 Chemical Test Results and Discussions

Comparing the results of chemical properties of examined contaminated soil samples with percentages added of oily wastewater (5%, 10%, 15%, and 20%), Table 5.5 and Figure 5.6. It can be noted that the values of TSS, Carbonates, and Hydrocarbons were increased with the increase of oily wastewater; this slight change in the results was due to the chemical reactions between the mineralogical composition of soil and oily wastewater, while Organic and $SO_3$ were decreased.

**Table 5.5** Chemical properties of contaminated soil samples with oily wastewater.

| Contaminated samples | Organic | TSS | pH | Carbonate | $SO_3$ | Hydrocarbon |
|---|---|---|---|---|---|---|
| 0% | 3.7 | 0.21 | 8.18 | 25.2 | 0.067 | - |
| 5% | 1.28 | 0.21 | 8.4 | 30.2 | 0.052 | 4 |
| 10% | 1.24 | 0.21 | 8.01 | 30.6 | 0.052 | 5 |
| 15% | 1.21 | 0.22 | 7.93 | 31.4 | 0.055 | 6 |
| 20% | 0.77 | 0.24 | 7.86 | 32 | 0.062 | 10 |

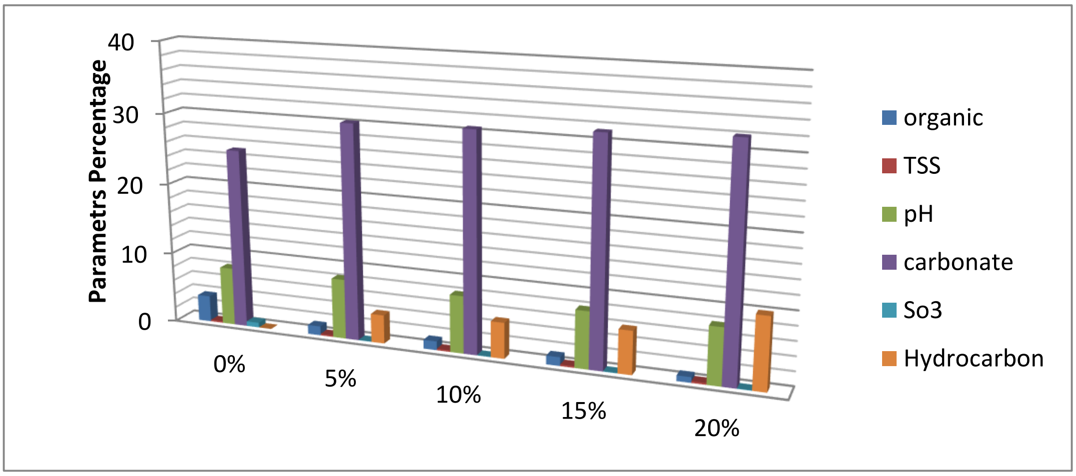



**Figure 5.6** Soil contamination with the percentages of oily wastewater.

### 5.2.2 Physical Test Results and Discussions

The main physical properties of soil were examined through conducting a serious of Atterberg limit tests, using both uncontaminated and contaminated soil samples with four percentages, 5%, 10%, 15%, and 20% of waste oil contamination.

From the results of Table 5.6 and Figure 5.7, the oily wastewater causes a slight effect on the values of liquid limit, increased by 1.3%, this due to the changes of the shape of soil particles by coating the surfaces with oil. In addition, will cause a small increase of the values of the Plastic limit (8.6%), due to the viscosity of the contaminant, finally small decrease, 7.3% of the values of PI have been observed.

**Table 5.6** Atterberg limit values for contaminated and uncontaminated soil samples.

| Percentages of contamination with oily wastewater | LL% | PL% | PI% |
|---|---|---|---|
| 0 | 37.8 | 14.7 | 23.1 |
| 5 | 38.7 | 22.16 | 16.5 |
| 10 | 39 | 21.6 | 17.3 |
| 15 | 39 | 21.8 | 17.1 |
| 20 | 39.1 | 23.3 | 15.8 |

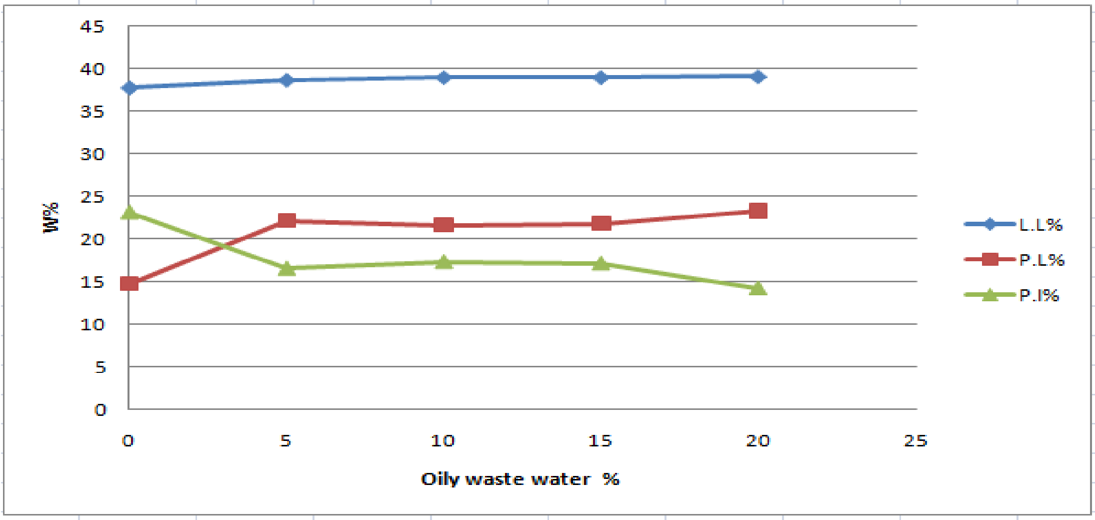



**Figure 5.7** Effect of oily wastewater contamination on the Atterberg Limits.

Similar results were obtained by Shah et al. (2003), they showed that the contaminated soils increase the values of Liquid Limit and Plastic Limit and a slight decrease in the values of PI as compared with uncontaminated clay soils. The reason behind these changes was, the cohesion of contaminated clay can increase in bonding by oil particles, and therefore it requires more water to change the consistency of contaminated clay. Elisha. (2012) reached to the same observation on soft clay, also Akinwumi et al. (2014), Reached the same observation, except for the values of PI which gives a slight decrease. Meanwhile, results obtained by Ur-Rehman et al., 2007, caused an increase in the Atterberg Limits. They proposed the reason behind this change is the extra cohesion provided to the clay particle by the oil.

### 5.2.3 Mechanical Test Results and Discussions

#### 5.2.3.1 Consolidation Test Results and Discussions for laboratory Contaminated Soil samples with Oily Wastewater

One dimensional consolidation test was carried out for both contaminated and uncontaminated samples to investigate its Compressibility, Coefficient of consolidation rate of swelling and coefficient of permeability.

For zero contaminated samples, four samples were chosen and took the average values, in order to obtain accurate results. For contaminated samples with oily wastewater, the same percentages have been used. Details of Cv results of one-dimensional consolidation tests for both zero and contaminated soil samples with oily wastewater have been illustrated in Appendix 1.

**<u>A-Zero contaminated samples</u>**

Consolidation parameters, K, and final moisture content values for all four zero contaminated samples are shown in Table 5.7, 5.8 and 5.9.

**Table 5.7** Consolidation parameters for all four zero contaminated samples.

Sample 1

| Parameter | Value |
|---|---|
| Initial void ratio ($e_o$) | 0.689 |
| Initial moisture content ($w_o$)% | 5.6 |
| Specific gravity( Gs) | 2.7 |
| Total unit weight ( □□t ), kN/m$^3$ | 15.6 |
| Overburden pressure(P'o), kPa | 28.17 |
| Preconsolidation stress, ( P'c ) , kPa | 79 |
| Compression index ( Cc) | 0.1818 |
| Recompression index ( Cr) | 0.0199 |

Sample 2

| Parameter | Value |
|---|---|
| Initial void ratio ($e_o$) | 0.688 |
| Initial moisture content ($w_o$)% | 5.6 |
| Specific gravity( Gs) | 2.7 |
| Total unit weight ( $\gamma_t$ ), kN/m$^3$ | 15.6 |
| Overburden pressure(P'o), kPa | 28.17 |
| Preconsolidation stress, ( P'c ) , kPa | 79 |
| Compression index ( Cc) | 0.1905 |
| Recompression index ( Cr) | 0.0230 |

Sample 3

| Parameter | Value |
|---|---|
| Initial void ratio ($e_o$) | 0.694 |
| Initial moisture content ($w_o$)% | 5.6 |
| Specific gravity( Gs) | 2.7 |
| Total unit weight ( $\gamma_t$ ), kN/m$^3$ | 15.6 |
| Overburden pressure(P'o), kPa | 28.17 |
| Preconsolidation stress, ( P'c ) , kPa | 79 |
| Compression index ( Cc) | 0.4551 |
| Recompression index ( Cr) | 0.0499 |

Sample 4

| Parameter | Value |
|---|---|
| Initial void ratio ($e_o$) | 0.693 |
| Initial moisture content ($w_o$)% | 5.6 |
| Specific gravity( Gs) | 2.7 |
| Total unit weight ( $\gamma_t$ ), kN/m$^3$ | 15.6 |
| Overburden pressure(P'o), kPa | 28.17 |
| Preconsolidation stress, ( P'c ) , kPa | 79 |
| Compression index ( Cc) | 0.1860 |
| Recompression index ( Cr) | 0.0722 |

**Table 5.8** Average values for (K) and (Cv) for zero contaminated soil samples.

| Loads (kg) | Average values of (K) for 4 samples (m/year) | Average values of (Cv) for 4 samples (m$^2$/year) |
|---|---|---|
| 1.5 | 0.00525 | 2.0071 |
| 3 | 0.00500 | 1.9341 |
| 6 | 0.00480 | 1.8145 |
| 12 | 0.00450 | 1.6237 |
| 24 | 0.00400 | 1.6420 |
| 48 | 0.00350 | 1.6147 |

**Table 5.9** Results of final moisture content for all four zero contaminated samples of consolidation tests.

| **Oily wastewater (%)** | 0% | 0% | 0% | 0% |
|---|---|---|---|---|
| **W (%)** | 27 | 27.06 | 28.06 | 29.14 |

**B-Contaminated sample**

Consolidation parameters for contaminated soil samples are shown in the Table 5.10;

**Table 5.10** Consolidation test results of uncontaminated and contaminated soil sample.

| Parameter | Value | Value | Value | Value | Value |
|---|---|---|---|---|---|
| Oily wastewater percentage | 0 | 5% | 10% | 15% | 20% |
| Initial void ratio (eo) | 0.6917 | 0.5644 | 0.5485 | 0.4949 | 0.4289 |
| Initial moisture content Mo% | 5.6 | 5.6 | 5.6 | 5.6 | 5.6 |
| Specific gravity( Gs) | 2.7 | 2.7 | 2.7 | 2.7 | 2.7 |
| Total unit weight ( γt ), kN/m 3 | 15.64999 | 16.92401 | 17.09702 | 17.71044 | 18.52833 |
| Overburden pressure(P'o), kPa | 28.16998 | 30.46321 | 30.77464 | 31.87879 | 33.35099 |
| Preconsolidation stress, ( P'c ) , kPa | 78.5 | 60 | 27 | 25 | 25 |
| Compression index ( Cc) | 0.253318 | 0.1706 | 0.1829 | 0.1794 | 0.2215 |
| Recompression index ( Cr) | 0.041261 | 0.0175 | 0.0146 | 0.0137 | 0.0161 |

Cv and K values for all contaminated soil samples are shown in Tables 5.11 and K values in Table 5.12 and Figure 5.8.

**Table 5.11** Cv results for contaminated soils with oily wastewater percentages.

| Stresses kPa | 0% | 5% | 10% | 15% | 20 % |
|---|---|---|---|---|---|
| **25** | 2.007 | 1.920 | 1.810 | 1.600 | 1.214 |
| **48** | 1.934 | 1.608 | 1.866 | 1.300 | 1.251 |
| **96** | 1.810 | 1.814 | 1.994 | 1.101 | 1.294 |
| **190** | 1.620 | 1.991 | 2.033 | 0.921 | 1.370 |
| **379** | 1.640 | 1.493 | 2.078 | 0.843 | 1.502 |
| **756** | 1.610 | 1.360 | 1.390 | 1.078 | 1.516 |

**Table 5.12** Values of K (m/year) for contaminated soil samples with oily wastewater.

| Stress (kPa) | 0% | 5% | 10% | 15% | 20% |
|---|---|---|---|---|---|
| **25** | 0.00525 | 0.001636 | 0.001935 | 0.00144 | 0.001468 |
| **48** | 0.0050 | 0.00166 | 0.001995 | 0.001218 | 0.00140 |
| **96** | 0.0048 | 0.001545 | 0.002132 | 0.001030 | 0.00139 |
| **190** | 0.0045 | 0.00140 | 0.002174 | 0.000863 | 0.00138 |
| **379** | 0.0040 | 0.001272 | 0.002222 | 0.000790 | 0.00137 |
| **756** | 0.0035 | 0.001200 | 0.001486 | 0.001010 | 0.00135 |

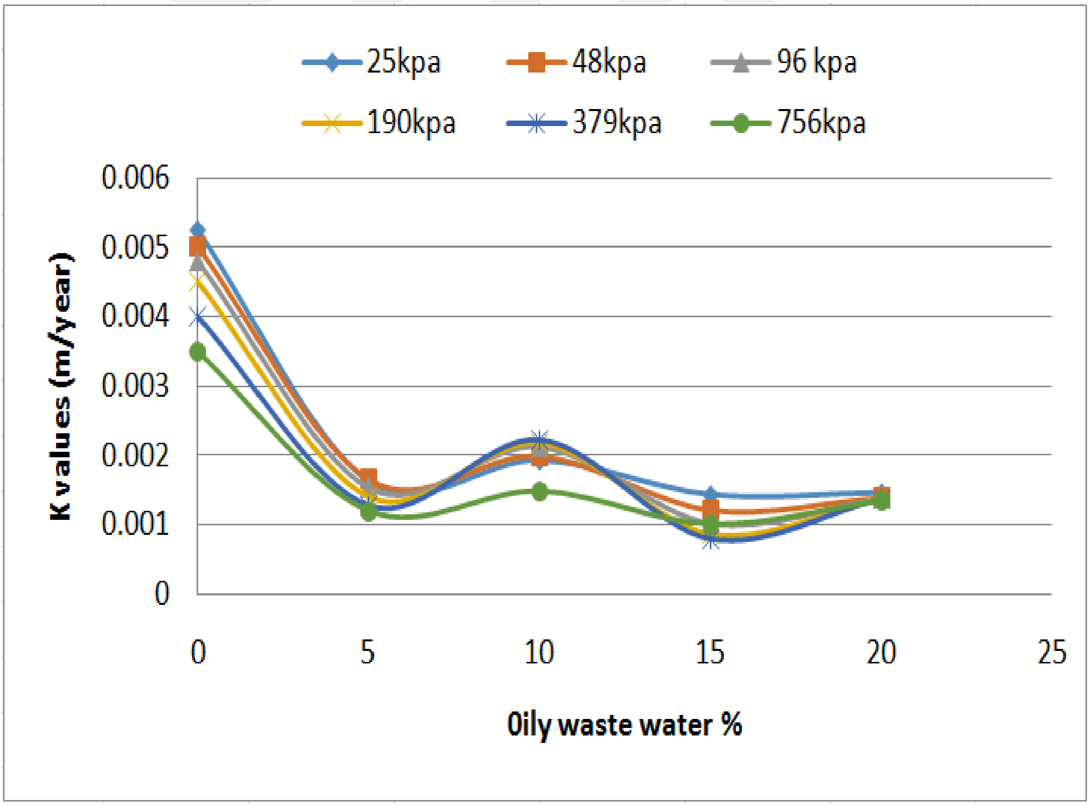



**Figure 5.8** K values versus percentage of oily wastewater

The effects of oil contamination on compression, void ratio and total unite weight are shown in the following Figures 5.9, 5.10 and 5.11.

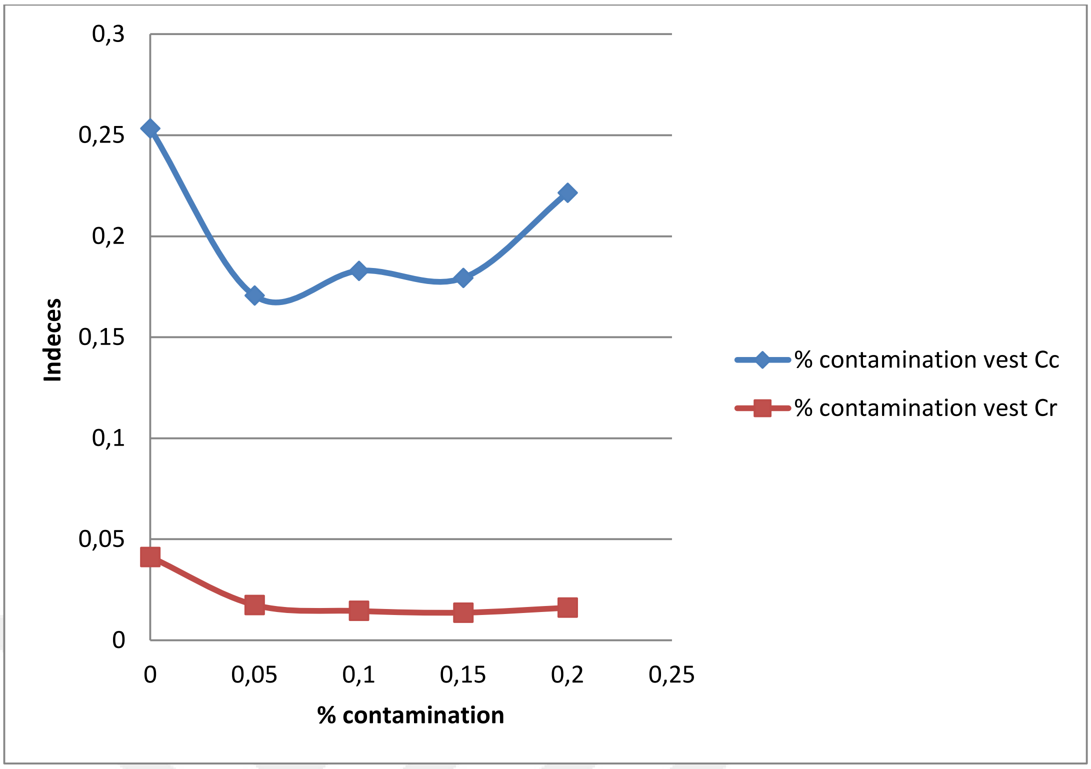



**Figure 5.9** Effect of percentage of oily wastewater contamination on compression and recompression indices.

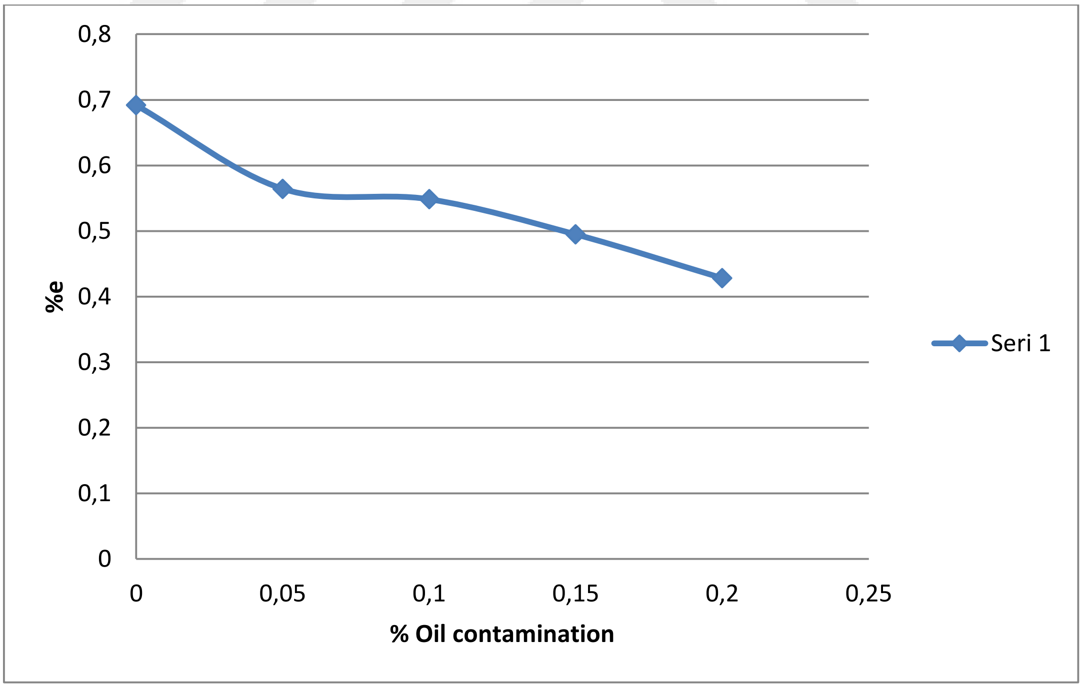



**Figure 5.10** Effect of percentage of oily wastewater contamination on void ratio.

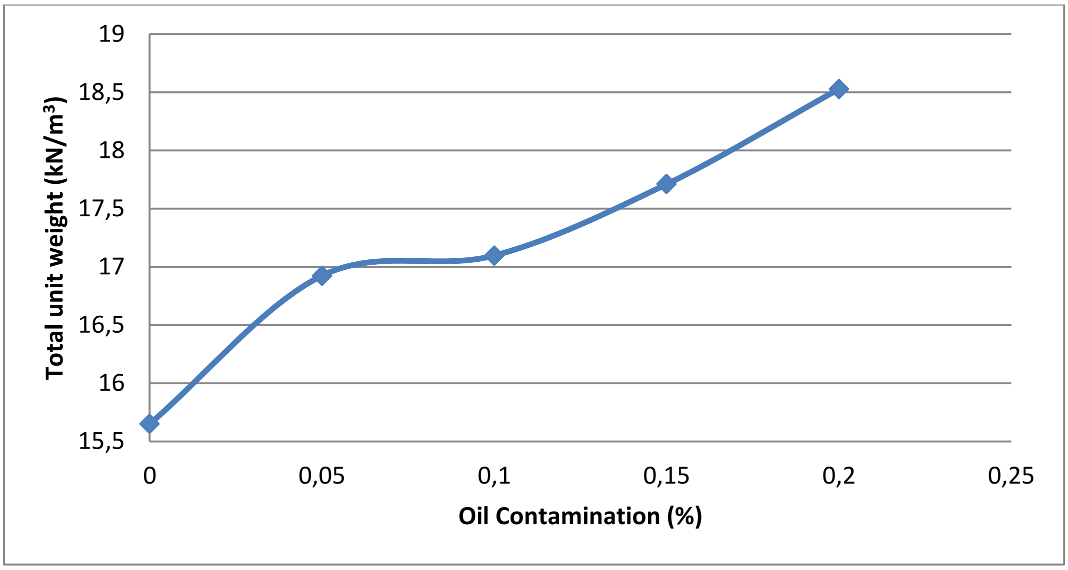



**Figure 5.11** Effect of percentage of oily wastewater contamination on unit weight (KN/m³).

- From the Figures and Tables presented, the following observations have been noticed;
- Table 5.7, shows the average values of Cv and K for uncontaminated soil samples decrease in the values were observed, this due to the decrease of the volume of voids of soil particles under the applied loads.
- Table 5.10 shows Cv results for all percentages of oil contamination and stresses. It can be observed that increasing the percentages of oily wastewater induces a considerable decrease in consolidation for most stresses. Results of Karkush and Kareem (2017), resembles the one obtained in this study.
- Results of K values for contaminated samples are clarified in Table (5-11) and Figure 5.8, it can be observed that K values decrease from zero soil contamination to 20%, the decrease for 5% contamination was 0.003%, for 10% contamination was 0.0026%, for 15% contamination was 0.0024% and for 20% contamination was 0.003. In general, adding oily wastewater to the soil induces a small reduction in permeability (K), due to the properties of oily wastewater mixture, because the first contact of the oil will be with the soil particles and decreases the volume of voids. Our results agree with the investigations of Rahman et al., (2010) also agrees with the work of Akinwumi et al. (2014).

