Department of Waste Management and Material Flow
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OPTIMIZATION of the ASSESSMENT and REHABILITATION of OLD LANDFILLS in KUWAIT

DISSERTATION
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Declaration of Independence

I hereby declare that present work is prepared and submitted by me independently and without any assistance from other than those cited and acknowledged in the thesis.

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Dedication

- To my beloved country …………………………………….. Kuwait
- To the sustainability that is most sought after ………....…… Environment
- To my idol, the man who has always inspired me and others.…………………………………………………….. Father
- To the women who has the greatest influence in my life …... Mother
- To the women who has always believed in me and stood by my side through her patience and encouragement ......….. Wife
- To the most precious gifts in life …………………………... Children
- To the companionship, I treasured …………………………. Brothers and Sisters

I dedicate this work...

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Summary

Due to the significant increase in urbanization, industrialization and development activities witnessed in Kuwait during the last four decades, most of the 18 landfill sites in the country became very close to residential, commercial and industrial areas. Landfilling has been and still the most common method for solid waste disposal in Kuwait. The active landfills reached a maximum of 12 operating landfills during the period 1990-2000. Currently, 4 landfills are still operating in Kuwait. Moreover, only three landfills are relatively free from human use, while the rest of the landfills are surrounded with significant proportions of human settlements, hence imposing potential threats to human health and the environment. These landfills intersect with both the existing metropolitan areas as well as with some of the newly proposed development plans stated in the 4th Kuwait Master Plan. No rehabilitation has been carried out for 9 landfill sites (constituting 44% of the total landfills area), and only partial rehabilitation has been conducted for 2 sites only (11%), whereas about 7 landfills (39%) are being protected by control measures, which involves mainly covering the landfill with soil layer, fencing and restriction for trespassing.

Jleeb Al-Sheyoukh landfill (JLF) was chosen for conducting this research. The site was selected being the largest landfill in Kuwait (with an estimated area of 5.5 km^2), located at a distance of less than 1 km from both residential areas and Kuwait International Airport, and hence is considered to be a potential health and environmental hazards to its surroundings. The scope of the experiments, field works and measurements conducted in JLF site throughout the course of this research was designed to include the following three research investigation programmes:

The evaluation of the environmental status of the total area of JLF site using direct and indirect monitoring and assessment methods,

1. The application of a rehabilitation project in a selected area (24m×24m) of JLF site utilizing the "*aerobic in-situ stabilization method*", and
2. The indirect monitoring of the changes occurring during and after the rehabilitation project by measuring the resistivity using both 2D and 3D geo-electrical measurements.

In the first investigation programme, detailed monitoring and measurements (using both direct and indirect methods) were implemented over 36 months period with the objective of proper assessment and evaluation of the total area of JLF waste disposal site. The investigations consisted of topographic surveys; borehole drilling, geo-electrical survey (i.e., resistivity measurements) and the assessment of cover layer, leachate, and ground water quality and landfill settlement. This detailed assessment programme has led to a better understanding of JLF site history, its environmental status and the current stage of the landfill.

The geo-electrical investigation (i.e., resistivity measurements) has been used for the first time in Kuwait as an indirect monitoring method for the determination of the volume, types, distribution and geometry of buried wastes in JLF site. The obtained results allowed producing 3D-visualization of the landfill body. A classification index for JLF subsurface materials resistivities was also developed for the first time in Kuwait during this research. The ranges of resistivity index was divided into six classes depending on the type of materials: organic waste 0-8 Ωm, transitional zone 8-12 Ωm (domestic waste/native soil, mostly contaminated soil depending on the location of the waste), groundwater 12-20 Ωm (resistivity in JLF area), sand-clayey 20-40 Ωm, sand 40-100 Ωm and construction waste amounts to more than 100 Ωm. The data obtained from the geo-electrical survey have been processed using a computer program called "GOCAD" to establish a 3D geometrical model of JLF site. It was possible from these resistivity ranges and GOCAD model to reconstruct JLF body into 4 bodies comprising; a cover layer with a volume of 4.5×10^6 m^3, construction waste with a volume of 0.36×10^6 m^3, organic waste and contaminated soil with a volume of 1.9×10^7 m^3 and a native soil body underneath the landfilling area.

The monthly landfill gas (LFG) measurements performed over a period of 33 months showed almost a constant average content of methane (about 30%) and an average content of carbon dioxide about 26%, while the oxygen is negligible and the mean ratio of CH_4/CO_2 was about 1.14. This indicates that the current status of the landfill was found to be approximately at the middle of its age (i.e., end of the "Air Infiltration Phase"). The assessment of the landfill cover showed high infiltration rates. However, the low humidity content in the landfill body was evident during the collection of leachate from the 50 boreholes, where only 2 samples were possible to be collected during a period of 3 years. Groundwater was found not to be affected, to a large extent, due to the very low formation of leachate. The results of groundwater analysis clearly confirmed that it was not contaminated. Parameters such as; heavy metals, BOD, COD, TOC, TPH, BTEX, PAHs and microbiological organisms were very low or even below the detection limits. This is a good indication that landfill leachate is not seeping to the groundwater table.

Measurements of settlement performed at 30 points in JLF site over a period of 30 months showed an overall average settlement across the whole JLF site of about 7 cm – approximately 2.8 cm per year. This low settlement rate confirms the low decay processes in the landfill body due the low humidity. This finding was supported by the very low encountered leachate and almost the constant LFG formation.

In the second investigation programme, a rehabilitation experiment has been planned and conducted in a selected area of 24m×24m "The Project Area" on the waste disposal site of Jleeb Al-Sheyoukh around borehole 18. The aim of the experiment was to explore the conditions under which the disintegration process can be accelerated by changing it from anaerobic to aerobic conditions. The "*in-situ aerobic stabilization method*" was applied in the project area over a period of 30 months to explore the possible rehabilitation of closed landfills for the purpose of land restoration. This experiment included the injection of air and water to enhance the aerobic stabilization process while applying both the direct and indirect assessment methods to monitor the changes occurring in the landfill body.

Following the application of the aeration experiment, a major shift in the landfill gas phase was observed from the end of "Air Infiltration Phase" toward the last phase of LFG phases "Aerobic Phase", thus accelerating the decay process and minimizing the life time of the landfill. This study demonstrated that the “in-situ aerobic stabilization method” applied in the project area of Jleeb Al-Sheyoukh landfill for the treatment of old waste deposits in landfills can significantly reduce the emission of VOCs in LFG by as much as 89%.

After one year of treatment in the project area, the waste loss measured from the settlement results (ca. 88 m^3) would amount to about 5.7% reduction of the waste mass in the project area. Assuming a waste volume in the total area of JLF is about 18,000,000 m^3, the waste loss after one year aeration would be more than 1,026,000 m^3. The observed drop in TOC, COD and TDS concentrations in the leachate of waste at certain locations of the waste body was very significant (i.e., COD from 1960 mg/l down to 160 mg/l). This decrease would indicate the accelerated decomposition initiated by the aeration process.

In the third investigation programme, a new monitoring approach was used for the first time to explore the possible employment of the resistivity measurements as an indirect monitoring of the disintegration processes occurring in the landfill body during the application of the aerobic in-situ stabilization method. Extensive geo-electrical measurements comprising 171 profiles (2D and 3D) were conducted in the project area over a period of 36 months. The results of 2D and 3D resistivity measurements showed that the overall mean value increased by about 40%. This significant increase after the aeration experiment is most probably related to the changes occurred in the physical properties of the buried materials due to the disintegration processes. The results also showed that resistivity measurement is largely affected by the amount of the injected water during the aeration experiment. The geo-electrical measurements appeared to be a possible alternative to minimize the cost, time and efforts spent in the monitoring of the landfills during the rehabilitation process in comparison with conventional direct monitoring methods.

In conclusion, the results obtained in this research clearly demonstrated the need for urgent assessment of all landfill sites in Kuwait, especially those with significant socio-economic and environmental impacts. The results derived from the monitoring programs designed and implemented in JLF site during this research can be adopted and applied in other landfills with similar contents. The implementation of the "in-situ aerobic stabilization" method is proved to be a very promising approach for the minimization of environmental effects as well as the safe reclamation of the landfilling areas which is about 3% of the total urban/municipal areas of Kuwait.

Contents

List of Abbreviations

2D	Two Dimensional
3D	Three Dimensional
3D-VisGW	Three dimensional visualization model of subsurface data
APHA	American Public Health Association
ARES	Automatic Resistivity System
ASTM	The American Society for Testing and Materials
ATD	Automatic Thermal Desorber
atm	"Atmosphere Pressure" Unit
AWWA	American Water Work Association
b.w	By weight
BHs	Boreholes
BOD_5	Biochemical Oxygen Demand
Br	Bromide
BTEX	Benzene, toluene, ethylbenzene and xylenes
C.S	Coarse Sand
Ca	Calcium
CH_4	Methane
Cl	Chloride
Cl_2	Chlorine
CO_2	Carbon dioxide
COD	Chemical Oxygen Demand
CRPG	Centre of Petrographic and Geochemical Research
CSO	Central Statistical Office - Kuwait
CSW	Construction/Demolition Solid Waste

DEM	Digital Elevation Model
EAD	Environmental Affairs Department
EC	Electrical Conductivity
eMISK	Environmental Monitoring System of Kuwait
E-T-I	Emission-Transmission-Immission-Concept
F.S	Fine Sand
GC/FID	Gas Chromatography with Flame Ionization Detector
GE	Geoelectric
GHG	Greenhouse Gases
GIS	Geographical Information System
GOCAD	Geological Object Computer Aided Design
GW	Groundwater
GWVP	Groundwater Vulnerability to Pollution
H_2S	Hydrogen Sulphide
HDPE	High Density Polyethylene
HSW	Household Solid Waste
I	Iodine
ICP	Induced Coupled Plasma
INJ	Injection
ISWM	Integrated Solid Waste Management
JLF	Jleeb Al-Sheyoukh Landfill
JM	Jleeb Al-Sheyoukh monitoring zones
K	Potassium
K.D.	Kuwaiti Dinar
KEPA	Kuwait Environment Public Authority
KFAS	Kuwait Foundation for the Advancement of Science

Kg	Kilogram
KISR	Kuwait Institute for Scientific Research
KM	Kuwait Municipality
km	Kilometer
km^2	Square Kilometer
LFG	Landfill Gas
LFM	Landfill mining
LSMS	Landfill Sites Management and Supervision
m	meter
MON	Monitoring
M.S	Medium Sand
MEW	Ministry of Electricity and Water - State of Kuwait
Mg	Magnesium
mg/L	milligrams per Liter
mm	millimeter
MPW	Ministry of Pubic Work - State of Kuwait
MSWM	Municipal Solid Wastes Management
mv	Millivolts
Na	Sodium
NH_3	Ammonia
NH_4	Ammonium
NH_4-N	Ammonium-Calculated as N
NO_2	Nitrogen dioxide
NO_3	Nitrate
PAHs	Polycyclic Aromatic Hydrocarbons
PAMS	Photochemical Assessment Monitoring Stations
PC	Peltier Cooling
pH	Negative logarithm of the hydrogen ion concentration in a solution

PO_4	Phosphate
ppb	Parts-per-billion
ppm	parts-per-million
PVC	Polyvinyl Chloride
Ra	Apparent Resistivity
RH	Relative Humidity
S	Sulphur
SET	Settlement
SO_4	Sulphate
SPOT	Système Pour l'Observation de la Terre "System for the Observation of the Earth"
SUC	Suction
SW	Solid Waste
SWM	Solid Waste Management
TDS	Total dissolved solids
TOC	Total Organic Carbon
TPH	Total petroleum hydrocarbon
UK	United Kingdom
UNDP	United Nations Development Programme
UNEP	United Nations Environment Programme
USEPA	United States Environmental Protection Agency
V.C.S	Very Coarse Sand
V.F.S	Very Fine Sand
VOCs	Volatile Organic Compounds
vol -%	Volume Percent
WEF	Water Environmental Federation
wt -%	Weight Percent

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1 Introduction and Problem Statement

1.1 Background

Rapid increase of per capita production of solid waste due to urbanization and economic growth has led to the adoption of different methodologies worldwide for handling and treatment of the refuse. With regard to these, a wide variety of treatments exist: reuse and recycling, composting, anaerobic digestion, incineration, and land disposal are the most common ones (Williams, 1998). Pyrolysis and gasification are in use to a lesser extent or on a smaller scale (Nolan, 2002). Regardless of the method chosen for treatment, all these methods produce residues, which are eventually disposed at open dumps or sanitary landfills (Westlake, 1995 and 1997; Williams, 1998).

After desposing of municipal solid wastes (MSW) in landfills; many biological, chemical, and physical processes start to take place which gradually lead to the emission of landfill gas (LFG) and seepage of leachates through ground (Williams, 2005). A significant fraction of the biodegradable portion of MSW is ultimately converted to gaseous end-products during the anaerobic stabilization of solid waste organic fractions (Abushammala, *et. al*., 2009). The duration of the degradation phases may vary depending on several factors (e.g. climatic and environmental conditions, waste characteristics, operational factors, etc.) and may last from decades to centuries (Wall and Zeiss, 1995; Townsend et al, 1996; Johannessen, 1999; Tchobanoglous and Kreith, 2002). Influencing factors such as waste composition, climate, and hydrological conditions can vary substantially from region to region (Yuen et. al. 1999).

The emission of LFG and the formation of leachate are of major concern to local communities because of the foul odor as well as due to the various potential health hazards associated with toxic organic and inorganic compounds present in LFG and in the leachate (Lemieux *et. al*., 2004; Parker *et. al*., 2002; Al-Muzaini, 2009). On the regional scale, LFG emissions are considered as a source of volatile organic compounds (VOCs) which contribute to the formation of photochemical oxidants. On the global scale, the emission of methane in LFG contributes to greenhouse effects. The waste sector is considered a significant contributor to greenhouse gas (GHG) emissions accountable for approximately 3-5% of the global greenhouse budget (IPCC, 2006). Atmospheric methane gas (CH_4) has more than doubled in the concentration over the last 150 years (Stern et.al., 2007).

1.2 Motivation and Scope

Despite all these facts, landfills are necessary components of the waste management system because landfills are the most flexible, cheap and reliable method of waste containment/treatment (Vázquez, R. V. 2008). Kuwait is one of the countries which adopted this waste disposal method, where landfilling is still the only practiced method. Nevertheless, closed landfills pose real threats to human health and the environment, and therefore, the rehabilitation and restoration of closed landfills are of utmost importance.

Kuwait lacks several important factors for the management of landfills such as:

- Site assessment (i.e., LFG emission, leachate composition, groundwater contamination, land settlement, waste geometry, etc...);
- Institutional and administrative framework (i.e., regulations, legislations, strategic plans, capacity building, etc...);
- Adoption of protection and rehabilitation alternatives (i.e., *in-situ* and *ex-situ* methods);
- Socioeconomic impacts (i.e., land value, land use, development plans, etc...); and
- Health impacts (air pollution and diseases).

Despite the efforts being made in the country by different researchers (Al-Mutairi, 2004; Al-Faraj, 2005; Al-Tahw, 2006; Al-Muzaini, 2009; Abdullah, 2010) and the governmental authorities (i. e., Kuwait Environment Public Authority and Kuwait Municipality), which addressed some of the relevant issues related to the above mentioned factors, no collective efforts have been made to conduct an overall assessment of landfilling situation in Kuwait.

The scope of this thesis addresses two major factors out of the above five factors. Firstly, total site assessment was applied in one of the largest landfill sites in Kuwait (Jleeb Al-Sheyoukh landfill) using both direct and indirect assessment methods. Such methods included the large-scale application of two dimensional (2D) geo-electrical measurements, for the first time in Kuwait, as an indirect assessment method which was combined with direct measurements (such as: LFG and land settlement measurements; soil, leachate and groundwater analysis; borehole drillings).

Secondly, the "*in-situ* aerobic stabilization" was applied in a small-scale over a period of 30 months to explore the possible rehabilitation of closed landfills for the purpose of land restoration. This experiment included the injection of air and water to enhance the aerobic stabilization process while applying both the direct and indirect assessment methods.

1.3 Objectives

The main objective of this study is to investigate the possibility of applying both direct and indirect monitoring methods for the assessment of landfill behaviour before, during and after the implementation of high pressure aeration technique "*In-Situ* Aerobic Stabilization". The stabilization of waste through the addition of water and air is expected to enhance the biological process in the landfill, which provides the opportunity to observe the expected accelerated changes in the landfill body and to assess the applicability of such indirect techniques in the future, which can result in minimizing the needs for the traditional direct monitoring parameters.

The specific objectives of this thesis are:

- To implement a large scale assessment program in one of the oldest and closed landfills in Kuwait, in order to assess the needs for full scale implementation of high pressure aeration technique for the whole landfill;
- To apply high pressure aeration technique as a rehabilitation alternative for the closed landfills in Kuwait;
- To evaluate the landfill behavior during the rehabilitation process through cost-effective and scientifically accepted indirect methods;
- To better understand the influencing factors and the conditions under which the aerobic stabilization process takes place in arid regions;
- To develop and optimize suitable rehabilitation procedures for landfill sites in arid regions;
- To explore the most suitable monitoring and evaluation methods during rehabilitation work; and
- To be able to quantify the degradation process under defined conditions.

1.4 Outline of the Thesis

This doctoral thesis approaches the various aspects to assess closed landfills using direct and indirect monitoring methods. It experiments the possible rehabilitation of closed landfills in Kuwait using "*In-Situ Aerobic Stabilization Method*".

The ***first chapter*** presents the introduction and problem statement. This chapter also mentions the reasons and factors that motivated the study. It further deals with the scope of this study and highlights the specific objectives of this research.

The ***second chapter*** presents review of literature on the principles and philosophy of waste management systems, the methods and the practices for the sustainable rehabilitation/remediation of old landfills. This chapter also discusses the various parameters influencing waste stabilization and illustrates the application of the different *in-situ* or *ex-situ* methods for waste stabilization.

The ***third chapter*** presents the issue of waste management in Kuwait by giving background information on Kuwait (i.e., its locations, climate, physiography, ground water and soil) and then addresses the types of solid wastes, their composition and quantities and trends in waste generation.

This chapter goes on to describe the role of government organizations in Kuwait that are responsible for solid waste and landfills management, and addresses the status of operating (open) and closed landfills. It presents statistical analysis of landfills with respect to landuse, population distribution and density and compliance with Kuwait Master Plans. The last part of the chapter addresses the issue of landfill rehabilitation/remediation by giving examples of the efforts being made in this regards, and suggests appropriate measures/factors to be taken into consideration.

The ***fourth chapter*** provides reasons for the selection of Jleeb Al-Sheyoukh landfill (JLF) for conducting the total assessment, by giving detailed site description. It further highlights the scope of the investigation programmes, the experimental setup and analytical methods used during the site assessment/evaluation.

The ***fifth chapter*** starts with an introduction about the direct and indirect methods that are most commonly used for the assessment of landfills. It describes the materials and methods used in the site assessment of JLF. It, then, continues to describe the sampling procedures, field tests and the analytical methods/measurements which were conducted for the determination of landfill gas (LFG) concentration and composition, land settlement, land cover, groundwater quality, leachate, geo-electrical measurements and modeling the data using 3D computer program (GOCAD). The later part of this chapter presents the results obtained during the assessment of JLF site, and delivers a detailed discussion of both the direct and indirect monitoring methods.

The ***sixth chapter*** addresses the application of the chosen rehabilitation method "*aerobic in-situ stabilization*" on a selected area of JLF site called "The Project Area". It provides an introduction to the objectives and concept behind the rehabilitation method applied. It goes on to describe the experimental setup, the monitoring and analytical methods followed during the experiment, and presents the results and outcomes. Towards the end, it delivers a detailed discussion about the results obtained during the *"aerobic in-situ stabilization*" experiment by discussing effects of air and water injection on the degradation of buried waste as observed through changes in the waste characteristics, the concentration and composition of LFG, and land settlement.

The ***seventh chapter*** starts with an introduction about the application of indirect monitoring methods (i.e., resistivity measurements) for the geo-electrical assessment of landfills before, during and after the implementation of aerobic *in-situ* stabilization experiment in the project area. It describes the materials, methods and the analytical procedures used for the assessment of the landfill in the project area before, during and after the experiment. It continues to present the results of the 2D and 3D geo-electrical assessment (i.e., resistivity measurements) conducted along the 21 profiles. It finally discusses the results obtained during the geo-electrical assessment conducted in the "Project Area" and evaluates the advantages and disadvantages of using the geo-electrical assessment as an indirect monitoring method and its possible applications on larger-scale.

The ***eighth chapter*** provides overall conclusions derived from the results, and discusses the salient achievements of the research.

The ***ninth chapter*** focuses on providing specific recommendations for future research and actions.

2 Sustainable Waste Management Systems

2.1 Principles and Philosophy

Waste management is a legal, organizational, technical and commercial system for sustainable utilization and disposal of the solid waste from industry, commerce and households. The evolution of waste management can be divided into 3 phases:

- **Past:** Most generated waste from houses, commercial and industrial areas were dumped in unsecured dumping sites and landfills. These sites became major environmental problems worldwide where the current and future generation will have to face their impacts.
- **Current situation (starting since 20 years):** Due to the problems associated with improper landfilling and waste dumping, several actions have been taken especially in the industrial countries to improve the waste management. During this period, the waste management practices and strategies were based on: avoidance, recycling and enhancement of landfilling procedures. The relevant scientific research and practices formed the basis for developing the sustainable concepts, laws, ordinances and administrations.
- **Future:** From low to high value utilization of the waste is the trend in the modern and sustainable WMS where landfilling and incineration are minimal.

Figure 2.1 demonstrates the above-mentioned phases summarizing solid waste management targets and goals.

Laws, ordinances, product responsibility, regulation of financing, technologies and qualified staff are the main components for the establishment of an effective and environmentally sound waste management system. A new approach in waste management policies focuses on product responsibility. This approach is considered to be the core of waste management policy in Germany (FME, 2007; Nassour, 2007; Nelles and Nassour, 2010). Product responsibility means that the conditions for an effective and environmentally sound waste avoidance and recovery are already created in the production stage. Producers and distributors must design their products in such a way as to reduce waste occurrence and allow environmentally sound recovery and disposal of the residual substances, both in the production of the goods and in their subsequent use (FEA, 2006; FME, 2007; Nelles, *et. al*., 2011a).

In the last decade, the trend of waste high value utilization has been also materialized through the development of an Integrated Solid Waste Management (ISWM) Hierarchy by UNEP (2005). The hierarchy views wastes as resources and explores opportunities for reusing, recycling, or composting, and treat the waste that cannot be reduced by the processes, reduce its volume before disposing off, and recover energy by incineration or any suitable process. Hence, disposal in landfill areas is restricted only to residues resulting from those options.

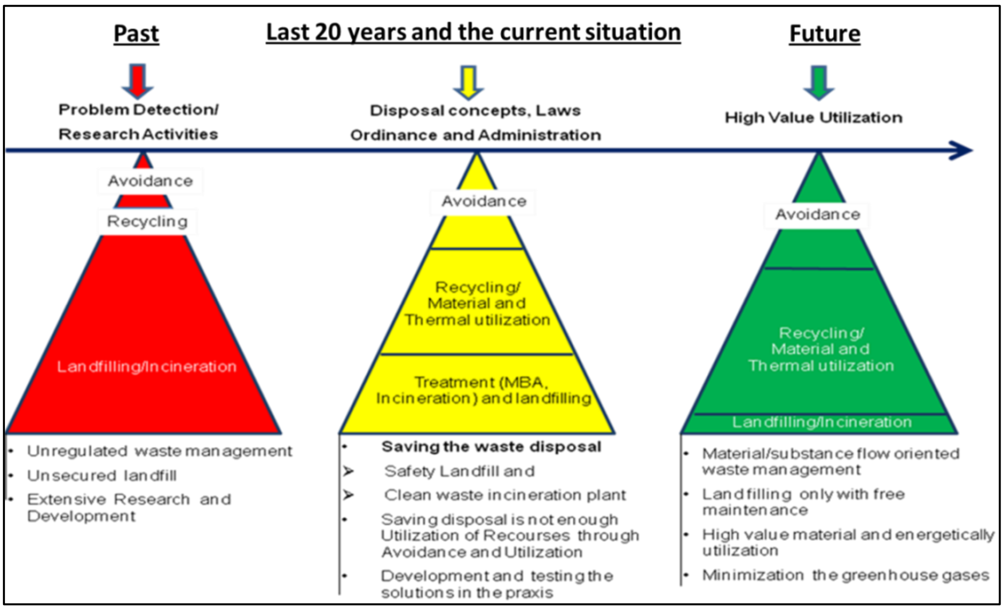

Figure (2.1): Phases of waste management evolution.

After the end of the landfilling period, landfills have to be closed with adequate measures (top cover sealing, gas collection utilization, leachate collection and treatment). Figure 2.2 illustrates the various phases of the landfill starting with deposition phase till the end of the aftercare phase (Rettenberger, 2010).

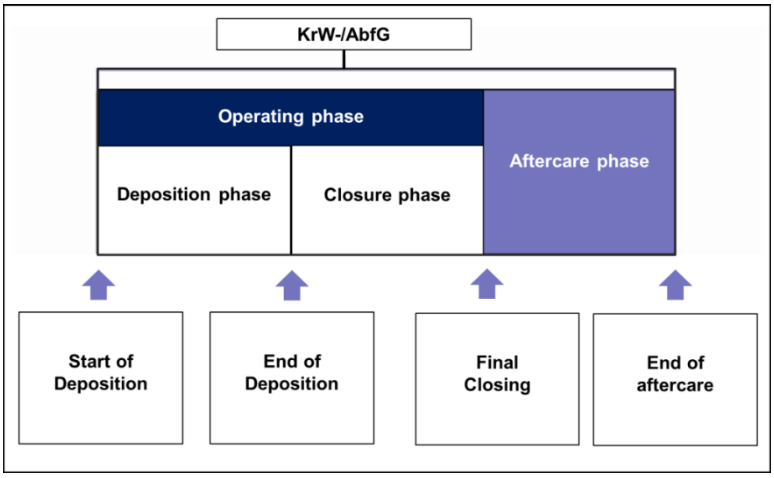

Figure (2.2): Landfill operating processes (Rettenberger, 2010)

2.2 Handling of Old Landfills

2.2.1 Rehabilitation Practices and Methods Implemented in Old Landfills

When dealing with old landfills, in the sense of finding a solution for the rehabilitation measures, we should consider the so called "Emission-Transmission-Immission-Concept (E-T-I-Concept)". This concept is described in details by Azzam and Lambarki (2004). The E-T-I-Concept means that decontamination focuses on the source of contaminant and thus the emission is eliminated. Encapsulation and protection of wastes in landfills means cut off the transport path of contaminants, the transmission. However, in this case the source of contaminant is still in place. The last possibility is restriction of use. This measure focuses on avoiding the emission (i.e., the concentration of the contaminants at the recipient point) by not using the groundwater for example, not entering the site (avoiding contact with the contaminant) etc.

Depending on the objectives of the rehabilitation/restoration process of old landfills (i..e, protection or remediation), several techniques could be implemented. The environmental and economical aspects are the main factors considered in the selection of available solution. Figure 2.3 demonstrates the different methods which could be applied for the rehabilitation of old landfill.

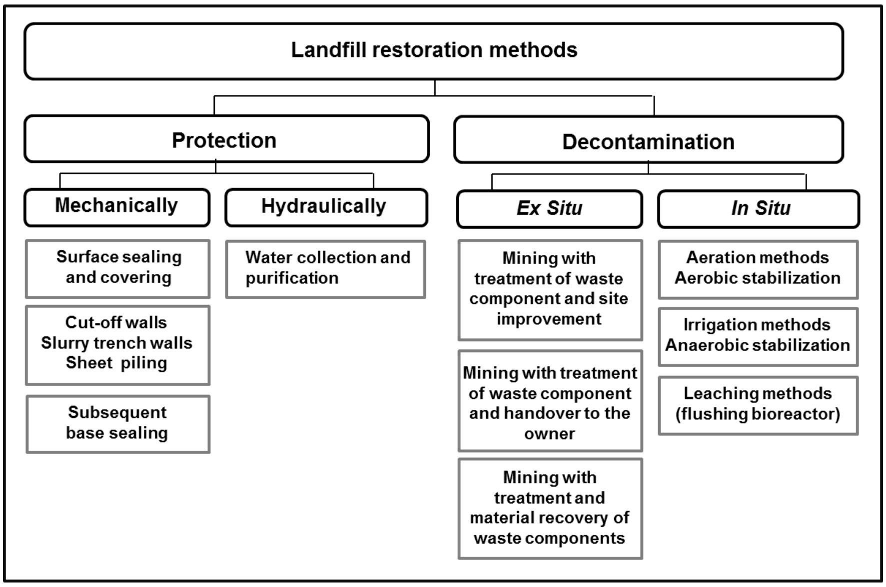

Figure (2.3): Restoration processes of old landfills (after Finck, 1999, modified by Meier, 2004).

The various alternatives/measures for the protection and/or decontamination methods of old landfills are illustrated in more details in the following sections.

2.2.2 Protection Methods

In addition to the horizontal and vertical encapsulation as well as the hydraulic action, which reduces the pollutant discharge from contaminated areas and prevents the pollutant dispersal, protection also include measures that restrict the mobility of contaminants by immobilization (Finck, 1999; Morscheck 2002). The immobilization methods are numerous and complex and based on different processes (Azzam, 2003). Figure 2.4 illustrates the various immobilization methods.

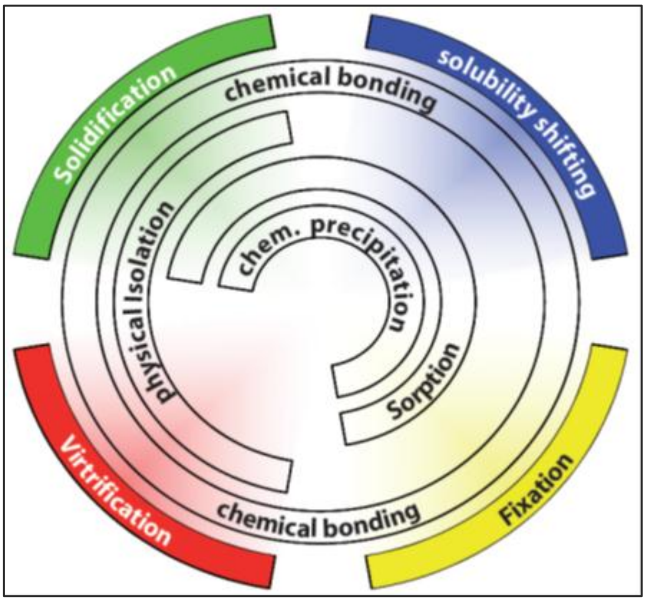

Figure (2.4): Methods for the Immobilization of Harmful Substances (Azzam, 2003).

Requirements of a "secure" landfill should be implemented in accordance with the national/international environmental regulations and specifications. Essentially, they are based on the so-called “multi-barrier concept” (Rettenberger, 2000). This consists of the Geological barrier, Bottom sealing, Surface sealing, Stabilization of slope, Surface water collection and in the broadest sense of the pre-treatment of the waste "inertization". Through this form of protection, negative impacts (i.e., leachate and gas emission) should be prevented after the end of the deposition phase (Finck, 1999). Therefore, generated landfill gas from operating and closed landfill has to be collected, treated and, as far as possible, recovered.

Depending on the methane content of the landfill gas, different gas utilization plants are used. It is also necessary to collect, treat and control the resulting leachate. The engineering processes for treating landfill leachate can be divided into two processes. The first one, converts individual substances and element groups chemically or bio-chemically (e.g. biological, chemical and thermal processes). The second one, groups individual substances and element groups by physical separation and concentration (e.g., through precipitation/flocculation, adsorption, membrane processes, evaporation/drying, or stripping) (Theilen, 1995). If all requirements are fulfilled, no harmful effects to the public are likely to occur according to the German laws and regulations (Paragraph10 of KrW-/AbfG, 2002) and the landfill can be considered as protected for this condition.

2.2.3 Decontamination Methods

Decontamination measures are remedial actions that should lead to the elimination or reduction of pollutants from landfills (Article 2, paragraph 7, BBodSchG, 1999). Under this definition both *in-situ* measures and *ex-situ* measures (on-and off-site processes) are included.

Landfill site remediation is a process that is employed under highly sensitive conditions such as:

- Groundwater aquifers at risk from uncontrolled leachate;
- Health hazards for nearby residents from naturally occurring toxins and synthetic compounds;
- Explosions and fire hazards from flammable gases and gas mixtures;
- High cost of after-care and control, particularly with regards to the capture of leachate and gas emissions; and
- Un-estimated additional risks associated with alternative solutions such as encapsulation, pump-and treat systems, and *in-situ* processes (ITU, 2010).

2.2.3.1 Ex-Situ Rehabilitation Processes

According to the German laws and regulations (KrW-/AbfG, 2002), the mining process of old landfills which are still in operation, includes the excavation and re-deposition of wastes (Brammer *et al*., 1997)**.** The landfill mining (LFM) measure is to be understood in a broader sense as a decontamination measure because the emission potential are very much reduced and eliminated especially at the affected site. This process is of two types: on-site and off-site, which are further divided into three deconstruction variants as shown in Figure (2.5).

Depending on the deconstruction variant (Horth, 2008), the excavated waste can be either directly re-deposited in the same site or in a new site without treatment, or it can be treated (biologically and/or thermally). The third variant includes the utilization of the waste (screening, materials and energy recovery) then the biological and/or thermal treatment before the final deposition in the suitable selected site.

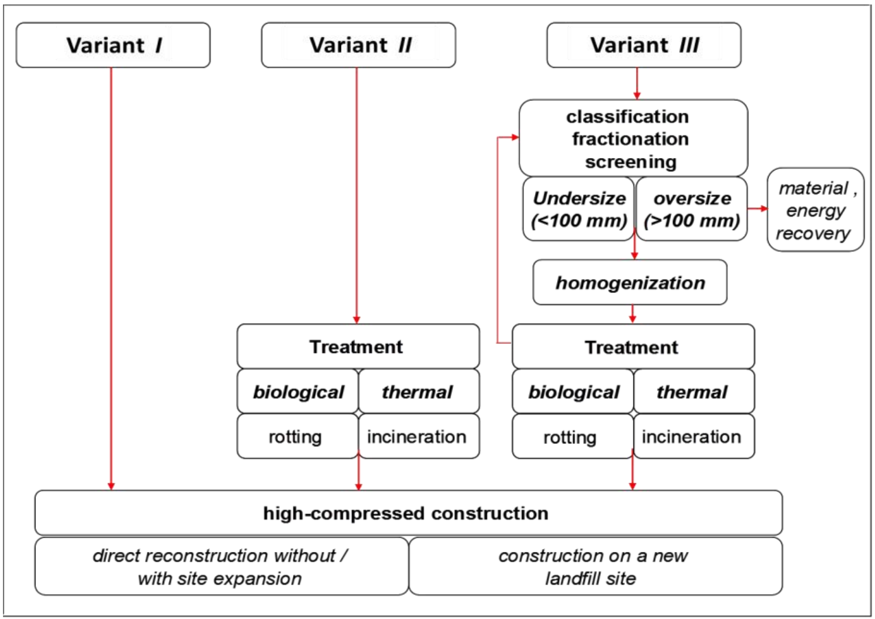

Figure (2.5): Deconstruction variants (Horth, 2006).

2.2.3.1.1 Varian-1: Deconstruction by relocation of untreated old waste

In this variant of deconstruction, the relocation of old waste is merely carried out. However, since the municipal wastes were deposited in the past without any treatment, the environmental and health effects should be taken into consideration during this process. For example, in Germany since 2005, the direct relocation of wastes can only take place if the classification criteria are fulfilled according to Annex 1 of the AbfAblV, 2002.

2.2.3.1.2 Variant-II: Deconstruction with waste treatment

In the second variant, a subsequent biological and/or thermal treatment of the old waste is carried out because the untreated waste still possesses significant degradation potentials for decades after their disposals. The biological treatment is divided into two procedures. Through aerobic treatment, degradable organic substances and harmful substances can be converted to the end-products CO_2, H_2O and into mineral salts as far as possible. This also applies to substances such as lignin or cellulose, which are difficult to degrade under anaerobic conditions (Morscheck, 2000).

In contrast, pollutants such as highly chlorinated hydrocarbons are problematic because they cannot be decomposed under aerobic conditions (Brammer *et al*., 1997; Collins *et al*., 2001). Therefore, at times, both anaerobic and aerobic treatments (alternation) are required to be carried out. This type of treatment takes place alternately, first in aerobic condition and then in controlled anaerobic environment. Using biological treatment, the reactivity of old waste is significantly reduced, which leads to inertization and stabilization which is sufficient to decrease leachate toxicity and contamination in the final dumping (Brammer *et al*., 1997; Brammer, 2000) depending on the intensity of the biological treatment. Even a leachate quality can be achieved, which allows the direct discharge of leachate into the receiving water (Brammer *et al*., 1997). This results in decrease in LFG production, since most organic carbon compounds are already converted by the treatment.

Biological treatment of waste barely increases the landfill volume by up to 5 wt-% TS (Collins et. al., 2001), because during the entire deposition period, a large proportion of the easily degradable organic matter gets easily converted under prevailing anaerobic conditions (Brammer *et. al*., 1997; Collins *et. al*., 2001). Whereas, the relocation of an old waste (without treatment) causes a landfill volume increase by about 8-30 vol-% (Rettenberger, 1998; Collins *et. al*., 2001). A gain in the volume of up to 40% is at times reported (Brammer et. al., 1997) depending on bulk density of the waste in the landfill.

In addition to the biological treatment, a thermal treatment (not in the sense of energy recovery) is also possible (Collins *et. al*., 2001). This can be carried out under the addition and admixture with fresh residual waste in a conventional incineration plant (usually grate combustion plants). The amount of permissible admixture is limited by the pollutants content and the material characteristics or rather the composition of the excavated waste. The non-recyclable slag has to be deposited a on suitable slag dumpsite.

2.2.3.1.3 Variant-III: Deconstruction with classification/fractionation and treatment of waste

The third variant of deconstruction is an extension of the second variant. By classifying and fractionating of the old waste using screening before or after the biological treatment, the mass of the deposited old waste can be reduced in relation to dry matter at least 15% (Brammer *et. al*., 1997).

The volume gain is dependent on the recyclable waste and it is very variable in the old landfills. Through screening, biological treatment and high-compressed reconstruction of old waste; a landfill volume gain of about 40 - 60% (Brammer *et al*., 1997; Rettenberger, 1998, 2002 and Steinemann, 2003) or rather about 70 vol-% (Spillmann, 1998) can be achieved. Here, for better separation of the material, the screening after biological treatment should be carried out, since the substances will have lower water content (Brammer *et. al*., 1997)**.** Figure 2.6 demonstrates the screening and classification of the excavated wastes in landfill mining process (Savage et. al., 1993).

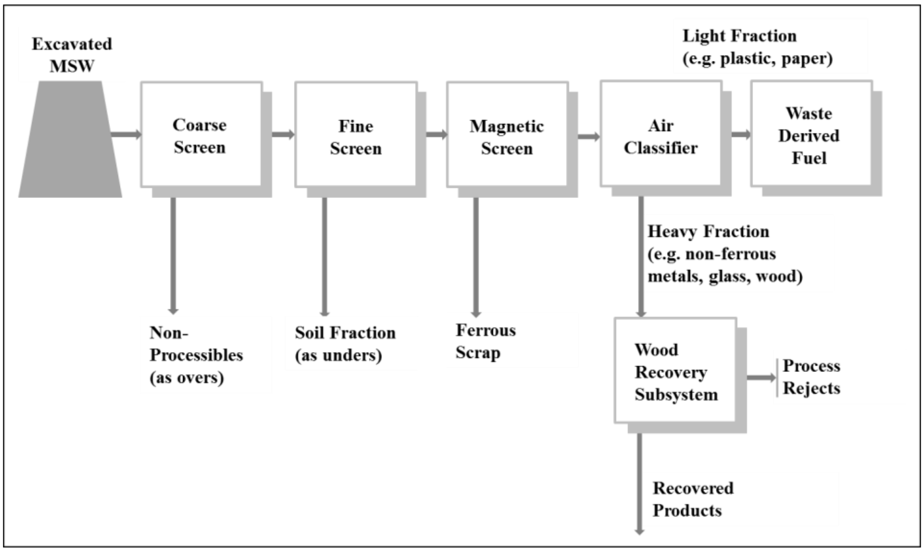

Figure (2.6): Screening and classification of excavated wastes in landfill mining process (Adopted by Horth, 2006 after savage et. al., 1993).

Safety measures (such as slope protection, leakage prevention, etc.) are necessary to protect workers, nearby residents and the environment, before landfill deconstruction takes place. An appropriate aeration method must also be applied in order to stabilize the waste and to prevent emission of foul odor before the excavation (Rettenberger, 1998; Collins *et. al*., 2001). Decreasing the water content also makes it more feasible to subsequent treatments like separation of recyclable fractions (Rettenberger, 1998)**.**

Through the deconstruction of old landfills (with or without treatment), their classification and fractionation, and by improved high-compressed reconstruction, for example, with a compactor in the thin film installation, the volume can further be reduced up to 70 vol-% (Spillmann, 1998; Collins *et. al*., 2001)**.**

This leads to the creation of new landfill space, and thus to the conservation of resources by reducing the space requirement. Space can also be managed better by re-depositing the waste on a pre-existing landfill, which has gained volume due to the application of an appropriate management strategy. This helps in eliminating a potential cause of hazard to the mankind. By treating old wastes, one can reduce the aftercare period, and the gained area of the rehabilitated site could be made available for other uses.

However, due to the high cost of waste deconstruction and material sorting, this is not always the most preferred type of solution. Moreover, there is also a risk of "Waste Transport", which may lead to additional costs and pollution.

2.2.3.2 *In-Situ* Rehabilitation Processes

The largest and long-lasting impact on the environment in old landfills is caused mainly through organic biodegradable substances and their transformation products. These substances/products are emitted continuously through leachate and LFG. Such emissions must be treated over many years to comply with the allowable discharge limits. It further adds-up to the operational costs during the landfilling and aftercare period. However, potential dangers to the surrounding areas and resources can be reduced and controlled through technical measures.

The main objective of the *in-situ* process is always the optimal stabilization of the waste to the degree possible. Hence, there is no excavation of the material for any type of treatment, and only the on-site measures are applied after carrying out following processes:

- Stimulation and acceleration of biological transformation processes and discharge of organic substances from the landfill body in the form of methane and/or carbon dioxide through the gas phase until a stable situation is reached. The biological conversion processes can be carried out in both anaerobic and aerobic environments (Rettenberger, 2000).

- Leaching processes by increased water exchange (flushing bioreactor landfill) would lead to the discharge of organic substances in the form of soluble components or as suspended solids with the landfill leachate. The process is carried out until only a low potential for exposure is proven (Blakey *et al*., 1997; Walker *et al*., 1997; Rettenberger, 2000)**.**

- Depending on the initial waste characteristics and the degree of biological pre-stabilization achieved during the initial anaerobic landfill phase, an accelerated degradation of organic compounds (e.g. hydrocarbons) can be achieved. Moreover, the *in-situ* aeration of old landfills offers the possibility of sustainably reducing the amounts of emitted greenhouse gas (Ritzkowski & Stegmann, 2007)**.** The main indicators to monitor the development of the stabilization process of the landfill are leachate composition, methane production, landfill settlement and *in-situ* waste temperature (Willem & Heyer, 2009)**.**

2.2.3.2.1 Aeration Methods

All aeration methods work on the same basic principle. It is important that the landfill body has sufficient high water content. By forcing insertion of oxygen into the landfill body, the environment changes from anaerobic to aerobic. Several methods for the aerobic *in-situ* stabilization of landfill are applied:

- High pressure aeration (e.g. BioPuster®, Austria)
- Low pressure aeration (e.g. Aero-Flott®, Germany)
- Pressure aeration and suction (e.g. Smell-Well®, Austria)
- Over Suction (e.g. DepoPlus®, Germany)
- Active air injection without active extraction (Willem & Heyer, 2009)

For example, Aero-Flott process has been implemented in many projects in Germany. Background information as well as the technical implementation of the low pressure landfill aeration system was comprehensively published elsewhere (Ritzkowski *et al*., 2001 and 2009; Heyer *et al*., 2001, 2003 and 2010).
In addition, detailed information on the impacts of aeration measures on the leachate and groundwater quality were described by Ritzkowski and Stegmann (2005). Figure (2.7) shows the fundamental concept of *in-situ* aeration by parallel air injection, exhaust extraction, and exhaust treatment via a system of several interconnected gas wells.

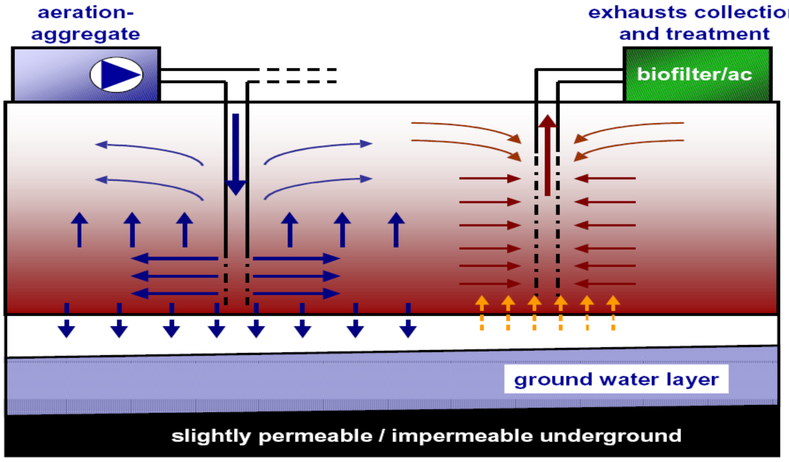

Figure (2.7): Basic principle of landfill remediation by *in-situ* aeration process (Heyer *et al*., 2010).

Because of the toxic effects of oxygen on the existing anaerobic micro-organisms (above all methane bacteria) the aerobic microorganisms can spread rapidly. The net result is that no more methane is formed and the existing proportion of methane is oxidized. Moreover, the remaining native-or derivative-organic substances start to decompose in an aerobic way. With this change, the degradation rate is increased by up to a factor of 5 to 10 (Brammer *et. al*., 1997; Krümpelbeck, 2000; Rettenberger, 2000; Heyer, 2010). Thus, leachate parameters can quickly meet the statutory conditions of discharge (Rettenberger, 2000). Furthermore, leaching rates (especially COD, NH4-N) are clearly faster reduced and have only a small harmful effect after aeration (Ritzkowski *et.al.* 2001).

Depending on the intensity and extent, the remaining organic compounds at the end of the stabilization consist of difficult- or non-degradable organic compounds, which can be metabolized only via a long aerobic period. These however, still have, a small residual gas potential (VKS & Atvdvwk, 2002). At the start of the aeration, increased land subsidence (i.e. settlement) processes take place because of the faster conversion of the organic components. Ziehmann (2001) assumes that subsidence appearances are scarcely observed after an aeration period of about 2 years.

The aerobic biodegradation process requires high quantity of water, in order to guarantee the microbial activity and to lower the temperature values. Microbial activity stops under a 15% b.w. moisture value, but the optimum values are between the 45% and the 65% b.w. In fact, below the 45% b.w., the activity of bacteria is too slow, while above the 65% water fills the voids and the oxygen diffusion is limited (Zanetti, 2008).

2.2.3.2.2 Irrigation Methods

Water is vital for biological processes. If the landfill is built and established with a surface sealing system and thus an encapsulation of the waste occur, little to no biological conversion processes will take place due to the lack of moisture. It is therefore important to assist the (micro-) biological, chemical and physical processes by targeted controlled water insertions already in the decommissioning phase. According to target-setting in the irrigation process, it is distinguished with water infiltration to increase the biological degradation performance and to enhance the leaching of the landfill body. The basic principle of water infiltration to increase the biological degradation performance consists of producing artificial optimum water content in the landfill body. This is about 35-40 wt -% for anaerobic processes (Rettenberger, 1999; Drees, 2000; Peters, 2000)**.**

Depending on the landfill, the infiltration of a defined amount of water takes place evenly over the waste to be treated, whereas the formed leachate in the cycle process is brought back into the landfill body. In this way on the one hand, a cleaning of the leachate occurs and on the other hand, an optimal decomposition of organic components takes place in the landfill body. It is assumed that at the end of irrigation measures only a small proportion of organic components exist (e.g. lignin, that cannot be decomposed and converted under anaerobic conditions), therefore land subsidence is expected at its lowest rate (Peters, 2000). In the process of leaching, the amount of infiltration in the landfill body is significantly increased in order to mobilize all water-soluble compounds in the landfill body (Rettenberger, 2000).

2.2.4 Parameters Influencing Waste Stabilization

Factors controlling municipal solid waste (MSW) stabilization have been reviewed and discussed by Yuen *et al*. (1994). The moisture content, pH, nutrients, absence of toxins, particle size and oxidation-reduction potential etc… appear to be the most important parameters. In addition, Yuen (1999) also showed that nutrients are generally adequate in most landfills except in nutrient-deficient pockets due to waste heterogeneity (See Table 2.1).

Table (2.1): Summary of factors influencing MSW degradation in landfills (Source: Yuen et al., 1994).

No.	Influencing factors	Criteria/Comments
1.	**Moisture**	Optimum: 60% and above
2.	**Oxygen**	Optimum redox potential for methanogenesis: -200 mv -300 mv < -100 mv
3.	**pH**	Optimum pH for methanogenesis: 6 to 8 6.4 to 7.2
4.	**Alkalinity**	Optimum alkalinity for methanogenesis: 2000 mg/L. Maximum organic acid concentration for methanogenesis: 3000 mg/L Maximum acetic acid/alkalinity ratio for methanogenesis: 0.8
5.	**Temperature**	Optimum temperature for methanogenesis; 40 ^{o}C 41 ^{o}C 36 ^{o}C (34 – 38 ^{o}C)
6.	**Hydrogen**	Partial hydrogen pressure for acetogenesis:<10-6 atm
7.	**Nutrients**	Generally adequate
8.	**Sulphate**	Increase in sulphate decrease in methanogenesis
9.	**Inhibitors**	Cation concentration producing moderate inhibition (ppm) Ammonium (Total) : 1500 – 3000 Sodium : 3500 – 5500 Potassium : 2500 – 4500 Calcium : 2500 – 4500 Magnesium : 1000 – 1500 Heavy metals: No significant influence Organic compounds: Inhibitory effect only in significant amount.

By optimizing operational control and environmental conditions within the waste (especially moisture content), more rapid and complete degradation of waste may be achieved (Karthikeyan and Kurian, 2007). The general objective is to produce a “stable waste” within a reasonable time scale, and thus ensure that the risk to the environment will be at an acceptable level when liner failure occurs (Westakle, 1997) and to keep the risk of environmental hazards to a minimum level in the case of old unlined landfills.

3 Waste Management in Kuwait

3.1 Introduction

During the last 10 years municipal solid waste generation has increased worldwide about 20%, of which a majority consists of household and commercial waste and it is expected to increase up to 40% by the year 2020 (OECD,2004).

The state of Kuwait is a relatively small country with industries oriented mainly towards the oil sector, petrochemicals. Since the oil started to be exported in 1946, where the income has started to rise, Kuwait began to face new challenges. The number of foreign laborers increased dramatically reaching almost double the Kuwaiti nationals (i.e. the total population of Kuwait in 2011 Census reached 3,065,850 inhabitants (CSO, 2011).

In addition, Kuwait has witnessed a rapid development in both economic and social sectors as well as the expanding of residential and commercial areas. These factors together resulted in various environmental problems. Waste was and is still one of the major environmental concerns of the Kuwaiti government. However, the uncontrolled disposal of generated waste, created several problems affecting public health, air, groundwater and soil.

Several studies have reported that the average citizen in Kuwait produces about 1.4 Kg/day of Municipal Solid Waste (MSW) (Koushki *et.al.* 2004a; Al-Humoud and Al-Mumin, 2006; ETC/RWM, 2008; Al-Salem; Lettieri, 2009; Nelles et al., 2010a and b and Nassour *et.al.,* 2010). In comparison with other neighboring countries in the region (greater in population and size), this MSW generation rate (1.4 Kg/person/day) is relatively higher than those reported for Egypt, Oman, Jordan and Tunisia, where a citizen generates 0.81, 0.7, 0.6 and 0.41 Kg/day, respectively. The average amount of MSW generated in Kuwait per citizen exceeds major Western countries, e.g. UK, Belgium, France, Italy and Spain. Moreover, the rapid expansions of residential areas pushed the people closer to uncontrolled dumping sites where they started to face many problems such as odors, settlements...etc.

Kuwait currently has over 18 active and closed landfills and dumping sites, These sites vary in sizes, contents and the volume of waste dumped into it, where 7 of these 18 sites are municipal solid waste landfills, whereas the remaining are construction debris and hazardous waste landfills.

3.2 Background Information on Kuwait

The State of Kuwait is located at the north-western corner of the Arabian Gulf and occupies an area of 17, 830 Km^2 (Figure 3.1). It is part of a large, low altitude desert which covers most of eastern Arabia. The land surface exhibits a low relief of gently undulating sandy or gravely desert, with elevations ranging from sea-level along the eastern coast to about 300 m above sea level in the south-eastern corner of the country.

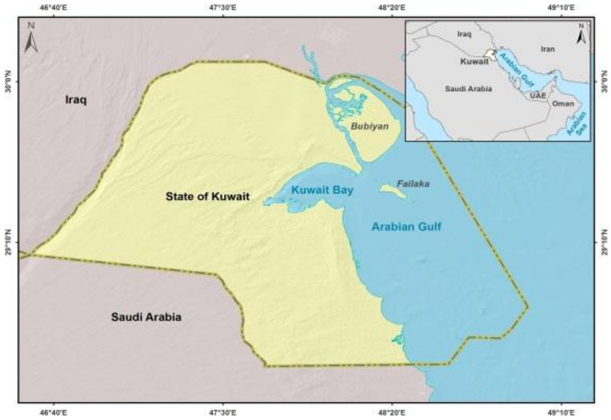

Figure (3.1): Location of the State of Kuwait.

3.2.1 Physiography

A dry, hot climate dominates the northern part of the Arabian Gulf, including Kuwait. Precipitation is scant, reaching a mean annual total of about 112 mm (see figure 3.2). Evaporation is very high and varies with location and season. Mean daily evaporation in Kuwait is 16.6 mm, ranging from 5.2 mm/day in winter (January) to 31 mm/day in summer (July). Kuwait is characterized by relatively wide range of diurnal and annual variations in air temperature. The annual air temperature ranges between 12°C in winter to 45°C in summer (see Figure 3.3).

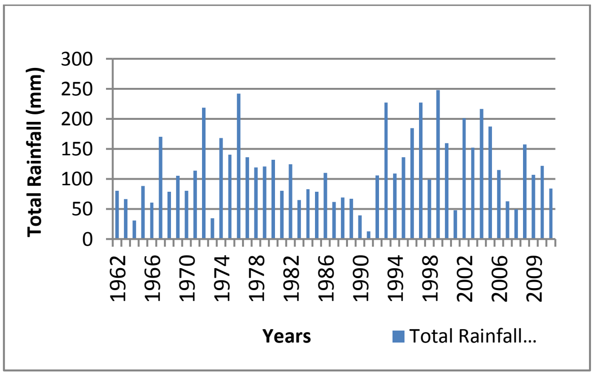

Figure (3.2): Annual mean precipitation in Kuwait (1962-2009) - Source: DGCA, 2011.

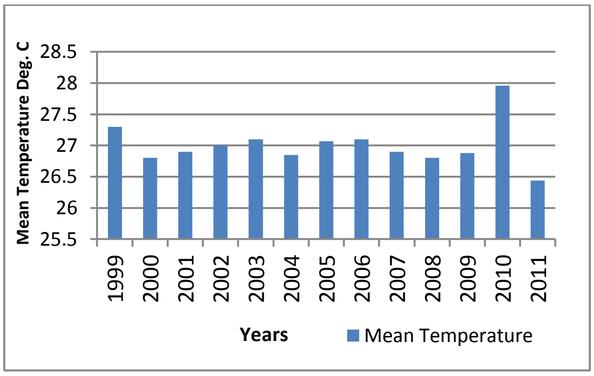

Figure (3.3): Annual mean air temperature in Kuwait (1999-2011) - Source: DGCA, 2011.

3.2.2 Soil

Kuwait's surface geology is defined by flat-lying Tertiary rocks overlying gently folded Cretaceous and Jurassic Formations (Milton, 1967; Carmen, 1996). In southern part of Kuwait, where almost all open and closed landfills are located (with the exception of Al-Jahra open landfill), the sediments consists of a sequence of unconsolidated, medium to coarse pebbly to gravelly sand with calcareous lenses (Al-Sarawi, 1980). The Kuwaiti desert soils, which constitute 80% of the country, can be described as aridosols with weekly developed profiles, sandy compositions, sandy textures and very low organic matter content (total organic carbon "TOC%" 0.3% on average) (El-Nawawy et al., 1993; Al-Houty et al., 1997; Al-Sarawi et al., 1998b). According to the comprehensive soil classification system, which is called Soil Taxonomy (SSSA, 1984; FAO, 1988) these soils are characteristic of dry climates. Recent soil survey for the State of Kuwait (KISR, 1999; KFAS, 2000) has been carried out for the characterization of soil types of Kuwait.

Superposing the map of landfill sites on the soil map of Kuwait (Figure 3.4) clearly shows that majority of landfills are located over the miscellaneous soil types (soils covering human exploitation areas such as quarries and residential areas), with the exception of the soils of Jleeb Al-Sheyoukh and Seventh Ring Road (N and S) landfills, which could be classified as torripsamments (soils consisting of sands eroded from sand dunes and sands deposited on plains "flat provinces" and valleys' floors). One of the diagnostic features of Kuwaiti desert soils is a subsurface horizon known locally as "Gatch". It is a caliche layer (duripan or hardpan) composed of a mixture of calcrete and silcrete hard, and impermeable fine calcareous sandstone (Al-Sarawi *et al*., 1998a). Due to its impervious nature, Gatch has been used as a landfill cover in most of the solid-waste disposal sites in Kuwait.

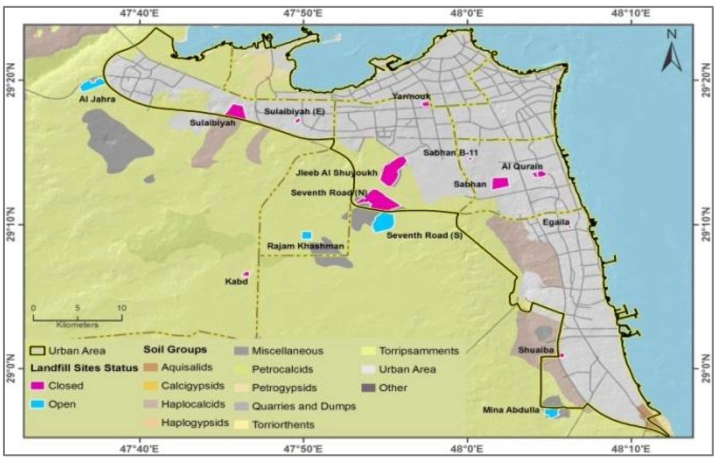

Figure (3.4): projection of landfill sites on the soil map (eMISK/KEPA, 2011).

3.2.3 Hydrogeology and Groundwater

The hydrogeology and groundwater resources of Kuwait have been discussed in detail by Mukhopadhyay *et.al*. (1996) and Al-Sulaimi & Akbar (1999) and overviewed by Al-Sulaimi & Al-Ruwaih (2005). The occurrence of useable GW in the country is restricted to the Tertiary Dammam Limestone Formation (Eocene) and the Kuwait Group (Mio-Pleistocene). It is possible to identify three aquifers separated by fractured aquitards in the Kuwait Group-Dammam Formation succession. The chemistry of almost all GW in the country is controlled by the dissolution of abundant quantities of gypsum and anhydrite disseminated throughout the GW aquifers and by common interaction between fresh water and recent marine water.

The salinity of GW is around 3,000 mg/L in the south-western part of Kuwait. It gradually increases towards the eastern and north-eastern parts of the country and with depth, reaching a level of 10,000 mg/l and nearer to the coastal areas. Consequently, in the absence of adequate control measures the risk of ground and subsurface water contamination remains high (UNEP, 1999)**.** In Kuwait, the usable groundwater is produced from different well-fields. This ground water is used for several purposes including the production of potable water and for irrigation by mixing with the desalinated water produced as bye-product of the power generation plants managed by the Ministry of Electricity and Water (MEW, 2010). Figure 3.5 shows the distribution of landfills and groundwater fields.

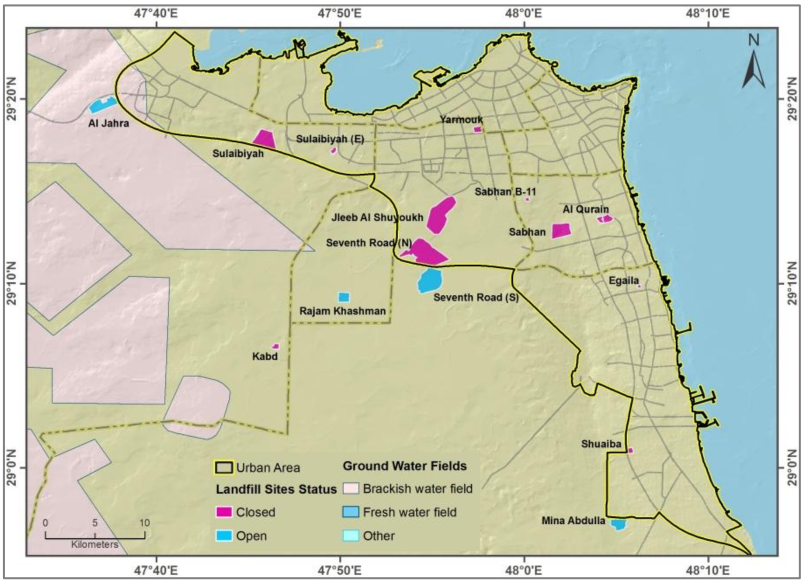

Figure (3.5): Projection of landfills on groundwater fields (eMISK/KEPA, 2011).

3.3 Background Information on Waste Management in Kuwait

3.3.1 Municipal Solid Waste Composition and Quantities

3.3.1.1 Solid Waste Types

In the past, landfill sites in Kuwait used to receive all types of solid wastes. This included residential, commercial and institutional wastes, discarded materials resulting from industrial operations, animal carcasses, expired food and medical wastes, as well as liquid wastes and sludge (Koushki et.al. 2004a). Kuwait Municipality defines MSW as the waste that includes but not limited to residential, industrial and commercial wastes, trees, wood, tires, plastics, furniture, cardboard, paper materials, steel, electrical appliances, foamed plastic, fine sand from construction, animal residue, slaughter house wastes, and bulky wastes. Construction/Demolition Solid Waste (CSW) includes concrete blocks, sand, bricks, hunting materials, used plumbing and bathroom equipment (KM, 2000; Al-Yaqout and Hamoda, 2002). Although construction and demolition debris are considered as MSW, they are collected, transported and disposed-off separately from the domestic (household) solid waste in designated landfills (KM, 2000). However, it should be noted that several types of solid wastes (including construction & demolition waste, steel and tires) are not being dumped anymore in the landfills; they are instead collected, sorted and recycled.

Recent studies indicate that the CDSW is the largest portion of solid waste disposed in MSW landfill sites in the country. It constitutes about 76% of the total MSW, whilst the remaining 24% represents the Household (Domestic) Solid Waste (HSW) (Al-Faraj, 2005; LSMS, 2007). As shown in Figure 3.6, food and vegetables (organic materials) form the largest portion of HSW. They constitute about 52% of the HSW total quantity followed by paper (≈18%), and then plastics (13%), while metals and glass represent only a small portion (≈5% each) (Al-Humoud, 2005).

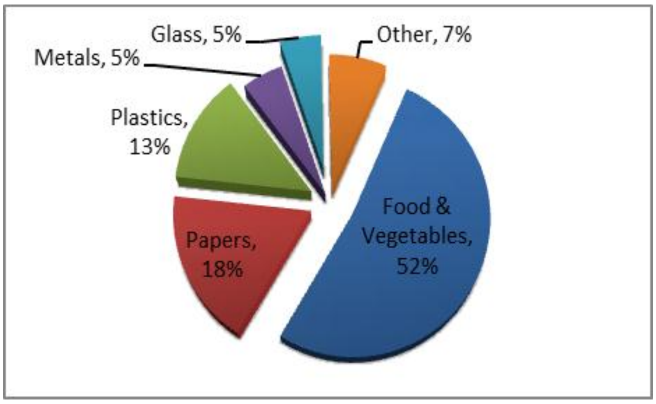

Figure (3.6): Typical composition of household solid wastes (Al-Humoud, 2005).

3.3.1.2 MSW Generation Trends

Over the past five decades (1970's – 2010), Kuwait has witnessed a significant increase in the amount of solid waste generated in the metropolitan areas of Kuwait. Table (3.1) summarizes the quantities and rates of solid waste received at MSW landfill sites in Kuwait during the period from 2000 to 2011 (Koushki *et al.*, 1998; Al-Faraj, 2005; LSMS, 2007; eMISK/KEPA, 2011). Trends of such MSW quantities are also shown in Figure 3.7.

Table (3.1): Quantities of solid waste received at MSW landfill sites in Kuwait from 2000 to 2011 (Al-Faraj, 2005; LSMS, 2007; eMISK/KEPA, 2011)

Year	Household SW (Ton)	Increasing Rate (%)	Construction Waste (Tons)	Increasing Rate (%)	Total (Tons)	Increasing Rate (%)
1997	880685	-	2784500	-	3665185	-
1998	999622	13.5	2685200	-3.5	3684835.5	0.5
1999	1079086	8	2892670	7.5	3971763.9	8
2000	1063697	-1.5	3918240	35.5	4981935.6	25.5
2001	1236771	16	4035390	3	5272177.3	6
2002	1289855	4	4758910	18	6048769.3	14.5
2003	1296365	0.5	3773880	-20.5	5070245.5	-16
2004	1107949	-14.5	4309200	14	5417134.5	7
2005	1113153	0.5	3699050	-14	4812203.5	-11
2006	1288379	16	6972465	88.5	8260859.7	71.5
2007	1558748	21	3926280	-43.5	5485049	-33.5
2008	1310036	-16	4481190	14.1	5791226	-5.6
2009	1153233	-12	2231695	-50.2	3384928	-41.6
2010	1408432	22	1568535	-29.7	2976967	-12.1
2011	1357395	-4	1276589	-18.6	2633984	-11.5

Figure 3.7 and Table 3.1 clearly show that the generation of household solid waste has gradually increased with the increase in population over the years. Figure 3.8 shows the density and distribution of municipal solid waste generation in Kuwait calculated on the basis of 1.4 Kg/capita for the population density in 2010 (eMISK/KEPA, 2011). It is evident from figure 3.8 that the highest solid waste generation rate is apparently concentrated in residential areas with the highest population density (i.e., Hawalli and Farawanieh Governorates).

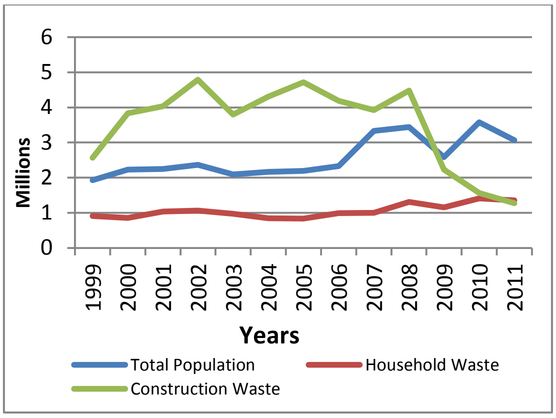

Figure (3.7): Trends of HSW generation in Kuwait during the period from 1999 to 2011 (eMISK/KEPA, 2011).

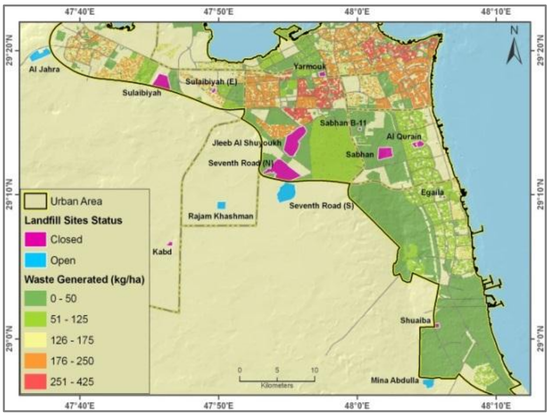

Figure (3.8): Density and distribution of municipal solid waste generation in Kuwait (eMISK/KEPA, 2011).

3.3.2 Cost of HSW Collection, Transportation and Disposal

The cost of household solid waste (HSW) collection and transportation as well as landfills sites operation and management has been recently discussed and reviewed by different authors (Koushki et al., 2004a; Al-Hajri, 2004; Muqeem, 2009).

In Kuwait, the government funds the entire household solid waste services (collection, transportation, and disposal). Collection and transportation of waste are typically conducted by approved contractors who have service contracts with Kuwait Municipality. However, the removals of private construction debris produced from building construction/demolition operations and their transportation to landfill site are undertaken by residents generating such wastes.

The collection and transportation of other MSW from industrial and commercial sectors are the responsibilities of the respective owners of these facilities. However, there is no tipping fee paid for landfilling, neither by the residents nor by the commercial users.

Studies regarding the cost of Solid Waste Management (SWM) in Kuwait revealed that about 61% of the total cost is allocated for collection and transportation. The remaining cost is for administrative services and disposal. In Kuwait, the cost of SWM (including waste collection, transportation, landfilling, wages, and land cost) in the year 2000 was estimated at 17.27 million K.D ($59,055,000), which amounts to 16.24 K.D ($56.0)/ton (Al-Hajri, 2004). However, such costs (management and operation) increase with the increase in collection, transportation and disposal costs.

A three year contract of 1,244,880 K.D ($4,300.000) for landfill operations was signed by Kuwait Municipality (LSMS, 2007). This is equivalent to landfill operation cost of 34,500 KD ($120,000) per month. This cost excludes the cost of exploited lands, used energy, and employee wages.

According to Kuwait Municipality, total cost of the contracts submitted for collection and transportation services during the period from 2002 to 2005 was about 35 million K.D. (Al-Hajri, 2004; LSMS, 2007). Collection/transportation cost was 7.5 K.D ($24.0) per ton in 2000, and currently exceeds 10 K.D ($32.0) per ton excluding the cost of waste disposal. A review of related literature on the cost of solid waste management is presented in the Table (3.2).

Kuwait Municipality contracted cost compares very well with those recorded elsewhere in the world, including non-industrialized and low-income nations (Koushki *et al.*, 2004a). Three factors are mainly responsible for the low cost of collection and transportation of household solid waste in the State of Kuwait (Koushki *et al.*, 2004b). These include: dramatically low labor and driver wage, low vehicle maintenance cost (cheap labor), and low energy cost (i.e., cost of fuel in Kuwait is less than 75 cents per gallon).

Table (3.2): Typical costs of municipal solid waste components (partly after Koushki, *et al.*, 2004)

Solid waste cost components (US$)				
City/State nation	**Landfill Tipping**	**Collection and Transport**	**Combustion**	**Total Waste Management**
U.S.A	10-80/ton[a]	3.5/ton mile[b]	-	-
Thailand[c]	-	2.9-10.4/ton	-	-
Canada[d]	80-120/ton	-	-	-
Kuwait[e]	-	24.0/ton	-	48/ton[l]
Hong Kong[f]	11.3/ton	-	-	-
Florida[g]	55.1/ton	16.6/ton	-	-
New York City[h]	-	-	-	143/ton
Philadelphia[i]	55.2/ton	48.5/ton	52.5/ton	-
Fairbanks, Alaska[j]	-	11.60/month/HH	-	1.0×10^{6}/year
Munster, Indiana[k]	-	120.4/ton	-	174/ton

[a]Afifi (2000); [b]Pollock (1987); [c]Danteravanich & Siriwong (1998); [d]Chung & Poon (1997); [e]Koushki *et al.*, (2004b); [f]Chung & Poon (1997); [g]Young (1991); [h]Clark (1993); [i]Rubenstein & Zandi (2000); [j]Koushki *et al.* (1997a and b); [k]US EPA (1997); [l]Al-Hajri (2004).

3.3.3 Solid Waste and Landfill Management Organizations in Kuwait

There are several stakeholders in Kuwait who are responsible for MSW management. The key stakeholders and their roles in MSW management in the country are shown in Table 3.3. It clearly shows that two governmental organizations; namely, Kuwait Municipality and Kuwait Environment Public Authority, are responsible for MSW management (MSWM) as well as landfill sites management, monitoring and rehabilitation.

Table (3.3): MSW stakeholders and their role in MSWM in Kuwait (partly after Muqeem, 2009).

Stakeholder	Role
Government (Council of Ministries)	Environmental laws and policies (divide responsibilities)
Kuwait Municipality	Regulations, guidelines and supervisions of waste collection, transportation and disposal, landfill sites rehabilitation
Kuwait EPA	Landfill sites monitoring and rehabilitation
Public	Waste generation and unofficial sorting
Waste Transporters	Collection and transportation
Small-Scaled Firms	Segregation, recycling and reuse
Landfill Contractors	Disposal activities, landfill site operation, and maintenance
Two Recycling Facilities for Construction and Demolition Wastes	Specialized for recycling construction and demolition wastes
Academic & Research Institutions e.g. Kuwait Institute for Scientific Research (KISR) and Kuwait University	Research projects and studies regarding MSW and landfill management

3.3.3.1 Kuwait Municipality

The management of MSW, including the supervision of waste collection, transportation and disposal, falls exclusively under the responsibility of Kuwait Municipality. Before the year 2002, the Department of Cleaning and Road Works in Kuwait Municipality includes a division for MSW Disposal Supervision. On 21st January 2002, a decree was issued by the Municipality Council to transfer MSW Landfill Sites Management and Supervision (LSMS) to the Environmental Affairs Department (EAD) at Kuwait Municipality.

Consequently, the EAD is currently responsible for landfill sites management. The department typically conducts such work by signing waste services contracts with private contractors for landfill sites operation (landfilling) and supervising the hired contractors during the implementation of their work. Other waste management strategies and programs, such as waste reduction, reuse and recycling, are also set by EAD (Muqeem, 2009).

3.3.3.2 Kuwait Environment Public Authority

The Kuwait Environment Public Authority (KEPA) was established in 1995 by the Law No. 21 of 1995, which was amended by the Law No. 16 of 1996 to carry out all the activities and functions that ensure the protection of the environment in the State of Kuwait (KEPA, 1996).

In 2001 KEPA issued the Executive Decree (known as Decision No. 210/2001; KEPA, 2001a), which empowered it to enforce environmental regulations and standards for the State of Kuwait.

According to Article (20) in the KEPA 210/2001 Decision, the selection of the landfill location requires a number of criteria for MSW landfills. These criteria include:

1. Subsurface water should be more than 10 m below the bottom of the landfill.
2. Distance between the landfill and any groundwater wells should be more than 2 km.
3. Landfill site should be far away from the agricultural and livestock activities, especially endangered animals.
4. There should be no slopes in the landfill area and it should be free from cracks and away from sensitive areas, such as earthquakes and floods areas.
5. Site should be located in dry areas.
6. Site selection should take into account the geological and hydrological characteristics of the area.
7. Site should be more than 5 km away from residential areas.
8. Quantities and types of soil at the site should be suitable for landfill lining and cover.

Landfill locations in Kuwait do not comply with many of the environmental regulations and standards that have been set by KEPA. The main reason for this is that the landfill criteria were issued in 2001 whereas all the existing landfill sites have been operating long before 2001 (Abdullah, 2010).

Moreover, the Environmental Strategy of Kuwait issued by the EPA (UNDP, 2002) did not include a strategic plan to provide a framework for an advanced MSW management system in Kuwait, which is capable of addressing the associated environmental problems from the existing open and closed landfills.

3.3.4 Landfills in Kuwait

Before 1970, municipal (household) waste in Kuwait was disposed-off via open-burning dumps (Koushki et.al. 2004a). With the increase of generated waste quantities, the year 1970 became the landmark for landfilling in Kuwait as the long-term areas for landfilling were officially designated. Jleeb Al-Sheyoukh and Al-Qurain landfills were among the first landfill sites to receive both construction and municipal wastes. Kuwait today has 18 official landfill sites, which are spread in and around the city of Kuwait (Figure 3.9). While majority of such sites are located within and around close proximity of the municipal limits, none of these sites were chosen on environmental basis. Instead, abandoned sites of sand quarries were an easy choice for the allocation of these landfills. These quarries were then filled by different types of waste materials to form landfills. Table 3.4 below provides details of the above landfill sites including the type of dumped wastes, status of landfill and the period of operation.

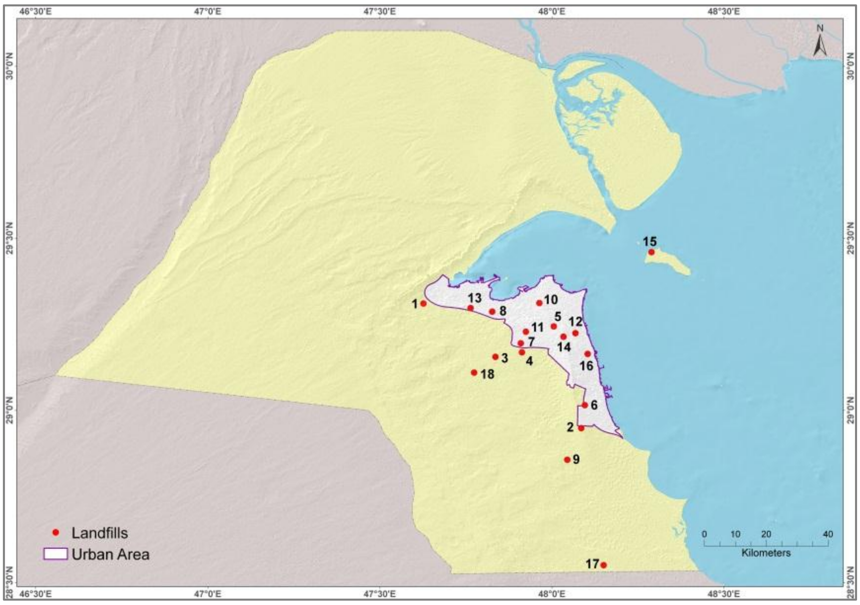

Figure (3.9): Locations of landfills in Kuwait in relation to urban areas.

Table (3.4): Details of the landfill sites in Kuwait.

Serial	Site Name	Waste Type	Filling Period		Status	Depth (m)	Area (km²)	Surrounding Area	Min. Distance from Residential Areas (km)
			From	To					
1	Al Jahra	HH+CD (Stopped) +WW(Stopped)	1986	Till date	Open	>15	1.72	Roads, Industrial Area, Residential Area, Military, Poultry, Farms	1.420
2	Mina Abdullah	HH+CD(Stopped)	1992	Till date	Open	>15	1.15	Roads, Industrial Area, Mining, Golf Course	4.665
3	Seventh Road (S)	HH	1992	Till date	Open	>15	4.21	Roads, Oil Field, Mining, Airport	5.680
4	Rajem Khashman (South 7th Ring Road)	Medical	1992	Till date	Open	Upto 10	1.00	Roads, Oil Field, Mining, Airport	5.680
5	Sabhan Block 11	CD	1980	1986	Closed	Upto 13	0.12	Roads, Industrial Area, Military area, Airport	2.895
6	Al Shuaiba	HH+CD	1986	1992	Closed	Upto 10	0.13	Roads, Industrial Area, Refinaries, Oil Field, Mining	6.550
7	Seventh Road (N)	CD+WW	1986	2005	Closed	Upto 15	4.81	Roads, Oil Field, Mining, Airport	2.725
8	East Sulaibiyah	CD	NA	1987	Closed	Upto 5	0.17	Roads, Industrial Area, Residential Area, Plantations	0.025
9	Araifjan	CD	2009	2009	Closed	Upto 6	0.20	Roads, Industrial Area, Residential Area, Plantations	1.000
10	Al Yarmouk	CD	NA	2004	Closed	Upto 10	0.42	Roads, Industrial Area, Residential Area	0.155
11	Jleeb Al Shuyoukh	HH+CD	1970	1993	Closed	Upto 27	5.50	Roads, Residential Area, Airport	0.127
12	Al Qurain	HH+CD	1975	1985	Closed	Upto 20	0.71	Roads, Residential Area	0.045
13	Sulaibiyah	HH+CD	1982	2005	Closed	Upto 15	2.76	Roads, Industrial Area, Residential Area, Agriculture	1.500
14	Sabhan Military	HH+CD	1984	1991	Closed	Upto 20	1.80	Roads, Industrial Area, Airport, Military Area	1.690
15	Failaka	HH+CD	NA	1990	Closed	NA	0.39	Residential Area, Chalet, Tourism	2.185
16	Al Egaila	HH+CD	NA	NA	Closed	NA	0.11	Roads, Residential Area, Mining	0.230
17	Al Wafra	HH+CD	NA	NA	Closed	NA	0.20	Roads, Agriculture, Resdential Area	0.500
18	Kabd	Poulitry and Cattle Waste	1999	2001	Closed	NA	0.37	Roads, Animal Farms, Residential Area	0.130

* HH: Household Wastes; CD: Construction & Demolition wastes; WW: Wastewater; NA: Not Available.