- From the Figure 5.9, for Cc, the general trends are that with an increase of the percentage of contamination the Cc increases, while Cr decreases, the reason behind is most probably due to properties of oily wastewater. The results of this study seem to be in agreement with the study of Ur-Rahman et al, (2012) and Elisha. (2012).
- Figure 5.10, shows that, in general, the void ratio decreased with the increase of the percentage of oil contamination, these results from the effect of a small quantity of oil in the oily wastewater during contamination. The study results agree with the results of Karkush and Kareem (2017).
- Figure 5.11, shows the percentage of oil contamination against total unit weight. This shows that the increase in the percentage of waste oil contamination will lead to an increase in total unit weight.

#### 5.2.3.2 Results and Discussions of Permeability Tests

**A- Laboratory permeability test results**

Contaminated soil samples have been investigated in the laboratory, for conducting permeability tests (constant head method). The remolded sample was prepared in the lab, having the same field density inside the permeability mold. Oily wastewater has been used instead of water for the test; this process is similar to those in the field, which will be clarified later.

The word diffusion (percolation) could be better to use instead of permeability, due to the viscosity effect, although this factor has been neglected because the oily wastewater obtained from the refinery contained more than 80% of water).The permeability result obtained was 0.272 E-3 cm/sec =0.0063E-5m/year. Details of the test results are shown in Table 5.13.

**Table 5.13** Laboratory permeability test results.

| lab permeability tests For Field works | | | |
|---|---|---|---|
| dalta H cm | t sec | k .E-03 cm/sec | modified K For 19degr.c. |
| 23 | 24 56 | 0.2498 | 0.2373 |
| 26 | 13.57 | 0.1427 | 0.1355 |
| 32 | 27.65 | 0.5139 | 0.4882 |
| 33 | 53.5 | 1.2615 | 1.1984 |
| 52.5 | 20.66 | 0.6372 | 0.6053 |
| 31 | 28.44 | 1.227 | 1.1656 |
| 24.5 | 44.65 | 1.948 | 1.8506 |
| 30 | 44.63 | 2.3249 | 2.2086 |
| 22 | 18.43 | 1.3363 | 1.2694 |
| 36 | 21.78 | 0.7315 | 0.6949 |
| 29 | 14.22 | 0.2566 | 0.2437 |
| 34 | 46.57 | 1.864 | 1.7708 |
| 24 | 17.25 | 1.0143 | 0.9635 |
| 45 | 27.75 | 0.431 | 0.4095 |
| Averiage value of K | = 0.285 E-3 cm/sec | | |
| modified | K= 0.272 E-3 cm/sec | | |

**B- Field permeability test results**

Two holes were dug inside the model pit; its dimensions were 40 cm diameter and 50 cm deep, Figure 5.14. 40 cm diameter plastic pipe was fixed in the first hole, for conducting one-dimensional penetration tests, while the second hole kept without pipe for measuring three-dimensional penetration tests. The oily wastewater was spilled to the two holes at the same time and the rate of percolation (diffusion) with time was recorded until the completion of the oily wastewater. Figures 5.12 and 5.13 show diffusion rates versos time for both cases.

Because of the three-dimensional field diffusion which is most likely are occurred on the polluted lands, determination of field permeability or (field diffusion) becomes necessary. Results of permeability (K) have been determined, (ASTM D6391- 2011), using this equation;

**K= (D/2) * Lin (h1/h2) / 2 (t2-t1)**

Were; (D/2) is the radius of the hole in meters. In refers to the national Logarithm, (h1 and h2) are the two consecutive depths of oily wastewater in meters. (t2- t1) expresses the time interval between two consecutive measurements in seconds. The value of K is in m/sec (neglecting the effect of viscosity of the oily wastewater because it contains less than 15% waste oil). Test results are shown in Table 5.14, from the Table,

**K value for the field test is 1.92541E-05 m/sec.**

**Table 5.14** Field results of permeability.

| 3D field permeability test results (D = 40 cm) | | | | | | |
|---|---|---|---|---|---|---|
| D m | Time mint | | H (cm) | | DH cm | k (m/sec) |
| 0.4 | 0 | 0 | 50 | 0.5 | 0 | 6.73424E-06 |
| 0.4 | 5 | 300 | 49 | 0.49 | 1 | 3.41883E-06 |
| 0.4 | 10 | 600 | 48.5 | 0.485 | 1.5 | 6.9447E-06 |
| 0.4 | 15 | 900 | 47.5 | 0.475 | 2.5 | 7.09247E-06 |
| 0.4 | 20 | 1200 | 46.5 | 0.465 | 3.5 | 7.24666E-06 |
| 0.4 | 25 | 1500 | 45.5 | 0.455 | 4.5 | 3.68328E-06 |
| 0.4 | 30 | 1800 | 45 | 0.45 | 5 | 3.72443E-06 |
| 0.4 | 35 | 2100 | 44.5 | 0.445 | 5.5 | 3.76652E-06 |
| 0.4 | 40 | 2400 | 44 | 0.44 | 6 | 7.66317E-06 |
| 0.4 | 45 | 2700 | 43 | 0.43 | 7 | 3.89868E-06 |
| 0.4 | 50 | 3000 | 42.5 | 0.425 | 7.5 | 5.98867E-06 |
| 0.4 | 60 | 3600 | 41 | 0.41 | 9 | 5.80188E-06 |
| 0.4 | 180 | 10800 | 27 | 0.27 | 23 | 1.28507E-05 |
| 0.4 | 240 | 14400 | 17 | 0.17 | 33 | 1.76664E-05 |
| 0.4 | 300 | 18000 | 9 | 0.09 | 41 | 2.25258E-05 |
| 0.4 | 360 | 21600 | 4 | 0.04 | 46 | 1.92541E-05 |
| 0.4 | 420 | 25200 | 2 | 0.02 | 48 | 1.92541E-05 |
| 0.4 | 480 | 28800 | 1 | 0.01 | 49 | |
| 0.4 | 540 | 32400 | 0 | 0 | 50 | |

After the end of the tests, samples were taken from the base and sides of the two holes to the laboratory for examining the Index properties, consolidation parameters and coefficient of permeability.

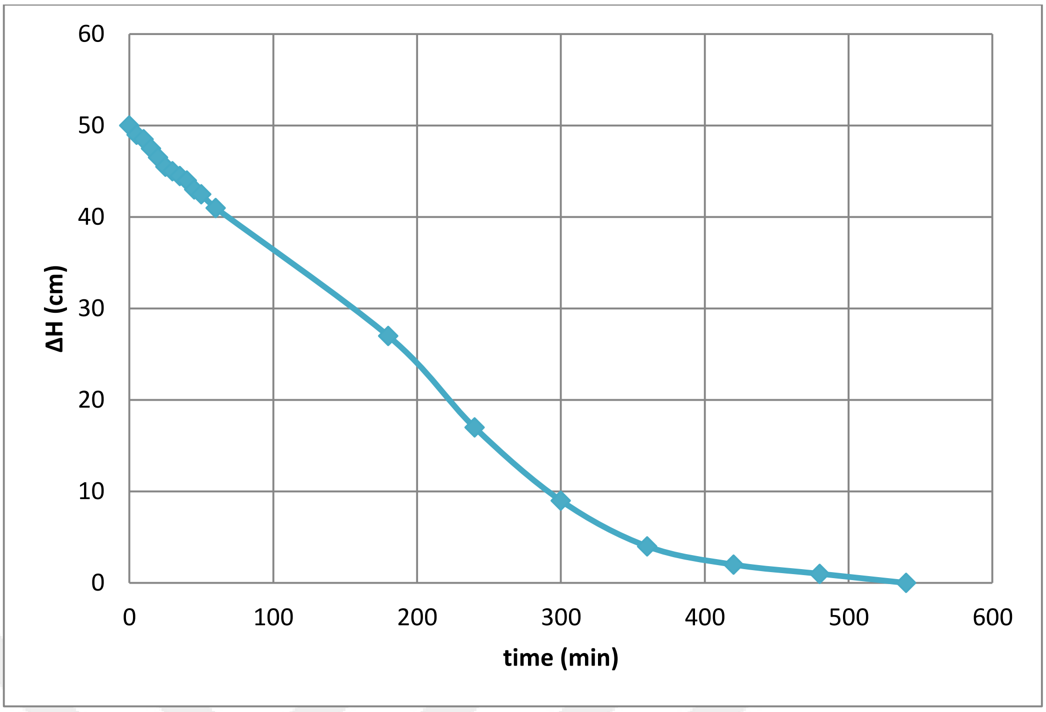



**Figure 5.12** One dimension penetration test.

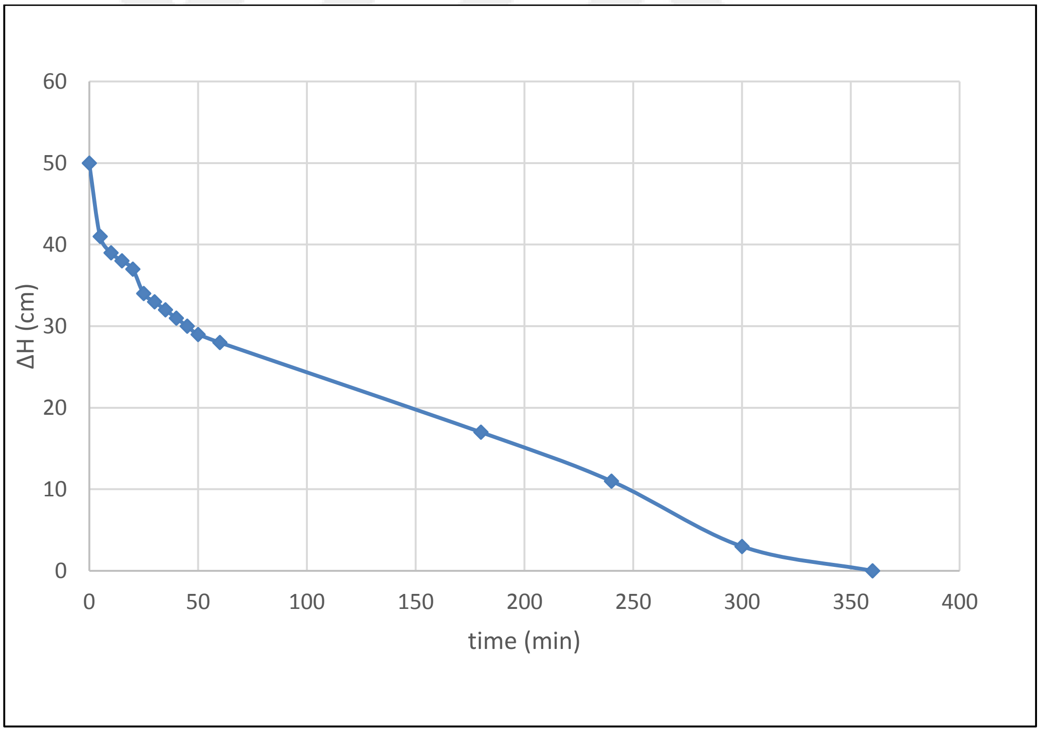



**Figure 5.13** Three dimension penetration test.

**Figure 5.14** Penetration pits for oily wastewater.

Table 5.15 shows the test results of Atterberg limit values and Tables from, 5.16 to 5.20 illustrates the consolidation test parameters for field permeability test samples.

**Table 5.15** Atterberg limit values.

| Sample position | LL | PL | PI |
|---|---|---|---|
| **Pit side** | 35.21 | 22.54 | 12.67 |
| **Pit base** | 33 | 24.65 | 8.35 |
| **uncontaminate** | 37.8 | 14.7 | 23.1 |

**Table 5.16** 1 D consolidation parameters.

| **Parameters** | **Value** |
|---|---|
| Initial void ratio ($e_o$) | 0.5644 |
| Initial moisture content ($w_o$)% | 5.6 |
| Specific gravity( Gs) | 2.7 |
| Total unit weight ( $\gamma_t$ ), kN/m $^3$ | 16.9 |
| Overburden pressure(P'o), kPa | 30.46 |
| Preconsolidation stress, ( P'c ) , kPa | 30 |
| Compression index ( Cc) | 0.2302 |
| Recompression index ( Cr) | 0.0167 |

**Table 5.17** 3 DV consolidation parameters.

| Parameter | Value |
|---|---|
| Initial void ratio ($e_o$) | 0.5644 |
| Initial moisture content ($w_o$)% | 5.6 |
| Specific gravity( Gs) | 2.7 |
| Total unit weight ($\gamma_t$ ), kN/m $^3$ | 16.9 |
| Overburden pressure(P'o), kPa | 30.46 |
| Preconsolidation stress, ( P'c ) , kPa | 30 |
| Compression index ( Cc) | 0.2310 |
| Recompression index ( Cr) | 0.0254 |

**Table 5.18** 3 DH consolidation parameters.

| Parameter | Value |
|---|---|
| Initial void ratio ($e_o$) | 0.5644 |
| Initial moisture content ($w_o$)% | 5.6 |
| Specific gravity( Gs) | 2.7 |
| Total unit weight ( $\gamma_t$ ), kN/m $^3$ | 16.9 |
| Overburden pressure(P'o), kPa | 30.46 |
| Preconsolidation stress, ( P'c ) , kPa | 50 |
| Compression index ( Cc) | 0.2426 |
| Recompression index ( Cr) | 0.0242 |

**Table 5.19** Values of (K) and (Cv) for field permeability test.

| Loading (Kg) | Stresses (kPa) | K values m/year | | | Cv values $m^2$/year | | |
|---|---|---|---|---|---|---|---|
| | | 1 DV | 3 DV | 3 DH | 1 DV | 3 DV | 3 DH |
| 1.5 | 25 | 0.001532 | 0.0200 | 0.0094 | 1.856 | 0.548 | 1.738 |
| 3 | 48 | 0.0156 | 0.0012 | 0.0090 | 3.234 | 1.497 | 1.655 |
| 6 | 96 | 0.0122 | 0.0011 | 0.0120 | 2.312 | 1.407 | 2.834 |
| 12 | 190 | 0.0112 | 0.0366 | 0.0065 | 1.371 | 0.479 | 2.195 |
| 24 | 379 | 0.0111 | 0.0030 | 0.0111 | 1.120 | 0.837 | 1.258 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 48 | 756 | 0.0110 | 0.0028 | 0.0110 | 1.211 | 1.789 | 1.780 |

**Table 5.20** Values of (Cc) and (Cr) for field permeability test.

| **Parameters** | **1 DV** | **3 DV** | **3 DH** |
|---|---|---|---|
| Initial Void Ration ($e_0$) | 0.5644 | 0.5644 | 0.5644 |
| Initial Moisture Content ($W_0$ %) | 5.6 | 5.6 | 5.6 |
| Specific Gravity (Gs) | 2.7 | 2.7 | 2.7 |
| Total Unit Weight ($\gamma t$) KN/m3 | 16.9 | 16.9 | 16.9 |
| Overburden pressure ($P_0$) Kpa | 30.46 | 30.46 | 30.46 |
| Preconsolidation Pressure (Pc) | 30 | 30 | 30 |
| Compression Index (Cc) | 0.2302 | 0.2310 | 0.2426 |
| Recompression Index (Cr) | 0.0167 | 0.0254 | 0.0242 |
| Final Moisture Content (Wf %) | 34.37 | 35.24 | 32.94 |

From the presented Tables, the following remarks and discussions have been made:

- Table 5.12 shows the results of the laboratory permeability test for remolded samples using oily wastewater instead of water. The results are also compared with those obtained from the laboratory consolidation test.
- Regarding the results of field permeability test values, Table 5.13 for field contaminated soil samples with oily wastewater, the results of 3D filed permeability (1.92541E-05 m/s) shows that the field clay soil is within the range of semi-permeable for civil engineering purposes, as shown in Table 5.21. (ASTM D6391-2011) and within the range of moderate for agricultural and conservation purposes, it can be observed that the effect of oily wastewater on the contamination of existing soil would be seen in long and medium-term periods.
- Table 5.14, shows the results of Atterberg limit values for samples taken from both sides of the contaminated pits. From the results, the effect of

contamination is observed comparing with zero contamination and would be comparable with those obtained from the laboratory-contaminated tests.

**Table 5.21** ASTM permeability classes**.**

**Soil permeability classes for agriculture and conservation**

| Soil permeability classes | Permeability rates[1] | |
|---|---|---|
| | cm/hour | cm/day |
| Very slow | Less than 0.13 | Less than 3 |
| Slow | 0.13 - 0.3 | 3 - 12 |
| Moderately slow | 0.5 - 2.0 | 12 - 48 |
| Moderate | 2.0 - 6.3 | 48 - 151 |
| Moderately rapid | 6.3 - 12.7 | 151 - 305 |
| Rapid | 12.7 - 25 | 305 - 600 |
| Very rapid | More than 25 | More than 600 |

**Soil permeability classes for civil engineering**

| Soil permeability classes | Coefficient of permeability (K in m/s) | |
|---|---|---|
| | Lower limit | Upper limit |
| Permeable | $2 \times 10^{-7}$ | $2 \times 10^{-1}$ |
| Semi-permeable | $1 \times 10^{-11}$ | $1 \times 10^{-5}$ |
| Impermeable | $1 \times 10^{-11}$ | $5 \times 10^{-7}$ |

A comparison between consolidation parameters for field and laboratory permeability test results are shown in Tables 5.22, 5.23 and 5.24 and Figures 5.14 to 5.20.

**Table 5.22** Comparison between (Cv) values obtained from consolidation test for field, and laboratory test samples.

| Loading Kg | Stresses kPa | Cv values for filed Permeability samples $m^2$/year | | | Cv values for contaminated s samples for consolidation tes $m^2$/year | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | 1 DV | 3 DV | 3 DH | 0% | 5% | 10% | 15% | 20% |
| 1.5 | 25 | 1.826 | 0.548 | 1.738 | 2.007 | 1.920 | 1.810 | 1.600 | 1.214 |
| 3 | 48 | 3.234 | 1.497 | 1.655 | 1.934 | 1.608 | 1.866 | 1.300 | 1.251 |
| 6 | 96 | 2.312 | 1.407 | 2.834 | 1.810 | 1.814 | 1.994 | 1.100 | 1.294 |
| 12 | 190 | 1.600 | 0.479 | 1.195 | 1.620 | 1.991 | 2.033 | 0.921 | 1.370 |
| 24 | 379 | 1.120 | 0.837 | 1.258 | 1.640 | 1.493 | 2.078 | 0.843 | 1.502 |
| 48 | 756 | 1.211 | 1.160 | 1.600 | 1.610 | 1.360 | 1.390 | 1.078 | 1.516 |

**Table 5.23** Comparison between (K) values obtained from consolidation test of field and laboratory permeability test samples.

| Loading (Kg) | Stresses (kPa) | K values for filed Permeability samples m/year | | | K values for contaminated soil samples for consolidation test m/year | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | 1 DV | 3 DV | 3 DH | 0% | 5% | 10% | 15% | 20% |
| 1.5 | 25 | 0.0157 | 0.0200 | 0.0094 | 0.00525 | 0.00163 | 0.00193 | 0.00278 | 0.00146 |
| 3 | 48 | 0.0156 | 0.0012 | 0.0090 | 0.0050 | 0.00166 | 0.00199 | 0.00185 | 0.00140 |
| 6 | 96 | 0.0122 | 0.0011 | 0.0120 | 0.0048 | 0.00154 | 0.00213 | 0.00157 | 0.00139 |
| 12 | 190 | 0.0112 | 0.0366 | 0.0065 | 0.0045 | 0.00140 | 0.00217 | 0.00131 | 0.00138 |
| 24 | 379 | 0.0111 | 0.0030 | 0.0111 | 0.0040 | 0.00127 | 0.00222 | 0.00120 | 0.00137 |
| 48 | 756 | 0.0110 | 0.0028 | 0.0110 | 0.0035 | 0.00120 | 0.00148 | 0.00150 | 0.00135 |

**Table 5.24** Comparison between (Cc) and (Cr) values obtained from consolidation test for Field and laboratory test samples.

| Parameters | Field Permeability Contaminated Soil Samples m/year | | | Laboratory Contaminated Soil Samples m/year | | | | |
|---|---|---|---|---|---|---|---|---|
| | 1 DV | 3 DV | 3 DH | 0 % | 5 % | 10 % | 15 % | 20 % |
| Initial Void Ration (e0) | 0.5644 | 0.5644 | 0.5644 | 0.6917 | 0.564 | 0.548 | 0.494 | 0.428 |
| Initial Moisture Content (W 0 %) | 5.6 | 5.6 | 5.6 | 5.6 | 5.6 | 5.6 | 5.6 | 5.6 |
| Specific Gravity (Gs) | 2.7 | 2.7 | 2.7 | 2.7 | 2.7 | 2.7 | 2.7 | 2.7 |
| Total Unit Weight (γt) KN/m3 | 16.9 | 16.9 | 16.9 | 15.649 | 16.924 | 17.097 | 17.710 | 18.528 |
| Overburden pressure (P 0) Kpa | 30.46 | 30.46 | 30.46 | 28.169 | 30.463 | 30.774 | 31.878 | 33.350 |
| Preconsolidation Pressure (Pc) | 30 | 30 | 50 | 78.5 | 60 | 27 | 25 | 25 |
| Compression Index (Cc) | 0.2302 | 0.231 | 0.242 | 0.253 | 0.170 | 0.182 | 0.179 | 0.221 |
| Recompression Index (Cr) | 0.016 | 0.025 | 0.024 | 0.0412 | 0.017 | 0.014 | 0.013 | 0.016 |
| Final Moisture Content (Wf %) | 34.37 | 35.24 | 32.97 | 27.8 | 27 | 27.06 | 28.06 | 29.14 |