The present state of municipal solid waste (MSW) disposal has been recently reviewed by several authors (Al-Meshan and Mahrous, 1999 and 2002; Al-Yaqout and Hamoda, 2002; KEPA 2002; Al-Faraj, 2005; Al-Tahw, 2006; Muqeem, 2009; Abdullah, 2010). All sites in Kuwait act as dumping grounds rather than safe landfill areas. Landfilling operation procedures used are neither safe for human nor for the environment. Part of the problem is that companies are lacking safe engineering practices operate the sites. Also, none of the sites were designed for sanitary landfilling, and do not contain designed liner or leachate collection system. These sites were selected at low relief desert areas which were used in the past as sand quarries. Average depths of these abandoned quarries are between 5-18 meters. The selection of such sites was not based on geological or environmental studies. Moreover, random landfilling practices of dumping mixed solid wastes were often used in these sites, which did not follow any waste separation techniques.

MSW landfills used to receive all kind of wastes such as household waste, industrial waste, oil products, agricultural wastes, spent chemical materials, and all sorts of liquid wastes. For example, the daily number of liquid waste tankers used to be received by landfills reached over 200 tankers (Al-Eisa *et al.*, 2011) Hazardous wastes from the oil industry and factories, contaminated soils, outdated medicine, non-gastric hospital waste, and embalmment products are also being dumped in MSW landfills. The different kinds of waste are dumped without any guidelines or separation methods. Most of the wastes are placed in high, steep slopes and usually exposed to the environment for a long period.

Landfilling has been the most common method for solid waste disposal in Kuwait over the last four decades (Al-Meshan and Mahrous, 1999). Figure 3.10 shows the trend of landfilling in Kuwait over the past four decades (newly established, active and closed landfills). It should be noted that Al-Egaila and Al-Wafra landfills (closed) are excluded from the chart in figure 3.10 due to non-avaialability of the establishment date.

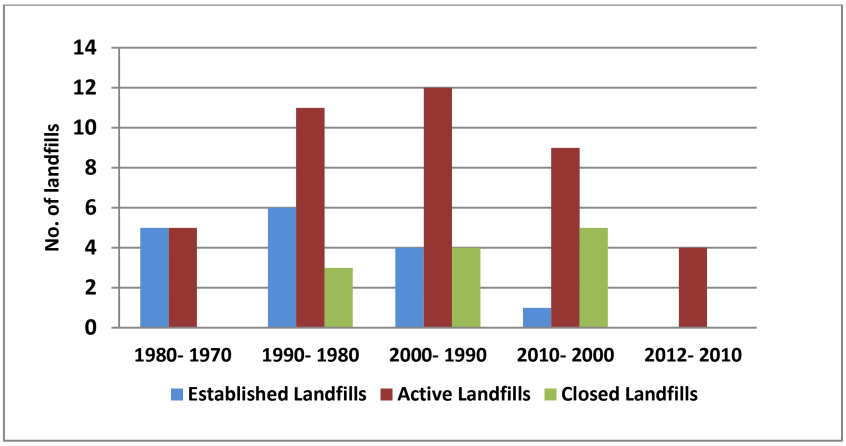

Figure (3.10): Trends of landfills in Kuwait over the past four decades.

It is clear from figure 3.10 that 11 landfills were established during the period 1970-1990. Following 1990, the establishment of new landfills started to decrease, where 4 new landfills were established during the period 1990-2000 and only 1 landfill during the last 10 years. The active landfills reached a maximum of 12 operating landfills during the period 1990-2000, which may be related to the reconstruction of Kuwait after the liberation from the Iraqi occupation (1990-1991). During the period 2000-2010 the number of active landfills dropped down from 12 to 9. Currently, only 4 landfills are still operating in Kuwait.

Figure 3.10 clearly shows that the government policy tends toward the minimization of active landfills in the country (66.6% reduction during the last two decades). The number of closed landfills increased over the last 3 decades reaching a total of 12 landfills, where the government is facing a major challenge in the after closer management of those landfills.

An analysis of the area under the closed and active landfills as shown in figure 3.11 below indicates that open/operating landfills constitute about 39% of the total area of landfills (29.06 km^2) whereas closed landfills constitute about 61%. Figure 3.12 shows the area of individual landfill sites in Kuwait.

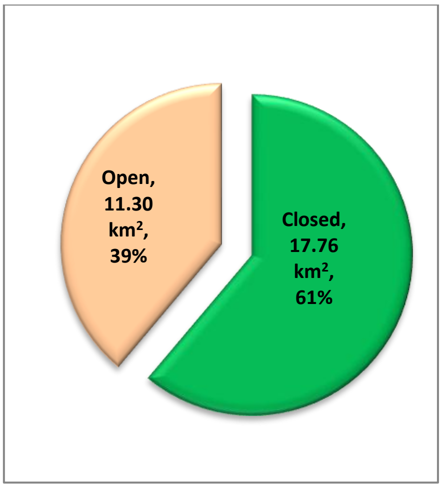

Figure (3.11): Area under closed and open landfill sites (km^2).

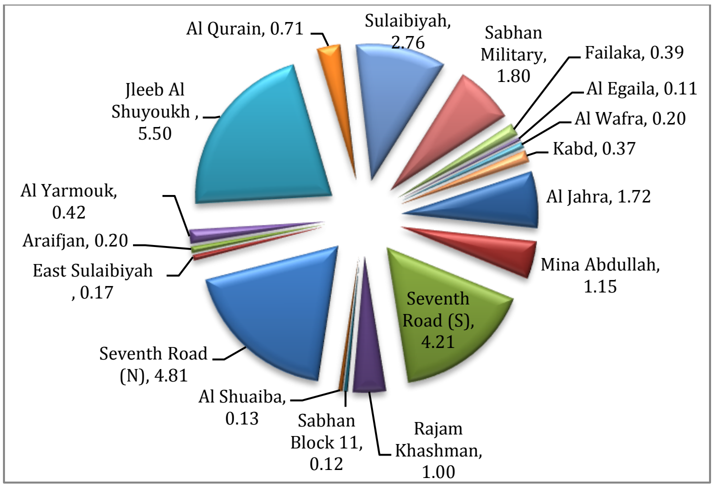

Figure (3.12): Area of individual landfill site in Kuwait (km^2).

3.3.5 Operating Landfills

Currently, Kuwait Municipality operates four landfills with total area of 11.30 km^2 (about 39% of the total landfills area in Kuwait), two of which are located in the south of 7th Ring Road area and are designated for household and construction solid waste. The remaining two landfills (namely, Al-Jahra and Mina Abdullah), are designated mainly to the disposal of household solid waste. Figure 3.13 is a satellite image map showing urban areas and the locations of open landfill sites in Kuwait.

Figure (3.13): Satellite image (SPOT, 2010) showing the locations of open landfill sites.

The operation procedures in the landfill were recently reviewed by Muqeem (2009) and Abdullah (2010). These procedures consisted of unloading the truck next to the edge of the quarry and then pushing the waste to the quarry by the Rubber-Tired Front End Loader until the ground level is reached. No compaction is performed for the waste due to the lack of sufficient equipment and tools. At the end of the day, waste is covered by a thin layer of sand or by sand mixed with construction demolition waste. Consequently, most of the waste would not be covered due to the steep slopes and the quarry irregularities. Liner and cover systems that serve as barriers and protective layers are not defined in Kuwait.

Based upon the afore-mentioned review, the main issues of concern, regarding the present SW landfilling practices followed in Kuwait, could be summarized in the following (Muqeem, 2009):

1. Absence of institutional capability regarding waste reduction, segregation, recycling, composting, landfilling operation, and maintenance.
2. Lack of expertise in solid waste managerial and engineering aspects. Most workers and personnel operating landfill sites are not familiar with the negative environmental impacts from landfills.
3. Lack of awareness of the public for the importance of waste reduction and segregation.
4. Lack of effective SW management strategies and enforcement of laws and regulations regarding SW management in Kuwait.

It thus noted that landfill sites have not been operated in a sustainable manner in Kuwait and several sites have been closed before their expected time period. In the absence of proper urban development planning, the landfills (both operating and closed) have ended up being too close to residential, commercial and industrial area.

3.3.6 Closed Landfills

Out of the 18 landfill sites, 14 sites are closed from operation (17.76 km^2, about 61% of the total landfills area in Kuwait). All of these closed sites are located within close proximity of the human habitation, thereby posing concerns on their health and environmental impacts as well as their proper management. Most landfills in Kuwait have not been operated in a sustainable manner, and hence several of them have seen premature closure. In the absence of a proper urban master plan or development strategy for organized and planned development, many landfill sites have ended up being in the close proximity to prime developmental areas for residential, commercial and industrial usages. Figure 3.14 is a satellite image map showing urban areas and the locations of closed landfill sites.

Figure (3.14): Satellite image (SPOT, 2010) showing the locations of closed landfill sites.

Out of 14 closed landfill sites, 9 sites contained mainly municipal organic wastes mixed with construction/demolition wastes; whereas 3 sites contain only construction/demolition wastes. The total area covered by the 9 sites containing municipal organic is about 11.97 km2, where Jleeb Al-Sheyoukh constitutes more than 45%, Sulaibiyah 23%, Sabhan Military 15%, Al-Qurain 5.9% and about 10% for the 5 remaining sites (see Figure 3.15).

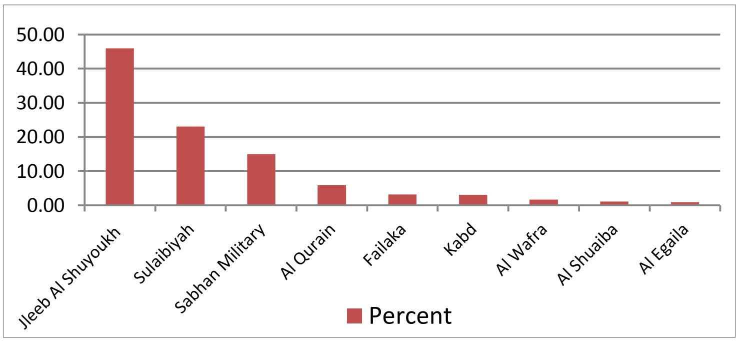

Figure (3.15): Percent distribution of closed landfill sites containing municipal organic wastes.

3.4 Analysis of Kuwait Landfills

A multipurpose analysis was made to assess the environmental and socioeconomic impacts of landfills in Kuwait. The problem was approached by defining an outside buffer zone of one (1) Km around each landfill site and then overlaying these buffer zones on landuse, landcover and the disaggregated population and population density maps. These maps were developed from the SPOT 2010 Satellite Images (eMISK/KEPA, 2011).

3.4.1 Areal Analysis:

Not all of the landfills are of the same sizes, and there exists a vast difference in the areal-extent of the different landfill sites. Figure 3.16 presents relative proportion of landfills out of the total coverage of landfill area (about 29.06 Km^2). This area amounts to about 3% of the total urban / municipal area (850 Km^2) of Kuwait. Out of the eighteen (18) landfill sites, only eight landfill falls under bigger landfills (larger than 1 Km^2 size) which constitute almost 90% of the total landfilling area (23 Km^2) whereas 10 smaller landfills (less than 1 Km^2 size) constitute about 10% (3Km^2) of the actual area under landfills.

The four (4) currently operating landfills constitute to about 32% (8 Km^2) of the total area of landfills, and the remaining 68% (18 Km^2) area falls under closed landfills. It can be seen from the figure 3.16 below that Jleeb Al-Sheyoukh alone has about 21% of the total land area under landfills. Jleeb Al-Sheyoukh, and Seventh Ring Road landfills are also fairly large ones, while all of the others are fairly small.

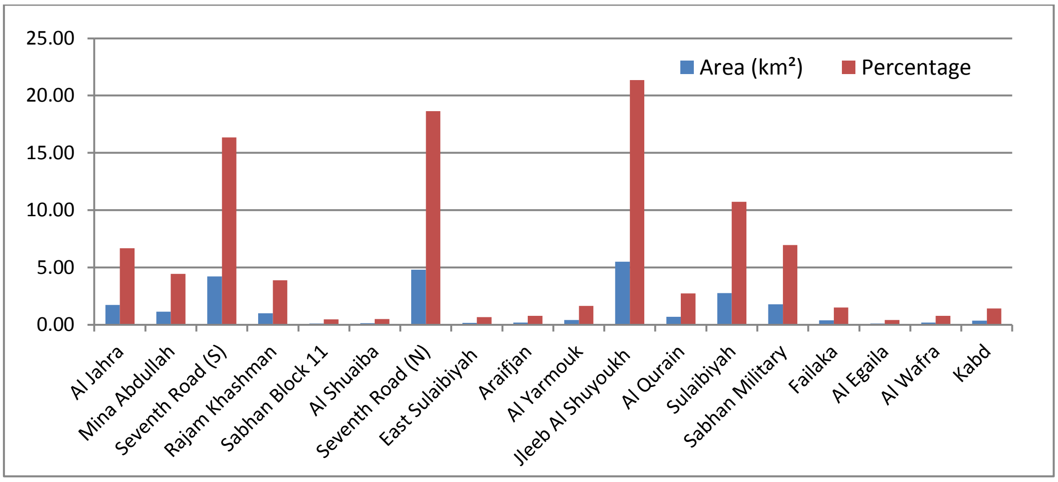

Figure (3.16): Relative proportion of individual landfills out of the total coverage of landfill area.

3.4.2 Landuse Analysis

The strategic analysis of each landfill site was carried out to evaluate the impact it may have on economic development. Four landuse categories were used in this analysis that was carried out for region falling under 1-km outside buffer of the existing landfills. These categories included: "Open Areas", "Human Use", "Agriculture" and "Water". Residential, industrial, commercial, and public services were combined together into ‘Human Use’ category.

Results presented in figure 3.17 below show that 11 landfill sites have access to very limited open areas around them (less than 7 km^2) whereas the landfill of Seventh Ring Road (North & South), Jleeb Al-Sheyoukh and Failaka are surrounded by large open areas (10 – 19 km^2). The most concerning situation prevails around the Sabhan Military, Mina Abdullah Al Qurain, Sulaibiyah, East Sulaibiyah, Jleeb al-Sheyoukh, and Al Yarmouk which are surrounded by categories of ‘Human Use’ and ‘Agriculture’.

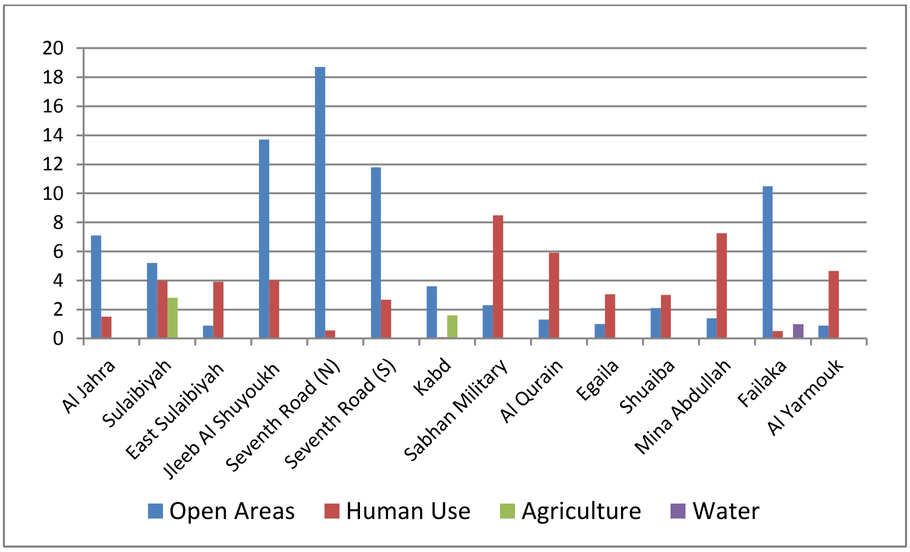

Figure (3.17): Area of different landuse categories around landfills sites.

Only three landfill sites (namely, North of Seventh Ring Road, Kabd and Failaka) are relatively free from the ‘Human Use’, while the rest of the landfills (constituting about 78% of the total area under the landfills) are surrounded with significant proportions of ‘Human Use’ class. Kabd stands out as the remotest location where the ‘Human Use’ class is represented minimally (~2%) of the total area under the landfill including outside buffer.

3.4.3 Population Analysis:

An attempt was made to analyze the human population within the immediate vicinity of 1 km buffer (from the landfill boarders) for the year 2005 and 2008; and hence, the percent of population growth was used to calculate and to project the population for the year 2011 (as shown in figure 3.18, below). Temporal change in the human population within the buffer zone and assessment of their exposure to the risks was carried out. It comes out clear that there are only few landfill sites (about 5) that have large human population growth within the immediate vicinity of landfills.

While the population growth has shown drastic increase around most landfill sites, the landfills surrounded by large human population (such as; Jleeb AL-Sheyoukh, East Sulaibiyah, Egaila and Al-Yarmouk) have also registered very high rates of growth between 2005 and 2008. The projected population for the year 2011 indicates that these areas are witnessing more development and population growth, and therefore, are at increased environmental risks, where rehabilitation measures are urgently needed.

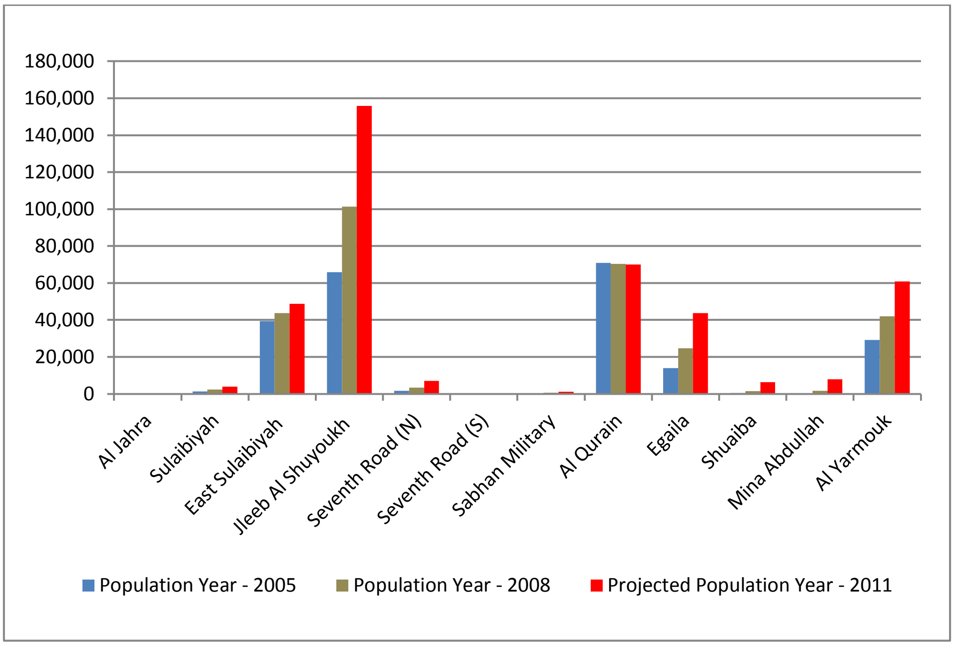

Figure (3.18): Population analysis of landfills and surrounding buffer regions.

3.4.4 Compliance with Kuwait Master Plan (2005)

Projection of landfill sites over the Kuwait Master Plan (2005) to identify possible conflicts with proposed usage of the land was made. The presence of current landfill locations were analyzed with respect to 4th Kuwait Master Plan 2005 (KM, 2008) as well as to their proximity to important services and installations. The purpose of this analysis is to investigate the possible conflicts between the locations of landfills sites and the landuse plans adopted in the 4th Kuwait Master Plan 2005. Figure 3.19 reveals that almost all landfills are located within or in the close proximities of the sensitive landuse areas.

There are unlined landfills that are intersecting both the existing metropolitan areas as well as some of the newly proposed developments. For example, it should be noted that both JLF landfill and North 7th Ring Road landfill were not taken into consideration in the 4th Master Plan. Figure 3.20 shows that whole of JLF landfill and most North 7th Ring Road landfill are within areas approved in the Master Plan for the expansion of Kuwait International Airport. Also, the newly suggested 6.5 Ring Road sits at the boarders of the expansion area of Kuwait International Airport. Moreover, some landfills are close to the proposed water fields and the lands designated for agriculture and poultry farms.

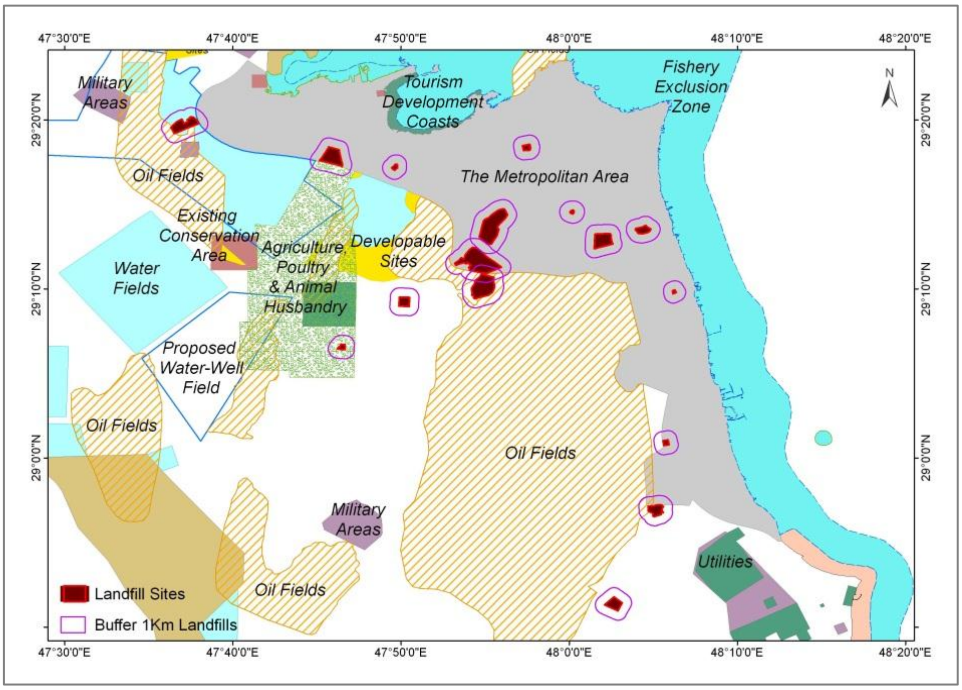

Figure (3.19): Landfills overlaid on 4th Master Plan.

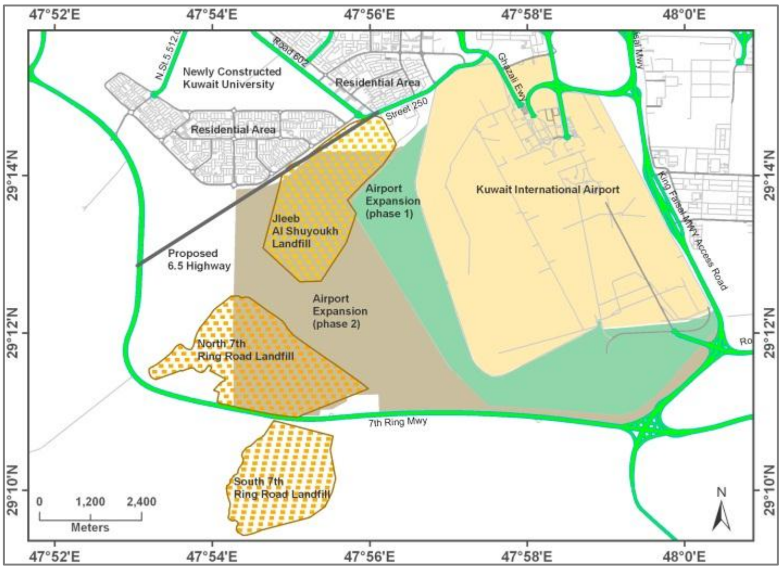

Figure (3.20): Intersection between the expansion plans for Kuwait International Airport and the nearby landfill sites.

Figure 3.21 below shows the locations of important services and installations against the backdrop of existing landfill sites. It is seen that certain landfills occupy locations that are strategic and important as they are closer to the sensitive landuse and services. For example, Jleeb Al-Sheyoukh may not be considered viable because of its proximity to Kuwait International Airport as well as to the nearby Abdulla Al-Mubarak residential area. Similarly, the landfill of Al-Jahra and Sulaibiyah may potentially pollute the groundwater fields. On a similar note, the sites of Shuaiba and Mina Abdullah are closer to the camping sites and may spoil the scenery and cause odor and other impacts to the air quality of the surrounding regions. The landfills of Al-Qurain and Egaila are amidst the residential areas and may pose potential threats of harmful gases and fire accidents.

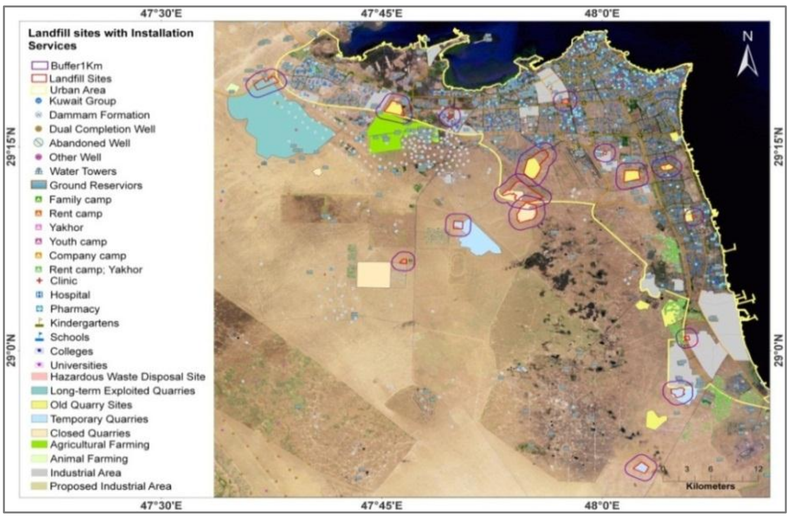

Figure (3.21): Landfill sites along with important services and installations.

3.5 Rehabilitation/Remediation of Landfills

The exploited area for closed landfill sites exceeds 17 km^2, which is a considerable area compared to the area accessible for development in Kuwait (which represents only 25% of the total area of the country) (Al-Faraj, 2005). Moreover, landfill sites in general, and closed landfills in particular, deprive present and future generations from valuable resources and increase dependency on land for waste disposal. It is thought that if Kuwait continues on the same pattern of waste generation and landfill sites mismanagement and hence more landfills closure, the required landfilling area is forecasted to be doubled in less than 15 years (Abdullah, 2010). Therefore, the conflict between urbanization and landfill sites locations, and hence the need for a proper strategy which will lead to waste reduction and less landfill areas throughout the country, including the rehabilitation of the existing closed landfills, are the main challenges facing municipal solid waste management in Kuwait (Miller, 1999; Al-Duaij, 1997; Al-Meshan and Mahrous, 1997; Al-Faraj, 2005; Muqeem, 2009).

Due to the increase in urbanization and development activities, some of those landfill sites became very close to residential, commercial and industrial areas. Examples of such landfill sites are Jleeb Al-Sheyoukh and Al-Qurain landfill sites. These sites encountered problems from improper management and random disposal of domestic and industrial waste in abandoned quarries. The areas surrounding these two sites were assigned for government housing projects without any appropriate environmental assessment of the landfill impacts on the housing units. Although Al-Qurain landfill site was closed in 1984, residents of the newly constructed housing area continued to complain from landfill odors and the self-burning of waste (Al-Sarawi *et al.,* 2001; Amie, 2001; Kwarteng and Al-Enezi, 2004; KEPA, 2001b and 2005). Similarly, the surrounding residential areas of Jleeb Al-Sheyoukh landfill sites suffered in 2002 from a massive 3 day fire that erupted in the whole landfilling area.

Out of the 18 landfills in Kuwait, only few have been rehabilitated or have been subjected to partial rehabilitation (see Appendix 1). As can be seen in figure 3.22 below, no rehabilitation has been carried out for 44% of the landfills, and only partial rehabilitation has been conducted for 2 sites (constituting 11% out of the total landfills area), whereas about 7 landfills (39%) are being protected by control measures, which largely involves fencing and restriction for trespassing.

Only one site (Al-Shuaiba) was subjected to total rehabilitation. This site contained limited quantities of wastes (mostly construction) where the waste was completely removed and the site was converted to accommodate hazardous asbestos waste. On the other hand, the assessment of landfills in Kuwait is also a matter of concern. As shown in figure 3.23 below only three landfills had been assessed, whereas the remaining fifteen (15) need to be assessed. It is important to note that very limited rehabilitation efforts (6% total and 11% partial) have been carried out on landfills in Kuwait.

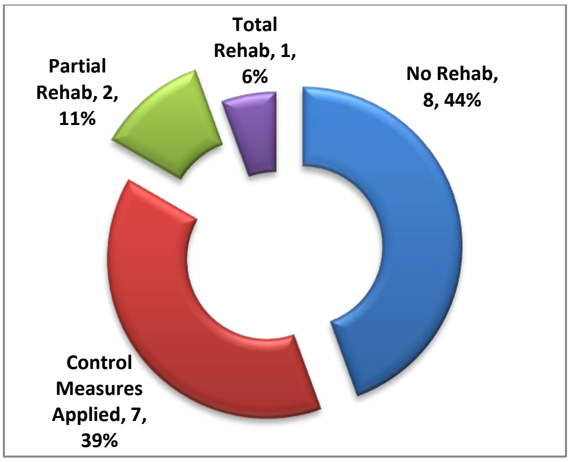

Figure (3.22): Status of rehabilitation in landfill sites in Kuwait.

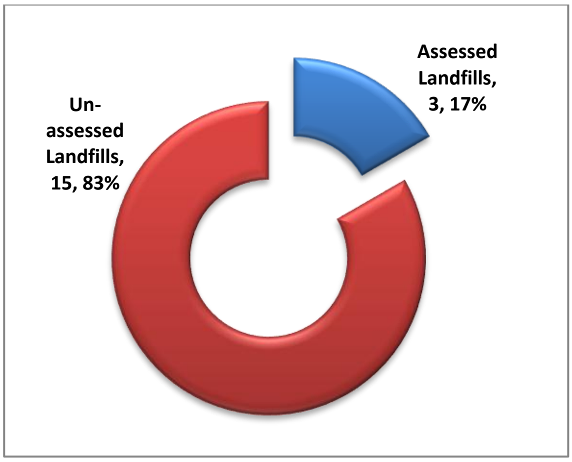

Figure (3.23): Assessment carried out in landfill sites in Kuwait.

Figure 3.24 shows that only 1 landfill site (Al-Qurain) has limited monitoring programme whereas the remaining 17 sites (constituting 94%) are not subjected to any monitoring procedures to assess their environmental effects (i.e., leachates, LFG emissions, groundwater contamination, and landfill settlement).

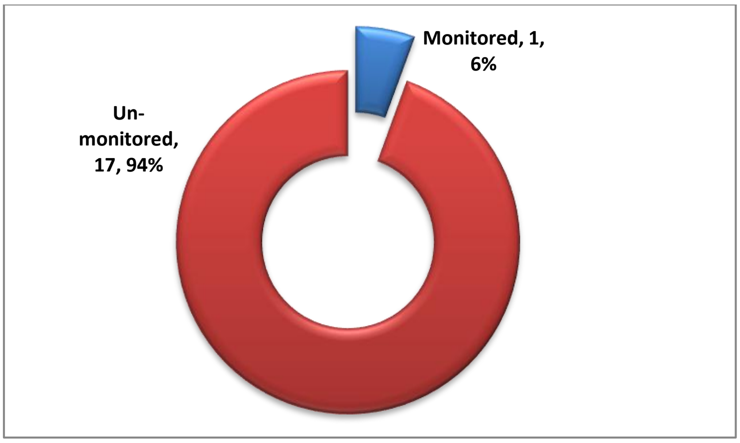

Figure 3.24: Status of monitoring in landfill sites in Kuwait.

An attempt was made by KEPA to control the environmental effects of Al-Qurain landfill site due to the rising number of complaints from residential areas around the landfill site (KEPA, 2001b).

This included monitoring program and a rehabilitation project for only one third of the landfill area. Results obtained from the monitoring program indicated that the CH_4 rate in the landfill ranged from 45-60% while CO_2 was in the range from 35 to 50%. (Al-Sarawi *et.al.*, 2001; KEPA, 2001b and 2005). The KEPA rehabilitation project was implemented through degassing and recovering the LFG for electricity production (Al-Ahmad *et al.*, 2003).

Furthermore, the exploited area for landfill sites (both closed and open) exceed 29.06 Km^2, which is quite significant compared to the area accessible for development in Kuwait. Landfill sites in general, and closed landfills in particular, deprive present and future generations from valuable resources and increase dependency on land for waste disposal.

As presented above the landfills of Kuwait are not properly managed and hence they pose a serious threat of various kinds of risks to human population living within the close proximity. Increasing population in these areas adds to these concerns and directs to the point that these landfills must be treated and managed properly before their surroundings are allowed for human use. Looking at the cost of the land, it is all the more justified to have a strategic waste management plan in Kuwait that takes into account actions that promote waste reduction, recycling and the reuse of materials.

It is thus timely that a systematic action is planned for rehabilitation, remediation and treatment of closed landfill sites. Based on the results of the above presented analyses, it may be suggested that the action must start first for the landfills that contain organic waste and are located amidst the residential areas and have large population growth and significant human settlement. Hence, landfill sites like Al-Qurain, Jleeb Al-Sheyoukh and Sulaibiyah should have priority over the other closed landfills where the process of land reclamation must precede other sites.

The main two factors which must be taken into consideration when selecting the restoration/rehabilitation method that should be applied in Kuwait are the environmental and health impacts as well as the limited land available for development. As discussed in Chapter 2 there are several methods and techniques which can be implemented for the restoration and rehabilitation of closed landfills (see figure 2.3 in Chapter 2, above).

The *in-situ* stabilization of buried organic wastes is the most suitable approach for the minimization of the environmental and health impacts prior to the excavation of waste and hence reclamation of the landfill site for development purposes.

There are three methods which can achieve the *in-situ* stabilization; they are "Aeration Method (aerobic)", "Irrigation Method (anaerobic)" and the "Leaching Method (flushing bioreactor)". The latter two methods are possibly more suitable for landfills with liners and they usually require a long period of time for the complete restoration of the landfill. On the contrary, the former method (Aeration Method) is probably more suitable for achieving fast stabilization, minimizing the environmental and health effects during the restoration process, reducing the aftercare period, and therefore making the site ready for excavation of buried wastes and finally reclamation of the land.

4 “Jleeb Al-Sheyoukh Landfill”- the Study Site

4.1 Introduction

Jleeb Al-Sheyoukh landfill was chosen for a detailed investigation, assessment and implementation of a pilot rehabilitation project employing the "*In-Situ* Aerobic Stabilization Method". Leachate composition, production of landfill gas, landfill settlement, and *in-situ* waste temperature has been usually used as indicators to gauge the biodegradation development (Yuen *et. al*. 1999). Yet, other influencing factors such as; landfill cover; waste quantity, quality and distribution; topography and groundwater vulnerability to pollution from the landfill were also determined and assessed.

4.1.1 Rationale for Site Selection

In order to select an appropriate landfill to implement the "*In-Situ* Aerobic Stabilization", certain criteria were developed. Being a closed municipal landfill in an urban area 15 km south-west of Kuwait city, Jleeb al-Sheyoukh landfill (JLF) is considered to be the largest landfill in Kuwait with an estimated area of 5.5 km^2. The Jleeb landfill is located at a distance of less than 1 km from both a residential area and Kuwait International Airport, and hence is considered to be a potential health and environmental hazard to its surroundings (Figure 4.1). The reasons for the selection of JLF can be summarized in the following:

- Poses potential health and environmental hazard to the vicinity of the landfill (the site is bounded by Kuwait International Airport and a residential area of 250,000 inhabitants located in the east and north, north-west side of the landfill, respectively);
- The landfill is located in the middle of around 22 km^2 native area that has not been subjected to any development due to the existing JLF;
- Environmental hazards associated with JLF behavior (e.g. gases and leachate emissions, groundwater contamination etc...). Several thousand cubic meters of landfill gases were emitted from JLF during the outbreak of fires in the year 2002, where LFG gases were recorded many kilometers away from the landfill by KEPA fixed air quality monitoring stations (Al-Ahmad, 2006) ;

- The high-rated value of land cost in the JLF area;
- The expansion of Kuwait International Airport in the west direction towards the landfill (which aims at raising the airport capacity from 8 to 25 million passenger/ year). The expansion plans, approved by the Council of Ministers (KM, 2008), suggest an extension of 11 km^2 in phase 1 along the border area of the eastern side of the landfill, whereas in phase 2 an extension of 32 km^2 is planned, which will cover the whole landfill area; and
- The newly designed and suggested highway (6.5 Ring Road) to the east of the landfill. This new high way is thought to be the only available space for solving the traffic jam in the area.

Figure (4.1) presents an index map of the location of JLF and its vicinity with future expansion plans.

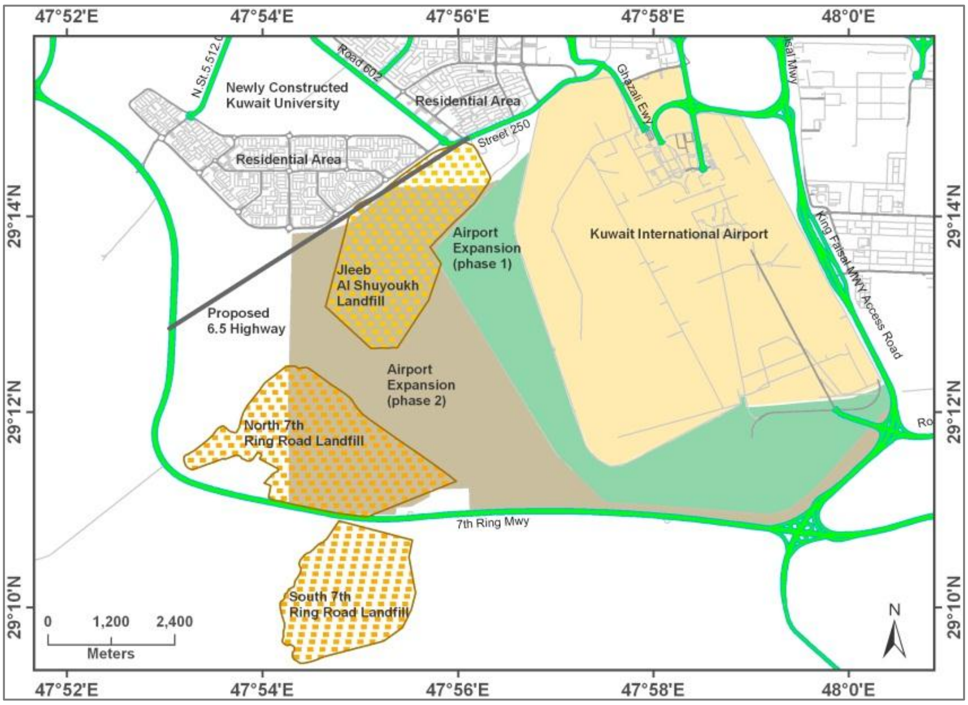

Figure (4.1): Location of Jleeb Al-Sheyoukh landfill Site and its vicinity.

4.1.2 Site Description

Jleeb Al-Sheyoukh landfill contains various types of mixed wastes including; domestic, industrial and construction waste materials which were dumped in a former sand quarry (Al-Ahmad et al., 2003). The site was originally a quarry area which was the first quarry to be used for solid waste landfilling purposes in Kuwait. The site did not fulfill the minimum environmental requirements prior to dumping in terms of site selection, design, and management. No records were found to indicate the exact volume, types, distribution and depth of waste. Moreover, the exact boundaries of the landfill are not known.

The height of JLF site above sea level ranges between 241-245 m. Being subjected to harsh weather conditions (i.e. annual rainfall 112 mm and mean temperature ranges between 18 ^{o}C in winter and 47 ^{o}C in summer), the landfill started to receive waste in 1970 and continued its operation until 1993 under the management of Kuwait municipality as the main landfilling area in the country.

During the years from 1991 (after the liberation of Kuwait) to 1993 (closure year), the landfill was considered the main disposal site for most types of waste collected from all sectors receiving 11,500 metric ton capacity of around 700-750 truck/day (Department of Environment, Kuwait Municipality, 2001). Site activities included burying and compacting contained wastes. JLF also acted as a gathering station for used lubrication oils, since it had the facility to accommodate large number of collecting tanks which were used to transport waste oil to recycling facilities (Department of Environment, Kuwait Municipality, 2001).

4.1.3 Data Collection and Interpretation

It was not possible to perform scientific assessment of the impacts of JLF site on the surrounding area, ground water and the environment, due to the lack of sufficient number of scientific research studies, data and records on the geological, ecological, hydrological and topographical features of the quarry prior to landfilling. Limited environmental studies were conducted to assess the landfill gases (Schrapp and Al-Mutairi, 2010) and leachate (Almuzaini, 2009), however, settlements, landfill cover efficiency and solid waste distribution after its closure are not available. Moreover, maps were not available to show expanse of total dumping area before the landfill was covered with surface sediments. Hence, the assessment and interpretation of the landfill through any pre-existing data was not feasible.

Nevertheless, it should be mentioned that the only exception to this was a series of procedures and measures taken in 2003 to control fires set out in the landfill for 3 days, which included the covering of the landfill with sandy materials brought from nearby quarry. Consequently, fifty boreholes were drilled randomly in the landfill and its surrounding areas to assess the landfill. However, these boreholes were not part of any environmental program (such as monitoring of LFG and leachate), and above all, no interpretation for the logs of these boreholes were ever made.

4.2 Scope of the Study

Bearing in mind that JLF is a virgin area without any adequate baseline information, a series of detailed site investigations had to be conducted for the purposes of assessing landfill geotechnical and environmental conditions, experimenting the applicability of the "*In-Situ Aerobic Stabilization* " for the rehabilitation of closed landfills in Kuwait, and to suggest a new method for the indirect monitoring of landfill behavior during the rehabilitation process.

In order to fulfill the objectives of this research, the scope of the experimental field works and measurements was designed to include three different investigation programmes as illustrated in Figure (4.2) below. The work conducted during this research included; field experiments, *in-situ* field measurements, sample collection and laboratory analyses. Table 4.1 summarizes the experimental setup, measurements and analytical procedures conducted during this research work.

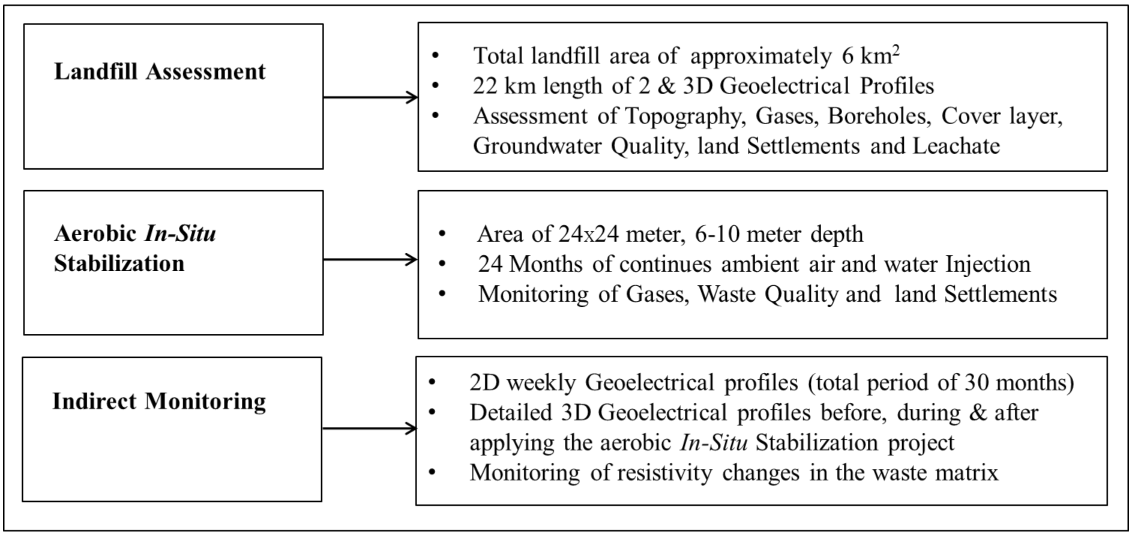

Figure (4.2): Summary of the 3 main investigations programs curried out in JLF.

It should be mentioned that the stabilization of waste matrix through the injection of ambient air is a new cost-effective method based on using a magnetic valve for adjusting and controlling the injected air volume and frequency in the landfill body. Results obtained during this research from applying the "*In-Situ* Aerobic Stabilization" were subjected to continuous monitoring program both directly (by measuring the landfill gas emissions and temperature, waste decomposition rate, settlement and the analysis of leachate obtained) and indirectly (by taking geo-electrical resistivity measurements in the project area using 2 and 3D profiles).

This approach has been suggested in the present study to provide new criteria to quickly indicate the validity and efficiency of the waste stabilization process and to indirectly monitor its progress. Consequently, this is required to be validated for large scale monitoring programs, when/where landfill rehabilitation projects are carried out. Accordingly, the findings of the *In-Situ* stabilization are to be estimated for full scale implementation in JLF, and hence both direct and indirect assessments were made in JLF.

Intensive measurements of both direct and indirect methods (including: waste depth, waste distribution and quantities, groundwater vulnerability to pollution, cover efficiency, settlements intensity, LFG's and intensive measurements of the landfill calculated resistivity) were made, and the results obtained were compared and validated to achieve the final assessment of the landfill. The aim of such full-scale assessment is to assess the needs for overall stabilization of JLF and to determine the associated constraints.

Table 4.1: Experimental setup and analytical methods

Type of experiment	Description of experiment/test	List of parameters	Number of samples/tests	Methods and Instruments
Landfill Gas	*In-situ* measurements of landfill gas emissions from Jleeb and project area	CH_4 , CO_2 , O_2 , H_2S, NH_3 Temperature Barometric Pressure	Weekly readings: 2008-2009-2010 **Jleeb LF:** 50 boreholes, 6-29 meter depth **Project Area**: 28 boreholes, 3 meter depth and 2 boreholes 5 meter depth	Standard hand-held device (GA 2000 Plus)-dual beam IR cell
	Collection of landfill gas samples from JLF and project area sites using Tedlar bags and subsequent laboratory analysis of Volatile Organic Compounds (VOC’s)	**Light VOCs:** 16 compounds, including: Ethylene, Propane, Acetylene, Propylene, Butane, Pentane, Dimethyl Butane, etc. **Heavy VOCs:** 32 compounds, including: Hexane, Cyclo-Hexane, Heptane, benzene, toluene, xylenes, Octane, Ethyl Benzene, Diethyl Benzene, Decane, etc.	**Jleeb LF:** 4 samples **Project Area:** 4 samples	Gas chromatography with flame ionization detector (GC/FID) - USEPA Method 18 , PAMS (Photochemical Assessment Monitoring Stations)1995
Waste Analysis	Collection of waste samples from project area using auger drill for 2 and 3 meters depth	pH, TOC, COD, TDS	**Project Area:** two locations, 2 and 3 meter depth in the years 2008, 2009 and 2010	Standard Methods for the Examination of Water and Wastewater- 21st edition 2005, (APHA, AWWA, WEF)

Type of experiment	Description of experiment/test	List of parameters	Number of samples/tests	Methods and Instruments
Leachate Analysis	Collection and analysis of leachate from Jleeb landfills site at different depth (1 – 21.7 m) during 2007, 2008 and 2009. Leachate was only available for 2007 but no sufficient leachate was available for collection in 2008, 2009 and 2010.	**Chemical analysis:** pH, SO_4, NO_3, Cl, BOD, COD, NH_4, PO_4, S, Br, Cl_2, I, TPH, Ca, K, Mg, and Heavy metals **Physical analysis:** Temperature, conductivity, suspended solids, turbidity	**Jleeb LF:** Only 2 samples from boreholes 15 and 17 were available for the year 2007 at depth 4.8m and 16m, respectively.	Standard Methods for the Examination of Water and Wastewater- 21st edition 2005, (APHA, AWWA, WEF)
Ground water Analysis	Collection and analysis of groundwater samples	**Anions & Cations:** K, Na, Ca, Mg, Cl, SO_4, Bicarbonate, Silicates, Total Hardness, TDS. Heavy Metals TOC, TPH Microbiology	**Jleeb LF:** Three samples were taken from 3 different wells in the year 2010	Standard Methods for the Examination of Water and Wastewater- 21st edition 2005, (APHA, AWWA, WEF)
Geo-electrical Survey	Measuring the resistivity of the buried materials in JLF, and in the project area, reaching the depth of max. 45 meter in Jleeb and max. of 10 meters in the project area	**Configurations:** Wenner-Schlumburger Wenner-Alpha Wenner-Beta Dipole-Dipole **Spacing**: 1, 2, 3 and 5 m.	2 and 3D Geo-electrical tomography by using 64 intelligent electrodes (multi electrodes cable) as indirect *in-situ* measurements through Automatic Resistivity System (ARES) for the assessment of the underground materials **Jleeb:** 30 profiles **Project Area:** 171 profiles	ASTM G57 - 06 Standard Test Method for Field Measurement of Soil Resistivity

Type of experiment	Description of experiment/test	List of parameters	Number of samples/tests	Methods and Instruments
Cover layer Tests	Sampling and analysis of soil used for covering the landfill site in Jleeb.	**Grain size analysis:** Gravel, very course sand, course sand, fine sand, very fine sand, mud. **Infiltration test** **Penetration test**	**Grain size analysis:** Sampling was performed at thirty points and from each point 4 transects were taken at 4 depths: 0.25m, 0.5m, 0.75m and 1m. **Infiltration and Penetration test:** measurements were taken in 30 point.	The American Standard Test Method for Particle-Size Analysis of Soil (ASTM D422, 63 (2007))
Topography (Surveying)	Topographic land survey to obtain coordinates of the landfill and its elevation	Latitude Longitude Relative height	**Points:** 15780 point **Locations**: Covering landfill and surrounding areas including boreholes and sampling points	Leica Total Station, Model TPS-1200t GRX 1200t (GNSS)
Landfill Settlement	Topographic land survey for vertical subsidence measurements	Latitude Longitude Relative height	**JLF area** : 30 points/monthly measurements **Project area** : 17 points/monthly measurements	Leica Total Station, Model TPS-1200t GRX 1200t (GNSS)
Aeration Experiment (Project area)	Applying high pressure aeration of ambient, water injection and gas suction in the waste matrix reaching the depth of 3 m.	Air volume and pressure Suction rate Volume of water injected	26 boreholes : - 12 suction, - 9 injection - 5 monitoring (4 at 3m and 1 at 5 m)	26 boreholes, Air pipeline network, air compressor (ABAC TANDEM 10, capacity 2232 L/min, 11bar), 9 high-pressure metal tanks (ca. 34 L), 9 magnetic control valves for air injection. Water tanks (2000 gallons).

5 Site Assessment using Direct and Indirect Methods

5.1 Introduction

A variety of assessment methods, direct and indirect, qualitative and quantitative methods, should be used to give adequate feedback to any environmental monitoring program to identify areas of low, moderate and high environmental risk.

In landfills, there are basically two types of assessment methods; *Direct Methods* of assessment requires direct field and laboratory work like sampling, measurements, borehole drilling …etc that provide results and information which can contribute to better understanding of the landfill situation. In contrast, the *Indirect Methods*, though helpful in interpreting the findings of direct methods (e.g. GIS, Surfer, GOCAD) or through applying advanced indirect *In-situ* measurements (e.g. Remote sensing, Geophysical surveys), are not always as useful in providing specific knowledge about the landfills as it is in the direct methods. However, it allows quicker and easier understanding to the monitoring agencies, researchers and the community in order to reduce the time, effort and money consumed for direct assessment and monitoring programs.

Any future planning related to landfill rehabilitation must focus on the environmental and economic factors. With such a fact, detailed information on the environmental hazard and impacts from JLF are to be assessed. Consequently, any decision in this regard will be influenced by the economical point of view. Questions that are important to be answered, and are more valuable, focus on gas recovery, landfill stabilization for hazard prevention and/or the rehabilitation of land, value restoration; whereas other questions are also required to be raised. Nevertheless, the final decision can only be taken based on sound environmental facts and assessment findings.

Yuen, et.al. (1999) defined full-scale landfill body as extremely heterogeneous, a feature that tends to be misrepresented by small-scale experiments. With such fact, it was essential to set a wide-range programme to assess JLF in order to identify the future needs of large-scale rehabilitation process and the specific needs for the implementation of aeration stabilization method.

5.2 Materials and Methods

5.2.1 Assessment Programme

Detailed assessment programme for most JLF landfill areas was designed. Table (5.1) presents the four phases of the assessment programme conducted in JLF, which includes the task duration in months and a brief description.

Table (5.1): The four phases of JLF assessment programme.

	Aim / Objectives	Description	Duration (month)
Phase 1	• Data collection & interpretation	• Reports, researches, interviews ..etc	• 2
	• Rough estimate of JLF boarders	• Satellite images & Aerial photographs	• 1
	• Interpreting BH data	• 3D visualization software's (GoCad, VisGW)	• 2
	• Designing the assessment program	• Direct & indirect assessment methods	• 0.5
	• Developing detailed data sheets	• excel data sheets, daily, weekly & monthly basis	• 0.25
	• Identifying required instrumentations	• Availability, methods, analytical procedures ..etc	• 1
Phase 2	• Conducting detailed topographical survey	• 5m detailed contour maps (X, Y and Z values)	• 1.5
	• Building 30 settlement measurement points	• Placing concrete blocks within certain grid system	• 1
	• Developing new LFG measurement heads	• Sampling valves measuring LF gases & temperature	• 1
	• Drilling 3 new groundwater wells	• Follows the regional flow SW-NE directions	• 0.5
	• Locating geoelectrical profiles positions	• X ,Y start and end values of the measured profiles	• 0.25
	• Locating cover layer tests positions	• Developing grid system of 250m*250m	• 0.25
Phase 3	• shooting wide range of geoelectrical profiles	• 2D profiles using stationary multiple-electrode array	• 18
	• Monitoring & collecting leachate samples	• Samples collected from previously drilled 50 BH's	• 36
	• Monitoring & measuring LFG's & VOC's	• In monthly basis in 50 available BH's	• 1
	• Monitoring & measuring settlement points	• Detecting elevation changes in the constructed points	• 36
	• Collecting groundwater samples	• Samples taken in depth ranging between 21-24 m	• 0.25
	• Collecting organic waste samples	• 2 & 3m depth at certain locations	• 0.25
Phase 4	• Preparing & analyzing the collected samples	• Laboratory work conducted in Kuwait & Germany	• 3
	• Data preparation	• Using available & 3D visualization software's	• 3
	• Results	• Presenting All measured parameters	• 2
	• Data Interpretation	• Interpreting the results	• 3
	• Conclusion & recommendations	• Overall Assessment of JLF	• 2
		Overall duration	**36 month**

The assessment programme was designed to produce a full-scale knowledge about JLF based on detailed direct and indirect measurements. Methodology of the current research work consisted of a comprehensive literature review on landfill assessment parameters and techniques, field work, onsite measurements, sample collection, laboratory testing and data analysis. Regarding the above mentioned four phases, JLF geological formation prior to sand excavations in the 1960's (quarrying) was considered, along with quarry conditions and geometry within the area before waste dumping in 1970 and the effect of the landfilling period (1970-1993) in respect to the waste volume, types, distribution and extent were also taken into consideration. The information extracted is valuable and can be considered as baseline for the comprehensive environmental survey of JLF.

5.2.2 Sampling Procedures and Analytical Methods

In the year 2003, prior to the aforesaid investigations, Kuwait Environment Public Authority (KEPA) drilled 50 boreholes (BHs); the perforated pipes used were made of Poly-Vinyl Chloride (PVC) materials. These boreholes were used in several landfill investigations such as the measurement of LFG's and for leachate observation and sampling.

5.2.2.1 Landfill Gases (LFG):

Biogas composition (i.e., CH_4, CO_2, O_2, NH_3 and CH_4/CO_2) was monitored using hand-held device (GA 2000 Plus infrared gas analyzer, Geotechnical Instruments, UK). Measurements of LFGs emissions and temperature were performed in the 50 boreholes for a period of 36 months. Figure 5.1 shows the setup used for LFG onsite measurements and sampling. LFG samples for the analysis of Volatile Organic Compounds (VOCs) were also collected from selected boreholes using a Tedlar bag and a small vacuum pump. Collected samples were analyzed for light and heavy VOCs components using gas chromatography equipped with flame ionization detection (GC/FID). Full details of the sampling and analysis of LFG (including VOCs) are presented in Appendix 2.

Locations of boreholes in Jleeb Al-Sheyoukh landfill	The GA 2000 Plus connected to the borehole head for the measurement of LFG, RH and temperature	Tedlar Teflon bag with small vacuum pump connected to the borehole head for VOCs sampling

Figure (5.1): Map showing the locations of boreholes and the setup used for LFG onsite measurements and sampling for VOCs.

5.2.2.2 Landfill Settlement:

Landfill subsidence (i.e., settlement) was recorded for a period of 24 months by means of measuring the vertical change in the 30 measurement points (observation posts) previously fixed on a grid of 250m×250m (Figure 5.2). Inscribing each of the points with identifying marks and numbers, the points (80×30×30 cm constructed as concrete blocks) were placed as measurement indicators for any changes on the surface across the landfill. The measurements were carried out on monthly basis by a total station (Leica DNA03, by Leica Geo-systems AG. Switzerland) as survey instrument, obtaining accuracy of less than 1cm for height measurements (z) and with 0.3 mm standard deviation per km.

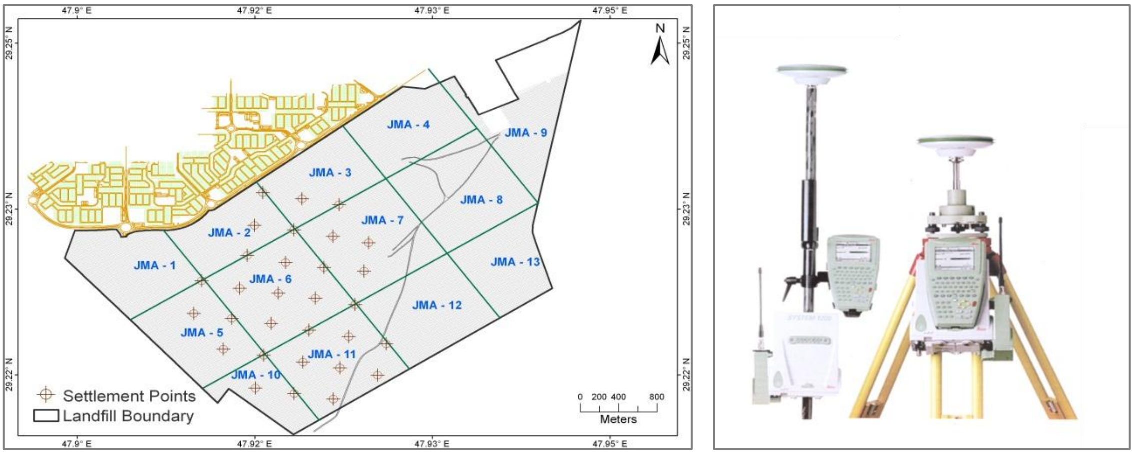

Figure (5.2): Grid and locations of the settlement points in JLF and the survey instrument Leica (DNA03) used for the measurements.

5.2.2.3 Landfill Leachate:

Landfill leachate samples were collected over a period of 36 months. Leachate samples were collected from the 50 boreholes (depending on the availability of leachate water in the boreholes) using Teflon and stainless-steel rope equipped with PVC pockets. Locations of the boreholes are the same as those presented in Figure 5.1 above. Collected samples were placed in a 1-liter glass bottles, placed in cool box and brought to the laboratory for analysis. *In-situ* measurements of total dissolved solids (TDS), temperature, pH and conductivity were made onsite in the collected samples. Leachate contaminants and heavy metal concentrations were determined in leachate samples using spectrophotometry and Induced Coupled Plasma (ICP), respectively. Full details of the analytical methods are described in Appendix 2.

5.2.2.4 Groundwater:

In order to assess the impacts of the dumped wastes on the quality of ground water in the total area of JLF, a comprehensive programme was designed (as shown in Figure 5.3, below) which presents the different phases of ground water assessment in JLF.

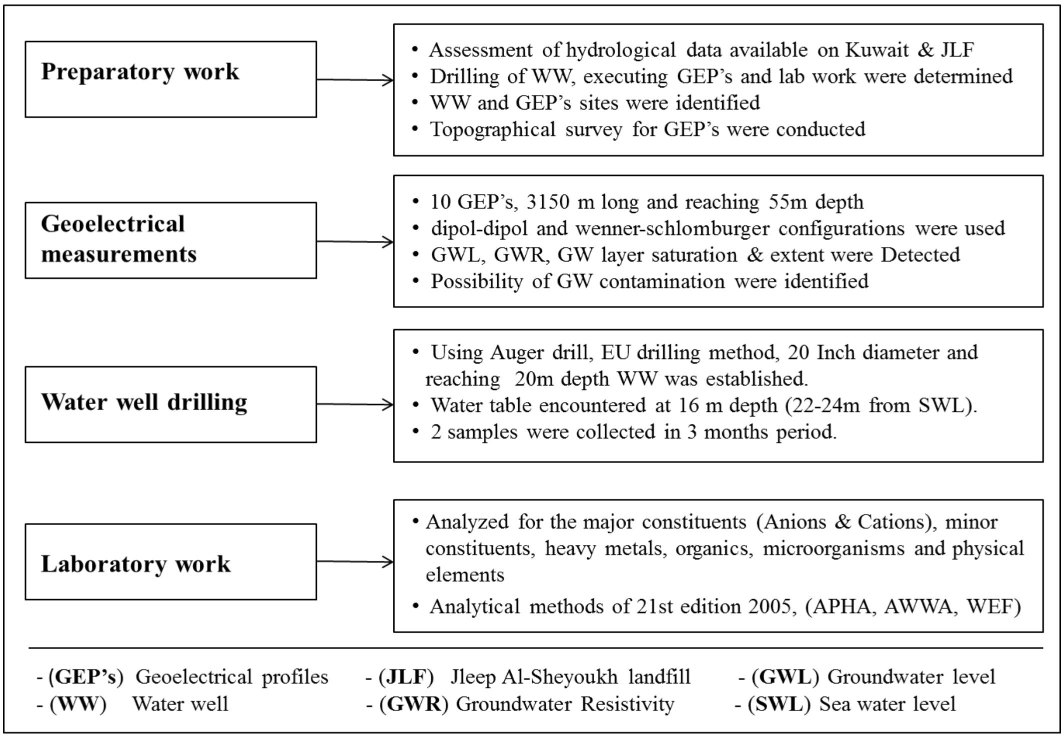

Figure (5.3): Phases of ground water assessment in JLF.

Three samples from the 3 newly drilled groundwater wells were collected throughout the course of the assessment. Figure 5.4 shows the location of the three water wells in Jleeb landfill. The samples were analyzed for the major constituents (Anions & Cations), minor constituents, heavy metals & trace elements, organics, microorganisms and physical elements. The collected samples were analyzed in the analytical laboratories of Kuwait Institute for Scientific Research (KISR), in accordance with the analytical procedures described in Standard Methods for the Examination of Water and Wastewater- 21st edition (APHA, 2005). Full description of the analytical methods used for the analysis of groundwater is presented in Appendix 2.

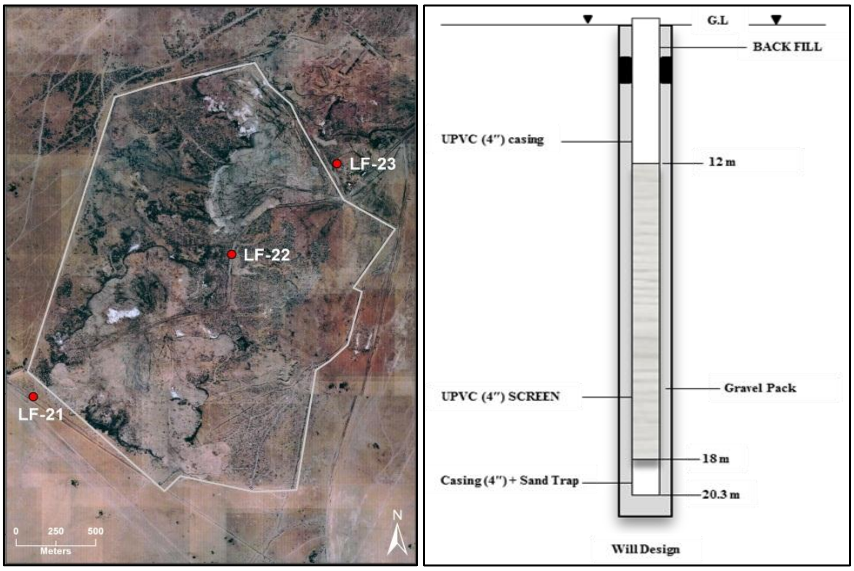

Figure (5.4): map showing the location of the three water wells in JLF site (LF-21, LF-22 and LF-23) and a drawing of the water well design.

5.2.2.5 Landfill Cover:

Three standard tests were performed to investigate the properties of the landfill cover. These were: Soil Grain Size Analysis, Infiltration Test and Penetration Test. Tests were carried out along a 250 m grid as shown in Figure 5.5, below. Samples were taken from 30 points located mostly inside the landfilling area. Tests were performed to determine efficiency of the landfill cover and its ability to contain the landfill body and the waste matrix. Full description of these test are presented in Appendix 2.

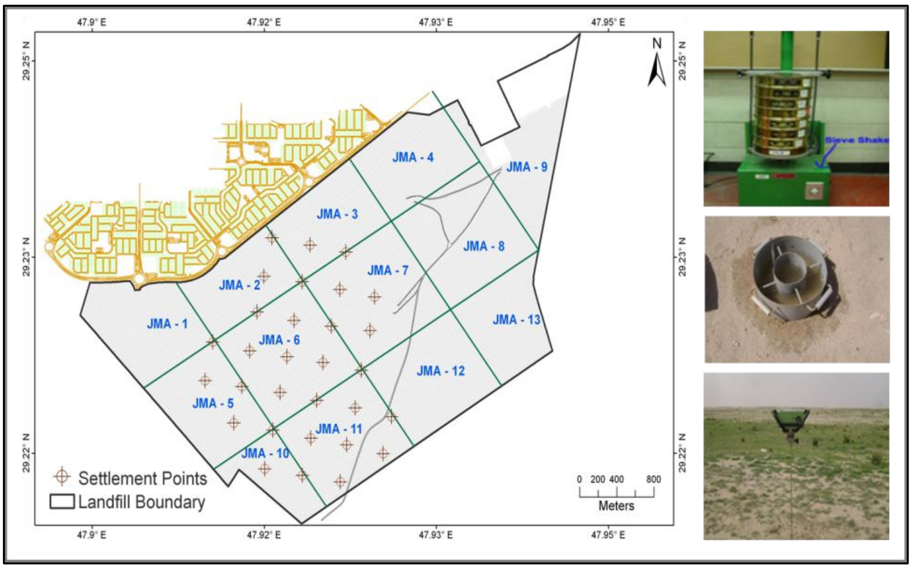

Figure (5.5): Schematic map showing the location of the 30 land cover measurement points in Jleeb landfill and the 3 tests used to measure grain size, infiltration and penetration of the landfill cover.

5.2.2.6 Geo-electrical Measurements:

The Geo-electrical method has been selected for the first time in Kuwait as an investigation method for to the estimation of the volume of disposed waste in JLF. The geo-electrical measurements have been carried out using the resistivity meter ARES (Automated Resistivity Meter) and 64 multi-electrodes in years 2007 and 2010. Field measurements were conducted in accordance with method described by The American Society for Testing and Materials (ASTM G57-06). The geo-electrical measurements were performed as shown in Figure 5.6 along different profiles mounting up to 30 profiles with various lengths (between 315 m 2715 m). The longest profile was chosen to provide a cross section of the landfill site.

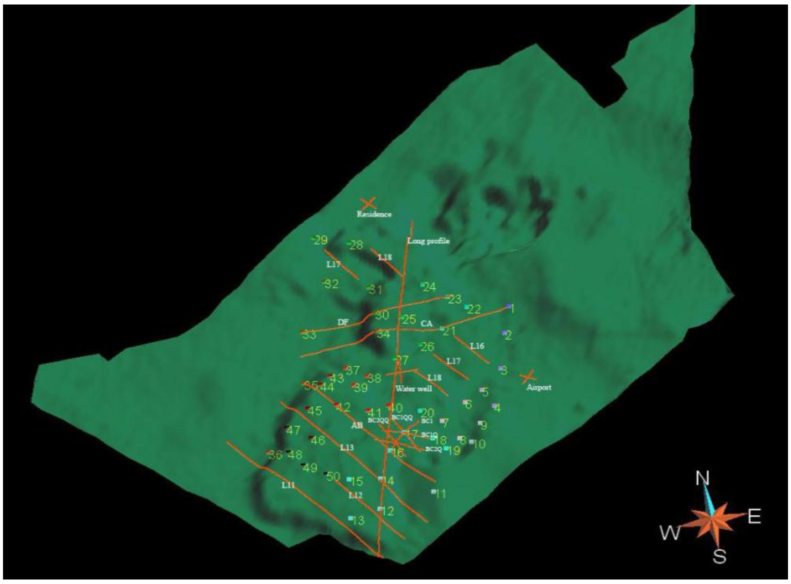

Figure (5.6): Geo-electrical profiles in the investigation area (in red) with the longest profile crossing JLF site (in yellow).

The distance between the electrodes (used spacing) was chosen to be 5, 3, and 2m and the Wenner-Schlumburger configuration was used (ASTM, 2001). Figure 5.7 presents the Electrical current transmission between the electrodes A, B while the potential is measured between M and N. This set of measurements can be repeated on all of the profile line indicating Z_1, Z_2,…, Zn (pseudo depth). Figures 5.8 and 5.9 show the measuring configuration and the measuring device, respectively.

The measured resistance R = V/I, is multiplied with K (geometrical factor), which describes the geometry of the used configuration resulting in the calculated resistivity (Ra), which can be calculated and displayed automatically (were, Ra=R.K).

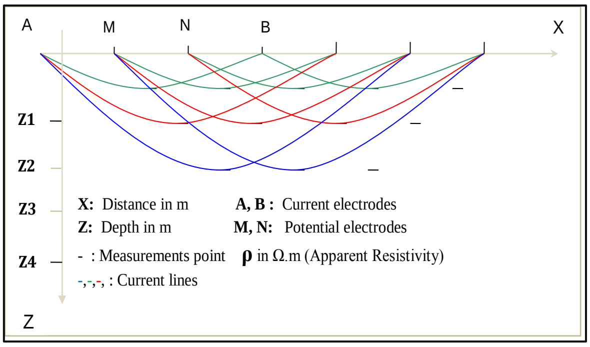

Figure (5.7): Measurement layout of the Geoelectric profiles.

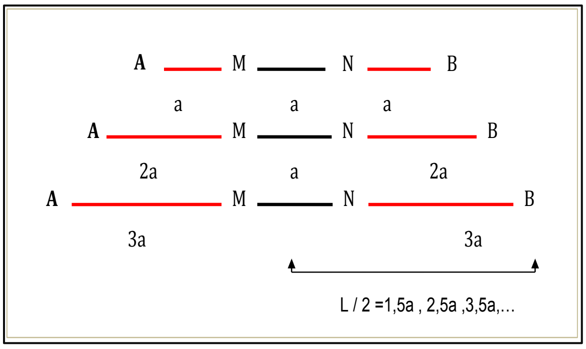

Figure (5.8): Wenner-Schlumburger Configuration, a=5 m.

Figure (5.9): The geo-electric measuring device (Automatic resistivity meter, ARES).

Figure (5.10): The investigation site and the measuring configuration.

For more than 315 m long profiles, the option roll along was used. This means that the profile is to be taken up by several measurement overlaps as shown in Figure 5.10, above. The goal of the 2D-inverse modeling in geo-electric measurements is to determine the layer parameters (h_1, h_2, h_3, $h.n_{-1}$), (ρ_1, ρ_2, ρ_3,…, ρn) from the measured spatial distribution of the electrical conductivities or calculated resistivity.

There are several software programs for the solution of the direct and inverse modeling. The results of the measurements were interpreted by using of the interpretation program DC2DINVRes. The measured resistivity was used as input-resistivity for creating 2D geological surface models.

5.2.2.7 Data Modeling:

To obtain the geometry of the waste body, the boreholes and the geo-electrical cross sections have been modeled using the 3D program GOCAD considering a sufficient thickness to be able to visualize the waste body. GOCAD stands for Geological Object Computer Aided Design. The software is developed by a research group consistent of researchers of geology, geostatistics, computer science, reservoir engineering and geophysics, hosted by the Center of Petrographic and Geochemical Research (CRPG) and the School of Geology at Nancy University.

GOCAD is a computer-aid approach for modeling of the geometry and properties of geological objects in the subsurface for applications in geology, geophysics and reservoir engineering. With GOCAD, consistent models can be built by using data of diverse types from heterogeneous origins and of different spatial distribution. For example, it allows the combination of drilling data with geo-electrical data. The resultant model can be rotated in all three dimensions and sliced at any intervals in x-, y- and z- directions. GOCAD also supports:

- Data import and export (more than 200 different file formats including: DXF, GXF, SHP, XYZ, SEGY, etc.);
- Modeling of horizontal geological boundaries;
- Modeling of folding and fault networks;
- Volume calculation;
- 2D maps generation;
- Cross sectional analysis, etc.

The discrete modeling with GOCAD involves the following steps:

- Define geo-objects like fault blocks and horizons in the area of interest;
- Define the geometry of geological objects by a finite set of nodes in the 3d space;
- Model the geological boundaries by bridging these nodes;
- Interpolate the geometry of a geological boundary with control points;
- Assign property data to objects; and
- Construct 3D body model.

The results of the GOCAD 3D modeling can show the shape of the different layers and the visualized images can be rotated in all directions. Furthermore, the program is able to calculate the volume of every layer or visualize it separately.

5.3 Results

5.3.1 Borehole Logs

In 2003, the Kuwait Environment Public Authority drilled 50 boreholes in JLF in order to identify the distribution and types of buried wastes (for complete presentation of results of the borehole logs, see Appendix 3). Nevertheless, no interpretation of these borehole logs had ever been made, and therefore, an attempt was made in this research work to correlate between the borehole logs using an advanced 3D-VisGW model (visualization of subsurface data, VHI Canada). The results presented in figure (5.11) indicate to the different types and distribution of buried waste materials. For example, it is evident from figure 5.11 below that most of the organic waste materials (red areas) are concentrated in the south-western and north-eastern parts of the old quarries which were used in the past for dumping waste in JLF.

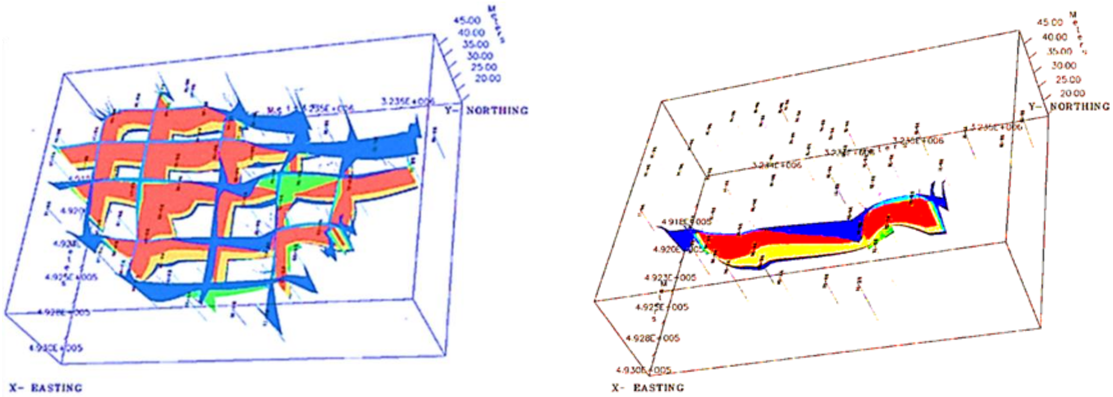

Figure 5.11: 3D presentation of boreholes data showing the correlation of the 50 boreholes in the JLF. Colour codes: dark blue (native soil); light blue (cover layer); green (CDD); red (organic wastes); yellow (contaminated soil).

The data of borehole logs presented in Figure (5.11) above were also used in the 3D GOCAD model along with geo-electrical measurements to identify the waste body in the landfill areas were no boreholes exist. Since the boreholes number and distribution were not sufficient to develop the model precisely, geo-electrical profiles have been measured and the results integrated into the model. Figure 5.12 shows the morphology of the site with the borehole locations and the used grid for surveying. The morphology traces the contours of the waste body. Some of the boreholes are located out of the waste body to ensure that in this area no waste has been deposited and to set limits for the waste body. Almost all drilled boreholes were dry, and hence only boreholes 15 and 17 had some leachate where two samples have been collected and taken for chemical analysis.

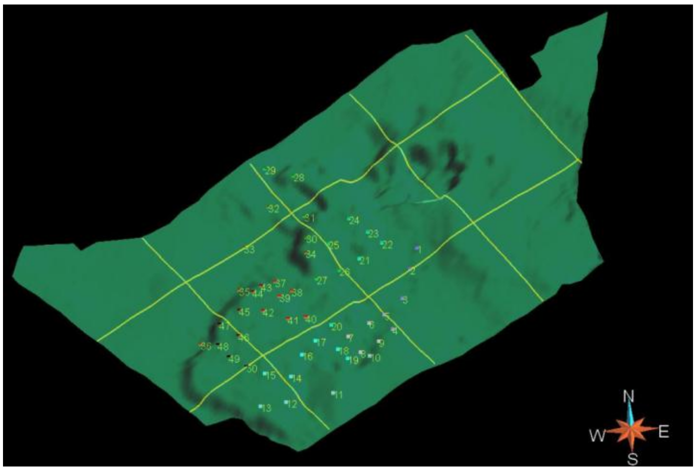

Figure 5.12: The location of the boreholes in the investigated area and the grid used for surveying.

5.3.2 Geo-electrical Measurements

The developed 3D geometrical model is based on the boreholes data and the geo-electrical profiles. To differentiate between the various categories of wastes with regard to the calculated resistivity, a statistical calculation has been made to understand the distribution of the resistivity in the waste body along the long profile (Figure 5.13). This was achieved through the correlation between the ranges of the measured resistivity and the actual data of boreholes existed along the long profile.

Table 5.2 shows the percentage distribution of the categories and their related resistivity. In some cases native soil could show the same resistivity as the construction waste, but because of the position with regard to the whole model it is considered as native soil. Also soil contaminated with leachate may show low resistivity and can be considered as domestic waste or transition zone.

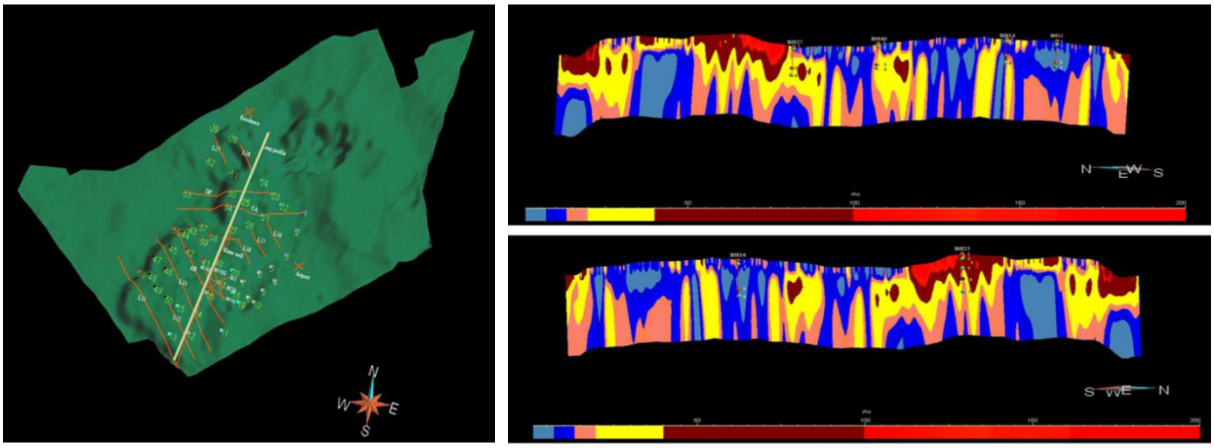

Figure (5.13): Boreholes along the long profile and the geo-electrical long profile with boreholes; views from both sides.

Table 5.2 also shows the statistical distribution of the waste category and the area as calculated from the 3D model also along the long profile. In geo-electrical measurements, the resistivity class of 0-12 Ωm (organic waste and contaminated soil) is 12 times bigger than the class of the construction waste. In the GOCAD 3D model, the map area of the organic waste and contaminated soil is also 12 times larger than the area of construction waste.

Table (5.2): Statistical distribution of the waste category and the area from the GOCAD 3D model along the long profile.

Number	Resistivity		Geo-electrical measurements	
	min	max	Category	Percentage
1031	0	8	Organic Waste	15,75%
1330	8	12	Transition Zone	20,34%
1803	12	20	Groundwater	27,57%
1417	20	40	Clayed Sand	21,67%
765	40	100	Sand	11,70%
194	100	420,78	Construction Waste	2,97%

GOCAD 3D Model	
Category	Map area (m^2)
Cover layer	5350
Construction waste	1925
Organic waste and contaminated soil	23082
Native soil	Bottom of native soil body was artificially set

Table 5.3 shows the derived classification of calculated resistivity for various types of materials found in JLF site.

Table (5.3): Classification of the resistivity of different materials as used in the model.

0 - 8 Ωm	Organic waste
8 - 12 Ωm	Transitional zone domestic waste/native soil, mostly contaminated soil depending on the location of the waste
12 - 20 Ωm	Groundwater up to a depth of ca.15 m
20 - 40 Ωm	Sand, clayey
40 - 100 Ωm	Sand
>100 Ωm	Construction waste

Figure 5.14 shows the long profile after processing using the classified resistivity.

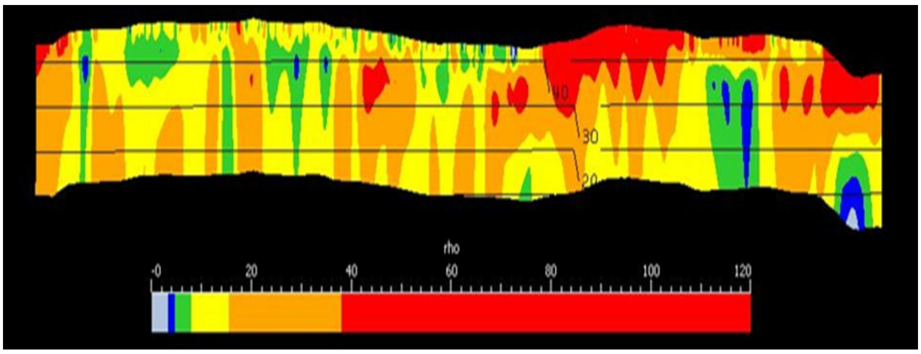

Figure (5.14): Long profile as processed considering the classified resistivity.

The same methodology was applied to the 30 measured profiles which were then processed using the GoCad 3D model as shown in Figure 5.15.

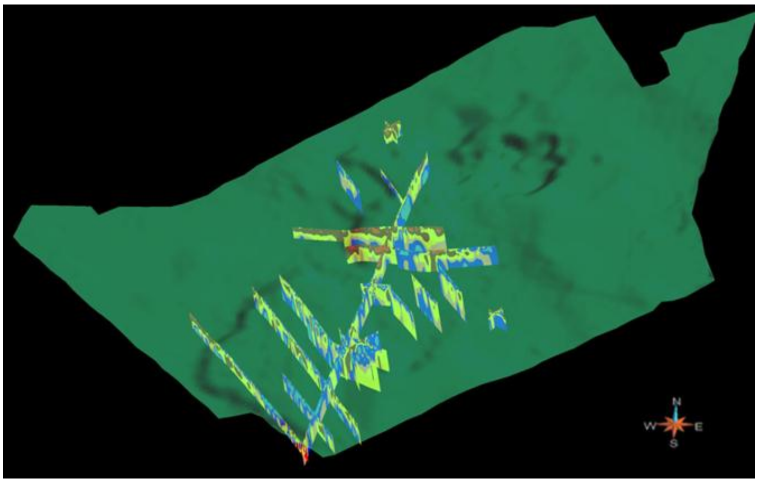

Figure (5.15): All geo-electrical profiles integrated into the 3D model.

The calculated spatial distribution of the modeled electrical resistivity has been correlated with the results obtained from the drilled boreholes and then displayed by the 3D program GoCad. Due to the large area under investigation and the required detailed grid (25mx25m), It was essential to start the assessment of JLF by developing the 3D model of the waste body using the indirect method (geo-electrical measurements) and to compare it with actual data from boreholes logs.

The indirect geo-electrical measurements enabled us in developing a clear picture of the large JLF site in a relatively short period of time which leads to a better understanding and design of the subsequent filed measurements and the proper interpretation of data (i.e., LFG, ground water, etc...).

5.3.3 Waste Type and Geometry

Borehole logs and geotechnical investigations have revealed that the deposited wastes consist mainly of domestic waste and marginally of construction waste. These two types have different resistivity with regard to the geoelectric profiles and thus can be well differentiated. In addition to the classification of the waste by borehole logging, the geo-electrical profiles have been used to complete the classification of the waste and visualize the waste body by 3D images. The resistivity of domestic waste ranges between 0 and 8 Ωm with a transitional zone which could rise to 12 Ωm. On the contrary, the resistivity of the construction waste amounts to more than 100Ωm. During the drilling process the waste was found to be dry in most of the landfill body with no signs of water or water content.

The GOCAD model has shown the waste body three dimensionally (Figure 5.16). Since it is not possible to differentiate between the resistivity of the contaminated soil underneath the waste and the waste resistivity, the contaminated soil is considered to belong to the waste. However, the differentiation between both types was easy to follow in the borehole logs. The model considers both, the borehole logs and the geo-electrical profile, so it is assumed that the waste body contains little contaminated soil. For practical purposes an image of isolines for the thickness of the waste has been developed (Figure 5.17).

Figure 5.17 shows that the thickness of the domestic waste does not exceed 10m in the vast bulk of the area. However, in a small part of the area the thickness reaches 20m. Looking at the construction waste (red body in Figure 5.16) it become obvious that the amount compared to the domestic waste is very small. Figure 5.18 shows the isolines for the thickness of the construction waste which does not exceed 5m in general.

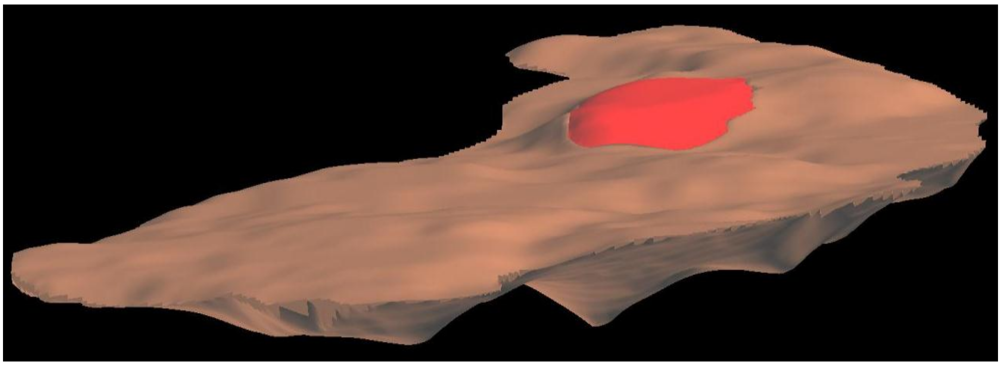

Figure 5.16: 3D body of the waste in JLF (red: construction waste, brown: domestic waste).

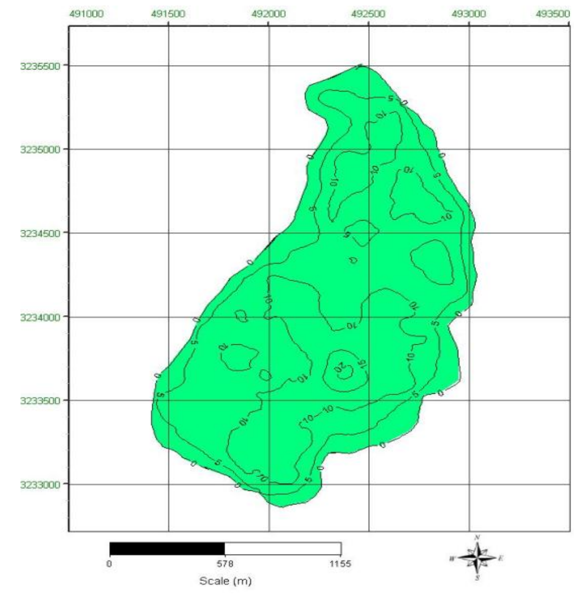

Figure (5.17): Isolines of the thickness of the domestic waste in JLF site.

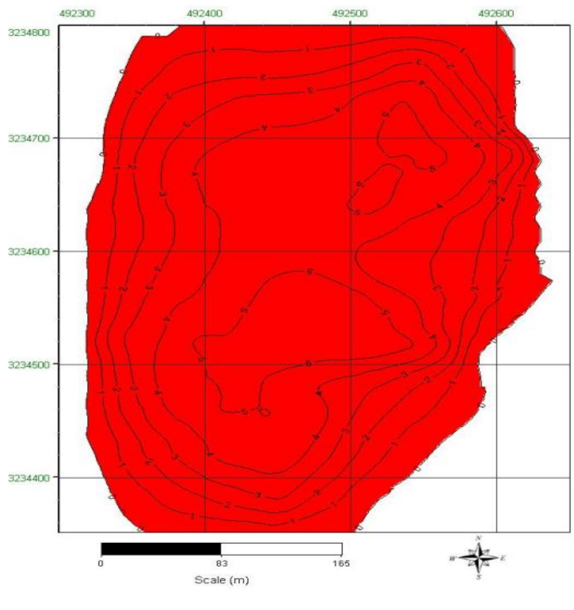

Figure (5.18): Isolines of the thickness of the construction waste in JLF site.

5.3.4 Cover Layer

The cover layer has been reconstructed using the geo-electrical profiles. Figure 5.19 shows the modeled thickness of the cover layer using the boreholes and the geo-electrical profiles. As it can be seen from Figure 5.29, the thickness is not uniform and can vary from 0.5m to more than 4m in a small part of the layer. Figure 5.20 shows the isolines of the thickness of the cover layer.

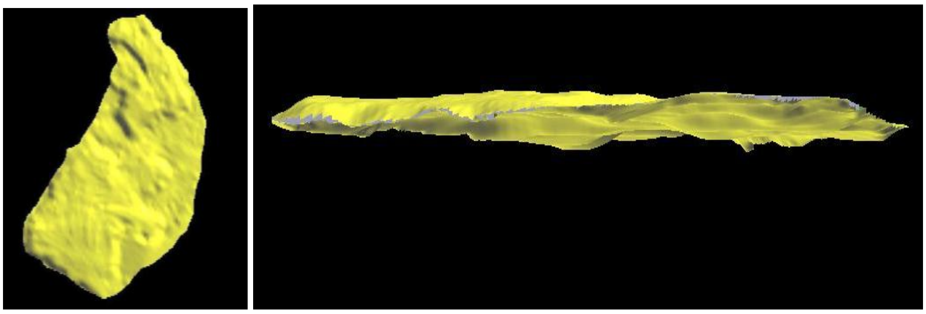

Figure (5.19): The cover layer of JLF site as modeled by GOCAD.

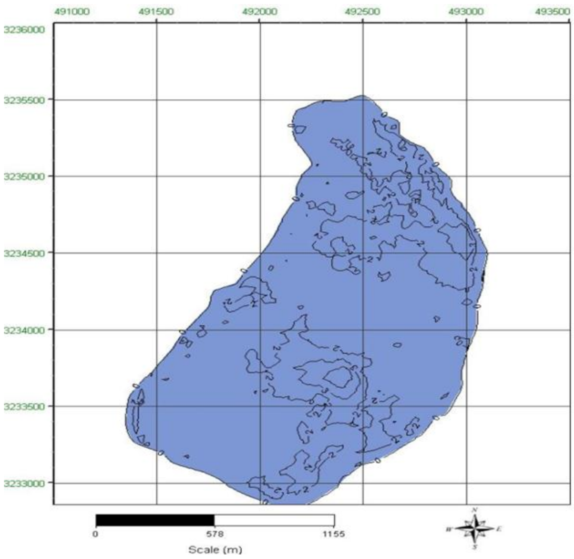

Figure (5.20): Isolines of the thickness of the cover layer in JLF site.

5.3.4.1 Grain Size Test:

A total of 120 soil samples were collected from 30 locations (4 samples each) in the landfill site. Samples were collected at depths of 25, 50, 75 and 100 cm and size analyses were carried out in accordance with the American Standard Test Method for Particle-Size Analysis of Soil (ASTM D422, 63, 2007). Table 5.4 Summarizes the results of the size analyses in locations 1 and 2 on landfill cover (Analytical results for locations 1-30 are summarized in Appendix 4).

Table (5.4): Examples of results of the size analyses in locations 1 and 2 on landfill cover.

	Date	Depth	Sand %						T.Mud	TOTAL %	Median		Mean		Sorting		Sed.Type
			Gr.	V.C.S	C.S	M.S	F.S	V.F.S			ϕ	mm	ϕ	mm	ϕ	mm	
1	4/010	0.25	3.65	12	9.6	15.6	27.45	28.1	3.67	99.98	1.84	0.28	1.45	0.366	1.54	0.344	(g)s
	4/010	0.5	1.76	12.3	7.57	13	33.04	29.6	2.73	100.00	1.98	0.25	1.56	0.3392	1.43	0.371	(g)s
	4/010	0.75	2.27	14	7.03	11.7	33.07	29.9	2.05	100.00	1.96	0.26	1.44	0.3686	1.5	0.354	(g)s
	4/010	1	0.63	12.8	7.87	12.8	34.45	29.8	1.67	99.98	1.97	0.26	1.57	0.3386	1.35	0.392	(g)s
2	4/010	0.25	6.52	12.62	10.90	18.65	21.47	26.06	3.51	99.73	1.6	0.342	1.3	0.420	1.660	0.316	(g)s
	4/010	0.5	5.82	15.60	11.78	18.17	22.31	22.47	3.35	99.50	1.4	0.371	1.2	0.448	1.640	0.321	(g)s
	4/010	0.75	3.35	10.52	9.25	16.56	28.84	27.89	2.77	99.18	1.9	0.276	1.5	0.351	1.460	0.364	(g)s
	4/010	1	2.71	12.62	9.58	15.48	29.86	27.03	2.61	99.89	1.8	0.281	1.4	0.369	1.480	0.359	(g)s

The table above clearly shows that the soil contains components covering gravel, very course sand, course sand, medium sand, fine sand and very fine sand. Also there is presence of silt and clay in a very little fraction (mostly less than 5%). The results can be compared with infiltration tests. Since the percentage of composition of silt and clay is very small, the landfill cover has a relatively high permeability to allow the infiltration of water during rainfall in this area.

5.3.4.2 Penetration Test

To evaluate the relative density of the cover layer, penetration tests have been performed in the area according to method described by The American Society for Testing and Materials (ASTM D1586 - 08a, 1984). The penetration test gives the pressure requested to penetrate a cone of 1 square cm c/s area with a pointed tip with 60º angle. The penetration test indirectly gives the strength of soil or the degree of compaction. The pressure required for 1 cm penetration increases with depth, which is expected due to increase in compaction of soil with depth. At certain locations, during penetration, there is sudden drop in pressure, which indicates local cavity. In some other locations, the penetrometer is not able to penetrate even with very high pressure indicating the presence of hard materials.

5.3.4.3 Infiltration Tests

In order to evaluate the cover layer characteristics, infiltration tests were carried out at different locations as shown in Figure 5.21 (white crosses).

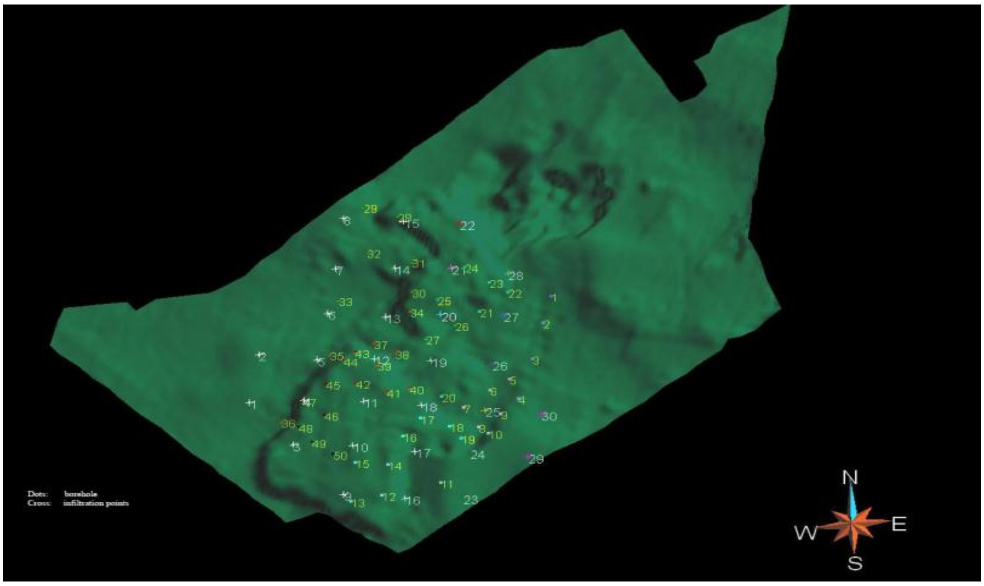

Figure (5.21): Location of the infiltration points (white crosses).

The infiltration test results for locations 1 to 10, 11 to 20 and 21 to 30 at the landfill site are presented in Figures 5.22, 5.23 and 5.24, respectively. It is evident from Figure 5.22 that in 4 locations (i.e., JM01, JM07, JM08 and JM09), about 16 cm of water infiltrate completely within 30 minutes. In Figure 5.23 it is 8 locations and in Figure 5.24 it is 7 locations. This clearly means that the run off during the sparse rain in Kuwait must be very small and most of the precipitating water enters into the landfill. It would appear that the elevation difference between the landfill and the surrounding area is also very small for accelerating the runoff. Hence, the landfill must be soaked to some extent during Nov-Jan every year.

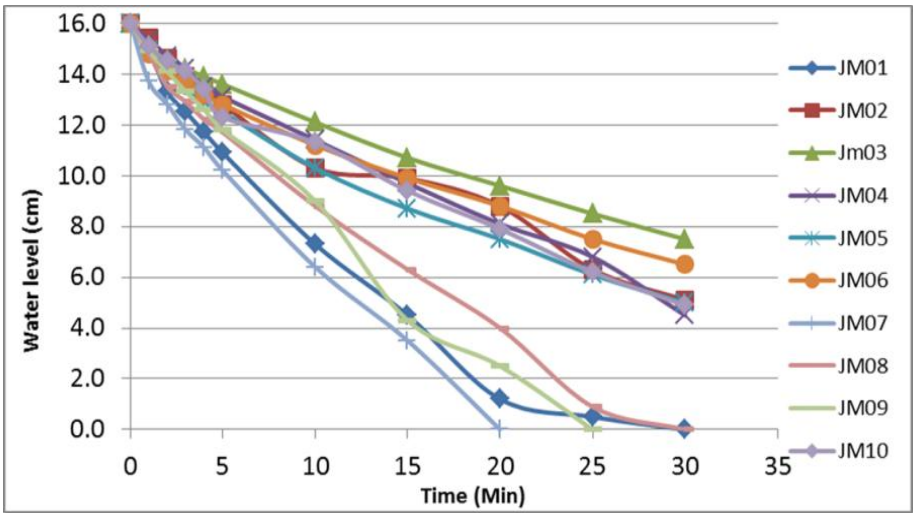

Figure (5.22): Infiltration rate with time for locations 1 to 10 on the landfill cover.

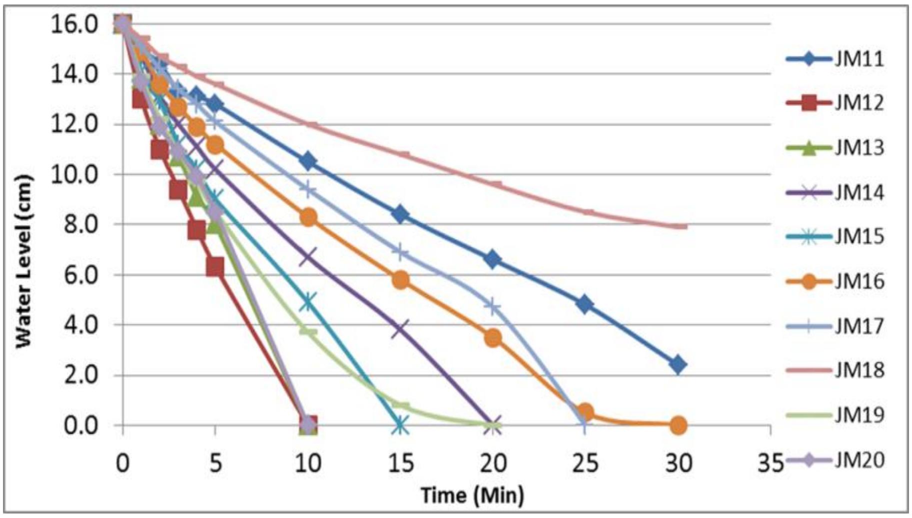

Figure (5.23): Infiltration rate with time for locations 11 to 20 on the landfill cover.

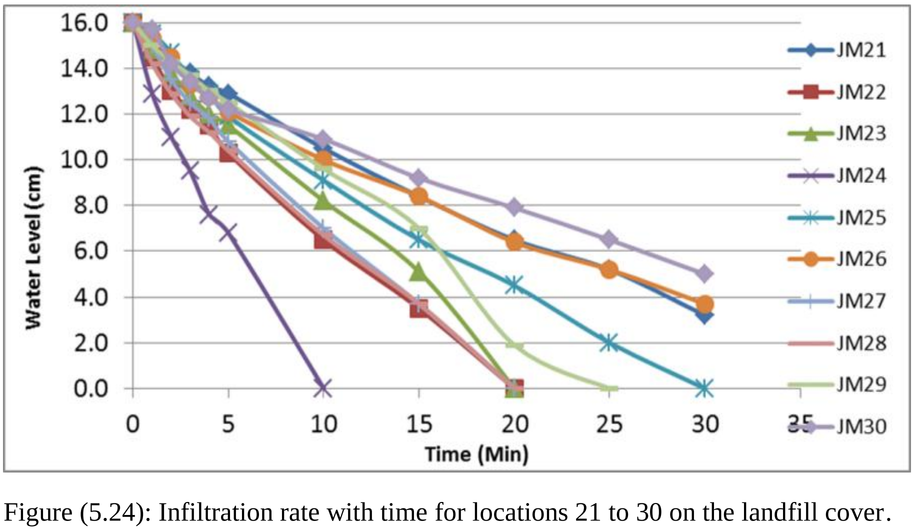

Figure (5.24): Infiltration rate with time for locations 21 to 30 on the landfill cover.

5.3.5 Landfill Gases

In order to characterize LFG emissions from all 50 boreholes in the total area of Jleeb Al-Sheyoukh waste disposal area, monthly gas measurements have been performed between March 2008 and December 2010. The concentrations of principal landfill gases such as; methane, carbon dioxide, oxygen, hydrogen sulfide and ammonia were measured on regular basis throughout the entire duration of the experiments (see Appendix 5). Also, attempts were made to characterize the emissions of volatile organic compounds (VOCs) from selected boreholes in the total area of JLF and the project area.

The data processing has been performed to assess the decay stage of the landfill and to evaluate the time scale in which the decay process influences the gas production. These results should be used to compare and evaluate the investigation results obtained from the aerobic *in-situ* stabilization experiment carried out in the project area with regard to the improvement of the gas production due to the air injection measures.

Out of the investigated 50 boreholes, only 32 boreholes showed the presence of methane gas in substantial amounts. Therefore, the data processing and the visualization of the results consider only the 32 boreholes. Figure 5.25 shows the results of the statistical analysis of the methane gas measurements conducted in the total area of JLF (presented as the monthly average of all 32 boreholes for the period of 33 months).

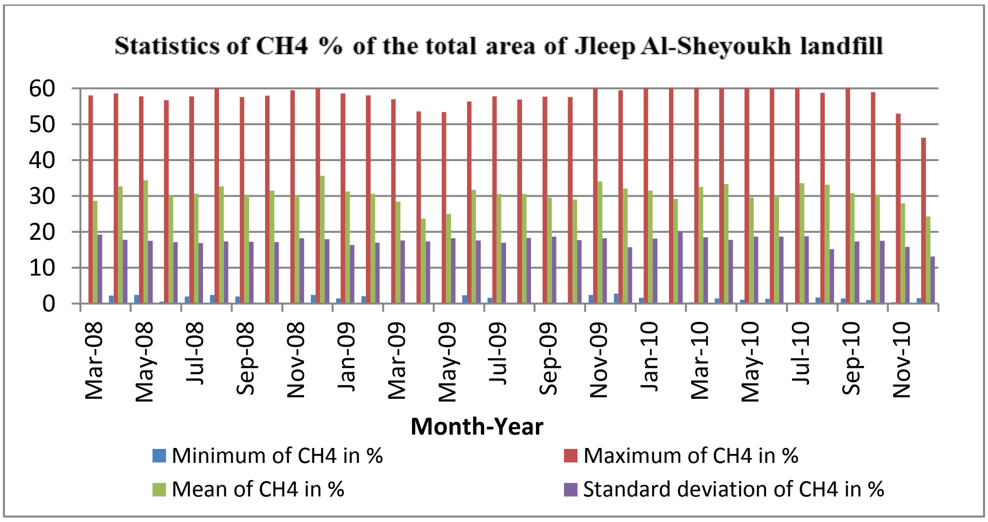

Figure (5.25): Average concentration of methane gas (average of 32 boreholes).

The maximum and the minimum values for methane gas show a very small fluctuation during the period of 33 months. Also, the mean value of the methane gas content for the whole area are almost constant over the 33 months as indicated by a standard deviation of less than 10%.

With an average value of 30.5% ±2.6%, the activity of the methane production does not indicate a stable methane phase. To verify this statement the average ratios of the methane and carbon dioxide contents have been calculated over the 33 months. Figure 5.26 shows the distribution of the ratios over 33 months.

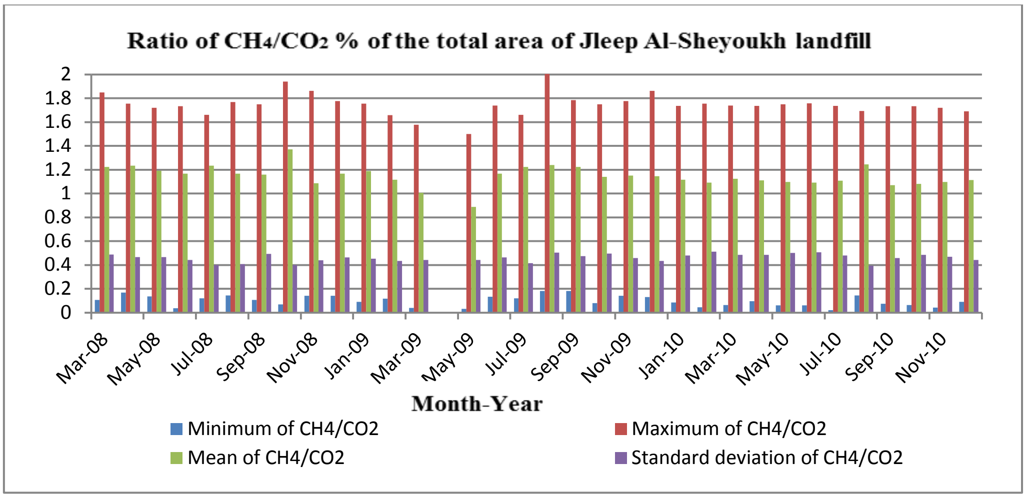

Figure (5.26): Average ratios of methane and carbon dioxide from the 32 boreholes.

The ratios are almost constant and deviate very little from 1.15 at a standard deviation of less than 10%. The statistical values are summarized in Table 5.5.

Table (5.5): Statistical values of CH_4 and O_2 content and the ratios of CH_4/CO_2.

	Statistics of CH_4	Standard deviation
Mean of Maximum values	58.2	3.20
Mean of mean values	30.59	2.65
Mean of Minimum values	1.15	0.94
	Statistics of Ratio CH4/CO2	Standard deviation
Mean of Maximum values	1.74	0.09
Mean of mean values	1.14	0.08
Mean of Minimum values	0.09	0.04
	Statistics 0f O_2	Standard deviation
Mean of Maximum values	13.98	5.05
Mean of mean values	2.92	1.43
Mean of Minimum values	0.41	0.54

By looking at the ratio of methane and carbon dioxide as well as the very small oxygen content, the landfill gas production phase can be evaluated. Figure 5.27 illustrates the different gas production phases in a waste disposal site during its lifetime.

By comparing the statistical values of the methane, carbon dioxide and oxygen, it is obvious that Jleeb Al-Sheyoukh Landfill stands at the end of the “air infiltration phase”, since the average content of methane is about 30% and the average content of carbon dioxide is about 26%, while the oxygen is neglected.

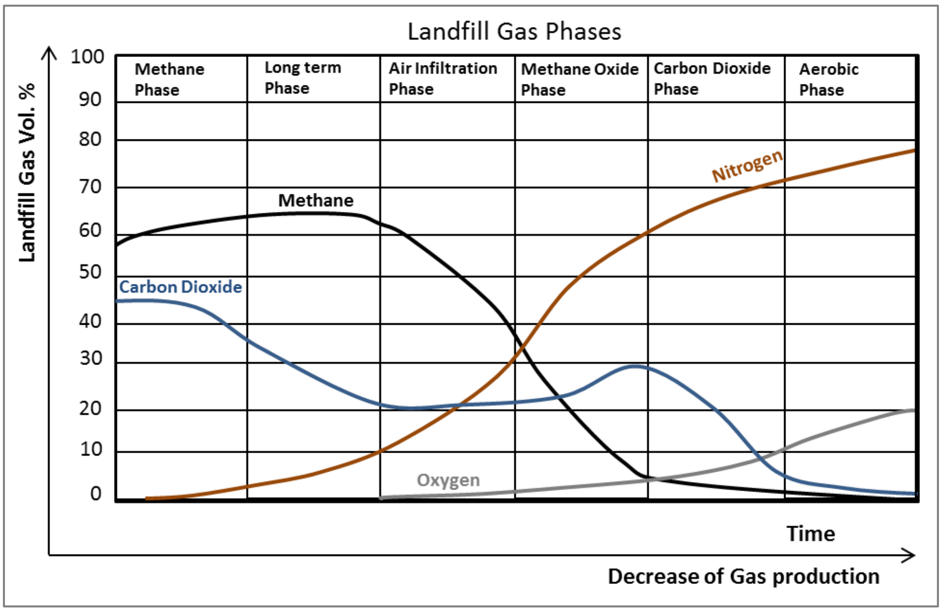

Figure (5.27): Landfill gas phases due to decay process (After Rettenberger, 2001).

If the ratio of methane/carbon dioxide becomes 1.0 or less, this indicates that the methane oxide phase has started. However, the values in this study indicate that the landfill Jleeb Al-Sheyoukh is still in the so-called “Air Infiltration Phase". Yet, the possibility that more humidity in the waste body might become a reason to change the landfill gas phase, in the long run, should not be ruled out.

Long-term gas monitoring over almost 3 years has been carried out to investigate the decay behavior in the landfill without any technical measures. The results are summarized in Figure 5.28 as isolines of methane gas distribution over the whole area at the beginning and at the end of the monitoring campaign.

The isolines show that the domestic waste is deposited in two separate pits and the distribution pattern in all images is constant over the 3 years. During this period of time no noticeable change in the methane gas production has been detected. This indicates that the decay process is almost stable and hence the life time of the landfill might be extended.

Only borehole 18 in which air injection tests have been carried out shows a change in the methane gas concentration. However, this data processing is important when it comes to evaluate the success of the injection measures in the project area.

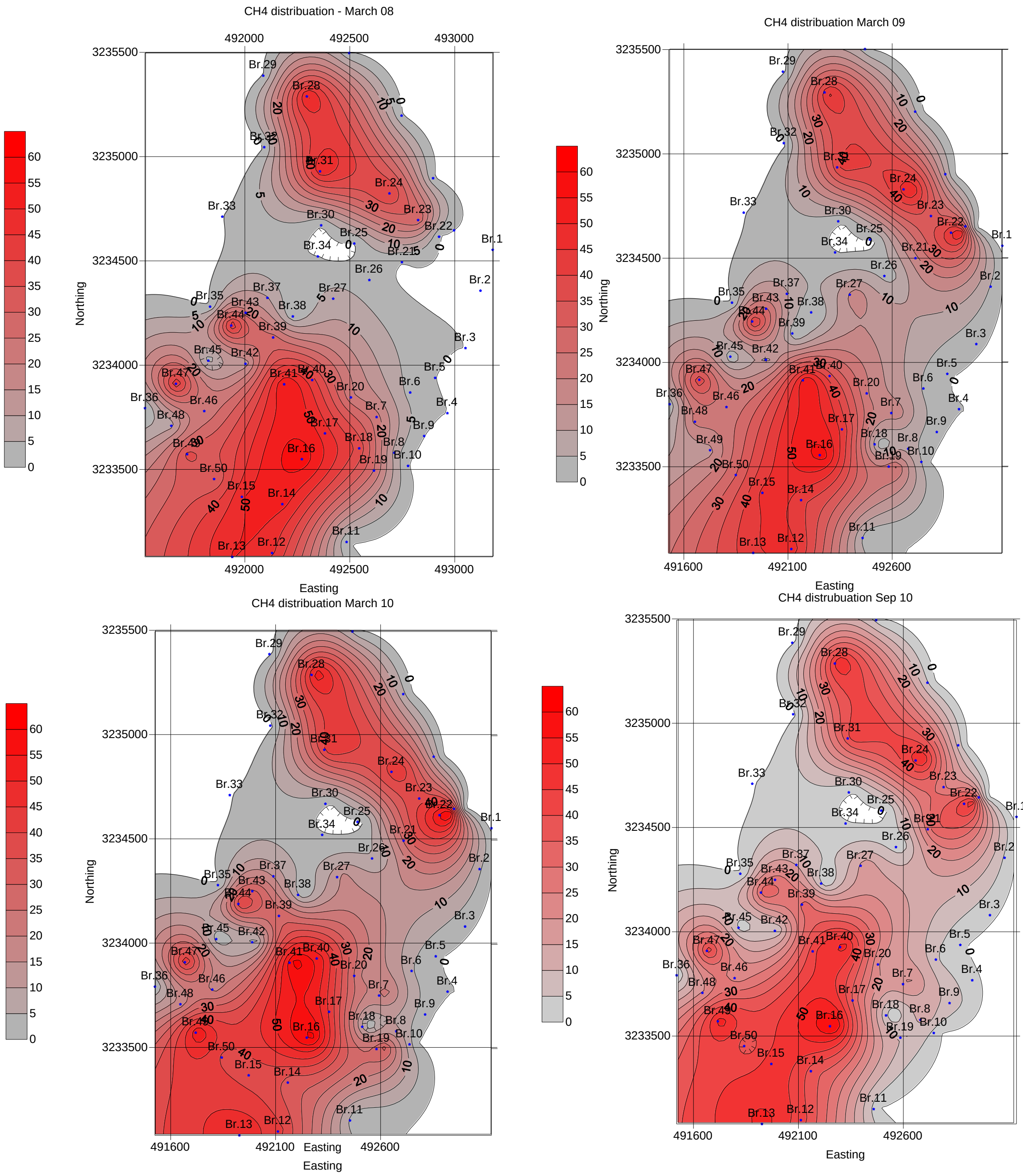

Figure (5.28): Methane gas distribution from March 2008 till September 2010.

Another important aspect is the comparison between the thickness of the waste in the 3D model and the methane gas distribution in the boreholes. Figure 5.29 shows the distribution of the waste thickness in the landfill.

It is evident from this figure that the waste thickness of 10m and more is concentrated in 2 areas in the northern and southern part separated from each other by a shallow division area in which no or very little waste has been deposited. The distribution of the methane gas in Figure 5.28 verifies this fact by showing the two areas with a maximum gas production. Thus, the gas concentration in the boreholes corresponds in general with the thickness of the domestic waste.

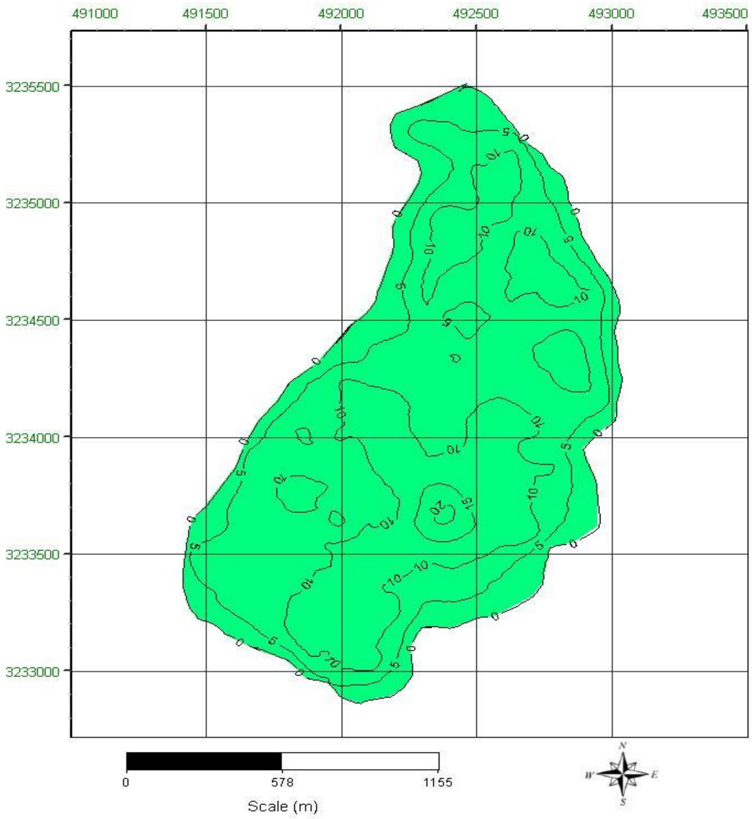

Figure (5.29): Distribution of the waste thickness in the landfill.

5.3.6 Settlement

A series of field measurements were conducted to study the long-term land settlement in JLF as waste decomposition in landfills is usually associated with land subsidence (i.e., settlement). The JLF site has been monitored for land settlement through a grid of 30 observation points. All points were fixed in a grid of 250m×250m covering the expected filling areas and part of the areas surrounding the landfill. Settlement measurements were performed during the period June 2008 – January 2011. The purpose of present study therefore is to analyze, if there is any measurable settlement within and around JLF, and whether the measured settlement in the expected filling areas is different from the immediate surrounding areas that are apparently devoid of filling.

Table 5.6 below shows the measured changes in height along the 30 observation points (JM01 – JM30). Figure 5.30 illustrates that the majority of points (about 83%) show less than 10 cm settlement within a period of about 2.5 years. Figure 5.30 also showed an overall average settlement across the whole JLF site of about 7 cm – approximately 2.8 cm per year with a maximum settlement of 21.22 cm at one location (JM15) and 1.2cm as the lowest measured settlement at another point (JM06).

Table (5.6): Measured changes in height along the 30 settlement observation points (JM01 – JM30).

Depth (in M)									
ID	Jun-08	Mar-09	Jan-12	Difference	ID	Jun-08	Mar-09	Jan-12	Difference
JM 01	41.00	40.99	40.96	-0.043	JM 16	45.39	45.38	45.30	-0.087
JM 02	41.31	41.31	41.16	-0.149	JM 17	46.67	46.67	46.60	-0.068
JM 03	47.01	47.01	46.96	-0.045	JM 18	47.32	47.32	47.23	-0.092
JM 04	46.27	46.26	46.13	-0.140	JM 19	43.75	43.75	43.71	-0.045
JM 05	41.21	41.20	41.17	-0.042	JM 20	45.39	45.39	45.37	-0.017
JM 06	38.53	38.52	38.52	-0.012	JM 21	46.39	46.39	46.28	-0.109
JM 07	39.85	39.85	39.79	-0.065	JM 22	44.95	44.95	44.92	-0.031
JM 08	43.90	43.89	43.84	-0.056	JM 23	48.79	48.79	48.74	-0.049
JM 09	48.31	48.31	48.15	-0.160	JM 24	49.05	49.04	48.96	-0.088
JM 10	50.31	50.31	50.31	0.000	JM 25	43.26	43.26	43.21	-0.047
JM 11	47.02	47.02	46.94	-0.076	JM 26	43.34	43.33	43.27	-0.067
JM 12	44.36	44.36	44.32	-0.036	JM 27	42.84	42.84	42.76	-0.076
JM 13	40.03	40.02	39.96	-0.066	JM 28	43.72	43.72	43.64	-0.076
JM 14	41.48	41.48	41.40	-0.084	JM 29	49.67	49.66	49.64	-0.033
JM 15	43.65	43.65	43.44	-0.212	JM 30	44.98	44.97	44.93	-0.052

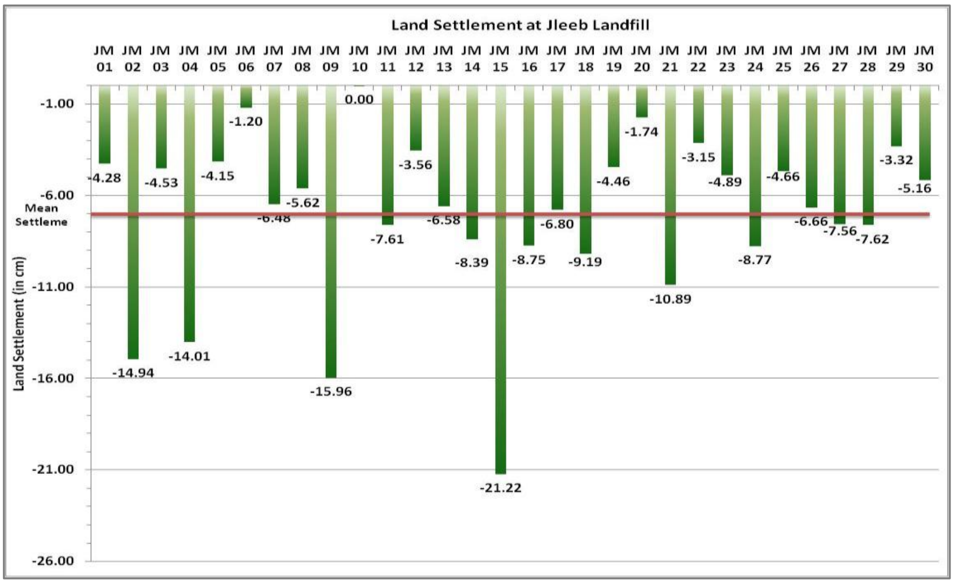

Figure 5.30: Measured settlement rates in JLF site along the 30 settlement observation points (JM01-JM30).

Figure (5.31) presents the isoline distribution of measured settlement in JLF where most of the high measured settlement rates were observed in the northern and southern parts of the landfill.

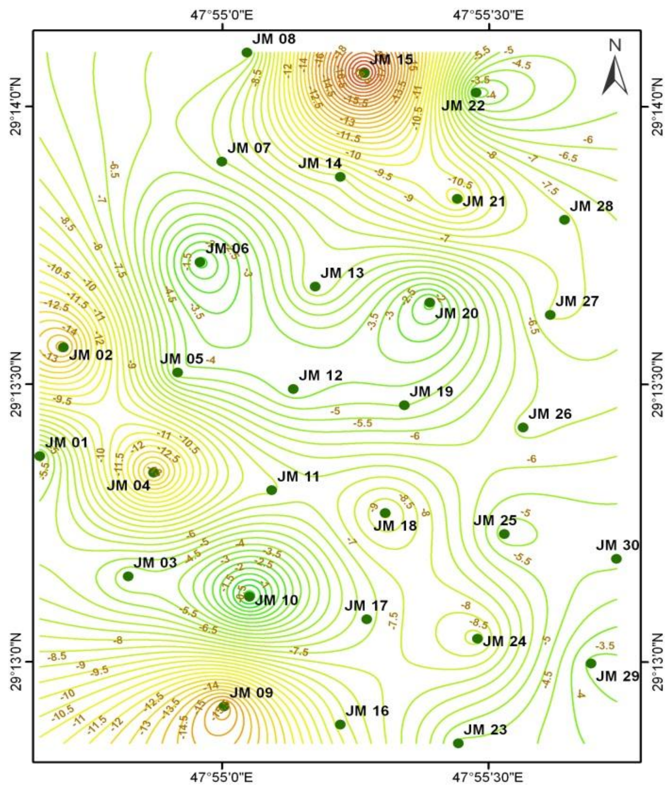

Figure (5.31): Isolines distribution of settlement points across JLF site.

5.3.7 Leachate

In order to investigate the physical and chemical characteristics of landfill leachate, various parameters including heavy metals were measured in landfill leachate. Table 5.7 presents the analytical results of physico-chemical characteristics of landfill leachate. The reported data represent the mean values of measured parameters in two samples collected from monitoring wells (boreholes 15 and 17) at JLF site.

Table (5.7): Physico-chemical characteristics and heavy metal concentration of JLF leachate.

Physico-chemical characteristics			**Heavy metals**		
Temperature	°C	20.7	As	mg/l	0.01
PH	unit	8	Ca	mg/l	6.75
Conductivity	mS/cm	3.03	Cd	mg/l	0.01
B.O.D	mg/l	40	Cr	mg/l	0.01
C.O.D	mg/l	789	Co	mg/l	0,01
Turbidity	FTU	345	Fe	mg/l	0.375
Total suspended solids	mg/l	316	Hg	mg/l	0.369
Nitrate	mg/l	77.5	Mg	mg/l	3.105
Nitrogen (NH3)	mg/l	9. 02	Mn	mg/l	0.16
Phosphorus, Reactive	mg/l	1.9	Mo	mg/l	0.01
Potassium (K)	mg/l	465	Ni	mg/l	0.025
Sulfate (So4+)	mg/l	165	Pb	mg/l	0.05
Sulfide	mg/l	0.241	Se	mg/l	0.01
Bromine	mg/l	1.47	Sn	mg/l	0.01
Chlorine total	mg/l	0.685	V	mg/l	0.01
Chloride (Cl)	mg/l	2.375	Zn	mg/l	0.02

Based on these analyzed parameters, a conclusion about the age and the degradation phase of JLF site can be drawn. In Table 5.8 the ranges of leachate concentrations depending on the degradation phase for some relevant parameters are presented after Kurse (1994).

Kruse investigated 33 landfills in Northern Germany, the leachate concentrations mainly derive from the late eighties and early nineties. He defined three characteristic periods according to the BOD_5/COD-ratio:

- Acid phase: $BOD_5/COD \geq 0.4$
- Transient phase: $0.4 > BOD_5/COD > 0.2$
- Methanogenic phase: $BOD_5/COD \leq 0.2$ (Stegmann, 2005).

According to this evaluation, the relatively low measured values BOD_5: COD ratio in Jleeb Al-Sheyoukh landfill leachate (BOD_5/COD-ratio = 0.05) indicates that the landfill is in the methanogenic phase. Furthermore, pH, sulfate chloride levels as well as measured values of heavy metals all are within the presented range of methanogenic phase as shown in Table 5.8.

Table (5.8): Constituents in leachates from MSW landfills (after Kruse, 1994).

Parameters	Unit	Acid phase Range	Acid phase Medium	Intermediate phase Range	Intermediate phase Medium	Methanoginic phase Range	Methanoginic phase Medium
pH- valuse	_	6.2 - 7.8	7.4	6.7 - 8.3	7.5	7.0 - 8.3	7.6
COD	mg/l	950 - 40,000	9,500	700 - 28,000	3,400	460 -8,300	2,500
BOD_5	mg/l	600 - 27,000	6,300	200 - 10,000	1,200	20 - 700	230
TOC	mg/l	350 - 12,000	2,600	300 - 1,500	880	150 - 1,600	660
AOX	mg/l	260 - 6,200	2,400	260 - 3,900	1,545	195 - 3,500	1,725
org. N	mg/l						
NH4-N	mg/l	17 - 1,650	740	17 - 1650	740	17 - 1650	740
TKN	mg/l	250 - 2,000	920	250 -2,000	920	250 -2,000	920
NO_2-N	mg/l						
NO_3-N	mg/l						
SO4	mg/l	35 - 925	200	20 - 230	90	25 - 2,500	240
Cl	mg/l	315 - 12,400	1,150	315 - 12,400	1,150	315 - 12,400	2,150
NA	mg/l	1 - 6,800	1,150	1 - 6,800	1,150	1 - 6,800	1,150
K	mg/l	170 - 1,750	880	170 - 1,750	880	170 - 1,750	880
Mg	mg/l	30 - 600	285	90 - 350	200	25 - 300	150
Ca	mg/l	80 - 2,300	650	40 - 310	150	50 - 1100	200
tot. P	mg/l	0,3 - 54	6,8	0,3 - 54	6,8	0,3 - 54	6,8
Cr	mg/l	0,002 -0,52	0,155	0,002 -0,52	0,155	0,002 -0,52	0,155
Fe	mg/l	3 - 500	135	2 - 120	36	4 - 125	25
Ni	mg/l	0,01- 1	0,19	0,01- 1	0,19	0,01- 1	0,19
Cu	mg/l	0,005 - 0,56	0,09	0,005 - 0,56	0,09	0,005 - 0,56	0,09
Zn	mg/l	0,05 - 16	2,2	0,06 - 1,7	0,6	0,09 - 3,5	0,6
As	mg/l	0,0053 - 0,11	0,0255	0,0053 - 0,11	0,0255	0,0053 - 0,11	0,0255
Cd	mg/l	0,0007 - 0,525	0,0375	0,0007 - 0,525	0,0375	0,0007 - 0,525	0,0375
Hg	mg/l	0,000002 - 0,025	0,0015	0,000002 - 0,025	0,0015	0,000002 - 0,025	0,0015
Pb	mg/l	0,008 - 0,4	0,16	0,008 - 0,4	0,16	0,008 - 0,4	0,16

Moreover, the experimental results of leachate at JLF were compared with the current German requirements for the leachate quality before discharge (see Table 5.9). Such a comparison would help in the evaluation of pollution levels and potentials as well as to develop recommendations to improve the present situation at this dumping site.

Table (5.9): Limiting concentrations for the discharge of treated leachate according to German standards (51. Anhang Rahmen-AbwasserVwV, Anonymus 1996).

Parameters	limiting concentration mg/l	Parameter	limiting concentration mg/l
COD	200	Chromium 0,5	0,5
BOD5	20	Chromium (VI)	0,1
Nitrogen, Total (NH4 + NO2 + NO3)	70	Nickel	1
Phosphorus, Total	3	Lead	0,5
Hydrocarbons	10	Copper	0,5
Nitrite-nitrogen	2	Zinc	2
AOX	0,5	Cyanide	0,2
Mercury	0,05	Sulfide	1
Cadmium	0.1		

The analysis of samples showed clearly that BOD and COD levels are exceeding the German requirements stipulated tolerance level of 20 mg/L and 200 mg/L for the discharge of treated leachate, respectively. It was found also that almost all concentrations of heavy metals in JLF leachate are below the German standard; except for mercury which is exceeding the German requirements (0.05 mg/L). In addition, sulfide and phosphorus are not exceeding the acceptable level of 1 mg/L, and 3 mg/L, respectively. The physicochemical characterization of the leachate from JLF landfill indicates that COD, BOD and mercury contents in the leachate are above the German standard.

However, it should be borne in mind that 2 leachate samples collected from the southern part of the landfill cannot be used to derive a solid conclusion about the leachate condition in the whole landfill area. Therefore, a continuous monitoring of the formation of leachate in the landfill should be considered. However, due the low leachate formation rate and the relatively low concentrations of contaminants in the leachate, it is expected that groundwater will not be affected, and therefore, measures such as leachate treatment facility is not required at this stage.

5.3.8 Hydrological Conditions

The determination of the water table level in the area of the JLF site has turned to be very difficult, since most of the boreholes were shallower than the water level. Only three points close to each other have defined a water depth, so that a reliable surface could not be constructed. To improve the reliability of construction, the results of the geoelectric measurements have been analyzed and additional three points were calculated and used to construct the water table (Figure 5.32). This water table has been used to construct the isoline of the water level from the surface. Figure 5.33 shows the isolines of the thickness of the unsaturated zone above the groundwater table. Figure 5.34 clearly demonstrates that the groundwater level is deeper than the waste body in most of the landfill, except in a small area (area of borehole 17) where the waste has its maximum thickness where the waste body dips about 4m into the groundwater.

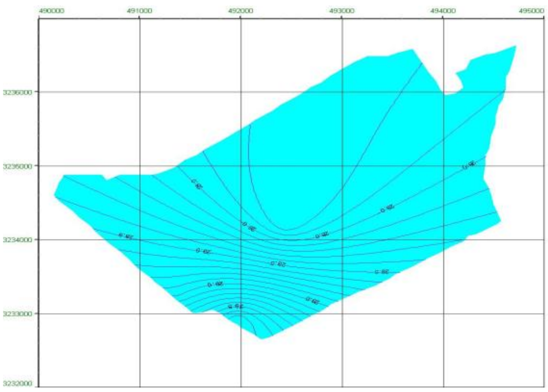

Figure (5.32): Groundwater table over N-NE in the landfill site.

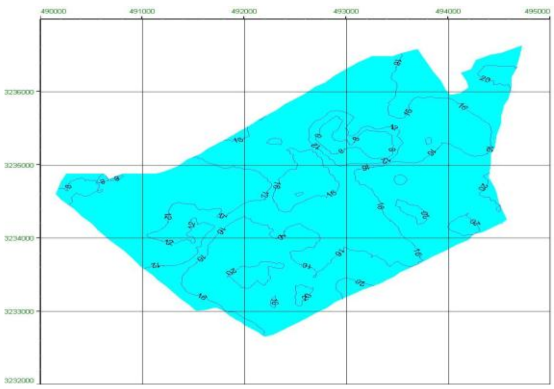

Figure (5.33): Isolines of the thickness of the unsaturated zone.

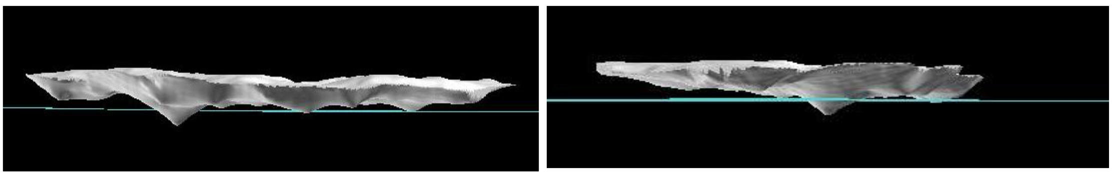

Figure (5.34): The waste body with regard to the groundwater table.

5.3.9 Ground Water Quality

Table 5.10 lists the results obtained from the analysis of samples collected from the three groundwater wells (LF-21, LF-22 and LF-23) as described earlier in section 5.2.2 "Sampling Procedures and Analytical Methods". The samples were analyzed for the major constituents (Anions & Cations), minor constituents, heavy metals, organics, microorganisms and physical elements.

As shown in the table below, there are relatively high concentrations of total dissolved solids (TDS), hardness, sulphate, chloride, sodium and relatively high electrical conductivity (EC). These results indicate the salty nature of the brackish groundwater present in the area. However, it should be noted that the concentration of other parameters (such as heavy metals, BOD, COD, TOC, TPH, BTEX, PAHs and microbiological organisms) are very low or even below the detection limits, which is a good indication that landfill leachate is not seeping to groundwater table. This finding is supported by the fact that very little amount of leachate were found in two boreholes out of the 50. This is also favored by the hydrological conditions and the dry climate of Kuwait with very low rainfall, which maintains very low leachate production.

Similar results were reported for Al-Sulaibiya landfill area where leachate samples were collected over a period of six months and their pollutant contents were measured, including heavy metal (Cd, Ni, Palladium and V), conventional pollutants (BOD, COD and TOC) and nutrients (ammonia and NO2) (Al-Muzaini et.al., 1995). The results obtained from these analyses showed that the concentrations of contaminants were higher in downstream wells than in upstream wells. It was suggested, however, that the leachate would not affect the groundwater quality since the landfill area is distant from water supply wells.

Al-Tahw (2006) carried out a detailed study to assess the vulnerability of GW to pollution stemmed from human activities, including landfills, in the State of Kuwait by using the Geographical Information System (GIS) technology. The groundwater vulnerability to pollution (GWVP) relied on seven variables; namely; hydrogeology (depth to water), net recharge, topography (percent slope), aquifer media, Vadose zone material, soil media and hydraulic conductivity (permeability).The study concluded that the GWVP by almost all landfills is low to very low.

Table (5.10): Analytical results of samples collected from three groundwater wells in JLF site.

Parameter	Unit	LF-21	LF-22	LF-23
pH		7.59	7.40	6.81
EC	µs/cm	8790	13000	6780
TDS	mg/l	6849	9850	6036
Alkalinity	mg/l	85	75	514
Bicarbonate	mg/l	85	75	514
Carbonate	mg/l	<0.1	<0.1	<0.1
Hardness	mg/l	2300	2800	2610
Calcium	mg/l	620	700	640
Magnesium	mg/l	183.4	256.4	185.6
Sodium	mg/l	1430	2210	950
Potassium	mg/l	68	59	147
Chloride	mg/l	1800	3200	820
Nitrate	mg/l	88.9	98.6	51.5
Ammonia	mg/l	<0.1	<0.1	<0.1
Boron	mg/l	3.9	5.2	6.5
Iron	mg/l	0.027	0.022	0.029
Fluoride	mg/l	4.5	4.7	3.4
Phosphate	mg/l	<0.1	0.1	0.5
Sulfide	mg/l	<0.1	<0.1	<0.1
Sulphate	mg/l	2600	2900	2700
COD	mg/l	<1.0	3.2	<1.0
BOD_5	mg/l	<1.0	<1.0	<1.0
Total Coliform	cfu/100	0	0	0
Fecal Coliform	cfu/100	0	0	0
E.coli	cfu/100	0	0	0
Streptococci Fecal	cfu/100	0	0	0
Salmonella	cfu/100	0	0	0
Coliphage Virus	cfu/100	0	0	0
Aluminium	mg/l	<0.05	<0.05	<0.05
Barium	mg/l	<0.05	<0.05	<0.05
Cadmium	mg/l	<0.01	<0.01	<0.01
Copper	mg/l	<0.01	<0.01	<0.01
Chromium	mg/l	<0.01	<0.01	<0.01
Lead	mg/l	<0.01	<0.01	<0.01
Lithium	mg/l	0.29	0.25	0.33
Manganese	mg/l	<0.01	<0.01	1.46
Nickel	mg/l	<0.01	<0.01	<0.01
Vanadium	mg/l	0.03	0.03	0.05
Zinc	mg/l	<0.01	<0.01	0.23
Silicate	mg/l	8.68	9.44	39.2
TOC (Total Organic Carbon)	mg/l	1.188	1.045	3.413
TPH	mg/l	0.221	0.204	0.312
BTEX (Benzene, tulouene and		<BDL	<BDL	<BDL
PAHs (Polycyclic Aromatic		<BDL	<BDL	<BDL

BDL: below detection limit. **BTEX**: detection limit range (0.04-0.1) µg/l. **PAHs**: detection limit range (0.004-0.08) µg/l.

5.3.10 Morphology and Site History

The original morphology of the area is flat with a very small inclination towards the sea. Since the area of JLF site originally served as a quarry for sand, 3 open pits with depth of down to 15m were excavated. Two have been used as dumping sites, and hence were filled with waste and soil material, but one is still open in place. The current surface of the site is modeled in 3D and presented in Figure 5.35 as a result of the topographical survey of the investigated area.

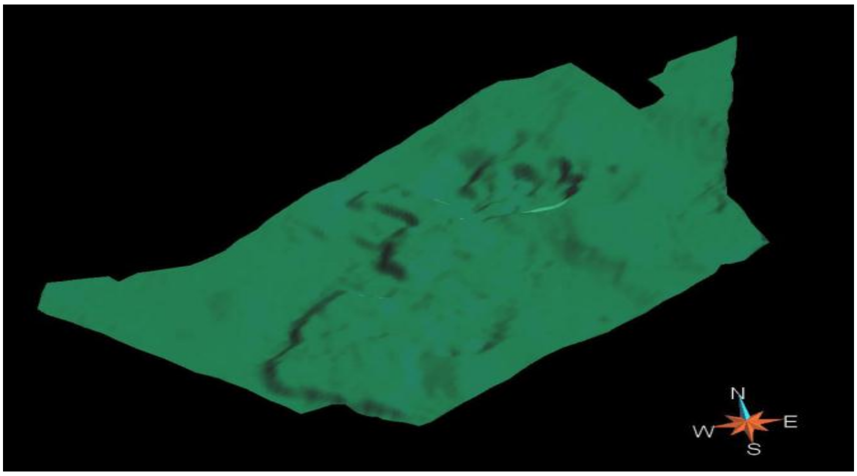

Figure (5.35): The surface topography of the 3D model of the investigated area.

The area in which the waste disposal site is located has been topographically surveyed. The survey has been conducted on the basis of a 25mx25m grid. The data have been used to reconstruct the surface topography in the 3D modeling using GOCAD software. Figure 5.36 shows the investigation area with the applied grid for the survey. The dimensions and elevation of the investigated area 3D model are presented in Figure 5.37.

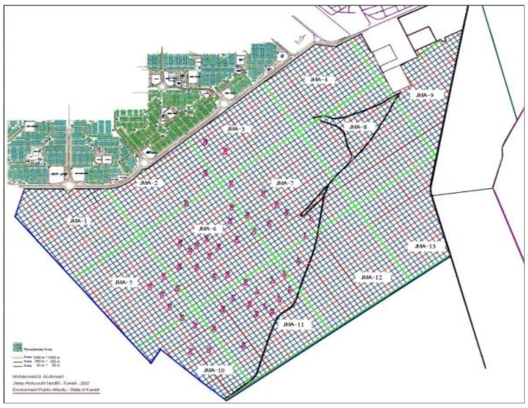

Figure (5.36): Schematic map of the investigated area showing the grid used in the survey.

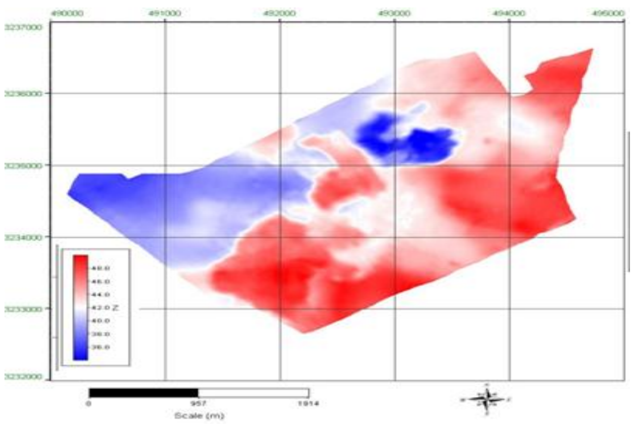

Figure (5.37): Schematic map of the investigated area showing the scale and the elevation of the 3D model.

The geological structure of the subsoil over the landfill area was constructed from drilling data, geo-electrical resistivity profiles and Digital Elevation Model (DEM) data.

The topography of ground surface was modeled from the DEM consisting of a grid of 25m×25m cells. The DEM with –x, -y, -z values were imported from Excel spread sheets into GOCAD as Point set object. A homogenous triangulated surface was then created from these points. The lithological outcrops derived from borehole data provided the lithological framework for the 3D reconstruction of the waste and native soil. Geo-electrical resistivity surveys were incorporated in order to obtain additional subsurface information in areas where drilling data were sparse.

The generation of the 3D model followed a two-step approach. The first step comprised the subdivision of the model into various bodies. In the second step, the surfaces of these bodies were used to form closed volumes to represent each individual body.

Based on outcrop analysis of borehole records, it was possible to group them into a succession of top of cover layer, top of construction waste, top of residence waste and contaminated soil, top of native soil and bottom surface. Then the following four bodies were modeled (from top to bottom) which are: cover layer, construction waste, residence waste and contaminated soil, and native soil. Namely; from the bottom up:

A. Geological body (Native Soil)
B. Waste body (domestic waste and contaminated soil)
C. Construction waste Body (construction waste)
D. Cover layer body (cover layer)

5.3.10.1 Geological Body – Native Soil

The geological body of the native soil is constrained by the boundary of top of native soil and a bottom surface, which is an artificially defined flat surface (Figures 5.38 and 5.39). In the landfill area, the native soil is cropped out (quarrying period) as the bottom of the waste body.

5.3.10.2 Waste Body – Domestic Waste and Contaminated Soil

Covering native soil, the body of domestic waste and contaminated soil is the most prominent feature, which extends over the whole landfill area (land filling period). This waste body is constrained by the boundaries of the top of native soil and the top of domestic waste (Figure 5.40). The area of the top of domestic waste is 2.4×10^6 m^2. It reaches a thickness of 0-22.62 m and thus has an approximate calculated volume of 1.9×10^7 m^3. The thickness of 22.62 m is located at Borehole 17, because the native soil is cropped out very deep in this borehole (19m). The waste body shows a complex internal structure dominated by domestic waste and contaminated soil. The kernel of this body is built up by domestic waste and the surrounding soil is contaminated. Figure 5.41 shows the model results. The brown color is the native soil and the light blue color is the domestic waste and the contaminated soil.

5.3.10.3 Construction waste Body – construction waste

The construction waste body occurs in the northern part of the landfill area. It reaches a thickness of 0-5.9m and thus the volume is about 0.36×10^6 m^3. The area of top of construction waste is 0.12×10^6 m^2 (Figure 5.42). Figure 5.43 shows the modeled native soil (brown color), domestic waste (light blue color) and construction waste (red color).

5.3.10.4 Cover layer Body – Cover layer

Cover layer body caps the whole part of landfill area. The top surface of the cover layer body is modeled by the DEM and constrained by the outline of landfill area. The thickness of this body is up to 4.55m. The area of top of cover layer is 2.7×10^6 m^2. The volume of this cover layer body is 4.5×10^6 m^3. Figures 5.44 and 5.45 show the boundaries of the cover layer, top of native soil and bottom surface and the geological body of the cover as modeled by GOCAD, respectively.

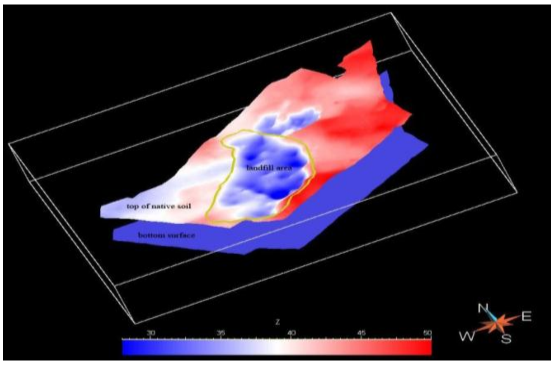

Figure (5.38): Top and bottom surface of the geological body. The yellow curve is the outline of the landfill area.

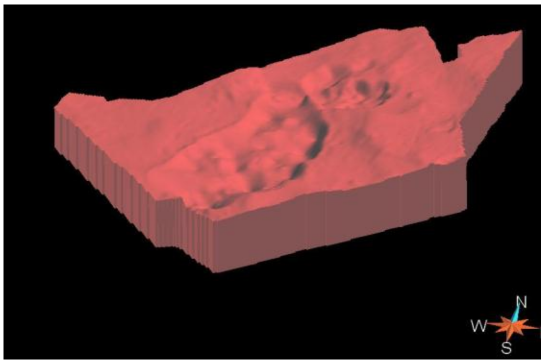

Figure (5.39): Geological body of native soil (brown color), the thickness of this body is artificially set.

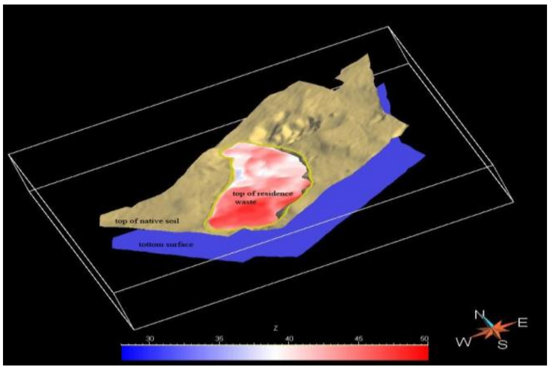

Figure (5.40): Boundaries of top of residence waste, top of native soil and bottom surface. Top of residence waste is painted by the elevation data.

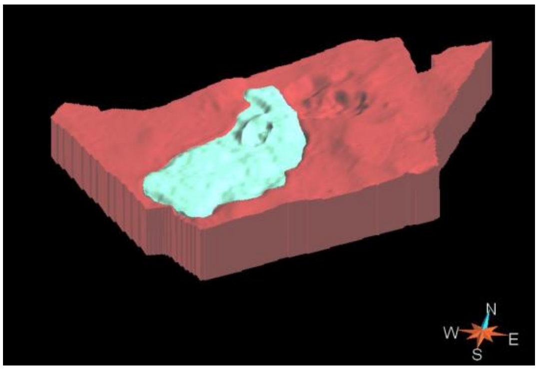

Figure (5.41): Geological body of native soil (brown color) and waste body of domestic waste and contaminated soil (light blue color).

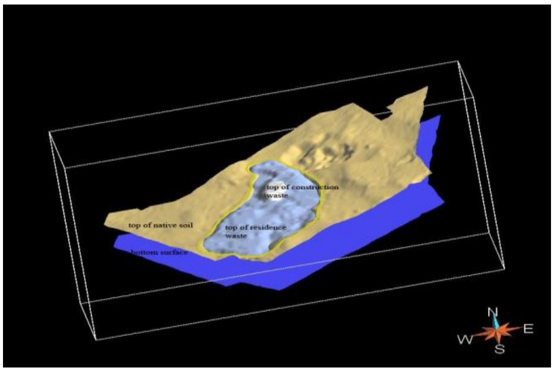

Figure (5.42): Boundaries of top of construction waste (white color), top of domestic waste, top of native soil and bottom surface.

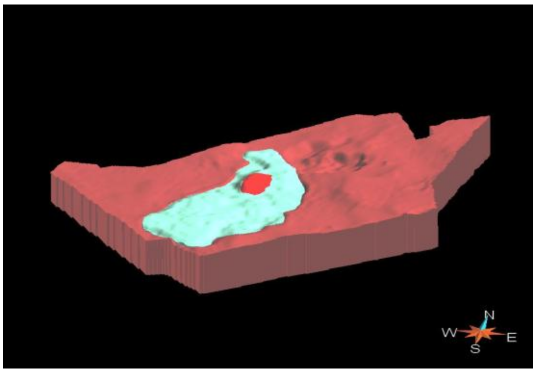

Figure (5.43): Native soil (brown color), domestic waste and contaminated soil (light blue color), and construction waste (red color).

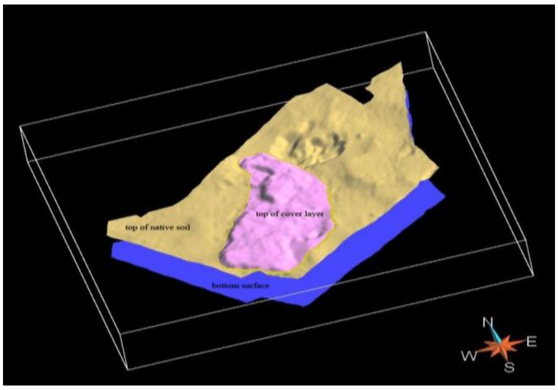

Figure (5.44): Boundaries of top of cover layer, top of native soil and bottom surface.

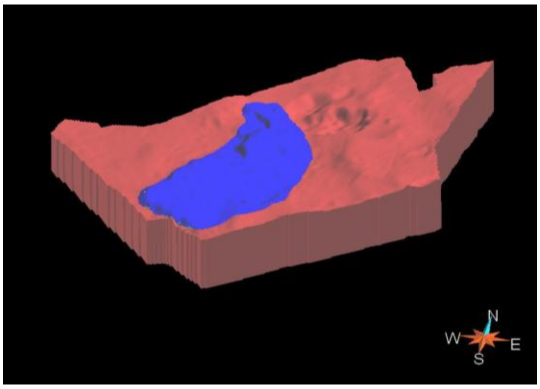

Figure (5.45): Native soil body (brown color) and cover layer (dark blue color). Waste and construction bodies are covered.

The statistical analysis of each geological body is summarized in Table 5.11.

Table 5.11: Thickness and volume estimates of each geological body.

Body	Lithology	Thickness (m)				Volume (m^3)	Resistivity (Ω.m)
		Median	Max	Mean	Std. Dev.		
A[1]	Native soil	-	-	-	-	-	20-100
B	Residence waste and contaminated soil	8.58	22.43	8.03	3.61	1.9×10^7	1-20
C	Construction waste	3.16	5.94	2.92	1.71	0.36×10^6	>100
D	Covering soil	1.62	4.56	1.64	0.663	4.5×10^6	

[1] Since the bottom surface of Geological body A is artificially set, the thickness is not statistically calculated.

5.4 Discussion

For the purpose of proper evaluation of the waste disposal site in Jleeb Al-Sheyoukh, a detailed investigation program was planned and carried out during the course of this research. The investigations consisted of topographic survey, borehole drilling, and assessment of cover layer, leachate, ground water quality, landfill settlement, and geo-electrical survey. The obtained data have been processed using a computer program called "GOCAD" to establish a 3D geometrical model of the landfill site.

After modeling the surface of the site using the topographical survey data, the borehole logs have been incorporated into the model and the corresponding layers of different materials encountered in the boreholes (i.e., cover soil, organic waste, construction waste, contaminated soil and native soil) have been connected together. The GOCAD allowed obtaining a rough model of the landfill body. In order to enhance the output of the produced model, it was found necessary to conduct geo-physical survey "geo-electrical tomography". The results of the geo-electrical profiles "with regard to the calculated resistivity" were processed and the calculated values have been evaluated. The profiles have been then used to finalize the GOCAD model. After visualization of the model the volume of each body has been calculated.

The final model obtained using GOCAD showed that the landfill in Jleeb Al-Sheyoukh site composed of mainly 4 bodies comprising; a cover layer with a volume of 4.5×10^6 m^3, construction waste with a volume of 0.36×10^6 m^3, organic waste and contaminated soil with a volume of 1.9×10^7 m^3 and a native soil body underneath the landfilling area.

The model revealed that the landfill area, which was originally used as a quarrying area, is composed of three quarries where two of them were used for landfilling purposes whereas the third one is still unused. For the first time, it was possible to define the geometry and locations of the used quarries and the types of buried wastes which were received during the landfilling period. It was also possible to extract from the model several facts such as the deepest point reaching 19 m in the southern pit and the maximum thickness of the waste body which reached 22.6 m, with a median of 8.58 m and 3.16 m for organic waste and construction waste, respectively.

With such information, it was possible to correlate between the location of the two major waste pits containing organic wastes and the landfill gas measured in the 50 boreholes. When overlaying the isolines maps of methane gas distribution over the two waste pits, it was evident that the highest concentrations of methane gas were observed above these two pits.

The monthly LFG measurements performed over a period of 33 months showed an average content of methane about 30% and an average content of carbon dioxide about 26%, while the oxygen is negligible and the mean ratio of CH_4/CO_2 was about 1.14. This indicates that JLF stands at the end of the "Air Infiltration Phase". During this period of time no noticeable change in the methane gas production has been detected which indicates that the decay process is almost stable and hence the life time of the landfill might be extended. The possibility that more humidity in the waste body might become a reason to change the landfill gas phase, should not be ruled out.

The low humidity content in the landfill body was evident during the collection of leachate from the 50 boreholes where only 2 samples were possible to be collected during a period of 3 years. The analysis of the two samples indicated that the concentrations of most pollutants were below the allowable German Standards for the discharge of treated leachate. However, levels of COD, BOD and mercury contents in the leachate exceeded the German standard.

Due to the low leachate formation and the relatively low concentrations of contaminants in the leachate, it was expected that groundwater will not be affected, and therefore, three water wells were drilled and samples were collected and analyzed. The results of groundwater analysis clearly confirmed that it was not contaminated. Parameters such as; heavy metals, BOD, COD, TOC, TPH, BTEX, PAHs and microbiological organisms were very low or even below the detection limits. This is a good indication that landfill leachate is not seeping to groundwater table.

In spite of the fact the landfill was relatively dry; the results obtained from the cover layer assessment (i.e., grain size analysis, penetration and infiltration tests) showed that the cover layer contains less than 5% of silt and clay, and therefore, the cover has relatively high permeability and high infiltration rates. This was confirmed by the results of the infiltration test where almost 70% of the 30 test locations have very high infiltration rates.

This means that the cover layer has no function to protect the waste body from infiltration water. The lack of inclination does not support the surface run off and contribute to the infiltration process. The sparse rainfall in Kuwait and the very high evaporation rate are also significant factors which contribute to the very low humidity of the waste body and the negligible amounts of leachate found in the landfill (only two leachate samples during three years period).

The higher settlement rate in landfills is usually associated with high biological degradation and decay processes which require certain amounts of humidity in the landfill body (Yuen & Styles, 2000). Measurements of settlement performed at 30 points in JLF site over a period of 30 months showed an overall average settlement across the whole JLF site of about 7 cm – approximately 2.8 cm per year. This low settlement rate confirms the low decay processes in the landfill body due the low humidity. This was supported by the very low encountered leachate and almost the constant LFG formation.

The large number of geo-electrical measurements conducted in JLF allowed for the first time in Kuwait to assign certain ranges of resistivity for different materials buried in the landfill. The distribution, depth and types of wastes were easy to be identified using these ranges. Similarly, these ranges can be used and applied to explore the types and distribution of buried wastes in other landfill sites in Kuwait taken into consideration that all landfills are of similar conditions. However, the effects of humidity and water content should be taken into consideration. The employment of the geo-electrical measurements in this study allowed the indirect assessment of the environmental conditions within the JLF. The high measured resistivity in the cover layer reaching more than 40 Ωm indicated the very low content of silt and clay and the presence of construction debris within the cover layer which in turn allows higher infiltration rates. This fact was confirmed by the filed measurements and laboratory tests.

Most of the resistivity measurements (>90%) within the organic waste range (0 – 8 Ωm) was concentrated in the upper part of the range (4 – 8 Ωm) which indicates the relatively low water content in the waste matrix. The water content is usually considered as a key factor in the biological decay process, and therefore, it was expected that the biodegradation in JLF would be relatively slow and hence the formation of LFG and leachate would be low. This was proved from the field measurements conducted on LFG and leachate.

The results of JLF assessment obtained during this study indicate that the current status of the landfill was found to be approximately at the middle of its age where LFG production is relatively constant and stable (at 30% CH_4) indicating the end of the "Air Infiltration Phase". The current assessment also showed that the humidity content is low and the cover layer has high infiltration rate, and therefore, when the conditions allow more humidity in the waste body, then it is expected that the biological process will increase toward the production of higher concentrations of LFGs driving the landfill back to second LFG phases "Long-Term Phase". Groundwater was found not to be affected, to a large extent, due to the very low formation of leachate.

The observed current slow biodegradation process in the landfill increases the aftercare period and hence the environmental effects and the associated economic costs would also increase. In conclusion, the high land value and to prevent any future environmental impacts, it is essential to select the best rehabilitation alternatives to shorten the aftercare period and restore the land.

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6 Aerobic In-Situ Stabilization

6.1 Introduction

The concept of the present landfill rehabilitation experiment called "*In-Situ* Aerobic Stabilization" is to investigate the conditions under which the degradation of the organic waste can be accelerated by transferring the biological process in the landfill from anaerobic to aerobic conditions and thus to speed up the decay process, and therefore, reduce the time required to reach complete stabilization of buried wastes. Hence, the site can be utilized as soon as possible after optimization and stabilization of the performance of the landfill as well as additional appropriate rehabilitation measures.

The acceleration in waste degradation and stabilization was accomplished through the injection of water and air to enhance microbial processes by changing the anaerobic milieu to aerobic and thus minimizing the potential to generate landfill gases (LFG).

The aeration was carried out by outlining an operational procedure to invoke high aeration system in an area selected near a specific well (no.18) which has high organic waste content in the JLF.