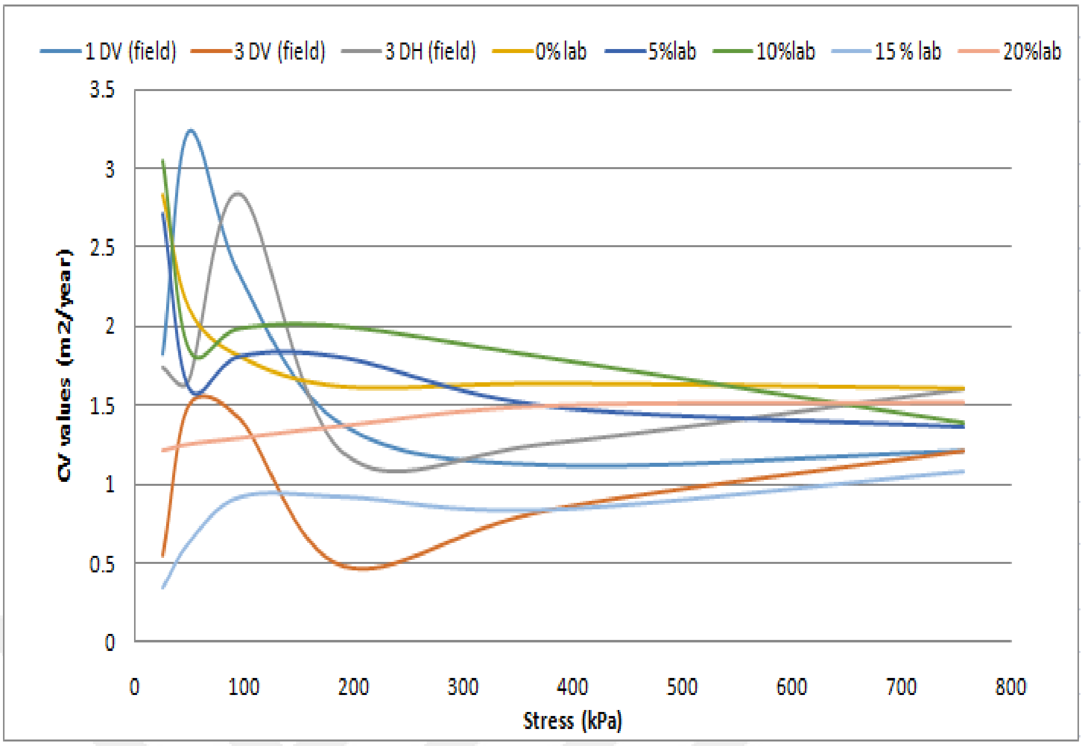



**Figure 5.15** Cv versus stress curve for field and lab contaminated samples.

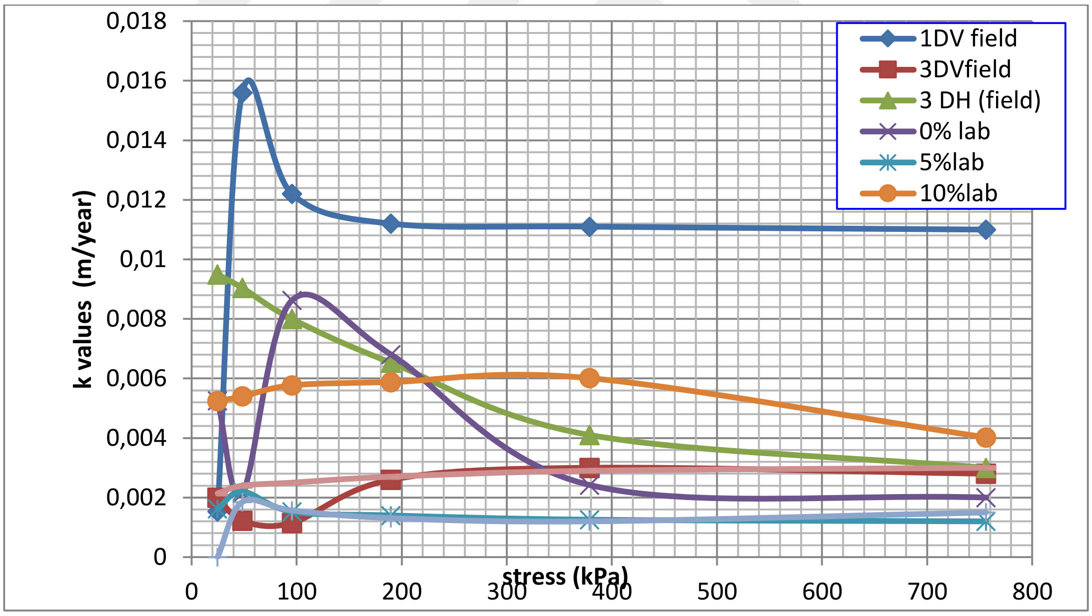



**Figure 5.16** K value versus stress curve for field and lab contaminated samples.

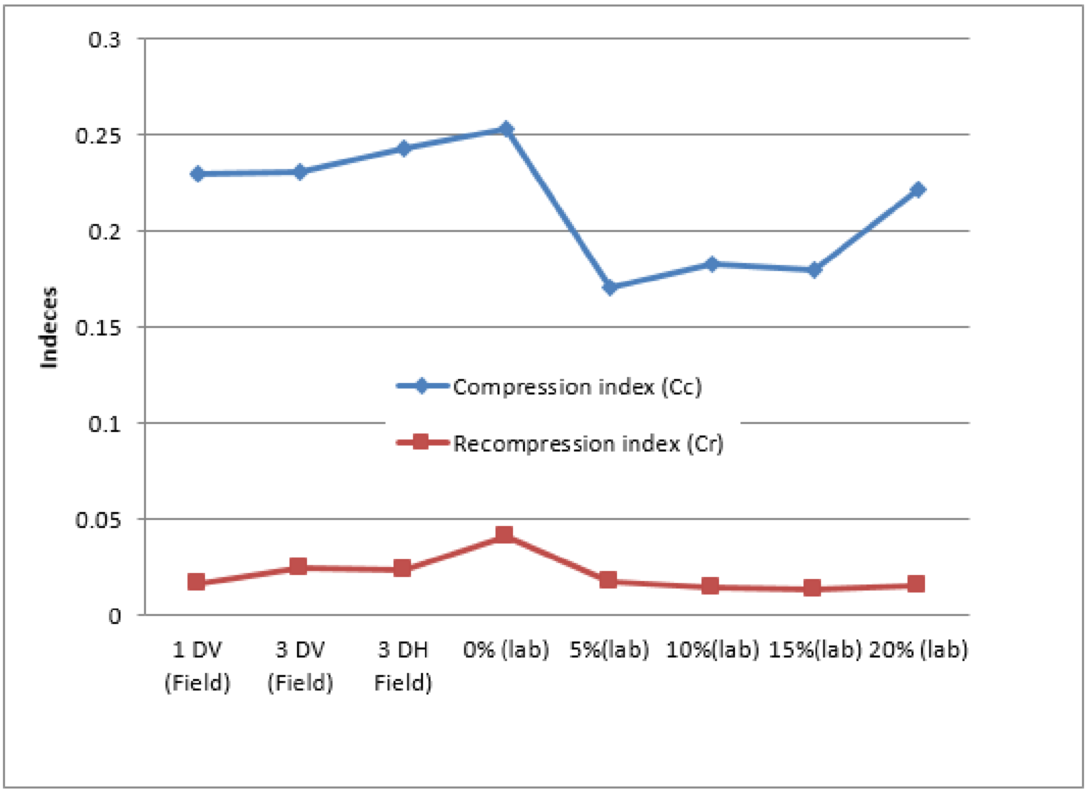



**Figure 5.17** Consolidation results for field and lab contaminated samples.

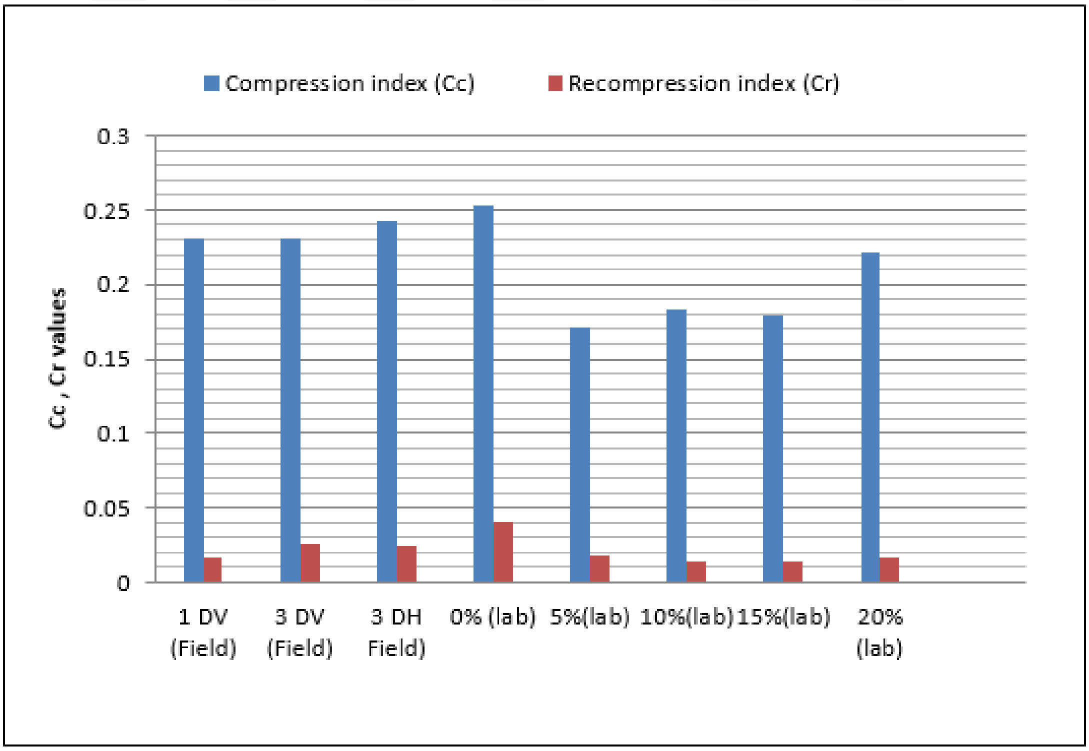



**Figure 5.18** Consolidation parameters for Field and Lab soil contamination samples.

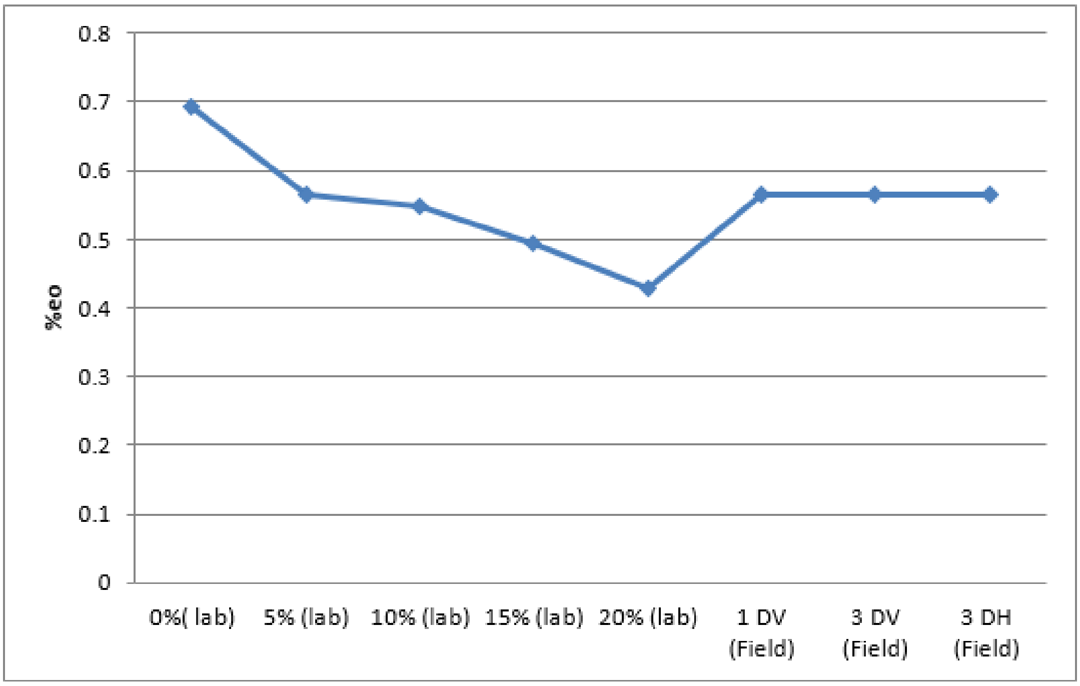



**Figure 5.19** Void ratio results of consolidation tests for field and laboratory contaminated soil samples.

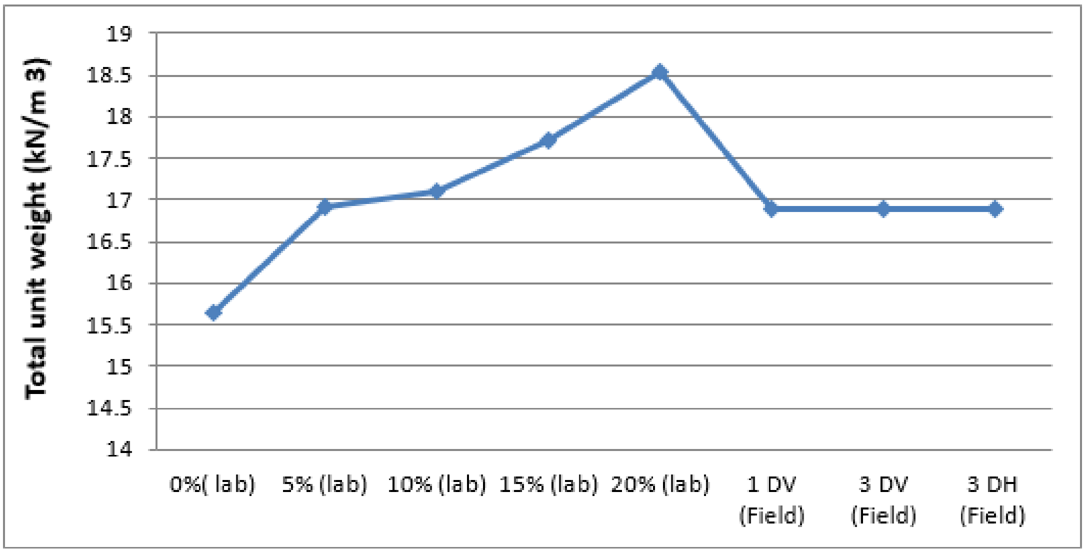



**Figure 5.20** Total unit weight results of consolidation tests for field and lab. Contaminated soil samples.

From the above-mentioned Tables and Figures, the following observations have been made,

- Cv values in Table 5.21 and Figure 5.14 in both tests show that the trends of the results are almost similar to the results of all percentages of contamination with oily wastewater for most stresses, especially for the high values.

- By looking at the Table 5.22 Figure 5.15, the trends of the (K) value curves are almost similar for most tests. At low stresses, higher results were recorded for field samples, especially for 1DV and 3DV.
- K value results for both field and laboratory contaminated soil samples obtained from consolidation tests, shows that adding oily wastewater in the field or in the lab, and induces a reduction in permeability especially for high-stress values, because the voids of the contaminated soil partially filled with oil, which is the reason of decreasing K values. Rahman et al. (2014)noted the same effect.
- Regarding the consolidation test parameters obtained from the tested samples of field permeability test, Cc and Cr which are shown in Table 5.23 and in the Figures 5.16 and 5.17. The high value of Cc could be observed for both tests, especially for field test samples. The results of Cr are close to each other and a slight decrease has been noted comparing it with zero contamination.
- Figure 5.18 shows the values of the void ratio, which decreases with an increase in oily wastewater percentages. Less decrease in the values of void ratio has been noted for field test samples; this could be due to the procedure of the laboratory test, which the samples are subjected to various stresses.
- The same observation has been noted for the test values of total unit weight Figure 5.19, a high increase in total unite weight recorded for laboratory tests while less increase noted for field test samples.

#### 5.2.3.3 Results and Discussions of Direct Shear Test

Direct shear test has been chosen for conducting several tests on both uncontaminated and contaminated soil samples with (5%.10%.15% and 20%) of oily wastewater, in order to investigate its effect on the values of Cohesion (C) and angle of internal friction $\phi$. The results are shown in Table 5.25.

**Table 5.25** Results of direct shear test for zero and all four percentages of contaminated soils with oily wastewater.

| % of Contamination | Cohesion (C) kPa | Angle of internal friction $\Phi$ (degree) |
|---|---|---|
| 0 | 17.2 | 18 |
| 5 | 17 | 28 |

| | | |
|---|---|---|
| 10 | 16.5 | 35 |
| 15 | 16.1 | 36 |
| 20 | 16 | 36 |

A comparison has been made between the results of cohesion and friction angle for all uncontaminated and contaminated remolded samples, details are shown in Figure 5.21 and 5.22.

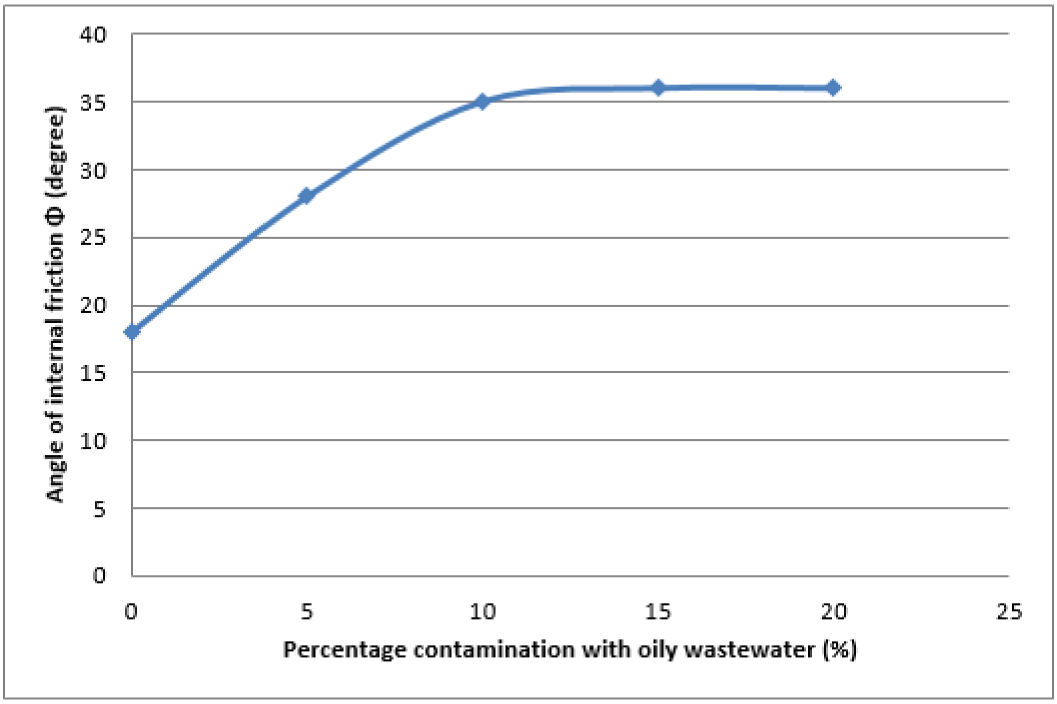



**Figure 5.21** Effect of oily wastewater contamination on friction angle/ ϕ.

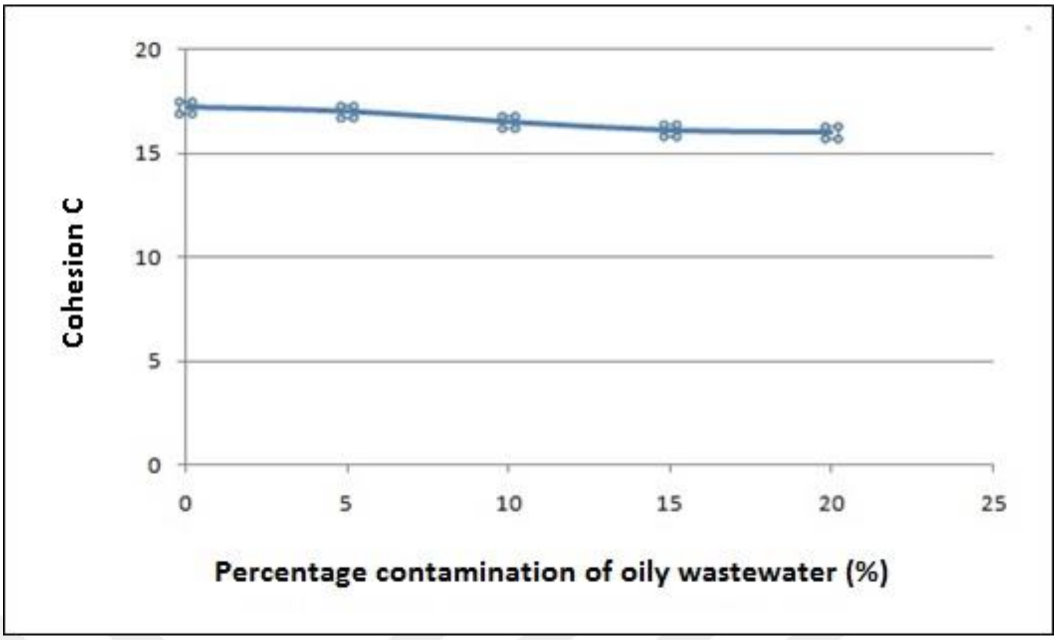



**Figure 5.22** Effect of oily wastewater contamination on Cohesion (C).

From the Figures 5.21 and 5.22, it can be noted that the angle of internal friction increased by 17% with increase of percentages of oil contamination , and also a slight decrease, 1.2% of Cohesion values were observed for all oily wastewater percentages contamination with examined soils, the proposed reason behind was due to the properties of oily wastewater ,the viscosity of remaining oil in the content of the oily wastewater will increase the slippage between the soil particles that causes reduction in the bonds between particles, hence decreases the cohesion. Studies of Karkush and Kareem (2017) supports this investigation in spite of they tested fuel oil on silt and clay soils, but in this study, the examined soil was lean clay with sand

In addition, results of shearing stress for all contaminated samples with oily wastewater shows a reduction in its values by 5% contamination, this leads to a reduction in bearing capacity values for the examined soil samples which have been taken in 50 cm depth, but for other percentages of contamination slight increase of shearing stress obtained, this may be a good indication for soil stabilization. Table 5.25 clarifies the results of shearing stress.

**Table 5.26** Results of shearing stress for contamination samples.

| Contamination percentages | Shearing stress , τ , $KN/m^3$ |
|---|---|

| | |
|---|---|
| 0 | 19.946 |
| 5 | 19.746 |
| 10 | 22.41 |
| 15 | 22.23 |
| 20 | 22.13 |

Alhassan and Fagge (2013) were noted that before while studying the behavior of contaminated clayey and sandy soils with engine oil.

Rassool (1999), Thaer (2011) and Khamehchiyan et al. (2007), have reached before to the same observations regarding cohesion and angle of internal friction values of clayey contaminated soils with oil.

## 5.3 Field Investigation Test Results and Discussions

### 5.3.1 Field Investigation Test Results and Discussions of the Model Pit

After conducting the test, for examining the rate of percolation (diffusion) of oily wastewater for all three different pits to the subsurface soils, Figure 5.22, and the following observations have been made.

- From the Figure 5.23, the diffusion rate results of the oily wastewater into the subsurface of the soil increased with increase of the head, this due to the pressure head effects especially for vertical directions this would leave quick effect on the groundwater, while for horizontal direction, the diffusion remains slow and its adverse effect would appear on the soil contamination. Another reason for the quick diffusion rate was due to the properties of the oily wastewater, which contains more water and less oil, therefore the viscosity and density would have less effect on the movement of the fluid into the soil. The equations of the three test graphs are:
    - **For 50cm head of oily wastewater:**
      **$Y = 0.0002X^2 – 0.1782 + 50.464$**
    - **For 100cm head of oily wastewater:**
      **$Y = 0.0004X^2 – 0.3904X + 90.062$**

- **For 200cm head of oily wastewater:**

  **$Y = 228.79e^{-0.016x}$**

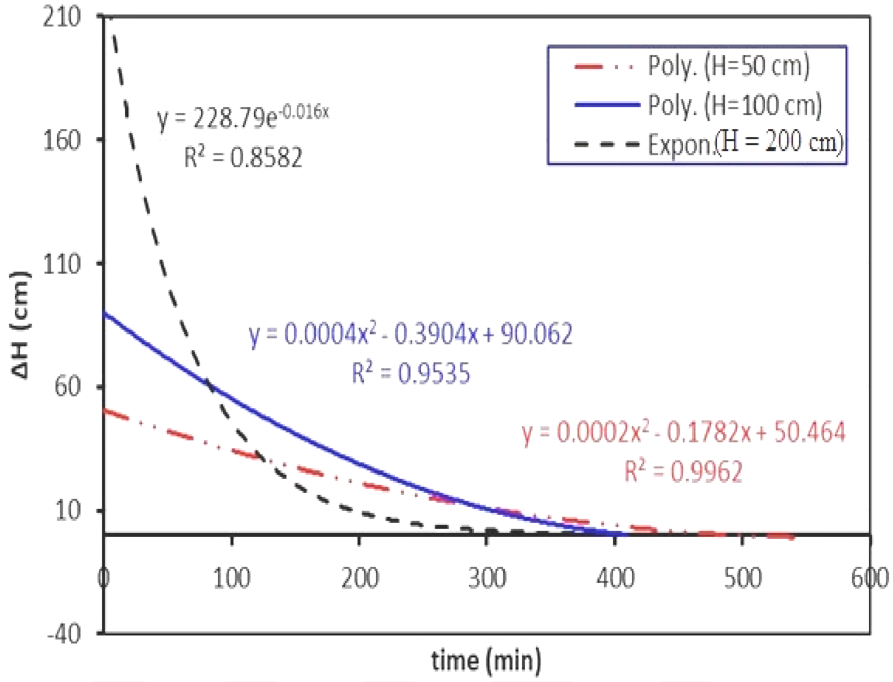



**Figure 5.23** Oily wastewater diffusion rate for 50cm, 100cm, and 200cm spilled heads.

- Contaminated soil samples were taken at the base of the pits downward vertically and horizontally in various distances until the effect of oily wastewater contamination disappears by vision and smell. Views of the contaminated process are shown in Appendix (2).

- Field investigation test regarding the chemical test results inside the pit model, the three tests for examining the soil contamination process were clarified in Tables 5.27 to 5.29 and Figures 5.24 to 5.36 the scientific discussion on the rate of oily wastewater percolation for all three heads is the effect of the head which had a positive influence on the rate of diffusion as shown in the Figures.