A key plan was set for the implementation of the treatment project in the chosen area by fulfilling certain criteria set as prerequisite for planning, designing, implementation, administration and monitoring the entire project.

This high aeration waste rehabilitation treatment process required in an integrated framework to be designed and enforced with a comprehensive plan of operational procedures. Important factors to be considered in this process were outlined and managed within the first phase of selecting a square area of 24m x 24m.

Following the selection of the prospective area for waste treatment, the second phase involved the allocation of positions to induce the various operational tasks requirements set for the performance of the high aeration rehabilitation process.

6.2 Materials and Methods

6.2.1 Project setup and operation

The experiment area in Jleeb Al-Sheyoukh landfill is situated near borehole 18. An area of 24×24m was selected as the location for experiment. Figure 6.1 shows the location of the experiment site with regards to the total area of JLF site.

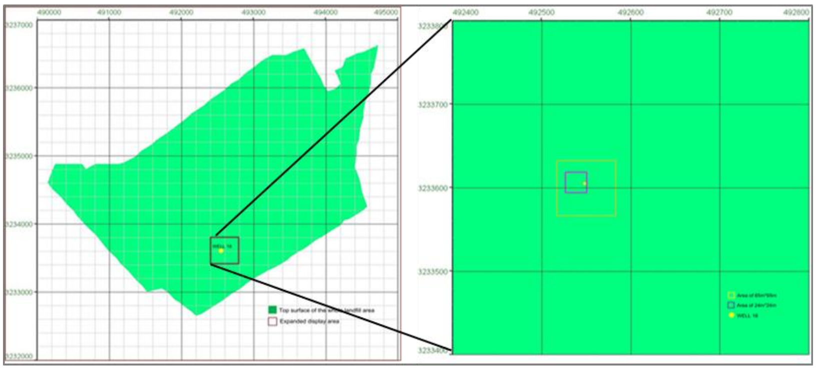


Figure (6.1): Location of the experiment site in Jleeb Al-Sheyoukh landfill.

6.2.2 Experiment Description

In the selected area, a total of 47 location points (for air and water injection as well as for control and sampling) were spread across a square area of 576 m^2 in a planned configuration to achieve the desired performance as allotted by the operational requirements set for the execution of the treatment process for the rehabilitation project. The plan and layout of the selected injection points are illustrated in Figure 6.2.

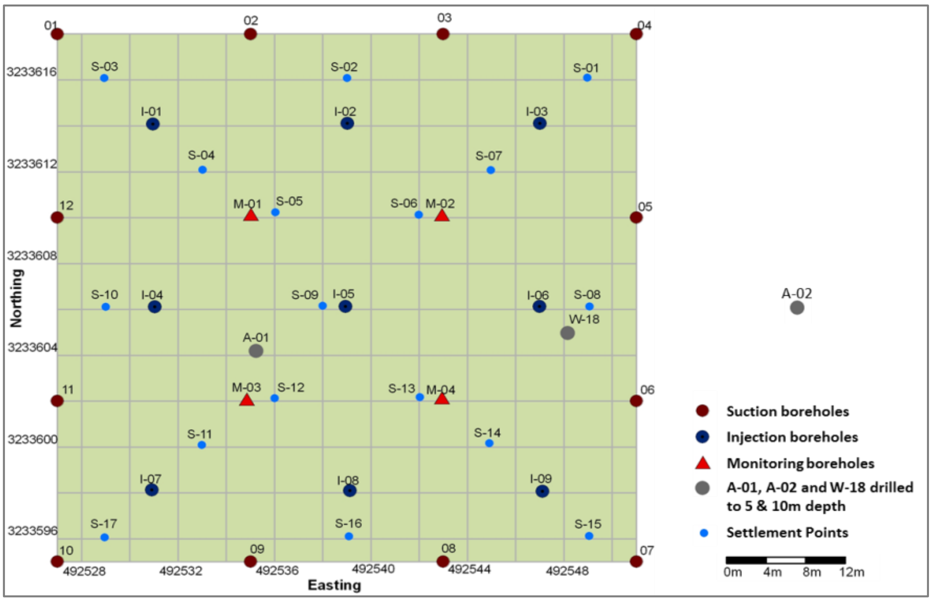


Figure (6.2): Plan and layout of the selected locations in the project area.

It should be kept in mind that the layout of the experiment was planned in a systematic way to optimize the procedure of connecting all equipments for different functions. The designed layout allows for efficient management of the system including parameters for the control of experiment in order to achieve a proper operation of the rehabilitation process. All 25 borehole heads were to be a part of a network of pipes connected in a relevant way to fulfill the requirements of the functional process. Figure 6.3 is an aerial photo of the setup in the project area. The technical details for the setup of all parts of the system are described below:

Figure (6.3): Aerial view of the project area.

6.2.2.1 Air Pipeline Network:

From the 25 boreholes drilled in the investigation area nine were placed in a configuration of 3 by 3 points each at an equal distance of 8 meters (see plan) and then were used as injection holes (INJ 01 to INJ 09). These nine injection points were fixed with 4 meter long metal pipes protruding 1 meter above the ground. Using DN50 PN 10, specially fabricated, epoxy coated steel pipes were fixed with electrical solenoid control valves and high pressure metal tanks (capacity 34 l) on the top end of each of the 4 meter pipes.

Three galvanized steel pipes, DN25 PN 10, with one closed end were placed parallel with 8 meters distance apart in three lines horizontally to facilitate 9 connection points placed next to each of the high pressure tanks. T-Connection made it possible to connect the nine tanks to the pressure system which were located 1 meter above the ground level by means of high pressures flexible rubber hose, DN20 PN 16. The nine injection points on these three rows were all connect to the main air supply pipe (galvanized steel pipe DN50 PN 10). Thus the completion of the air pressure pipeline layout made it possible to direct this steel pipe as the main supply line to be connected to the air pressure source.

6.2.2.2 Water Pipeline Network:

The configuration designed for the nine air injection points were also used to serve as the medium for water flow into the system. Initially the nine vertical injection steel pipes (INJ 01 to INJ 09) were added with 25 mm hole opening about 5 cm above the ground level. Then the layout of the horizontal placed air pressure pipelines were duplicated with a second network of pipes utilizing the same formation of 3 rows with 3 connection points each, utilizing 3 PVC pipes DN 32 with one end closed. These 9 T-connection points were to facilitate the inflow of water required by the aeration area. To overcome the back pressure to be produced by the air pressure during the injection process, 9 brass check valves were connected in between the vertical injection steel pipes and the T-connections by means of 25mm rubber hoses. The nine water inlet points on these three rows were all connected to the main water supply pipe (PVC pipe DN50). Hence, the completion of the water inlet pipeline layout made it possible to direct this PVC pipe as the main supply line to be connected to the water source.

6.2.2.3 Suction/Border Pipeline Network:

The project design implicated the use of 16 borehole points as suction points. These were placed into two sets of separate sequences of 12 points and 4 points. The first set of 12 borehole points (SUC 01 to SUC 12) were placed within an equally divided formation starting from one corner with a distance of 8 meter apart, as a square to ring around the perimeter of the 24m x 24m area. These twelve suction points were fixed with 3.5 meter long PVC pipes piercing 0.5 meter above the ground. Specially perforated PVC pipes, DN50 were fixed with specially designed probe borehole heads on the top end of each of the 3.5 meter pipes.

A ring of PVC pipes, DN50, were placed horizontal along the perimeters around the area to facilitate 12 connection points placed 8 meter apart next to each of the probe borehole heads. The twelve T-connections made it possible to connect the borehole heads to the suction system which were located 0.5 meter above the ground level by means of HDPE double-wall corrugated pipes, 55mm diameter. The twelve gas suction points in these four sides, which form a ring around the aeration area, were all connected to the main suction pipe, (PVC pipe DN50) via a T-junction. Thus, the completion of the outer suction pipeline layout allows this PVC pipe as the main supply line to be connected to the gas suction source directly.

6.2.2.4 Suction/Monitor Pipeline Network:

The second set of 4 borehole points (MON 01 to MON 12) was placed in an equally divided formation on the four corners of a square near the middle of the selected area 8 meters apart. These four suction points were fixed with 3.5 meter long PVC pipes piercing 0.5 meter above the ground. Specially perforated PVC pipes, DN50 were fixed with specially designed probe borehole heads on the top end of each of the 3.5 meter pipes. Two PVC pipes, DN50, with one closed end were placed parallel 8 meters apart in two horizontal lines facilitate 4 connection points placed 8meter apart next to each of the probe borehole heads.

The four T-connections made it possible to connect the borehole heads to the suction system which were located 0.5 meter above the ground level by means of HDPE double-wall corrugated pipes, 55mm diameter. The four gas suction points on the two rows were all connected to another main suction pipe, (PVC pipe DN50). Hence, the completion of the inner suction pipeline layout made it possible to direct this PVC pipe as the second main supply line to be connected to the gas suction source.

6.2.2.5 Settlement Blocks:

The project design implicated the use of 17 blocks as observation points to indicate variation in land settlement. The set of 17 settlement points (SET 01 to SET 17) were placed in such configuration as to cover most selected area representatively. The seventeen settlement blocks were specially designed and constructed for this project to act independently in order to recorder the settlement at place of location. The area in the selected location was dug to accommodate the block to a depth of 0.8 meter into the capping layer.

The settlement blocks made from PVC cylindrical object with a diameter of 150 mm and a length of 1 meter with one end firmly closed and buried 0.8m into the potholes at the selected locations. Once the cylinders were firmly placed, they were filled with excavated material and sealed with flat PVC caps firmly. This method was employed to minimize the influence of weight density between the block and the surrounding area. Thus, the blocks layout allows the measurement of the land settlement without influencing the settlement process.

6.2.2.6 Test Equipment and Steps

Such a field experiment with a complex operational process requires numerous apparatus and parts to ensure autonomous and stable operation. Also two 6 x 2m prefabricated container rooms were constructed to accommodate the equipment and to serve as control and monitoring station. Mainly three systems were installed to achieve the objectives of the project; namely, the air pressure, the water injection and the suction systems

6.2.2.7 The Air Pressure System:

Air Supply – A compressor system to generate the required air pressure and volume to the aeration of the landfill body was selected to supply the rehabilitation facility with compressed air. A twin head compressor unit (model ABAC TANDEM 10) with the capacity to generate 2232 LT/MIN or 78.8 CFM of compressed air and produce up to 11bar of pressure was installed.

The aeration rate to the nine injection tanks could be adjusted separately by utilizing one or both of the compressor heads. The supply from this unit was subject to control ensuring the flow of air to maintain the required pressure within the pressure tanks before every discharge into the aerated body.

6.2.2.8 The Water Injection System:

Water Supply – The water storage system was designed to supply water required by the aeration process utilizing gravity as pressure from the twin water tanks with holding capacity of 2000 gallons. Two PE plastic tanks (1000 gallons capacity each), were installed on a metal tower standing at a height of 3 meter above the ground level.

The two tanks were connected by the mean of a PVC pipe, DN50 as main water pipe, to the water injection pipeline network spread over the project area. To control the flow of water to the aeration area 2 inch electrical solenoid valve was used to control the flow and volume of water required by the area on timed interval.

6.2.2.9 The Suction System:

Centrifugal fan pump (flow rate 350m^3/h; 92.887kPa inlet pressure) has been used to establish the required suction pressure. The border suction system had been connected to the suction pump (model MEIDINGER –S-GRN48) to suck the gas and moisture from the outer section of the aeration area.

The suction at the suction points is 20% higher than the volume of the air which is injected into the landfill. Thus prevention of leakage of landfill gas to the surrounding body of landfill and from the surface of the landfill into the atmosphere is enabled. Using the monitoring data of the total gas volume of the treatment process a chemical balance of the reaction process can be computed. The suction facility consisted of one channel suction pump blowers in maximum with a nominal capacity of 400 m^3/hours.

The pipeline of the monitor suction system coming from the aeration area was connected to the condensation tank, to separate any moisture (leachate) transported with the gas. Next to the pump room there was a gas probe stand to analyze the gas composition omitted from the monitoring points.

6.2.2.10 The Bio Air Filter:

A six tier bio filter was constructed to enable the gas collected from aeration area to be treated from VOC, and neutralized into non-toxic gas composition to be released into the atmosphere. The bio air filter was connected to the suction pump via 120mm PVC pipe.

6.2.3 Analytical Procedures

This chapter describes the sampling procedures and the analytical methods which were followed during the implementation of the aerobic *in-situ* stabilization in the project area of JLF. This included several direct methods such as; collection of borehole logs, performing LFG measurements, sampling and analysis of VOCs, performing filed measurements for the determination of landfill settlement and the collection of waste samples for waste characterization and analysis.

6.2.3.1 Boreholes

Twenty five boreholes were drilled at a depth of 3 m in the project area (see Figure 6.2, above). Moreover, two additional boreholes (A1 and A2) were drilled at a depth of 5 m. These boreholes were used to serve the following purposes:

- Borehole logs were taken to verify the geo-electrical measurements
- To monitor LFG emission
- For the monitoring and control the experiment (i.e., injection of air and water)
- Collection of waste samples for the identification of waste composition and for analyzing the chemicals leaching with waste eluates.

6.2.3.2 Landfill Gas Measurements

The composition of LFG (i.e., CH_4, CO_2, O_2, NH_3 and CH_4/CO_2) was monitored during the aeration experiment from all boreholes in the project area (see figure 6.2, above) using hand-held instrument (GA 2000 Plus infrared gas analyzer, Geotechnical Instruments, UK) and following the same procedures as described in Appendix 2.

6.2.3.3 VOCs Sampling and Analysis

LFG samples for the analysis of Volatile Organic Compounds (VOCs) were also collected from selected boreholes in JLF and the project area (see figure 6.4) using a Tedlar bag and a small vacuum pump as described in section 5.2.2.1. Collected samples were analyzed for light and heavy VOCs components using gas chromatography equipped with flame ionization detection (GC/FID). Full details of the analysis of VOCs are presented in Appendix 2.

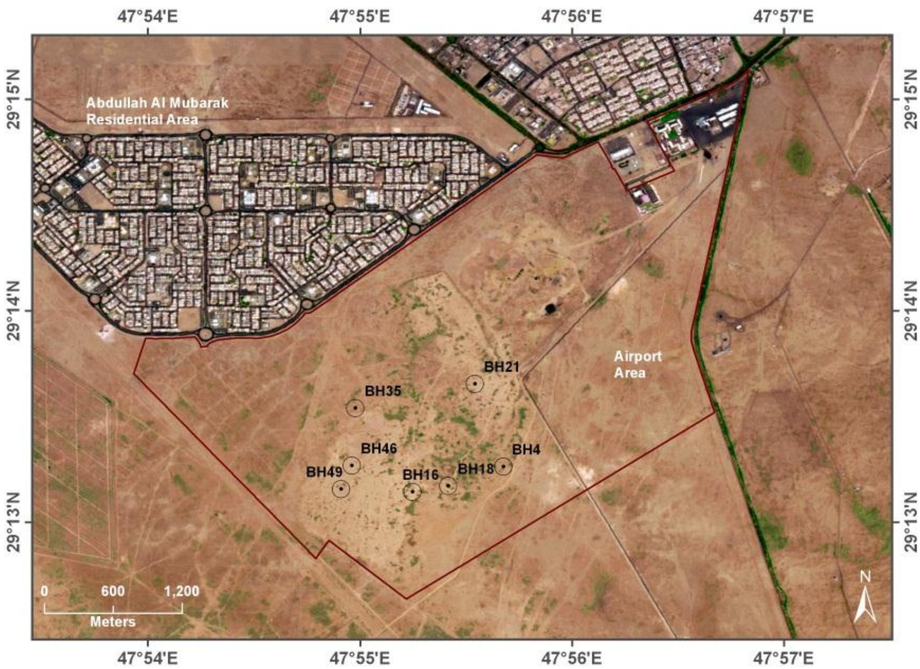


Figure (6.4): Location of boreholes used for the collection of VOCs samples from JLF site and the project area.

6.2.3.4 Settlements

The purpose of these field measurements is to investigate if there is any measurable land-subsidence (i.e., settlement) within and around the project area, and whether the measured subsidence is different from immediate surrounding areas that are apparently devoid of landfilling.

The measurements were carried out on monthly basis in 17 points within the project area using a Surveying Total Station (Leica DNA03, by Leica Geo-systems AG. Switzerland). Measurements were carried out according to the same procedures followed in the assessment of the total area in Jleeb landfill site (see section 5.2.2.2, above)

6.2.3.5 GOCAD

To obtain the geometry of the waste body in the project area, the boreholes and the geo-electrical cross sections have been modeled using the 3D program GOCAD as previously described in section 5.2.2.7, above. GOCAD stands for Geological Object Computer Aided Design, which is a computer-aid approach for modeling of the geometry and properties of geological objects in the subsurface.

With GOCAD consistent models can be built by using data of diverse types from heterogeneous origins and of different spatial distribution.

6.2.3.6 Waste Characterization

Two types of tests were performed on waste samples collected from the project area. The first test was intended for the physical characterization of the different kinds composing the waste (i.e., wood, metals, paper, plastics and others). The second test was performed on the waste eluates for the characterization of chemicals leaching from the waste.

6.2.3.6.1 Analysis of Waste Eluates

Waste samples were collected from two locations in the project area (point GE24 and point GE40, see figure 6.27 in section 6.3.3.1) at depths of 2 and 3 meters.

Known weights of the collected waste samples were soaked in distilled water and were placed in the shaker for 24 hours. Then, the formed leachates were filtered under vacuum and the waste eluates were analyzed for various parameters (including: Temperature; Conductivity; pH; COD; and TDS;) according to the analytical procedures described in "Standard Methods for the Examination of Water and Wastewater- 21st edition, APHA, 2005". Full details of the sample preparation and the analytical methods used for the analysis of waste eluates are presented in Appendix 2.

6.2.3.6.2 Waste Composition

A landfill excavation was deemed necessary to explore and study the composition of waste in the project area after the completion of the aeration experiments and hence to extrapolate the findings on the JLF total area if a similar rehabilitation process was to be applied in the future.
Therefore, a part of the project area (about 3m depth with a total quantity of 853 Kg) was excavated and the waste composition was determined using manual sorting and identification and the gravimetric method.

6.3 Results

6.3.1 Gases

6.3.1.1 Landfill Gases

Long term gas monitoring over almost 3 years period (March 2008 – Dec. 2010) has been carried out to investigate the decay behavior in the total area of JLF (where no rehabilitation measure was applied) and also in the project area during the rehabilitation experiment "*In-Situ* Aerobic Stabilization".

Monitoring wells were chosen to enable assessment of the effect of the experiment, both vertically and horizontally, on the decay process within the project area and in its immediate vicinity (if any). Figure 6.5 shows the locations of all wells used for monitoring the behavior of LFG before, during and after the rehabilitation process.

Figure (6.5): Location of boreholes 18, 20, 43, Monitoring Wells, A1 and A2.

During this experiment, several results were obtained from the different locations of the monitoring wells. Before the start of the experiment, all wells were initially at the stage of the "Air Infiltration Phase". After the experiment, significant changes in LFG concentration were observed at the various wells locations, and hence, different shifts LFG phases were also observed. Tables 6.1 and 6.2 summarize the results obtained from the different wells.

Table (6.1): Gas composition during the experiment for different wells (mean value).

Well no.	Well Description	Status	CH_4	CO_2	O_2
18	Inside the project area, total depth of 7m	before injection	37.7	26.26	1.5
		final reading	3.29	3.52	15.6
Monitoring 1	Inside the project area, total depth of 3m	before injection	36.7	29	0.5
		final reading	24.11	16.76	5.08
Monitoring 4	Inside the project area, total depth of 3m	before injection	36	28.7	0.5
		final reading	27.28	19.76	5.3
A1	Inside the project area, total depth of 5m	before injection	33.7	25	1.1
		final reading	18.7	16.7	7.4
A2	Outside the project area, total depth of 5m	before injection	36	21.8	0.5
		final reading	25.2	21.8	4.87
Suction 1	At the border of the project area total depth of 3m	before injection	37.7	29.9	0.5
		final reading	21.47	20.65	4.4
Suction 4	At the border of the project area total depth of 3m	before injection	36.3	28.7	0.5
		final reading	28.04	22.77	3.7
43	Outside the project area, total depth of 9m	before injection	45.97	35.57	0.7
		final reading	48.16	32.1	2.5

Table (6.2): The shifts in LFG phases observed in the monitoring wells.

Well no.	Well Description	Landfill Gas Phase	
		Before injection	**After injection**
18	Inside the project area	End of Air Infiltration Phase	Aerobic Phase
Monitoring 1	Inside the project area	End of Air Infiltration Phase	End of Carbon Dioxide Phase
Monitoring 4	Inside the project area	End of Air Infiltration Phase	End of Carbon Dioxide Phase
A1	Inside the project area	End of Air Infiltration Phase	End of Carbon Dioxide Phase
A2	Outside the project area	End of Air Infiltration Phase	Middle of Carbon Dioxide Phase
Suction 1	At the border of the project area	End of Air Infiltration Phase	Methane Oxide Phase
Suction 4	At the border of the project area	End of Air Infiltration Phase	Methane Oxide Phase
BH 43	Outside the project area	End of Air Infiltration Phase	End of Air Infiltration Phase

In order to assess the influence of air and water injection as well as air suction on the overall results, it was deemed necessary to apply different scenarios during the experiment. These included the commencement and termination of air & water injection as well the start and stop of air suction pumps.

To evaluate the status of the decay process in a waste disposal site, it is important to look at the gas composition and at the quotient of methane and carbon dioxide. Both help to identify the phase of waste disintegration according to figure 6.6. More detailed analysis of LFG results for the various monitoring wells, including the results of the different applied scenarios (i.e., pumps start and stoppage) is given below.

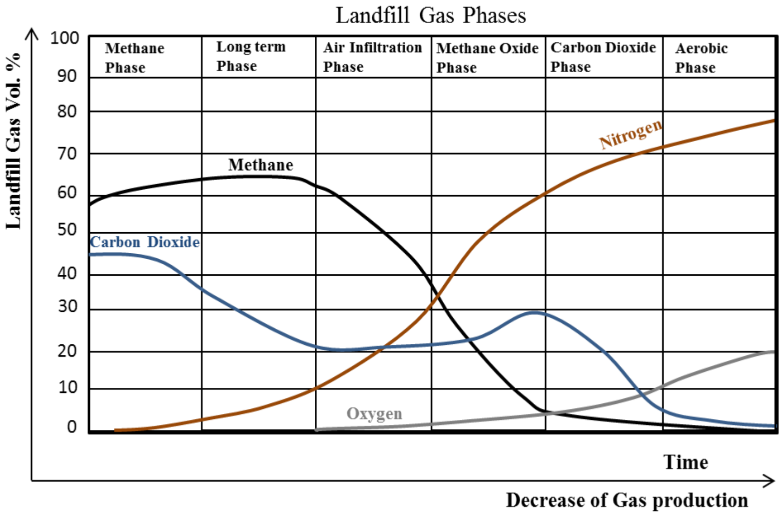


Figure (6.6): Gas phases in a waste disposal site (After Rettenberger, 2001).

6.3.1.1.1 Borehole 18:

The results for borehole 18 (which is located in the project area) are summarized in Figures 6.7 and 6.8. These results demonstrate the composition of the LFG during the experiment and the ratio of methane and carbon dioxide, respectively.

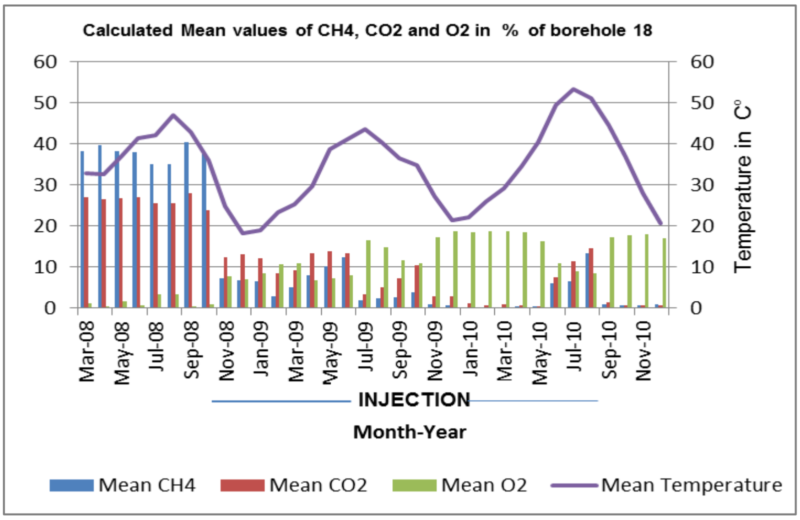


Figure (6.7): Mean values of methane, carbon dioxide, and oxygen in well No. 18.

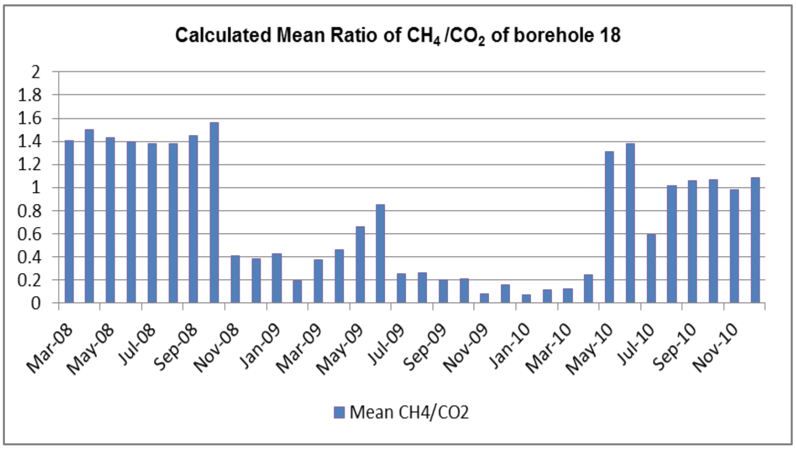


Figure (6.8): Calculated mean ratio of methane and carbon dioxide in well No. 18.

The statistical evaluation of these parameters in borehole 18 is shown in the figures 6.9 and 6.10 for the period before, during and after the experiment. Taking into consideration the parameters before and after the experiment to identify the phase of the waste, it is obvious that the phase before the experiment (before injection) was at the end of "air infiltration phase". However, a significant change in LFG concentration (CH_4: from 37.7% down to 3.29%, CO_2: 26.26% down to 3.52% and O_2: rises from 1.5% to 15.6%) was observed during and after the experiment (final reading) due to the waste decay process indicating the shift to the last phase of LFG "Aerobic Phase" (see Figure 6.11).

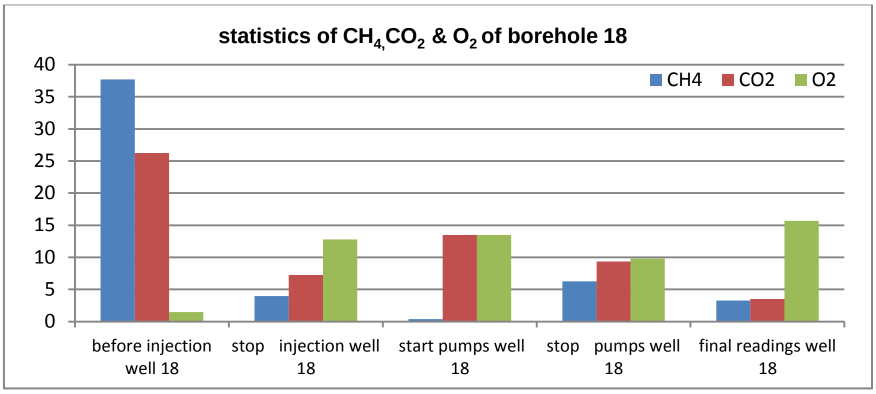


Figure (6.9): Gas composition before, during and after the experiment.

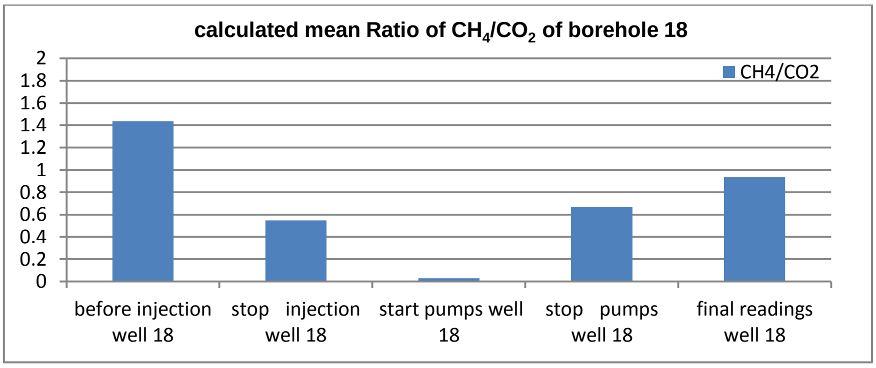


Figure (6.10): Ratio of methane and carbon dioxide before, during and after the experiment.

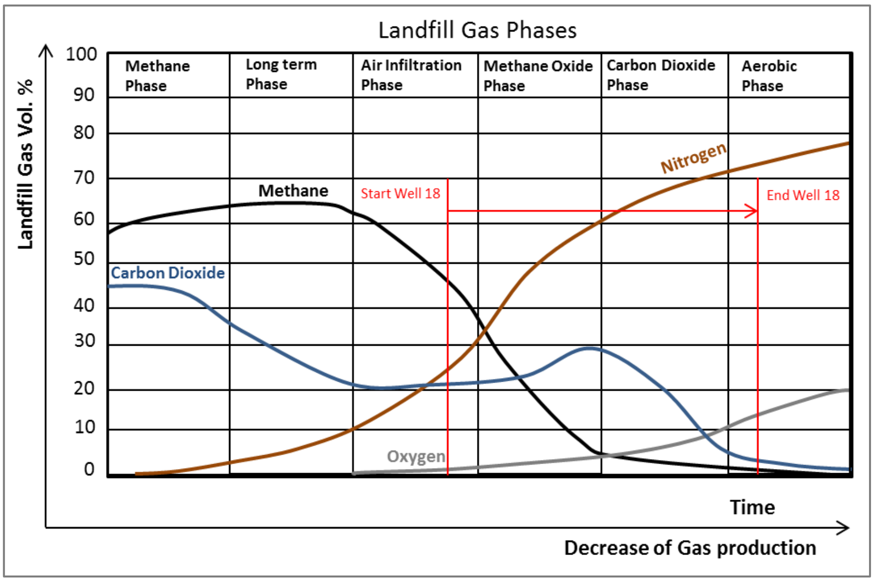


Figure (6.11): The shift in LFG phase in well 18 before and after the experiment.

6.3.1.1.2 Borehole 43:

In order to confirm that the changes observed in borehole 18 occurred due to the experiment, the gas composition and the ratio of borehole 43 (which is located outside the project area, but not far away from borehole 18) have been recorded and evaluated. The results are shown in Figures 6.12 and 6.13.

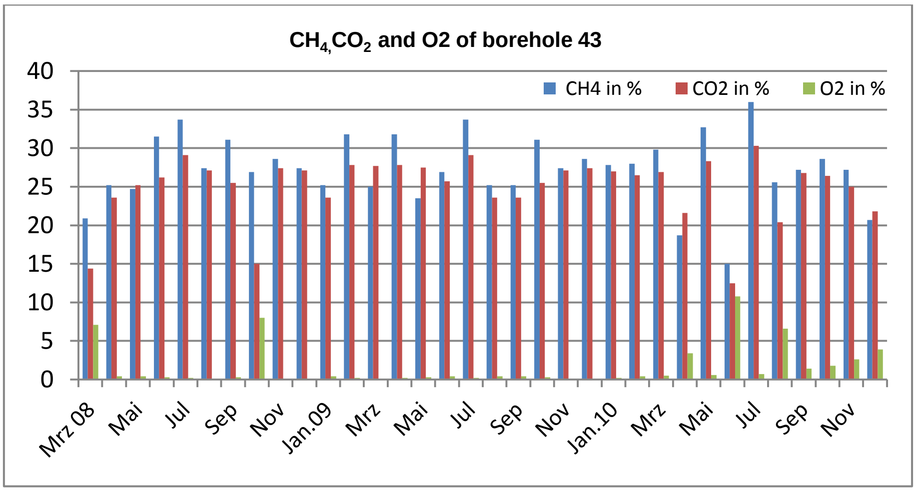


Figure (6.12): Gas composition in borehole No. 43 outside the project area.

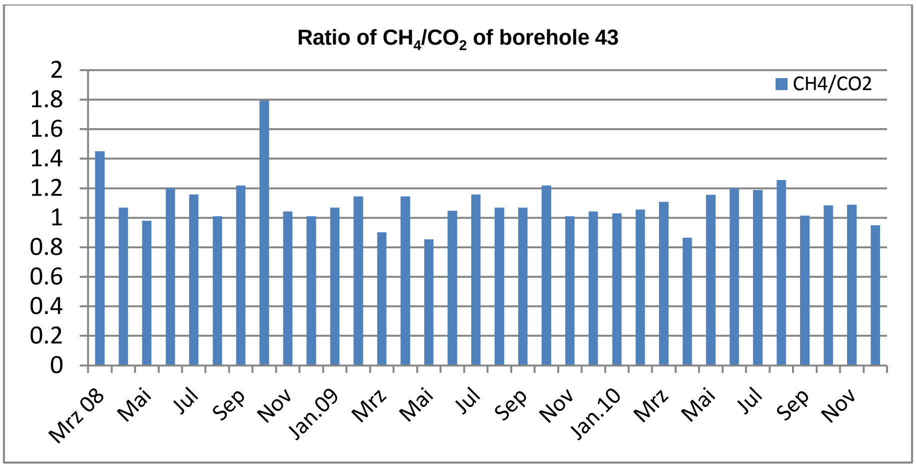


Figure (6.13): Ratio of methane and carbon dioxide in borehole No. 43 outside the project area.

Looking at the results of borehole 43, it is obvious that the concentrations of CH_4 and CO_2 and the ratio CH_4/CO_2 remained fairly constant at about, 28%, 25% and 1.1, respectively. These results indicate that LFG phase of borehole 43 is still at the stage of "Air Infiltration Phase" or at least the beginning the “Methane Oxide Phase”.

However, at the end of the experiment in November 2010, borehole 43 as well as other boreholes such as borehole 20 is still at the stage of "Air Infiltration Phase" or at least the beginning the “Methane Oxide Phase”, while borehole 18 clearly shows a major shift towards the “Aerobic Phase”, as illustrated in Figure 6.11. These results provide a compelling evidence of the success of the experiment in accelerating the decay process in the project area.

6.3.1.1.3 Wells A1 and A2:

The aeration in the project area was applied at a depth of 3m. To assess the vertical extent of the aeration, two wells (A1 and A2, see figure 6.5) were drilled at a depth of 5m (the perforation of the borehole pipe was only in the last 1 meter to ensure the collection of LFG at a 5m depth). Borehole A1 is located within the project area (24mx24m), whereas borehole A2 is located just outside of the project area (4 m from the boarder). A2 showed in comparison to A1 less oxygen and higher methane and carbon dioxide content and thus indicates that the effects of the experiment have reached the area of well A2 but to a lesser extent. The statistical evaluation is shown in Figures 6.14 and 6.15. Both wells (A1 & A2) show a shift towards the “Carbon Dioxide Phase”, which also indicates the success of the experiment when compared to the results of boreholes 20 and 43.

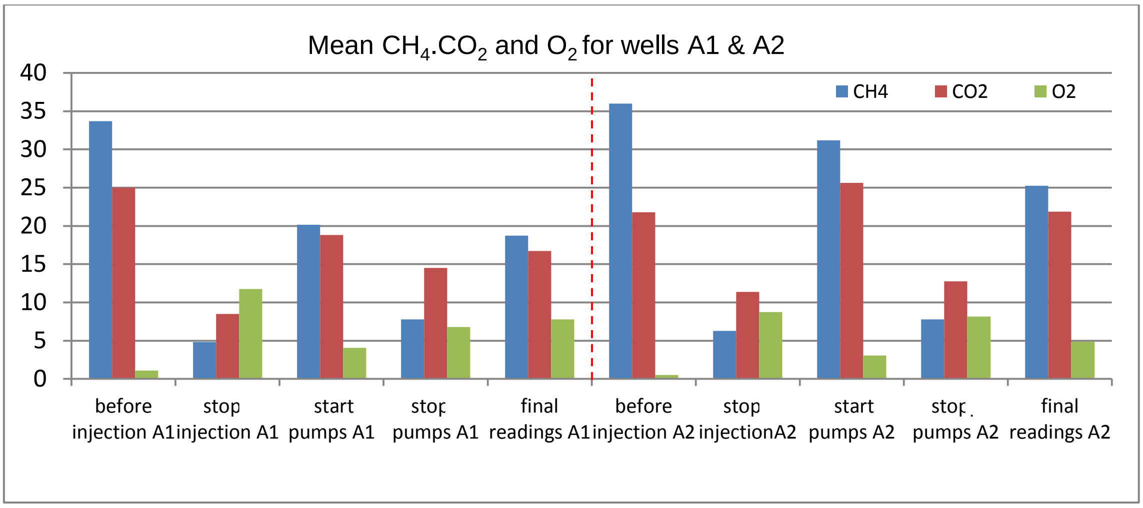


Figure (6.14): Gas composition of the wells A1 and A2 during the experiment.

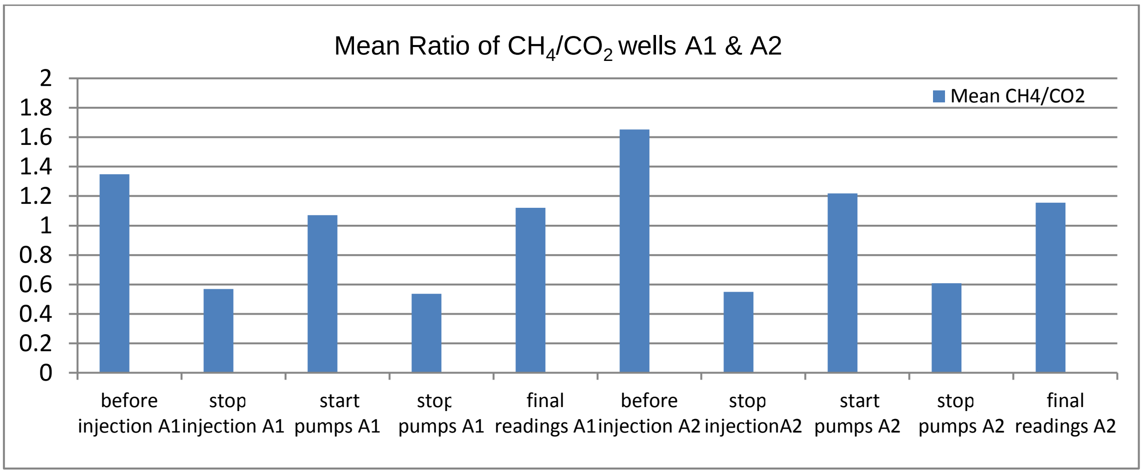


Figure (6.15): Ratio of methane and carbon dioxide in the wells A1 and A2 during the experiment.

6.3.1.1.4 Monitoring Wells (M1, M2, M3 and M4):

The four monitoring wells in the project area showed gas composition with around 5% oxygen and carbon dioxide of 18-20% which indicate a phase shift from "Air Infiltration Phase" to at least the “Carbon Dioxide Phase” (Figure 6.16).

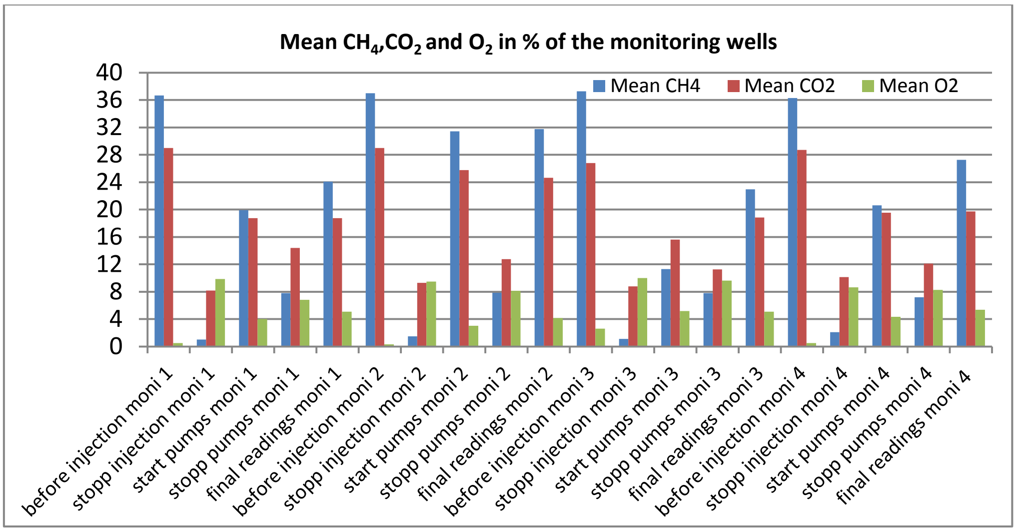


Figure (6.16): Gas composition of the 4 monitoring wells

6.3.1.1.5 Suction Wells:

The suction wells (12 wells located at the boundaries of the project area, see figure 6.2) recorded an increase in the oxygen content to about 4%. At the same time the methane gas decreases from initial concentration between 36-37% down to about 23-29% and also the carbon dioxide decreases from 27-29% to 20-24% (Figure 6.17). These changes has not caused a major shift in the LFG phase but shows that the disintegration has been accelerated compared to the total area without treatment (e.g. results of BHs 43 and 20).

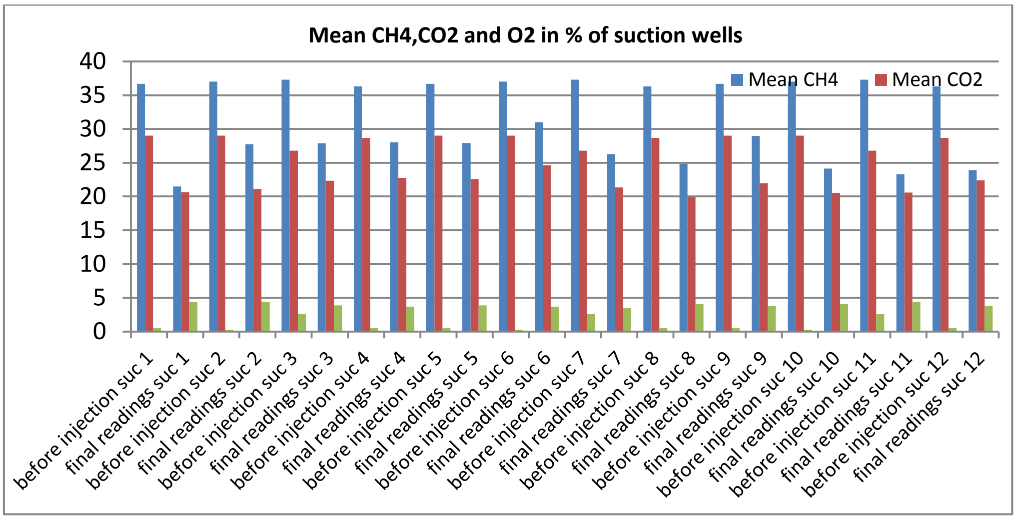


Figure (6.17): Gas composition in suction wells on the boundary of the project area.

6.3.1.2 Toxic Gases[1]

During the period May–August 2010, twenty samples were collected from selected wells boreholes in the total JLF area and the project area (See figure 6.4) for the purpose of comparing the possible reduction in the emission of toxic gases as a result of the aeration process applied in the project area. Collected samples were analyzed for their contents of 50 volatile organic compounds (VOCs) according to the method described in Appendix 2.

Table 6.3 below gives brief description of the boreholes used for sampling. Boreholes located in areas of native soil where no wastes exist (BH 4 and 35), boreholes with low-methane productivity (BH 21 and 46), boreholes with high-methane productivity (BH 16 and 49). The locations of all of the previous boreholes were chosen in the total area of JLF outside the project area and were not subjected to the aeration process. Borehole 18 in the project area was chosen to represent the effects of the *in-situ* aerobic stabilization on the reduction of VOCs emission. Table 6.2 also lists the results of total VOCs concentrations (sum of 50 compounds) measured in LFG emissions from the monitoring wells in the project area and in the total area of JLF site. Concentrations of total VOCs ranged from as low as 1.3±0.5 ppm in wells located in native soil areas up to 57.1±6.9 ppm in wells of high-productivity areas.

Table (6.3): Description of VOC sampling and results in JLF site.

Borehole No.	Waste depth (m)	Max CH_4 Productivity during sampling	No. of Samples	Total* VOC concentration(ppm)	
				Mean ± STD	Range (Min-Max)
4 & 35	Native soil (No buried waste underneath)	2%	4	1.3 ± 0.5	(0.78–1.7)
21 & 46	10 and 12	30% Low productivity	4	13.1 ± 2.9	(9.4–15.7)
16 & 49	12 and 6	60% High productivity	4	57.1 ± 6.9	(51.9–67.2)
18	7	3.29% After aeration	8	6.3 ± 1.6	(4.7–9.1)

*Sum of 50 VOCs

1 During the course of this research, data generated on this topic were accessed and analyzed in a scientific article "Characterization, Concentrations and Emission Rates of Volatile Organic Compounds from Two Major Landfill Sites in Kuwait" which was published in the American Journal for Environmental Research, 8 (1): 56-63, 2012. The full article is attached in appendix 8.

Figure 6.18 compares the average concentrations of individual VOCs (50 compounds) measured in LFG samples collected from the different BHs in JLF site. It is evident from Table 6.2 and figure 6.16 that the composition of VOCs and the magnitude of measured concentrations in borehole 18 in the project area (after the aeration period) lies between the levels of VOCs measured in the native soil (4 and 35) and the low productivity (21 and 46) wells in JLF total area. Moreover, the highest concentrations of VOCs in all sampling sites were observed for; styrene, *m*-methyl-toluene and di-ethylated-benzenes.

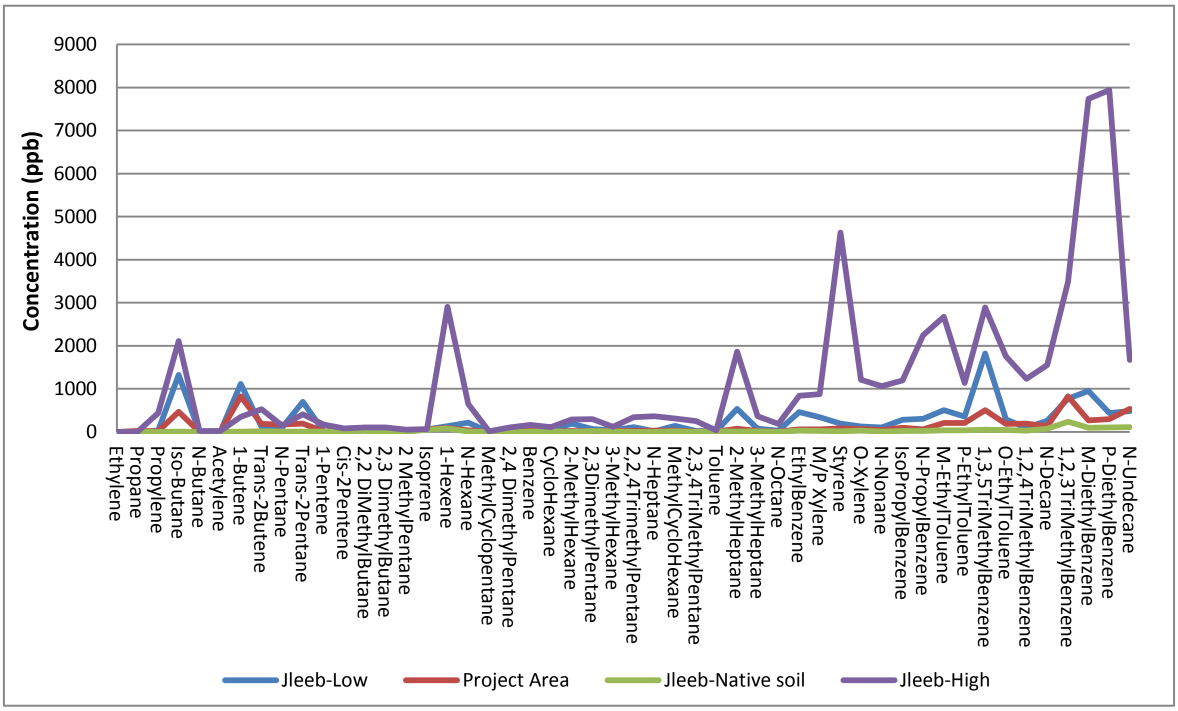


Figure (6.18): Comparison of VOCs concentrations between low-productivity wells, native soil wells and the Project Area wells in Jleeb Al-Sheyoukh landfill (units are in ppb).

Table 6.4 represents a statistical summary of major aromatic VOCs concentrations (i.e., benzene; toluene; ethyl-benzene; *m*-, *p*-, and *o*-xylenes and styrene). Benzene concentrations ranged from as low as 5 ppb in LFG emissions from low-productivity wells and up to 252.1 ppb in LFG emissions from high-productivity wells. Xylene isomers and styrene were present in LFG emissions at much higher concentrations than benzene, toluene and ethyl-benzene. The concentration of styrene reached as high as 4718.0 ppb in high-productivity wells in JLF. Similar results were reported for the concentrations of 13 VOCs (BTEX and styrene) in LFG emissions from landfills in Kuwait and South Korea (Schrapp and Al-Mutairi 2010; Kim *et al*, 2006).

Table (6.4): A statistical summary of major aromatic VOCs concentrations measured in Jleeb Al-Sheyoukh and selected landfill sites in South Korea.

Sampling well	Concentration of Major Aromatic VOCs (in ppb)							Ratio B/T[5]
	Benzene	Toluene	EthylBenzene	*m&p*-Xylene	*o*-Xylene	Styrene	∑BTEX+S[1]	
Native soil (wells: 4 & 35)	3.9±7.8[2] (5.0 – 15.7)[3]	15.7±10.9 (5.0 – 23.8)	30.5±20.2 (11.4 – 48.0)	20.5±8.1 (12.2 – 31.2)	31.7±13.0 (18.2 – 47.7)	17.7±6.3 (11.0 – 25.6)	125.1±53.3 (66.1-181.2)	0.6±0.4 (0.2 – 1.0)
Low-productivity wells (wells: 21 & 46)	21.8±36.2 (5.0 – 75.5)	24.3±8.4 (16.2 – 32.4)	462.2±374.3 (125.4 – 824.5)	339.0±292.7 (76.8 – 621.0)	124.1±59.3 (86.7 – 212.1)	195.8±45.9 (154.6 – 260.2)	1169.6±706.7 (504.6-1939.4)	0.8±1.0 (0.3 – 2.3)
High-productivity wells (wells: 16 & 49)	160.0±78.2 (72.1 – 252.1)	35.3±17.1 (18.3 – 50.6)	836.6±324.4 (495.2 – 1178.8)	874.0±140.0 (683.4 – 1010.2)	1213.1±484.5 (598.9 – 1659.2)	4633.2±103.2 (4488.2 – 4718.0)	7752.3±935.5 (6557.5-8565.3)	5.6±3.7 (1.4 – 10.5)
Project Area (well: 18)	53.0±14.7 (33.2 – 76.3)	8.9±2.9 (6.3 – 15.0)	57.8±13.1 (38.1 – 74.2)	56.4±19.5 (37.3 – 87.5)	67.3±29.6 (36.3 – 117.3)	82.9±47.2 (43.9 – 161.0)	326.5±78.0 (239.8-445.3)	6.1±1.1 (5.0 – 8.2)
Summer (2004)[6] **Winter (2004)[6]**	767 490	17333 12000	821 420	NM[4]	NM[4]	519 282	19440 13192	0.04 0.04
Korea[7] **Site A (NJ)** **Site B (WJ)** **Site D (HC)** **Site E (NH)**	 31.8 924 828 117	 259 2610 1808 21.9	 NM 982 1264 53.7	 10.4 1045 946 43.2	 45 NM 1269 48.9	 NM 91.5 66 248	 346.2 5652.5 6181 532.7	 0.12 0.35 0.46 5.3

1 ∑BTEX+S: Sum of benzene; toluene; ethylbenzene; *m,p,and o*-xylenes and styrene.
2 Mean ± standard deviation.
3 Concentration range (min – max).
4 NM: not measured.
5 Dincer and Muezzinoglu (2006)
6 Schrapp and Al-Mutairi (2010): Only mean values were reported
7 Kim et al, (2006).

6.3.2 Settlement

The decay process of the municipal waste and the gradual compaction of the dumped material due to own weight cause settlement in the site surface. The 17 settlement blocks have served as observation points for the settlement survey. Since the dumped waste in the project area is at least 15 years old, the compaction process due to its own weight must have been completed. However, due to the disintegration process, mass loss and restructure of coarse waste pieces cause compaction and thus settlement. The distribution of the settlement blocks is shown in Figure 6.19.

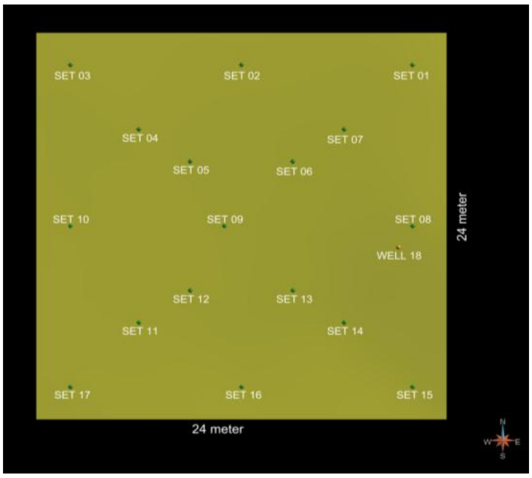


Figure (6.19): Settlement blocks in the project area.

The values of the settlement measurements in the project area have been used to visualize the distribution by calculating the isolines of the settlement (Figure 6.20). A 3D model shows also the difference in settlement in the project area (Figure 6.21). A small corner shows only 8cm of settlement while the major area has experienced settlements of more than 20cm. As the disintegration process of organic waste is gradual the settlement due to disintegration is also gradual. The loss in waste volume during the experiment is shown in Figure 6.22. The curve in this figure shows 3 phases.

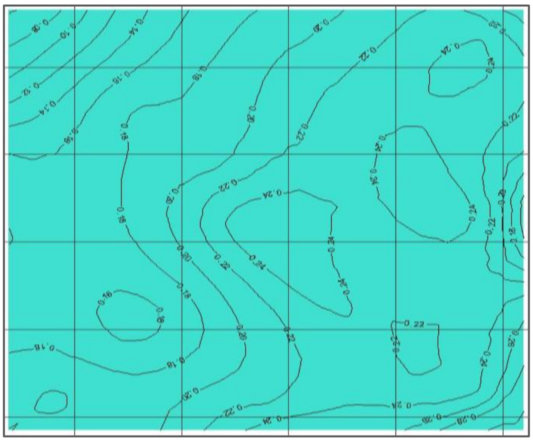


Figure (6.20): Isolines of the settlement between October 2008 and October 2010

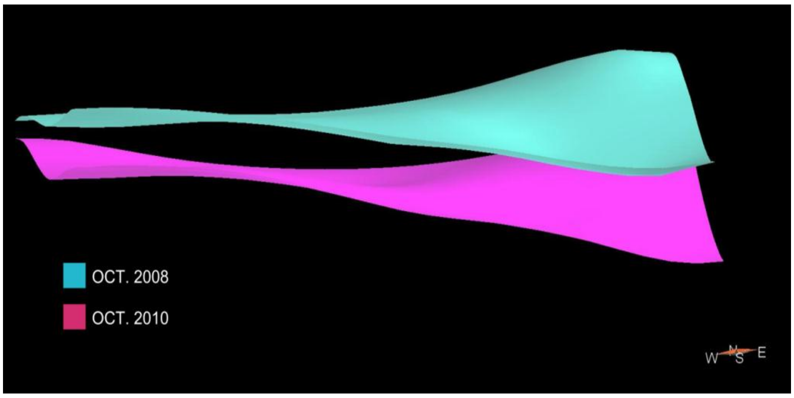


Figure (6.21): 3D image of the settlement surface in the project area.

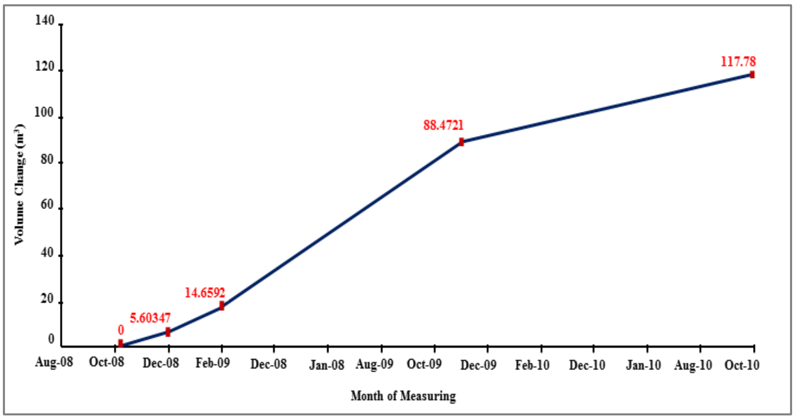


Figure (6.22): The volume change calculated due to settlement in the project area.

The *first phase* is the *primary phase* in which the decay process changes from anaerobic to aerobic conditions. This phase took only a period of about 3 months. After triggering the aerobic process the *secondary phase* (linear phase) started in which the aerobic decay process is accelerated. This phase shows almost linear volume loss over a period of about one year. The *third phase* is the tertiary phase in which the disintegration process is slowed down.

The settlement values in the project area are presented in Figure 6.23. All values show high settlement ranges between min. 10 and max. 26cm.

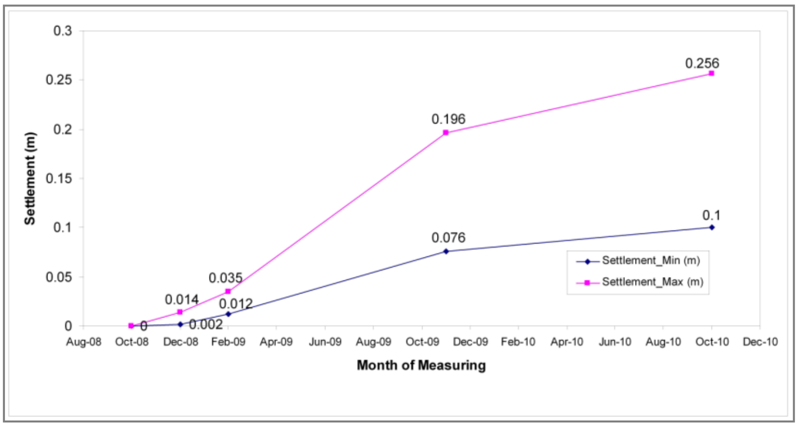


Figure (6.23): Maximum and minimum settlement in the project area.

Experience gained up to now at landfill sites which are stabilized aerobically, shows that the settlements occurring during aerobic *in-situ* stabilization may account for up to 10% of the initial height within a few years, as a result of the accelerated mass degradation (Heyer et.al, 2005). Figure 6.25 compares the extent of maximum settlement measured in the project area (which was subjected to aerobic in situ stabilization) with the maximum settlement observed in the nearest settlement blocks surrounding the project area (JM17, JM18, JM24 and JM25, see layout in figure 6.24). Bearing in mind that aeration in the project area was applied at a depth of 3m and its effects reached down to 4m and that the cover layer thickness ranged from 1 to 1.5m, then the calculated initial height would be about 2.5 – 3.0 m. Therefore, the expected reduction of 10% from the initial height in the project area will range between 25 – 30 cm.

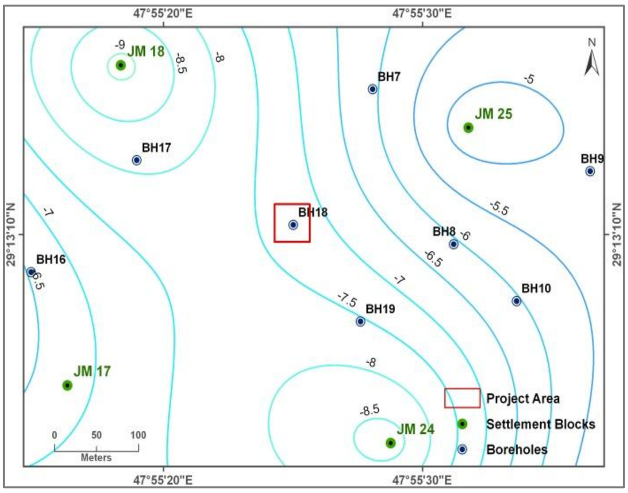


Figure 6.24: layout of the nearest settlement blocks surrounding the project area.

As shown in figure 6.25, the settlement rate in the four settlement blocks surrounding the project area (JM17, JM18, JM24 and JM25) showed a maximum value of 9.19 cm over a period of 30 months (June 2008 – January 2011) - approximately 3.67 cm per year. However, the settlement rate in the project area reached a maximum value of 19.6 cm after one year and 25.6 cm after 2years period (2008-2010).

In comparison, the settlement rate in the project area is almost 5.34 times higher than the rate of settlement in the surrounding area within the four settlement blocks, whereas the average rate of settlement in the project area in the first year reached 13.6cm which is 4.85 times higher than the average settlement rate in the total area of JLF (see Figure 6.26). This indicates that the disintegration process in the project area is more advanced than in the rest of JLF site.

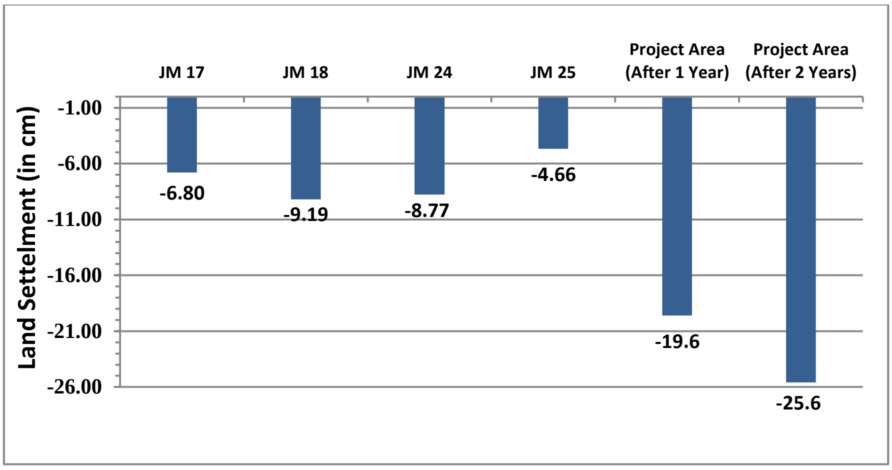


Figure (6.25): Comparison of maximum settlement rate between the project area and the nearest four settlement blocks surrounding the project area.

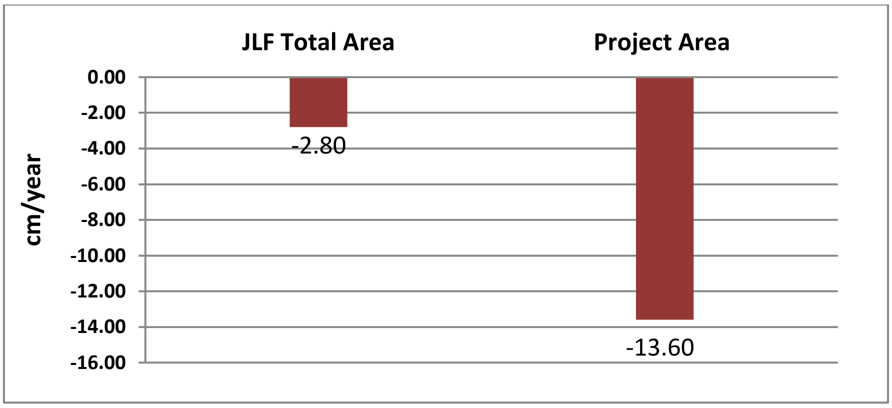


Figure (6.26): Comparison of average settlement rates between the project area and JLF total area.

The settlement and loss of waste volume and the statistical evaluation of the gases during the experiment are shown in Figures 6.27 and 6.28. The curves in figure (6.27) show 3 phases of the degradation process. The first phase is the primary phase in which the decay process changes from anaerobic to aerobic conditions. This phase took just as long as about 3 months. After triggering the aerobic process the secondary phase (linear phase) started in which the aerobic decay process is accelerated. This phase shows almost linear volume loss over a period of about one year. The third phase is the tertiary phase in which the disintegration process is slowed down.

When the volume losses are calculated for one m² area and one month, considering also the thickness of the waste, the results show that the volume losses in the project area due to rehabilitation experiment are more than 6 times higher than in the total area without treatment. The curves showing the gas composition before and after the experiment are used to identify the phase of the waste.

It is obvious that the phase before experiment is end of “air infiltration gas”. However, after the experiment the gas composition and the CH_4/CO_2 ratio show that the waste decay process status has shifted to the last phase the “aerobic phase”. Also these curves show by the change of the gas composition due to decay process three phases (see Figure 6.28), as describe in chapter 6.

These results indicate the success of the experiment in accelerating the decay process within 3 to 4 months in the project area. Although the gas composition shows a tremendous change within the first phase, the volume losses and settlement process can take about a year to show the final status.

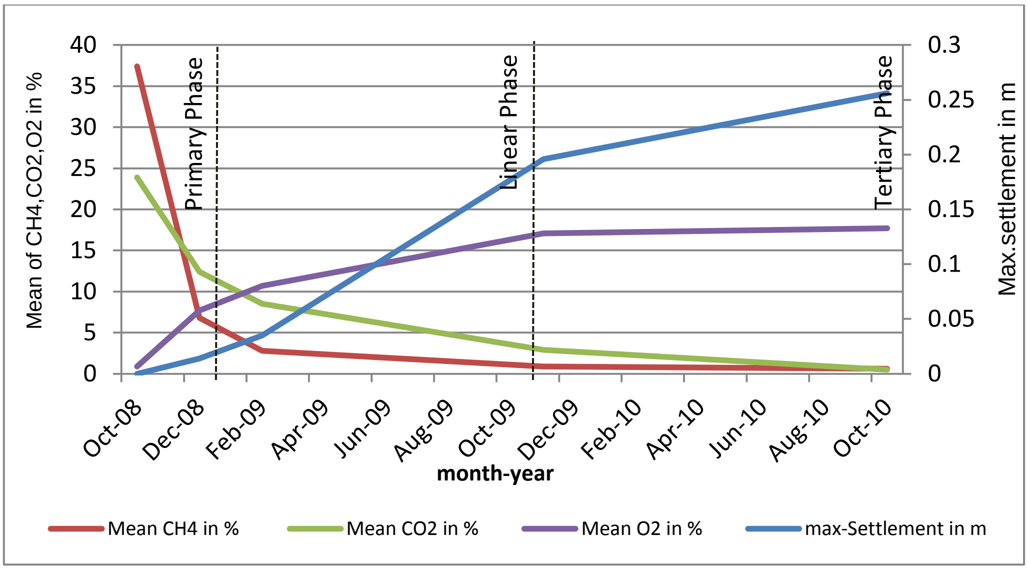


Figure (6.27): Change of mean CH_4, CO_2 and O_2 in % and the max. settlement in m. around borehole 18.

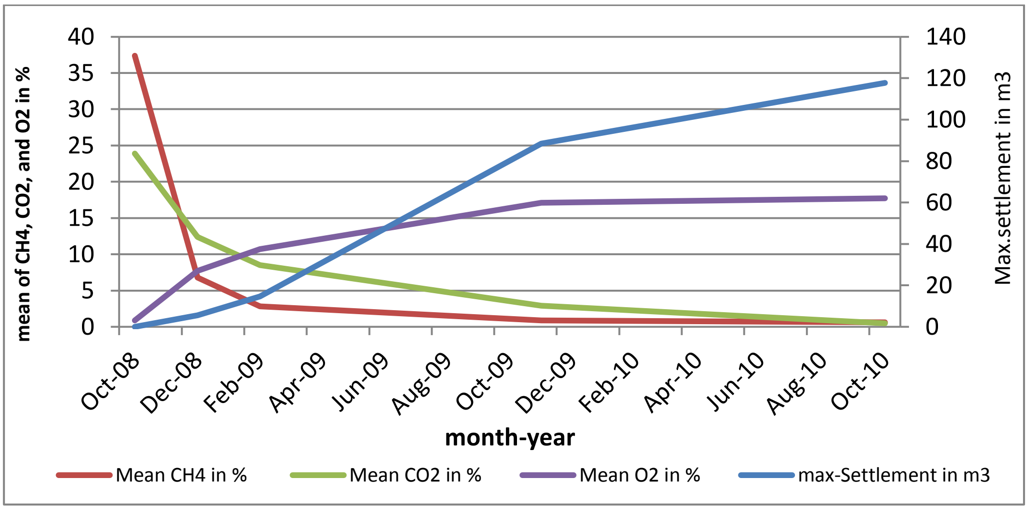


Figure (6.28): Change of mean CH_4, CO_2 and O_2 in % and the max. settlement in m^3 around borehole 18.

6.3.3 Waste Characterization

Two types of tests were performed on waste samples collected from the project area. The first test was intended for the physical characterization of the different kinds composing the waste (i.e., wood, metals, paper, plastics and others). The second test was performed on the waste eluates for chemical characterization. These tests were intended to analysis and evaluate the solid waste samples acquired at different times from the project area at JLF.

The results derived from these tests were set as basis to understand the changes in condition of solid wastes deposited with relation to the performance of the rehabilitation process in the landfill.

6.3.3.1 Analysis of Waste Eluates

The observed high settlement rates in the project area in comparison to the total area, due to the disintegration of wastes, was further investigated by collecting waste samples from point GE24 and point GE40 at depths 2 and 3 meters, respectively, as shown in Figure 6.29, below.

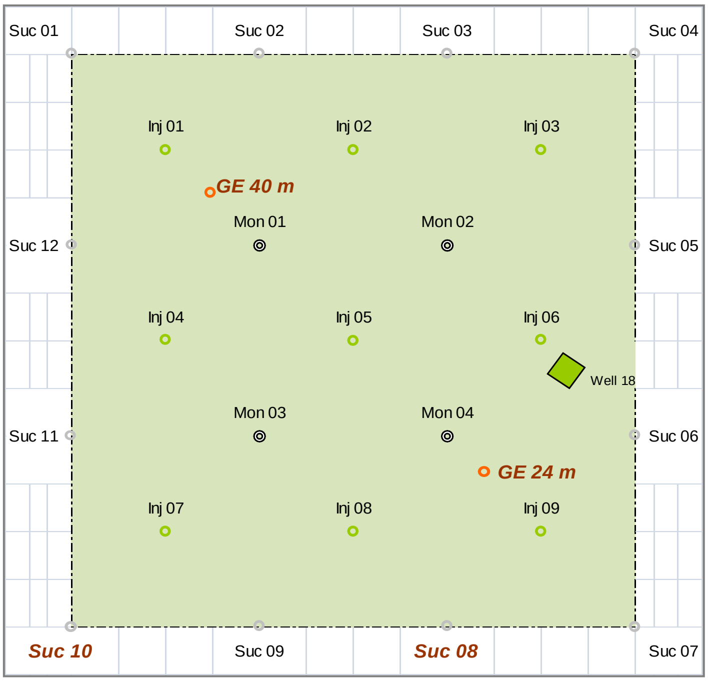


Figure (6.29): Locations of points GE24 and GE40 used for sampling of waste.

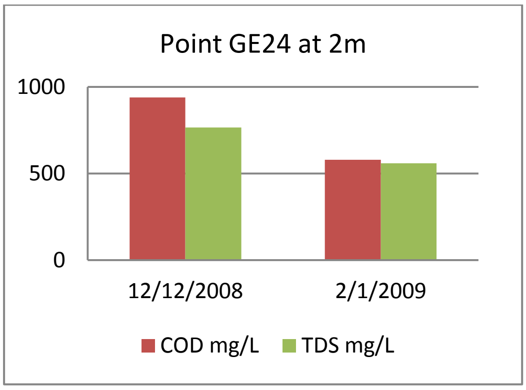
Ten waste samples were treated and analyzed as described in Appendix 2. The results of chemical analysis of the waste eluates are presented in Table 6.5, below. The results show a general trend toward the decrease in the concentration of various parameters over time (2008 – 2009). Table 6.5 also shows the calculated percent reduction in certain parameters (such as TOC, COD and TDS), where the percent reduction in COD at 2m ranges between 16.66% to 38.29% whereas the percent reduction was significantly higher reaching up to 85% at 3m where the aeration within the project area takes place.

Similar results were reported for Legago landfill in north Italy (Cossu et.al, 2006) where the reduction in COD ranged between 16.55 – 36.52% after 8 months of applying aerobic *in-situ* stabilization.

Other parameters showed similar decrease with regards to both depth and time as shown in figures 6.30 and 6.31. This finding confirms that the biodegradable organic materials in the waste body were subjected to disintegration due to the application of the aeration process in the project area.

Table (6.5): Analytical results of waste samples collected in the project area.

Sample Date	Borehole ref.	Sample Depth (m)	pH	TOC mg/L	COD mg/L	TDS mg/L
Dec. 2008	GE24	2	8.47	120.01	940	766
Feb. 2009	GE24		8.9	51.19	580	560
Percent reduction (%)				**57.34%**	**38.29%**	**26.89%**
June 2008	GE24	3	8.83	99.41	680	1132
Dec. 2008	GE24		8..81	51.59	560	818
Feb. 2009	GE24		8.93	41.75	480	523
Percent reduction (%)				**58.00%**	**29.41%**	**53.79%**
Dec. 2008	GE40	2	8.22	49.29	360	868
Feb. 2009	GE40		8.2	30.68	300	576
Percent reduction (%)				**37.75%**	**16.66%**	**33.64%**
June 2008	GE40	3	7.8	85.55	1960	944
Dec. 2008	GE40		8.26	36.05	300	839
Feb. 2009	GE40		8.71	21.83	286	630
Percent reduction (%)				**74.48%**	**85.40%**	**33.26%**



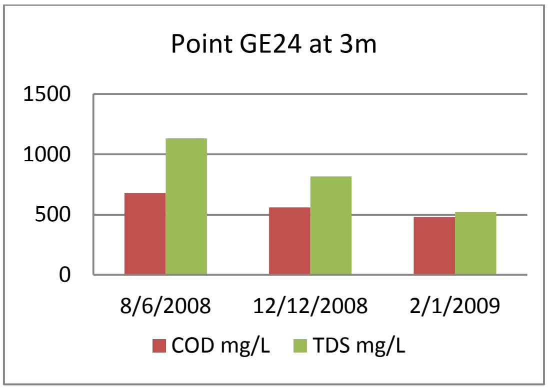
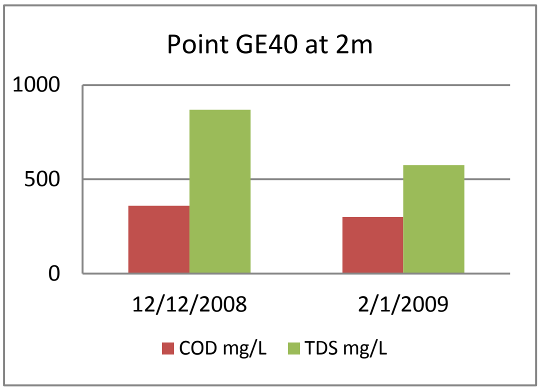


Figure (6.30): Decrease in TOC, COD and TDS in points GE24 at depths 2 and 3m.



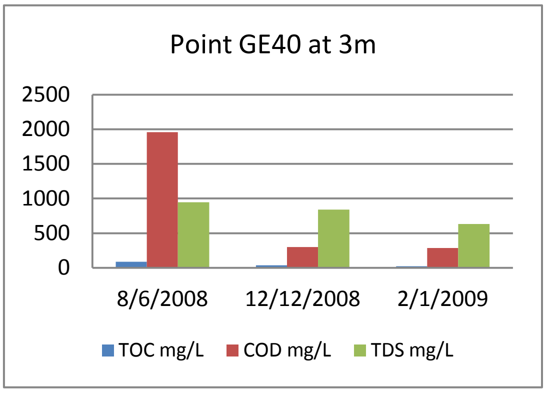


Figure (6.31): Decrease in TOC, COD and TDS in points GE40 at depths 2 and 3m.

Waste composition

Table 6.6 and Figure 6.32 show that the excavated materials was mainly composed of 24% soil/sand, 24% paper, 19% wood, 13% plastics and the remaining 20% was distributed between metals, rubber, glass, textile and construction/demolition debris.

Table (6.6): Mass and percent composition of excavated materials from the project area.

Material Category	Mass (Kg)	Percent composition %
WOOD	158	19
METAL	44	5
GLASS	21	2
PLASTIC	107	13
PAPER	206	24
TEXTILE	26	3
RUBBER	29	3
SOIL / SAND	206	24
CONSTRUCTION /DEMOLITION	31	4
OTHERS, MIXED	25	3
Total	853	100

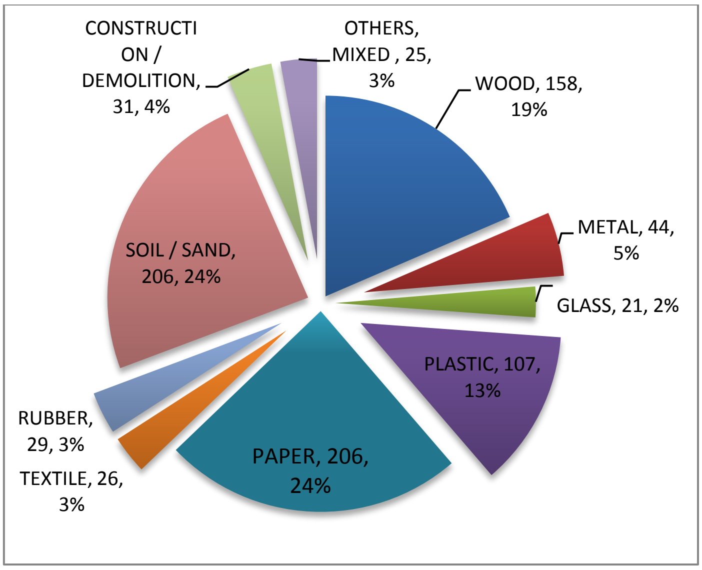


Figure (6.32): Percent composition of excavated materials from the project area.

Figure 6.31 shows examples of some of the excavated materials (i.e., soil and paper) and the apparent effects of the aeration experiment on the degradation of the materials due the aerobic stabilization process.

Before Injection "Aeration" After Injection "Aeration"

Figure (6.33): Photos of the excavated materials before and after the experiment.

6.4 Discussion

A rehabilitation experiment has been planned and conducted in a selected area of 24mx24m on the waste disposal site of Jleeb Al-Sheyoukh near borehole 18. The aim of the experiment was to explore the conditions under which the disintegration process can be accelerated by changing it from anaerobic to aerobic conditions. The air and water injection has been maintained for the period of two years (from October 2008 until October 2010). During this period the settlement and the composition of the landfill gases have been monitored for the whole landfill site.

In addition, after the experiment a large volume of waste was excavated and the composition of the types of wastes was determined and the eluates of waste samples were analyzed for their contents of certain pollutants. In order to evaluate the effectiveness of the experiment and to quantify the changes in the system, the monitoring results have been statistically processed and a comparison between the project area and the rest of the JLF site has been made.

It is well established that the life of landfill waste goes through various stages and phases starting with the "Methane Phase" and ending with the "Aerobic Phase" as illustrated in Figure 6.6 above (see section 6.3.1.1). This process might take several decades depending on the condition of the landfill. The findings of Chapter 5 indicated that JLF was at the end of the "Air Infiltration Phase". Following the application of the aeration experiment, a major shift in the landfill gas phase toward the "Aerobic Phase" occurred in the project area, thus accelerating the decay process and minimizing the life time of the landfill.

The results of the experiment also showed that although the aeration was applied at 3m depth in the project area, the effects were observed to reach a depth of 5m, but to a lesser extent where the LFG phase shifted only to "Carbon Dioxide Phase". The results of LFG monitoring in wells outside the project area showed no shift through the duration of the experiment where the JLF site is still at the end of the "Air Infiltration Phase".

The total VOCs emission from the project area is about one-half of the emission from the low-productivity wells and about one-tenth of total VOCs emission from high-productivity wells in JLF. This significant reduction in VOCs emissions from the project area can be attributed to the high and rapid biological aerobic reactivity taking place in the project area.

If this significant difference is converted into percent reduction in total VOCs emission relative to the emission from the high-productivity wells, then the *in-situ* aerobic stabilization can speed up the decomposition of the biodegradable organic wastes and significantly reduce VOCs emissions by about 89% in comparison with the anaerobic biological reactions which usually needs several decades to decompose the buried wastes. The average emission of ∑BTEX+S from monitoring wells in the project area was significantly reduced from 7752.3 ppb down to 326.5 ppb which is only 200 ppb higher than the measured ∑BTEX+S emissions from the native soil boreholes (125.1 ppb) in the background of JLF site.

The results of the settlement monitoring and the gas composition show explicitly that the decay process has been accelerated in the project area. There is a strong indication that within the first three months the system has changed into aerobic conditions. An effective disintegration process has taken place for about one year. After one year a tertiary phase started and the process was slowed down. The reason for such behaviour could be the decrease of the amount of organic matter or the disintegration behaviour of different types of organic matter. However, it is neither viable nor economically feasible to carry out such rehabilitation measures for longer than one year.

It is expected that the end phase "Aerobic Phase" in the landfills is to be reached in many decades, however, under the aerobic *In-Situ Injection* it was reached in only one year period. In Kuwait, the recovery of the landfill gases through degassing in Qurain landfill is a process that has been applied for almost more than 12 years and yet CH_4 rate is above 60% which considered being still in the Methane phase or long term phase.

After one year of treatment in the project area, the measured waste loss from the settlement results (ca. 88 m^3) would amount to about 5.7% reduction of the waste mass in the project area. However, it should be noted that as the waste degradation proceeds, the solid primary substrates will be broken down and their volume and strength decrease, and therefore, some settlement will occur but at a lesser rate than the waste decomposition suggest (Senior E., 1995). With such a fact, it is expected that some voids would exist within the waste body and will not be accounted for in the calculated settlement rate (5.7%). Hence, a higher waste loss is possible. Assuming a waste volume in the total area of JLF is about 18,000,000 m^3, the waste loss after one year aeration would be more than 1,026,000 m^3.

The results obtained from the chemical analysis of waste eluates showed noticeable decrease in the concentrations of certain parameters (TOC, COD and TDS) before and during the aeration period. The drop in COD concentration in the eluate of waste at certain locations of the waste body (e.g. GE40 at 3m) was very significant (i.e., from 1960 mg/l down to 160 mg/l). This decrease would indicate the accelerated decomposition initiated by the aeration process.

Waste in landfills may become a repository of raw materials or valuable materials for future generations (Spillmann *et.al.* 2009 and 2001). After the aeration experiment conducted in the project area, the materials excavated from the project site showed types and quantities that can be utilized in various processes and purposes. The percent composition of the waste was as follows: 24% soil/sand; 24% paper; 19% wood; 13% plastics and the remaining 20% were composed of other materials (metals, rubber, glass, textile and construction/demolition debris). If these results where to be extrapolated on JLF site where the volume of waste materials is estimated at 18 million m^3, then the approximate quantities of useable materials would be estimated as follows: soil = 4.3 million m^3; paper = 4.3 million m^3; wood = 3.4 million m^3; plastics = 2.3 million m^3; and almost 1 million m^3 of metals . Although the composition and quantities of the excavated materials from the project area may not fully represent those of the whole JLF site, yet it is obvious that such huge quantities would require the need for an integrated management plan and designated facilities for the utilization of materials (i.e., recycling, thermal process, industry, metallurgy etc...).

7 Indirect Monitoring of Waste Disintegration

7.1 Introduction

As described earlier in chapter 6, two years experiment was conducted in a selected area in JLF applying *in-situ* high pressure aeration. Direct monitoring methods were used to assess the relationship between the remediation process including air and water injection and their intervals with the various parameters (such as landfill gases, waste quality and land settlement) set to be as direct indicators for the rate of waste degradation. At the same time and during the aeration experiment, geo-electrical measurements (e.g. calculated resistivity) were also used as an indirect monitoring method to evaluate the behavior of the landfill during the aeration experiment in the project area. In parallel to the direct monitoring methods, both 2 and 3D geo-electrical measurement profiles were performed on weekly, monthly and yearly basis. This chapter presents, discusses and evaluates the results and findings obtained from the application of the indirect monitoring method and to explore its suitability for application on a large scale in landfills with the purpose of minimizing the time, efforts and resources, which are usually needed for the assessment of landfills using the direct monitoring methods.

7.2 Materials and Methods

7.2.1 Geo-electrical tomography setup and measurements

The DC-geo-electrical investigation method (ASTM G57-06, 2006) has been applied in this rehabilitation experiment (air and water injection) as a tool to examine the spatial distribution of the waste and as a method to monitor possible changes in the specific electrical resistivity of the waste during the experiment in the project area. As shown in Figure 7.1, a detailed setup of the geo-electrical measurements was designed and conducted in an area of 64m×64m around the area of borehole 18. Three sets of 3D geo-electrical measurements were performed before, during and after the aeration experiment, as listed in Table 7.1. As shown in Figure 7.1, the setup consisted of 10 measuring profiles in the easterly direction (E) and 11 profiles in the northerly direction (N). The distance between each profile in both directions was set at 4m. In each profile, a total of 64 electrodes have been used at a separation of 1m with a maximum depth of 11.5 m. The measurement configuration was chosen according to Wenner to Wenner Array configuration (ASTM G57-06, 2006).

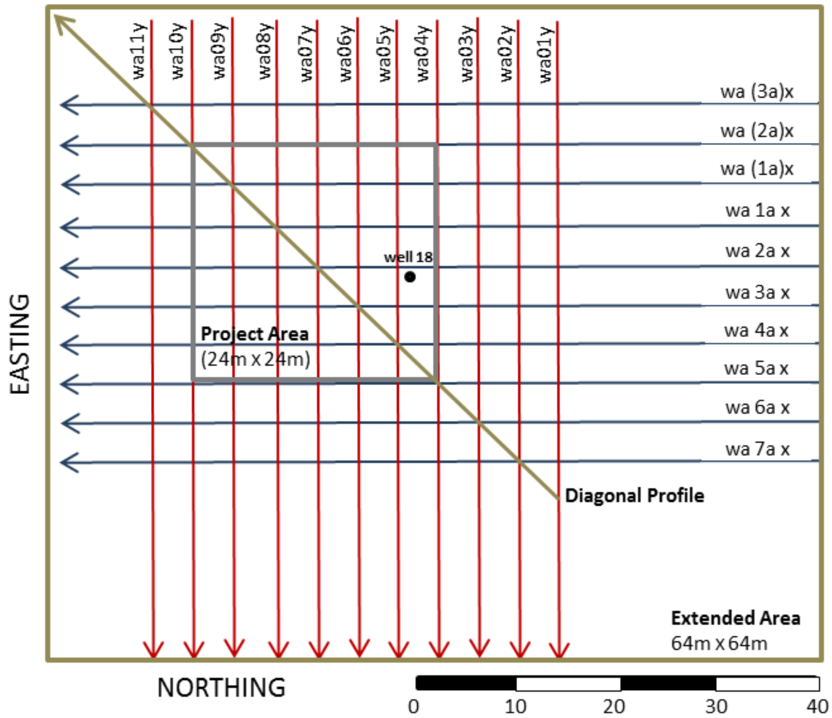


Figure 7.1: Layout of the geo-electrical survey covering the project area.

Table (7.1): Set up of the 3D geo-electrical measurement profiles.

	3D Geo-electrical Measurement Profile		
	1st Set	**2nd Set**	**3rd Set**
Date (start – end)	26/3 – 17/4, 2008	28/12/2008 – 7/1/2009	6/8 – 16/8, 2010
Configuration	Wenner α Wenner β	Wenner α Wenner β	Wenner α Wenner β
Distance between profiles (m)	4	4	4
Distance between electrodes (m)	1	1	1
Maximum depth (m)	11.5	11.5	11.5
Project Status (Air & water injection)	Before	During	4 months after the project completion

The 1st set of 3D geo-electrical profile was conducted before the start of the aeration experiment in order to set the baseline information about the measured resistivity for future comparison during and after the implementation of the air and water injection. The selection of the project area "24m×24m" was made feasible from this set of measurements.

The 2nd set of 3D geo-electrical profile was conducted for a period of 10 days during the aeration experiment to monitor the changes in resistivity and to assess the influence of the injected air and water within and around the project area.

The 3rd and final set of 3D geo-electrical measurements were conducted in August 2010 to assess the effects on resistivity following the completion of the experiment on April 4th 2010.

Additional 2D geo-electrical measurements were conducted along a transverse profile (see Figure 7.1, above). Table 7.2 lists set up of the 2D geo-electrical measurement profiles. This profile consisted of 64 electrodes using 1m spacing with a maximum depth of 11.5 m electrical penetration.

The measurement configuration was chosen according to Wenner Array (ASTM G57-06, 2006). The measurement of the transverse profile took place for the first time on October 18th 2008 (before the start of the aeration experiment) to set the baseline of resistivity along this profile. On 18th November 2008 (1 week after the start of the experiment, 6th November 2008), the measurements along the transverse profile were conducted on weekly basis until December 29th 2010. This diagonal profile in the project area would allow the continuous assessment of changes in resistivity on weekly basis allowing the follow up of the expected rapid changes occurring in the waste body due to the accelerated rate of decomposition as a result of the injected air and water.

Table (7.2): Set up of the 2D geo-electrical measurement profiles.

2D Geo-electrical Measurement Profile	
Date (start – end)	18th October, 2008 - 29th December 2010
Configuration	Wenner α , Wenner β
Distance between electrodes	1m
Profile length	63m
Maximum depth	11.5m
Frequency of measurement	weekly
Project Status (Air & water injection)	Before , during and after

7.3 Analytical procedures

7.3.1 Resistivity Measurement

The geo-electrical measurements have been carried out in the project area using the same resistivity meter ARES (Automated Resistivity Meter) and '64 multi-electrodes' method, which was applied in section 5.2.2.6, above. Field measurements were conducted in accordance with method described by The American Society for Testing and Materials (ASTM G57-06, 2006). The geo-electrical measurements were performed along the 21 profiles and the diagonal profile as shown in Figure 7.1, above. The distance between the electrodes (used spacing) was chosen to be 1m and the Wenner-Schlumburger configuration was used (ASTM, 2006).

The results of the measurements were interpreted by using of the interpretation program DC2DINVRes. The measured resistivity was used as input-resistivity for creating 2D geological surface models.

7.3.2 Data Modeling Using GOCAD

To obtain the geometry of the waste body in the project area, the boreholes and the geo-electrical cross sections have been modeled using the 3D program GOCAD as previously described in section 5.2.2.6, above. GOCAD stands for Geological Object Computer Aided Design, which is a computer-aid approach for modeling of the geometry and properties of geological objects in the subsurface. With GOCAD consistent models can be built by using data of diverse types from heterogeneous origins and of different spatial distribution.

The model allows the combination of drilling data with geo-electrical data. The resultant model can be rotated in all three dimensions and sliced at any intervals in x-, y- and z-directions. The results of the GOCAD 3D modeling can show the shape of the different layers and the visualized images can be rotated in all directions. Furthermore, the program is able to calculate the volume of every layer or visualize it separately.

7.4 Results

7.4.1 Geometry of the Project Area

The results of the resistivity measurements conducted during the 1st geo-electrical field survey (26/3 – 17/4, 2008) along the 21 profiles in an area of 64m×64m (see figure 7.2) showed various values ranging from 1 Ω.m to more than 400 Ω.m . The results of these measurements were compared with the resistivity classification of various materials presented in chapter 5 (see table 5.3). In order to visualize the geometry of the waste body and the surface morphology of the project area, the results of the geo-electrical profiles and the detailed topographic survey have been used for the 3D modeling using the software GOCAD. The results of the GOCAD showed that the 64m×64m area is mostly filled with organic waste to a depth of 10m, except an area of native soil, which falls within the project area and the extended area, as shown in Figure 7.3. The thickness of the cover layer is presented in Figure 7.4 as isolines image.

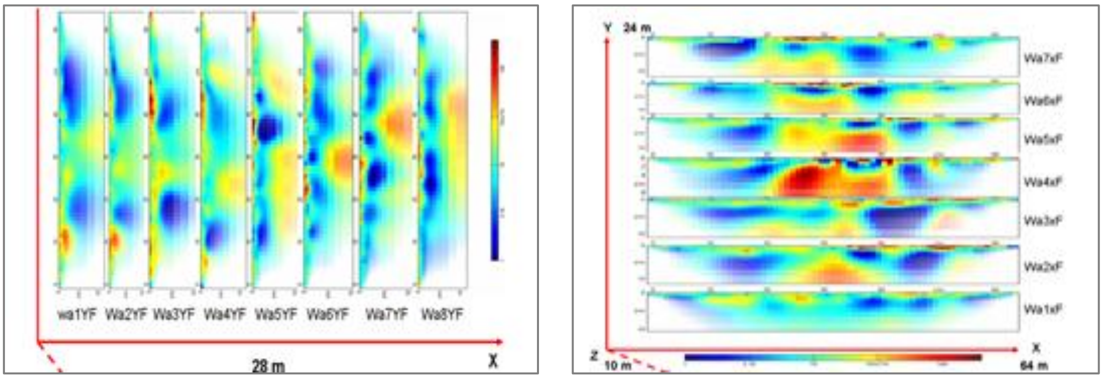


Figure (7.2): Measured resistivity along the Northing and Easting profiles (high resistivity shown in red color indicates the native soil).

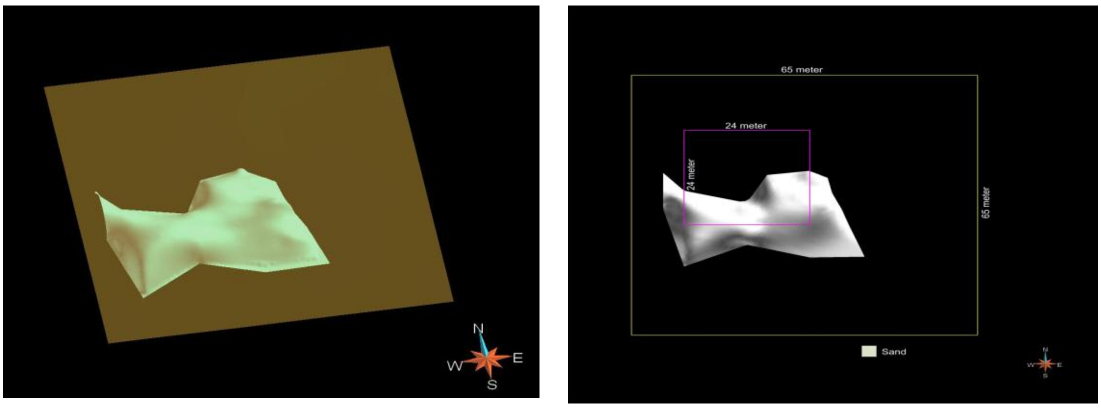


Figure (7.3): 3D image of native soil in the extended area.

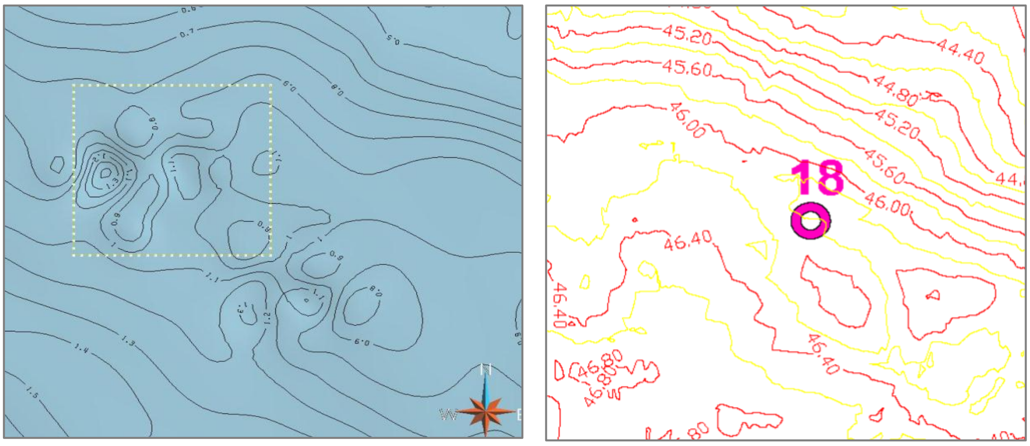


Figure (7.4): Thickness of the cover layer in the project area.

In addition, 25 borehole logs in the selected project area (24m×24m) were used to verify the above mentioned findings (the data of these boreholes are presented in Appendix 6) and were also used later for the aeration experiment.

7.4.2 Behavior of the landfill during the aeration process

7.4.2.1 2D Geo-electrical Assessment

The measured resistivities along the diagonal (transverse) profile were used to investigate the temporal changes of the resistivity before, during and after the aeration experiment. 2D measurements were performed along the diagonal profile on weekly basis where the total number reached 108 weeks. Figure 7.5 shows selected profiles for weeks: 1(before aeration); 48 (maximum measured resistivity); 56 and 68 (during aeration); 80 (lowest measured resistivity) and 108 (final measurement profile). Selected sets of calculated profiles (on a monthly basis) are presented in appendix 7.

A time-based analysis on the measured data has been made and the resistivity profiles have been visualized on monthly basis as presented in Figure 7.6. The initial profile of October 18th 2008 is considered as the baseline profile (i.e., before the injection experiment started) where the resistivity decreased from 12.71 Ω.m at a depth of 2.17 m down a lowest value 3.81 Ω.m at a depth of 3.5 meters and then gradually increased up to a value of 22.5 Ω.m at a depth of 11.6 meters. It is clear from figure 7.6 that the measured resistivity at various depths followed almost the same trend as the baseline profile.

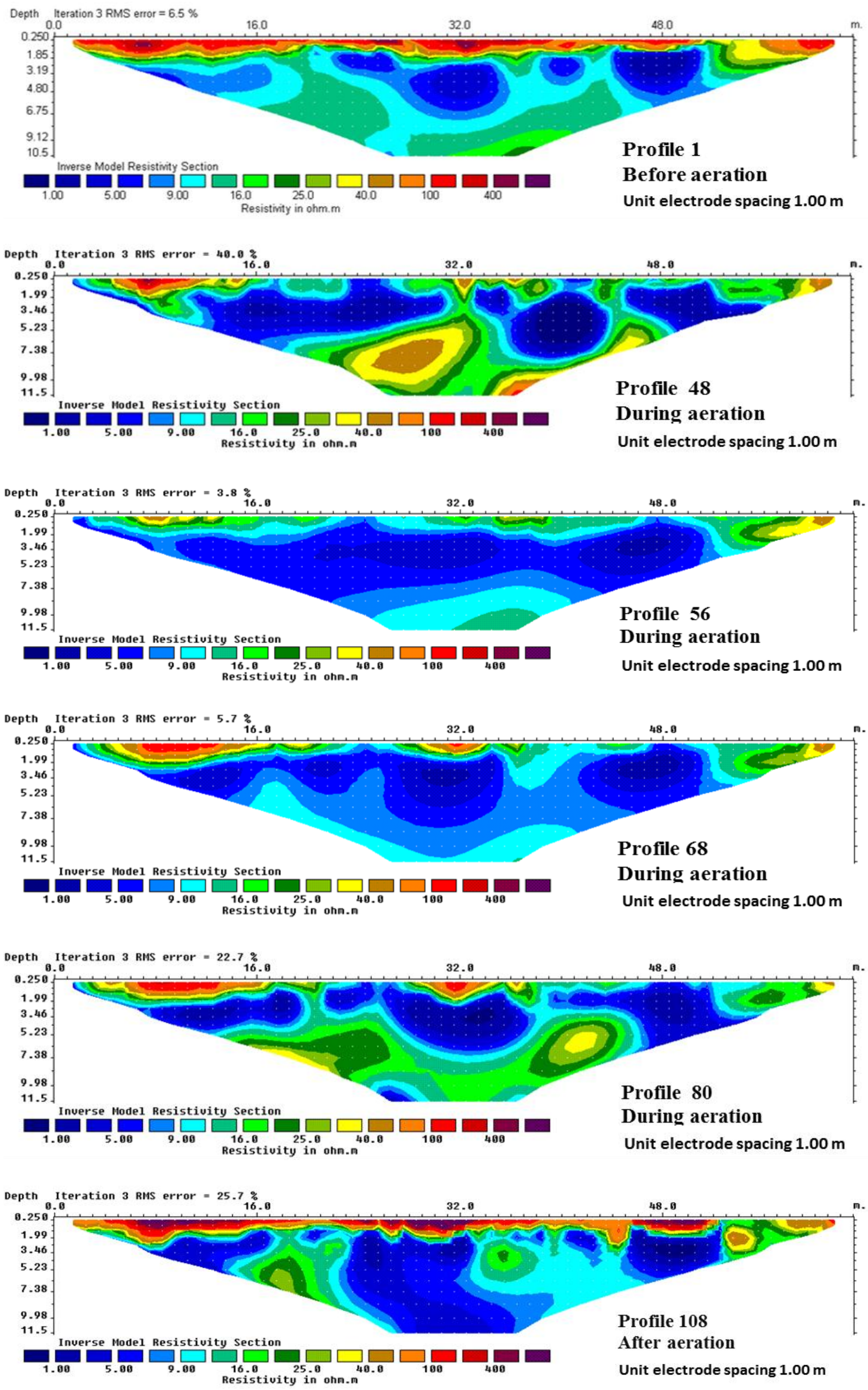


Figure (7.5): Measured resistivities along the diagonal (transverse) profile in selected weeks (1, 48, 56, 68, 80 and 108).

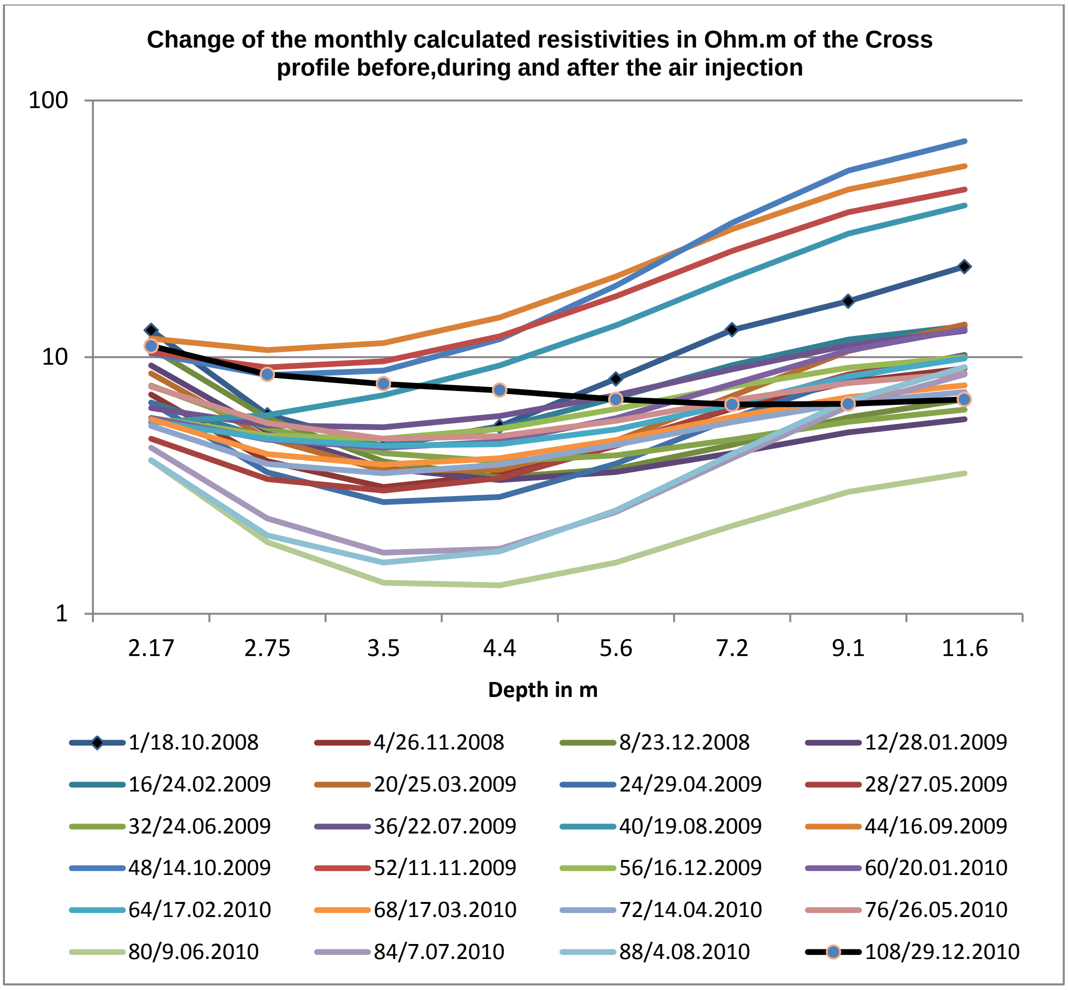


Figure (7.6): Resistivity of the cross profile presented on monthly basis. (Number before the date represents the week number from the start of 2D measurement, 108 weeks in total).

To investigate the influence of the water supply on the disintegration process and thus the production of methane and carbon dioxide gases, the measured resistivities along the diagonal profile has been assessed for possible existence of a relation between them (i.e., water supply, gas production and resistivity).

Figure 7.7 shows the relationship between the intervals of water supply and the measured resistivities. The graph shows an obvious phase shift of about 3-4 months between the trends of the water supply and the electrical resistivity. For instance, the suspension of water supply in the period between March and July 2009 caused a noticeable increase in the electrical resistivity between July and September 2009. Hence, only the air injection has influenced the resistivity in this period (possibly leading to the dry out of the waste matrix).

As shown in Figure 7.7, the water injection has caused (apart from the suspension period) a decrease in the resistivity. The resistivity was measured on the 24.03.2008, 8 months before the experiment started and a value of 14.7 Ω.m has been obtained.

After water injection of almost four months at the beginning of the test (period1), the resistivity decreased from 14.7 Ω.m to about 3.4 Ω.m (period 2). The resistivity in period 2 could not be maintained at a very small water supply index. The water supply index is the ratio of the time period of water injection to the time period of air injection.

As the water injection in period 3 was fully stopped, it took about four months for the resistivity to be increased (period 4). The resistivity increased back in period 4 to the original value (14 Ω.m). In period 4 water injection started in higher intensity reaching a water index of about 0.02. This has caused again a decrease of the resistivity to a value of about 2-4 Ω.m as shown in period 5. Again it took 4 months for the water injection to influence the resistivity.

The following conclusion can be drawn from this experiment:

Geoelectric measurement (resistivity) can be considered as indicator for the needed water content in the rehabilitation process.

The influence of the water injection (rate and intensity) needs about 4 months to reach the optimum condition for the disintegration process. This applies under the given conditions at Jleeb (arid conditions, organic waste in the methane phase, injection conditions, etc.).

To maintain optimum conditions (under given situation) the water injection should cause a drop of the resistivity by about 80% (from 14.7 Ω.m to about 3 Ω.m). This means the water content in the waste body increases up to a value of more than 25% which is required for the optimization of the disintegration process.

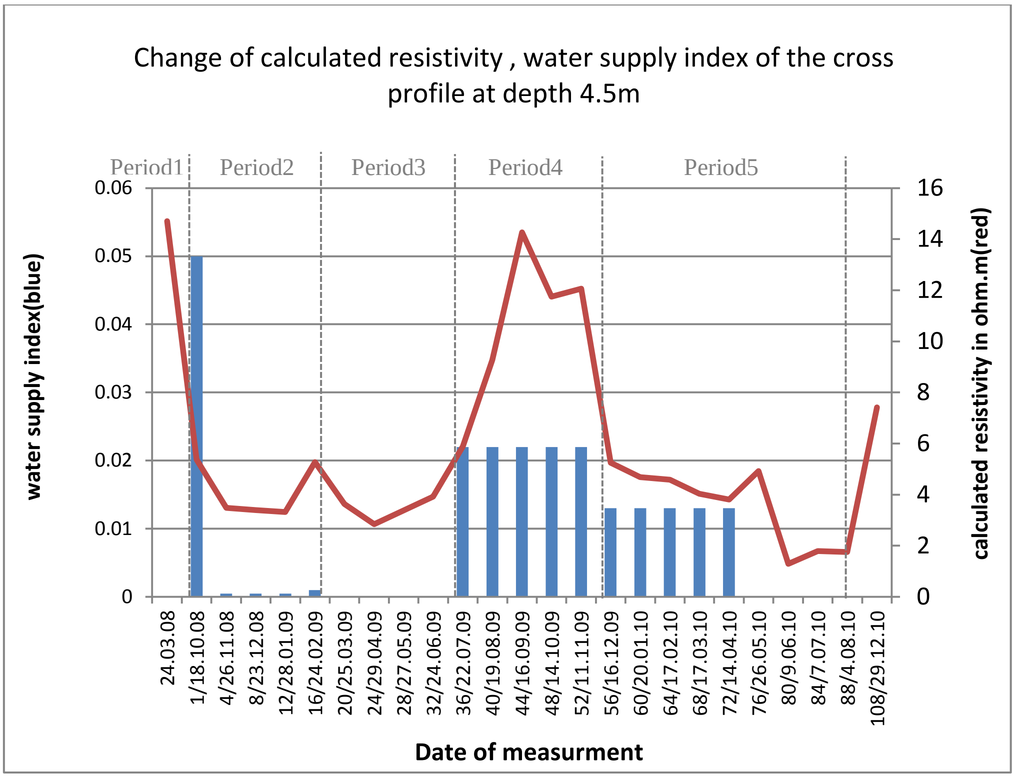


Figure 7.7: Changes of calculated resistivity (in red) and water supply index (in bleu) of the cross profile at depth 4.5m.

As shown in Chapter 6 (figures 6.6 and 6.8), the period of March till July 2009 showed an increase of the production of methane and accordingly an increase of the ratio methane/carbon dioxide. The suspension of water injection has led to decay slowdown, since the waste started to dry out due to the injection of air only. Thus for the process of aerobic decomposition moisture is needed and can be monitored by geo-electrical methods.

As shown in figure 7.8, profiles measured in weeks 40, 44, 48, and 52 (after the water injection was stopped in April 2010) showed the highest shifts in the measured resistivity where it reached almost 69.51 Ω.m at a depth of 11.6m, whereas the same depth showed much lower resistivity in week 80 reaching 3.53 Ωm.

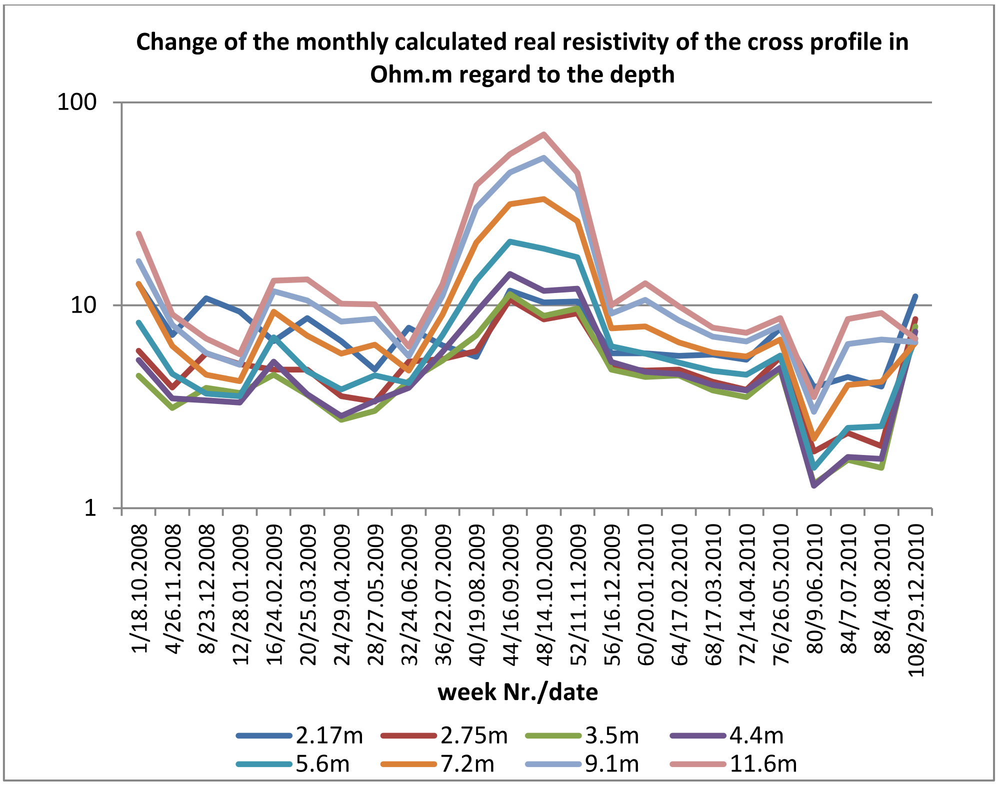


Figure (7.8): Monthly resistivity of the cross profile for different depths.

Figure 7.9 compares the initial baseline profile of 18th October 2008 (week 1) with the final profile of 29th December 2010 (week 108). It is apparent from this figure that the measured resistivities in the final profile started to increase up to a depth of 5.6m in the region of the waste and decreases starting from 5.6m depth in the region of the native soil. This anomaly is most pronounced in the deep region of the native soil.

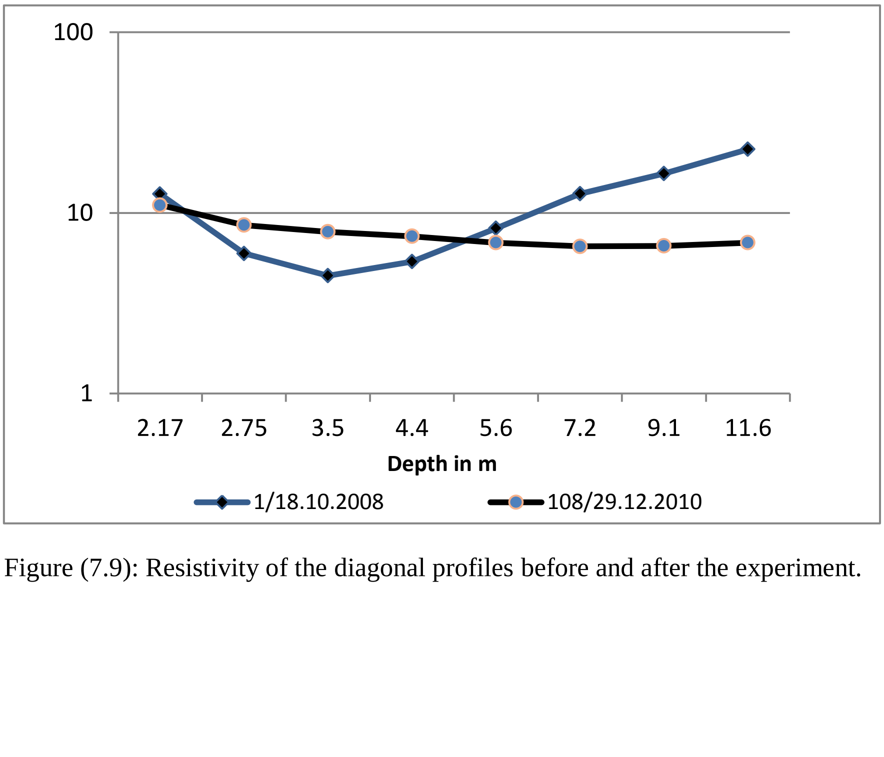


Figure (7.9): Resistivity of the diagonal profiles before and after the experiment.

The changes in resistivity between 2008 and 2010 are illustrated in Figure 7.10, where it is clear that the low resistivity measured in the region up to 5m depth (the region of organic waste) has increased by about 3Ωm, whereas in the deeper region (the region of native soil with originally higher resistivity values), showed a significant decrease in resistivity of about 10 Ωm.

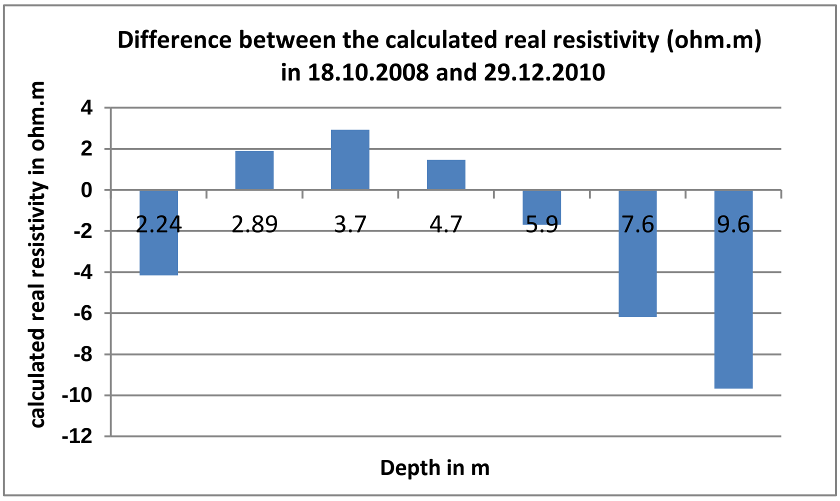


Figure (7.10): Resistivity development between 2008 and 2010.

Figure 7.11 shows a comparison of two measurements (vertical electrical sounding) conducted in 2007 and 2011 along the profile BC1 in the total area of the landfill site (see figure 7.12). It is apparent from figure 7.11 that the resistivity values in the deeper waste region starting from 8m depth showed minor changes, whereas the resistivity of the region 3-7m depth were subject to major changes.

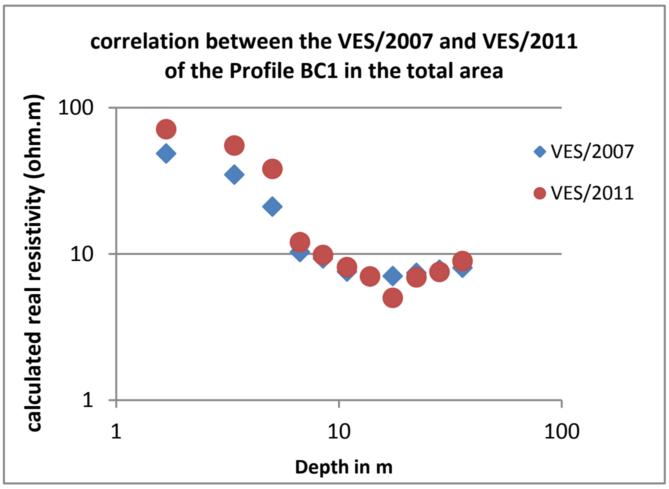


Figure (7.11): Comparison of the resistivity measured in 2007 and 2011 for the BC1 profile.

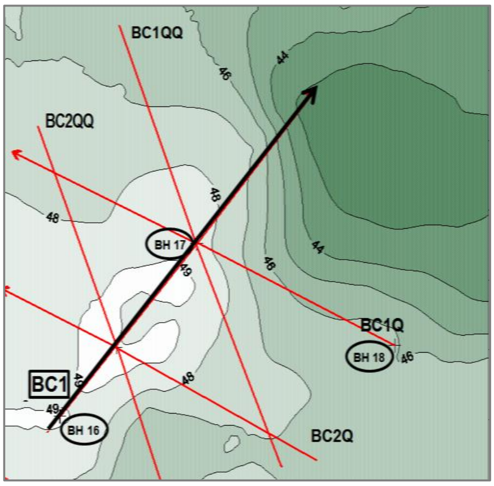


Figure (7.12): Location of BC1 profile in the total area (black arrow).

7.4.2.2 3D Geo-electrical Assessment

In order to assess the effects of aeration on the measured resistivity, a series of 3D geo-electrical measurements were conducted in an area of 64m×64m (21 profiles covering the project area and its surroundings) before, during and after the aeration experiment. GOCAD software was used to combine the results obtained during the 1st set of measurements (2008) to produce 3D image of the initial situation of the project area before commencing the aeration experiment (see figure 7.13). In addition, the results of the 25 borehole logs drilled were also used to verify the subsurface measured resistivities. It was found that the subsurface within the area of 64m×64m is composed of a cover layer up to 2m thick, waste layer ranging from 2-8m thick and a native soil starting as from 8m depth. Figure 7.13 also shows that the waste in the larger investigation area 64x64m is separated by a ridge of native soil.

Figure 7.14 shows a decrease of the resistivity due to water injection. Even the native soil in the deeper regions is obviously water saturated, and hence shows in general small resistivity. After the end of the experiment and the termination of air and water injection, the resistivity increased as shown in Figure 7.15. Statistical calculations were made on the real measured resistivities for each of the 21 profiles in order to determine the minimum, maximum and mean values for each profile and each year (2008, 2009 and 2010). Table 7.3 shows the lowest and highest measured resistivities for the three conducted 3D sets. For example, the minimum measured resistivities for the 21 profiles conducted in the year 2008 ranged between 0.14 Ω.m (lowest) to 2.81 Ω.m (highest) with a mean value of 1.411 Ω.m. Similarly, the maximum measured resistivities for the 21 profiles conducted in the year 2008 ranged between 36.12 Ω.m (lowest) to 120.9 Ω.m (highest) with a mean value of 83.676 Ω.m.

Resistivity measurement in landfills is largely influenced by the water content and the saturation of the waste (Yoon and Park, 2001; Carpenter et.al, 2009). Therefore, it was expected that the resistivity would decrease after the injection of water in the boreholes. This was apparent in the noticeable decrease in measured resistivities in the second set of 3D image (figure 7.14). For example, as presented in Table 7.3 and figures 7.16 and 7.17 that the mean maximum resistivity decreased from about 83.676 Ω.m in the year 2008 to about 46.878 Ω.m in the year 2009. After the end of the experiment, the resistivity increased to about 144.07Ω.m in the year 2010.

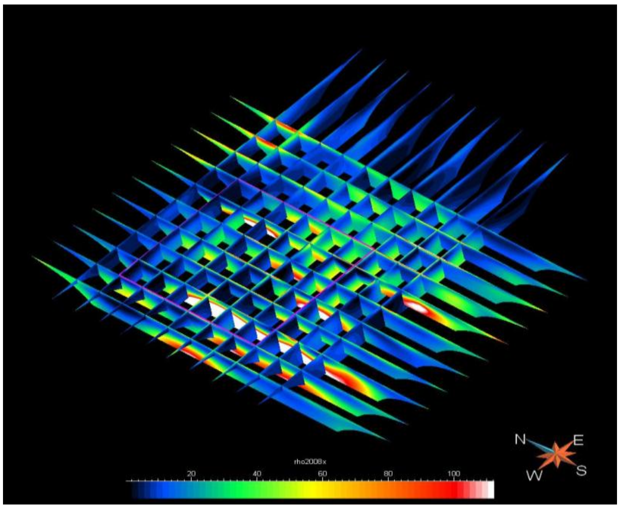


Figure (7.13): Results of the first 3D geo-electrical survey (2008) before the aeration experiment. Blue color represents organic wastes, whereas colors from green to white in the resistivity scale represent native soil with varying degrees of water and silt contents.

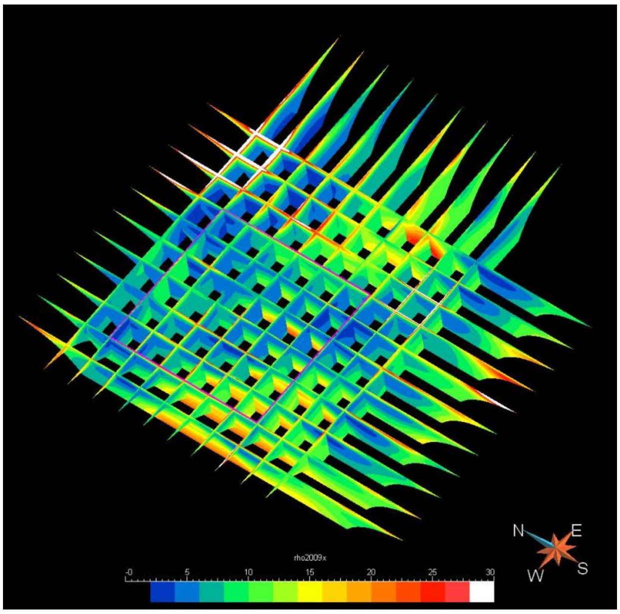


Figure (7.14): Results of the 3D geo-electrical survey (2009) after the aeration experiment

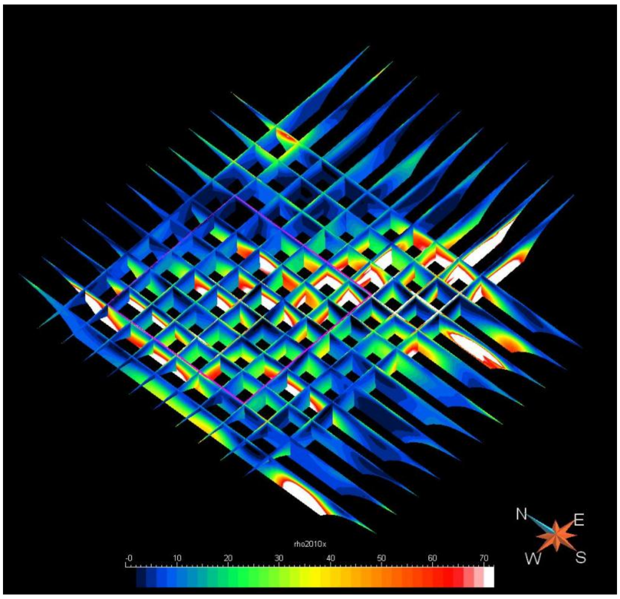


Figure (7.15): Results of the 3D geo-electrical survey (2010) after the end of the aeration experiment.

The processing of the 3D sets of results conducted in 2008, 2008 and 2010 in the project area (in both measuring directions) indicates that the mean of the average values of resistivity in the measurement taken in 2010 is about 5 Ωm higher than those taken in 2009 and 2008.

One should keep in mind that the geo-electrical survey conducted in 2010 has been carried out 4 months after the termination of the experiment. Therefore, the increase in resistivity is possibly the result of the accelerated drying of the waste due to disintegration and air injection.

Table (7.3): Statistical values of the real resistivity in the easterly and northerly direction.

Statistical values, calculated for real resistivity in the easterly direction of the performed geo-electrical surveys 2008, 2009 and 2010						
	Year	Lowest	Highest	Overall Mean	Average deviation	Standard deviation
Minimum	2008	0.14	2.81	1.41	0.62	0.79
Maximum	2008	36.12	120.90	83.68	27.30	31.59
Mean	2008	9.31	14.79	11.43	1.33	1.69
Minimum	2009	2.47	4.76	3.82	0.62	0.76
Maximum	2009	36.17	70.59	46.88	8.22	10.76
Mean	2009	9.66	11.22	10.44	0.43	0.54
Minimum	2010	0.67	2.61	1.62	0.60	0.68
Maximum	2010	52.46	290.67	144.07	74.97	88.24
Mean	2010	8.91	29.75	15.77	5.66	7.04
Statistical values, calculated for real resistivity in the northerly direction of the performed geo-electrical surveys 2008, 2009 and 2010						
Minimum	2008	0.20	2.86	1.54	0.65	0.82
Maximum	2008	41.90	161.87	83.91	31.59	40.32
Mean	2008	9.18	21.24	12.23	2.11	3.33
Minimum	2009	2.43	4.06	3.26	0.36	0.48
Maximum	2009	30.21	68.79	45.15	11.58	13.86
Mean	2009	9.62	13.54	11.31	0.96	1.17
Minimum	2010	0.27	2.15	1.31	0.45	0.56
Maximum	2010	92.95	441.04	197.14	75.88	105.10
Mean 10		14.04	25.29	17.38	2.96	3.98

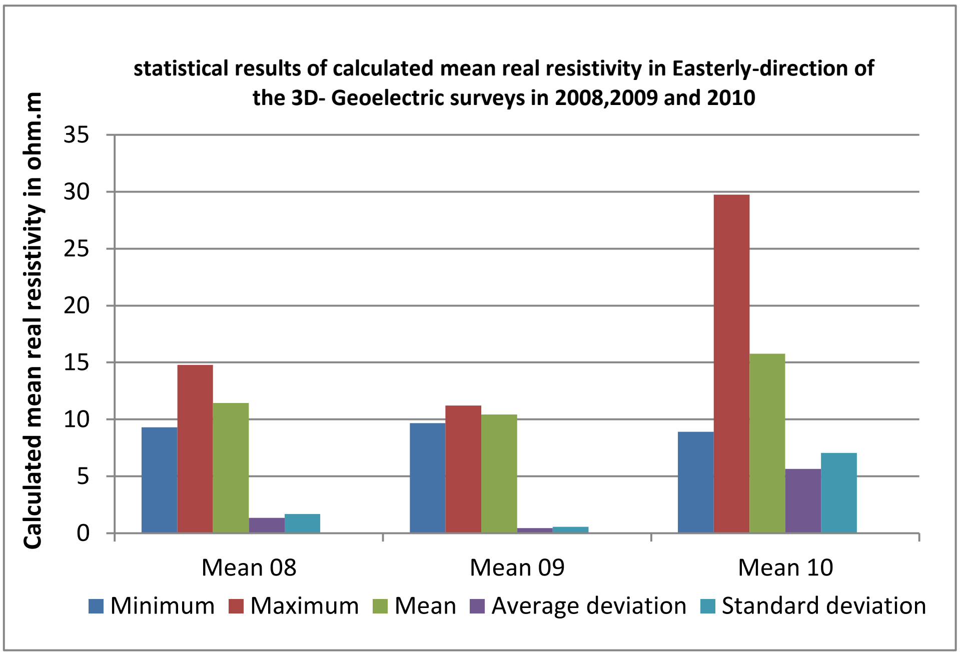


Figure (7.16): Statistical results of the resistivity surveys (easterly direction).

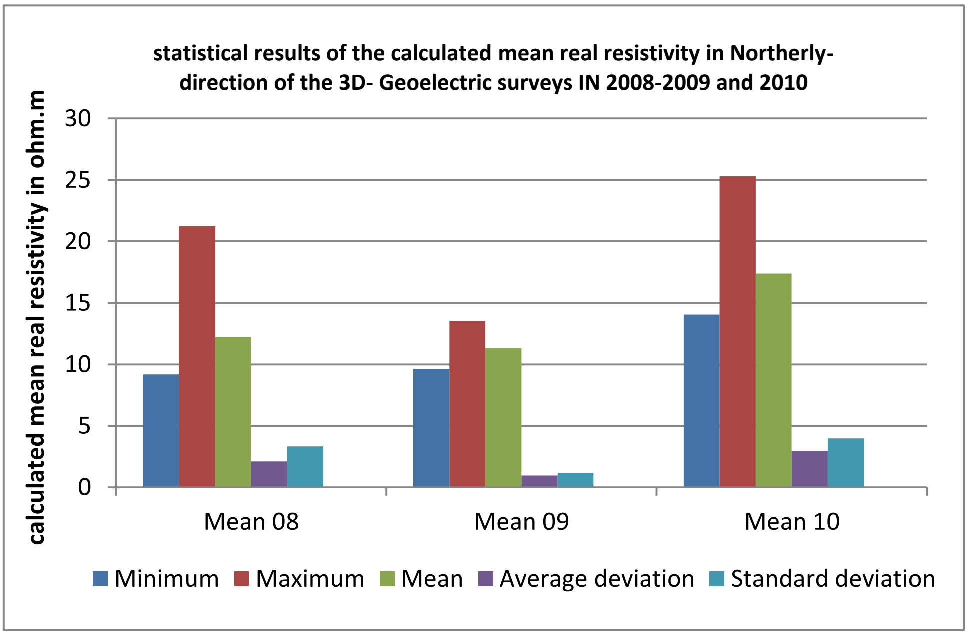


Figure (7.17): Statistical results of the resistivity surveys (northerly direction).

7.5 Discussion

The results of the 1st set of 3D geo-electrical measurements conducted before the start of the experiment showed that the area is mostly filled with organic waste to a depth of 10m, except an area of native soil, which falls within the project area (24m×24m) and the extended area (64m×64m).

The statistical processing of the 3D sets of results conducted in 2008, 2009 and 2010 in the project area (in both measuring directions, see table 7.3) showed that the overall mean value in the easterly direction increased from 11.42 Ω.m in 2008 to 15.76 Ω.m in 2010 (about 38%). Similarly, the overall mean value in the northerly direction increased from 12.22 Ω.m in 2008 to 17.38 Ω.m in 2010 (about 42.22%). This significant increase in the overall mean resistivity values after the aeration experiment is most probably related to the changes occurred in the physical properties of the buried materials due the disintegration processes.

Results of the 2D weekly measured resistivities along the diagonal (transverse) profile, after the experiment, also showed a maximum increase of about 3 Ω.m at a depth of 3.7m (the region of organic wastes). Nevertheless, it should be noted that resistivity measurements are affected by the water injected during the experiment. This was observed in the decrease in resistivities measured during the aeration experiment where the overall mean value decreased in the easterly direction from 11.42 Ω.m in 2008 to 10.43 Ω.m in 2009 (about 9.49% reduction). Similarly, the overall mean value decreased in the northerly direction from 12.22 Ω.m in 2008 to 11.30 Ω.m in 2009 (about 8.14% reduction).

The results revealed the possibility of applying the indirect monitoring for the assessment of high-pressure *in-situ* aeration method for detecting the changes occurring in the waste matrix with reference to the physical properties measured by the resistivity. The geo-electrical measurements appeared to be a possible alternative to minimize the cost, time and efforts spent in the monitoring of the landfills during the rehabilitation process, yet it is to take into consideration the constrains to have a better and more reliable results.

The results also show that geo-electrical measurement, as an indirect method to assess the rehabilitation process, is largely affected by the amount of the injected water. Therefore, a direct indication of the degradation process could not be exactly identified by measuring the resistivity due to the above mentioned effects of water and air injection. Hence, an indirect assessment of the degradation process using the geo-electrical method is not easily feasible.

The heterogeneous nature of the landfills (for example; the waste type, compaction rate, water content) doesn't allow the proper control and monitoring of influencing parameters through the geo-electrical measurements. This was observed during the experimental work applied in the project area in JLF. Thus the design of experimental work in a controlled environment is needed.

Although the 3D image of the resistivity of the waste body provides detailed picture about the structure and status of the landfill, yet it requires a lot of efforts and resources if it was to be applied on large-scale landfills. Therefore, well-chosen and designed 2D profiles would be a good alternative which can be implemented on short intervals, and hence would cover larger areas with minimum time and resources.

8 Conclusions

The government of Kuwait is facing a major challenge in the post-closer management of landfills. Till date, fourteen landfill sites are closed from operation (17.76 km^2, about 61% of the total landfill area in Kuwait). All of these ‘closed’ sites are located within close proximity of human habitation, thereby posing concerns on their health and environment and deserve proper management. The current assessment of landfills in Kuwait conducted in this research showed that 44% of the landfills have no rehabilitation programs, and only partial rehabilitation has been carried out for 2 sites (constituting 11% out of the total landfill area), whereas about 7 landfills (39%) are being protected by control measures, which largely involve fencing and restriction for trespassing.

Full-scale assessment program, conducted in JLF site, revealed the heterogeneous nature of JLF, caused due to improper dumping of waste materials. This conclusion was drawn from the classification of resistivities of the subsurface materials in JLF, which was developed for the first time in Kuwait as part of this work. This further helped in reconstructing the JLF into 4 distinct parts: a cover layer, construction waste, organic waste and/or contaminated soil, and a native soil body underneath the landfilling area.

The current status of the landfill is found to be approximately at the middle of "Air Infiltration Phase". It is found that the humidity content is low and the cover layer has sufficiently high infiltration rates. It is therefore expected that favoring conditions may allow increase in humidity within the waste body, which in turn will accelerate the biological process toward the production of higher amount of LFG’s driving the landfill to second LFG phases called the "Long-Term Phase".

The settlement rate is found to be very low (2.8 cm/year) due to the poor decaying process. Groundwater beneath the landfill is found un-affected to a large extent due to very low production of leachate. The observed slow biodegradation in the landfill is likely to increase the aftercare period further, and hence the environmental impacts and associated economic costs are likely to increase.

In conclusion, it is essential to select the best rehabilitation alternatives to restore the land and shorten the aftercare period in order to prevent future environmental impacts and also to save on increasing demand for costly land. Hence, it is important to better understand the influencing factors on the rehabilitation process under such arid conditions. This study helps not only to explore the best rehabilitation conditions, but also to optimize the rehabilitation measures and to deliver the tools for the quantification of the success of these rehabilitation measures.

The aerobic *in-situ* stabilization method, as a rehabilitation alternative for restoration of closed landfill sites, was experimented for the first time in Kuwait. It resulted in a major shift in pushing the landfill gas phase toward the final phase called "The Aerobic Phase", by accelerating the process of decay, and by minimizing the life time of the landfill. This was achieved within the first three months itself, where the system fully changed into aerobic conditions, and triggered effective disintegration that continued for about a year. In contrast, the recovery of landfill gases through degassing in Al-Qurain landfill has lasted for over 12 years and yet CH_4 rate is above 60%, which indicates that the landfill is still passing through the "Methane Phase" or "Long Term Phase".

It is also found that the *in-situ* aerobic stabilization (applied in JLF) can significantly reduce the emissions of volatile organic compounds (VOCs) by about 89% in comparison with the anaerobic biological processes. These findings are supported by the results of the chemical analysis of waste eluates showing noticeable decrease in the concentration of select parameters compared between pre-aeration and aeration period, indicating accelerated decomposition due to induced aeration.

After one year of applying aerobic *in-situ* stabilization in the "Project Area", the measured loss of waste volume, interpreted from the settlement results (ca. 88 m^3) amounted to about 5.7% reduction in the volume within the "Project Area". Assuming the total waste in JLF to be about 18,000,000 m^3, the loss after one year of aeration could yield more than 1,026,000 m^3.

Taking the extrapolation further based on the composition of the excavated material from the samplings carried out during the present study, the approximate quantities of useable materials in the entire JLF could be estimated as follows: soil = 4.3 million m^3; paper = 4.3 million m^3; wood = 3.4 million m^3; plastics = 2.3 million m^3; and almost 1 million m^3 of metals. Although, not fully representative of the whole JLF site, these huge figures are large enough to justify the need for an integrated management plan and designated facilities for the utilization of the excavated materials (i.e. recycling, thermal process, industry etc...).

It should be noted that Kuwait's 4th Master Plan approved two phases of the proposed expansion plan of Kuwait International Airport, which overlaps with the defined boundary of JLF site. It is critical that the government postpones the second phase of Airport expansion, until a full rehabilitation is carried out in the JLF and 7th Ring Road (North) landfill sites.

The use of the ‘resistivity measurements’, as an indirect technique to monitor the landfill disintegration, during the application of ‘aerobic *in-situ* stabilization’ is explored. The results of extensive 2D and 3D resistivity measurements showed 40% increase in the overall mean value, which is a reflection of possible changes in the physical properties of the buried materials due to the disintegration of waste. The geo-electrical measurements thus appear to be a possible and potential alternative to the conventional direct monitoring methods; which are economical in cost, time and efforts spent in the monitoring of the landfills. However, like any other indirect method it has constraints that should be carefully taken into consideration. The results of resistivity measurement showed direct influence of the amount of injected water, which must be carefully handled during the interpretation of results to avoid mistakes.

Although, 3D resistivity measurements provided detailed picture of the structure and status of the landfill, it requires large amount of efforts and resources to be applied on larger landfills. A well-planned and designed 2D resistivity measurement could be a good alternative, which can be implemented in short intervals, and hence would allow larger area coverage by utilizing minimum time and resources.

In conclusion, the results obtained in this research clearly demonstrate an urgent need for assessment of all landfill sites in Kuwait, especially those posing significant socio-economic and environmental impacts. The lessons learnt from this work carried out in JLF site can be adapted and applied in other landfills of similar nature. The "*in-situ* aerobic stabilization" proved very promising for reducing environmental impacts, and for safe reclamation of landfills constituting about 3% of the urban/municipal area of Kuwait.

9 Recommendations

Throughout the course of this research many issues were addressed to enhance and improve the waste management policies, research, and technologies for assessment, monitoring and rehabilitation of landfills. Summary of these recommendations is given as below:

Adopt a new waste management approach that considers utilization of high-value materials and energy recovery. Immediate need for mechanical, biological and thermal treatment should be considered to minimize environmental impacts associated with uncontrolled landfilling practices.

Develop clear and defined rules and responsibilities for waste handling in order to regulate the waste cycle (production, generation, collection, transportation, and disposal). Such rules and responsibilities should include producers, government authorities, private sector and others.

Develop necessary legislations and regulations that cover the entire waste management process in Kuwait. This should be updated and revised frequently in order to accommodate changing needs.

Develop a national master plan for waste management in Kuwait, which must incorporates all related stakeholders and sectors (i.e. government, non-government, private, research institutes, etc.). The master plan should consider the timeframe for its implementation and set targets to ensure timely goal achievements.

Conduct a comprehensive survey to develop a national geographical database for waste management. The geo-database should allow stakeholders and the public to contribute, participate and share information to help improve the waste management practices.

Establish designated training programs for enhancing national capacities in the field of waste management. Involvement of national and international research institute, universities, and experts is essential to ensure future success of an efficient waste management programme in the country.

The 5th Kuwait Master Plan, which is currently under preparation, should take into consideration the presence of ‘closed’ and ‘operating’ landfills to plan out future land-uses in an around their geographic vicinity.

Develop a priority plan for the assessment and long-term monitoring of landfills in Kuwait. The priority plan should consider best available rehabilitation alternatives according to the nature of individual landfills, types of buried wastes, surrounding land-uses, and environmental and socio-economic aspects.

Government should postpone second phase of expansion of the Kuwait International Airport, which was approved in 4th Kuwait Master Plan, until a full rehabilitation is conducted in the landfill sites of JLF and 7th Ring Road (North).

Develop groundwater vulnerability map by identifying groundwater resources, which are vulnerable to pollution from landfills. The developed map should consider both the existing and future landfill sites.

Adopt ‘resistivity measurements’ (geo-electrical) as an indirect method for the assessment of the subsurface landfill materials, waste types, depth, extent, quantities, boundaries and humidity content. This indirect method will ensure better results in terms of reduced time, efforts and the cost.

Adopt ‘resistivity measurements’ (geo-electrical) as a potential method for long-term monitoring of the waste matrix in landfills. A well-designed 2D-geo-electrical profile can clearly and rapidly present, and track changes occurring in the landfill body to aid the management with better informed decisions.

Adopt ‘resistivity’ based classification index, developed in this research work for the differentiation of subsurface materials in old landfills. This classification index can be further adapted to accommodate other landfill and substrate conditions (i.e. water contents and types of buried materials).

Explore the applicability of other indirect geophysical measurements and methods for the assessment of landfill sites in Kuwait.

Apply "high pressure *in-situ* aerobic stabilization method" in large-scale rehabilitation projects in Kuwait. This method was found as a very promising alternative for the rehabilitation of old landfills in Kuwait. It significantly shortens the aftercare period and associated environmental impacts, thereby reduces the costs.

Adopt the use of magnetic valves in controlling the volume of injected air and its frequency in the landfill body as it worked out as a new cost-effective method. Results were found encouraging for its application in large-scale rehabilitation projects.

Develop an integrated management plan for the excavation of wastes materials from stabilized old landfills following rehabilitation. Expected large quantities would need designated facilities for utilization of the excavated materials (i.e., recycling, thermal process, industry, metallurgy etc...).

Conduct further research in a controlled environment to study the influence of water content on measured resistivity during the disintegration of various waste materials. The influence of air on the disintegration process should also be investigated. The heterogeneous nature of the landfills (for example; the waste type, compaction rate, water content) doesn't allow proper control and monitoring of influencing parameters.

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11 Thesin

1. During the period of 1970-2011, eighteen landfills were established in old and abandoned sand quarries in Kuwait covering an area of 29.06 km^2. This area amounts to about 3% of the total urban/municipal area (850 Km^2) of Kuwait. The depth of these landfills may reach as deep as 30 meters. These landfills do not comply with many of the national environmental regulations and standards.

2. Landfilling has been the most common method for solid waste disposal in Kuwait over the last four decades. The active landfills reached a maximum of 12 operating landfills during the period 1990-2000. Currently, only 4 landfills are still operating in Kuwait.

3. The government of Kuwait is facing a major challenge in the after closer management of closed landfills. Fourteen landfill sites are closed from operation (17.76 km2, about 61% of the total landfills area in Kuwait). All of these closed sites are located within close proximity of the human habitation, thereby posing concerns on their health and environmental impacts as well as their proper management.

4. Due to the increase in urbanization and development activities, most of the landfill sites in Kuwait became very close to residential, commercial and industrial areas. Out of the 18 landfill sites, only three landfills are relatively free from human use, while the rest of the landfills are surrounded with significant proportions of human settlement, hence imposing potential threats to human health.

5. Almost all landfills in Kuwait are located within or in the close proximities of the sensitive landuse areas. These landfills intersect both the existing metropolitan areas as well as some of the newly proposed development plans stated in 4th Kuwait Master Plan.

6. No rehabilitation has been carried out for 44% of the landfills, and only partial rehabilitation has been conducted for 2 sites (constituting 11% out of the total landfills area), whereas about 7 landfills (39%) are being protected by control measures, which largely involves fencing and restriction for trespassing.

7. Only 1 landfill site (Al-Qurain) has limited monitoring programme whereas the remaining 17 sites (constituting 94%) are not subjected to any monitoring procedures to assess their environmental effects.

8. It is suggested that the rehabilitation process must start first for the landfills that contain organic waste and are located amidst the residential areas and have large population growth and significant human settlement. Hence, landfill sites like Al-Qurain, Jleeb Al-Sheyoukh and Sulaibiyah should have priority over the other closed landfills where the process of land reclamation must precede other sites.

9. Jleeb Al-Sheyoukh landfill was chosen to conduct a detailed investigation, assessment and implementation of a pilot rehabilitation project employing the "In-Situ Aerobic Stabilization". This site was selected being the largest landfill in Kuwait (with an estimated area of 5.5 km^2), located at a distance of less than 1 km from both residential areas and Kuwait International Airport, and hence is considered to be a potential health and environmental hazards to its surroundings.

10. The scope of the experimental field works and measurements conducted in JLF site was designed to include three different investigation programs. These are: the assessment of JLF site using direct and indirect methods, the application of aerobic in-situ stabilization project, and the indirect monitoring of the resistivity changes using both 2D and 3D geo-electrical measurements.

11. The approach of this research provides new criteria to indicate quickly the validity and efficiency of the waste stabilization process and to indirectly monitor its progress. Consequently, the newly suggested criteria for the indirect monitoring are to be validated for large scale monitoring programs when landfill rehabilitation projects are carried out. Accordingly, the findings of the In-Situ stabilization project are to be estimated for full scale implementation.

12. The use of magnetic valve in adjusting and controlling the injected air volume and frequency in the landfill body during the aerobic stabilization of waste matrix is a new cost-effective method. The results were found to be very encouraging for its application in large-scale rehabilitation projects.

13. Detailed assessment programme for most JLF landfill areas was designed and implemented over 36 months period to produce a full-scale knowledge about JLF (based on detailed direct and indirect measurements). This detailed assessment programme has led to the determination of the JLF site history, the development of 3D-topographical maps, the reconstruction of the geometry of buried waste (depth, types, extent, and boundaries), the classification of various types of buried materials and underneath soils (based on resistivity measurements and borehole logs), leachate characteristics, vulnerability of groundwater to pollution, efficiency of the cover layer, magnitude of land settlement and the potentials for gas production.

14. To apply the "high pressure in-situ aerobic stabilization method" in large-scale rehabilitation projects in Kuwait. It was found that application of this method is a very promising alternative for the rehabilitation of old landfills in Kuwait as it significantly shortens the aftercare period and the associated environmental pollution and thus reduces the related costs.

15. The geo-electrical investigation (i.e., resistivity measurements) has been used for the first time in Kuwait as an indirect monitoring method for the determination of the volume, types, distribution and geometry of buried wastes in JLF. The obtained results allowed, for the first time in Kuwait, to produce 3D-visualization of the landfill body.

16. A classification index of landfills subsurface materials resistivities was developed for the first time in Kuwait. The ranges of resistivity was divided into six classes depending on the type of materials: organic waste 0-8 Ωm, transitional zone 8-12 Ωm (domestic waste/native soil, mostly contaminated soil depending on the location of the waste), groundwater 12-20 Ωm (resistivity in JLF area), sand-clayey 20-40 Ωm, sand 40-100 Ωm and construction waste amounts to more than 100 Ωm.

17. A 3D geometrical model using computer assisted software (GOCAD) was created based on borehole logs and geo-electrical profiles. The model revealed the heterogeneous nature of JLF and the improper dumping of waste materials where it was found that the landfill is composed of mainly 4 bodies comprising; a cover layer with a volume of 4.5×10^{6} m^{3}, construction waste with a volume of 0.36×10^{6} m^{3}, organic waste and contaminated soil with a volume of 1.9×10^{7} m^{3} and a native soil body underneath the landfilling area.

18. A rehabilitation experiment has been planned and conducted in a selected area of 24x24m on the waste disposal site of Jleeb Al-Sheyoukh near borehole 18. The aim of the experiment was to explore the conditions under which the disintegration process can be accelerated by changing it from anaerobic to aerobic conditions.

19. The assessment of the degradation process using the geo-electrical method is not easily feasible. The heterogeneous nature of the landfills (for example; the waste type, compaction rate) doesn't allow the proper control and monitoring of influencing parameters through the geo-electrical measurements. This was observed during the experimental work applied in the project area in JLF. Thus the design of experimental work in a controlled environment is needed. However the water content can be monitored.

20. For the monitoring of the high pressure aeration process, gas and water can indicate the success of the disintegration process. However, gas and water can be influenced by the continuous air injection maintaining the aerobic conditions in waste matrix. Hence, the continuous resistivity measurement is a better indicator for the water content which is essential for the disintegration during the aerobic phase. This means that resistivity is obviously a viable monitoring method during the rehabilitation conditions.

21. Further research in controlled environments is needed to study the influence of water content on the measured resistivity during the disintegration of various waste materials. The influence of air on the disintegration process should also be investigated. The heterogeneous nature of the landfills (for example; the waste type, compaction rate, water content) doesn't allow the proper control and monitoring of influencing parameters.

12 Curriculum Vitae

MOHAMMAD DAWOOD AL-AHMAD

Personal Information:

Name	Mohammad D. S. Al-Ahmad
Date & Place of Birth	11th December 1971 / Kuwait
Nationality	Kuwaiti
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Address	Environment Public Authority P.O. Box : 4552 (Safat) 13046, Kuwait
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Higher Education and Qualifications:

University/Institute	Degree(s) or Diploma(s) obtained:	Graduation
Kuwait University "State of Kuwait"	BSc in Geology • Major - Geology • Minor - General Administration	1996
University of Rostock "Germany"	PhD in Environmental Engineering "Waste Management"	2008 - Present

Language skills: **Competence on a scale of 1 to 5 (1 - excellent; 5 - basic)**

Language	Reading	Speaking	Writing
Arabic	Native	Native	Native
English	1	2	2

Employment History:

Organization	Date	Post/Position
Kuwait Environment Public Authority **“www.epa.org.kw”**	2009- present	Director - Environmental Inspection, Monitoring and Emergency Department
	1999-2009	Head of Division - Environmental Monitoring Division - Director General Office
	1998-1999	Researcher – Soil and Desertification Division -Department of Soil and Arid Lands
	1997-1998	Researcher – Coastal Development Division -Department of Soil and Arid Lands

Volunteer Supervisory Duties:

Organization	Date	Post/Position
Kuwait Environmental Protection Society **“www.keps.org.kw”**	2010- present	Chairman of the board “Election”
	2010- present	Editor-in-Chief, “AlBea’a” Magazine – A dedicated environmental monthly magazine
	1996-2010	Active member
Environment Public Authority Employees Union	2005-2008	Founder and Chairman
Kuwait Science Club **“www.ksclub.org”**	1999-2002	Managing Director, “Al-Majarra” Scientific Magazine, A dedicated Scientific monthly magazine
	1999-2000	Director, Planning Office
	1996-1999	Director, Environmental Affairs Office
	1996-1998	Director, Training and Project Department
Kuwait Journalist Association **“www.kja-kw.com”**	2000- present	Active member

Research Projects:

Date	Project
2012	Assessing the environmental conditions of landfill sites in Failaka Island – a preliminary study. Partnerships Technical Bureau (PTB), Landfill Rehabilitation Committee “The Trio-Committee” - Council of Ministers, State of Kuwait, (P.I).
2011	Assessing the Environmental conditions of the former Asbestos Factory site in Al-Rai Area. Landfill Rehabilitation Committee “The Trio-Committee” - Council of Ministers, State of Kuwait, (P.I).
2011	Setting Regulations for Collection and Transportation of industrial waste water in Kuwait– Phases I & II. Institute for Waste, Waste Water and Infrastructure-Management (INFA, Germany), Landfill Rehabilitation Committee “The Trio-Committee” - Council of Ministers, State of Kuwait, (P.I).
2011	Assessing the environmental conditions of the construction waste landfill site in Sabhan Industrial Area (Block, 11). Landfill Rehabilitation Committee “The Trio-Committee” - Council of Ministers, State of Kuwait, (P.I).
2004 - 2005	Evaluating the level of Public Awareness for using Re-cycled Paper in the State of Kuwait, Kuwait Journalist Association. Kuwait Environment Public Authority, [in Arabic], (Co-I).
2003 - 2008	Illustrated Encyclopaedia for Coral Reefs in the State of Kuwait. Kuwait Environment Public Authority, Kuwait Science Club, Kuwait, [in Arabic], (P.I).
2001 - 2002	Installing Mooring Buoys in the Marine Environment of Kuwait. Kuwait Environment Public Authority, Kuwait Diving Team (KSC), Phase II, Kuwait, [in Arabic], (Co-I).
1994 - 1995	Assessing the Impact of Kuwait Science Club on the Kuwaiti Society, Planning office, Kuwait science club, Kuwait, [in Arabic], (Co-I).

(P.I): Principal Investigator, (Co-I): Co-Investigator.

Projects Participation:

Date	Project
2011 - 2014	Rationalizing Water Consumption in Arab Countries - Arab Fund for Economic and Social Development, Kuwait Environmental Protection Society, State of Kuwait, (P.M).
2010 - 2012	Establishing a Geo-Environmental Data Bank in the state of Kuwait - the Environmental Monitoring Information System of Kuwait (eMISK). Environment Public Authority, State of Kuwait, (P.M).
2009 - 2011	Studying, Establishing and Evaluating a natural wastewater treatment plant “Constructed Wetlands”- capacity of 650 people. Landfill Rehabilitation Committee “The Trio-Committee”- Council of Ministers, State of Kuwait, (P.M).
2009 - 2010	Studying and Establishing Industrial wastewater treatment plant “Wafra Km-30”- capacity of 7500 m3. Landfill Rehabilitation Committee “The Trio-Committee”- Council of Ministers, State of Kuwait, (T.M).
2009	Establishing of a reception facility for wastewater effluents transferred by sewage tankers for treatment in Um-Al-Hayman Wastewater Treatment Plant - the National Committee for the Rehabilitation of Landfill Sites "The Trio-Committee"- Council of Ministers, State of Kuwait, (T.M).
2005	Construction of a designated landfill site in East-Shuaiba Industrial Area for the disposal of Asbestos. Environment Public Authority, Landfill Rehabilitation Committee “The Trio-Committee” - Council of Ministers, State of Kuwait, (T.M).
2004	The Rehabilitation of Shuaiba landfill site in East-Shuaiba Industrial Area. Landfill Rehabilitation Committee “The Trio-Committee” - Council of Ministers, State of Kuwait, (T.M).
2002 - 2008	Undertaking protective measures in 5 landfill sites in Kuwait. Landfill Rehabilitation Committee “The Trio-Committee” - Council of Ministers, State of Kuwait, (T.M).
1999 - 2004	The Rehabilitation of Al-Qurain landfill site in Kuwait. Environment Public Authority, State of Kuwait, (T.M).
2002 - 2003	National Committee for Evaluating and Preparing the Rehabilitation Strategy for the Landfill Areas in the State of Kuwait, EPA, Kuwait, (T.M).

(P.M): Project Manager, (T.M): Team Member.

Membership in National Committees and Working Groups:

Date	Committees / Work Groups
2012 - Present	Technical committee for environmental research programme. Kuwait Foundation for the Advancement of Scientific (KFAS), State of Kuwait.
2011 - Present	Working group for studying and evaluating the initiatives in Kuwait. The Partnerships Technical Bureau (PTB) “for studying development projects and initiatives”. Ministry of Finance, State of Kuwait.
2011 - Present	Joint Technical Group, Iraqi aggression compensation projects, Public Authority for Assessment of Compensation for Damages resulting from Iraqi Aggression, State of Kuwait.
2011	Special commission for investigating the causes of gas leakage in the city of Al-Ahmadi, Council of Ministers, State of Kuwait.
2010 – 2011	Permanent National Committee to Combat Desertification, Environment Public Authority, State of Kuwait.
1997 – 2004	Permanent National Committee to Combat Desertification (Reporter), Environment Public Authority, State of Kuwait.
2002 - Present	Landfill Rehabilitation Committee “The Tri-Committee” - Council of Ministers, State of Kuwait.
2002 - 2004	Permanent National Committee for the follow-up of fish kill events (Reporter), the Environment Public Authority, State of Kuwait.
2002	Working group for control and containment of fires erupted in of Jleeb Al-Sheyoukh and Sabhan landfill sites. Environment Public Authority, State of Kuwait.
2001 - 2006	Scientific committee for the reviewing and publishing environmental publications (peer-reviewed publications, Reporter), Environment Public Authority, State of Kuwait.
2001 - 2005	National Committee for the rehabilitation of gravel quarry sites in Kuwait, Council of Ministers, State of Kuwait.

Membership in KEPA Committees and Working Groups:

Date	Committees / Work Groups
2012	Scientific Committee, regional dust conference, Environment Public Authority, State of Kuwait.
2011 - Present	Follow up Implementation Committee, Environment Public Authority projects within Kuwait national development plan 2010/2011-2013/2014, Environment Public Authority, State of Kuwait.
2010 - Present	High level committee between the Environment Public Authority and the Oil Sector, Kuwait petroleum corporation, State of Kuwait.
2010 - Present	Permanent Committee for environmental violation, Environment Public Authority, State of Kuwait.
2010 - Present	National committee for the establishment of new industrial areas, Environment Public Authority, State of Kuwait.
2010 - Present	National committee for the establishment of Environmental Compliance Fund, Environment Public Authority, State of Kuwait.
2001 - 2002	Working group of Agriculture and Land, Kuwait Environmental Strategy, Environment Public Authority, State of Kuwait.
1998	Working group for the follow-up of Al-Wafra farms incident in Kuwait (Chairman), Environment Public Authority, State of Kuwait.

Other Activities:

Participating in the reconstruction of Kuwait University after the liberation of Kuwait, February 1992
Participating in the reconstruction of Kuwait Science Club after the liberation of Kuwait, February –April, 1992.

Grants and Awards:

Date	**Award**
2012	Kuwait Electronic Award – field of electronic health, “Beatona.net, Kuwait Official Environmental portal”. Awarded to Kuwait Environment Public Authority (Project Manager), Kuwait foundation for the advancement of science (KFAS), Kuwait.
2010	Special Achievement Award in GIS, “The Establishment of the Environmental Monitoring Information System of Kuwait (eMISK)”. (Project Manager), Environmental Systems Research Institute (ESRI), Redland, USA.
2008	GCC Award, Best Environmental Practices – field of awareness, “Beatona magazine”. Awarded to Kuwait Environment Public Authority (Managing editor), The General Secretariat of the Gulf Cooperation Council (GCC), Riyadh, Saudi Arabia.
2003	British House of Commons Environmental Award, “The Rehabilitation of Al-Qurain landfill site in Kuwait”. Awarded to Kuwait Environment Public Authority (Project Team Member), British House of Commons, Great Britain.
2000	1^{st} Place, "Kuwait Marine Environment - Film", awarded to the Kuwait Diving Team, Kuwait Science Club (film writer and supervisor), The International Marine Films Festival, Tabraka, Tunisia.
1999	Gold Medal - INREKEE BADELLA, "Best Scientific Applied Project for youths" awarded to the Kuwaiti Delegation (Technical manager of the Kuwait Delegation). 7th International Science Expo (ESI-99), International Movement for Science and Technology, Beubla, Mexico.
1998	Gold medal, “The Geology of The United Arab Emirates (UAE) – research project”, 4^{th} International Science Expo (ESI-93), International Movement for Science and Technology (MILSET), Texas, USA.