**Table 5.27** Chemical test results for contaminated soils with oily wastewater for 0.5m head of oily wastewater**.**

| sample location | organic | TSS | pH | carbonate | $SO_3$ | Hydrocarbon |
|---|---|---|---|---|---|---|
| Horizontal,1 0cm from the pit base | 3.6 | 0.24 | 7.68 | 33.4 | 0.06 | 0.63 |

|  |  |  |  |  |  |  |
|---|---|---|---|---|---|---|
| Horizontal 20cm from the pit base | 3 | 0.22 | 7.66 | 34.1 | 0.058 | 0.51 |
| Horizontal 30cm from the pit base | 2.8 | 0.22 | 7.65 | 34.3 | 0.055 | 0.43 |
| Horizontal40cm from the pit base | 2 | 0.21 | 7.62 | 33.2 | 0.054 | 0.4 |
| Vertical 10cm from the pit base | 3.6 | 0.24 | 7.68 | 33.4 | 0.06 | 0.63 |
| Vertical 20cm from the pit base | 3.5 | 0.26 | 7.6 | 33.2 | 0.063 | 0.6 |
| Vertical 30cm from the pit base | 3 | 0.26 | 7.68 | 33 | 0.061 | 0.55 |
| Vertical 50cm from the pit base | 2.5 | 0.26 | 7.7 | 32.8 | 0.061 | 0.51 |
| Zero contaminated sample | 3.7 | 0.21 | 8.18 | 25.2 | 0.067 | - |

**Table 5.28** Chemical test results for contaminated soils with oily wastewater for 1 m head of oily wastewater.

| Sample location | organic | T.S.S. | pH | carbonate | $SO_3$ | Hydrocarbon |
|---|---|---|---|---|---|---|
| Horizontal, 10cm from the pit base | 1.6 | 0.29 | 8.64 | 37.31 | 0.068 | 0.75 |
| Horizontal 20cm from the pitbase | 0.56 | 0.26 | 8.65 | 37.2 | 0.064 | 0.73 |
| Horizontal 30cm from the pit base | 0.545 | 0.26 | 8.58 | 37.1 | 0.062 | 0.71 |
| Horizontal40cm from the pit base | 0.658 | 0.26 | 8.56 | 37 | 0.063 | 0.70 |
| Vertical 10cm from the pit base | 1.24 | 0.29 | 7.9 | 37.5 | 0.073 | 0.98 |
| Vertical 20cm from the pit base | 1.21 | 0.28 | 8.09 | 37.2 | 0.07 | 0.92 |
| Vertical 30cm from the pit base | 0.92 | 0.25 | 8.06 | 37.1 | 0.063 | 0.8 |
| Vertical 50cm from the pit base | 0.62 | 0.26 | 8.56 | 37 | 0.066 | 0.8 |
| Zero contaminated sample | 3.7 | 0.21 | 8.18 | 25.2 | 0.067 | - |

**Table 5.29** Chemical test results for contaminated soils with oily wastewater for 2m/head of oily wastewater.

| Sample Location | organic | TSS | pH. | carbonate | $SO_3$ | Hydrocarbon |
|---|---|---|---|---|---|---|
| Horizontal,10 cm from the pit | 1.81 | 0.28 | 8.65 | 40 | 0.069 | 1 |
| Horizontal 20cm from the pit base | 1.14 | 0.27 | 8.13 | 36.4 | 0.68 | 0.95 |
| Horizontal 30cm from the pit base | 1.14 | 0.26 | 8.18 | 35 | 0.068 | 0.95 |
| Horizontal50cm from the pit base | 1.04 | 0.26 | 8.42 | 34 | 0.068 | 0.9 |
| Vertical1 0cm from the pit base | 1.68 | 0.28 | 8.07 | 40 | 0.067 | 1.5 |
| Vertical 20cm from the pit base | 1.31 | 0.27 | 8.57 | 36.2 | 0.067 | 1.47 |
| Vertical 30cm from the pit base | 1.14 | 0.27 | 8.65 | 33.6 | 0.067 | 1.45 |
| Vertical 60cm from the pit base | 1.07 | 0.27 | 8.54 | 33.6 | 0.067 | 1.4 |
| Zero contaminated soil samples | 3.7 | 0.21 | 8.18 | 25.2 | 0.067 | - |

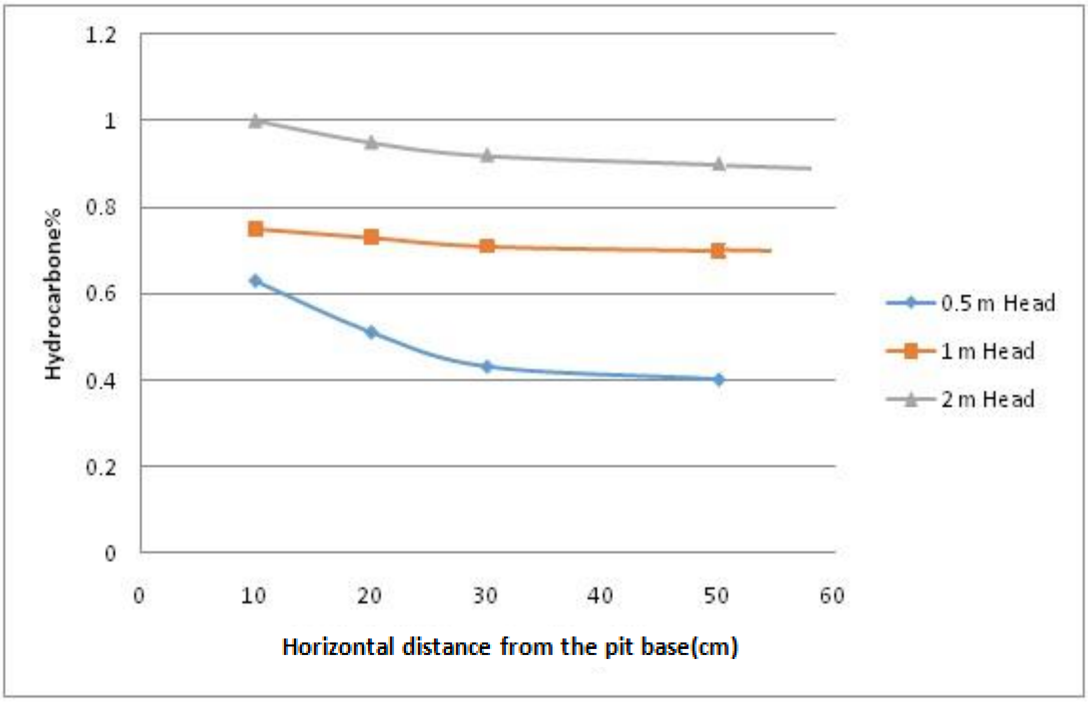



**Figure 5.24** Horizontal contaminated results of hydrocarbon content for polluted soil for all heads of oily wastewater