Conferences and scientific journals:

Al-Ahmad, M. D.; Dimashki, M.; Nassour, A. and Nelles, M., (2012). “Characterization, Concentrations and Emission Rates of Volatile Organic Compounds from Two Major Landfill Sites in Kuwait”. American Journal of Environmental Sciences, 8 (1), pp. 56-63.
Faisal, K.; **Al-Ahmad, M. D.** and Shaker, A., (2012). "Remote Sensing Techniques as a Tool for Environmental Monitoring". The 22nd Congress of the international society for photogrammetry and remote sensing (ISPRS). 25 August – 1 September 2012, Melbourne, Australia.
Nassour, A.; **Al-Ahmad, M. D.**.; El-Naas, A. and Nelles, M., (2011). “Practice of Waste Management in the Arab Region”. Contribution in: Kühle-Weidemeier, M.: (editors): waste-to-Resources 2011-4. International Conference MBT and sorting systems, conference proceedings, 24-26 May 2011, pp. 81-91, ISBN 978-3-86955-747-2 (05/ 2011).
Al-Ahmad, M., (2011). “From the Drawer to the Browser, Making the Change for a Better Presentation of Environmental Data in Kuwait”. Keynote Speech, ESRI Middle East and Africa User Conference (MEAUC), Beirut, Lebanon, November 2011.
Al-Eisa, E. E.; **Al-Ahmad, M. D.** and Taha, A. M., (2011). “Design and management of a sewage pit through discrete-event simulation”. Simulation: Transactions of the Society for Modeling and Simulation International.: http://sim.sagepub.com/content/early/2011/03/02/0037549711398262.Abstract.
Al-Ahmad, M. D.; Talaat, A. and Hermsmeyer, D., (2011). “Environmental Monitoring Information System of Kuwait (eMISK)”. Arab-German Year Book 2011, Arab-German Chamber of Commerce and Industry (Ghorfa), Berlin, Germany, May 2011.
Nelles, M.; **Al-Ahmad, M. D.**; CAI, J.; Dorn, T. and Nassour, A., (2010). “Waste Management in the Arab Region and China”. Lecture and contribution in: Erdin, E.; Kranert, M.; Akini, G.; Azbar, N.; Özmihci, S; Gök, G.; Sarptas, H.; “5th Turkish-German Waste Conference”, pp. 397-411, ISBN 978-3-8356-3228-8, 25-27/11/2010, Izmir, Turkey.

Nelles, M.; Nassour, A.; Majanny, A and **Al-Ahmad, M. D.**, (2010). "International Waste Management in Transition - Current Developments in Arabic Countries". Abstract in: Lorber, k. D.; Aldrian, A.; Arnsberg, A.; Bezama, A.; Wruss, k. (editors): DepoTech Jan. 2010 - waste management, waste technology, landfill engineering and landfills, proceedings to the DepoTech 2010 by November 2010, Leoben/Austria, ISBN 978-3-200-02018-4, p. 814 (11 / 2010), [*in German*].
Dorn, T.; **Al-Ahmad, M. D.**; Nassour, A. and Nelles, M., (2009). "International waste management as Zukunfstaufgabe - current developments in the Arab region and the People's Republic of China". Contribution in issue 9 of the journal "Garbage and Waste", page 448-454, ISSN 0027-2957 (9/2009) b, [*in German*].
Al-Sarawi, M.A., Al-Enezi, M. and **Al-Ahmad, M. D.**, (2005). "Enforcement of Environmental Legislations". The Gulf Conference on Environment and Sustainability, Kuwait. 3-5 December. 2005. [*in Arabic*].

Contribution to Books and Periodicals:

Al-Ahmad, M. D., (2010). "Sewage and Industrial Wastewater Transported through Tankers; Problems and Solutions", Landfill Rehabilitation Committee "The Trio-Committee" - Council of Ministers, State of Kuwait.
Al-Ahmad, M. D., and Habashi, B., Illustrated Encyclopedia for Coral Reefs in the State of Kuwait, (2008). Kuwait Environment Public Authority in cooperation with Kuwait diving team (Kuwait Science Club - KSC) and the United Nation Development Program (UNDP), 1st edition, Kuwait. ISBN: 99906-48-09, 266 p., [*in Arabic*].
Al-Ahmad, M. D., (2004). "Kuwait in 100 years", Major Kuwaiti Events in the 20th Century", Privately published, Kuwait, [*in Arabic*].
Al-Ahmad, M. D., Mahrous, F. and Mouawad, M., (2003). "Current Status and Strategy for the Rehabilitation of Closed Landfills in Kuwait". Environmental Refereed Books Series. Published by Kuwait Environment Public Authority, Kuwait. ISBN: 99906-48-02-6, [*in Arabic*].
Al-Ahmad, M. D., (2002). "Science Clubs", Privately published book, Kuwait, 288 p., ISBN: 99906-48-02-6, [*in Arabic*].

13 Appendices

Appendix (1): Status of landfill sites in Kuwait

Appendix (2): Experimental and Analytical Procedures

Appendix (3): Results of BoreASWhole Logs in the Total Area of JLF

Appendix (4): Results of grain size analysis for locations 4-30

Appendix (5): LFG measurements in the Total Area of JLF (2008-2010)

Appendix (6): Results of Boreholes Logs in the Project Area

Appendix (7): 2D measured diagonal profiles (27 Months)

Appendix (8): Publication

Appendix (1): Status of landfill sites in Kuwait

Serial	Site Name	Waste Type	Filling Period		Status	Depth (m)	Area (km²)	Surrounding Area	Min Dist from Res Area (km)	Rehab Status	Assessment	Rehab Project	Responsible Agency	Monitoring	Remarks
			From	To											
1	Al Jahra	HH+CD(Stopped)+WW(Stopped)	1986	Till date	Open	>15	1.72	Roads, Industrial Area, Residential Area, Military, Poultry, Farms	1.420	No Rehab	No	No	NA	No	-
2	Mina Abdullah	HH+CD(Stopped)	1992	Till date	Open	>15	1.15	Roads, Industrial Area, Mining, Golf Course	4.665	Control Measures Applied	No	No	NA	No	-
3	Seventh Road (S)	HH	1992	Till date	Open	>15	4.21	Roads, Oil Field, Mining, Airport	5.680	No Rehab	No	No	NA	No	-
4	Rajam Khashman (South 7th Ring Road)	Medical	1992	Till date	Open		1.00	Roads, Oil Field, Mining, Airport	5.680	No Rehab	No	No	NA	No	-
5	Sabhan Block 11	CD	1980	1986	Closed	Upto 13	0.12	Roads, Industrial Area, Military area, Airport	2.895	Partial Waste Removal	Yes	Yes	Public Authority for Industry	No	Approved by EPA for Total Removal by PAI
6	Al Shuaiba	HH+CD	1986	1992	Closed	Upto 10	0.13	Roads, Industrial Area, Refinaries, Oil Field, Mining	6.550	Converted to Asbestos Landfill	Yes	Yes	PAI	No	Waste transferred to Mina Abdalla and Landfill was converted to Asbestos Landfill after applying environmental measures.
7	Seventh Road (N)	CD+WW	1986	2005	Closed	Upto 15	4.81	Roads, Oil Field, Mining, Airport	2.725	Control Measures Applied	No	No	NA	No	-
8	East Sulaibiyah	CD (??)	NA	1987	Closed	Upto 5	0.17	Roads, Industrial Area, Residential Area, Plantations	0.025	No Rehab	No	No	NA	No	-
9	Araifjan	CD	2009	2009	Closed	Upto 6	0.20	Roads, Industrial Area, Residential Area, Plantations	1.000	Control Measures Applied	No	No	NA	No	-
10	Al Yarmouk	CD	NA	2004	Closed	Upto 10	0.42	Roads, Industrial Area, Residential Area	0.155	Control Measures Applied	No	Yes	Public Authority for Agriculture and Fish Resources	No	Apporved by EPA to be converted to Public Greenary by PAAFR
11	Jleeb Al Shuyoukh	HH+CD	1970	1993	Closed	Upto 27	5.50	Roads, Residential Area, Airport	0.127	Control Measures Applied	No	No	NA	Yes (Settlement, Gas Reading and Lechate)	PhD thesis on comprehensive site assessment, data analysis and recommendation, available from library document no: ????
12	Al Qurain	HH+CD	1975	1985	Closed	Upto 20	0.71	Roads, Residential Area	0.045	Partical Rehab (34% Gas Suction and 66% Control Measures)	Yes	No	EPA and Municipality	Yes	-
13	Sulaibiyah	HH+CD	1982	2005	Closed	Upto 15	2.76	Roads, Industrial Area, Residential Area, Agriculture	1.500	Control Measures Applied	No	No	NA	No	-
14	Sabhan Military	HH+CD	1984	1991	Closed	Upto 20	1.80	Roads, Industrial Area, Airport, Military Area	1.690	Control Measures Applied	No	No	NA	No	-
15	Failaka	HH+CD	-	1990	Closed		0.39	Residential Area, Chalet, Tourism	2.185	No Rehab	No	No	NA	No	The island is under development planning. Environmental assessment including the landfills is part of the planning process.
16	Al Egaila	HH+CD	-	-	Closed		0.11	Roads, Residential Area, Mining	0.230	MA and Sham (??)	No	No	NA	No	-
17	Al Wafra	HH+CD	-	-	Closed		0.20	Roads, Agriculture, Resdential Area	0.500	MA and Noora (??)	No	No	NA	No	Site location is not known from Municipality
18	Kabd	Poultry and Cattle Waste	1999	2001	Closed		0.37	Roads, Animal Farms, Residential Area	0.130	MA and Noora (??)	No	No	NA	No	-

Appendix (2): Experimental and Analytical Procedures

2.1 Landfill Gas Measurements:

Biogas composition (i.e., CH_4, CO_2, O_2, NH_3 and CH_4/CO_2) was monitored using hand-held device (GA 2000 Plus infrared gas analyser, Geotechnical Instruments, UK). Measurements of LFGs emissions and temperature were performed in the 50 boreholes for 36 months. Special capping head was designed for the boreholes to obtain more accurate readings (Figure App.2.1). The 3" PVC existing pipe was capped by adding 3"×3" PVC male adapter with 3" removable cap, 36"×1" PVC pipe of one meter long attached to the cap by 1" PVC male adapter ends with union and cap for temperature probe. Both 1/4" outlet and stop valve were fixed for the in-situ LFG measurement and for the collection of LFG samples.

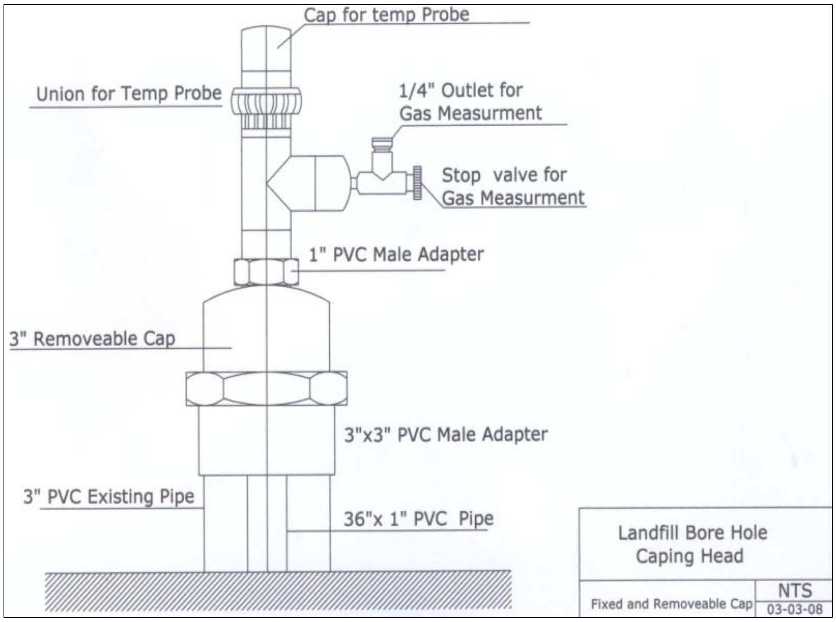


Figure (App.2.1): Design of special capping head for boreholes to facilitate the onsite measurements of LFG and the collection of LFG for VOCs analysis.

2.2 VOCs Sampling and Analysis:

LFG samples for the analysis of Volatile Organic Compounds (VOCs) were collected from selected boreholes. During the period May–August 2010, twenty samples were collected from selected monitoring wells in the total area and the project area in Jleep Al-Sheyoukh landfill.

Collected samples were brought to the analytical laboratory for the analysis of volatile organic compounds (VOCs) in landfill gas. Fifty individual VOCs were identified and quantified in this study, ranging from simple aliphatic and aromatic hydrocarbons to di- and tri- methylated benzenes.

Analysis of VOCs in the collected gas samples was accomplished by following USEPA Method PAMS (Photochemical Assessment Monitoring Stations). The analytical system included a gas chromatography system (Perkin Elmer) equipped with flame ionization detector (GC/FID). The gas chromatography system (GC) was also equipped with a Perkin Elmer Automatic Thermal Desorber (ATD 400). The VOC samples contained in Tedlar bags were analyzed by introducing them into the GC/FID system with the aid of Peltier cooling (PC) and the thermal desorption (TD) method (PC/TD system). Using this PC/TD system, the target VOC in LFG samples were then pre-concentrated in a liquid N2-free cold trap (packed with both Carbosil adsorbent) at −15 ◦C. Trapped VOC were then released thermally by heating the cold trap for 2 min at 320 ◦C.

A 30-meters GC capillary column (BP1) was used for the chromatographic separation of the different VOCs. After elution from the capillary column, identification of individual VOCs compounds was achieved by the flame ionization detector (GC/FID) connected at the end of the capillary column. Figures App.2.2 and App.2.3 show the GC/FID chromatograms recorded during the identification of light and heavy molecular weight VOCs in LFG samples, respectively. Appropriate calibration procedures were employed to ensure GC/FID reliability and accuracy. The GC/FID system was calibrated using a standard calibration cylinder (Spectra Gases, UK) containing all light and heavy molecular weight VOCs at a concentration of 100 ppb each. Detection limits for all VOCs was about 5 ppb.

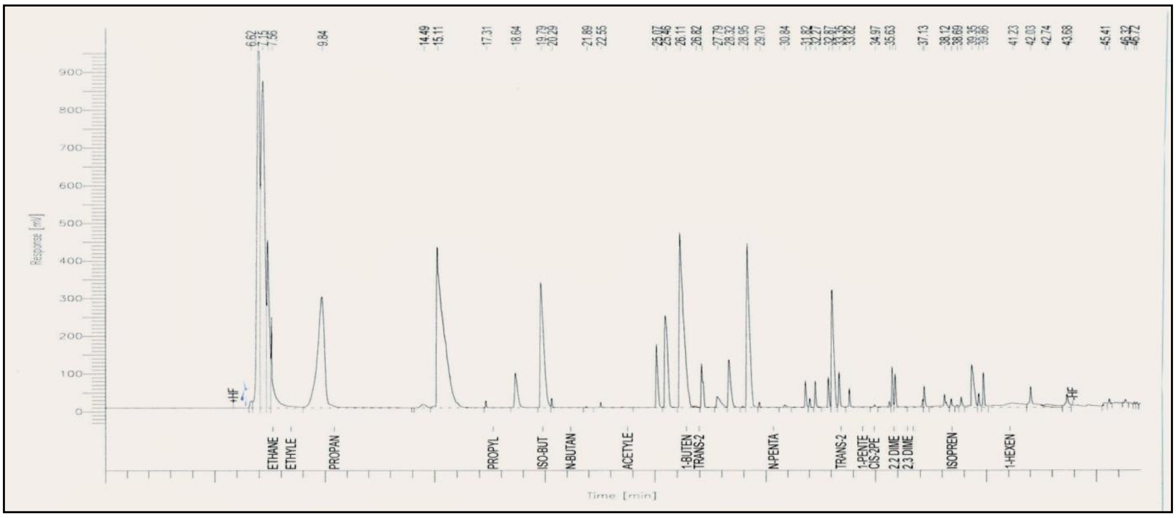


Figure (App.2.2): GC/FID chromatogram of light VOCs identified in LFG samples.

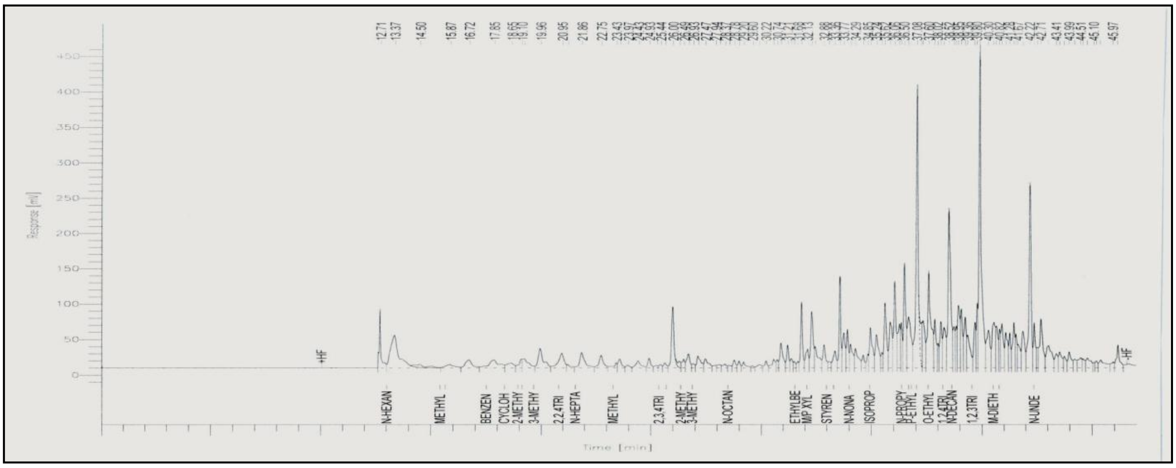


Figure (App.2.3): GC/FID chromatogram of heavy VOCs identified in LFG samples.

2.3 Analysis of Landfill Leachate:

Contaminants and heavy metals were analyzed in leachate samples using the methods described in the Standard Methods for the Examination of Water and Wastewater (21st edition 2005).

For the determination of heavy metals, a 50 ml sample of the collected leachate was placed in a digestion tube and acidified by adding 10 ml of HNO_3 (69%) and then cooling to room temperature. The sample was then subjected to filtration and mixing. Concentrations of heavy metals were determined using Induced Coupled Plazma Spectrometer (ICP- OES, Varian Australia Pty. Ltd, Australia).

A standard spectrophotometer (DR 2800) was used for the determination of contaminants in leachate samples (i.e., total suspended solids, chemical oxygen demand, phosphorus, nitrate, ammonia, potassium, sulfate, chlorine, chloride, sulfide, bromine, calcium, magnesium, iodine, and turbidity). The stated approved method in the DR 2800 manual and in the Standard Methods for the Examination of Water and Wastewater (21st edition 2005) were followed in the analysis of the these parameters.

2.4 Groundwater Analysis:

The type of analysis for which a sample was being collected determined the type of bottle, preservative, holding time and filtering requirements employed. Three samples from the 3 newly drilled groundwater wells were collected throughout the course of the assessment. Groundwater samples were collected with Teflon bailers to prevent cross-contamination issues associated with submersible pumps and the associated hosing. On-site filtration was carried out for samples prepared for dissolved metals analysis; a vacuum type filter is used and decontaminated prior to and between uses. Samples were preserved after filtering. Samples were collected directly from the sampling device into appropriate laboratory cleaned containers and were labeled according to sampling location while all preserved at 4ºC and transported to the laboratory.

The samples were analyzed for the major constituents (Anions & Cations), minor constituents, heavy metals & trace elements, organics, microorganisms and physical elements. The collected samples were analyzed in the analytical laboratories of Kuwait Institute for Scientific Research (KISR), in accordance with the analytical procedures described in the Standard Methods for the Examination of Water and Wastewater(21st edition 2005).

The organic analysis included total organic carbon (TOC), total petroleum hydrocarbon (TPH), benzene, toluene, ethylbenzene ...etc. Total coliform, fecal coliform, E.coli, streptococci fecal, salmonella and coliphage virus were also analyzed. Following the standard operating procedures instruments were used for sampling, while the pH, temperature, EC, dissolved oxygen and alkalinity were measured in-situ on site. Probes were calibrated at the beginning of the sampling day.

2.5 Landfill Cover:

2.5.1 Grain Size

Analyses: were carried out at each location by collecting soil samples at 25, 50, 75 and 100 cm the ground level. This test is performed to determine the percentage of different grain sizes (i.e., gravel, very course sand, course sand, fine sand, very fine sand and mud) contained within the covering layer in Jleep landfill site. The test was carried out according to "the American Standard Test Method for Particle-Size Analysis of Soils NO (ASTM, D422, 63, 2007). Figure App.2.4, below shows the equipment used in the test. The test was performed according to the following procedures:

- All sieves and the bottom pan were cleaned and dried.
- The weight of each sieve as well as the bottom pan were recorded using an accurate electric balance.
- Dry samples were weighed accurately using an electrical sensitive balance.
- The weight of each empty sieve as well as the bottom pan was recorded.
- Sieves were assembled in the ascending order of sieve numbers as shown in figure 9 above.

- Soil sample was carefully poured into the top sieve and the cap was placed on it.
- The sieve stack was placed in the mechanical shaker for 10 minutes.
- The sieve stack was removed from the shaker and the weight of each sieve with its retained soil was carefully recorded. In addition, the weight of the bottom pan with its retained fine soil was also recorded.
- The mass of soil retained on each sieve was obtained by subtracting the weight of the empty sieve from the mass of the sieve + retained soil.
- The percent of soil retained on each sieve was calculated by dividing the weight retained on each sieve by the original sample mass.

Figure (App.2.4): Equipment used for the determination of grain size percent distribution is samples collected from the covering layer in Jleeb landfill site.

2.5.2. Infiltration Test:

The infiltration test is used to determine the ability of water to move into and through the soil. This test depicts the velocity or speed at which water enters into the soil. It is usually measured by the depth (in mm) of the water layer that can enter the soil in one hour (i.e., an infiltration rate of 15 mm/hour means that a water layer of 15 mm on the soil surface, will take one hour to infiltrate).

Because of the great number of fac¬tors which can affect the flow of water through soils, it is best to use this test on a relative basis. This means that a number of tests could either be run at the same time at different sites or at the same site at different times. In this work and due to the time shortage we followed the first approach where conducted the infiltration test in April 2010 at thirty points in Jleeb Landfill site. A double-rings infiltrometer (12cm-diameter inner ring, 30cm-diameter outer ring and 20cm total height) was manufactured locally to perform the infiltration test (see Figure App.2.5, below).

Figure (App.2.5): The double-rings infiltrometer device used to perform the infiltration test.

Below are the steps which were followed to perform the infiltration test:

- Step 1: The double-rings infiltrometer was inserted about 3-5 cm into the soil using a timber and a hammer. A measuring ruler was inserted to the side of the inner ring for measuring the drop in water level.
- Step 2: Water was poured into the inner ring until the depth is approximately 16 cm. At the same time, water was also added to the space between the two rings to the same depth. The water in the space between the two rings is to prevent any lateral spread of water from the infiltrometer.
- Step 3: The start time was recorded when the test began and the water level was noted on the measuring rod.
- Step 4: The drop in water level in the inner ring on the measuring ruler was recorded every minute during the first 5-minutes interval and the every 5 minutes until end of the test period (30 minutes).
- Step 5: At the end of test, the infiltrometer was removed and the depth of the wet zone was measured by carefully excavating the wet soil underneath with a shovel until the dry soil appears and then measuring the depth in cm with the ruler.

2.5.3 Penetration Test:

The resistance to penetrate the soil is a mean for determining the ground load-bearing capacity, and the ease with which roots will grow through the ground (important when agricultural, rural- and civil engineering techniques are involved). The resistance to penetration is a mechanical characteristic that, given a certain texture, depends on changing parameters such as the degree of humidity, density and the strength of the connection between mineral particles.

In this work, penetration measurements were made at 30 points in Jleeb Landfill site using an electronic penetrometer (Eijkelkamp 06.15 Penetrologger, see Figure App.2.6, below) together with a data logger, allowing for immediate storage and processing of the data in the data logger.

Figure (App.2.6): The Penetrometer device used to perform the penetration test at Jleep Landfill.

2.6 Analysis of Waste Eluants:

These tests were intended to analysis and evaluate the 14 solid waste samples acquired at different times from the project area at Jleeb landfill. The results derived from these tests were set as basis to understand the changes in condition of solid wastes deposited with relation to the performance of the rehabilitation process in the landfill.

2.6.1 Procedures

Various tests were conducted on the solid waste samples provided to determine the values for the different parameters. The tests to be conducted were divided into two separate phases.

In the first phase, 14 samples of solid waste with approximately weights of 50 grams each were provided to determine the moisture content (dry mass) of these samples. An analytical balance – capable of weighing down to 0.0001g was used for weighing the samples. Drying of the samples was done in an electrical oven set to a constant temperature of 105° C for the duration of 4 hours. This test concluded with the values of % dry mass. (% of dry mass = (g of sample after drying) / (g of sample before drying) x 100).

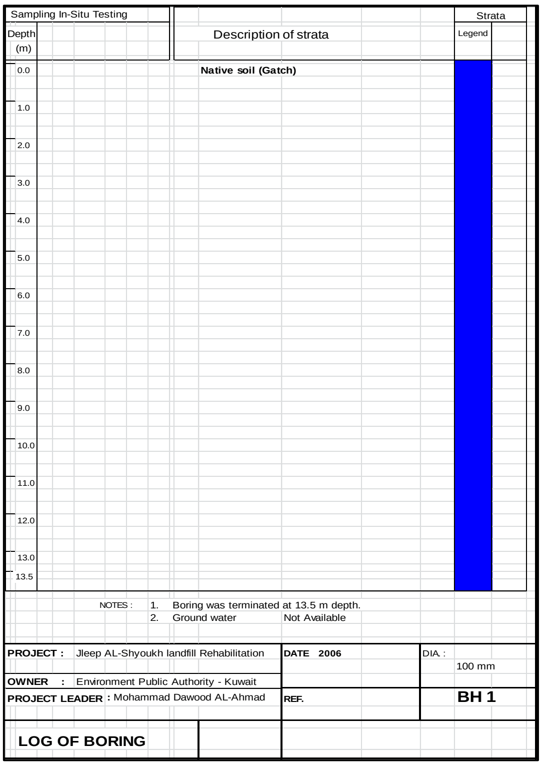
In the second phase, 14 samples of the same solid waste with calculated weights between 103-112 grams were provided. The 14 samples were utilized for the formation of leachates mixtures. The leachate samples were prepared as follows:

- A mixture with the calculated grams of solid waste and 1 liter of distilled water were poured and mixed in plastic bottles.
- A shaker machine was used to form the required sample to a liquid mixture; this process was continued for duration of 24 hours for each sample. This process resulted with a uniform and homologized mixture from the solid waste sample in the form of leachate.
- The leachates mixtures were left aside for separation of sediment and water at room temperature for 1-3 hours.
- The surface water was removed by decantation and filtered through a filter holder by pressure filtration (vacuum flask). This process resulted with the required volume of filtered liquid for the determination of physical and chemical parameters.

2.6.2 Laboratory tests

Leachate samples were tested according to analytical procedures described in the "Standard Methods for the Examination of Water and Wastewater (21st edition 2005)" to determine the following parameters: Temp, pH, Conductivity, TOC, COD, BOD_5, TDS, Salinity and Turbidity.

Appendix (3): Boreholes Logs in the Total Area of JLF



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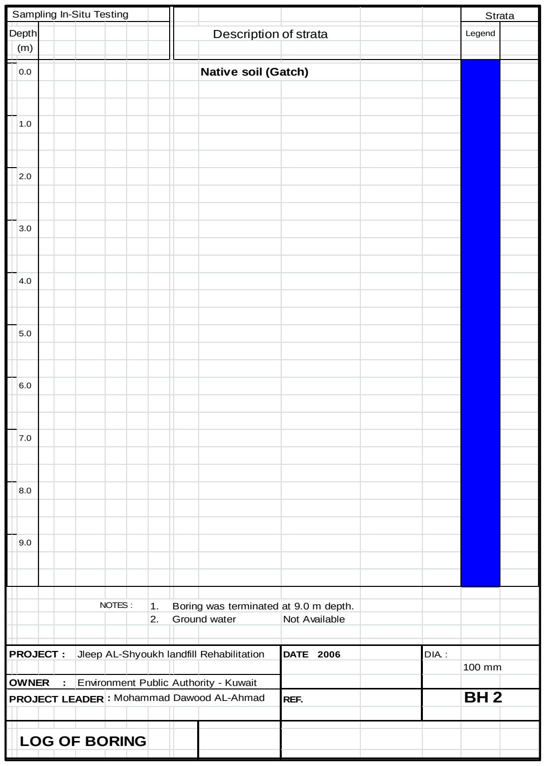

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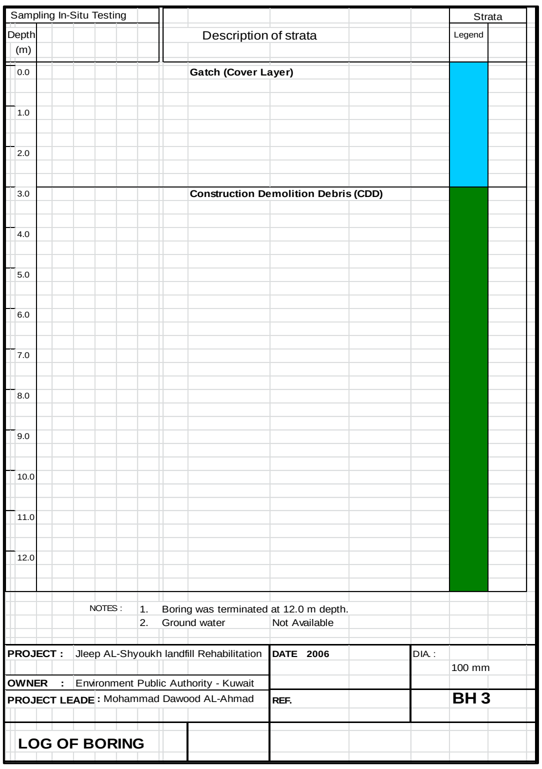

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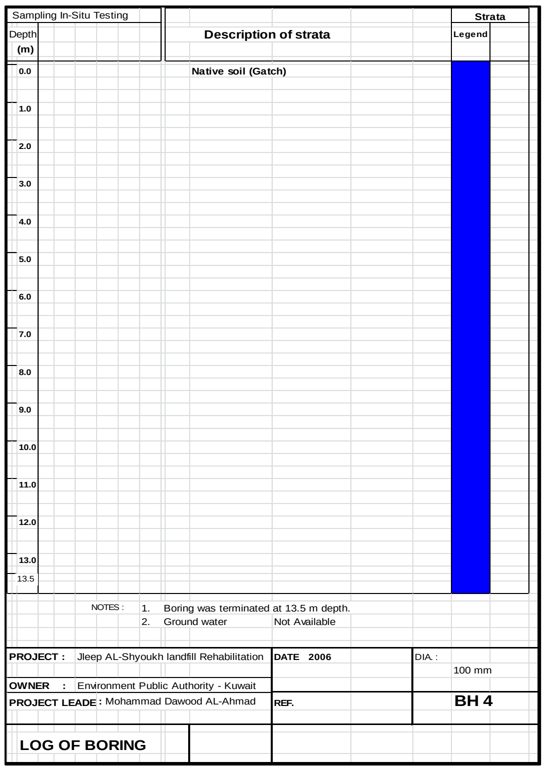

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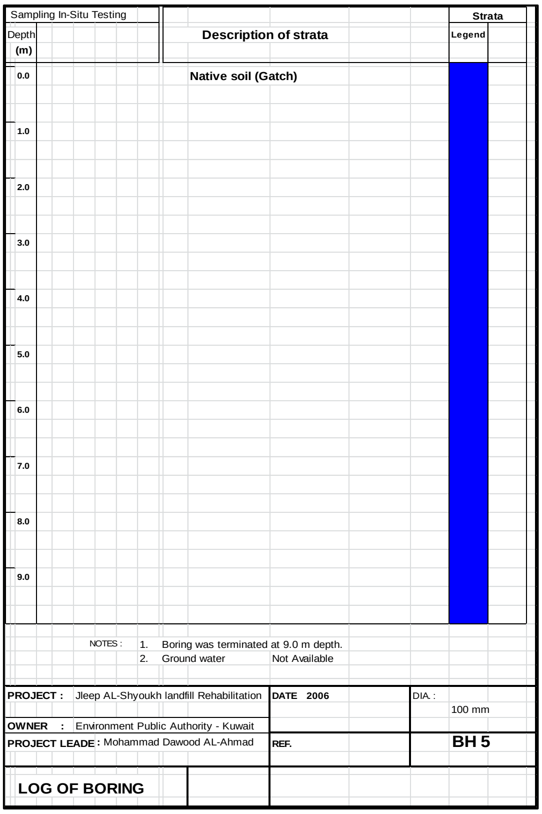

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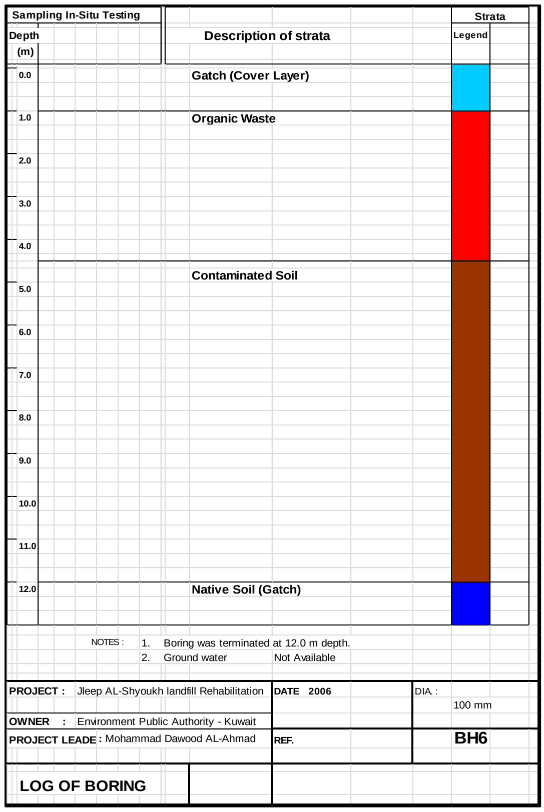

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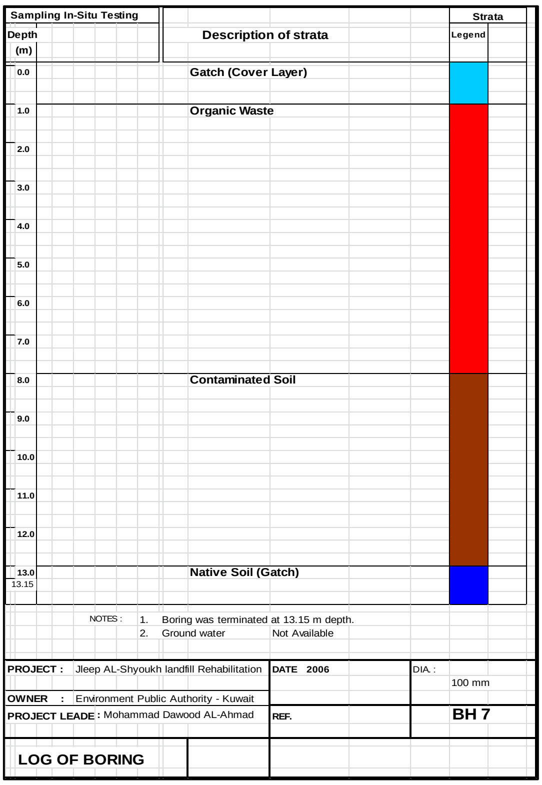

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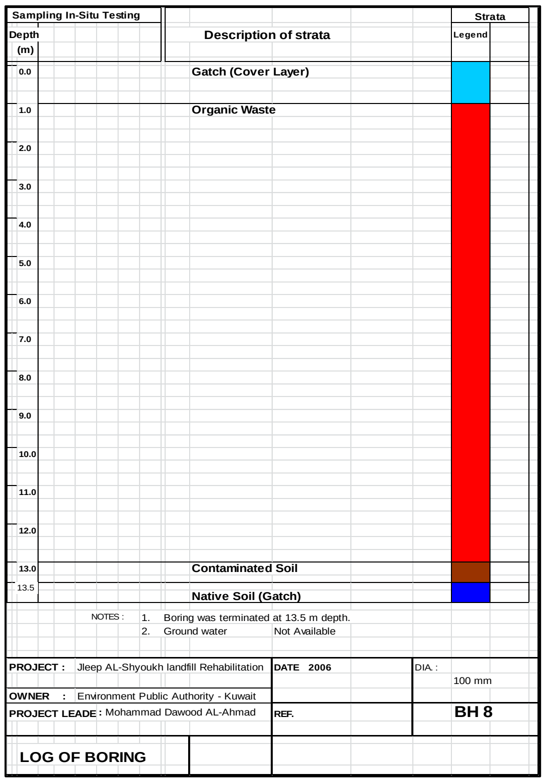

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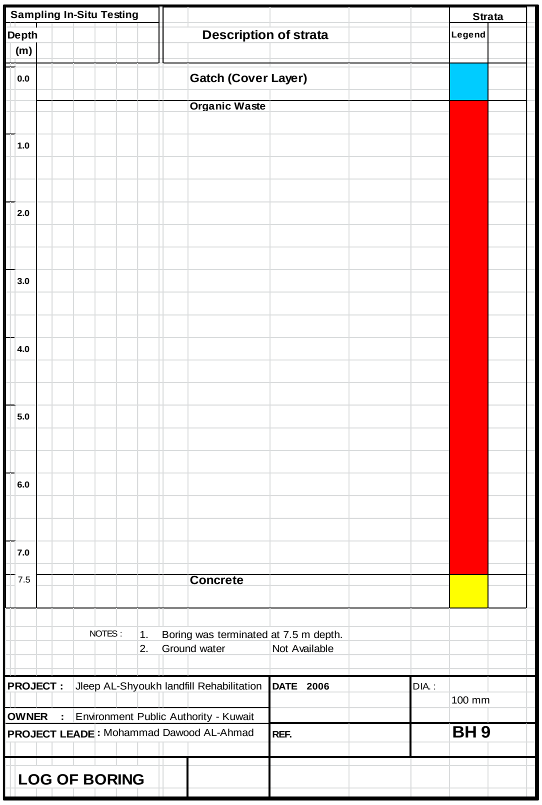

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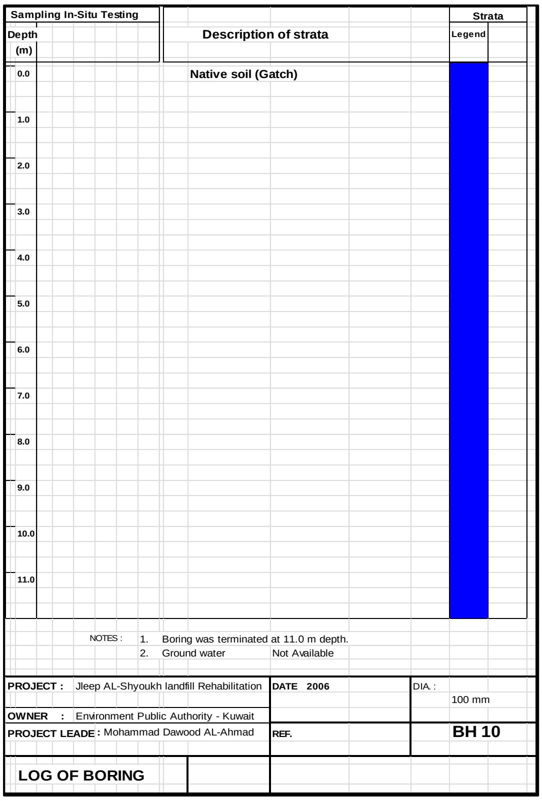

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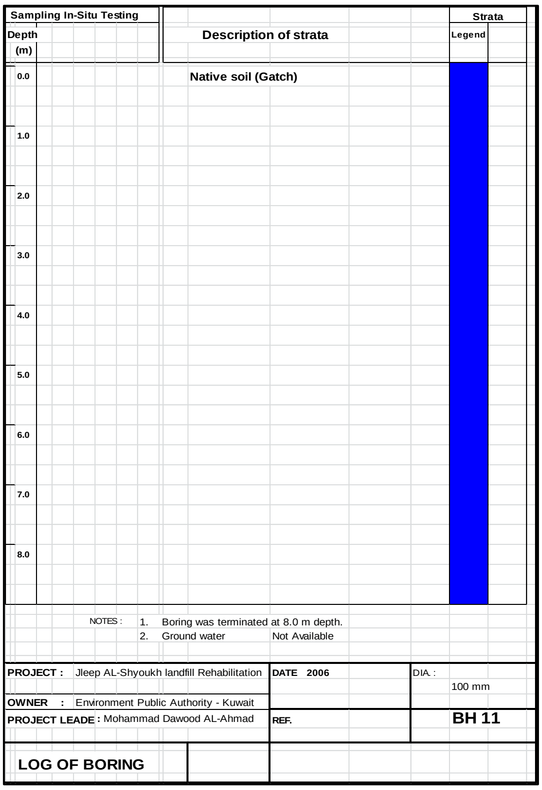

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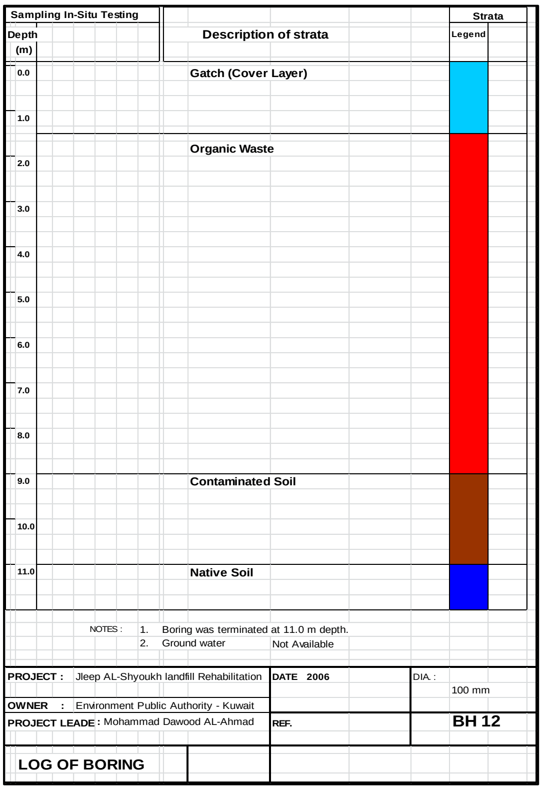

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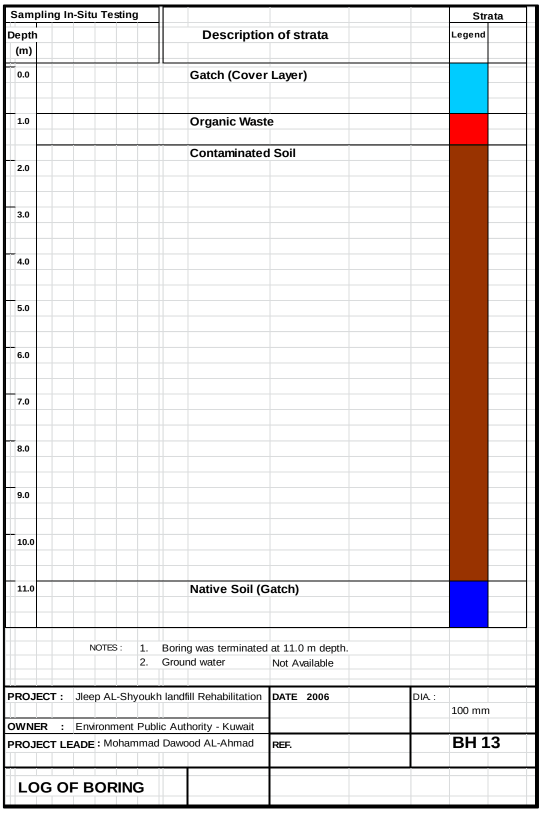

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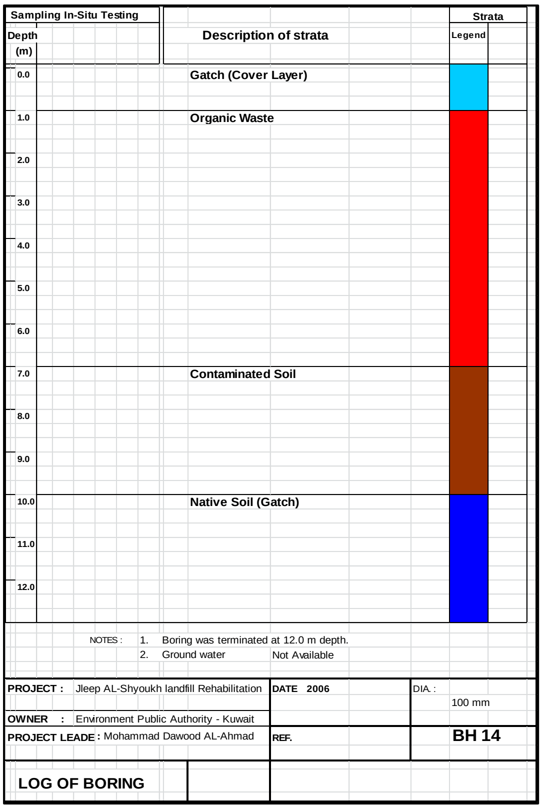

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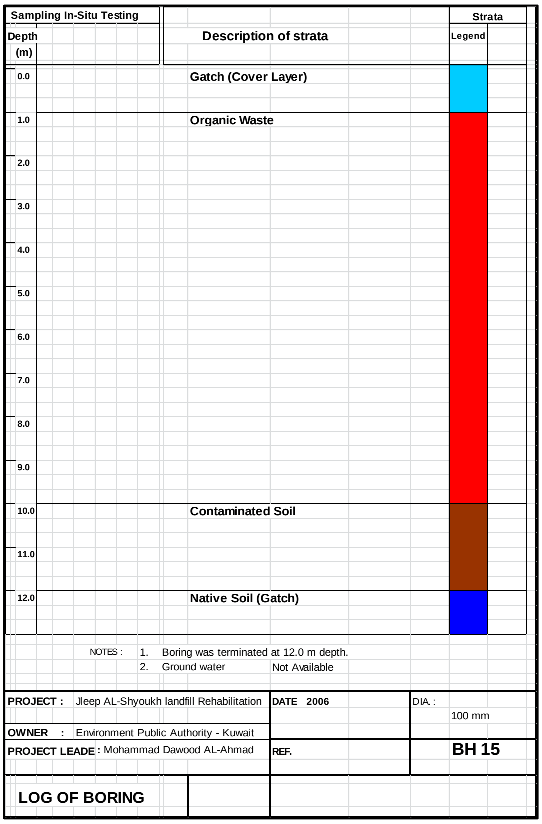

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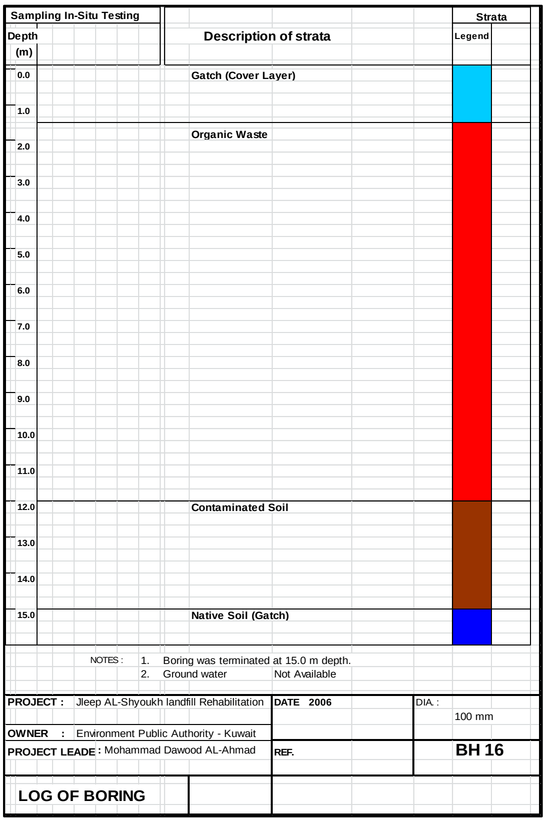

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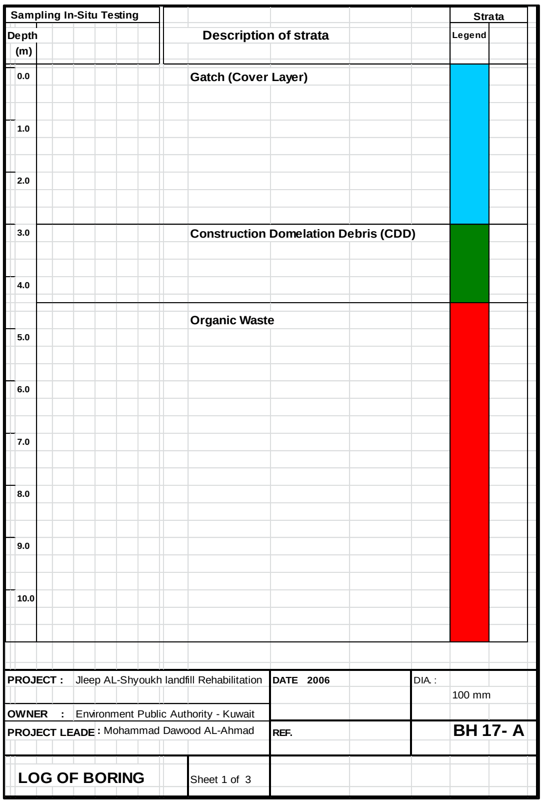

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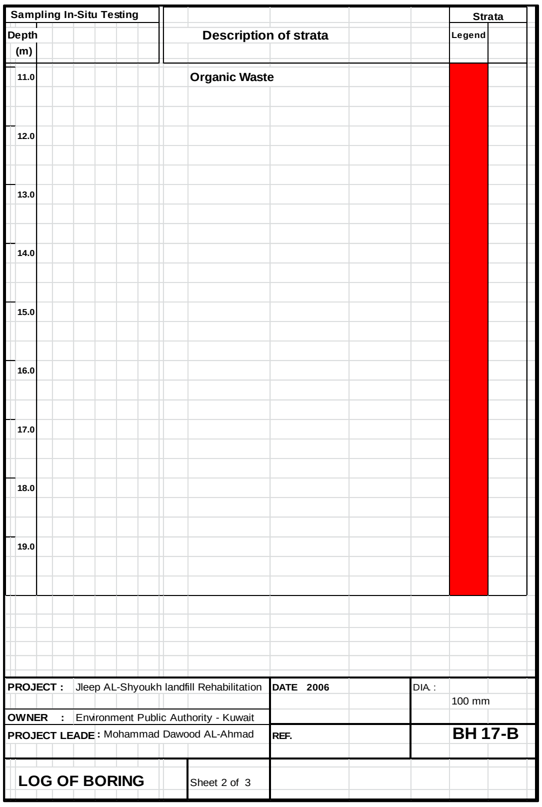

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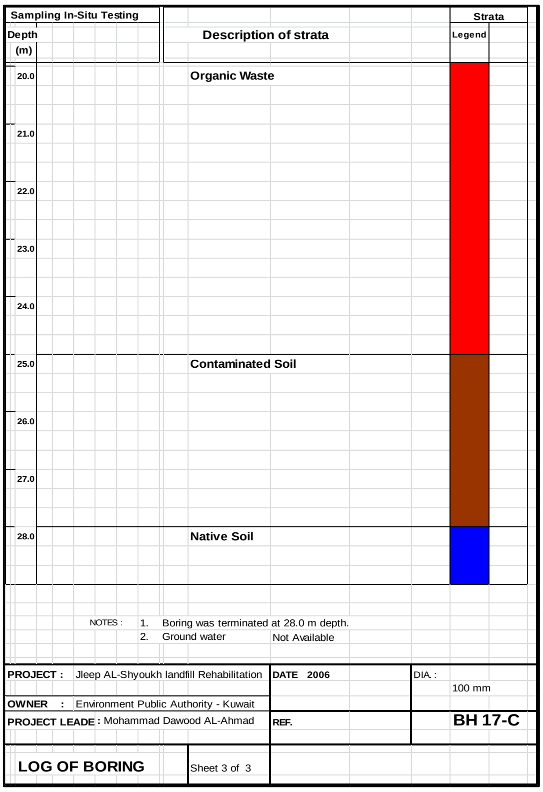

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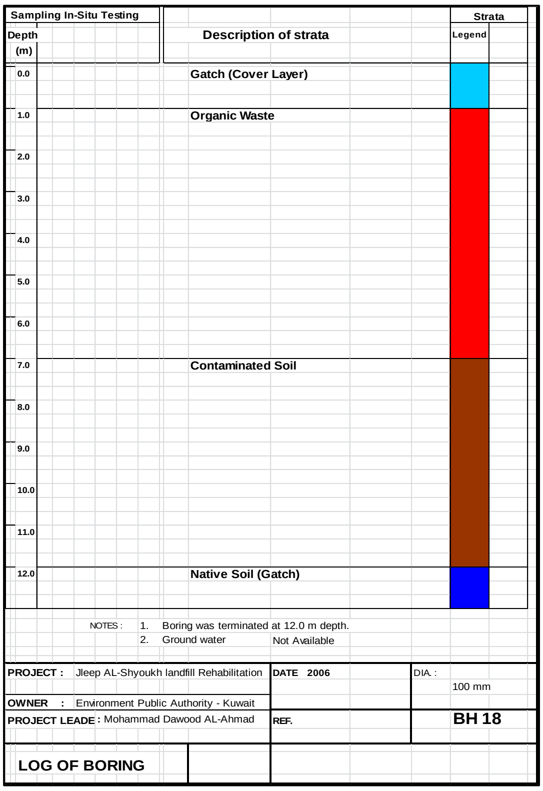

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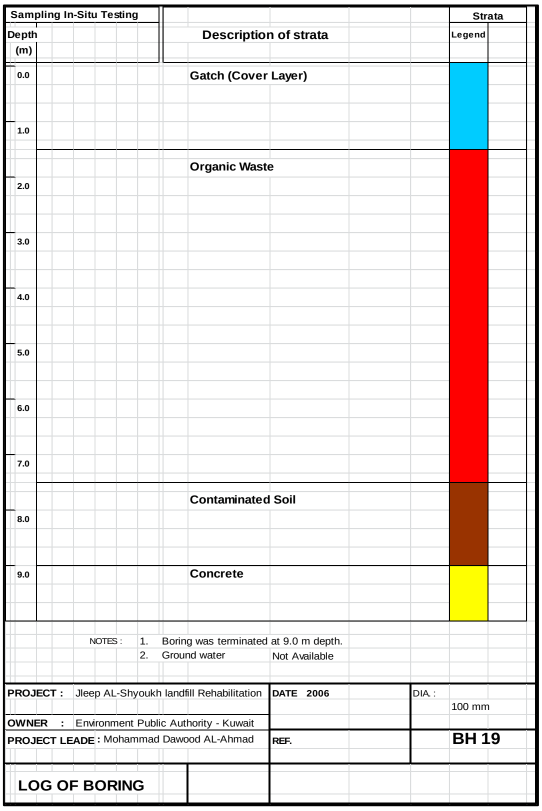

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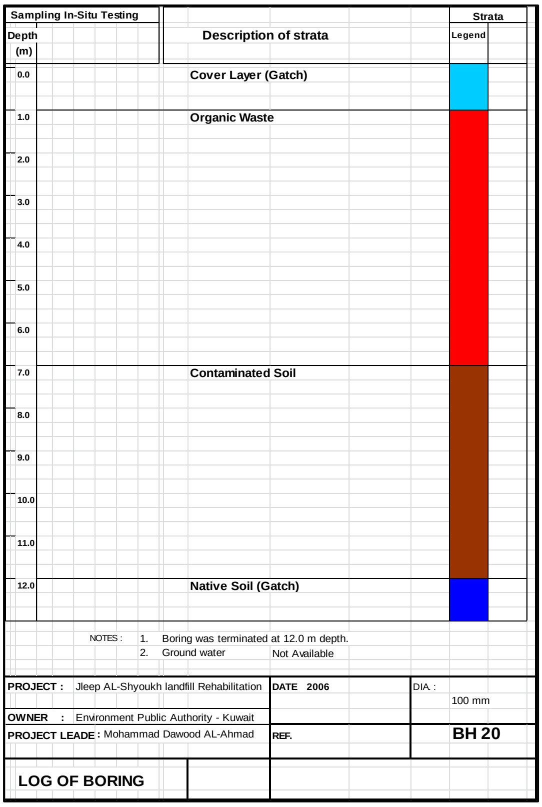

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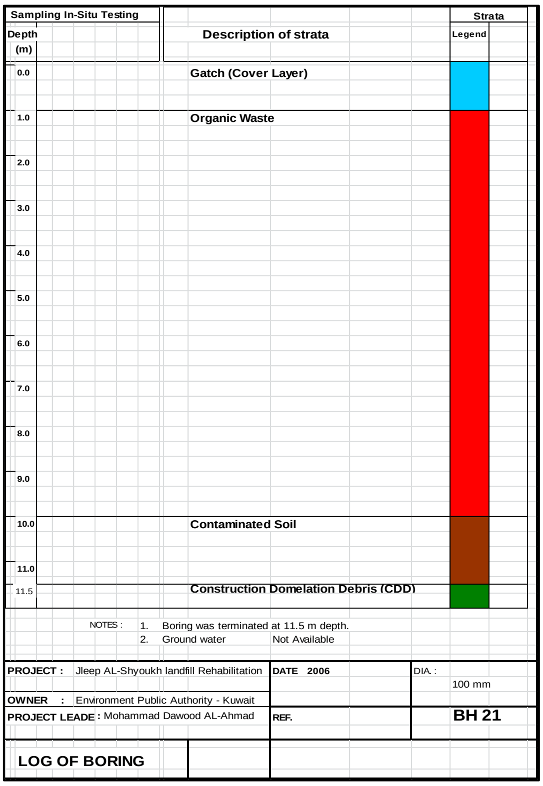

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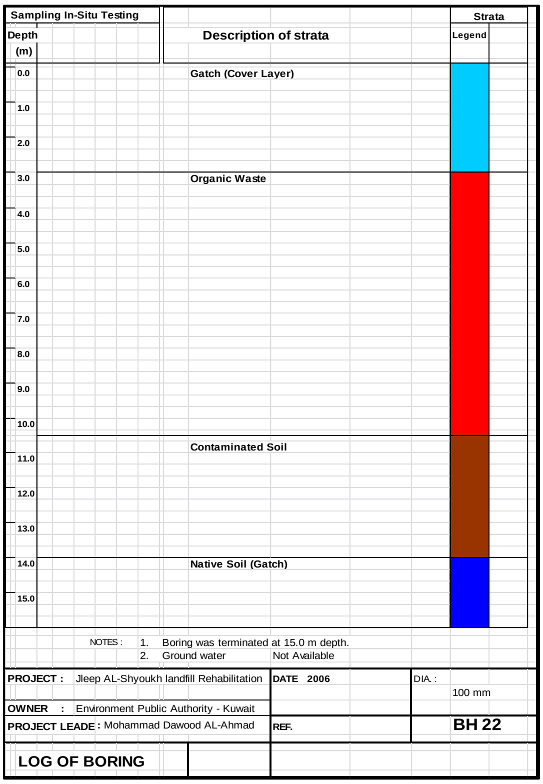

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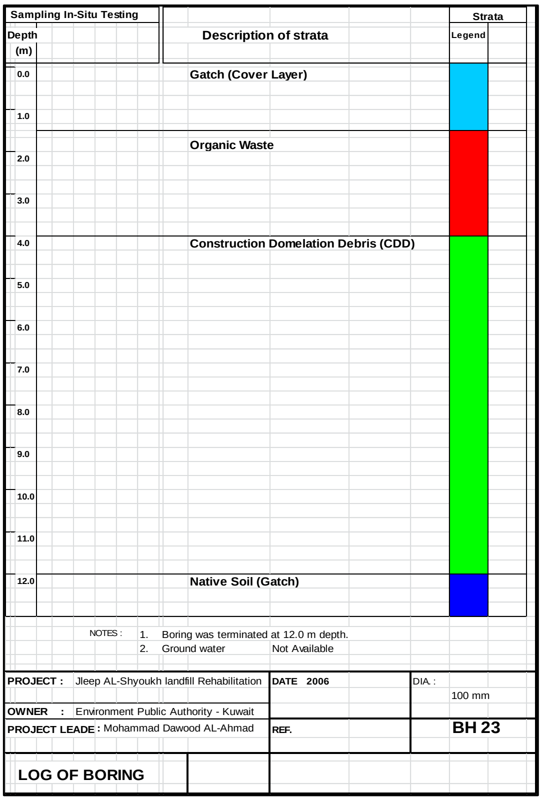

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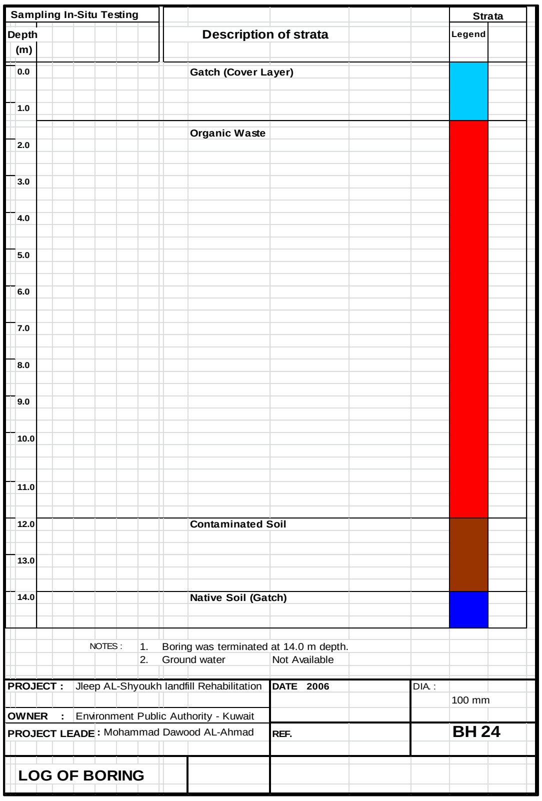

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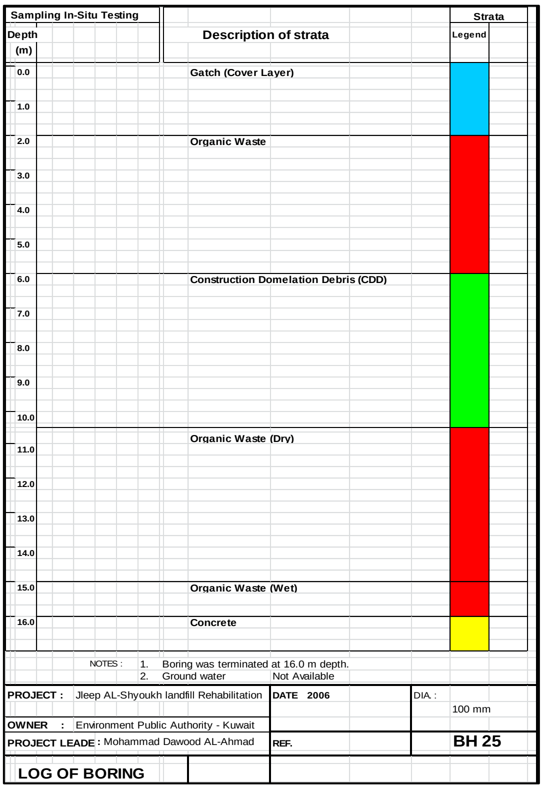

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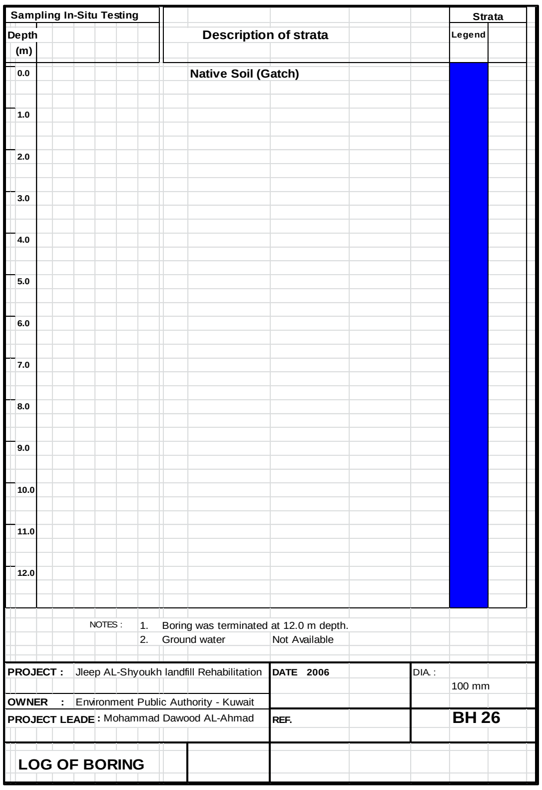

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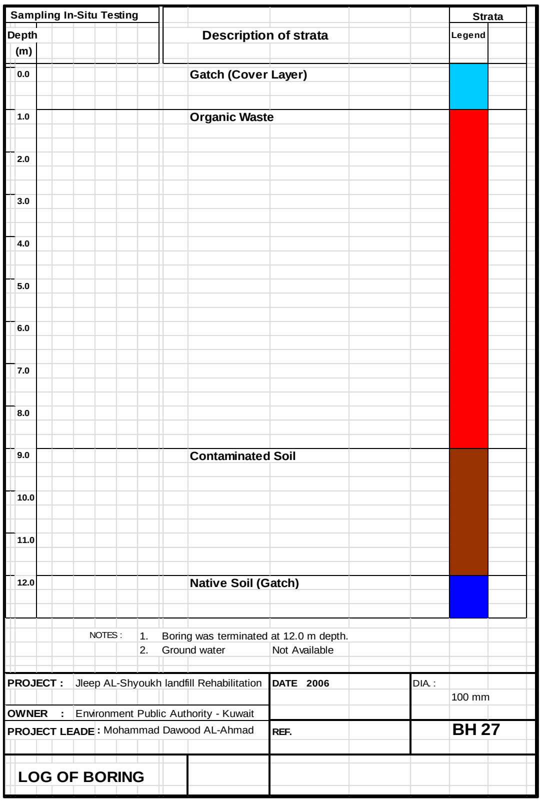

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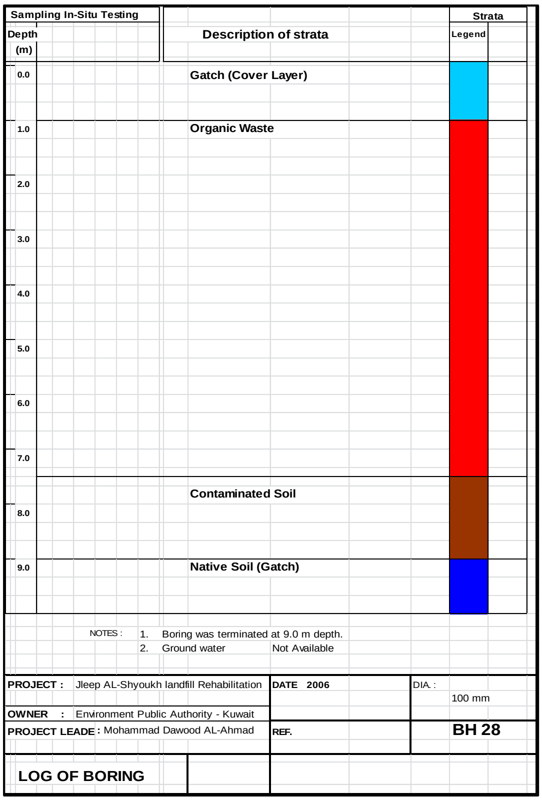

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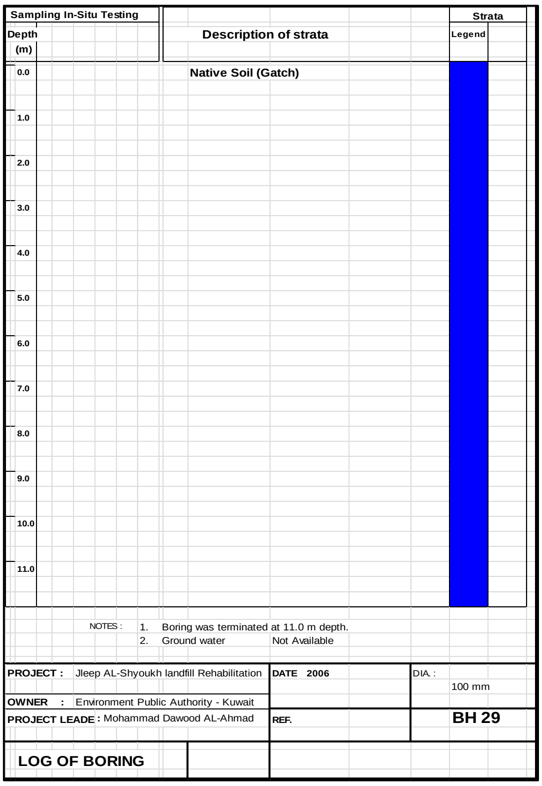

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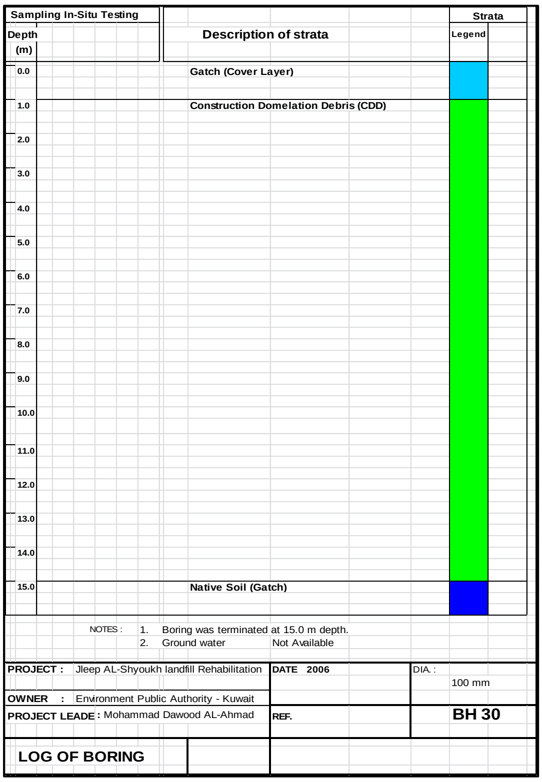

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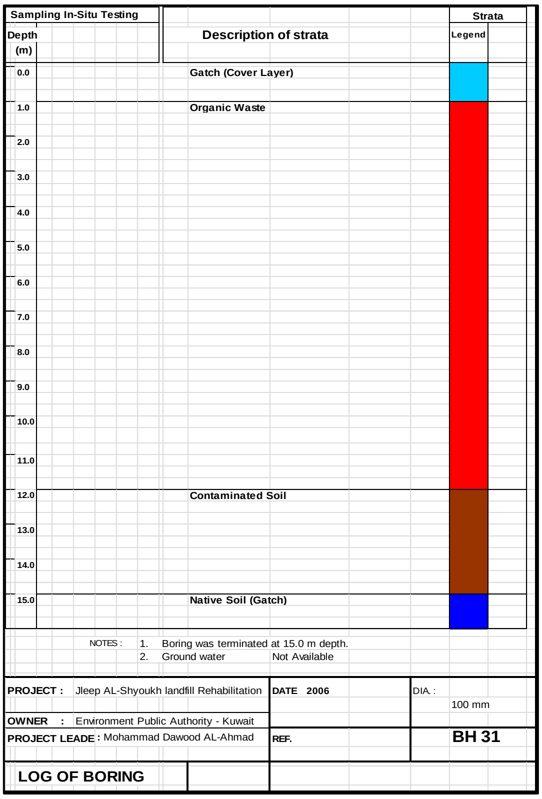

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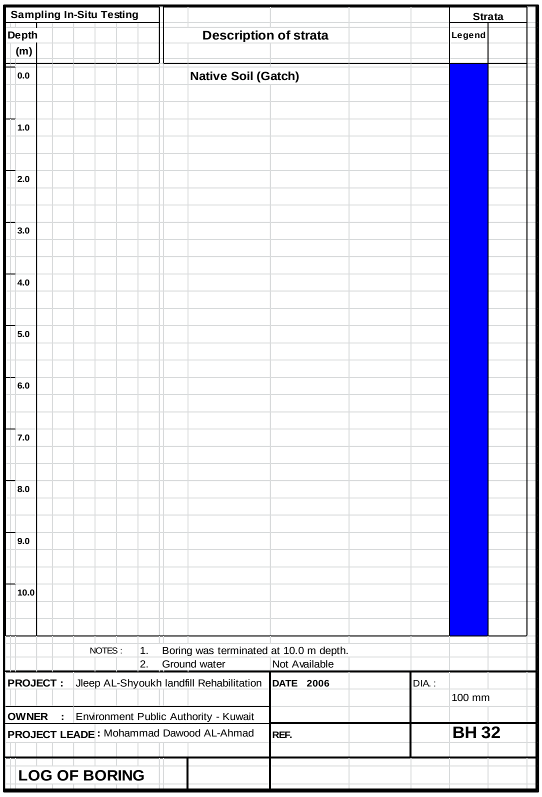

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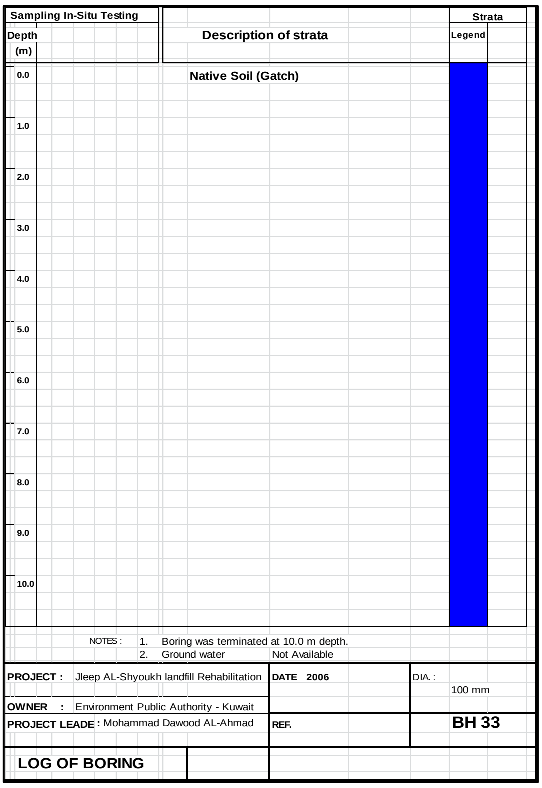

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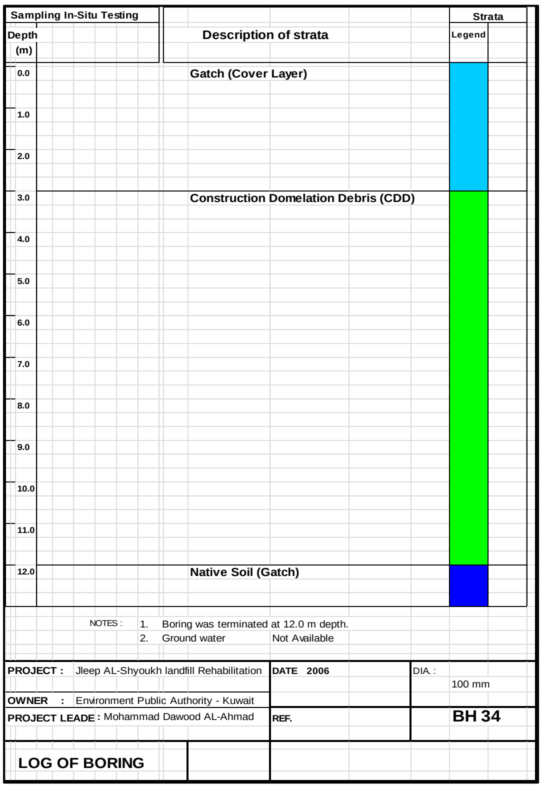

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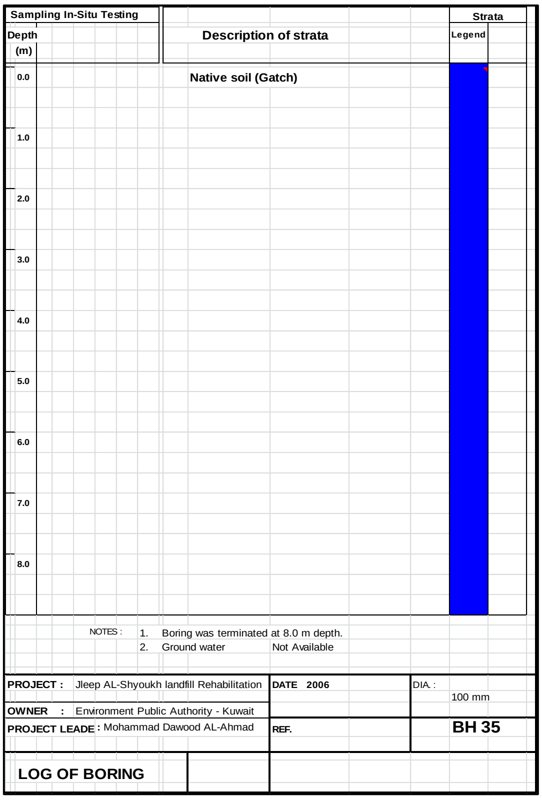

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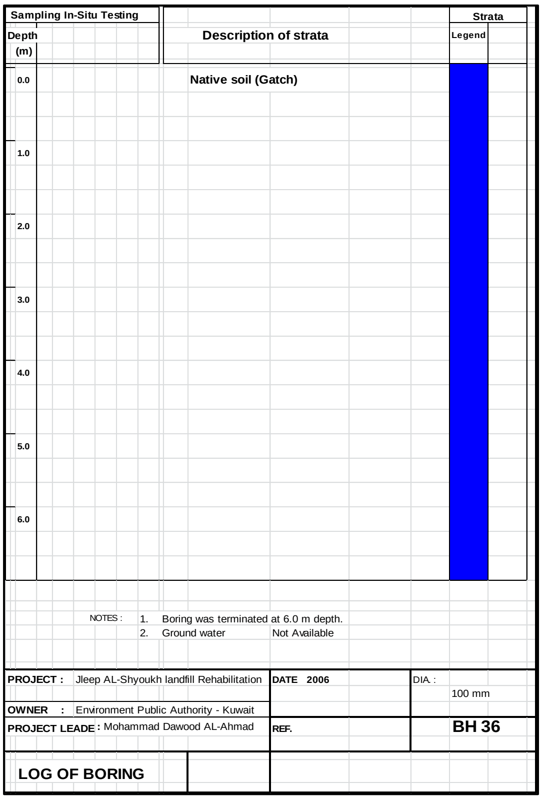

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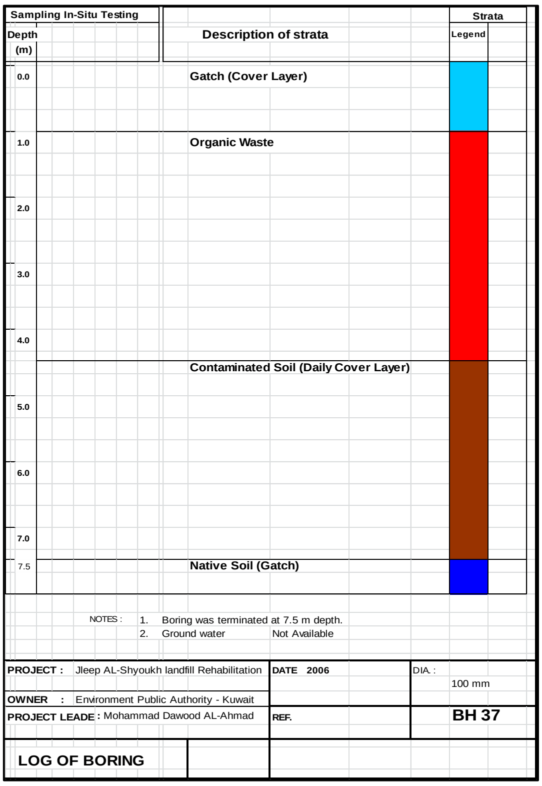