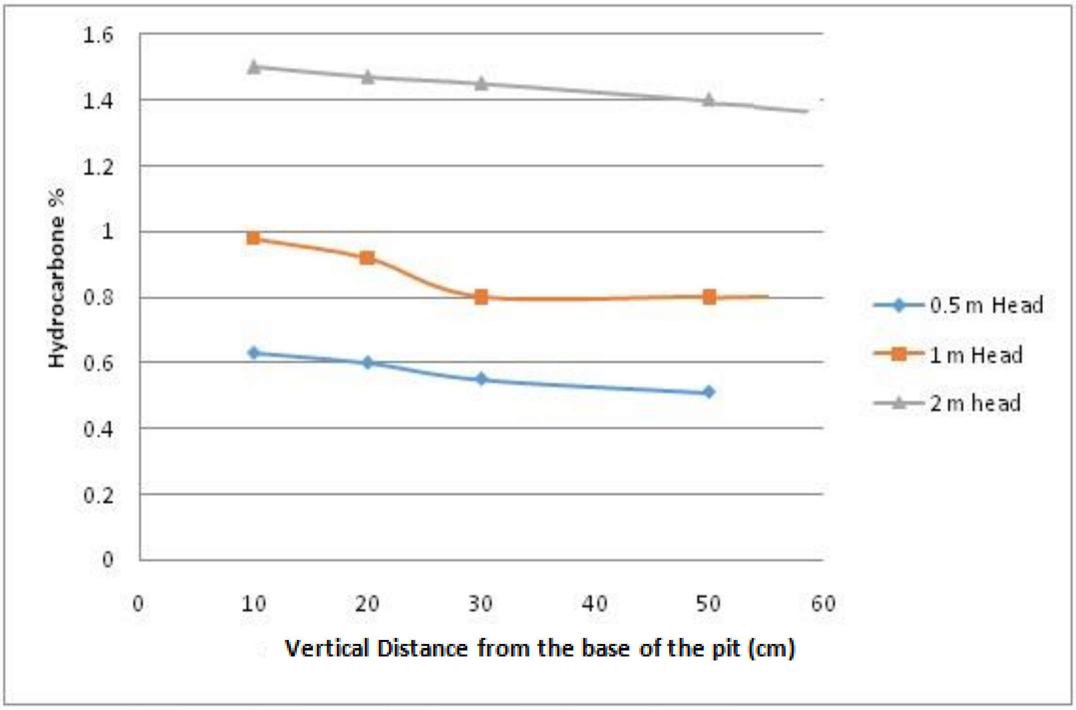



**Figure 5.25** Vertical contaminated results of hydrocarbon content for polluted soil for all heads of oily wastewater.

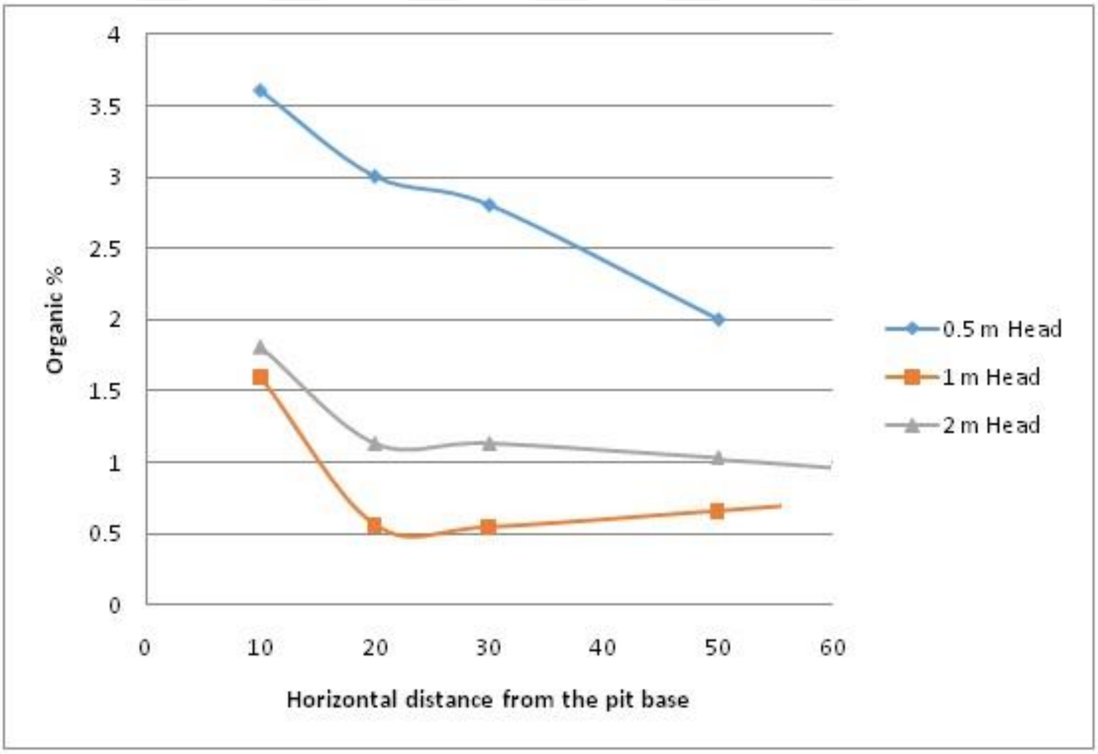



**Figure 5.26** Horizontal contaminated results of organic content for polluted soil for all heads of oily wastewater.

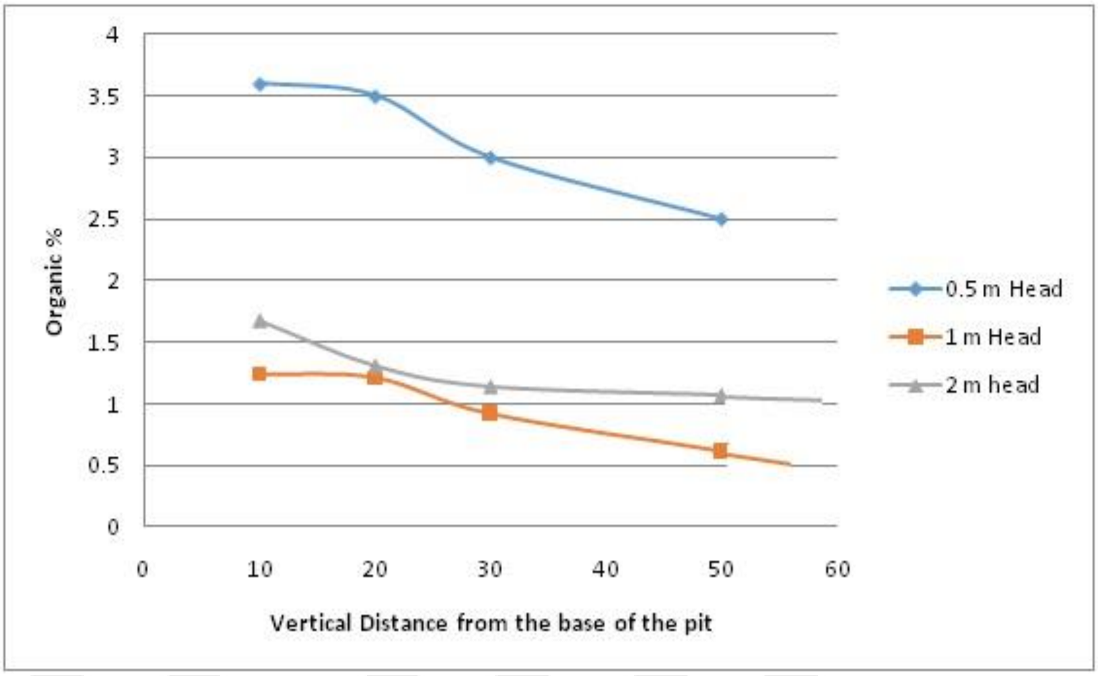



**Figure 5.27** Vertical contaminated results of organic content for polluted soil for all heads of oily wastewater.

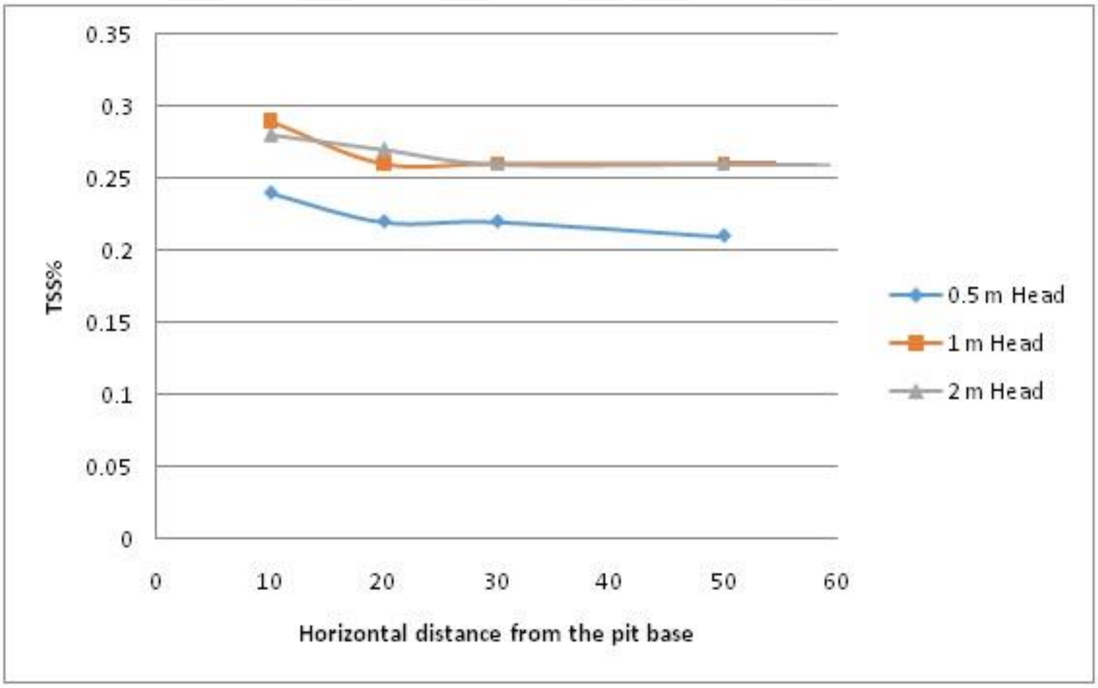



**Figure 5.28** Horizontal contaminated results of TSS content for polluted soil for all heads of oily wastewater.

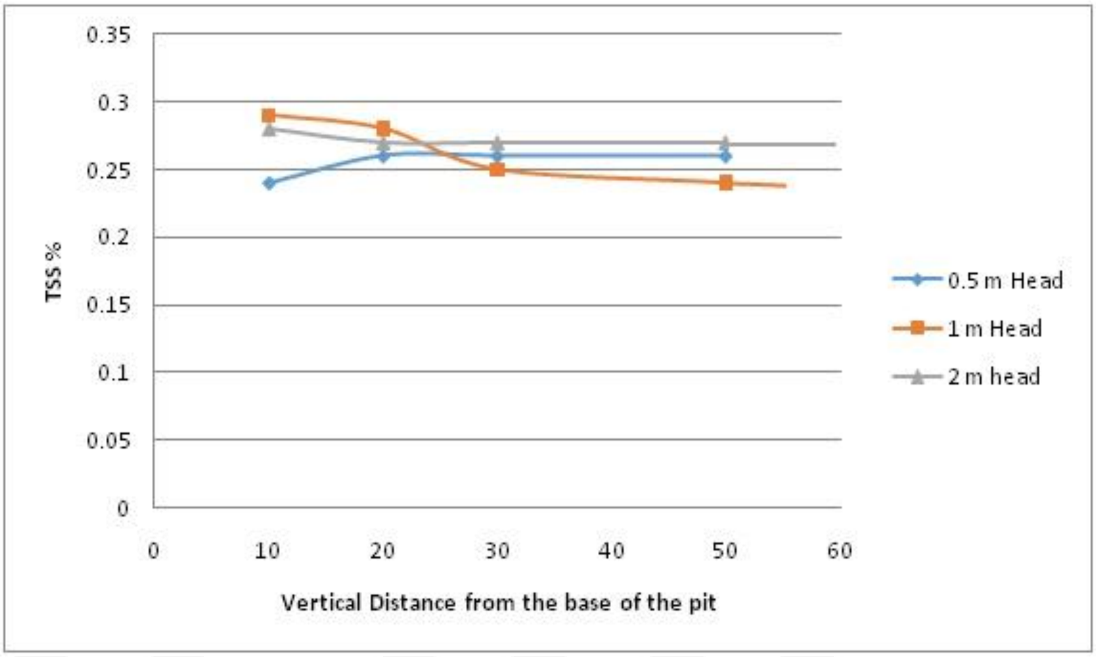



**Figure 5.29** Vertical contaminated results of TSS content for polluted soil for all heads of oily wastewater .

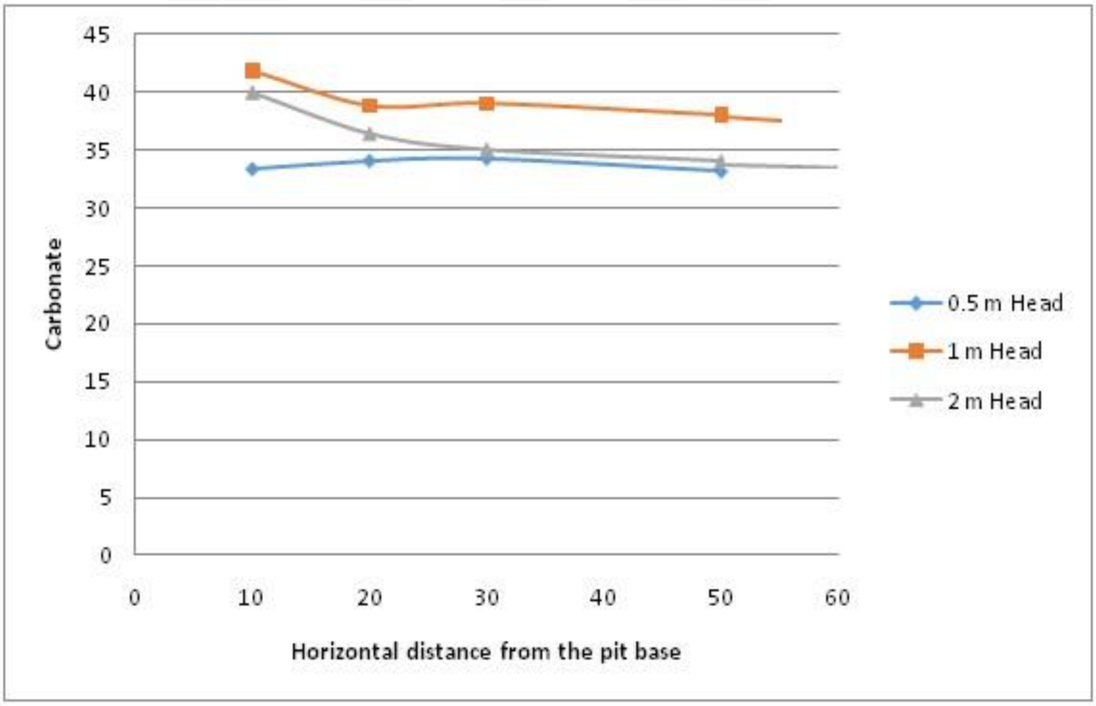



**Figure 5.30** Horizontal contaminated results of carbonates content for polluted soil for all heads of oily wastewater

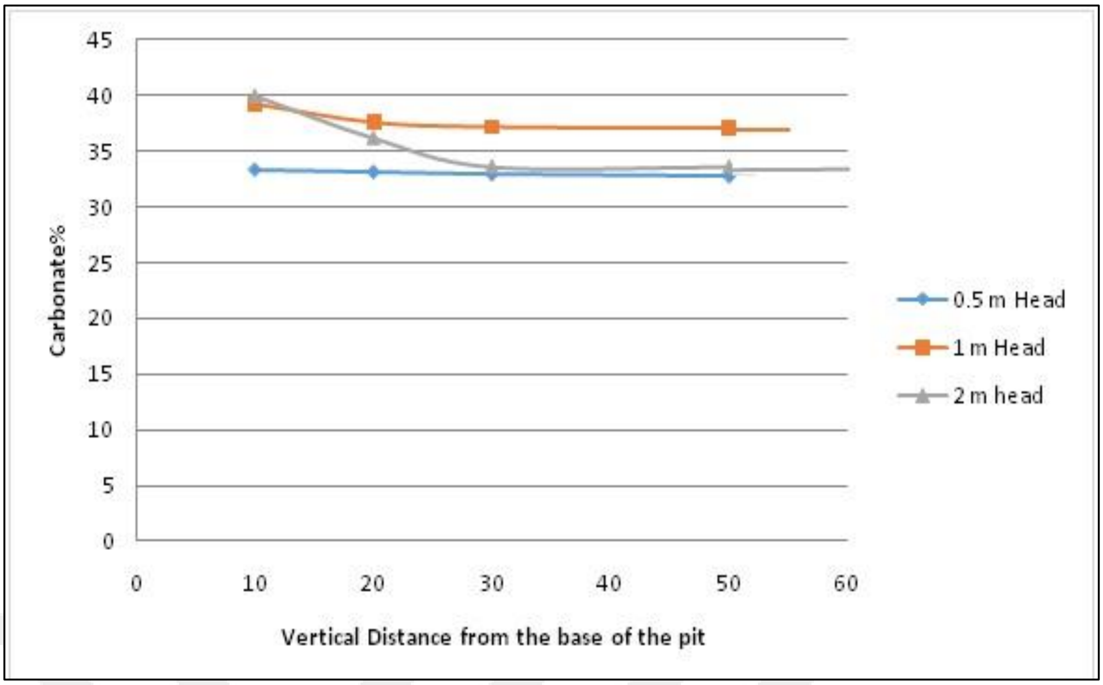



**Figure 5.31** Vertical contaminated results of carbonates content for polluted soil for all heads of oily wastewater

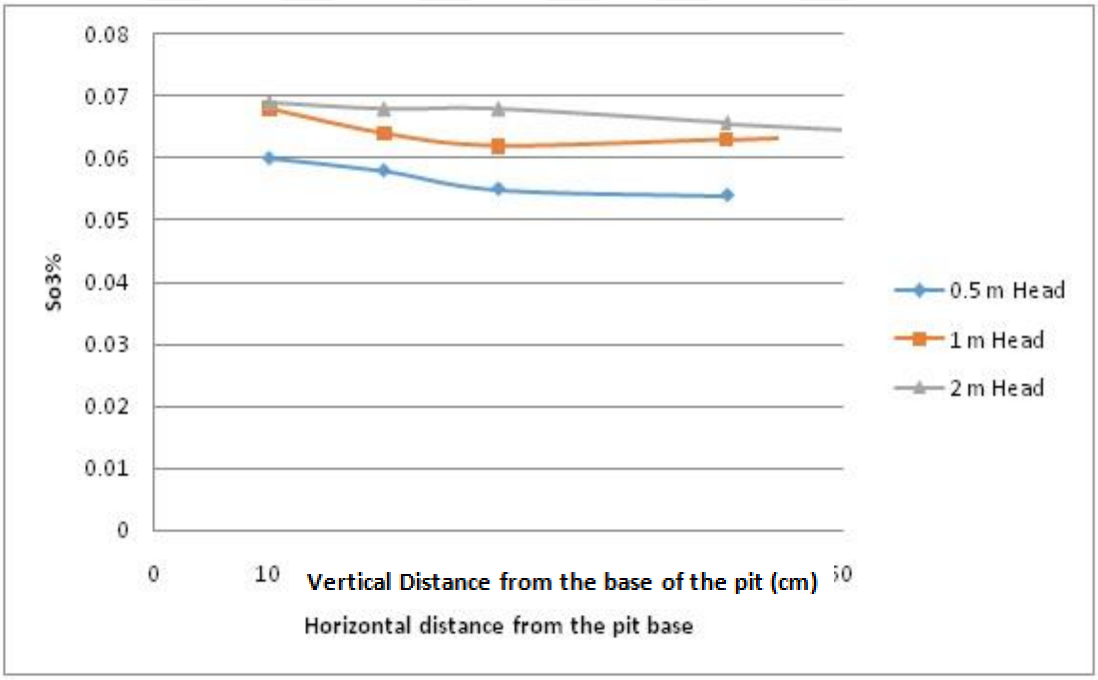



**Figure 5.32** Horizontal contaminated results of $SO_3$ content for polluted soil for all heads of oily wastewater.

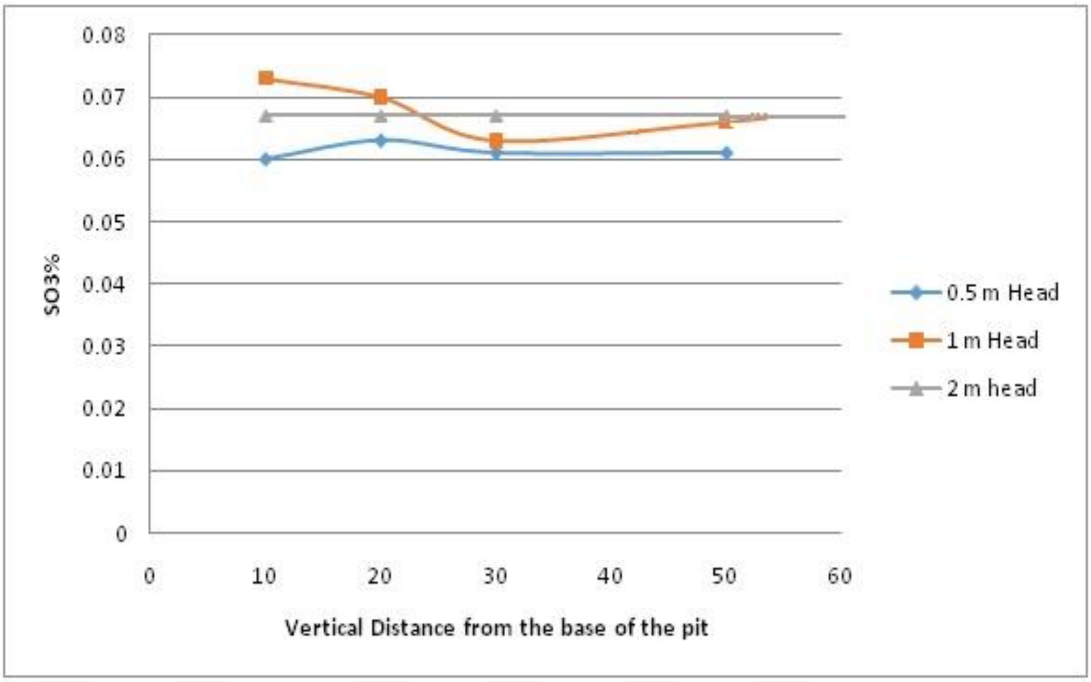



**Figure 5.33** Vertical contaminated results of $SO_3$ content for polluted soil for all heads of oily wastewater .

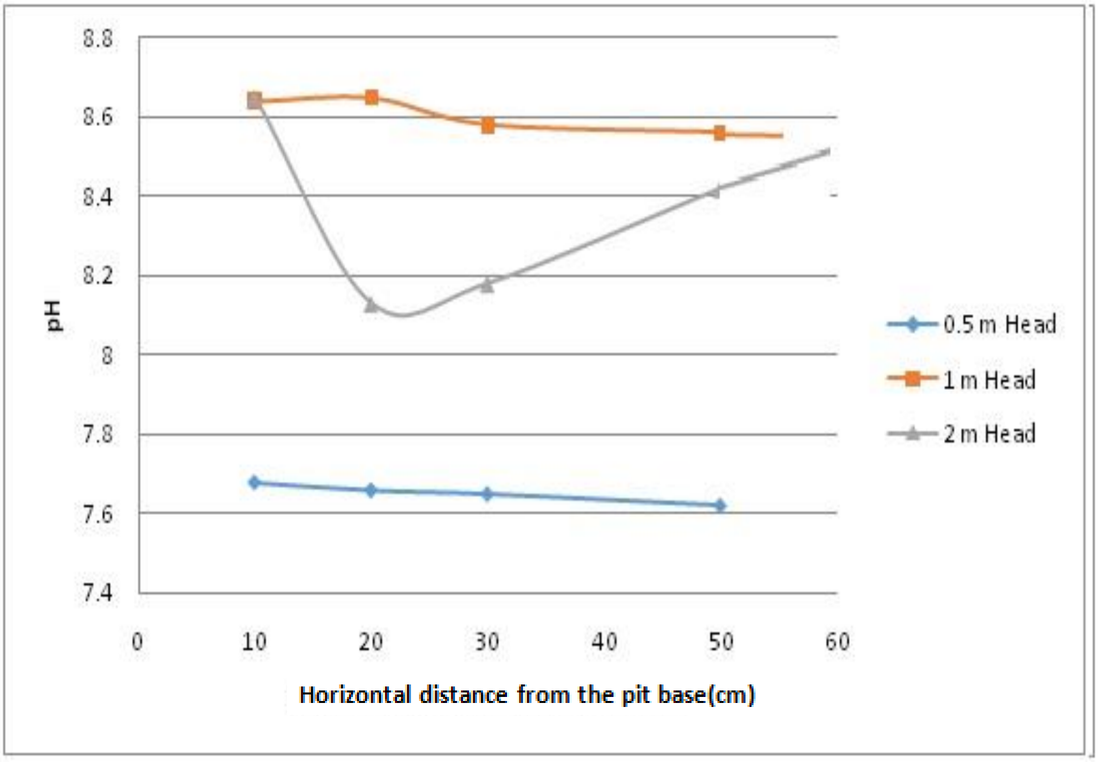



**Figure 5.34** Horizontal contamination results of pH content for polluted soil for all of oily wastewater.

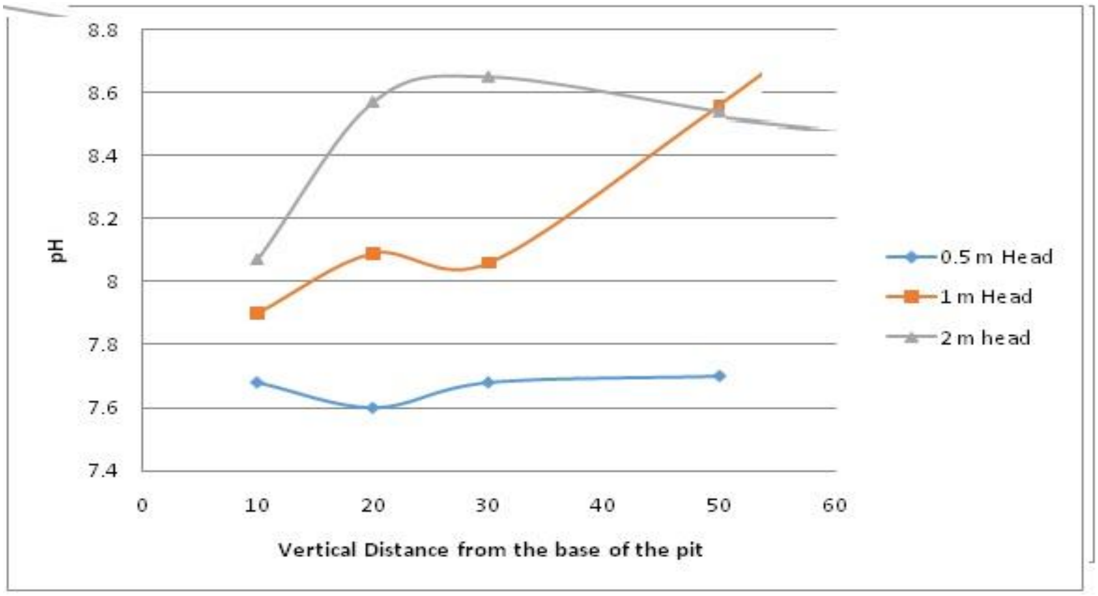



**Figure 5.35** Vertical contamination results of pH content for polluted soil for all of oily wastewater .

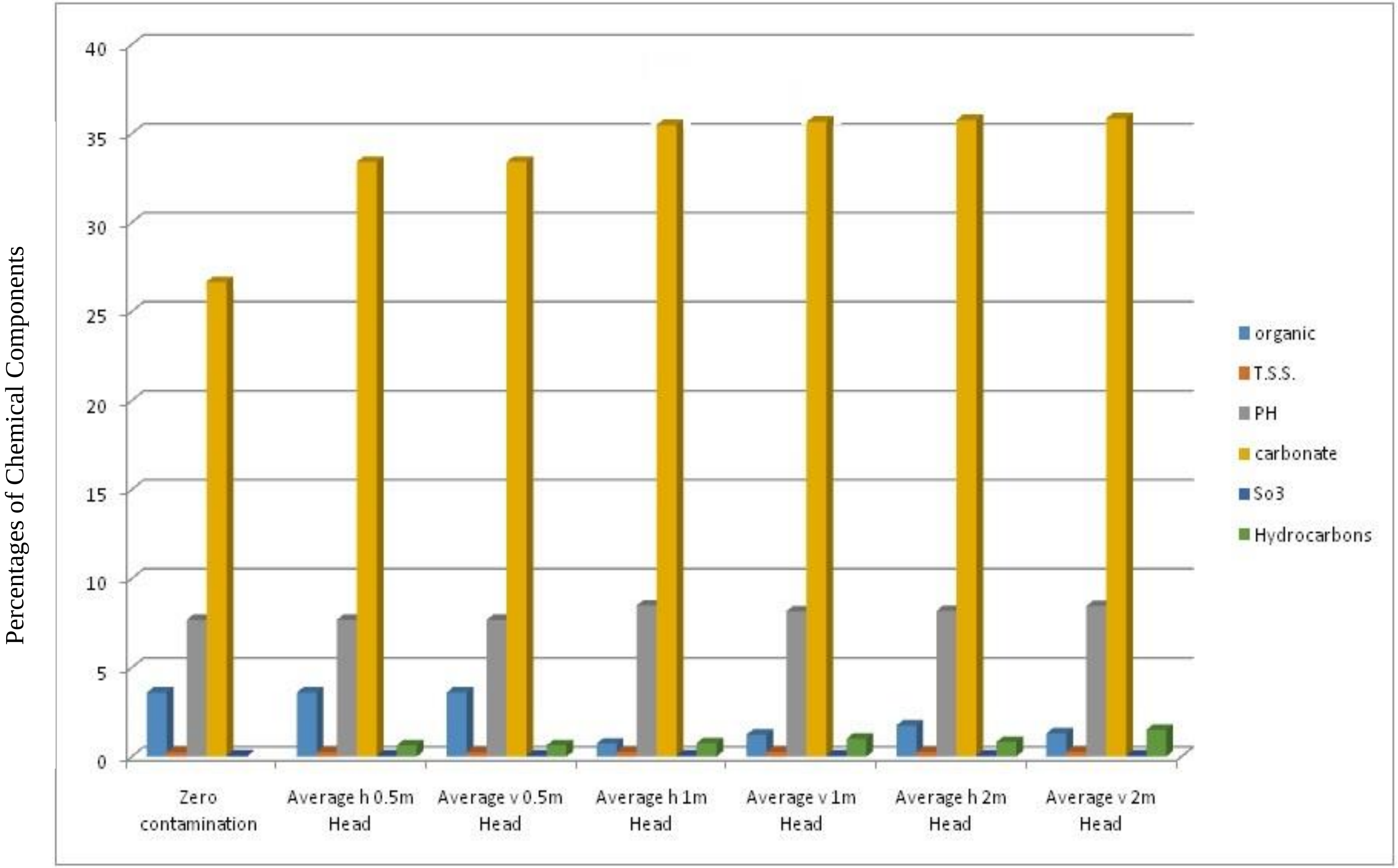



**Figure 5.36** Oil contamination results for all chemical test components and all oily wastewater heads.

The degree of chemical soil contaminations fluctuated for all chemical parameters; Organic, TSS, pH, Carbonates, $SO_3$, and Hydrocarbon. Generally, the effect of oily wastewater on the soil contamination appeared at the base of the pits and disappeared at nearly 40 cm, 50 cm and 60 cm far from the pit base for 0.5 m, 1 m and 2 m respectively. Details of the contamination process explained as follows:

1. Contamination results of soil chemical pollution with hydrocarbon (Figure 5.23, 5.24). From the results of contaminated soil with Hydrocarbon, it can be noted that the percentages of contamination were increased by increasing the oily wastewater head, higher results were recorded for vertical diffusions than for horizontal for all three heads due to the head pressure effect. The percentage increase was 0.21% for horizontal direction and 0.32% for vertical direction for 0.5m head of oily wastewater. The percentage increase for 1m and 2m head was almost close to each other and were 0.225% for horizontal direction and 0.56% for the vertical direction.
2. Contamination results of chemical soil pollution with organic (Figure 5.25, 5.26). Results of Organic content in the examined soil for all three heads of added oily wastewater showed a slight decrease compared with zero contamination soil. For 0.5m head the recorded value were 0.9% for horizontal direction and 0.69% for vertical directions. The contamination effect disappeared at 40cm far from the pit base. For 1m head, a slight decrease has been observed, 2.56% and 2.77% for horizontal and vertical directions respectively, and the effect of contamination disappeared on nearly 50 cm from the pit base. For 2m head, the decreased results were 2.28% and 2.32% in horizontal and vertical directions respectively, and the effect of contamination disappeared 0n 60cm far from the pit base. Therefore, the Organic contamination effect of soil with oily wastewater was limited because generally, it appears mostly near top soil layers.
3. Contamination results of soil pollution with TSS (Figure 5.27, 5.28). Total soluble salt (TSS) results for all three heads of oily wastewater for both directions showed a slight increase, the recorded values were 0.065% and 0.055% horizontally and vertically respectively.
4. Contamination results of soil pollution with carbonate (Figure 5.29, 5.30). In general, Carbonate results were decreased for both directions and for all three

heads of added oily wastewater comparing it with zero contaminated soil results. For 0.5 m head percentage increase were 8.75% and 8.1% for horizontal and vertical directions respectively. For 1m head the results were, 11.95% and 12% horizontally and vertically increased .For 2m head the results were 11.15% and 10.65% horizontally and vertically increased.

5. Contamination results of soil pollution with $SO_3$ (Figure 5.31, 5.32). By looking at the contamination results of $SO_3$, it can be noted that, the effect of oily wastewater on the soil contamination was limited for both directions. A slight decrease in the results have been recorded for 0.5 m head, 0.0065% and a slight increase recorded for 1m head 0.002%, for both directions, while a slight increase has been observed, for 2m head of oily wastewater, 0.002% for both directions.
6. Contamination results of soil pollution with pH (Figure 5.33, 5.34). High results were recorded for pH, for 1m and 2m/heads of oily wastewater, while for 0.5 m head a few results were recorded. This gives an indication that pH would appear more in high soil depths. For 0.5 mr head the results were decreased by 0.53% and 0.49% horizontally and vertically respectively, for 1mr head of oily wastewater a slight increase was recorded, 0.42% and 0.33% for horizontal and vertical directions, while for 2m head, the results increased by 0.35% and 0.37% horizontally and vertically
7. Overall results of soil contamination for all three heads of oily wastewater have been illustrated in Figure (5.35). From the Figure it can be noted that the results of Carbonates increased with the increase of the head of oily wastewater, the same observation was noted for pH. Organic appears more in zero contamination and for 0.5m head results, due to the effect of the pressure head. Small changes in the results of TSS and SO3 have been observed. Finally, Hydrocarbon results recorded high values for 1m and 2m heads for both vertical and horizontal directions.

In conclusion, the following two results have been obtained;

* Between the above-mentioned results with those obtained in Table (5.4) and the results are shown in Table (5.29).

* Between the average contamination results of Hydrocarbon as a( main chemical contaminated components) for all three heads with the results of Direct shear test of laboratory contaminated samples, Table 5.24 and Figures 5.20, 5.21, and the results are shown in Table 5.30.

**Table 5.30** Percentages of Chemical contamination for all three heads of oily wastewater.

| Oily wastewater | Organic | TSS | pH | Carbonate | $SO_3$. | Hydrocarbon |
|---|---|---|---|---|---|---|
| 0.5m Horizontal distance | Less than 5% | 15%-20% | More than 20% | More than 20% | 15%-20% | Less than 5% |
| 0.5m Vertical distance | Less than 5% | More than 20% | More than 20% | More than 20% | 20% | Less than 5% |
| 1m Horizontal distance | 15%-20% | More than 20% | Less than 5% | More than 20% | More than 20% | Less than 5% |
| 1m Vertical distance | 15%-20% | More than 20% | 5%-10% | More than 20% | More than 20% | Less than 5% |
| 2m Horizontal distance | Less than 5% | More than 20% | Less than 5% | More than 20% | More than 20% | Less than 5% |
| 2m Vertical distance | Less than 5% | More than 20% | 5%-10% | More than 20% | More than 20% | Less than 5% |

**Table 5.31** Direct shear parameters for Hydrocarbon contaminated samples heads of spilled oily wastewater. for all three

| Head, mr | Contamination results | C kPa | Φ (degree) |
|---|---|---|---|
| o.5 | 0.53 | 17.17 | 18.5 |
| 1.0 | 0.78 | 16.92 | 18.75 |
| 2.0 | 1.2 | 16.5 | 19.2 |

From the Table 5.30, we can observe that the actual percentages of chemical soil contaminations with oily wastewater have been reported; this would give us an indication that oily wastewater has large effects on soil contamination and the results varied from less than 5% up to 20% for all chemical components of all three heads, this would lead to various expected environmental problems. From the Table 5.31, it can be noted that a slight decrease in the values of Cohesion and a slight increase angle of internal friction have been obtained.

### 5.3.2 Field Investigation Test Results and Discussions of the contaminated soils of the Lagoon site of Kawergosk Refinery

The results of field investigations of the lagoon site of the Kawergosk refinery are shown in Table 5.32 and Figures 5.37, 5.38 from the Figure it can be noted that all chemical contamination parameters recorded high values at the base of the lagoon and decreased toward the surface, this would be due to the hydrostatic pressure head effect of the oily wastewater on the subsurface soils. The values of Direct shear parameters for the average contamination results of Hydrocarbon as a (main chemical contaminated components)for all four lagoon locations have been found using the results of Direct shear test of laboratory contaminated samples, Table 5.21 and Figures 5.21, 5.22 the results are shown in Table 5.33. From the results, it can be noted that slight decrease (1.44%) of the values of Cohesion have been noted, and 14% of the values of angle of internal friction increased.

**Table 5.32** Contamination of soil for the Lagoon outside of the refinery.

| **Contaminations** | **S1 (3 m depth, 4 m far from the base)** | **S2 (2.5 m depth, 3m far from the base)** | **S3 (1.5 m depth, 2m far from the base)** | **S4 (1.5 m depth, 1.5m far from the base)** |
|---|---|---|---|---|
| Organic | 7.12 | 5.91 | 0.81 | 0.17 |
| TSS | 0.26 | 0.21 | 0.2 | 0.21 |
| pH | 7.6 | 7.59 | 7.57 | 7.56 |
| Carbonate | 37 | 36 | 35.8 | 26.4 |
| $SO_3$. | 0.08 | 0.07 | 0.065 | 0.064 |
| Hydrocarbons | 8 | 5 | 3 | 1 |

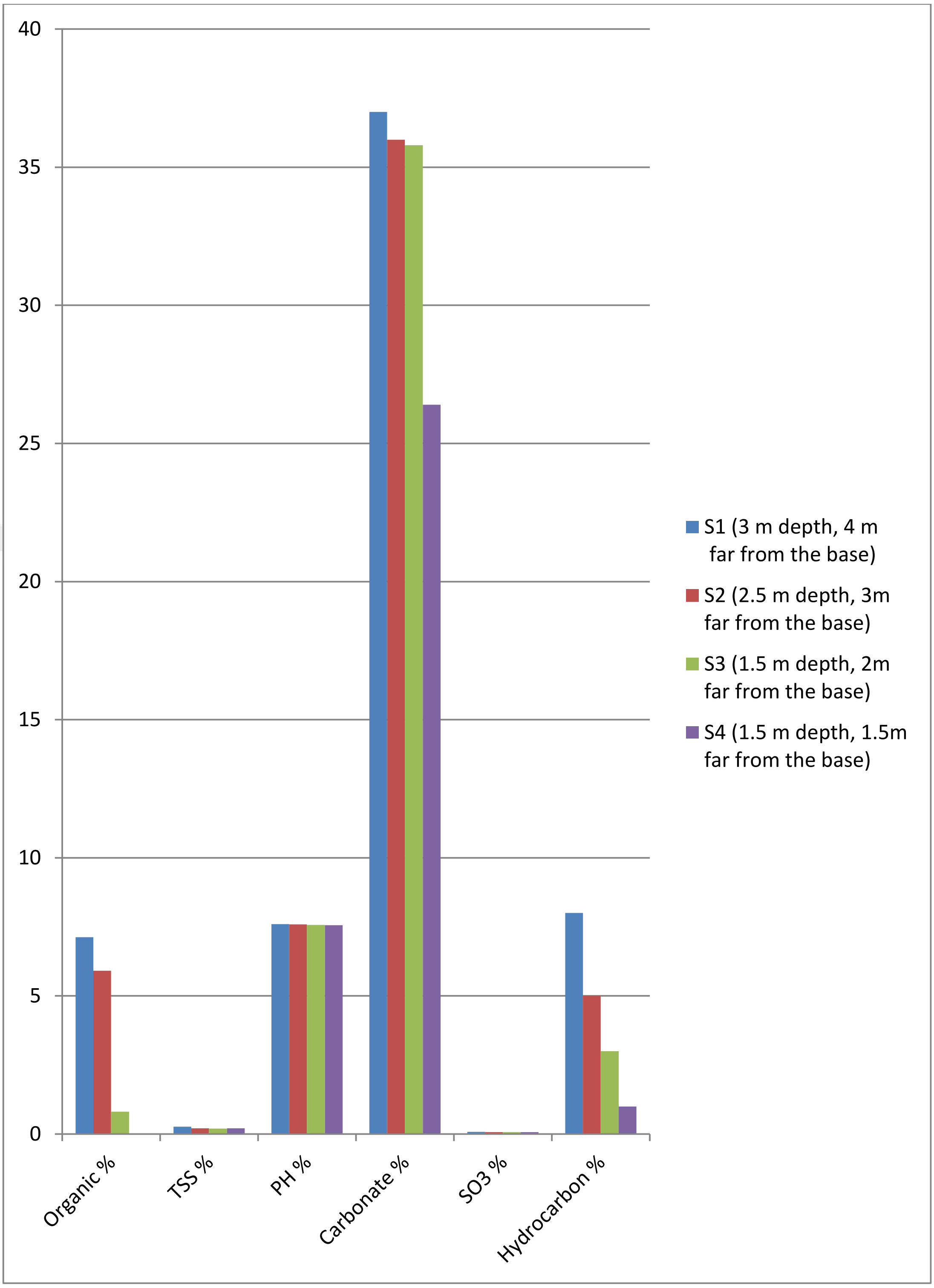



**Figure 5.37** Bar chart for soil chemical pollution of the lagoon site.

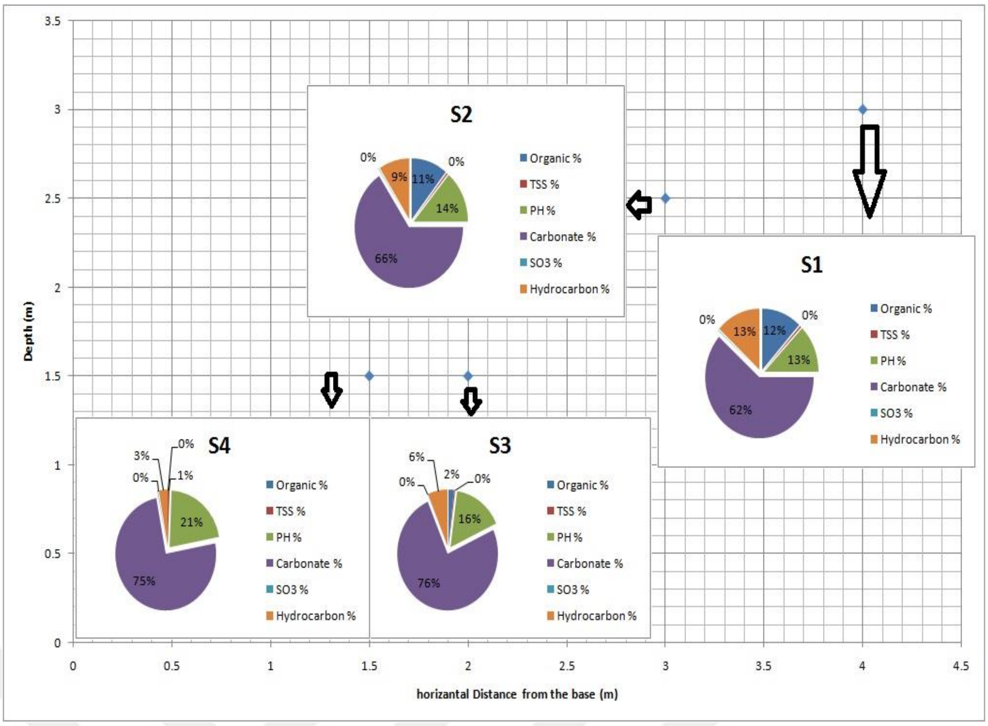



**Figure 5.38** Sample locations of the field lagoon and its chemical properties.

**Table 5.33** Direct shear parameters for Hydrocarbon contaminated samples for all four locations in the Lagoon.

| Location | Hydrocarbon Contamination | C (kPa) | Φ (degree) |
|---|---|---|---|
| S1 | 8 | 17.48 | 22 |
| S2 | 5 | 17 | 28 |
| S3 | 3 | 16.52 | 32 |
| S4 | 1 | 16.04 | 36 |

### 5.3.3 Comparison between chemical contamination results for both field and lagoon samples.

In Tables 5.34 and Figure 5.39 (a and b) a comparison between the chemical contaminated results of the field pit tests and the Lagoon site tests showed almost a comparable results for all chemical contamination components except the hydrocarbon ,that could be because the contamination durations of lagoon site were much higher than the field pit duration tests because the oily wastewater may lift for long-duration time before remediation process starts in the wastewater treatment plant, while the field pit tests were completed in short duration, Figure 5.23.

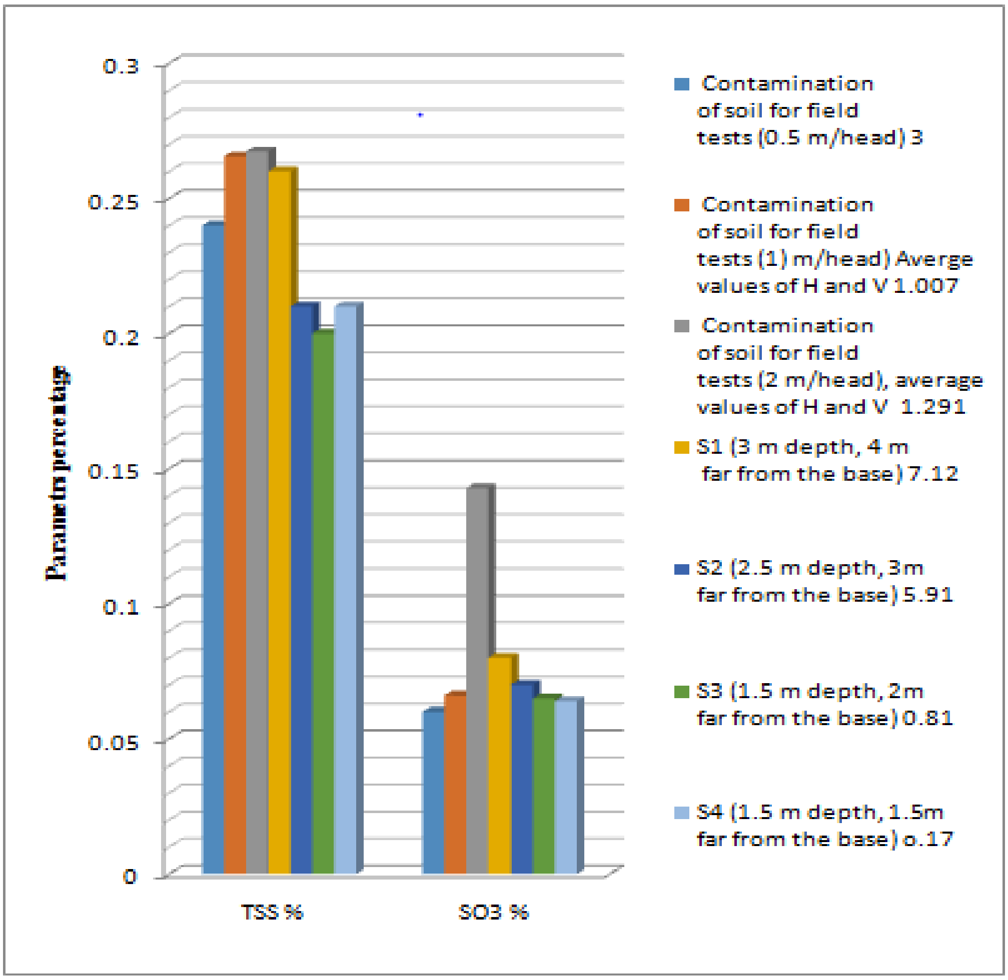
Another comparison between the results of direct shear test parameters obtained from the Hydrocarbon contaminations for both field tests has been shown in Table 5.35. From the results, a slight decrease in the values of Cohesion was observed, while for Angle of internal friction results of the lagoon site were higher than those of field tests.

**Table 5.34** Comparison between Chemical test Results of Contaminated Soils with oily wastewater, for both Field test and Lagoon Site of Kawergosk Refinery.

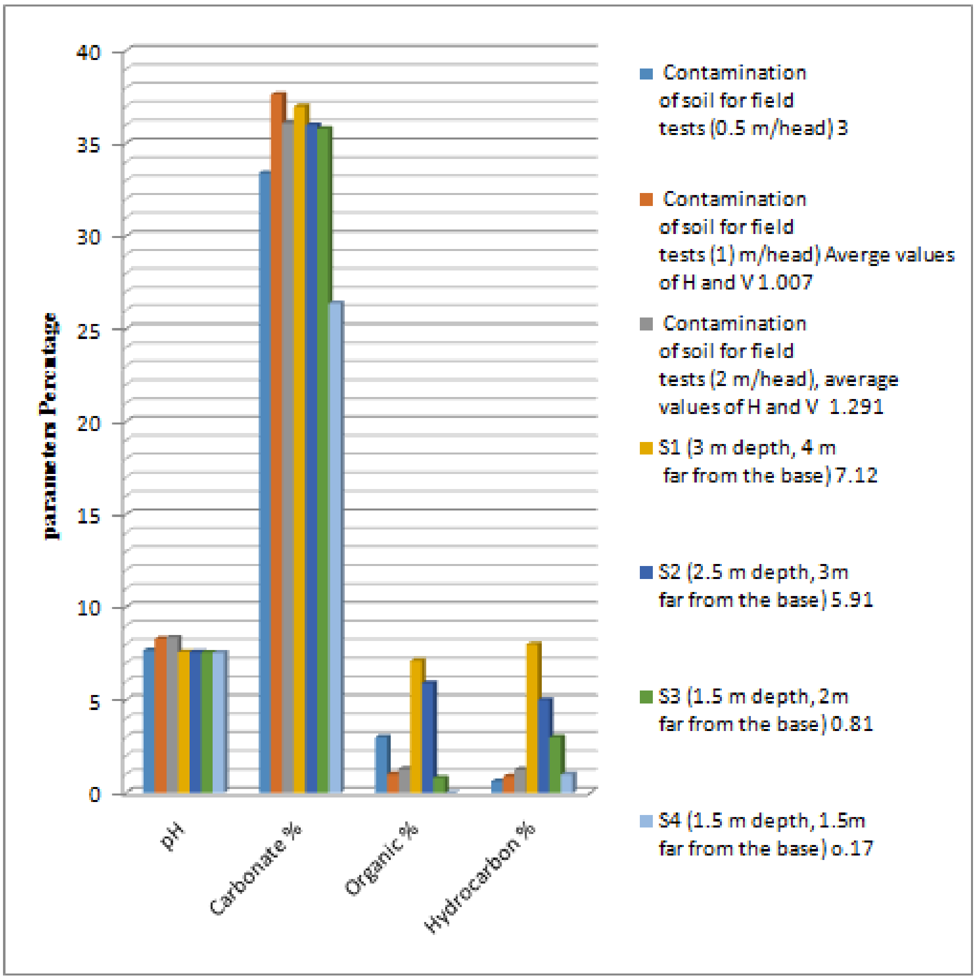
| Chemical Test Parameters | Contamination of soil for Field tests (0.5 m/head) Average values of H and V | Contamination of soil for Field tests (1) m/head) Average values of H and V | Contamination of soil for Field tests (2 m/head), average values of H and V | Contamination of soil for the Lagoon outside of the refinery | | | |
|---|---|---|---|---|---|---|---|
| | | | | S1 (3 m depth, 4 m far from the base) | S2 (2.5 m depth, 3m far from the base) | S3 (1.5 m depth, 2m far from the base) | S4 (1.5 m depth, 1.5m far from the base) |
| Organic % | 3.0 | 1.007 | 1.291 | 7.12 | 5.91 | 0.81 | 0.17 |
| TSS % | 0.24 | 0.266 | 0.268 | 0.26 | 0.21 | 0.2 | 0.21 |
| pH % | 7.68 | 8.304 | 8.383 | 7.6 | 7.59 | 7.57 | 7.56 |
| Carbonate % | 33.4 | 37.176 | 36.100 | 37 | 36 | 35.8 | 26.4 |
| $SO_3$% | 0.06 | 0.066 | 0.143 | 0.08 | 0.07 | 0.065 | 0.064 |
| Hydrocarbon % | 0.63 | 0.875 | 1.250 | 8 | 5 | 3 | 1 |

**Table 5.35** Comparison between the results of direct shear parameters for hydrocarbon contaminated samples for both field test samples.

| Chemical Test | Field Test 0.5 m/head | | Field Test 1 m/head | | Field Test 2 m/head | | Field Lagoon Test S1 | | Field Lagoon Test S2 | | Field Lagoon Test S3 | | Field Lagoon Test S4 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | C kPa | Φ Degree | C kPa | Φ Degree | C kPa | Φ Degree | C kPa | Φ Degree | C kPa | Φ Degree | C kPa | Φ Degree | C kPa | Φ Degree |
| Hydrocarbon | 17.17 | 18.5 | 16.92 | 18.75 | 16.5 | 19.2 | 17.48 | 22 | 17 | 28 | 16.52 | 32 | 16.04 | 36 |




(a)




(b)

**Figure 5.39** a and b Comparison between Chemical test Results of Contaminated Soils with oily waste water, for both Field test and Lagoon Site of Kawergosk Refinery.

# CHAPTER 6

# CONCLUSIONS AND RECOMMENDATIONS

## Conclusions

The conclusion section of this study includes an environmental investigation regarding the air pollutions and soil contaminations in the oil field and refinery zones of southwest of Erbil city, also its effect on geotechnical properties of soil.

## 6.1 Environmental pollution

Form the environmental investigations on the polluted zone near oil fields and refineries, figure 5.1, it can be concluded that the majority of the lands will be highly polluted and affected by the existence of the large and small non-modernized refineries. Air was severely polluted by harmful gases especially Co and $h_2s$. The surrounding soils were also covered by huge agricultural lands, which made farmers leave away and find other places to stay.

### 6.1.1 Chemical test results

Results of chemical tests on examined soils before and after contamination with oily wastewater, table 5.4, showed a positive effect on the chemical contaminated parameters, pH, Gypsum, Carbonates, Chlorite and Sulphate, while a large effect on hydrocarbons recorded.

## 6.2 Geotechnical conclusions of the results

### 6.2.1 Physical test results

Physical test results of Atterberg limit values on both zero and contaminated soils with oily wastewater, table 5.5 and figure 5.4, showed a slight increase on the values of

Liquid limit and Plastic limit, the reason behind was the properties of the oily wastewater which contains more than 80% water.mechanical test results.

The mechanical tests conducted were, one-dimensional consolidation test, direct shear tests, and field and laboratory permeability tests, on both zero and contaminated soil samples with various percentages of oily wastewater. From the results obtained, the following conclusions have been made:

1- The remolded clayey samples have been used in mechanical tests.
2- It has been shown that the oily wastewater has a clear impact on the geotechnical properties of the clayey soil around the Kawergosek refinery area.
3- Four percentages (5%.10%.15% and 20%) of oily wastewater of the refinery have been used for contamination with clay soils in this investigation.
4- The results of one-dimensional consolidation test on both contaminated and uncontaminated soil samples showed that table 5.9 and 5.10, Cv values decreased with the increase of applied stresses, Cc values increased with the increase of contamination with oily wastewater, while Cr decreased, Void-ratio decreased while total-unite weight increased with the increase of soil contamination with oily wastewater.
5- Permeability results K for both field and laboratory contaminated soil samples showed that, adding oily wastewater in the field or in the laboratory induces a reduction in permeability values. Table 5.11 and figure 5.8.
6- A comparison results of both field and laboratory test samples for consolidation test revealed that the trends of Cv and K curves are almost similar. A reduction in K values has been noted for both test samples, table 5.21 and 5.22. Cc results showed higher values while Cr results were close to each other. Finally the void ratio result decreased for both tests figure 5.18 while total unite weights increased figure 5.19.
7- The effect of oily wastewater contamination on shear strength parameters depends on the degree of the contamination of soils. The increase of the percentage of contamination leads to the increase of angle of internal friction, and also a slight decrease of cohesion was observed for all percentages of oily wastewater contamination, table 5.24 and figures 5.20, 5.21, as a result of the viscous behavior of contaminated soils.

8- In addition, results of shearing stress for all contaminated samples with oily wastewater showed a reduction in its values by 1.2%, this leads to a reduction in bearing capacity values for the examined soil samples that have been taken in (50 cm) depth, therefore the soil either to be removed or stabilized for civil engineering project purposes, table 5.25

### 6.2.2 Field study regarding soil pit tests

Results of the field test investigations regarding Diffusion (percolation of the oily wastewater to the soil) showed that the examined soil was highly polluted chemically. For all examined depths of oily wastewater. Also, the result showed that the land would be within the range of semi-permeable and could be taken into consideration for urban development, finally, the result showed that the majority of other parts of the land would be within the range of moderate for agricultural and conservation purposes.

### 6.2.3 Field study regarding effect of oily wastewater heads on diffusion rates

Overall results of soil contamination for all three heads of oily wastewater have been illustrated in figure 5.35. From the figure it can be noted that results of Carbonates increased with the increase of the head of oily wastewater, the same observation was noted for pH Organic appears more in zero contamination and for 0.5m head results due to the effect of the pressure head. Small changes in the results of TSS and SO3 have been observed. Finally, Hydrocarbon results recorded high values for 1m and 2m heads for both vertical and horizontal directions.

A comparison between the above-mentioned results with those obtained in table 5.4 has been made, and the results are shown in table 5.29, which gives a percentage of all chemical contaminations for all three heads of oily wastewater. Also, results of Hydrocarbon (as a main chemical contaminated components) for all three heads have been used with the results of direct shear test of laboratory contaminated samples, table 5.24 and figures 5.20, 5.21 to determine its correspondence shear parameters shown in table 5.30. From the table, it can be noted that a slight decrease in the values of Cohesion and angle of internal friction has been observed.

### 6.2.4 Field Investigation Test Results and Discussions of the contaminated soils of the Lagoon site of Kawergosk Refinery

The results of field investigations of the lagoon site of the Kawergosk refinery, table 5.31 and figures 5.36, 5.37, showed that all chemical contamination parameters recorded high values at the base of the lagoon and decreased toward the surface, this would be due to the hydrostatic pressure head effect of the oily wastewater on the subsurface soils. The values of Direct shear parameters for the average contamination results of Hydrocarbon for all four lagoon locations have been found, table 5.32 using the results of Direct shear test of laboratory contaminated samples, table 5.20 and figures 5.20, 5.21, From the results, it can be noted that a slight decrees (1.44%) of the values of Cohesion have been noted, and 14% of the values of angle of internal friction increased.

### 6.2.5 Comparison between chemical contamination results for both field and lagoon samples

The chemical soil contamination results recorded in the Lagoon site generally showed high values, especially for hydrocarbon compared with the soil pit tests. From both field tests, one can observe that the diffusion rate of oily wastewater is proportional with the height of the spilled oily wastewater, due to the pressure head effect, the vertical rate results showed higher results than the horizontal one due to the anisotropy properties of examined subsoils, and the effect of chemical soil contaminations is also proportional with the diffusion rates of oily wastewater for both directions. Table 5.30 and figures 5.36 and 5.37

In tables 5.31 and figure 5.38 a comparison between the chemical contaminated results of the field pit tests and the Lagoon site tests showed almost a comparable results for all chemical contamination components except the hydrocarbon, that could be because the contamination durations of lagoon site were much higher than the field pit duration tests because the oily wastewater might remain for a long period before remediation process starts in the wastewater treatment plant, while the field pit tests were completed in a short while, figure 5.22.

Another comparison between the results of direct shear test parameters obtained from the Hydrocarbon contaminations for both field tests has been shown in table 5.34. From the results, a slight decrease in the values of cohesion was observed, while for Angle of internal friction results of the lagoon site were higher than those of field tests.

### 6.3 Recommendations

The following recommendations were suggested:

Further study should be carried out on the polluted region (South West of Erbil city) in order to investigate water pollution problems regarding the existence of oil fields and refineries.

1- Further study is required on the effect of gas emissions from the oil fields and refineries on air pollution and finding solutions for that.
2- More investigations required regarding soil contamination and its effect on the geotechnical properties to cover surrounding areas of the oil fields and refineries in order to take necessary actions by the authorities to prohibit the extension of the oil industry so as not to object urban development.
3- To understand the behavior of oily wastewater on soil contamination, the micromechanics relationship between chemical components and soil particles to be studied.
4- Investigation should be extended to cover other scopes such as safety sections of oil industries.