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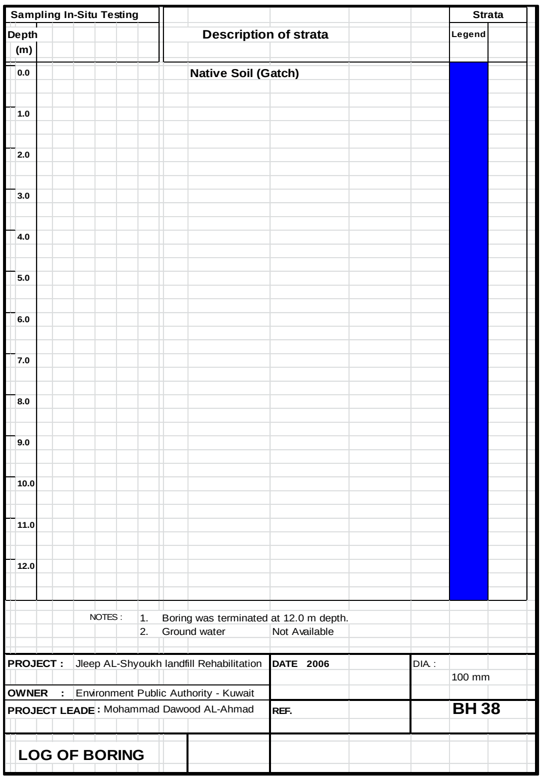

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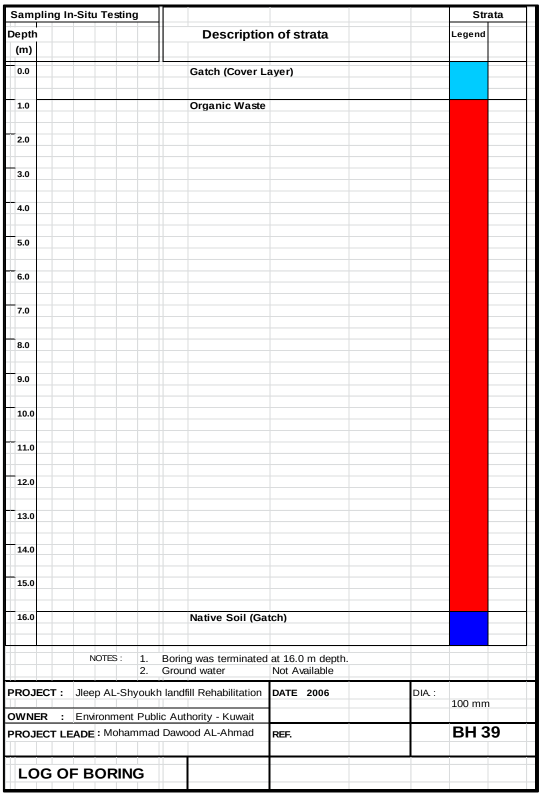

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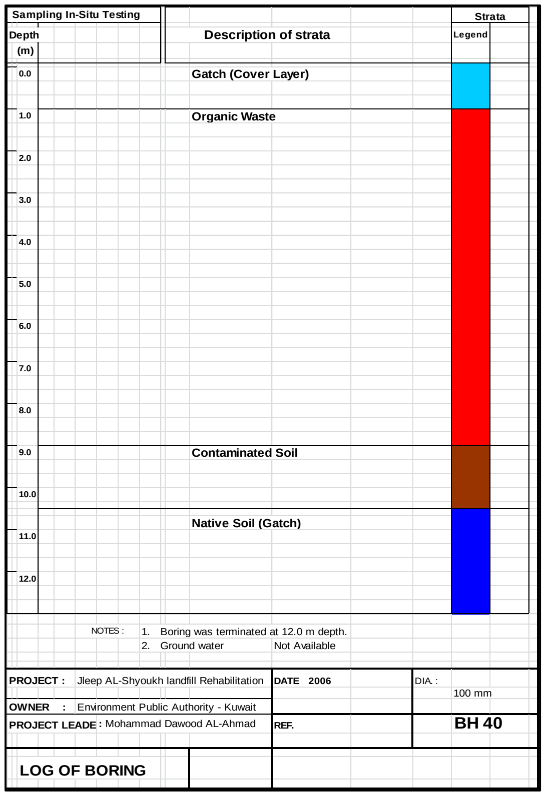
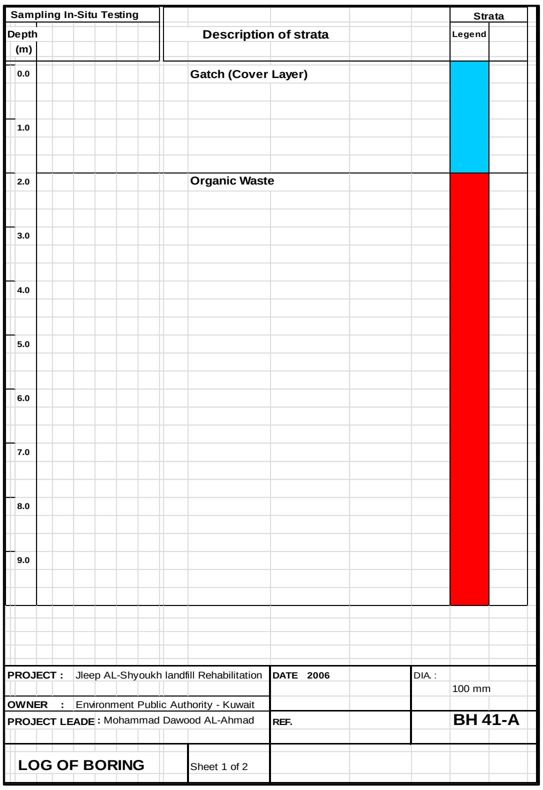
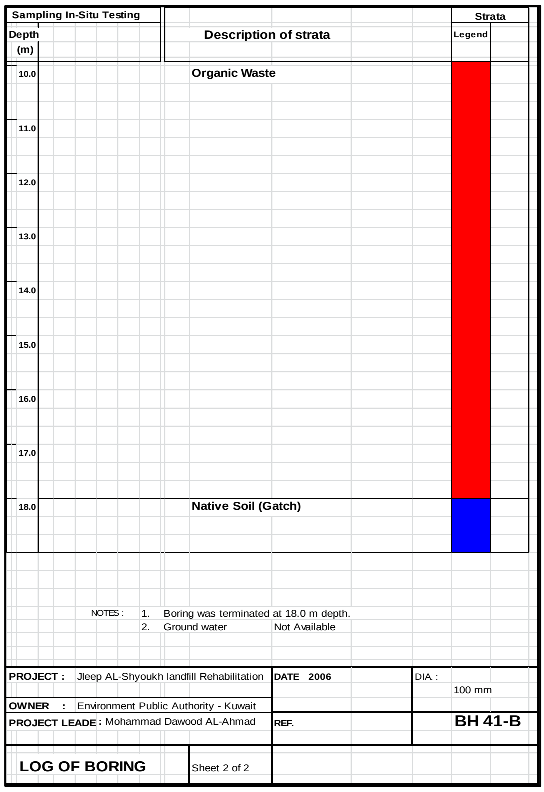


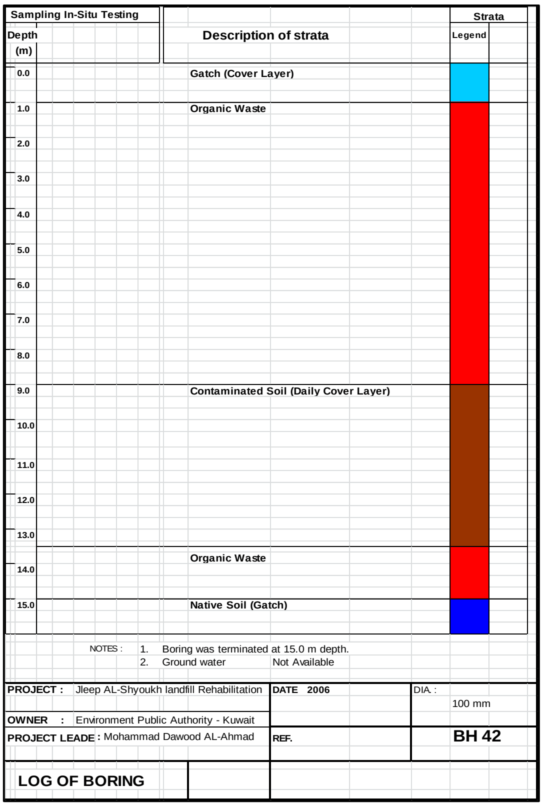
Borehole (40)



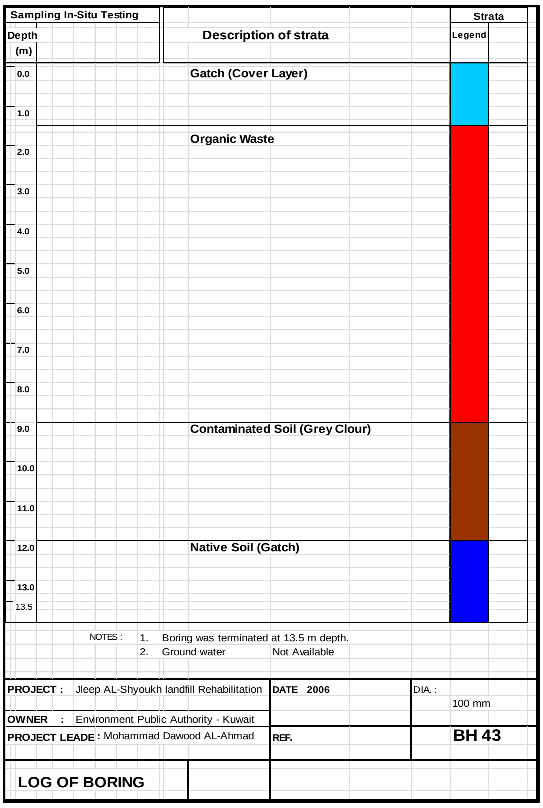
Borehole (41-A)



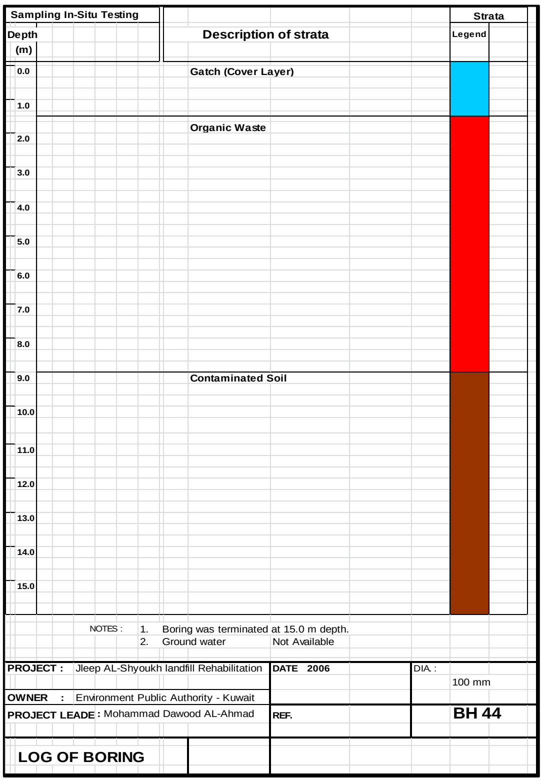
Borehole (41-B)



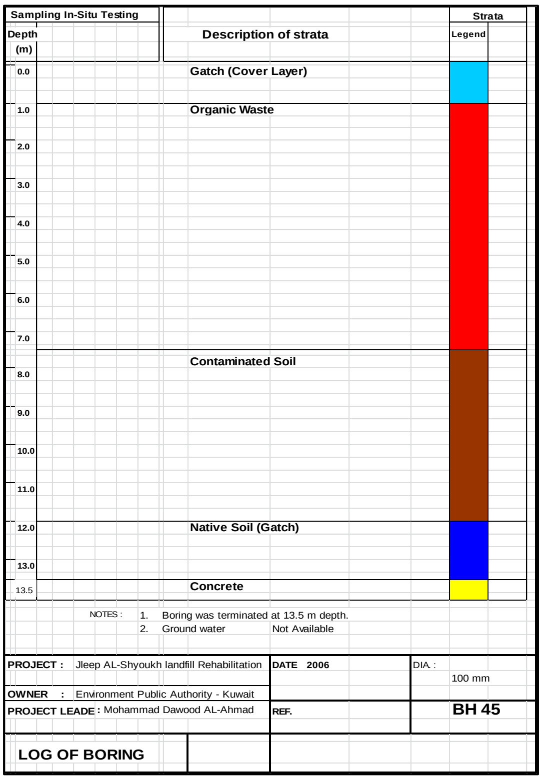
Borehole (42)



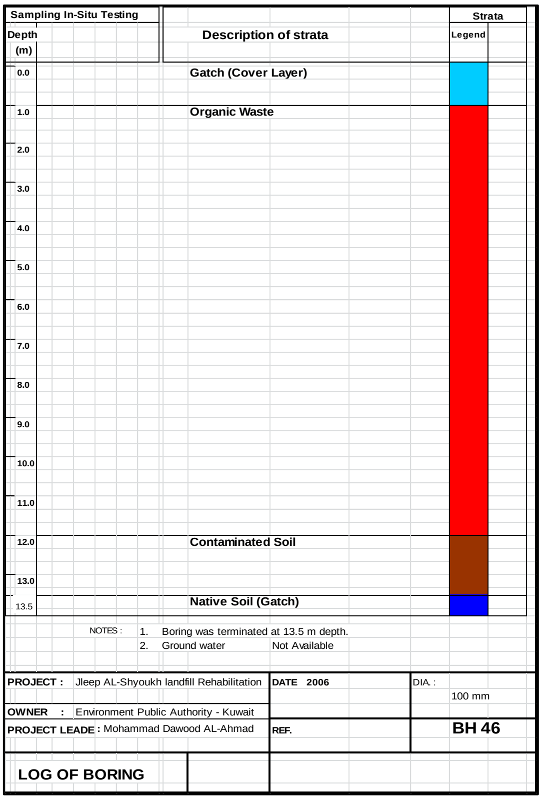
Borehole (43)



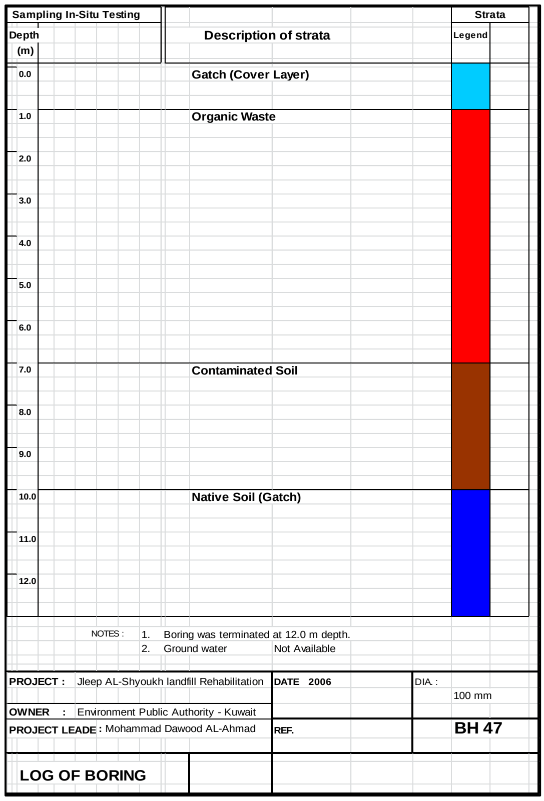
Borehole (44)



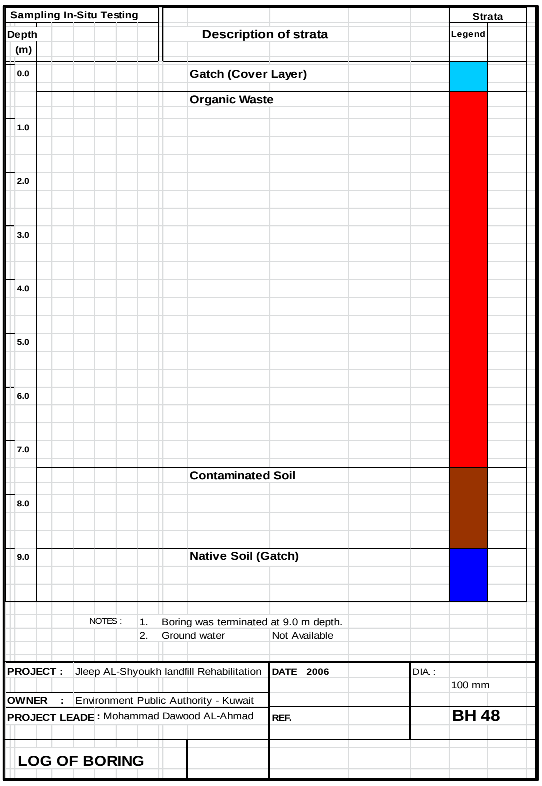
Borehole (45)



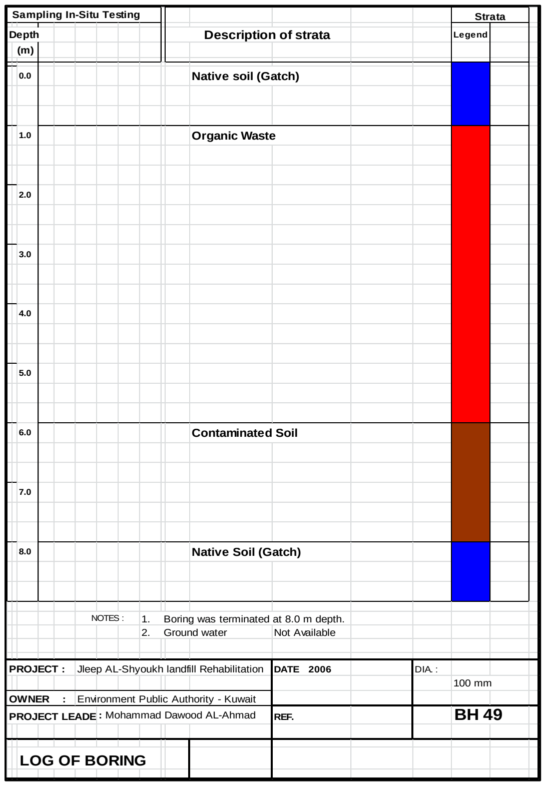
Borehole (46)



Borehole (47)



Borehole (48)



Borehole (49)

Sampling In-Situ Testing Depth (m)	Description of strata	Strata Legend
0.0	Gatch (Cover Layer)	
	Organic Waste	
1.0		
2.0		
3.0		
4.0		
5.0		
6.0		
7.0		
	Contaminated Soil	
8.0		
9.0		
10.0	Native Soil (Gatch)	
11.0		
12.0		

NOTES : 1. Boring was terminated at 12.0 m depth.
2. Ground water Not Available

PROJECT : Jleep AL-Shyoukh landfill Rehabilitation	**DATE 2006**	DIA : 100 mm
OWNER : Environment Public Authority - Kuwait		
PROJECT LEADE : Mohammad Dawood AL-Ahmad	**REF.**	**BH 50**
LOG OF BORING		

Borehole (50)

Appendix (4): Results of grain size analysis for locations 1-30

Figure (App. 4.1): Grain size analysis for locations 1-5

	Date	TR	Sand %						Mud %					T.Mud	TOTAL %	Median		Mean		Sorting		Type Of sorting	C/S	Sed.Type
			Gr.	V.C.S	C.S	M.S	F.S	V.F.S	C.SL	M.SL	F.SL	V.F.SL	Clay			ϕ	mm	f	mm	f	mm			
1	4/010	0.25	3.65	12	9.6	15.6	27.45	28.1	-	-	-	-	-	3.67	99.98	1.84	0.279	1.45	0.366	1.54	0.344	p.s		(g)s
	4/010	0.5	1.76	12.3	7.57	13	33.04	29.6	-	-	-	-	-	2.73	100.00	1.98	0.254	1.56	0.3392	1.43	0.371	p.s		(g)s
	4/010	0.75	2.27	14	7.03	11.7	33.07	29.9		-	-	-	-	2.05	100.00	1.96	0.257	1.44	0.3686	1.5	0.354	p.s		(g)s
	4/010	1	0.63	12.8	7.87	12.8	34.45	29.8	-	-	-	-	-	1.67	99.98	1.97	0.255	1.57	0.3386	1.35	0.392	p.s		(g)s
2	4/010	0.25	6.52	12.62	10.90	18.65	21.47	26.06	-	-	-	-	-	3.51	99.73	1.6	0.342	1.3	0.420	1.660	0.316	p.s		(g)s
	4/010	0.5	5.82	15.60	11.78	18.17	22.31	22.47	-	-	-	-	-	3.35	99.50	1.4	0.371	1.2	0.448	1.640	0.321	p.s		(g)s
	4/010	0.75	3.35	10.52	9.25	16.56	28.84	27.89	-	-	-	-	-	2.77	99.18	1.9	0.276	1.5	0.351	1.460	0.364	p.s		(g)s
	4/010	1	2.71	12.62	9.58	15.48	29.86	27.03	-	-	-	-	-	2.61	99.89	1.8	0.281	1.4	0.369	1.480	0.359	p.s		(g)s
3	4/010	0.25	6.68	9.10	20.76	34.23	13.09	10.75	-	-	-	-	-	5.37	99.98	0.9	0.536	1.0	0.507	1.560	0.339	p.s		gs
	4/010	0.5	8.30	9.85	19.98	33.25	15.22	9.19	-	-	-	-	-	4.20	99.99	0.9	0.555	0.8	0.559	1.56	0.339	p.s		gs
	4/010	0.75	10.38	12.02	20.89	29.88	14.19	9.19	-	-	-	-	-	3.45	100.00	0.7	0.599	0.7	0.624	1.64	0.321	p.s		(g)s
	4/010	1	17.78	11.88	20.77	24.85	12.08	8.51	-	-	-	-	-	4.10	99.97	0.5	0.707	0.4	0.785	1.990	0.25	p.s		gs
4	4/010	0.25	8.53	9.72	23.05	38.68	11.12	5.82	-	-	-	-	-	3.03	99.95	0.7	0.603	0.6	0.64	1.41	0.38	p.s		gs
	4/010	0.5	12.57	10.61	21.69	34.76	10.81	6.21	-	-	-	-	-	3.35	100.00	0.6	0.642	0.5	0.72	1.64	0.32	p.s		gs
	4/010	0.75	15.83	11.14	18.86	30.31	11.83	7.84	-	-	-	-	-	4.13	99.94	0.6	0.647	0.5	0.73	1.89	0.27	p.s		gs
	4/010	1	23.48	10.60	18.76	27.82	10.03	6.26	-	-	-	-	-	2.99	99.94	0.4	0.785	0.0	0.94	2.16	0.22	p.s		gs
5	4/010	1	6.3	7.96	20.5	43.2	16.9	0.1	-	-	-	-	-	5.16	100.04	0.84	0.559	0.76	0.5905	1.33	0.398	p.s		gs
	4/010	2	8.34	13.8	27.6	37.1	9.56	0.02	-	-	-	-	-	3.58	99.98	0.51	0.702	0.35	0.7846	1.2	0.435	p.s		gs
	4/010	3	4.94	12.3	31	38.8	8.66	1.6	-	-	-	-	-	2.68	100.00	0.54	0.688	0.46	0.727	1.07	0.476	p.s		(g)s
	4/010	4	2.86	14.5	37.1	39.3	4.68	0.48	-	-	-	-	-	0.98	100.00	0.4	0.758	0.33	0.7955	0.86	0.551	p.s		(g)s

Figure (App. 4.2): Grain size analysis for locations 6-10

6	4/010	**1**	**1.78**	**7.5**	**22.8**	**44.6**	**20.2**	**0.24**	**-**	**-**	**-**	**-**	**-**	**2.96**	**100.01**	**0.9**	**0.554**	**0.85**	**0.5548**	**0.95**	**0.518**	**m.s**		**(g)s**
	4/010	**2**	**1.8**	**7.78**	**25.3**	**44.8**	**14.5**	**0.62**	**-**	**-**	**-**	**-**	**-**	**5.18**	**100.00**	**0.82**	**0.566**	**0.81**	**0.5704**	**1.15**	**0.451**	**p.s**		**(g)s**
	4/010	**3**	**4.36**	**7.52**	**24.7**	**48.4**	10.8	**0.24**	**-**	**-**	**-**	**-**	**-**	**3.94**	**99.95**	**0.76**	**0.591**	**0.66**	**0.6329**	**1.01**	**0.497**	**p.s**		**(g)s**
	4/010	**4**	3.08	11.3	28.7	52.9	3.3	0.00	-	-	-	-	-	0.76	**100.00**	0.6	0.66	0.44	0.7371	0.79	0.578	m.s		(g)s
7	4/010	**0.25**	4.41	9.67	16.9	25.8	17.7	20.5	-	-	-	-	-	5.04	**100.00**	1.25	0.42	1.26	0.4175	1.54	0.344	p.s		(g)s
	4/010	**0.5**	5.94	14	12.4	20	21.5	22.3	-	-	-	-	-	3.95	**100.02**	1.4	0.379	1.18	0.4414	1.64	0.321	p.s		gs
	4/010	**0.75**	6.01	13.4	9.9	18	24.2	25.7	-	-	-	-	-	2.72	**99.97**	1.6	0.33	1.25	0.4204	1.63	0.323	p.s		gs
	4/010	**1**	4.94	13.7	8.37	17.6	26.4	26.5	-	-	-	-	-	2.41	**99.92**	1.71	0.306	1.31	0.4033	1.58	0.335	p.s		(g)s
8	4/010	**0.25**	2.5	7.04	22.8	30.5	14.9	17.9	-	-	-	-	-	4.4	**99.96**	1.09	0.65	1.25	0.4204	1.39	0.382	p.s		(g)s
	4/010	**0.5**	0.77	5.43	23	30.5	17.5	18.5	-	-	-	-	-	4.32	**100.01**	1.21	0.432	1.35	0.3923	1.3	0.406	p.s		(g)s
	4/010	**0.75**	4.8	8.47	23.6	29.7	14.2	14.9	-	-	-	-	-	4.36	**100.01**	0.95	0.518	1.1	0.4665	1.49	0.356	p.s		(g)s
	4/010	**1**	5.86	14.8	36.9	28.5	8.5	4.46	-	-	-	-	-	0.98	**100.00**	0.32	0.801	0.34	0.79	1.17	0.444	p.s		gs
9	4/010	**0.25**	8.76	7.79	17.5	37.2	16.4	8.99	-	-	-	-	-	3.28	**99.87**	0.93	0.525	0.89	0.5396	1.53	0.346	p.s		gs
	4/010	**0.5**	15.41	17.1	27.7	25.6	9.2	3.75	-	-	-	-	-	1.04	**99.79**	0.15	0.901	0.04	0.9727	1.49	0.356	p.s		gs
	4/010	**0.75**	6.96	13.3	25.1	32.1	114.3	6.33	-	-	-	-	-	1.9	**199.99**	0.63	0.646	0.6	0.6598	1.35	0.392	p.s		gs
	4/010	**1**	10.27	13	23.5	30.8	14.4	6.7	-	-	-	-	-	1.48	**100.04**	0.6	0.66	0.52	0.6974	1.47	0.361	p.s		gs
10	4/010	**0.25**	2.63	6.55	21	43.6	14.2	8.37	-	-	-	-	-	3.68	**99.95**	0.96	0.514	1.03	0.4897	1.22	0.429	p.s		(g)s
	4/010	**0.5**	4.74	9.12	27.8	38.3	12.8	5.49	-	-	-	-	-	1.84	**100.01**	0.71	0.611	0.71	0.6113	1.19	0.438	p.s		(g)s
	4/010	**0.75**	15.29	11.6	31.5	32.5	6.68	1.92	-	-	-	-	-	0.49	**99.90**	0.26	0.835	0.03	0.9794	1.4	0.379	p.s		gs
	4/010	**1**	11.9	11.8	29.2	34.5	9.27	3.04	-	-	-	-	-	0.32	**100.00**	0.41	0.753	0.24	0.8467	1.33	0.398	p.s		gs

Figure (App. 4.3): Grain size analysis for locations 11-15

11	4/010	**0.25**	12.38	6.31	17.7	38.6	14.5	8.22	-	-	-	-	-	2.25	**99.96**	0.85	0.55	0.69	0.62	1.7	0.31	PS		gS
	4/010	**0.5**	11.97	6.69	19.3	36	14.1	9.12	-	-	-	-	-	2.81	**99.95**	0.84	0.55	0.75	0.59	1.7	0.31	PS		gS
	4/010	**0.75**	13.98	9.58	23.4	33	12.1	6.16	-	-	-	-	-	1.73	**99.87**	0.59	0.66	0.4	0.757	1.64	0.32	PS		gS
	4/010	**1**	18.88	10.6	23.6	31.9	9.68	4.22	-	-	-	-	-	1.12	**100.00**	0.39	0.76	0.02	0.986	1.77	0.293	PS		gS
12	4/010	**0.25**	3.77	10.3	28.4	40.2	11	4.84	-	-	-	-	-	1.51	**100.03**	0.68	0.624	0.63	0.646	1.11	0.463	p.s		(g)s
	4/010	**0.5**	6.24	7.21	20.6	35.7	15.1	11.8	-	-	-	-	-	3.37	**99.96**	0.95	0.518	1.02	0.493	1.45	0.366	ps		gs
	4/010	**0.75**	5.2	9.62	22.7	31.7	14.6	13.2	-	-	-	-	-	3.09	**100.01**	0.9	0.536	1	0.5	1.46	0.363	ps		gs
	4/010	**1**	5.86	9.14	23.8	33.8	13.7	10.7	-	-	-	-	-	3.06	**100.03**	0.83	0.563	0.91	0.532	1.43	0.371	ps		gs
13	4/010	**0.25**	0.69	2.29	26.6	36.3	16.8	15.2	-	-	-	-	-	2.03	**99.98**	1.08	0.473	1.27	0.415	1.12	0.461	ps		(g)s
	4/010	**0.5**	5.41	6.46	24.8	32.4	14.4	13.1	-	-	-	-	-	3.54	**100.04**	0.92	0.528	1.07	0.476	1.44	0.368	ps		gs
	4/010	**0.75**	8.16	7.18	26.5	32.2	13.3	10.7	-	-	-	-	-	2	**100.04**	0.76	0.59	0.85	0.555	1.46	0.363	ps		gs
	4/010	**1**	16.24	12	29.8	26.7	9.84	5	-	-	-	-	-	0.37	**99.98**	0.25	0.841	0.07	0.953	1.6	0.329	ps		gs
14	4/010	**0.25**	7.22	8.83	20.2	32.1	13.5	12	-	-	-	-	-	6.09	**100.00**	0.93	0.525	1.03	0.489	1.61	0.327	ps		gs
	4/010	**0.5**	11.93	10.7	21.8	30.7	12.3	8.62	-	-	-	-	-	3.94	**100.02**	0.68	0.624	0.62	0.651	1.7	0.307	ps		gs
	4/010	**0.75**	17.79	9.74	21.4	30.4	12	6.79	-	-	-	-	-	1.83	**100.03**	0.53	0.693	0.23	0.853	1.88	0.272	ps		gs
	4/010	**1**	23.33	13.3	25	26.6	7.68	3.37	-	-	-	-	-	0.79	**99.99**	0.05	0.966	-0.25	0.669	1.78	0.292	ps		gs
15	4/010	**0.25**	6.43	6.05	12.4	25.3	20.6	22.3	-	-	-	-	-	6.91	**100.02**	1.5	0.354	1.45	0.366	1.6	0.329	ps		gs
	4/010	**0.5**	4.52	6.18	15	29.3	19.4	18.5	-	-	-	-	-	7.19	**100.02**	1.35	0.392	1.41	0.376	1.5	0.354	ps		(g)s
	4/010	**0.75**	12.03	10.5	19.1	27.4	13.9	12.1	-	-	-	-	-	4.84	**99.97**	0.81	0.574	0.78	0.582	1.84	0.279	ps		gs
	4/010	**1**	10.66	12.8	19.3	25.3	13.2	7.84	-	-	-	-	-	10.86	**100.03**	0.79	0.578	0.88	0.544	1.85	0.277	ps		gs

Figure (App. 4.4): Grain size analysis for locations 16-20

16	**4/010**	**0.25**	9.55	7.54	18.5	30	16.4	14.2	-	-	-	-	-	3.74	**99.96**	0.99	0.503	0.99	0.503	1.67	0.314	ps		gs
	4/010	**0.5**	10.23	9.54	19.8	28.5	14.4	13.8	-	-	-	-	-	3.7	**100.03**	0.87	0.547	0.88	0.543	1.71	0.306	ps		gs
	4/010	**0.75**	7.07	10.6	20.1	27.9	16.2	14.8	-	-	-	-	-	3.34	**99.96**	0.95	0.517	0.98	0.507	1.58	0.507	ps		gs
	4/010	**1**	7.66	8.88	18.5	28.4	17.5	16.4	-	-	-	-	-	2.73	**99.95**	1.03	0.489	1.05	0.483	1.57	0.337	ps		gs
17	**4/010**	**0.25**	5.04	8.25	23.9	39	13.8	7.94	-	-	-	-	-	2.05	**99.99**	0.83	0.563	0.84	0.558	1.27	0.415	ps		gs
	4/010	**0.5**	3.77	10.5	14.4	22	26.9	20	-	-	-	-	-	2.54	**99.98**	1.5	0.254	1.3	0.406	1.44	0.368	ps		(g)s
	4/010	**0.75**	1.63	10.4	17.2	23.2	25.8	19	-	-	-	-	-	2.77	**99.98**	1.41	0.376	1.31	0.403	1.37	0.386	ps		(g)s
	4/010	**1**	5.45	8.83	20.1	38.3	14.9	9.77	-	-	-	-	-	2.62	**100.03**	0.91	0.532	0.93	0.525	1.36	0.389	ps		gs
18	**4/010**	**0.25**	10.5	8.19	18.4	32.7	14	11.6	-	-	-	-	-	4.6	**100.01**	0.9	0.535	0.88	0.543	1.72	0.304	ps		gs
	4/010	**0.5**	10.5	8.17	18.4	32.8	14	11.6	-	-	-	-	-	4.6	**100.00**	0.9	0.536	0.88	0.545	1.72	0.301	ps		gs
	4/010	**0.75**	15.19	10.7	18	29.5	13.4	9.86	-	-	-	-	-	3.37	**99.97**	0.71	0.611	0.54	0.687	1.87	0.274	ps		gs
	4/010	**1**	29.05	10.8	16.9	23.9	10.4	7.37	-	-	-	-	-	1.6	**100.01**	0.12	0.92	-0.34	0.578	2.41	0.188	vps		gs
19	**4/010**	**0.25**	3.36	5.36	21.8	43	15.2	8.33	-	-	-	-	-	3.04	**100.01**	0.96	0.514	1.02	0.493	1.21	0.432	ps		(g)s
	4/010	**0.5**	13.32	8.52	20.3	35	13.2	7.11		-	-	-	-	2.11	**99.59**	0.72	0.607	0.53	0.693	1.66	0.316	ps		gs
	4/010	**0.75**	16.38	11.3	23.9	31.9	10.5	4.84	-	-	-	-	-	1.2	**100.00**	0.44	0.737	0.15	0.901	1.67	0.314	ps		gs
	4/010	**1**	17.86	12.2	25.8	31.4	8.84	3.12	-	-	-	-	-	0.81	**100.00**	0.3	0.812	0	1	1.61	0.328	ps		gs
20	**4/010**	**0.25**	19.74	6.79	14.7	34.9	13.4	7.78	-	-	-	-	-	2.75	**100.06**	0.75	0.595	0.22	0.858	2.32	0.2	VPS		gS
	4/010	**0.5**	23.95	9.26	15.2	30.5	12	7.07	-	-	-	-	-	1.94	**99.93**	0.55	0.683	0.01	0.993	2.24	0.212	VPS		gS
	4/010	**0.75**	18.6	8.84	15.9	31.7	14.3	8.56	-	-	-	-	-	2.04	**99.95**	0.72	0.611	0.33	0.795	2.03	0.245	VPS		gS
	4/010	**1**	17.04	11	17.6	30.7	13.7	8.46	-	-	-	-	-	1.66	**100.05**	0.64	0.642	0.36	0.779	1.87	0.274	PS		gS

Figure (App. 4.5): Grain size analysis for locations 21-25

21	4/010	0.25	7.54	8.47	21.5	40.4	12.6	7.54	-	-	-	-	-	1.95	99.92	0.8	0.574	0.76	0.59	1.35	0.39	PS		gS
	4/010	0.5	24.03	9.17	17.9	27.7	10.6	7.93	-	-	-	-	-	2.69	100.00	0.46	0.727	-0.05	0.923	2.38	0.192	VPS		gS
	4/010	0.75	34.14	8.71	14.1	22.2	9.34	8.51	-	-	-	-	-	3.01	99.96	0.03	0.979	-0.68	0.335	3.08	0.118	VPS		sG
	4/010	1	38.84	9.26	14.5	20.3	8.2	6.5	-	-	-	-	-	2.44	100.00	-0.38	0.543	-1.04	0.188	3.03	0.122	VPS		sG
22	4/010	0.25	10.22	7.53	19.1	37.5	13.1	8.19	-	-	-	-	-	4.24	99.79	0.85	0.55	0.8	0.574	1.62	0.325	PS		gS
	4/010	0.5	22.24	9.94	23.5	29	10.2	3.81	-	-	-	-	-	1.32	100.00	0.27	0.829	-0.15	0.786	1.96	0.257	PS		gS
	4/010	0.75	19.24	7.75	17.9	28.9	15.3	8.39	-	-	-	-	-	2.51	99.98	0.67	0.628	0.28	0.823	2.17	0.222	VPS		gS
	4/010	1	21.83	12	22.7	28.3	9.41	4.6	-	-	-	-	-	1.01	99.88	0.24	0.847	-0.11	0.837	1.85	0.277	PS		gS
23	4/010	0.25	5.98	9.17	9.17	18.7	20.8	29.7	-	-	-	-	-	6.48	100.01	1.85	0.277	1.52	0.348	1.64	0.321	PS		gS
	4/010	0.5	5	9.84	10.1	17.7	26.2	26.8	-	-	-	-	-	4.32	99.98	1.8	0.287	1.46	0.36	1.56	0.339	PS		gS
	4/010	0.75	6.39	11.3	9.22	15.8	33.5	20.3	-	-	-	-	-	3.35	99.81	1.73	0.301	1.3	0.406	1.61	0.328	PS		gS
	4/010	1	5.27	13	8.38	14.7	24.6	29.1	-	-	-	-	-	4.95	99.92	1.88	0.272	1.42	0.374	1.66	0.316	PS		gS
24	4/010	0.25	4.24	17.1	13.8	17.8	17.9	23.9	-	-	-	-	-	5.14	99.88	1.35	0.392	1.19	0.44	1.65	0.329	PS		(g)S
	4/010	0.5	3.72	15.1	13.2	29.4	19.6	16.4	-	-	-	-	-	2.63	99.98	1.13	0.457	1.05	0.483	1.5	0.354	PS		(g)S
	4/010	0.75	2.69	13.8	13.6	18.5	22.2	25.4	-	-	-	-	-	3.87	99.99	1.57	0.337	1.31	0.403	1.55	0.342	PS		(g)S
	4/010	1	4.19	20.9	8.36	11.7	33.3	20.1	-	-	-	-	-	1.46	99.95	1.65	0.318	1.17	0.444	1.55	0.342	PS		(g)S
25	4/010	0.25	3.12	9.3	22.3	35.5	14.5	11.3	-	-	-	-	-	3.78	99.82	0.93	0.525	1.03	0.489	1.37	0.387	PS		(g)S
	4/010	0.5	5.54	11.1	23.7	28.9	14.3	13.2	-	-	-	-	-	3.14	99.90	0.85	0.555	0.95	0.518	1.49	0.356	PS		gS
	4/010	0.75	3.5	10.4	22.2	30.6	13.7	15.3		-	-	-	-	4.3	100.02	0.95	0.518	1.09	0.469	1.46	0.363	PS		(g)S
	4/010	1	4.44	9.87	22.2	30.8	17.2	12.3	-	-	-	-	-	3.04	99.91	0.94	0.521	1.01	0.497	1.42	0.374	PS		(g)S

Figure (App. 4.6): Grain size analysis for locations 26-30

26	4/010	**0.25**	20.52	10.6	21.7	29	10.4	6.1	-	-	-	-	-	1.54	**99.90**	0.38	0.768	0.04	0.973	1.93	0.262	PS		gS
	4/010	**0.5**	38	8.5	18	21.8	9.52	3.37	-	-	-	-	-	0.72	**99.95**	-0.28	0.637	-1.27	0.129	3.16	0.112	VPS		sG
	4/010	**0.75**	14.21	12.3	25	30.2	12.2	5.11	-	-	-	-	-	0.96	**99.98**	0.45	0.732	0.27	0.829	1.56	0.339	PS		gS
	4/010	**1**	36.93	9.98	18.6	21.5	9.29	3.04	-	-	-	-	-	0.7	**99.99**	-0.33	0.588	-0.99	0.203	2.68	0.156	VPS		sG
27	4/010	**0.25**	6.22	9.38	34	44.6	3.38	0.02	-	-	-	-	-	2.34	**99.96**	0.51	0.702	0.4	0.758	0.92	0.528	MS		gS
	4/010	**0.5**	16.40	11.44	27.39	40.19	3.4	0.70	-	-	-	-	-	0.48	**99.98**	0.34	0.791	-0.04	0.938	1.37	0.387	PS		gS
	4/010	**0.75**	8.6	10.3	41.7	36.6	2.5	0.0	-	-	-	-	-	0.26	**100.03**	0.27	0.829	0.17	0.888	0.93	0.525	MS		gS
	4/010	**1**	12.4	16.5	33.6	35.4	1.09	0.0	-	-	-	-	-	0.20	**99.15**	0.15	0.903	-0.05	0.923	1.08	0.473	PS		gS
28	4/010	**0.25**	11.76	17.8	19.8	39.9	7.19	0.0	-	-	-	-	-	3.59	**99.99**	0.52	0.697	0.22	0.858	1.3	0.406	PS		gS
	4/010	**0.5**	22.70	12.16	23.24	37.40	3.38	0.00	-	-	-	-	-	1.1	**99.98**	0.17	0.888	-0.32	0.597	1.62	0.325	PS		gS
	4/010	**0.75**	18.10	15.00	23.58	39.96	2.70	0.00	-	-	-	-	-	0.66	**100.00**	0.23	0.853	-0.14	0.798	1.34	0.395	PS		gS
	4/010	**1**	14.41	8.90	23.07	49.04	3.9	0.00	-	-	-	-	-	0.66	**99.97**	0.56	0.678	0.14	0.908	1.32	0.401	PS		gS
29	4/010	**0.25**	3.3	13.0	11.5	41.2	27.1	0.5	-	-	-	-	-	3.29	**99.87**	1.05	0.483	0.82	0.566	1.16	0.448	PS		(g)S
	4/010	**0.5**	2.7	13.1	9.8	40.8	28.1	1.6	-	-	-	-	-	3.95	**100.00**	1.1	0.467	0.86	0.551	1.23	0.426	PS		(g)S
	4/010	**0.75**	2.0	11.8	8.8	39.8	33.8	0.2	-	-	-	-	-	3.72	**100.03**	1.21	0.432	1	0.5	1.07	0.477	PS		(g)S
	4/010	**1**	3.56	15.44	7.94	36.92	33.6	0.00	-	-	-	-	-	2.6	**100.06**	1.13	0.457	0.8	0.574	1.18	0.441	PS		(g)S
30	4/010	**0.25**	4.19	9.59	28.74	53.51	2.78	0.0	-	-	-	-	-	1.18	**99.99**	0.61	0.655	0.45	0.732	0.8	0.574	MS		(g)S
	4/010	**0.5**	6.69	9.07	26.2	51.34	5.17	0.00	-	-	-	-	-	1.58	**100.00**	0.63	0.646	0.46	0.727	0.96	0.515	MS		gS
	4/010	**0.75**	18.56	13	28.8	36.9	2.14	0.00	-	-	-	-	-	0.58	**99.92**	0.16	0.895	-0.2	0.724	1.37	0.386	PS		gS
	4/010	**1**	4.19	9.59	28.7	53.5	2.78	0.0	-	-	-	-	-	1.18	**99.99**	-0.03	0.953	-0.28	0.637	1.24	0.423	PS		gS

Appendix (5): LFG measurements in the Total Area of JLF (2008-2010)

Table App. 5.1: LFG measurements in Borehole 01

Jleeb Al Shuyoukh Landfill, LF Gas Monitoring																	BH 01
ID	DATE	MONTH	CH4	CO2	O2	BAL	NH3	H2S	TEMP	CH4 %	PEAK	PEAK	MIN	CH4/	BARO	REL.	Res
			%	%	%	%	ppm	ppm	DegC	LEL%	CH4%	CO2%	O2%	CO2%	mb	PRESS.mb	Nitro%
JALEEB01	3/31/2008 9:59	MAR 08	0	0.5	18.8	80.7	0	5	29.5	0	0	0.6	18.8	0	998	-0.16	9.64
JALEEB01	4/13/2008 10:02	APR 08	0	2.9	18.7	78.4	2	0	29.3	0	1.7	8.3	15.2	0	1007	-0.03	7.71
JALEEB01	5/18/2008 11:48	MAY 08	0	1.1	18.5	80.4	11	0	36.8	0	0	2	17.9	0	998	1.25	10.47
JALEEB01	6/1/2008 9:50	JUN 08	0	0.7	19.2	80.1	1	1	39.4	0	0	0.7	19.2	0	997	1.61	7.52
JALEEB01	7/6/2008 8:09	JUL 08	0.1	1	18.9	80	0	2	40.5	2	0.1	1.6	18.8	0.1	992	-0.07	8.56
JALEEB01	8/9/2008 9:09	AUG 08	0	1.5	19.5	79	0	0	45.7	0	0.2	2.9	19.1	0	1009	-0.01	5.29
JALEEB01	9/11/2008 10:20	SEP 08	0	1.5	19.4	79.1	0	0	44.7	0	0	3.7	19.1	0	1001	0.09	5.77
JALEEB01	10/12/2008 10:31	OCT 08	0	2.3	18.9	78.8	0	0	34.1	0	0	4.7	18.6	0	1003	0.03	7.36
JALEEB01	11/13/2008 10:05	NOV 08	0	2.9	18.7	78.4	2	0	19.3	0	0	2.8	18.7	0	1005	-0.03	7.71
JALEEB01	12/13/2008 11:28	DEC 08	0	0.6	19.5	79.9	0	213		0	0	2.1	17.1	0	1015	-0.02	6.19

Table App. 5.2: LFG measurements in Borehole 02

Jleeb Al Shuyoukh Landfill, LF Gas Monitoring																	BH 02
ID	DATE	MONTH	CH4	CO2	O2	BAL	NH3	H2S	TEMP	CH4 %	PEAK	PEAK	MIN	CH4/	BARO	REL.	Res
			%	%	%	%	ppm	ppm	DegC	LEL%	CH4%	CO2%	O2%	CO2%	mb	PRESS.mb	Nitro%
JALEEB02	3/31/2008 9:47	MAR 08	0	0.8	18.2	81	0	3	30.1	0	0	1	18.2	0	999	-0.1	12.2
JALEEB02	4/13/2008 10:08	APR 08	0	3.4	14.8	81.8	4	0	28.9	0	0	3.3	14.8	0	1007	0.08	25.86
JALEEB02	5/18/2008 11:43	MAY 08	0	2.6	15.8	81.6	4	0	36.9	0	0	2.6	15.8	0	998	-0.4	21.88
JALEEB02	6/1/2008 9:55	JUN 08	0	1.1	17.6	81.3	1	3	40.2	0	0	1.1	17.7	0	998	0.01	14.77
JALEEB02	7/6/2008 8:12	JUL 08	0	0.7	18.9	80.4	1	3	38.5	0	0	0.9	18.9	0	992	-0.07	8.96
JALEEB02	8/9/2008 9:45	AUG 08	0	1	19.6	79.4	0	4	46.4	0	0	1.4	19.5	0	1009	-0.12	5.31
JALEEB02	9/11/2008 9:18	SEP 08	0	2.7	16.9	80.4	0	0	44.4	0	0	2.7	16.9	0	1003	0.61	16.52
JALEEB02	10/12/2008 10:36	OCT 08	0	1.8	18	80.2	0	0	34.9	0	0	2.4	17.9	0	1003	0.01	12.16
JALEEB02	11/13/2008 10:10	NOV 08	0	0.2	17.7	82.1	98	0	18.8	0	0	0.2	17.8	0	1006	0.08	25.86
JALEEB02	12/13/2008 11:32	DEC 08	0	1.1	19.2	79.7	0	148	15.5	0	0	1.1	19.2	0	1010	0.08	7.12
JALEEB02	7/1/2009 10:48	JAN 09	0	0.6	19.3	80.1	314	5	18.1	0	0	0.6	18.6	0	1006	-0.13	7.15
JALEEB02	8/2/2009 4:22	FEB 09	0	2	18.8	79.2	176	0	22.9	0	0.3	8.6	14.8	0	1006	-0.03	7.18
JALEEB02	17/3/2009 2:52	MAR 09	0	5.8	14.7	79.5	3	0	26.6	0	0	5.8	14.6	0	1007	0.21	23.93
JALEEB02	21/4/2009 8:40	APR 09	0	1.6	18.2	80.2	2	0	27.4	0	0	1.6	18.2	0	1009	0.09	11.4
JALEEB02	26/5/2009 6:54	MAY 09	0	1.3	18.4	80.3	2	0	35.8	0	0	2.1	17.8	0	994	1.51	10.75
JALEEB02	7/6/2009 10:48	JUN 09	0	1.2	17.5	81.3	1	1	40.1	0	0	1.2	17.5	0	996	0.4	15.15
JALEEB02	2/7/2009 4:22	JUL 09	0	0.8	18.9	80.3	1	3	38.5	0	0	0.9	18.9	0	1001	-0.07	8.96
JALEEB02	8/12/2009 8:29	AUG 09	0	1.9	17.2	80.9	0	0	46.6	0	0	1.9	17.2	0	1001	-0.01	15.88
JALEEB02	9/4/2009 8:59	SEP 09	0	1.2	18.6	80.2	0	1	32.7	0	0	1.5	18.6	0	1001	1.89	9.89
JALEEB02	10/11/2009 8:36	OCT 09	0	2.7	16.9	80.4	0	0	32	0	0	2.7	16.9	0	1003	0.61	16.52
JALEEB02	13/11/2009 10:05	NOV 09	0	1.1	19.2	79.7	0	148	31.5	0	0	1.1	19.2	0	1010	0.08	7.12
JALEEB02	26/12/2009 6:54	DEC 09	0	0.2	17.7	82.1	98	0	31.9	0	0	0.2	17.8	0	1006	0.08	25.86
JALEEB02	1/17/2010 10:48	JAN 10	0	1.8	17.4	80.8	101	0	21.9	0	0	1.7	17.4	0	1015	-0.13	15.03
JALEEB02	2/28/2010 11:00	FEB 10	0	2.2	17.1	80.7	22	0	24.5	0	0.5	2.2	17.2	0	1006	-0.08	16.06
JALEEB02	3/16/2010 10:20	MAR 10	0	1.2	17.9	80.9	25	0	33.5	0	0.4	1.2	17.4	0	1000	0.86	13.24
JALEEB02	4/21/2010 15:28	ARP 10	0	2.5	17	80.5	10	0	39.4	0	0	2.5	17	0	993	-0.16	16.24
JALEEB02	5/19/2010 10:27	MAY 10	0.1	0.9	17.5	81.5	209	0	47.8	2	61.9	35.1	0.6	0.11	996	-0.03	15.35
JALEEB02	6/22/2010 10:21	JUN 10	0	2.1	17.5	80.4	36	1	45.7	0	63.2	35.5	0.5	0	992	-0.17	14.25
JALEEB02	7/20/2010 9:54	JUL 10	0	3.8	15.7	80.5	0	1	47.3	0	62.6	35.4	0.7	0	984	-21.05	21.15
JALEEB02	8/18/2010 9:52	AUG 10	0	0.9	18.3	80.8	239	0	47.7	0	58.6	34.3	0.9	0	987	-0.09	11.63
JALEEB02	9/19/2010 11:22	SEP 10	0.1	1.1	18.7	80.1	207	0	46.3	2	1.5	1.1	18	0.09	990	-0.04	9.41
JALEEB02	10/19/2010 10:41	OCT 10	0	2	17.7	80.3	122	0	37.9	0	57.1	33.3	1.8	0	999	-0.03	13.39
JALEEB02	11/7/2010 10:55	NOV 10	0	2.4	16.6	81	72	0	28.7	0	57.5	32.7	1.7	0	1004	0.59	18.25
JALEEB02	12/20/2010 13:55	DEC 10	0	2.3	17.4	80.3	0	0	23.8	0	27.4	15.9	10.6	0	1009	0.19	14.53

Table App. 5.3: LFG measurements in Borehole 03

Jleeb Al Shuyoukh Landfill, LF Gas Monitoring																	BH 03
ID	DATE	MONTH	CH4	CO2	O2	BAL	NH3	H2S	TEMP	CH4 %	PEAK	PEAK	MIN	CH4/	BARO	REL.	Res
			%	%	%	%	ppm	ppm	DegC	LEL%	CH4%	CO2%	O2%	CO2%	mb	PRESS.mb	Nitro%
JALEEB03	3/31/2008 9:59	MAR 08	0	0.6	18.7	80.7	0	6	29.9	0	0	0.8	18.6	0	998	-0.14	10.01
JALEEB03	4/13/2008 10:15	APR 08	0	1.8	17.2	81	10	0	29.2	0	0	2.6	17.3	0	1007	-0.1	15.98
JALEEB03	5/18/2008 11:52	MAY 08	0	3.5	11.6	84.9	0	0	37	0	0	3.5	11.6	0	998	-0.29	41.05
JALEEB03	6/1/2008 10:00	JUN 08	0	1.4	16.7	81.9	1	2	40.8	0	0	1.3	16.5	0	998	-26.58	18.77
JALEEB03	7/6/2008 8:15	JUL 08	0	0.4	18.9	80.7	1	4	40.1	0	0	0.6	18.9	0	992	-0.14	9.26
JALEEB03	8/9/2008 9:47	AUG 08	0	0.6	19.7	79.7	0	5	46.8	0	0	0.9	19.5	0	1009	-0.08	5.23
JALEEB03	9/11/2008 9:22	SEP 08	0	2.1	17.7	80.2	0	0	44	0	0	2.3	17.4	0	1004	0.03	13.29
JALEEB03	10/12/2008 11:00	OCT 08	0	3.2	13.7	83.1	0	0	34.6	0	0	3	13.9	0	1003	-0.04	31.31
JALEEB03	11/13/2008 10:14	NOV 08	0	0.6	19.6	79.8	118	0	19.2	0	0	0.6	19.6	0	1006	-0.1	15.98
JALEEB03	12/13/2008 11:30	DEC 08	0	2.1	17.3	80.6	0	201	14.4	0	0	2	17.5	0	1015	-0.01	15.21
JALEEB03	7/1/2009 10:44	JAN 09	0	0	19.7	80.3	365	4	17.5	0	0	0.1	19.6	0	1005	0.09	5.83
JALEEB03	8/2/2009 4:26	FEB 09	0	1.1	19.5	79.4	222	0	22.3	0	0	1.5	18.9	0	1005	-20.37	10.47
JALEEB03	17/3/2009 2:55	MAR 09	0	5.6	13.5	80.9	3	0	27.2	0	0	5.6	13.5	0	1007	0.07	29.87
JALEEB03	21/4/2009 8:44	APR 09	0	3	15.8	81.2	2	0	27.2	0	0	3.5	15.7	0	1009	0.08	21.48
JALEEB03	26/5/2009 6:57	MAY 09	0	5	14	81	2	0	36.2	0	0	6	12.9	0	994	1.3	28.08
JALEEB03	7/6/2009 10:44	JUN 09	0	2	15.3	82.7	1	2	39.8	0	0	2	15.4	0	996	0.48	24.87
JALEEB03	2/7/2009 4:26	JUL 09	0	0.4	18.9	80.7	1	8	40.1	0	0	0.6	18.9	0	1002	-0.14	9.26
JALEEB03	8/12/2009 8:34	AUG 09	0	4.5	11.3	84.2	0	0	47.5	0	0	4.4	11.2	0	1001	-0.15	41.49
JALEEB03	9/4/2009 9:04	SEP 09	0	2.2	15.9	81.9	0	0	33.8	0	0	2.2	15.6	0	1001	0	21.8
JALEEB03	10/11/2009 8:41	OCT 09	0	2.1	17.7	80.2	0	0	31.8	0	0	2.3	17.4	0	1004	0.03	13.29
JALEEB03	13/11/2009 10:10	NOV 09	0	2.1	17.3	80.6	0	201	31.9	0	0	2	17.5	0	1015	-0.01	15.21
JALEEB03	26/12/2009 6:57	DEC 09	0	0.6	19.6	79.8	118	0	32.7	0	0	0.6	19.6	0	1006	-0.1	15.98
JALEEB03	1/17/2010 10:44	JAN 10	0	0	18.8	81.2	176	0	20	0	0	0.2	18.4	0	1015	-0.14	10.14
JALEEB03	2/28/2010 11:05	FEB 10	0	1	18.3	80.7	63	0	25.7	0	0	1.1	18.2	0	1006	-0.06	11.53
JALEEB03	3/16/2010 10:25	MAR 10	0	3	15.2	81.8	0	0	36.7	0	0	3.6	14.2	0	1001	0.95	24.34
JALEEB03	4/21/2010 15:31	ARP 10	0	6.2	9.9	83.9	0	1	38.1	0	0	6.2	9.9	0	993	-0.15	46.48
JALEEB03	5/19/2010 10:31	MAY 10	0.1	0.9	17.7	81.3	66	0	47.1	2	0.2	0.6	18	0.11	997	-0.35	14.39
JALEEB03	6/22/2010 10:25	JUN 10	0	0.4	0	0	40	0	45.4	0	0	0.6	18.8	0	992	0.81	0
JALEEB03	7/20/2010 9:57	JUL 10	0	5.7	11.8	82.5	0	1	48.4	0	0.1	5.7	11.8	0	985	0.16	37.9
JALEEB03	8/18/2010 9:55	AUG 10	0	1.4	17.6	81	117	0	48.5	0	0	1.4	17.6	0	988	1.32	14.47
JALEEB03	9/19/2010 11:25	SEP 10	0	0.4	19.2	80.4	200	0		0	0.1	0.5	18.8	0	991	0.04	7.82
JALEEB03	10/19/2010 10:44	OCT 10	0	1.3	18.6	80.1	138	0	34.1	0	0	0.8	18.6	0	1000	-0.04	9.79
JALEEB03	11/7/2010 10:59	NOV 10	0	2.4	16.5	81.1	37	0	25.3	0	0	2.4	16.5	0	1005	0.1	18.73
JALEEB03	12/20/2010 13:58	DEC 10	0	0.8	18.5	80.7	0	0	24.3	0	0	0.8	18.6	0	1009	0.17	10.77

Table App. 5.4: LFG measurements in Borehole 04

Jleeb Al Shuyoukh Landfill, LF Gas Monitoring																	BH 04
ID	DATE	MONTH	CH4	CO2	O2	BAL	NH3	H2S	TEMP	CH4 %	PEAK	PEAK	MIN	CH4/	BARO	REL.	Res
			%	%	%	%	ppm	ppm	DegC	LEL%	CH4%	CO2%	O2%	CO2%	mb	PRESS.mb	Nitro%
JALEEB04	3/31/2008 12:06	MAR 08	0	1	18.9	80.1	0	1	38.5	0	0	1.1	18.8	0	998	-0.21	8.66
JALEEB04	4/13/2008 10:20	APR 08	0	0.9	19.2	79.9	8	0	29.8	0	0	1.4	18.8	0	1007	-0.18	7.32
JALEEB04	5/18/2008 11:56	MAY 08	0	1.7	17.5	80.8	0	0	36.5	0	0	2.4	17.4	0	998	-0.35	14.65
JALEEB04	6/1/2008 10:05	JUN 08	0	0.8	18.1	81.1	1	6	40.5	0	0	1.1	18	0	998	1.26	12.68
JALEEB04	7/6/2008 8:17	JUL 08	0.2	0.4	18.6	80.8	1	4	38.6	4	0.2	0.4	18.3	0.5	991	-21.08	10.49
JALEEB04	8/9/2008 9:49	AUG 08	0	0.5	19.6	79.9	0	6	47	0	0	0.5	19.5	0	1009	-0.07	5.81
JALEEB04	9/11/2008 9:08	SEP 08	0	0.9	19.2	79.9	0	3	43.3	0	0	1.6	18.8	0	1003	-0.04	7.32
JALEEB04	10/12/2008 11:03	OCT 08	0	1.2	18.3	80.5	0	6	34.9	0	0	2	17.6	0	1003	-0.09	11.33
JALEEB04	11/13/2008 10:20	NOV 08	0	0.5	19.7	79.8	145	0	19.7	0	0	0.4	19.9	0	1006	-0.18	7.32
JALEEB04	12/13/2008 11:53	DEC 08	0	0.6	19.6	79.8	1	183	13.9	0	0	1.2	19.5	0	1010	0.14	6.19
JALEEB04	7/1/2009 10:54	JAN 09	0	0.1	19.9	80	380	0	15.1	0	0	0.2	19	0	1006	0.51	4.78
JALEEB04	8/2/2009 4:30	FEB 09	0	1.2	19.6	79.2	270	0	22.4	0	0	2.7	18.6	0	1004	-0.13	4.06
JALEEB04	17/3/2009 2:58	MAR 09	0	0.1	19.6	80.3	2	0	26.5	0	0	5.5	13.8	0	1007	0.03	6.21
JALEEB04	21/4/2009 8:49	APR 09	0	0	19.5	80.5	2	0	26.7	0	0	0	19.1	0	1009	0.02	6.79
JALEEB04	26/5/2009 7:00	MAY 09	0	0	19.1	80.9	2	0	35.9	0	0	0	18.7	0	994	1.53	8.7
JALEEB04	7/6/2009 10:54	JUN 09	0	0.8	18.4	80.8	0	6	40.1	0	0	1.3	18	0	997	0.49	11.25
JALEEB04	2/7/2009 4:30	JUL 09	0.1	0.2	18.6	81.1	1	4	38.6	4	0.2	0.4	18.3	0.5	1006	-21.08	10.49
JALEEB04	8/12/2009 8:38	AUG 09	0	1.5	18.8	79.7	0	2	46.5	0	0	2.9	17.5	0	1001	0.14	8.64
JALEEB04	9/4/2009 9:10	SEP 09	0	1	18.9	80.1	0	4	33.3	0	0	1.6	18.3	0	1001	-0.06	8.66
JALEEB04	10/11/2009 8:46	OCT 09	0	0.9	19.2	79.9	0	3	31.8	0	0	1.6	18.8	0	1003	-0.04	7.32
JALEEB04	13/11/2009 10:14	NOV 09	0	0.6	19.6	79.8	1	183	32.9	0	0	1.2	19.5	0	1010	0.14	6.19
JALEEB04	26/12/2009 7:00	DEC 09	0	0.5	19.7	79.8	145	0	30.6	0	0	0.4	19.9	0	1006	-0.18	7.32
JALEEB04	1/17/2010 10:54	JAN 10	0	0	18.9	81.1	136	0	20.9	0	0	0.1	18.6	0	1015	-0.15	9.66
JALEEB04	2/28/2010 11:27	FEB 10	0	0.8	18.2	81	32	0	25.5	0	0	1.1	18.1	0	1006	-0.06	12.2
JALEEB04	3/16/2010 10:30	MAR 10	0	0.8	18.4	80.8	15	0	33.8	0	0	0.6	18.2	0	1001	0.2	11.25
JALEEB04	4/21/2010 15:34	ARP 10	0	1.9	17.4	80.7	7	0	36.5	0	0	1.9	17.4	0	993	-0.2	14.93
JALEEB04	5/19/2010 10:36	MAY 10	0.1	1.4	17.4	81.1	52	0	48	2	0.1	1.1	17.7	0.07	997	-0.3	15.33
JALEEB04	6/22/2010 10:29	JUN 10	0	1.6	17.8	80.6	15	0	44.8	0	0	0.6	18.2	0	992	-0.3	13.32
JALEEB04	7/20/2010 10:00	JUL 10	0	0.6	17.8	81.6	25	0	45.9	0	0	0.9	17.7	0	985	0.48	14.32
JALEEB04	8/18/2010 9:58	AUG 10	0	0.5	18.4	81.1	105	0	49.6	0	0	1	18.4	0	988	0.83	11.55
JALEEB04	9/19/2010 11:27	SEP 10	0	2	17.6	80.4	140	0	45.7	0	0	2.1	17.5	0	991	-0.12	13.87
JALEEB04	10/19/2010 10:47	OCT 10	0	0.5	18.7	80.8	141	0	35.5	0	0	0.7	18.6	0	1000	0.34	10.11
JALEEB04	11/7/2010 11:04	NOV 10	0	0.3	18.8	80.9	103	0	27.6	0	0	0.3	18.8	0	1005	0.13	9.84
JALEEB04	12/20/2010 14:00	DEC 10	0	0.9	18.3	80.8	0	0	24.1	0	0	1.1	18.4	0	1009	0.21	11.63

Table App. 5.5: LFG measurements in Borehole 05

Jleeb Al Shuyoukh Landfill, LF Gas Monitoring																	BH 05
ID	DATE	MONTH	CH4	CO2	O2	BAL	NH3	H2S	TEMP	CH4 %	PEAK	PEAK	MIN	CH4/	BARO	REL.	Res
			%	%	%	%	ppm	ppm	DegC	LEL%	CH4%	CO2%	O2%	CO2%	mb	PRESS.mb	Nitro%
JALEEB05	3/31/2008 12:08	MAR 08	0	0.9	18.6	80.5	0	4	33.8	0	0	1.2	18.6	0	998	-0.23	10.19
JALEEB05	4/13/2008 10:24	APR 08	0	0.6	19.2	80.2	7	0	30.4	0	0	0.9	19.1	0	1007	-0.06	7.62
JALEEB05	5/18/2008 11:39	MAY 08	0	2.4	17.4	80.2	17	0	36.9	0	0	7	17.2	0	998	-0.27	14.43
JALEEB05	6/1/2008 10:10	JUN 08	0	0.7	17.9	81.4	1	8	40.3	0	0	0.8	17.9	0	998	1.61	13.74
JALEEB05	7/6/2008 8:20	JUL 08	0	0.4	18.7	80.9	1	5	39.2	0	0	0.5	18.7	0	991	-0.11	10.21
JALEEB05	8/9/2008 9:51	AUG 08	0	0.3	19.6	80.1	0	7	47.1	0	0	0.4	19.6	0	1009	-0.07	6.01
JALEEB05	9/11/2008 10:20	SEP 08	0	1	18.5	80.5	0	4	43.9	0	0	0.9	18.5	0	1003	-0.03	10.57
JALEEB05	10/12/2008 11:47	OCT 08	0	0.9	18.2	80.9	0	6	35.9	0	0	1.4	18	0	1003	-0.1	12.1
JALEEB05	11/13/2008 10:24	NOV 08	0	0.6	19.5	79.9	161	0	20.5	0	0	0.5	19.4	0	1005	-0.06	7.62
JALEEB05	12/13/2008 11:50	DEC 08	0	0.6	19.6	79.8	1	170	17.8	0	0	2.4	17.8	0	1010	0.06	6.29
JALEEB05	7/1/2009 10:58	JAN 09	0	0.7	18.9	80.4	390	3	16.1	0	0	0.9	18.9	0	1004	-0.07	8.96
JALEEB05	8/2/2009 4:32	FEB 09	0	0.7	19.2	81	300	0	23.4	0	0	0.7	18.7	0	1006	-0.14	11.83
JALEEB05	17/3/2009 3:01	MAR 09	0	2.4	17.6	80	3	0	27.3	0	0	2.4	17.6	0	1006	0.36	13.47
JALEEB05	21/4/2009 8:52	APR 09	0	0.7	18.8	80.5	2	0	27.5	0	0	0.9	18.7	0	1008	0.04	9.44
JALEEB05	26/5/2009 7:02	MAY 09	0	0.9	18.4	80.7	2	0	35.7	0	0	1.1	18.3	0	993	3.45	11.15
JALEEB05	7/6/2009 10:58	JUN 09	0	0.7	17.8	81.5	0	9	40.5	0	0	0.8	17.8	0	996	-0.22	14.22
JALEEB05	2/7/2009 4:32	JUL 09	0	0.4	18.7	80.9	1	5	39.2	0	0	0.5	18.7	0	1001	-0.11	10.21
JALEEB05	8/12/2009 8:47	AUG 09	0	2.1	18.5	79.4	0	7	41.5	0	0	6.1	15.4	0	1001	-0.01	9.47
JALEEB05	9/4/2009 9:18	SEP 09	0	0.5	18.9	80.6	0	6	33.9	0	0	0.7	18.8	0	1001	-0.03	9.16
JALEEB05	10/11/2009 8:51	OCT 09	0	1	18.5	80.5	0	4	32.2	0	0	0.9	18.5	0	1003	-0.03	10.57
JALEEB05	13/11/2009 10:20	NOV 09	0	0.6	19.6	79.8	1	170	32.7	0	0	2.4	17.8	0	1010	0.06	6.29
JALEEB05	26/12/2009 7:02	DEC 09	0	0.6	19.5	79.9	161	0	29.5	0	0	0.5	19.4	0	1005	-0.06	7.62
JALEEB05	1/17/2010 10:58	JAN 10	0	0.7	18.3	81	79	0	22.4	0	0	0.7	18.2	0	1014	-0.14	11.83
JALEEB05	2/28/2010 11:32	FEB 10	0	0.3	19	80.7	11	0	27.4	0	0	0.3	18.9	0	1005	-0.09	8.88
JALEEB05	3/16/2010 10:33	MAR 10	0	0.4	18.6	81	26	0	33.6	0	0	0.4	18.6	0	1000	-0.2	10.69
JALEEB05	4/21/2010 15:37	ARP 10	0	2	17.4	80.6	0	1	36.5	0	0	2	17.4	0	993	-0.22	14.83
JALEEB05	5/19/2010 10:39	MAY 10	0.1	0.6	17.9	81.4	24	0	47.7	2	0.1	0.6	17.9	0.17	996	-0.5	13.74
JALEEB05	6/22/2010 10:32	JUN 10	0	1.4	16.8	81.8	28	1	45.8	0	0	1.9	16.8	0	992	0.89	18.3
JALEEB05	7/20/2010 10:03	JUL 10	0	1.7	17	81.3	0	1	50.5	0	0	1.7	17	0	984	0.13	17.04
JALEEB05	8/18/2010 10:00	AUG 10	0	0.6	18.6	80.8	97	0	49.5	0	0	0.6	18.5	0	988	1.81	10.49
JALEEB05	9/19/2010 11:30	SEP 10	0	0.4	19.1	80.5	133	0	44.9	0	0	0.4	19.1	0	991	0.65	8.3
JALEEB05	10/19/2010 10:49	OCT 10	0	0.4	19.1	80.5	98	0	36.1	0	0	0.4	19.1	0	999	-0.05	8.3
JALEEB05	11/7/2010 11:07	NOV 10	0	0.7	18.5	80.8	88	0	26.4	0	0	0.7	18.4	0	1004	0.12	10.87
JALEEB05	12/20/2010 14:03	DEC 10	0	0.9	18.6	80.5	0	0	23.7	0	0	0.9	18.6	0	1009	0.15	10.19

Table App. 5.6: LFG measurements in Borehole 06

youkh Landfill, LF Gas Monitoring																BH 06
DATE	MONTH	CH4	CO2	O2	BAL	NH3	H2S	TEMP	CH4 %	PEAK	PEAK	MIN	CH4/	BARO	REL.	Res
		%	%	%	%	ppm	ppm	DegC	LEL%	CH4%	CO2%	O2%	CO2%	mb	PRESS.mb	Nitro%
3/31/2008 12:18	MAR 08	2.8	14.3	0.9	82	0	0	31.6	56	3	13.6	0.9	0.2	998	0.54	78.6
4/13/2008 10:28	APR 08	2.2	13	1	83.8	0	0	29.7	44	2.3	12.3	1	0.17	1007	0	80.02
5/18/2008 11:35	MAY 08	2.4	17.7	0.8	79.1	0	0	38.2	48	2.5	17.6	0.8	0.14	998	0.06	76.08
6/1/2008 10:14	JUN 08	2.9	12.8	1.3	83	1	0	41.1	58	2.9	12.5	1.3	0.23	998	0.42	78.09
7/6/2008 8:27	JUL 08	2.7	3.1	15.6	78.6	0	0	43	54	6.6	5.4	12.3	0.87	992	-0.52	19.63
8/9/2008 10:35	AUG 08	2.9	3.4	15.1	78.6	0	3	48.6	58	2.9	3.3	15.1	0.85	990	-0.02	21.52
9/11/2008 9:18	SEP 08	2.7	13.6	1	82.7	0	0	44.1	54	2.7	13.1	1.1	0.2	1004	0.17	78.92
10/12/2008 11:49	OCT 08	0.2	2.9	13.8	83.1	0	0	34.9	4	0.2	2.9	13.8	0.07	1003	-0.14	30.94
11/13/2008 10:28	NOV 08	0	0.3	19.7	80	183	0	19.7	0	0	0.2	19.5	0	1006	0	80.02
12/13/2008 11:57	DEC 08	2.5	17.7	1.4	78.4	1	0	14.8	50	2.7	17.5	0.8	0.14	1010	0.18	73.11
7/1/2009 11:01	JAN 09	2.2	13	1	83.8	390	0	18.2	44	2.3	12.3	1	0.17	1007	0	80.02
8/2/2009 4:35	FEB 09	2.8	14.3	0.9	82	265	0	23.7	56	3	13.6	0.9	0.2	1007	-0.54	18.61
17/3/2009 3:03	MAR 09	1	18.7	0.4	79.9	3	0	27.2	20	1	19.4	0.4	0.05	1007	-0.14	78.39
21/4/2009 8:55	APR 09	0.2	6.5	11.8	81.5	0	1	31.2	4	0.2	6.5	12	0.03	1007	0.04	36.9
26/5/2009 7:05	MAY 09	0	5.6	14.2	80.2	2	0	36.4	0	0	5.6	14.3	0	994	1.5	26.52
7/6/2009 11:01	JUN 09	2.9	14.6	1.2	81.3	0	0	40.5	58	3.2	14.3	1.2	0.2	996	2.12	76.76
2/7/2009 4:35	JUL 09	1.6	3.3	15.6	78.6	0	1	43	54	2.6	5.4	12.3	0.87	1001	-0.52	19.63
8/12/2009 8:43	AUG 09	2.3	12.7	1.7	83.3	0	0	45.1	46	2.4	12.4	1.7	0.18	1000	0.05	76.87
9/4/2009 9:14	SEP 09	0	0.7	18.6	80.7	0	5	34	0	0	0.8	18.6	0	1001	-0.01	10.39
10/11/2009 8:58	OCT 09	2.7	13.6	1	82.7	0	0	32.7	54	2.7	13.1	1.1	0.2	1004	0.17	78.92
13/11/2009 10:24	NOV 09	2.5	17.7	1.4	78.4	1	0	32	50	2.7	17.5	0.8	0.14	1010	0.18	73.11
26/12/2009 7:05	DEC 09	2.8	21.6	0.2	75.4	0	5	26.5	56	3.4	21.9	0.3	0.13	1005	0.93	74.64
1/17/2010 11:01	JAN 10	1.7	16.1	2.4	79.8	0	0	21.8	34	1.7	16.1	2.4	0.11	1015	-0.16	70.73
2/28/2010 11:36	FEB 10	1.4	16.2	2.6	79.8	0	0	25.9	28	1.4	16.2	2.6	0.09	1005	-0.06	69.97
3/16/2010 10:36	MAR 10	2	17.4	1.6	79	0	0	36.2	40	2	17.4	1.6	0.11	1001	2.26	72.95
4/21/2010 15:39	ARP 10	1.4	14.6	6.1	77.9	0	1	38.3	28	1.4	15	5.4	0.1	993	-0.19	54.84
5/19/2010 10:41	MAY 10	1.4	13.6	5.7	79.3	0	0	47.4	28	1.4	13.5	5.9	0.1	997	-0.26	57.75
6/22/2010 10:35	JUN 10	3	20.5	1.1	75.4	0	1	47.1	60	3.1	20.9	0.9	0.15	992	-0.22	71.24
7/20/2010 10:11	JUL 10	18.5	22.3	5.5	53.7	0	6	48.9	200	19.2	20.9	5.7	0.83	984	0.06	32.91
8/18/2010 10:02	AUG 10	1.7	11.7	8.4	78.2	0	0	50.7	34	1.6	11.6	8.6	0.15	988	0.7	46.45
9/19/2010 11:32	SEP 10	3.1	19.1	3.4	74.4	0	0	48.8	62	3.1	19.1	3.5	0.16	991	-0.11	61.55
10/19/2010 10:52	OCT 10	2.3	14.1	7.4	76.2	0	0	36.1	46	2.3	14	7.5	0.16	1000	0.07	48.23
11/7/2010 11:09	NOV 10	2.3	16.4	5.1	76.2	0	0	13.9	46	2.3	16.4	5.1	0.14	1004	0.1	56.92
12/20/2010 14:04	DEC 10	1.5	16.6	4.4	77.5	0	0	23.8	30	1.5	16.5	4.4	0.09	1009	0.12	60.87

Table App. 5.7: LFG measurements in Borehole 07

Jleeb Al Shuyoukh Landfill, LF Gas Monitoring																	BH 07
ID	DATE	MONTH	CH4	CO2	O2	BAL	NH3	H2S	TEMP	CH4 %	PEAK	PEAK	MIN	CH4/	BARO	REL.	Res
			%	%	%	%	ppm	ppm	DegC	LEL%	CH4%	CO2%	O2%	CO2%	mb	PRESS.mb	Nitro%
JALEEB07	3/31/2008 12:27	MAR 08	21.7	24.8	0.7	52.8	0	0	33.4	200	23.6	24.4	0.7	0.88	998	-0.28	50.15
JALEEB07	4/14/2008 11:29	APR 08	21.3	25.8	0.5	52.4	0	0	32.8	200	23	25.7	0.5	0.83	1003	0.06	50.51
JALEEB07	5/18/2008 11:00	MAY 08	20.5	25.4	0.5	53.6	0	0	37.8	200	21.8	25.4	0.5	0.81	998	1.06	51.71
JALEEB07	6/1/2008 10:17	JUN 08	20.1	25.3	0.6	54	0	0	41.4	200	22.2	25.2	0.6	0.79	998	1.48	51.73
JALEEB07	7/6/2008 8:30	JUL 08	23.3	26.9	0.6	49.2	0	0	42.1	200	25.3	26.8	0.6	0.87	992	-0.32	46.93
JALEEB07	8/9/2008 10:22	AUG 08	23.8	24.6	2.2	49.4	0	0	46.9	200	24.8	24.5	1.7	0.97	988	-0.07	41.08
JALEEB07	9/11/2008 9:22	SEP 08	21.8	27.1	0.3	50.8	0	0	44	200	22.6	27	0.3	0.8	1003	1.25	49.67
JALEEB07	10/12/2008 11:52	OCT 08	20.9	23.5	0.9	54.7	0	0	36.3	200	22.3	22.5	0.9	0.89	1003	-0.12	51.3
JALEEB07	11/13/2008 11:29	NOV 08	0.7	1.3	18.7	79.3	184	0	22.8	22	0.9	0.9	17.8	0.54	1003	0.06	50.51
JALEEB07	12/13/2008 12:14	DEC 08	21.6	27.6	0.9	49.9	0	0	14.8	200	23	27.3	0.5	0.78	1010	0.1	46.5
JALEEB07	7/1/2009 11:06	JAN 09	18.4	20.5	1.8	59.3	170	0	18.5	200	20	20.4	1.1	0.9	1004	-0.37	52.5
JALEEB07	8/2/2009 4:38	FEB 09	22.7	26.1	0.2	51	12	0	22.7	200	23.2	26.4	0.2	0.87	1006	-0.04	50.24
JALEEB07	17/3/2009 3:05	MAR 09	17.8	28.1	0.1	54	2	0	27.1	200	17.9	28.2	0.1	0.63	1007	2.3	53.62
JALEEB07	21/4/2009 8:58	APR 09	15.6	25.4	2.1	56.9	2	0	26.9	200	15.6	25.5	2.2	0.61	1008	0.02	48.96
JALEEB07	26/5/2009 7:07	MAY 09	17.5	28.8	0.2	53.5	2	3	35.8	200	18.4	29	0.2	0.61	994	-0.01	52.74
JALEEB07	7/6/2009 11:06	JUN 09	20.7	25.6	0.6	53.1	0	0	40.7	200	22.3	25.6	0.6	0.81	996	-0.24	50.83
JALEEB07	2/7/2009 4:38	JUL 09	23.3	26.9	0.6	49.2	0	0	42.1	200	25.3	26.8	0.6	0.87	1002	-0.32	46.93
JALEEB07	8/12/2009 8:51	AUG 09	23.3	23.5	0.4	52.8	0	0	43.2	200	24.1	23.3	0.4	0.99	1001	-0.04	51.29
JALEEB07	9/4/2009 9:23	SEP 09	18.5	18.7	4.3	58.5	0	0	34.8	200	19.9	18.5	4.3	0.99	1001	2.13	42.25
JALEEB07	10/11/2009 9:03	OCT 09	21.8	27.1	0.3	50.8	0	0	33.1	200	22.6	27	0.3	0.8	1003	1.25	49.67
JALEEB07	13/11/2009 10:28	NOV 09	21.6	27.6	0.9	49.9	0	0	31.9	200	23	27.3	0.5	0.78	1010	0.1	46.5
JALEEB07	26/12/2009 7:07	DEC 09	18.7	24.2	3.7	53.4	0	11	26.8	200	19.9	26.2	0.2	0.77	1006	-0.26	39.41
JALEEB07	1/17/2010 11:06	JAN 10	21.7	26.7	1.1	50.5	0	0	22.3	200	21.7	26.7	1.1	0.81	1015	-0.15	46.34
JALEEB07	2/28/2010 11:40	FEB 10	20.5	25.6	1.4	52.5	0	0	26.8	200	20.7	25.7	1.4	0.8	1005	-0.03	47.21
JALEEB07	3/16/2010 10:39	MAR 10	21.9	27	0.7	50.4	0	0	36.8	200	22	27.1	0.7	0.81	1001	-0.21	47.75
JALEEB07	4/21/2010 15:42	ARP 10	19.9	26.7	0.9	52.5	0	1	37.1	200	20	26.5	1	0.75	993	-0.17	49.1
JALEEB07	5/19/2010 10:45	MAY 10	22.2	27.8	0.5	49.5	0	0	49.1	200	22.3	27.8	0.6	0.8	997	-0.33	47.61
JALEEB07	6/22/2010 10:38	JUN 10	18.8	24.5	2.8	53.9	0	0	47.1	200	18.8	24.5	2.8	0.77	992	-0.25	43.32
JALEEB07	7/20/2010 10:12	JUL 10	21.8	27.2	2	49	0	7	48.7	200	21.7	27	2.4	0.8	985	-17.94	41.44
JALEEB07	8/18/2010 10:05	AUG 10	23.4	29	1.2	46.4	0	0	49.9	200	23.4	28.9	1.2	0.81	988	2.18	41.86
JALEEB07	9/19/2010 11:35	SEP 10	21.5	27.6	1.9	49	0	0	44.8	200	21.6	27.7	1.9	0.78	991	-0.04	41.82
JALEEB07	10/19/2010 10:54	OCT 10	19.3	24.7	3.9	52.1	0	0	38.3	200	19.2	24.6	3.9	0.78	1000	0.06	37.36
JALEEB07	11/7/2010 11:12	NOV 10	20.2	26.4	2.6	50.8	0	0	28.5	200	20.3	26.4	2.6	0.77	1004	0.12	40.97
JALEEB07	12/20/2010 14:07	DEC 10	12.8	17.3	7.7	62.2	0	0	24.6	200	15.3	20.6	5.8	0.74	1009	0.2	33.09