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# APPENDIX

**Contains:**

1-Additional Figures for consolidation and Direct shear tests

A- Additional consolidation Figures for laboratory contaminated samples

B- Additional consolidation Figures for field contaminated samples

C- Additional Figures for direct shear tests

2-Additional plates

3-Additional Tables

4-Published articles

1-Additional Figures for consolidation and Direct shear tests

A- Additional Figures for laboratory contaminated samples

1- Zero contaminated samples

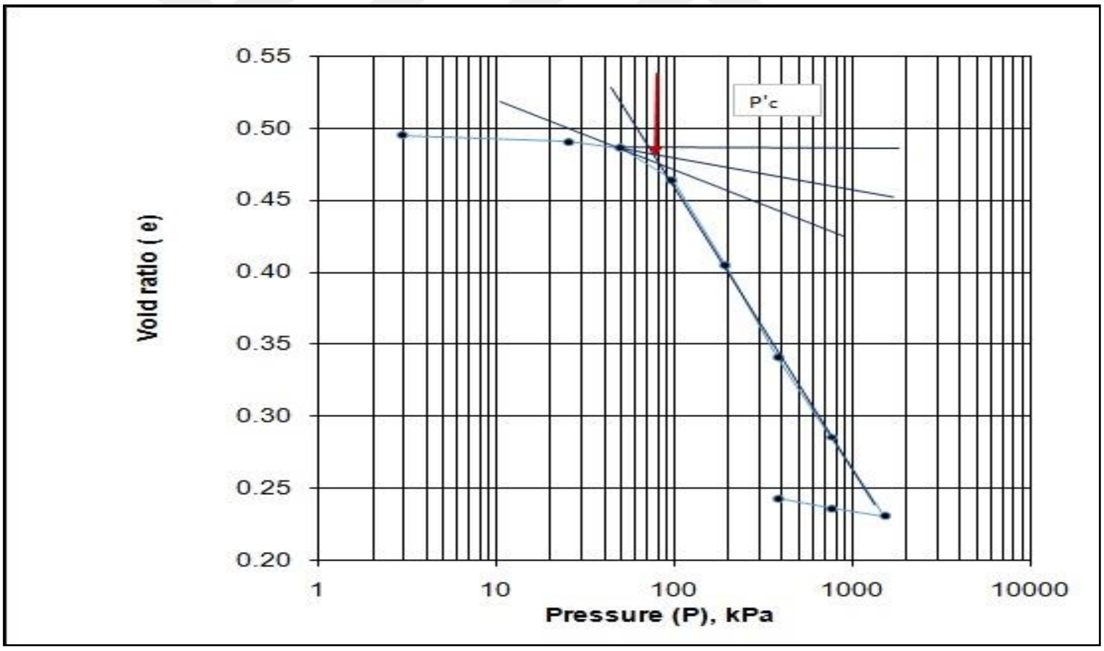



**Figure (1)** Void ratio – pressure plot for sample one

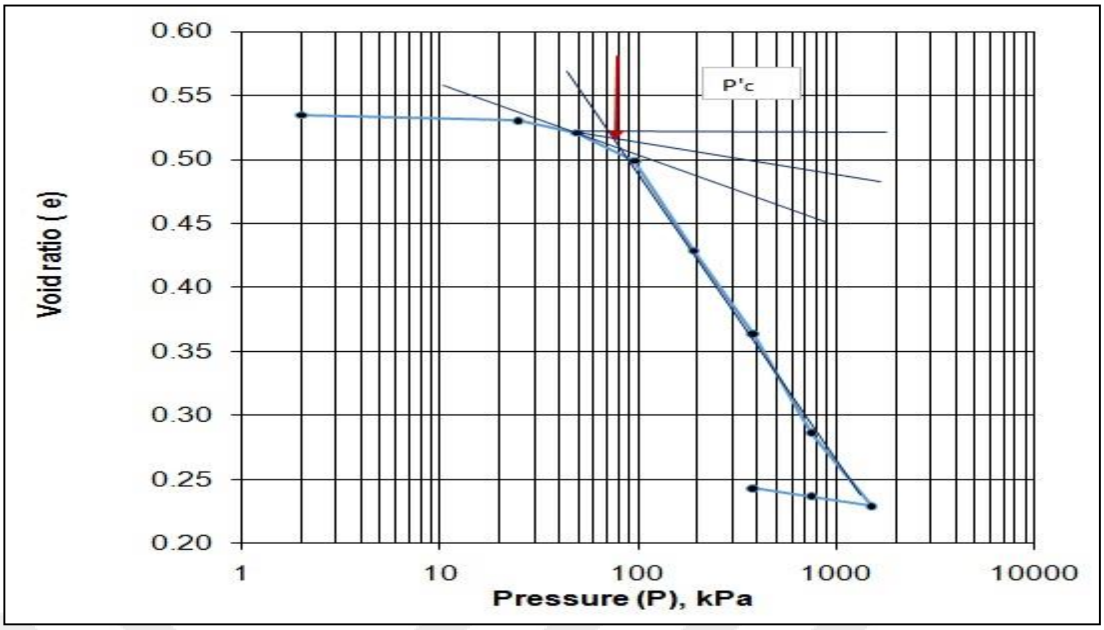



**Figure (2)** Void ratio – pressure plot for sample two

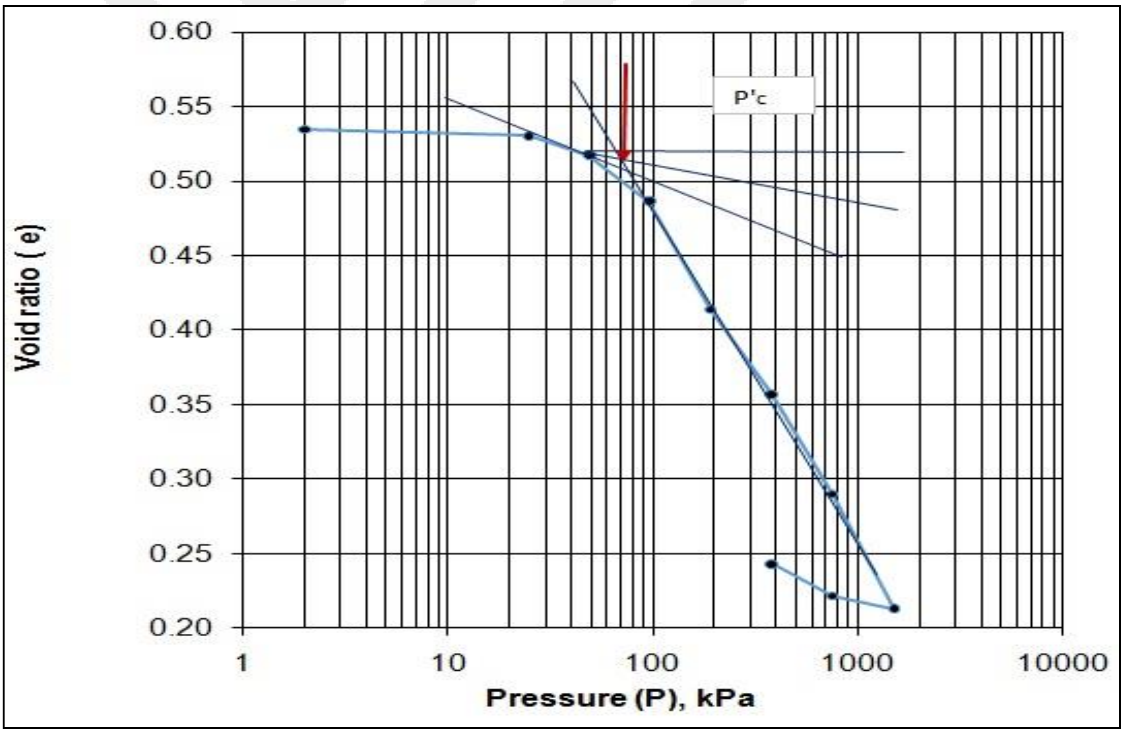



**Figure (3)** Void ratio – pressure plot for sample three

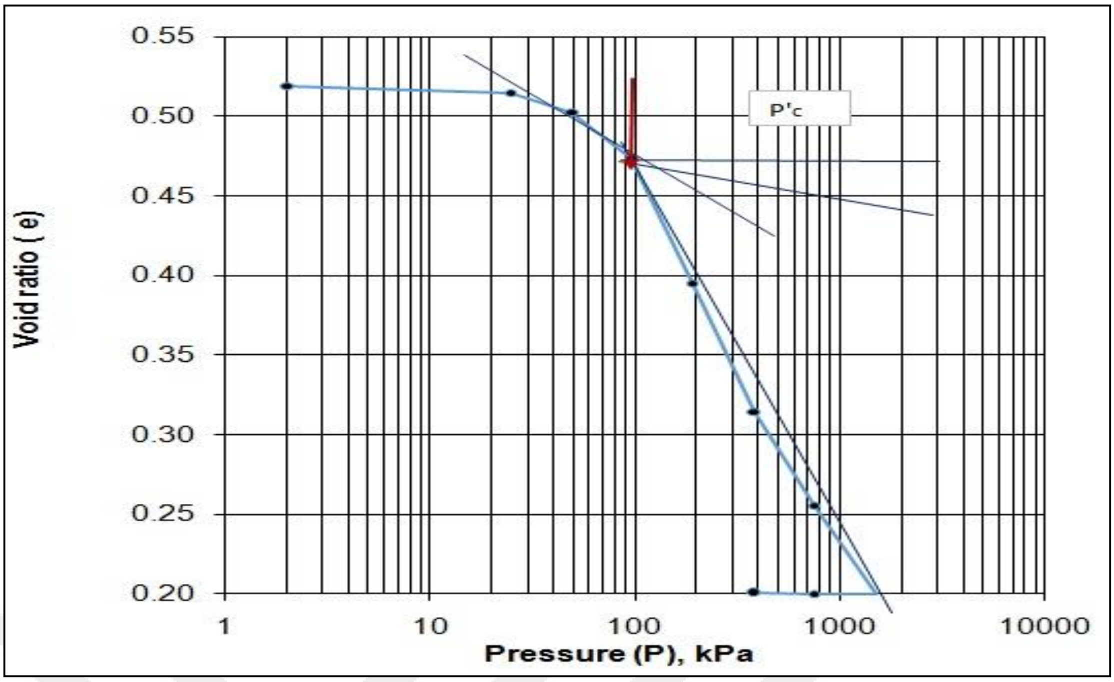



**Figure (4)** Void ratio – pressure plot for sample four

**2- B contaminated samples**

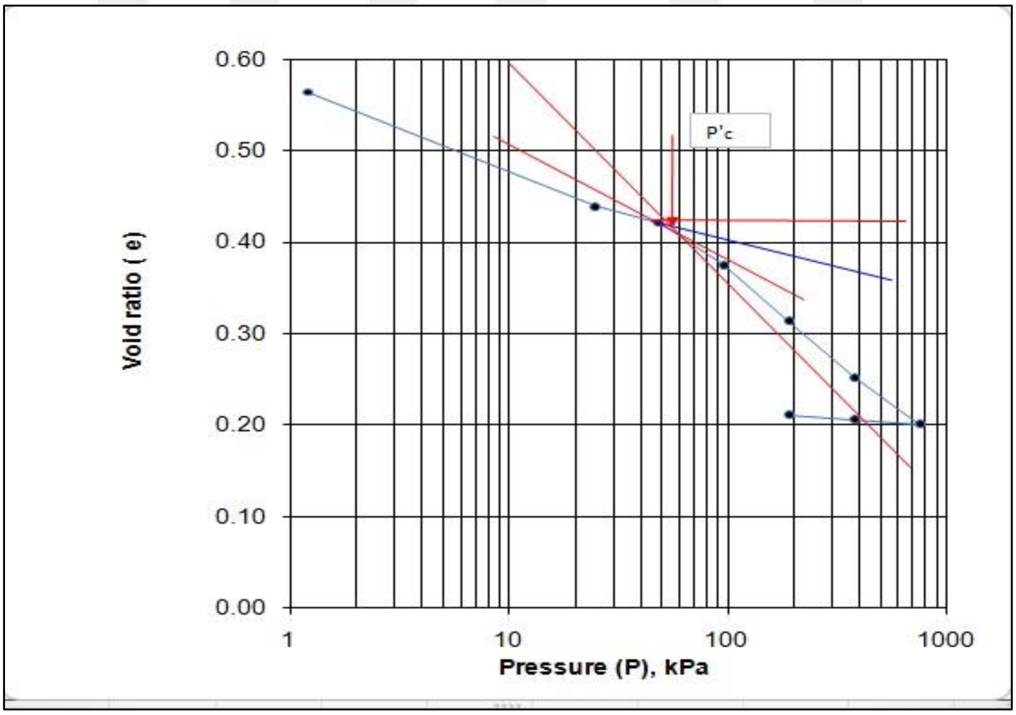



**Figure (1)** Void ratio – pressure plot for 5% waste samples

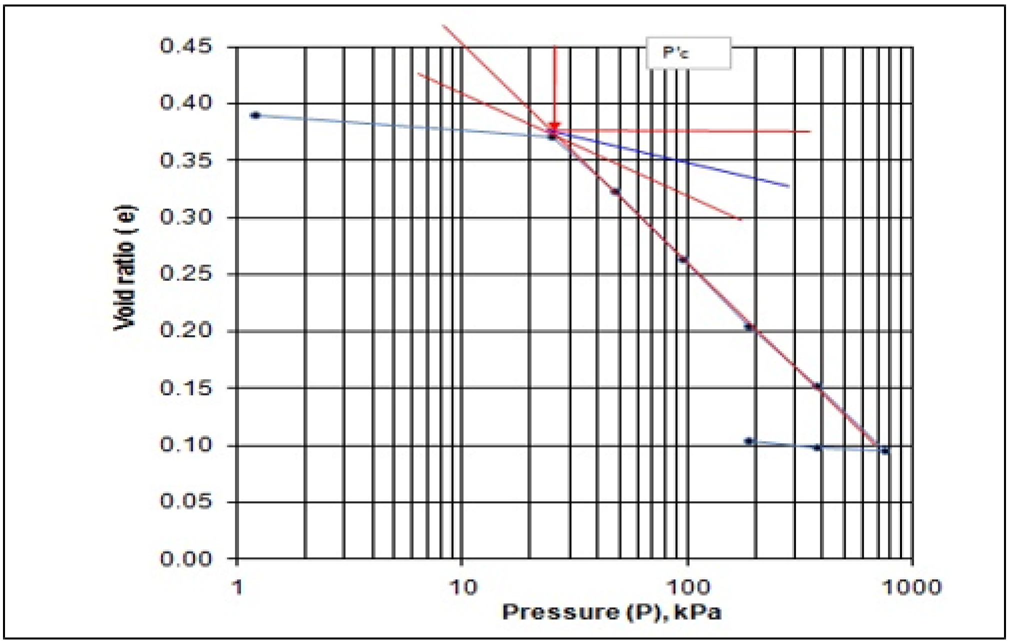



**Figure (2)** Void ratio – pressure plot for 10% waste samples

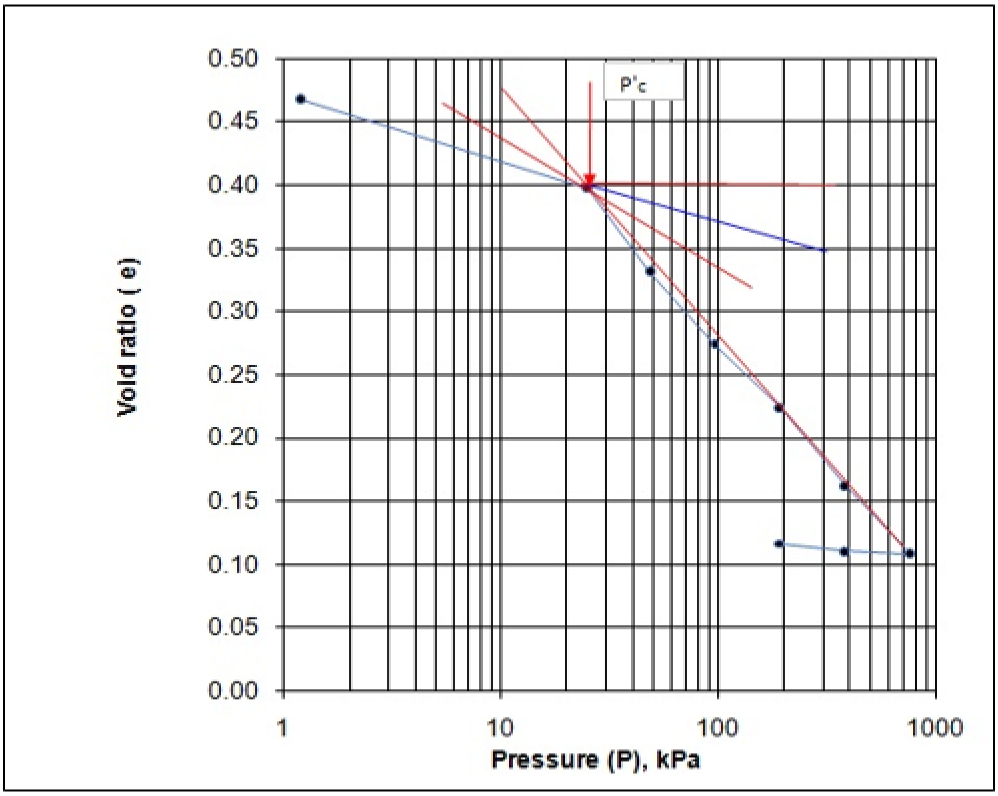



**Figure (3)** Void ratio – pressure plot for 15% waste samples

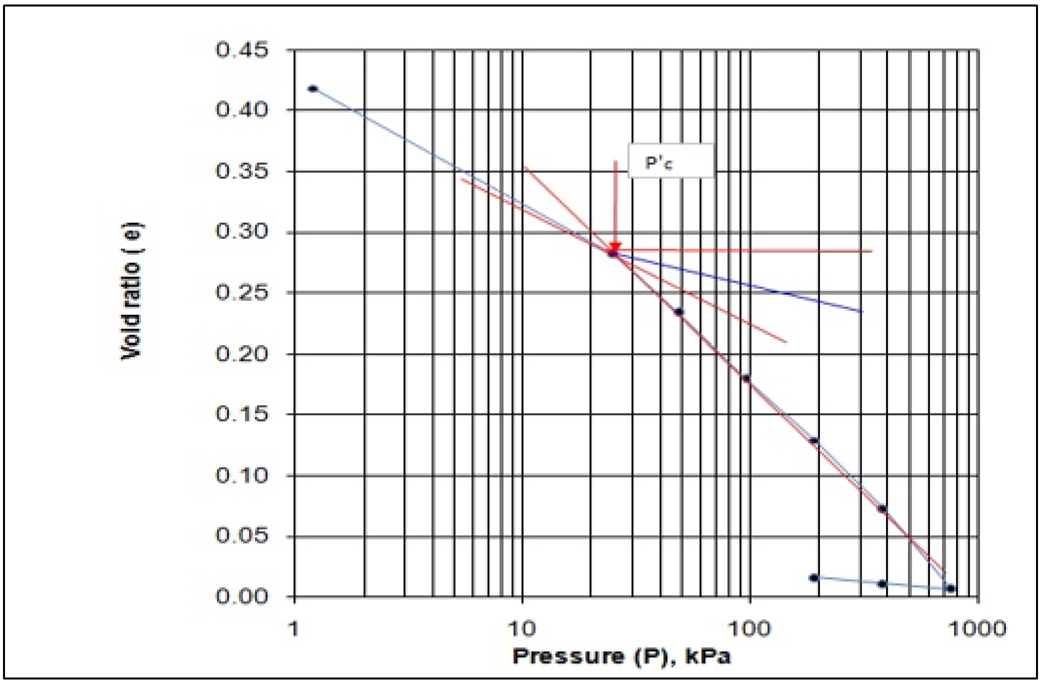



**Figure (4)** Void ratio – pressure plot for 20% waste samples

## B- Additional consolidation Figures for field contaminated samples

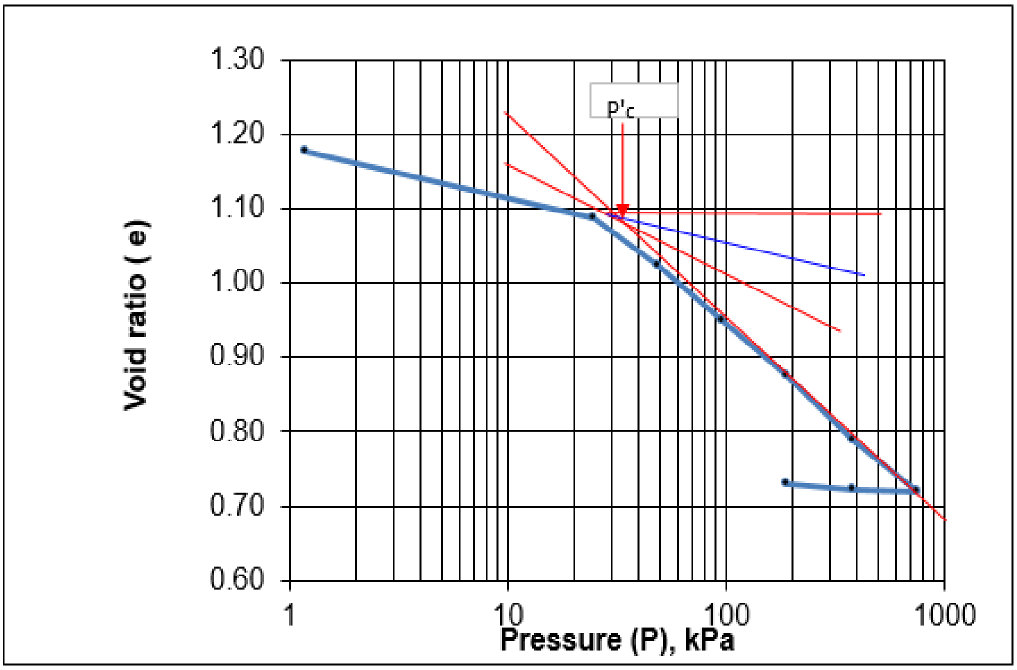



**Figure (1)** Void ratio – pressure plot for 1 D waste penetration

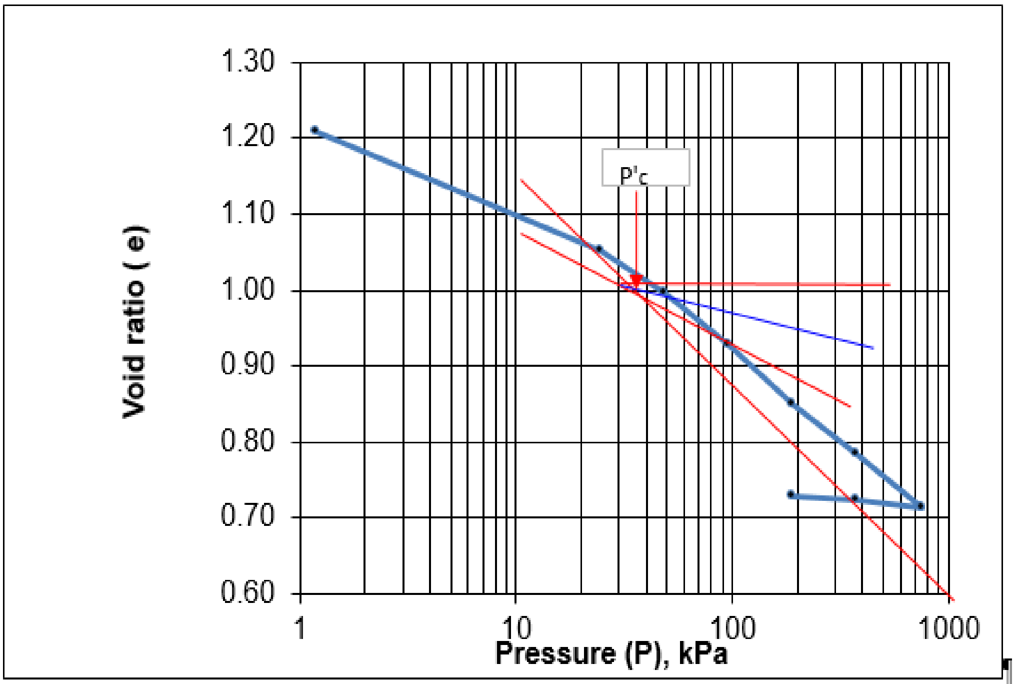



**Figure (2)** Void ratio – pressure plot for 3 DV waste penetrations

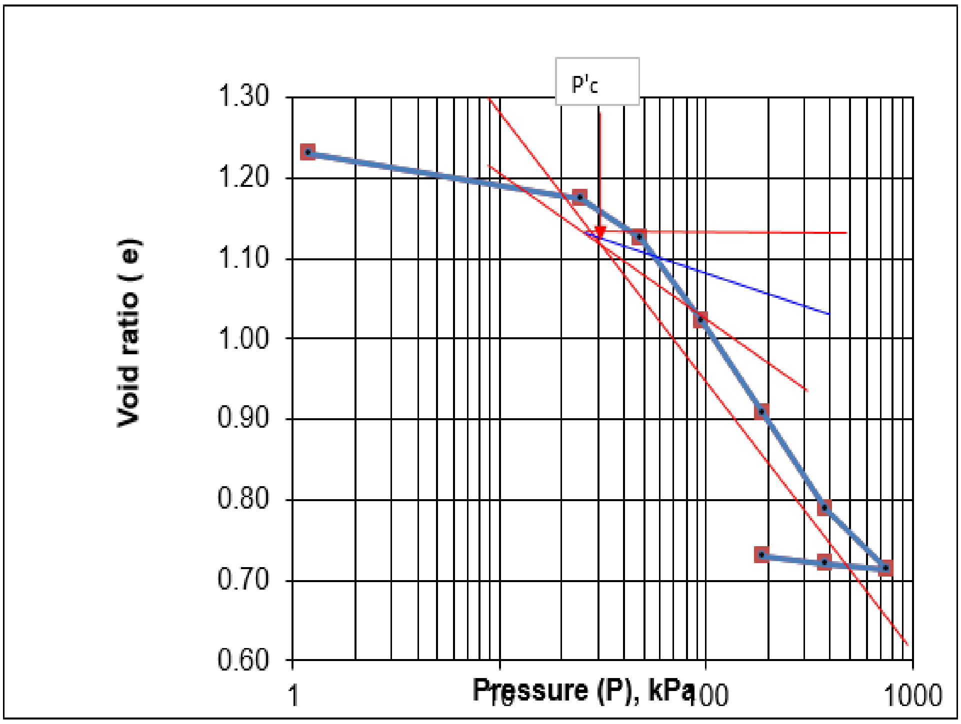
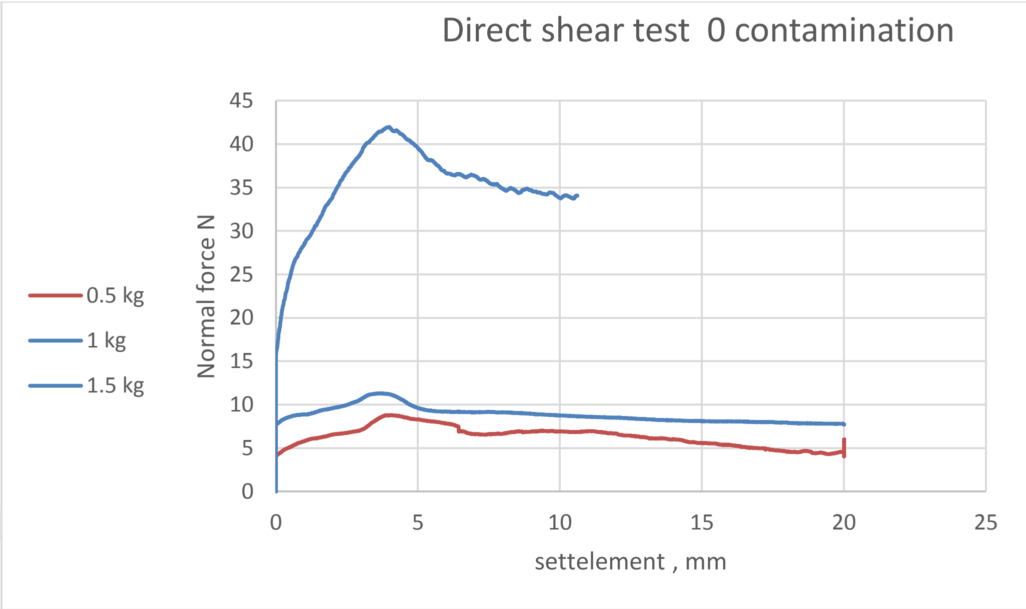



**Figure (3)** Void ratio – pressure plot for 3 DH waste penetrations

### C- Additional Figures for direct shear tests



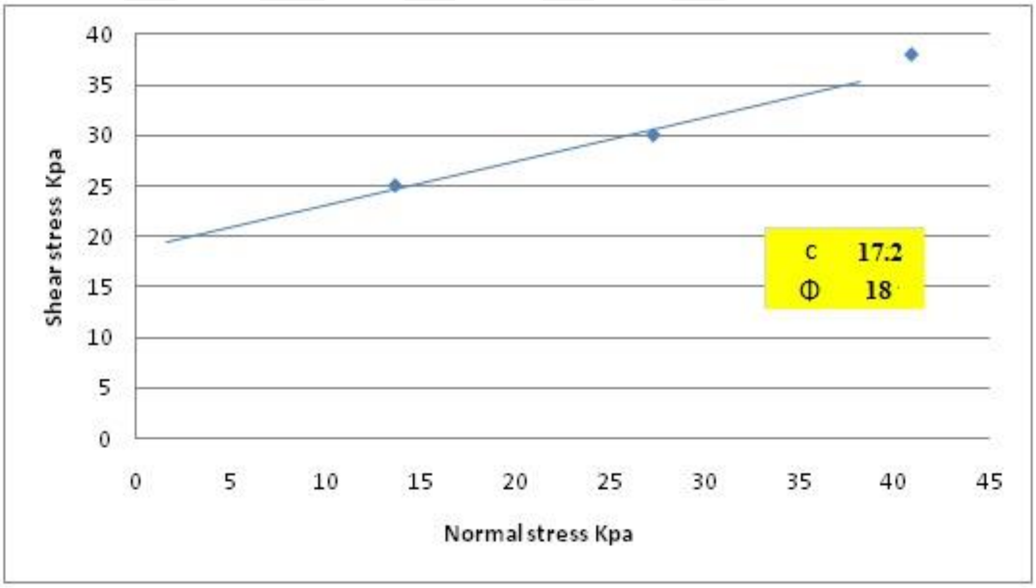
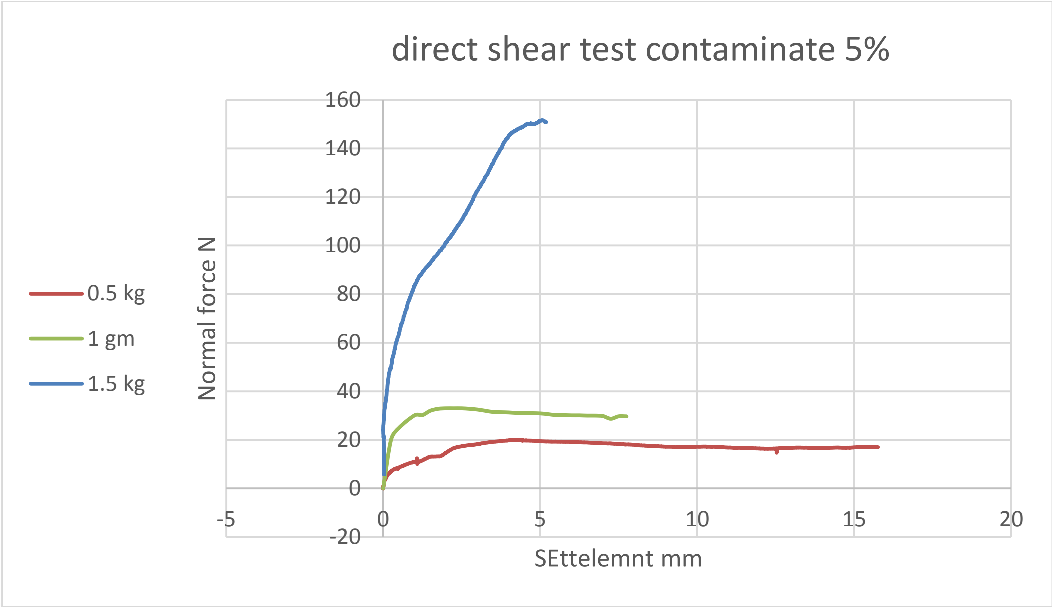




**Figure (1)** (Direct shear test for zero contaminated sample)



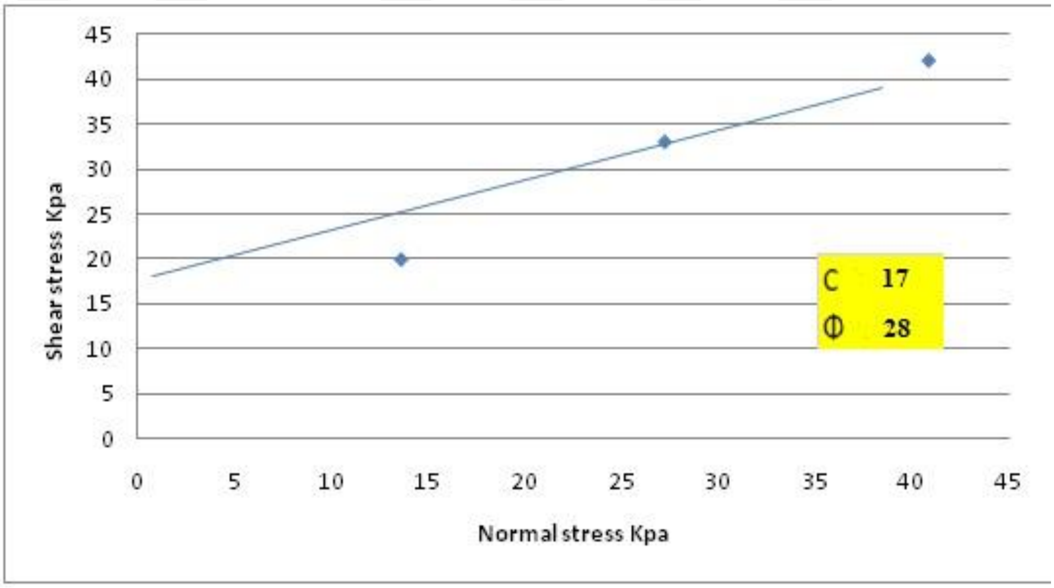
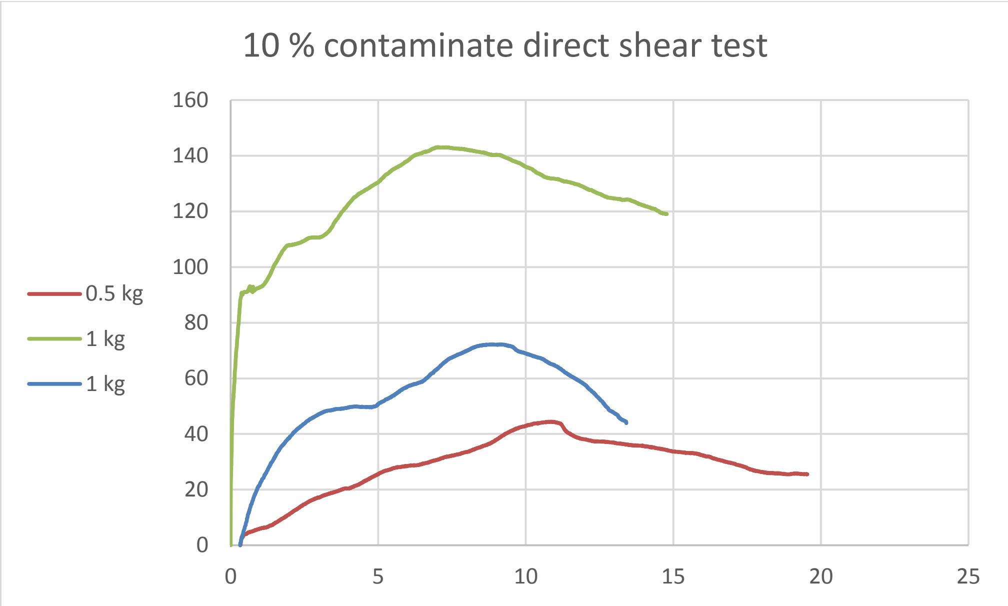




**Figure (2)** (direct shear test for 5% contaminated sample)



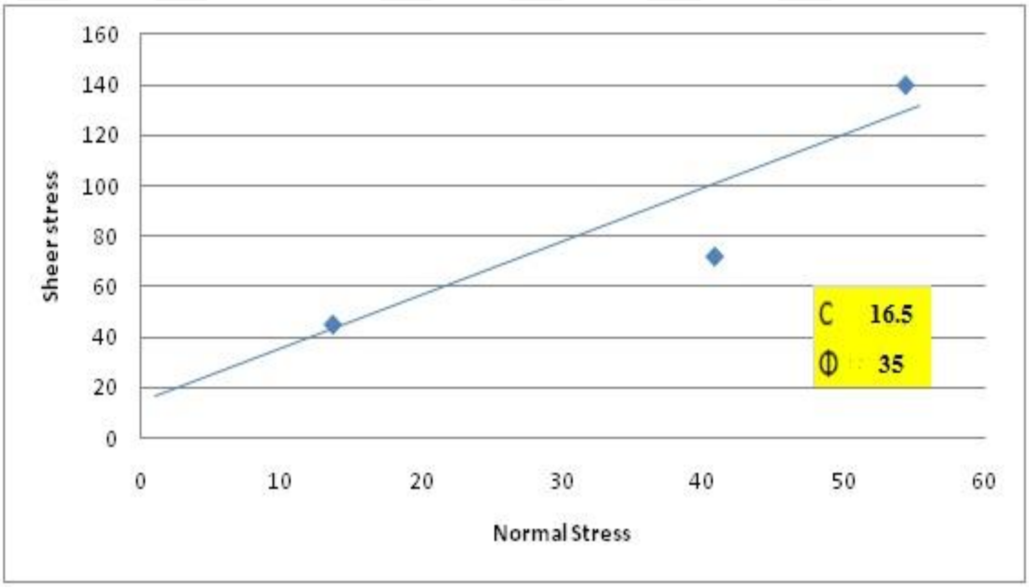
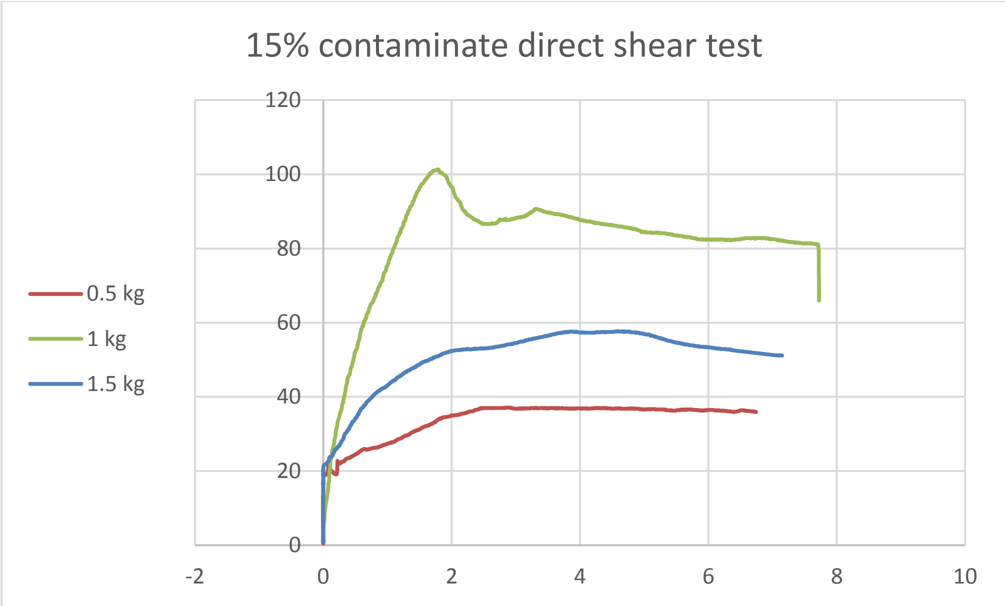




**Figure (3)** (direct shear test for 10% contaminated sample).



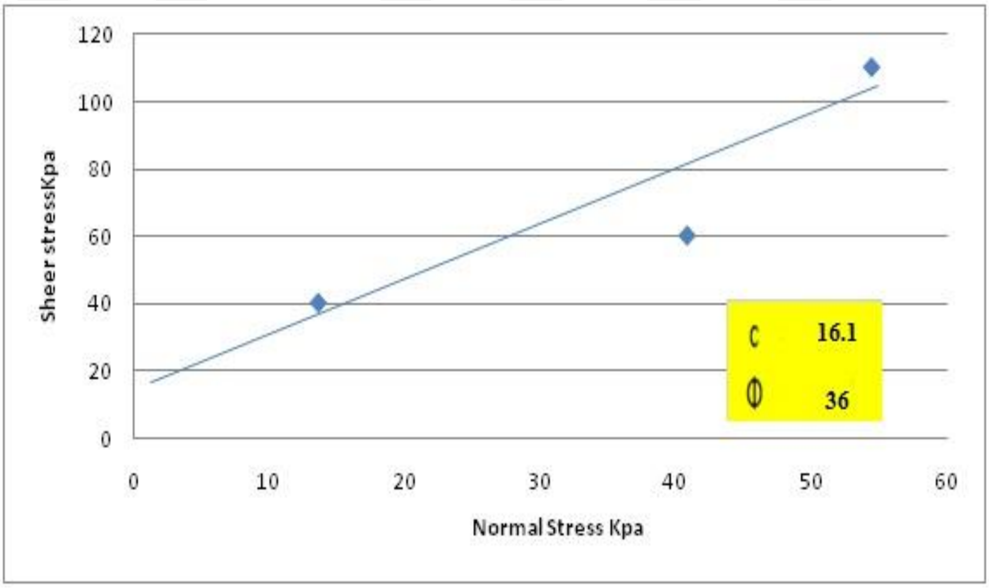
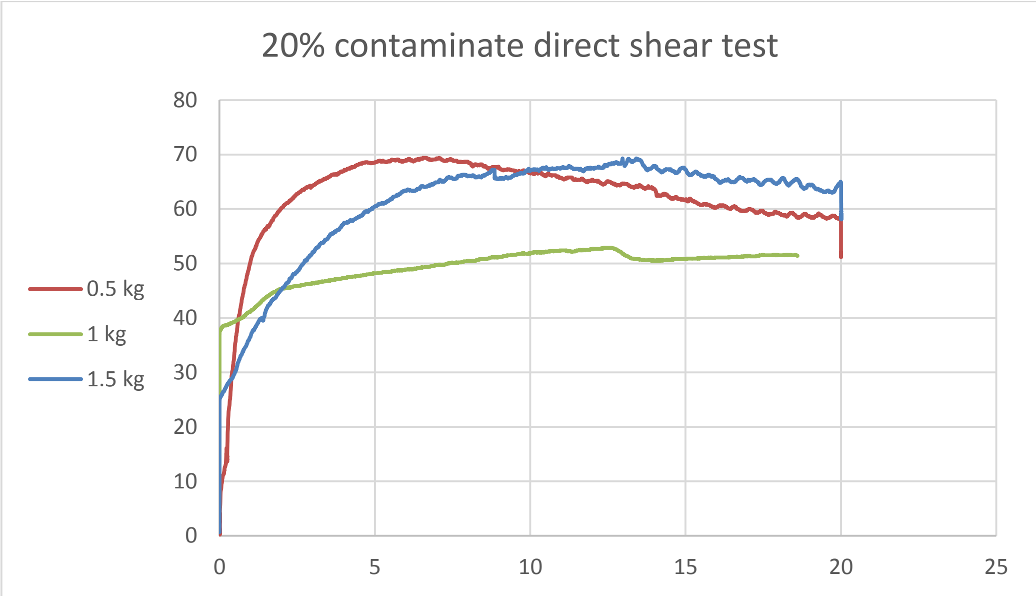




**Figure (4)** (direct shear test for 15% contaminated sample)



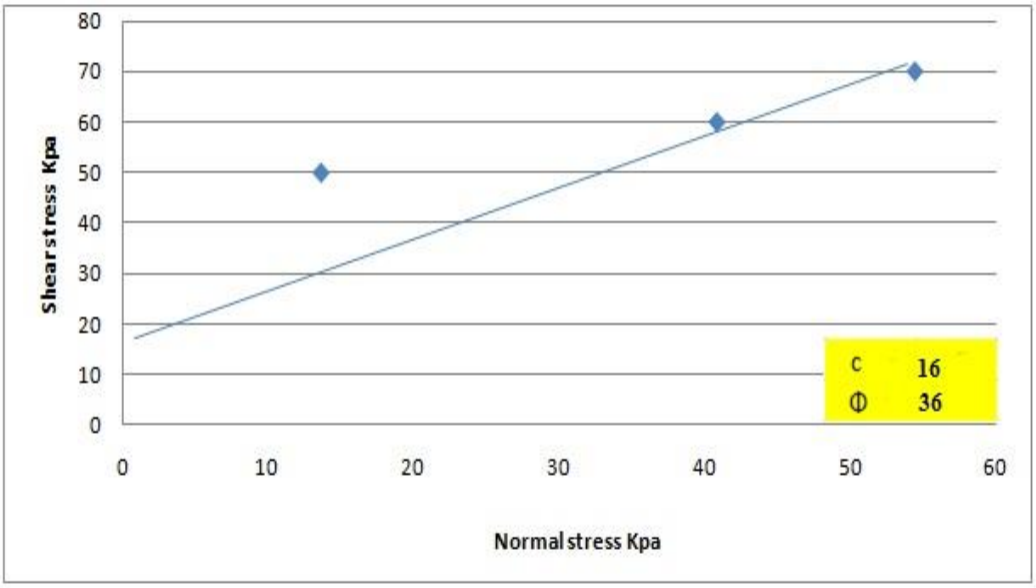




**Figure (5)** (direct shear test for 20% contaminated sample)

2- **Additional plates**

**Figure (1)** Refinery site and lagoon

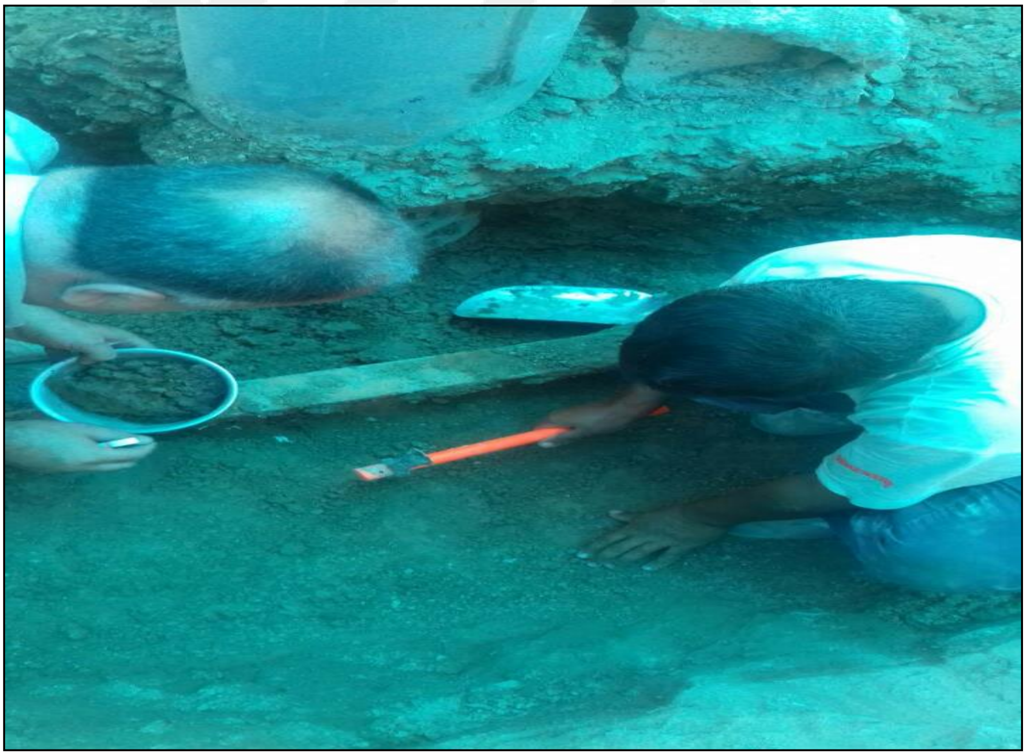


**Figure (2)** Field investigation

**Figure (3)** Views of undeveloped small refineries.

**Figure (4)** Field pit.

**Figure (5)** Laboratory test.

**Figure (6)** Lagoon site investigation.

**3-Additional Tables**

**Table (4.4)** Permeability, specific gravity and field dry density of natural soil

| Falling Head Permeability Test | | | |
|---|---|---|---|
| Item | Test No. | | |
| | 1 | 2 | 3 |
| Diameter of specimen, D (cm) | 10 | 10 | 10 |
| Length of specimen, L (cm) | 14.2 | 14.2 | 14.2 |

| | | | | Field Densiy | |
|---|---|---|---|---|---|
| | calibration of unit weight of ottawa sand | | | | |
| | weight of mold | 4155.5 | g | weight of gallon can | 545.2 |
| | weight of proctor + sand | 5445.5 | g | gallon + wet soil | 2616.7 |
| | volume of mold | 932.1 | cm3 | gallon+dry soil | 2571.9 |
| | dry unit weight sand | 1.389 | g/cm3 | moisture unit weight of soil in field = | 1.379543 |
| | calibration cone | | | | |
| before us | bottle+cone+sand | 4849.9 | | moisture content in field | 0.022105 |
| after use | bottle+cone+sand | 3194.7 | | | |
| | weight of sand to fill cone | 1655.2 | | dry unit weight in field = | 1.349708 |
| | results field test | | | | |
| before us | bottle+cone+sand | 8590.7 | | | |
| after use | bottle+cone+sand | 4849.8 | | | |
| | weight of sand in hole | 2085.7 | | | |
| | volume of hole | 1501.584 | | | |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Specific gravity test | | | | | | | | |
| | | w1 | weight of empty flask | | | | | | | |
| | | w2 | weight of fask+full water | | | | | | | |
| | | w3 | weight of soil + flask | | | | | | | |
| | | w4 | weight of soil + full water | | | | | | | |
| | | w5 | weight of water | | | | | | | |
| | | w6 | weight of soil | | | | | | | |
| | w1 | w2 | w3 | w4 | T | w5 | w6 | w4-w3 | Gs | |
| 1 | 141.8 | 662.12 | 188.31 | 689.84 | 23 | 520.32 | 40.51 | 501.53 | 2.155934 | |
| 2 | 147.47 | 657.82 | 172.18 | 681.29 | 23 | 510.35 | 30.71 | 509.11 | 24.76613 | |
| 3 | 151.93 | 662.99 | 206.57 | 698.58 | 23 | 511.06 | 51.46 | 492.01 | 2.701312 | |
| | | | | | | | | | Average | T |
| | | | | | | | | | 9.874458 | 23 |
| | Gs | w6/(w5-(w4-w3) | | | 2.155934 | | | | | |
| | | | | | 24.76613 | | | | | |
| | | | | | 2.70 | | | | | |

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F. K. Medhat, M. Carpuzcu, A. Al-Obaidi. (2018). Effect of oily wastewater head spills of the refineries on the diffusion rate and contamination of soils/ A case study of Kawergosek (Erbil city) Refinery. ***Polytechnic Journal***, Vol. 9, **1.**