Table App. 5.8: LFG measurements in Borehole 08

Jleeb Al Shuyoukh Landfill, LF Gas Monitoring																	BH 08
ID	DATE	MONTH	CH4	CO2	O2	BAL	NH3	H2S	TEMP	CH4 %	PEAK	PEAK	MIN	CH4/	BARO	REL.	Res
			%	%	%	%	ppm	ppm	DegC	LEL%	CH4%	CO2%	O2%	CO2%	mb	PRESS.mb	Nitro%
JALEEB08	3/31/2008 12:50	MAR 08	7.7	18.4	1.1	72.8	0	0	32.3	154	8.4	18	0.7	0.42	997	-0.41	68.64
JALEEB08	4/13/2008 11:06	APR 08	8.2	18.9	0.5	72.4	0	0	30.3	164	8.6	18.7	0.5	0.43	1006	0.8	70.51
JALEEB08	5/18/2008 10:56	MAY 08	9	18.5	0.6	71.9	0	0	37.4	180	9.5	18.3	0.7	0.49	998	-0.22	69.63
JALEEB08	6/1/2008 10:57	JUN 08	9.9	17.6	0.5	72	0	0	40.4	198	10	17.4	0.5	0.56	997	-0.44	70.11
JALEEB08	7/6/2008 8:33	JUL 08	11.2	21	0.5	67.3	0	0	42.5	200	11.8	20.9	0.5	0.53	991	-0.39	65.41
JALEEB08	8/9/2008 9:57	AUG 08	10.8	20.9	0.6	67.7	0	1	47.2	200	11.4	20.6	0.3	0.52	988	-0.08	23.31
JALEEB08	9/11/2008 9:08	SEP 08	9.7	17.7	0.4	72.2	0	0	44.6	194	9.8	17.5	0.4	0.55	1003	0.62	70.69
JALEEB08	10/12/2008 11:55	OCT 08	5.4	11.6	7.7	75.3	0	0	36.7	108	7.9	14.3	7.7	0.47	1002	-0.31	46.19
JALEEB08	11/13/2008 11:06	NOV 08	0	0.6	19.3	80.1	190	0	20.3	0	0	0.3	19.5	0	1006	0.8	70.51
JALEEB08	12/13/2008 12:07	DEC 08	9.9	21.4	0.6	68.1	0	0	14.7	198	10.2	21.2	0.3	0.46	1010	0.03	65.83
JALEEB08	7/1/2009 11:11	JAN 09	8.2	18.9	0.5	72.4	0	0	17.9	164	8.6	18.7	0.5	0.43	1006	0.8	70.51
JALEEB08	8/2/2009 4:41	FEB 09	11.1	19.2	0.5	69.2	20	0	23.5	200	11.5	19	0.6	0.58	1005	0.32	67.31
JALEEB08	17/3/2009 3:08	MAR 09	5.8	20.6	0.1	73.5	15	18	26.1	116	8.2	20.7	0	0.28	1006	-0.5	73.12
JALEEB08	21/4/2009 9:02	APR 09	5.6	20.3	0.3	73.8	5	58	27.8	112	5.6	20.3	0.3	0.28	1008	0.03	72.67
JALEEB08	26/5/2009 7:10	MAY 09	7.4	21.7	0.1	70.8	5	79	36.2	148	7.6	21.9	0.1	0.34	993	2.7	70.42
JALEEB08	7/6/2009 11:11	JUN 09	8.9	20.2	0.3	70.6	1	0	38.6	178	9.3	20.1	0.3	0.44	998	0.97	69.47
JALEEB08	2/7/2009 4:41	JUL 09	11.2	21	0.5	67.3	0	0	42.5	200	11.8	20.9	0.5	0.53	1002	-0.39	65.41
JALEEB08	8/12/2009 8:56	AUG 09	8.8	18.1	0.4	72.7	0	0	46.5	176	8.9	18	0.5	0.49	1001	-0.05	71.19
JALEEB08	9/4/2009 10:03	SEP 09	11.1	19.2	0.5	69.2	0	0	34.7	200	11.5	19	0.6	0.58	1000	0.32	67.31
JALEEB08	10/11/2009 9:37	OCT 09	9.7	17.7	0.4	72.2	0	0	32.8	194	9.8	17.5	0.4	0.55	1003	0.62	70.69
JALEEB08	13/11/2009 11:29	NOV 09	9.9	21.4	0.6	68.1	0	0	31.6	198	10.2	21.2	0.3	0.46	1010	0.03	65.83
JALEEB08	26/12/2009 7:10	DEC 09	8.3	9.9	11.3	70.5	0	4	29.4	166	8.7	10	11.3	0.84	1004	0.06	27.79
JALEEB08	1/17/2010 11:11	JAN 10	9.4	20.2	1	69.4	0	0	21.5	188	9.4	20.2	1	0.47	1014	-0.16	65.62
JALEEB08	2/28/2010 11:45	FEB 10	8.3	19.4	1.1	71.2	0	1	26.8	166	8.3	19.4	1.2	0.43	1005	-0.1	67.04
JALEEB08	3/16/2010 10:43	MAR 10	7.7	18.2	2.1	72	0	7	36.2	154	7.7	18.2	2.2	0.42	1001	-0.25	64.06
JALEEB08	4/21/2010 15:45	ARP 10	6.4	20.8	0.4	72.4	0	30	36.8	128	6.4	20.8	0.4	0.31	993	0.21	70.89
JALEEB08	5/19/2010 10:47	MAY 10	6.8	15.2	5.6	72.4	0	19	48.1	136	6.7	15.2	5.6	0.45	996	1.77	51.23
JALEEB08	6/22/2010 10:41	JUN 10	10	19.4	3.4	67.2	0	24	48	200	10.1	19.4	3.4	0.52	992	0.31	54.35
JALEEB08	7/20/2010 10:15	JUL 10	10.8	23.2	0.7	65.3	0	29	49	200	10.8	23.1	0.7	0.47	985	0.09	62.65
JALEEB08	8/18/2010 10:07	AUG 10	7.5	15.5	7	70	0	12	51.3	150	7.4	15.5	7.1	0.48	988	0.04	43.54
JALEEB08	9/19/2010 11:36	SEP 10	12.6	16	5	66.4	0	0	36	200	12.8	16.1	4.1	0.79	991	-0.16	47.5
JALEEB08	10/19/2010 10:56	OCT 10	9.3	20.4	3.5	66.8	0	6	38.4	186	9.3	20.4	3.6	0.46	1000	-0.1	53.57
JALEEB08	11/7/2010 11:15	NOV 10	8.5	18.8	4.5	68.2	0	1	29.4	170	8.5	18.8	4.5	0.45	1004	0.06	51.19
JALEEB08	12/20/2010 14:10	DEC 10	1.6	4.4	16.1	77.9	0	0	23.1	32	3.9	5.9	12.6	0.36	1009	0.16	17.04

Table App. 5.9: LFG measurements in Borehole 09

Jleeb Al Shuyoukh Landfill, LF Gas Monitoring																	BH 09
ID	DATE	MONTH	CH4	CO2	O2	BAL	NH3	H2S	TEMP	CH4 %	PEAK	PEAK	MIN	CH4/	BARO	REL.	Res
			%	%	%	%	ppm	ppm	DegC	LEL%	CH4%	CO2%	O2%	CO2%	mb	PRESS.mb	Nitro%
JALEEB09	3/31/2008 13:00	MAR 08	0	8.8	9.5	81.7	0	0	34.5	0	0.2	8.6	9.4	0	997	-0.45	45.79
JALEEB09	4/13/2008 11:10	APR 08	0	8.9	10.1	81	0	0	30.7	0	0	8.8	10.1	0	1006	-0.14	42.82
JALEEB09	5/18/2008 10:52	MAY 08	0	3.9	13.5	82.6	15	0	37.5	0	0	4.6	13.6	0	998	1.91	31.57
JALEEB09	6/1/2008 10:51	JUN 08	0	6.6	11.2	82.2	0	10	41.1	0	0	6.5	11.3	0	996	0.04	39.86
JALEEB09	7/6/2008 8:35	JUL 08	0	10.5	8.3	81.2	0	0	41.5	0	0.2	10.5	8.3	0	990	0.23	49.83
JALEEB09	8/9/2008 9:59	AUG 08	0.9	1.3	17.1	80.7	0	11	48.3	18	0.7	1.2	17.3	0.69	988	-0.01	16.06
JALEEB09	9/11/2008 10:20	SEP 08	0	9.7	10.2	80.1	0	0	45	0	0	9.7	10.2	0	1003	-0.31	41.54
JALEEB09	10/12/2008 11:57	OCT 08	0	3.3	16.1	80.6	0	14	36.1	0	0.2	5.7	16	0	1002	-0.29	19.74
JALEEB09	11/13/2008 11:10	NOV 08	0	0.7	19.3	80	181	0	20.8	0	0	0.7	19.1	0	1006	-0.14	42.82
JALEEB09	12/13/2008 12:03	DEC 08	0	10	10.2	79.8	1	34	15	0	0	9.9	10	0	1010	0.08	41.24
JALEEB09	7/1/2009 11:15	JAN 09	0	2.5	17.8	79.7	120	0	19.5	0	1.6	10.6	13.6	0	1003	-0.19	12.42
JALEEB09	8/2/2009 4:44	FEB 09	0	6.9	10.6	82.5	70	0	24.4	0	0.5	9.1	10.7	0	1004	-0.14	42.43
JALEEB09	17/3/2009 3:11	MAR 09	0	0.7	18.7	80.6	0	2	27.7	0	4.7	19.6	0.2	0	1006	0.02	9.91
JALEEB09	21/4/2009 9:05	APR 09	0	6.8	12.6	80.6	0	0	27.5	0	0	6.8	12.6	0	1008	0.02	32.97
JALEEB09	26/5/2009 7:12	MAY 09	0	7.6	12	80.4	0	1	36.5	0	0	7.8	12	0	993	1.89	35.04
JALEEB09	7/6/2009 11:15	JUN 09	0	8.6	10	81.4	1	5	39.4	0	0	8.5	10	0	998	0.69	43.6
JALEEB09	2/7/2009 4:44	JUL 09	0	10.5	8.3	81.2	0	5	41.5	0	0.2	10.5	8.3	0	1002	0.23	49.83
JALEEB09	8/12/2009 8:59	AUG 09	0	4	15.9	80.1	0	24	44.3	0	0	8.6	14.6	0	1000	-0.07	20
JALEEB09	9/4/2009 9:52	SEP 09	0	3.2	16.4	80.4	0	0	34.2	0	0.3	5.8	16.4	0	1000	-0.22	18.41
JALEEB09	10/11/2009 9:33	OCT 09	0	9.7	10.2	80.1	0	0	33.1	0	0	9.7	10.2	0	1003	-0.31	41.54
JALEEB09	13/11/2009 11:06	NOV 09	0	10	10.2	79.8	1	34	33.5	0	0	9.9	10	0	1010	0.08	41.24
JALEEB09	26/12/2009 7:12	DEC 09	0	0.7	19.3	80	181	0	29.2	0	0	0.7	19.1	0	1006	-0.14	42.82
JALEEB09	1/17/2010 11:15	JAN 10	0	2.3	16.7	81	126	0	22	0	0	2.2	16.7	0	1014	-0.17	17.87
JALEEB09	2/28/2010 11:49	FEB 10	0	8.3	11.2	80.5	0	0	26.8	0	0.1	8.3	11.2	0	1005	-0.12	38.16
JALEEB09	3/16/2010 10:47	MAR 10	0	5.7	13.3	81	0	0	35.6	0	0.5	5.7	13.3	0	1000	0.67	30.73
JALEEB09	4/21/2010 15:47	ARP 10	0	9.6	9.9	80.5	0	0	37.4	0	0	9.5	9.9	0	993	-0.21	43.08
JALEEB09	5/19/2010 10:51	MAY 10	0.1	1.5	17.1	81.3	144	0	49.3	2	0.2	1.5	17.1	0.07	996	-0.35	16.66
JALEEB09	6/22/2010 10:44	JUN 10	0	6.3	13.1	80.6	0	0	48.1	0	0.1	6.3	13.1	0	992	0.34	31.08
JALEEB09	7/20/2010 10:18	JUL 10	0	6.6	12.8	80.6	43	1	49.7	0	0.1	6.5	13.1	0	984	0	32.22
JALEEB09	8/18/2010 10:10	AUG 10	0	3.9	15.1	81	102	0	49.3	0	0	3.8	15.2	0	988	-0.18	23.92
JALEEB09	9/19/2010 11:37	SEP 10	6.5	12.9	8.6	72	0	2	46.7	130	12.6	15.8	5.7	0.5	991	-14.38	39.49
JALEEB09	10/19/2010 10:59	OCT 10	0	2.4	16.8	80.8	139	0	38.8	0	0.1	2.4	16.8	0	1000	-0.06	17.3
JALEEB09	11/7/2010 11:17	NOV 10	0	3	16.3	80.7	34	0	29.1	0	0.1	3.2	16.1	0	1004	0.08	19.09
JALEEB09	12/20/2010 14:12	DEC 10	1.9	5.2	14.4	78.5	0	0	23.1	38	1.9	5.2	14.8	0.37	1009	0.14	24.07

Table App. 5.10: LFG measurements in Borehole 10

Jleeb Al Shuyoukh Landfill, LF Gas Monitoring																	BH 10
ID	DATE	MONTH	CH4	CO2	O2	BAL	NH3	H2S	TEMP	CH4 %	PEAK	PEAK	MIN	CH4/	BARO	REL.	Res
			%	%	%	%	ppm	ppm	DegC	LEL%	CH4%	CO2%	O2%	CO2%	mb	PRESS.mb	Nitro%
JALEEB10	3/31/2008 13:07	MAR 08	0	9.5	8.1	82.4	0	0	33.4	0	0	9	8.1	0	996	-0.47	51.78
JALEEB10	4/13/2008 11:14	APR 08	0	10.2	8.3	81.5	0	0	30.6	0	0	10	8.3	0	1006	-0.12	50.13
JALEEB10	5/18/2008 10:48	MAY 08	0	6.9	10.6	82.5	17	0	36.6	0	0.5	9.1	10.7	0	998	-0.14	42.43
JALEEB10	6/1/2008 10:46	JUN 08	0	10.4	8.4	81.2	0	5	41.6	0	0.2	10.1	8.4	0	996	-0.19	49.45
JALEEB10	7/6/2008 8:38	JUL 08	0	11.8	7.3	80.9	0	0	39.8	0	0	11.7	7.3	0	992	-0.38	53.31
JALEEB10	8/9/2008 10:01	AUG 08	0.1	13.5	13.7	72.7	0	6	48.4	1	5.2	13.5	13.5	0.01	988	-0.26	25.21
JALEEB10	9/11/2008 9:18	SEP 08	0	11.7	8.8	79.5	0	0	45.2	0	19.6	17.1	8.5	0	1002	-0.23	46.24
JALEEB10	10/12/2008 12:00	OCT 08	0	2.9	14.1	83	0	7	35.7	0	0	2.9	14.2	0	1002	-0.32	29.7
JALEEB10	11/13/2008 11:15	NOV 08	0	0.4	19.7	79.9	209	0	20.6	0	0	0.4	19.5	0	1006	-0.12	50.13
JALEEB10	12/13/2008 12:10	DEC 08	0	12.8	7.7	79.5	0	22	16.4	0	0	12.7	7.6	0	1010	0.1	50.39
JALEEB10	7/1/2009 11:18	JAN 09	0	10.2	8.3	81.5	190	0	17.8	0	0	10	8.3	0	1006	-0.12	50.13
JALEEB10	8/2/2009 4:48	FEB 09	0	9.8	9.6	80.6	50	0	25.1	0	0	9.7	9.5	0	1005	-0.31	44.31
JALEEB10	17/3/2009 3:13	MAR 09	0	12.4	7.6	80	0	0	27.2	0	0	12.9	7.5	0	1006	3.85	51.27
JALEEB10	21/4/2009 9:08	APR 09	0	8.2	11.6	80.2	0	0	27.1	0	0	8.3	11.5	0	1008	0.08	36.35
JALEEB10	26/5/2009 7:15	MAY 09	0	8.8	11	80.2	0	0	35.6	0	0	8.8	11	0	993	3.46	38.62
JALEEB10	7/6/2009 11:18	JUN 09	0	10.5	8.1	81.4	1	0	38.2	0	0	10.3	8.1	0	998	1.68	50.78
JALEEB10	2/7/2009 4:48	JUL 09	0	11.8	7.3	80.9	0	0	39.8	0	0	11.7	7.3	0	1002	-0.38	53.31
JALEEB10	8/12/2009 9:04	AUG 09	0	5.3	12.8	81.9	0	5	42.2	0	0	5.2	12.8	0	1000	0.01	33.52
JALEEB10	9/4/2009 9:56	SEP 09	0	5.3	12.8	0	0	0	34	0	0	5.1	12.8	0	1001	-0.09	0
JALEEB10	10/12/2009 10:25	OCT 09	0	11.7	8.8	79.5	0	0	32.6	0	19.6	17.1	8.5	0	1002	-0.23	46.24
JALEEB10	13/11/2009 11:10	NOV 09	0	12.8	7.7	79.5	0	22	32	0	0	12.7	7.6	0	1010	0.1	50.39
JALEEB10	26/12/2009 7:15	DEC 09	0	0.4	19.7	79.9	209	0	28.5	0	0	0.4	19.5	0	1006	-0.12	50.13
JALEEB10	1/17/2010 11:18	JAN 10	0	9.3	10.4	80.3	0	0	20.8	0	0	9.2	10.4	0	1014	-0.18	40.99
JALEEB10	2/28/2010 11:53	FEB 10	0	11	9	80	0	0	26.5	0	0	11	8.9	0	1005	-0.08	45.98
JALEEB10	3/16/2010 10:51	MAR 10	0	9.5	10	80.5	0	0	35.8	0	0	9.5	10	0	1000	-0.06	42.7
JALEEB10	4/21/2010 15:50	ARP 10	0	12.2	7.9	79.9	0	0	36.4	0	0	12.2	7.9	0	993	-0.2	50.04
JALEEB10	5/19/2010 10:54	MAY 10	0	6.7	12.6	80.7	0	0	48.7	0	0.1	6.6	12.7	0	996	-0.37	33.07
JALEEB10	6/22/2010 10:48	JUN 10	0	11	9.1	79.9	0	0	46.3	0	0	11	9.1	0	992	0.13	45.5
JALEEB10	7/20/2010 10:21	JUL 10	0	9.5	10.3	80.2	0	0	48.7	0	0	9.5	10.4	0	984	0.2	41.27
JALEEB10	8/18/2010 10:13	AUG 10	0	8	11.8	80.2	0	0	49.3	0	0	7.9	11.8	0	988	-0.16	35.6
JALEEB10	9/19/2010 11:40	SEP 10	0	1.4	17.9	80.7	235	0	46.2	0	0.2	1.4	17.9	0	991	-0.18	13.04
JALEEB10	10/19/2010 11:01	OCT 10	0	9.7	11	79.3	15	0	37.5	0	0	9.6	11	0	999	-0.05	37.72
JALEEB10	11/7/2010 11:20	NOV 10	0	8.3	12.1	79.6	0	0	27.8	0	0	8.3	12.1	0	1004	0.08	33.86
JALEEB10	12/20/2010 14:15	DEC 10	0	3.7	16	80.3	0	0	22	0	0	3.8	16.1	0	1009	0.29	19.82

Table App. 5.11: LFG measurements in Borehole 11

Jleeb Al Shuyoukh Landfill, LF Gas Monitoring																	BH 11
ID	DATE	MONTH	CH4	CO2	O2	BAL	NH3	H2S	TEMP	CH4 %	PEAK	PEAK	MIN	CH4/	BARO	REL.	Res
			%	%	%	%	ppm	ppm	DegC	LEL%	CH4%	CO2%	O2%	CO2%	mb	PRESS.mb	Nitro%
JALEEB11	3/31/2008 13:19	MAR 08	0	1.9	18	80.1	0	28	32.6	0	0	5.8	15.8	0	996	-0.33	12.06
JALEEB11	4/13/2008 11:23	APR 08	0	2	19	79	40	0	31.1	0	0.3	8.6	14.8	0	1006	-0.03	7.18
JALEEB11	5/18/2008 12:07	MAY 08	0	0.5	18.7	80.8	5	0	36.9	0	0	0.9	18.6	0	997	-0.28	10.11
JALEEB11	6/1/2008 11:02	JUN 08	0	1.6	17.8	80.6	0	40	40.8	0	0	7	13.8	0	997	-0.35	>>>>
JALEEB11	7/6/2008 8:41	JUL 08	0	0.5	18.8	80.7	0	4	41.3	0	0.1	0.8	18.6	0	991	-0.26	9.64
JALEEB11	8/9/2008 10:03	AUG 08	1	1.4	17.7	79.9	0	10	48.4	20	0.8	2.6	17.8	0.71	988	-0.03	12.99
JALEEB11	9/11/2008 9:22	SEP 08	0	2.3	18.8	78.9	0	19	44	0	0.3	6.9	15.1	0	1003	1.22	7.84
JALEEB11	10/12/2008 12:03	OCT 08	0	4.8	17.3	77.9	0	0	37.2	0	34.8	22.1	5.2	0	1001	-0.28	12.51
JALEEB11	11/13/2008 11:23	NOV 08	0	8	19.7	72.3	330	0	21.4	0	0.1	8.1	18.7	0	1003	-0.03	7.18
JALEEB11	12/13/2008 16:25	DEC 08	0	1.1	19.9	79	0	102		0	0.6	6.1	13.1	0	1008	0.09	3.78
JALEEB11	7/1/2009 11:25	JAN 09	0	2	19	79	200	0	20.5	0	0.3	8.6	14.8	0	1006	-0.03	7.18
JALEEB11	8/2/2009 4:51	FEB 09	0	1.7	19.2	79.1	204	0	23	0	0.1	1.7	18.5	0	1006	-0.71	7.56
JALEEB11	17/3/2009 3:16	MAR 09	0	0.1	19.2	80.7	0	0	27.6	0	0	4.9	10.7	0	1006	-0.26	8.12
JALEEB11	21/4/2009 9:29	APR 09	0	0	19.5	80.5	1	0	28.5	0	0	0.1	18.7	0	1007	-0.23	6.79
JALEEB11	26/5/2009 7:19	MAY 09	0	0	19.3	80.7	0	0	37	0	0	0.1	18.1	0	993	-0.02	7.75
JALEEB11	7/6/2009 11:25	JUN 09	0	1.8	18.7	79.5	0	5	38.2	0	2.5	10.2	14.7	0	997	-0.12	8.81
JALEEB11	2/7/2009 4:51	JUL 09	0	0.5	18.8	80.7	0	4	41.3	0	0.1	0.8	18.6	0	1003	-0.26	9.64
JALEEB11	8/12/2009 9:18	AUG 09	0	1.5	19	79.5	0	30	41.2	0	0.5	9.7	16.3	0	1000	-0.11	7.68
JALEEB11	9/4/2009 10:20	SEP 09	0	2.8	18.4	78.8	0	0	33.8	0	9.8	12.4	14	0	1000	-0.28	9.25
JALEEB11	10/11/2009 9:42	OCT 09	0	2.3	18.8	78.9	0	19	32.8	0	0.3	6.9	15.1	0	1003	1.22	7.84
JALEEB11	13/11/2009 11:15	NOV 09	0	1.1	19.9	79	0	102	31.9	0	0.6	6.1	13.1	0	1008	0.09	3.78
JALEEB11	26/12/2009 7:19	DEC 09	0	8	19.7	72.3	330	0	23.6	0	0.1	8.1	18.7	0	1003	-0.03	7.18
JALEEB11	1/17/2010 11:25	JAN 10	0	0	19	81	177	0	22.2	0	0	0.3	18.2	0	1014	-0.17	9.18
JALEEB11	3/1/2010 10:01	FEB 10	0	0.2	18.3	81.5	136	0	24.2	0	59.1	34.1	1.8	0	1000	0.45	12.33
JALEEB11	3/16/2010 10:54	MAR 10	0	0.3	18.6	81.1	164	0	37.4	0	0	0.6	18.4	0	1000	-0.23	10.79
JALEEB11	4/21/2010 15:53	ARP 10	0	0.4	18.6	81	187	0	37.3	0	0	0.6	18.5	0	993	-0.11	10.69
JALEEB11	5/19/2010 10:58	MAY 10	0	0	18.9	81.1	47	0	47.6	0	0	0.7	18.2	0	996	-0.2	9.66
JALEEB11	6/22/2010 10:53	JUN 10	0	0.3	18.1	81.6	125	0	46	0	0	0.2	18.1	0	992	0.51	13.18
JALEEB11	7/20/2010 10:24	JUL 10	0	0.8	17.1	82.1	97	0	48.5	0	0	0.6	17.3	0	984	-0.05	17.46
JALEEB11	8/19/2010 9:30	AUG 10	0	0.5	18.2	81.3	238	0	45.3	0	57.8	34.2	0.9	0	989	-0.13	12.5
JALEEB11	9/19/2010 11:43	SEP 10	0	10.6	10.1	79.3	0	0	40.1	0	0	10.6	10.1	0	991	-0.15	41.12
JALEEB11	10/19/2010 11:04	OCT 10	0	1	17.8	81.2	141	0	38.5	0	0	0.6	18.2	0	999	0.03	13.92
JALEEB11	11/7/2010 11:22	NOV 10	0	0.2	18.5	81.3	105	0	31	0	0	0.4	17.8	0	1004	0.42	11.37
JALEEB11	12/20/2010 14:16	DEC 10	0	4.1	15.9	80	0	0	25.9	0	0	4.5	14.7	0	1009	0.18	19.9

Table App. 5.12: LFG measurements in Borehole 12

Jleeb Al Shuyoukh Landfill, LF Gas Monitoring																	BH 12
ID	DATE	MONTH	CH4	CO2	O2	BAL	NH3	H2S	TEMP	CH4 %	PEAK	PEAK	MIN	CH4/	BARO	REL.	Res
			%	%	%	%	ppm	ppm	DegC	LEL%	CH4%	CO2%	O2%	CO2%	mb	PRESS.mb	Nitro%
JALEEB12	3/31/2008 13:27	MAR 08	45.8	28.3	1.5	24.4	1	0	34.4	200	57.8	27.8	1.4	1.62	995	-0.34	18.73
JALEEB12	4/13/2008 11:27	APR 08	47.8	29.2	0.7	22.3	0	0	31.6	200	54.9	29	0.7	1.64	1005	-0.04	19.65
JALEEB12	5/18/2008 12:11	MAY 08	44.9	28.7	1	25.4	0	0	37.8	200	52.7	28.4	1	1.56	997	-0.37	21.62
JALEEB12	6/1/2008 11:06	JUN 08	42	28.4	1.4	28.2	0	0	41.5	200	51	28.3	1.4	1.48	996	-0.45	22.91
JALEEB12	7/6/2008 8:45	JUL 08	40.6	25	1.8	32.6	0	0	44.1	200	41.1	24.8	1.7	1.62	991	-0.44	25.8
JALEEB12	8/9/2008 10:05	AUG 08	42.7	30.7	1.5	25.1	0	0	47.5	200	49.9	30.5	1.5	1.39	988	-0.06	19.43
JALEEB12	9/11/2008 9:08	SEP 08	48.8	28	0.7	22.5	0	0	44.9	200	50.2	27.6	0.7	1.74	1002	0.16	19.85
JALEEB12	10/12/2008 12:06	OCT 08	39.5	24.8	2.3	33.4	0	0	37	200	42.5	24.4	2.4	1.59	1001	-0.21	24.71
JALEEB12	11/13/2008 11:27	NOV 08	48.9	30.7	1.5	18.9	0	0	21.4	200	49.1	29.8	1.5	1.59	1005	-0.04	19.65
JALEEB12	12/13/2008 16:30	DEC 08	47.6	31.8	1	19.6	0	0		200	50.4	31.4	0.5	1.5	1008	0.13	15.82
JALEEB12	7/1/2009 11:30	JAN 09	37.8	29.2	0.7	32.3	110	0	17.7	200	40.1	29	0.7	1.29	1005	-0.04	19.65
JALEEB12	8/2/2009 4:55	FEB 09	38.1	29.5	1.7	30.7	120	0	27.6	200	38.1	29.6	1.1	1.29	1006	-0.24	29.05
JALEEB12	17/3/2009 3:19	MAR 09	46.5	33.2	0.2	20.1	2	4	27.2	200	46.5	33.5	0.2	1.4	1005	0.19	19.34
JALEEB12	21/4/2009 9:32	APR 09	32	25.5	3.4	39.1	3	3	31.6	200	32.1	25.6	3.4	1.25	1006	-0.23	26.25
JALEEB12	26/5/2009 7:22	MAY 09	32.8	30.9	1.4	34.9	1	1	37.3	200	33	30.9	1.3	1.06	992	1.4	29.61
JALEEB12	7/6/2009 11:30	JUN 09	45.2	30.1	0.6	24.1	0	0	40.2	200	51.3	30	0.6	1.5	997	0	21.83
JALEEB12	2/7/2009 4:55	JUL 09	40.6	25	1.8	32.6	0	0	44.1	200	41.1	24.8	1.7	1.62	1004	-0.44	25.8
JALEEB12	8/12/2009 9:23	AUG 09	41.4	22.3	2.7	33.6	0	0	41.1	200	43	22	2.7	1.86	1000	-0.31	23.39
JALEEB12	9/4/2009 10:26	SEP 09	31.9	18.5	4.5	45.1	0	0	35.2	200	32.2	18.4	4.5	1.72	1000	0.52	28.09
JALEEB12	10/11/2009 9:46	OCT 09	48.8	28	0.7	22.5	0	0	34	200	50.2	27.6	0.7	1.74	1002	0.16	19.85
JALEEB12	13/11/2009 11:23	NOV 09	47.6	31.8	1	19.6	0	0	32.7	200	50.4	31.4	0.5	1.5	1008	0.13	15.82
JALEEB12	26/12/2009 7:22	DEC 09	48.9	30.7	1.5	18.9	0	0	24.7	200	49.1	29.8	1.5	1.59	1005	-0.04	19.65
JALEEB12	1/17/2010 11:30	JAN 10	39.1	24.7	3.5	32.7	0	0	22.3	200	39.2	24.7	3.5	1.58	1013	-0.13	19.47
JALEEB12	3/1/2010 10:05	FEB 10	46.5	28.9	2	22.6	0	0	25.1	200	46.5	28.8	2	1.61	1000	-0.05	15.04
JALEEB12	3/16/2010 10:57	MAR 10	40.5	26.7	3	29.8	0	0	35.9	200	40.5	26.7	3.1	1.52	1000	-0.17	18.46
JALEEB12	4/21/2010 15:56	ARP 10	47.9	31.3	1.7	19.1	0	1	37.9	200	48	31.3	1.7	1.53	992	-0.09	12.67
JALEEB12	5/19/2010 11:01	MAY 10	40.3	28.1	2.6	29	0	0	47.7	200	40.3	28.1	2.7	1.43	995	-0.31	19.17
JALEEB12	6/22/2010 10:56	JUN 10	45.1	33.1	1.3	20.5	0	0	47.6	200	45.2	33.1	1.3	1.36	991	0.59	15.59
JALEEB12	7/20/2010 10:27	JUL 10	44.4	31.6	3	21	0	6	50.1	200	44.3	31.5	3	1.41	984	-0.01	9.66
JALEEB12	8/19/2010 9:33	AUG 10	28.7	23	4	44.3	0	0	47.2	200	29.2	23.3	4	1.25	988	-0.15	29.18
JALEEB12	9/20/2010 11:14	SEP 10	40.8	31.3	2.3	25.6	0	0	44.4	200	40.7	31.2	2.3	1.3	995	0.09	16.91
JALEEB12	10/19/2010 11:07	OCT 10	44.1	33.2	2.2	20.5	0	0	38.9	200	44.2	33.2	2.2	1.33	999	0.04	12.18
JALEEB12	11/7/2010 11:26	NOV 10	39.5	29.1	3.6	27.8	0	0	29	200	39.6	29.1	3.6	1.36	1003	-13.85	14.19
JALEEB12	12/20/2010 14:20	DEC 10	19.9	13.3	11.4	55.4	0	0	25	200	20.2	13.4	11.3	1.5	1008	0.15	12.31

Table App. 5.13: LFG measurements in Borehole 13

Jleeb Al Shuyoukh Landfill, LF Gas Monitoring																	BH 13
ID	DATE	MONTH	CH4	CO2	O2	BAL	NH3	H2S	TEMP	CH4 %	PEAK	PEAK	MIN	CH4/	BARO	REL.	Res
			%	%	%	%	ppm	ppm	DegC	LEL%	CH4%	CO2%	O2%	CO2%	mb	PRESS.mb	Nitro%
JALEEB13	3/31/2008 13:34	MAR 08	50.3	30.8	0.8	18.1	0	0	33.7	200	57.5	30.6	0.8	1.63	995	1.13	15.08
JALEEB13	4/13/2008 11:31	APR 08	47.3	28.4	0.4	23.9	0	0	31.4	200	48.5	28.2	0.4	1.67	1005	-0.1	22.39
JALEEB13	5/18/2008 12:14	MAY 08	48.2	31.2	0.6	20	0	0	37	200	53.1	31	0.6	1.54	997	0.14	17.73
JALEEB13	6/1/2008 11:10	JUN 08	45.7	29.4	0.7	24.2	0	0	41.6	200	47.6	29.3	0.7	1.55	996	-0.42	21.55
JALEEB13	7/6/2008 8:47	JUL 08	46.2	31.3	1.4	21.1	0	0	39.7	200	48.5	31.3	1.4	1.48	990	1.27	15.81
JALEEB13	8/9/2008 10:07	AUG 08	48.2	33.8	0.4	17.6	0	0	46.8	200	54.8	33.5	0.4	1.43	988	-0.29	16.09
JALEEB13	9/11/2008 10:20	SEP 08	45.8	30.8	0.4	23	0	0	42.5	200	47.5	30.8	0.4	1.49	1002	-0.36	21.49
JALEEB13	10/12/2008 12:09	OCT 08	45.2	29.7	0.8	24.3	0	0	38.2	200	46	29.6	0.8	1.52	1001	-0.25	21.28
JALEEB13	11/13/2008 11:31	NOV 08	49	33.1	0.2	17.7	0	0	21.3	200	49	33	0.3	1.48	1004	-0.1	22.39
JALEEB13	12/13/2008 16:34	DEC 08	52.3	33.9	0.7	13.1	0	0	10.2	200	54.6	33.6	0.2	1.54	1008	2.11	10.45
JALEEB13	7/1/2009 11:33	JAN 09	47.3	28.4	0.4	23.9	0	0	15.9	200	48.5	28.2	0.4	1.67	1005	-0.1	22.39
JALEEB13	8/2/2009 4:58	FEB 09	49.9	35.1	0.2	14.8	2	0	23.6	200	50.7	35.3	0.2	1.42	1006	4.92	14.04
JALEEB13	17/3/2009 3:21	MAR 09	44.1	32.1	0.1	23.7	1	5	27	200	44.3	32.3	0	1.37	1005	-0.13	23.32
JALEEB13	21/4/2009 9:35	APR 09	38.1	29.5	0.7	31.7	2	13	27.6	200	38.1	29.6	0.8	1.29	1006	-0.24	29.05
JALEEB13	26/5/2009 7:24	MAY 09	16.5	15	5	63.5	0	4	37.2	200	30	26.2	4.3	1.1	992	0.11	44.6
JALEEB13	7/6/2009 11:33	JUN 09	47	30.9	0.3	21.8	0	0	39.2	200	48.1	30.7	0.3	1.52	997	-0.16	20.67
JALEEB13	2/7/2009 4:58	JUL 09	46.2	31.3	1.4	21.1	0	0	39.7	200	48.5	31.3	1.4	1.48	1004	1.27	15.81
JALEEB13	8/12/2009 9:27	AUG 09	48.7	28.1	0.7	22.5	0	0	40.7	200	50.4	27.9	0.7	1.73	1000	-0.14	19.85
JALEEB13	9/4/2009 10:30	SEP 09	44.7	26.6	1.4	27.3	0	0	34.5	200	45.8	26.4	1.4	1.68	1000	-0.32	22.01
JALEEB13	10/11/2009 9:51	OCT 09	45.8	30.8	0.4	23	0	0	33.7	200	47.5	30.8	0.4	1.49	1002	-0.36	21.49
JALEEB13	13/11/2009 11:27	NOV 09	52.3	33.9	0.7	13.1	0	0	30.6	200	54.6	33.6	0.2	1.54	1008	2.11	10.45
JALEEB13	26/12/2009 7:24	DEC 09	49	33.1	0.2	17.7	0	0	24.8	200	49	33	0.3	1.48	1004	-0.1	22.39
JALEEB13	1/17/2010 11:33	JAN 10	50.2	30.8	0.7	18.3	0	0	22.1	200	50.4	31	0.7	1.63	1013	-0.16	15.65
JALEEB13	3/1/2010 10:09	FEB 10	50.6	30.9	0.8	17.7	0	0	24.7	200	51.1	31.1	0.8	1.64	1000	-0.12	14.68
JALEEB13	3/16/2010 11:02	MAR 10	49.5	29.7	1.1	19.7	0	0	35.2	200	49.7	29.7	1.1	1.67	999	0.68	15.54
JALEEB13	4/21/2010 15:58	ARP 10	53.5	34.9	0.5	11.1	0	0	38.6	200	53.5	34.9	0.6	1.53	992	0.08	9.21
JALEEB13	5/19/2010 11:03	MAY 10	49.1	31.7	0.6	18.6	0	0	47.6	200	49.1	31.8	0.6	1.55	995	-0.18	16.33
JALEEB13	6/22/2010 10:58	JUN 10	46.5	31.5	1.7	20.3	0	0	47.6	200	46.8	31.5	1.7	1.48	991	-0.04	13.87
JALEEB13	7/20/2010 10:30	JUL 10	44.8	30.5	2.8	21.9	0	0	49.1	200	44.8	30.5	2.8	1.47	983	0.39	11.32
JALEEB13	8/19/2010 9:35	AUG 10	41.3	28.5	2.6	27.6	0	0	48	200	41.3	28.5	2.6	1.45	989	-0.12	17.77
JALEEB13	9/20/2010 11:16	SEP 10	51.6	35.9	0.8	11.7	0	0	44.4	200	51.6	35.9	0.8	1.44	994	0.01	8.68
JALEEB13	10/19/2010 11:09	OCT 10	49	33.6	2	15.4	0	0	34.1	200	49.2	33.6	2	1.46	999	0.08	7.84
JALEEB13	11/7/2010 11:28	NOV 10	47.4	32	2.5	18.1	0	0	28.1	200	47.4	32	2.5	1.48	1003	0.25	8.65
JALEEB13	12/20/2010 15:01	DEC 10	27.7	20.6	3.3	48.4	0	0	27	200	27.9	20.9	3.1	1.34	1008	-7.13	35.93

Table App. 5.14: LFG measurements in Borehole 14

Jleeb Al Shuyoukh Landfill, LF Gas Monitoring																	BH 14
ID	DATE	MONTH	CH4	CO2	O2	BAL	NH3	H2S	TEMP	CH4 %	PEAK	PEAK	MIN	CH4/	BARO	REL.	Res
			%	%	%	%	ppm	ppm	DegC	LEL%	CH4%	CO2%	O2%	CO2%	mb	PRESS.mb	Nitro%
JALEEB14	3/31/2008 13:43	MAR 08	51.7	30.9	1	16.4	0	0	33.6	200	59.2	30.7	0.9	1.67	995	-0.29	12.62
JALEEB14	4/13/2008 11:39	APR 08	51.7	30.2	0.4	17.7	0	0	31.5	200	54.9	30.1	0.4	1.71	1005	-0.01	16.19
JALEEB14	5/18/2008 12:17	MAY 08	49.2	30.9	0.5	19.4	0	0	37.6	200	55.6	30.8	0.5	1.59	997	0.26	17.51
JALEEB14	6/1/2008 11:15	JUN 08	47.7	30.1	0.7	21.5	0	0	41	200	53.5	29.9	0.8	1.58	996	-0.26	18.85
JALEEB14	7/6/2008 8:50	JUL 08	49.5	32.1	0.9	17.5	2	0	42.4	200	51.9	31.8	0.9	1.54	990	0.26	14.1
JALEEB14	8/9/2008 10:09	AUG 08	41.3	28.6	1.6	28.5	0	0	46.7	200	48.9	28.4	1.4	1.44	988	-0.13	22.45
JALEEB14	9/11/2008 9:18	SEP 08	49.9	29.4	0.7	20	0	0	43.1	200	52	29.3	0.7	1.7	1002	0.07	17.35
JALEEB14	10/12/2008 12:13	OCT 08	42.9	27.7	2.6	26.8	0	0	37.5	200	42.9	27.6	2.6	1.55	1001	-0.26	16.97
JALEEB14	11/13/2008 11:39	NOV 08	41.7	30.2	0.4	27.7	0	0	21.5	200	41.7	29.5	0.4	1.38	1005	-0.01	16.19
JALEEB14	12/15/2008 16:51	DEC 08	47.8	32.6	0.4	19.2	0	0		200	48.9	32.4	0.2	1.47	1007	0.25	17.69
JALEEB14	7/1/2009 11:37	JAN 09	34.3	27	4.5		4	3	16.3	200	46.1	32.7	1.7	1.27	1005	0.05	17.19
JALEEB14	8/2/2009 5:02	FEB 09	42.1	30.6	3.8	23.5	0	0	23.5	200	42.5	30.7	3.8	1.38	1004	-0.03	9.14
JALEEB14	17/3/2009 3:24	MAR 09	40.4	32	0.1	27.5	1	6	26.4	200	42.8	32	0.1	1.26	1006	0.09	27.12
JALEEB14	21/4/2009 9:39	APR 09	32.7	27.2	2.4	37.7	2	8	28.3	200	33.1	27.3	2.3	1.2	1006	-0.13	28.63
JALEEB14	26/5/2009 7:27	MAY 09	3.3	3.7	17.6	75.4	0	0	37.1	66	31.2	26.1	4.3	0.89	993	2.72	8.87
JALEEB14	7/6/2009 11:37	JUN 09	48.5	31	0.6	19.9	0	0	40	200	52.6	30.8	0.6	1.56	997	-0.11	17.63
JALEEB14	2/7/2009 5:02	JUL 09	49.5	32.1	0.9	17.5	2	0	42.4	200	51.9	31.8	0.9	1.54	1004	0.26	14.1
JALEEB14	8/12/2009 9:31	AUG 09	43.3	22.9	3.6	30.2	0	0	49.4	200	45	22.7	3.6	1.89	1000	-7.9	16.59
JALEEB14	9/4/2009 10:14	SEP 09	38.8	22.7	1	37.5	0	0	35.1	200	39.9	22	1.1	1.71	1000	0.99	33.72
JALEEB14	10/11/2009 10:00	OCT 09	49.9	29.4	0.7	20	0	0	33.9	200	52	29.3	0.7	1.7	1002	0.07	17.35
JALEEB14	13/11/2009 11:31	NOV 09	47.8	32.6	0.4	19.2	0	0	29.5	200	48.9	32.4	0.2	1.47	1007	0.25	17.69
JALEEB14	26/12/2009 7:27	DEC 09	41.7	30.2	0.4	27.7	0	0	23.6	200	41.7	29.5	0.4	1.38	1005	-0.01	16.19
JALEEB14	1/17/2010 11:37	JAN 10	34.5	24.6	3.6	37.3	0	0	22.2	200	34.4	24.6	3.6	1.4	1013	-0.16	23.69
JALEEB14	3/1/2010 10:14	FEB 10	43.2	30.5	0.2	26.1	0	0	25.8	200	43.2	30.6	0.2	1.42	1000	0	25.34
JALEEB14	3/16/2010 11:06	MAR 10	31.8	22.3	4.9	41	0	0	37.5	200	31.8	22.3	4.9	1.43	999	-0.23	22.48
JALEEB14	4/21/2010 16:01	ARP 10	40.1	29.6	0.7	29.6	0	0	37.9	200	40.2	29.6	0.8	1.35	992	-0.02	26.95
JALEEB14	5/19/2010 11:06	MAY 10	33.7	23.3	4.4	38.6	0	0	47.9	200	33.7	23.3	4.4	1.45	995	-0.19	21.97
JALEEB14	6/22/2010 11:02	JUN 10	42.4	29.8	1.4	26.4	0	0	47.3	200	42.5	29.9	1.4	1.42	991	-0.22	21.11
JALEEB14	7/20/2010 10:34	JUL 10	45.6	32	1.1	21.3	0	0	49.7	200	45.6	32	1.1	1.43	983	0.2	17.14
JALEEB14	8/19/2010 9:39	AUG 10	23.5	17.1	9.7	49.7	0	0	47.5	200	23.5	17.2	9.7	1.37	989	0.14	13.03
JALEEB14	9/20/2010 11:19	SEP 10	36.4	25.9	4.5	33.2	0	0	38.5	200	36.4	25.9	4.5	1.41	994	0.14	16.19
JALEEB14	10/19/2010 11:12	OCT 10	39	27.6	3.5	29.9	0	0	39.3	200	39	27.6	3.5	1.41	999	0.14	16.67
JALEEB14	11/7/2010 11:31	NOV 10	33.4	23.5	5.6	37.5	0	0	27.1	200	33.4	23.5	5.6	1.42	1003	0.17	16.33
JALEEB14	12/20/2010 14:25	DEC 10	21.4	14.9	10.1	53.6	0	0	23.7	200	21.4	14.9	10.1	1.44	1008	0.18	15.42

Table App. 5.15: LFG measurements in Borehole 15

Jleeb Al Shuyoukh Landfill, LF Gas Monitoring																		BH 15
ID	DATE	MONTH	CH4	CO2	O2	BAL	NH3	H2S	TEMP	CH4 %	PEAK	PEAK	MIN	CH4/	BARO	REL.	Res
			%	%	%	%	ppm	ppm	DegC	LEL%	CH4%	CO2%	O2%	CO2%	mb	PRESS.mb	Nitro%
JALEEB15	3/31/2008 13:50	MAR 08	49.6	31.7	0.9	17.8	0	0	32.7	200	56.5	31.4	0.7	1.56	995	-0.24	14.4
JALEEB15	4/13/2008 11:35	APR 08	49.1	31.1	0.5	19.3	0	0	31.2	200	51.9	31	0.5	1.58	1005	-0.04	17.41
JALEEB15	5/18/2008 12:21	MAY 08	48.2	31.5	0.5	19.8	0	0	36.8	200	50.3	31.5	0.5	1.53	997	0.08	17.91
JALEEB15	6/1/2008 11:20	JUN 08	46.1	30.9	0.8	22.2	0	0	41.4	200	50.8	30.5	0.8	1.49	996	-24.13	19.18
JALEEB15	7/6/2008 8:52	JUL 08	47.6	29.8	0.4	22.2	0	0	45.6	200	48.1	29.5	0.4	1.6	991	-0.32	20.69
JALEEB15	8/9/2008 10:11	AUG 08	45.6	29.9	1.6	22.9	0	0	44.5	200	50.4	29.6	1.7	1.53	989	-0.23	16.85
JALEEB15	9/11/2008 9:22	SEP 08	44.8	30	1.1	24.1	0	0	42.3	200	47.9	29.9	1.1	1.49	1002	0.02	19.94
JALEEB15	10/12/2008 12:18	OCT 08	40.8	29.5	1.9	27.8	0	0	36	200	49.4	29.4	1.7	1.38	1001	-0.13	20.62
JALEEB15	11/13/2008 11:35	NOV 08	49.5	32.8	0.8	16.9	0	0	19.7	200	49.7	32.5	0.8	1.51	1005	-0.04	17.41
JALEEB15	12/13/2008 16:44	DEC 08	52	34.4	0.5	13.1	0	0		200	54.1	34	0.2	1.51	1008	0.26	11.21
JALEEB15	7/1/2009 11:42	JAN 09	49.1	31.1	0.5	19.3	0	0	17.5	200	51.9	31	0.5	1.58	1005	-0.04	17.41
JALEEB15	8/2/2009 5:05	FEB 09	47.1	34.5	0.2	18.2	0	0	24.2	200	48.4	35	0.2	1.37	1005	-0.1	15.86
JALEEB15	17/3/2009 3:27	MAR 09	47.3	34.7	0.1	17.9	8	11	26.2	200	47.3	34.8	0.1	1.36	1005	0.42	17.52
JALEEB15	21/4/2009 9:42	APR 09	40.9	32.5	0.5	26.1	3	6	27.7	200	41.1	33.5	0.4	1.26	1006	-0.23	24.21
JALEEB15	26/5/2009 7:30	MAY 09	38.2	33.4	0.8	27.6	2	1	37.1	200	38.6	33.4	0.7	1.14	992	3.65	24.58
JALEEB15	7/6/2009 11:42	JUN 09	44.4	29.7	0.9	25	0	0	39.3	200	45.7	29.5	0.9	1.49	998	0.43	21.6
JALEEB15	2/7/2009 5:05	JUL 09	47.6	29.8	0.4	22.2	0	0	45.6	200	48.1	29.5	0.4	1.6	1003	-0.32	20.69
JALEEB15	8/12/2009 9:35	AUG 09	44.3	28.8	1.8	25.1	0	0	50.4	200	46.3	28.6	1.8	1.54	1000	-0.14	18.3
JALEEB15	9/4/2009 10:34	SEP 09	45.7	31.2	1.2	21.9	0	0	34.5	200	48.3	31.2	1.2	1.46	1000	1.49	17.36
JALEEB15	10/11/2009 9:55	OCT 09	44.8	30	1.1	24.1	0	0	33.4	200	47.9	29.9	1.1	1.49	1002	0.02	19.94
JALEEB15	13/11/2009 11:39	NOV 09	52	34.4	0.5	13.1	0	0	29.9	200	54.1	34	0.2	1.51	1008	0.26	11.21
JALEEB15	26/12/2009 7:30	DEC 09	49.5	32.8	0.8	16.9	0	0	24.6	200	49.7	32.5	0.8	1.51	1005	-0.04	17.41
JALEEB15	1/17/2010 11:42	JAN 10	47.9	30.5	1.2	20.4	0	0	21.6	200	48	30.5	1.2	1.57	1013	-0.1	15.86
JALEEB15	3/1/2010 10:18	FEB 10	47.1	32.6	0.2	20.1	0	0	34.8	200	47.3	32.7	0.2	1.44	1000	-0.27	19.34
JALEEB15	3/16/2010 11:09	MAR 10	37.7	28.1	2	32.2	0	0	36.7	200	37.6	28.1	2	1.34	999	0.98	24.64
JALEEB15	4/21/2010 16:04	ARP 10	50.7	34.6	0.6	14.1	0	0	36.1	200	50.8	34.6	0.6	1.47	992	-0.19	11.83
JALEEB15	5/19/2010 11:09	MAY 10	40.8	28.8	1.9	28.5	0	0	46.6	200	41	28.8	2	1.42	995	-0.26	21.32
JALEEB15	6/22/2010 11:05	JUN 10	48.8	33.2	0.8	17.2	0	0	47.4	200	48.8	33.3	0.8	1.47	990	1.32	14.18
JALEEB15	7/20/2010 10:37	JUL 10	56.4	36.3	0.8	6.5	0	7	51.7	200	56.5	36.2	0.8	1.55	983	0.27	3.48
JALEEB15	8/19/2010 9:41	AUG 10	44.8	31.8	2	21.4	0	0	47.5	200	44.9	31.9	2	1.41	989	0.42	13.84
JALEEB15	9/20/2010 11:22	SEP 10	48.2	32.5	1.4	17.9	0	0	45.6	200	48.2	32.5	1.4	1.48	994	0.07	12.61
JALEEB15	10/19/2010 11:15	OCT 10	51.2	33.6	1.8	13.4	0	0	39.2	200	51.3	33.6	1.8	1.52	999	-0.02	6.6
JALEEB15	11/7/2010 11:34	NOV 10	47.6	30.2	3.5	18.7	0	0	29.1	200	47.5	30	3.5	1.58	1003	0.21	5.47
JALEEB15	12/20/2010 14:27	DEC 10	30.1	18.3	9.4	42.2	0	0	17.2	200	30.4	18.6	9.1	1.64	1008	-8.66	6.67

Table App. 5.16: LFG measurements in Borehole 16

Jleeb Al Shuyoukh Landfill, LF Gas Monitoring																	BH 16
ID	DATE	MONTH	CH4	CO2	O2	BAL	NH3	H2S	TEMP	CH4 %	PEAK	PEAK	MIN	CH4/	BARO	REL.	Res
			%	%	%	%	ppm	ppm	DegC	LEL%	CH4%	CO2%	O2%	CO2%	mb	PRESS.mb	Nitro%
JALEEB16	3/31/2008 13:59	MAR 08	58.1	33	1.2	7.7	0	0	32.4	200	64.9	32.6	0.7	1.76	995	0.07	3.16
JALEEB16	4/14/2008 11:20	APR 08	58.6	33.4	0.3	7.7	0	1	32.5	200	66.5	33.3	0.3	1.75	1004	0.46	6.57
JALEEB16	5/18/2008 12:24	MAY 08	57.6	33.5	0.4	8.5	0	0	37.1	200	65.8	33.4	0.4	1.72	997	-0.12	6.99
JALEEB16	6/1/2008 11:25	JUN 08	56.7	32.7	0.5	10.1	0	0	41.5	200	64.4	32.4	0.5	1.73	995	-32.39	8.21
JALEEB16	7/6/2008 8:53	JUL 08	51.1	34.8	0.3	13.8	1	0	44.2	200	53.1	34.7	0.3	1.47	990	0	12.67
JALEEB16	8/9/2008 10:13	AUG 08	60.3	34.1	0.5	5.1	0	0	47.1	200	63.3	33.7	0.1	1.77	992	0.62	3.21
JALEEB16	9/11/2008 9:08	SEP 08	57.6	32.9	0.4	9.1	0	0	42.5	200	62.1	32.8	0.4	1.75	1002	-23.84	7.59
JALEEB16	10/12/2008 16:54	OCT 08	58	32.1	0.5	9.4	0	0	36.5	200	59.6	32	0.5	1.81	1002	-0.12	7.51
JALEEB16	11/13/2008 11:20	NOV 08	59.5	35.4	0	5.1	0	2	20	200	59.5	35.1	0	1.68	1005	0.46	6.57
JALEEB16	12/15/2008 16:46	DEC 08	60.2	33.9	0.4	5.5	0	0		200	62.4	33.7	0.2	1.78	1007	0.58	3.99
JALEEB16	7/1/2009 11:46	JAN 09	58.6	33.4	0.3	7.7	1	0	18.9	200	66.5	33.3	0.3	1.75	1004	0.46	6.57
JALEEB16	8/2/2009 5:11	FEB 09	58.1	35	0.5	6.4	0	0	22.8	200	66.2	34.7	0.6	1.66	1004	-0.02	2.77
JALEEB16	17/3/2009 3:29	MAR 09	57	36.1	0	6.9	1	16	27.1	200	56.9	36.1	0	1.58	1004	0.18	6.9
JALEEB16	21/4/2009 9:46	APR 09	53.6	35.5	0.2	10.7	3	30	28.8	200	54	35.6	0.3	1.51	1006	-0.05	9.94
JALEEB16	26/5/2009 7:32	MAY 09	53.4	35.6	0.2	10.8	3	7	37	200	54.4	35.8	0.2	1.5	992	0.07	10.04
JALEEB16	7/6/2009 11:46	JUN 09	56.4	32.4	0.3	10.9	1	0	39.4	200	65.8	32.4	0.4	1.74	998	0.11	9.77
JALEEB16	2/7/2009 5:11	JUL 09	51.1	34.8	0.3	13.8	1	0	44.2	200	53.1	34.7	0.3	1.47	1003	0	12.67
JALEEB16	8/12/2009 9:39	AUG 09	56.9	32.1	0.5	10.5	0	0	49.6	200	62.7	32.1	0.5	1.77	999	-0.15	8.61
JALEEB16	9/4/2009 10:09	SEP 09	54.5	31.9	1	12.6	0	0	35.4	200	62.7	31.8	1	1.71	1001	0.35	8.82
JALEEB16	10/11/2009 10:05	OCT 09	57.6	32.9	0.4	9.1	0	0	34.3	200	62.1	32.8	0.4	1.75	1002	-23.84	7.59
JALEEB16	13/11/2009 11:35	NOV 09	60.2	33.9	0.4	5.5	0	0	30.3	200	62.4	33.7	0.2	1.78	1007	0.58	3.99
JALEEB16	26/12/2009 7:32	DEC 09	59.5	35.4	0	5.1	0	2	24.2	200	59.5	35.1	0	1.68	1005	0.46	6.57
JALEEB16	1/17/2010 11:46	JAN 10	60.8	35	0.3	3.9	0	0	22.2	200	60.8	35.1	0.3	1.74	1013	-0.02	2.77
JALEEB16	3/1/2010 10:22	FEB 10	62.1	35.4	0.3	2.2	0	0	24.9	200	62.3	35.5	0.3	1.75	1000	0.2	1.07
JALEEB16	3/16/2010 11:13	MAR 10	61.9	35.6	0.3	2.2	0	0	35.5	200	62	35.7	0.3	1.74	999	0.09	1.07
JALEEB16	4/21/2010 16:06	ARP 10	61.5	35.4	0.6	2.5	0	1	37.4	200	61.5	35.4	0.6	1.74	992	2.99	0.23
JALEEB16	5/19/2010 11:13	MAY 10	62.3	35.6	0.4	1.7	0	0	46.4	200	62.3	35.6	0.4	1.75	995	-0.09	0.19
JALEEB16	6/22/2010 11:10	JUN 10	59.5	34.1	0.9	5.5	0	0	46.4	200	59.4	34.1	0.9	1.74	990	-0.4	2.1
JALEEB16	7/21/2010 10:54	JUL 10	60.8	35	1	3.2	0	0	48.2	200	60.8	34.7	1.1	1.74	983	0.01	0
JALEEB16	8/19/2010 9:44	AUG 10	58.8	34.7	0.8	5.7	0	0	47.5	200	58.7	34.7	0.8	1.69	988	-0.1	2.68
JALEEB16	9/20/2010 11:24	SEP 10	60.9	35.1	0.7	3.3	0	0	45	200	61	35.1	0.7	1.74	994	0.21	0.65
JALEEB16	10/19/2010 11:17	OCT 10	58.5	33.8	1.3	6.4	0	0	39.5	200	58.6	33.9	1.3	1.73	999	0.32	1.49
JALEEB16	11/7/2010 11:37	NOV 10	53	30.8	2.7	13.5	0	0	30.6	200	52.9	30.7	2.7	1.72	1003	0.31	3.29
JALEEB16	12/20/2010 14:29	DEC 10	46.3	27.4	4.7	21.6	0	0	24.6	200	46.3	27.4	4.8	1.69	1008	0.25	3.83

Table App. 5.17: LFG measurements in Borehole 17

Jleeb Al Shuyoukh Landfill, LF Gas Monitoring																	BH 17
ID	DATE	MONTH	CH4	CO2	O2	BAL	NH3	H2S	TEMP	CH4 %	PEAK	PEAK	MIN	CH4/	BARO	REL.	Res
			%	%	%	%	ppm	ppm	DegC	LEL%	CH4%	CO2%	O2%	CO2%	mb	PRESS.mb	Nitro%
JALEEB17	3/31/2008 14:09	MAR 08	47.1	31.1	1.4	20.4	0	0	41.9	200	51.2	30.7	0.7	1.51	995	-0.27	15.11
JALEEB17	4/14/2008 11:24	APR 08	45.1	30.2	0.5	24.2	0	0	43.4	200	48.3	30.1	0.5	1.49	1003	0.21	22.31
JALEEB17	5/18/2008 11:07	MAY 08	42.9	29.8	0.7	26.6	0	0	36.1	200	47	29.4	0.6	1.44	998	-0.32	23.95
JALEEB17	6/1/2008 10:27	JUN 08	24.7	19.9	3.7	51.7	0	0	42.8	200	26.6	19.4	3.8	1.24	997	-0.27	37.71
JALEEB17	7/6/2008 8:55	JUL 08	25.9	21.2	8	44.9	0	0	40.3	200	55.3	31.7	0.8	1.22	992	-0.47	14.66
JALEEB17	8/9/2008 10:14	AUG 08	29.4	26.6	1.5	42.5	0	23	47.4	200	31.4	26.4	0.6	1.11	988	-0.17	36.83
JALEEB17	9/11/2008 10:20	SEP 08	28.2	25.7	0.3	45.8	1	0	43.9	200	29.3	25.5	0.3	1.1	998	-0.12	44.67
JALEEB17	10/12/2008 12:27	OCT 08	21.3	17.3	5.4	56	0	0	39.7	200	21.9	17.1	5.4	1.23	1002	-11.35	35.59
JALEEB17	11/13/2008 11:24	NOV 08	32	34.9	1.9	31.2	110	0	18.5	200	32.4	34.7	2	0.92	1003	0.21	22.31
JALEEB17	12/15/2008 16:43	DEC 08	34.7	22.9	6.5	35.9	0	0		200	34.7	22.4	6.3	1.52	1007	0.09	11.33
JALEEB17	7/1/2009 11:50	JAN 09	39.6	26.4	0.4	33.6	0	0	17.5	200	41	26.2	0.5	1.5	1003	1.71	32.09
JALEEB17	8/2/2009 5:14	FEB 09	37.9	27.1	0.7	34.3	0	0	26.5	200	41.8	27	0.7	1.4	1006	-0.25	31.65
JALEEB17	17/3/2009 3:32	MAR 09	40.1	31.7	0.1	28.1	6	18	30.4	200	40.4	31.8	0.1	1.26	1005	1.74	27.72
JALEEB17	21/4/2009 9:50	APR 09	15.7	19.1	5.1	60.1	3	10	29.4	200	16	19.1	5.1	0.82	1006	-0.16	40.82
JALEEB17	26/5/2009 7:35	MAY 09	38.4	30.8	0.8	30	4	12	37.7	200	38.7	31.2	0.7	1.25	992	0.92	26.98
JALEEB17	7/6/2009 11:50	JUN 09	22	17.8	4.6	55.6	0	0	42.2	200	22.3	17.7	4.6	1.24	995	-0.27	38.21
JALEEB17	2/7/2009 5:14	JUL 09	25.9	21.2	8	44.9	0	0	40.3	200	55.3	31.7	0.8	1.22	1003	-0.47	14.66
JALEEB17	8/12/2009 9:44	AUG 09	19.9	16.3	6.1	57.7	0	0	46.8	200	20	16.1	6.1	1.22	1000	-0.27	34.64
JALEEB17	9/4/2009 9:35	SEP 09	32.5	19.9	6.6	41	0	0	34.3	200	32.5	19.9	6.6	1.63	1000	-9.54	16.05
JALEEB17	10/11/2009 9:13	OCT 09	8.5	10.3	10.3	70.9	0	0	37.7	170	8.5	10.3	10.3	0.83	1003	0.34	31.97
JALEEB17	13/11/2009 11:20	NOV 09	34.7	22.9	6.5	35.9	0	0	31.5	200	34.7	22.4	6.3	1.52	1007	0.09	11.33
JALEEB17	26/12/2009 7:35	DEC 09	32	34.9	1.9	31.2	110	0	26.2	200	32.4	34.7	2	0.92	1003	0.21	22.31
JALEEB17	1/17/2010 11:50	JAN 10	35	27.6	1.2	36.2	0	0	31.8	200	59.9	34.4	0.4	1.27	1013	-7.72	31.66
JALEEB17	3/1/2010 10:26	FEB 10	49.7	33.7	0.3	16.3	0	0	31.5	200	49.8	33.8	0.3	1.47	1000	0.08	15.17
JALEEB17	3/16/2010 11:16	MAR 10	38.8	29	1.3	30.9	0	0	38.7	200	39	29	1.3	1.34	999	-0.25	25.99
JALEEB17	4/21/2010 16:09	ARP 10	48	31.4	2.3	18.3	0	1	39.2	200	48	31.4	2.3	1.53	992	-0.12	9.61
JALEEB17	5/20/2010 10:24	MAY 10	7.2	5.5	15.3	72	0	0	44	144	62.6	35.6	0.6	1.31	995	0.06	14.17
JALEEB17	6/22/2010 11:13	JUN 10	32.5	25.3	2.2	40	0	0	48.3	200	32.4	25.4	2.2	1.28	990	-0.23	31.68
JALEEB17	7/21/2010 10:57	JUL 10	38.8	28.5	1.6	31.1	0	0	51.1	200	38.9	28.6	1.6	1.36	982	0.04	25.05
JALEEB17	8/19/2010 9:46	AUG 10	49.5	32.3	1.3	16.9	0	0	47.8	200	49.6	32.2	1.3	1.53	988	-0.14	11.99
JALEEB17	9/20/2010 11:27	SEP 10	29	23.6	2.3	45.1	0	0	46.9	200	29.1	23.6	2.3	1.23	994	0.43	36.41
JALEEB17	10/19/2010 11:19	OCT 10	35.8	26.4	2.5	35.3	41	0	34.1	200	35.8	26.4	2.5	1.36	999	0.25	25.85
JALEEB17	11/7/2010 11:40	NOV 10	32.3	23.2	4.3	40.2	0	0	28.1	200	32.5	23.3	4.3	1.39	1003	0.17	23.95
JALEEB17	12/20/2010 14:32	DEC 10	30.6	23.1	4.1	42.2	0	0	36	200	46.3	27.2	4.2	1.32	1008	0.15	26.7

Table App. 5.18: LFG measurements in Borehole 18

Jleeb Al Shuyoukh Landfill, LF Gas Monitoring																	BH 18
ID	DATE	MONTH	CH4	CO2	O2	BAL	NH3	H2S	TEMP	CH4 %	PEAK	PEAK	MIN	CH4/	BARO	REL.	Res
			%	%	%	%	ppm	ppm	DegC	LEL%	CH4%	CO2%	O2%	CO2%	mb	PRESS.mb	Nitro%
JALEEB18	3/31/2008 14:19	MAR 08	38.1	27.1	1.2	33.6	1	0	32.8	200	41.1	26.7	0.7	1.41	995	-0.36	29.06
JALEEB18	4/14/2008 11:15	APR 08	39.6	26.4	0.4	33.6	0	1	32.6	200	41	26.2	0.5	1.5	1003	1.71	32.09
JALEEB18	5/18/2008 10:39	MAY 08	38.2	26.7	1.6	33.5	0	0	36.9	200	42.4	25.9	0.4	1.43	998	0.03	27.45
JALEEB18	6/1/2008 10:33	JUN 08	37.9	27.1	0.7	34.3	0	0	41.4	200	41.8	27	0.7	1.4	997	-0.25	31.65
JALEEB18	7/7/2008 8:57	JUL 08	0.4	2.7	18	78.9	0	30	42.1	8	5.9	8.3	13.3	0.15	991	-0.38	10.86
JALEEB18	8/9/2008 10:16	AUG 08	35.1	25.5	3.4	36	0	0	46.9	200	34.7	25.2	3.5	1.38	988	-0.15	23.15
JALEEB18	9/11/2008 9:18	SEP 08	40.4	27.9	0.4	31.3	0	0	42.8	200	42.5	27.8	0.4	1.45	1003	-0.21	29.79
JALEEB18	10/12/2008 12:32	OCT 08	37.4	23.9	0.9	37.8	0	0	36.1	200	37.7	23.8	0.9	1.56	1002	-0.17	34.4
JALEEB18	11/13/2008 11:15	NOV 08	27.3	22.3	1.7	48.7	145	0	20.2	200	27.5	22.1	1.8	1.22	1003	1.71	32.09
JALEEB18	12/15/2008 17:00	DEC 08	17.6	20.5	2.3	59.6	0	0		200	18.3	20.4	2.1	0.86	1007	0.1	50.91
JALEEB18	7/1/2009 11:55	JAN 09	10.4	12.5	10.5	66.6	120	4	19.9	200	10.6	12.5	10.5	0.83	1003	-0.1	26.91
JALEEB18	8/2/2009 5:18	FEB 09	1.8	1.6	19.1	77.5	0	0	24.9	36	2.3	2	18.8	1.13	1004	-0.24	10.89
JALEEB18	17/3/2009 3:41	MAR 09	0	0.1	19.4	80.5	0	5	26.3	0	18.5	20	0.9	0	1005	3.17	7.17
JALEEB18	21/4/2009 9:54	APR 09	1.3	13.4	3.8	81.5	2	10	32.9	26	1.3	13.4	3.8	0.1	1006	-0.11	67.14
JALEEB18	26/5/2009 7:37	MAY 09	0.7	9.6	8	81.7	3	16	41	14	0.7	9.7	8	0.07	992	-0.12	51.46
JALEEB18	7/6/2009 11:55	JUN 09	0	1.6	15.5	82.9	0	10	43.9	0	0	1.7	15.1	0	994	0.57	24.31
JALEEB18	2/7/2009 5:18	JUL 09	0.4	2.7	18	78.9	0	23	42.1	8	5.9	8.3	13.3	0.15	1003	-0.38	10.86
JALEEB18	8/12/2009 9:12	AUG 09	0.4	7.2	18.3	74.1	0	0	48.4	8	0.5	7.5	17.4	0.06	1005	0	4.93
JALEEB18	9/4/2009 9:41	SEP 09	0	0.6	19.1	80.3	0	11	33.2	0	0	1.7	18.4	0	1001	-0.2	8.1
JALEEB18	10/11/2009 9:18	OCT 09	0	3.5	11.6	84.9	0	0	37	0	0	3.5	11.6	0	1001	-0.29	41.05
JALEEB18	13/11/2009 11:24	NOV 09	0.3	1.4	17.1	81.2	2	10	29.2	8	0.4	1.5	17	0.21	1006	-0.11	67.14
JALEEB18	26/12/2009 7:37	DEC 09	0	1.2	19.9	78.9	145	0	25.3	0	20	20.4	1.1	0	1004	-0.37	52.5
JALEEB18	1/17/2010 11:55	JAN 10	0	0.2	18.6	81.2	285	0	25.5	0	35.3	27.4	1.3	0	1013	-0.24	10.89
JALEEB18	3/1/2010 10:30	FEB 10	0	1.1	17.9	81	281	0	29.5	0	0.8	1	17.8	0	1000	-0.14	13.34
JALEEB18	3/16/2010 11:20	MAR 10	0.3	0.6	18.6	80.5	497	0	40	6	0.4	0.6	18.4	0.5	999	-0.28	10.19
JALEEB18	4/21/2010 16:12	ARP 10	0.1	0.1	19.4	80.4	280	0	38.5	2	0.4	0.4	18.3	1	992	-0.27	7.07
JALEEB18	5/20/2010 10:26	MAY 10	10.3	7.3	11.8	70.6	0	0	45.7	200	10.5	7.5	11.6	1.41	996	-0.19	26
JALEEB18	6/22/2010 11:20	JUN 10	10	9.9	10.1	70	0	0	46.4	200	17.4	19.3	5.1	1.01	990	-0.24	31.82
JALEEB18	7/21/2010 11:01	JUL 10	7.3	13.1	5.1	74.5	0	0	53.6	146	37.8	27.6	1.5	0.56	983	-0.11	55.22
JALEEB18	8/19/2010 9:48	AUG 10	13.3	8.1	9.7	68.9	0	0	48.4	200				1.64	989	-0.26	32.23
JALEEB18	9/20/2010 11:29	SEP 10	0.1	0.9	18.2	80.8	468	0	47.1	2	0.9	1.1	16.9	0.11	994	-0.16	12
JALEEB18	10/19/2010 11:22	OCT 10	0.7	0.5	17.7	81.1	410	0	34.1	14	0.8	0.6	17.3	1.4	999	-0.1	14.19
JALEEB18	11/8/2010 10:47	NOV 10	0.6	0.5	17.4	81.5	0	0	33.5	12	0.8	0.7	16.8	1.2	1004	0.01	15.73
JALEEB18	12/20/2010 14:34	DEC 10	15.1	11.1	8	65.8	0	0	27.9	200	15.5	11.8	7.5	1.36	1008	0.15	35.56

Table App. 5.19: LFG measurements in Borehole 19

Jleeb Al Shuyoukh Landfill, LF Gas Monitoring																	BH 19
ID	DATE	MONTH	CH4	CO2	O2	BAL	NH3	H2S	TEMP	CH4 %	PEAK	PEAK	MIN	CH4/	BARO	REL.	Res
			%	%	%	%	ppm	ppm	DegC	LEL%	CH4%	CO2%	O2%	CO2%	mb	PRESS.mb	Nitro%
JALEEB19	4/1/2008 9:46	MAR 08	24.9	23	0.4	51.7	0	0	28.7	200	27.7	22.3	0.5	1.08	998	-0.27	50.19
JALEEB19	4/13/2008 11:18	APR 08	25.6	23.8	0.4	50.2	0	0	31.4	200	27.8	23.6	0.4	1.08	1006	0.74	48.69
JALEEB19	5/18/2008 10:44	MAY 08	28.2	25.7	0.3	45.8	0	1	37.8	200	29.3	25.5	0.3	1.1	998	-0.12	44.67
JALEEB19	6/1/2008 10:42	JUN 08	23.3	24	0.5	52.2	0	0	40.7	200	25	23.9	0.5	0.97	997	0.49	50.31
JALEEB19	7/6/2008 8:59	JUL 08	29.7	24.6	0.5	45.2	0	0	42	200	29.9	24.3	0.5	1.21	991	-30.02	43.31
JALEEB19	8/9/2008 10:18	AUG 08	29.8	24.5	2.6	43.1	0	0	47.7	200	30.6	24.4	2.6	1.22	988	-0.12	33.27
JALEEB19	9/11/2008 9:22	SEP 08	22.9	23	0.3	53.8	0	0	42.3	200	23.3	22.7	0.4	1	1003	0.15	52.67
JALEEB19	10/12/2008 12:33	OCT 08	25.4	21.6	2.9	50.1	0	0	35.8	200	26.6	21.4	2.9	1.18	1002	-15.75	39.14
JALEEB19	11/13/2008 11:18	NOV 08	22.1	30.2	16.2	31.5	0	20	16.5	200	22.1	30.1	16.4	0.73	1006	0.74	48.69
JALEEB19	12/15/2008 16:56	DEC 08	32.2	28	0.4	39.4	0	0		200	32.7	27.7	0.2	1.15	1007	0.9	37.89
JALEEB19	7/1/2009 11:59	JAN 09	25.6	23.8	0.4	50.2	90	0	17.5	200	27.8	23.6	0.4	1.08	1006	0.74	48.69
JALEEB19	8/2/2009 5:21	FEB 09	29.3	26.8	0.2	43.7	0	0	23.7	200	29.7	26.8	0.2	1.09	1006	-0.06	42.94
JALEEB19	17/3/2009 3:39	MAR 09	25.7	27.3	0	47	5	20	26.8	200	25.8	27.3	0	0.94	1006	1.99	47
JALEEB19	21/4/2009 9:58	APR 09	22.7	26.1	0.2	51	2	31	28.1	200	23.2	26.4	0.2	0.87	1006	-0.04	50.24
JALEEB19	26/5/2009 7:40	MAY 09	18.5	25.9	0.2	55.4	3	35	36.9	200	18.5	26.5	0.1	0.71	992	2.05	54.64
JALEEB19	7/6/2009 11:59	JUN 09	21.9	23.4	0.4	54.3	0	0	39.9	200	22.5	23.2	0.4	0.94	995	-0.29	52.79
JALEEB19	2/7/2009 5:21	JUL 09	29.7	24.6	0.5	45.2	0	35	42	200	29.9	24.3	0.5	1.21	1003	-30.02	43.31
JALEEB19	8/12/2009 9:08	AUG 09	24.5	20.9	0.5	54.1	0	0	50.1	200	24.9	20.7	0.5	1.17	1000	-0.12	52.21
JALEEB19	9/4/2009 9:45	SEP 09	13.7	11.6	10	64.7	0	0	34.3	200	13.7	11.3	10	1.18	1001	-0.26	26.9
JALEEB19	10/11/2009 9:22	OCT 09	22.9	23	0.3	53.8	0	0	32.2	200	23.3	22.7	0.4	1	1003	0.15	52.67
JALEEB19	13/11/2009 11:15	NOV 09	32.2	28	0.4	39.4	0	0	28.5	200	32.7	27.7	0.2	1.15	1007	0.9	37.89
JALEEB19	26/12/2009 7:40	DEC 09	22.1	30.2	16.2	31.5	0	20	25.6	200	22.1	30.1	16.4	0.73	1006	0.74	48.69
JALEEB19	1/17/2010 11:59	JAN 10	30.3	27.2	0.4	42.1	0	0	21.8	200	30.3	27.2	0.4	1.11	1013	3.27	40.59
JALEEB19	3/1/2010 10:35	FEB 10	32.3	28	0.3	39.4	0	0	24.5	200	32.4	28.1	0.3	1.15	1000	0.15	38.27
JALEEB19	3/18/2010 10:01	MAR 10	31.9	27.9	0.3	39.9	0	0	31.8	200	31.9	27.9	0.3	1.14	1001	-0.01	38.77
JALEEB19	4/21/2010 16:15	ARP 10	28.5	25.5	1.6	44.4	0	3	37	200	28.7	25.6	1.7	1.12	992	-0.13	38.35
JALEEB19	5/20/2010 10:31	MAY 10	14.8	19.4	4	61.8	0	4	45.6	200	14.8	19.4	4.1	0.76	996	-0.11	46.68
JALEEB19	6/23/2010 10:05	JUN 10	8.7	23.3	0.5	67.5	0	0	46.3	174	61.2	34.9	0.5	0.37	989	0.07	65.61
JALEEB19	7/21/2010 11:05	JUL 10	6.8	20.9	3.1	69.2	0	0	49.6	136	6.5	19.6	4.3	0.33	983	-0.14	57.48
JALEEB19	8/19/2010 9:52	AUG 10	11.9	17.3	6.6	64.2	0	0	47.7	200	11.9	17.3	6.6	0.69	989	-0.18	39.25
JALEEB19	9/20/2010 11:33	SEP 10	10.1	16.2	6.7	67	0	0	45.6	200	10	16.1	6.7	0.62	994	0.08	41.67
JALEEB19	10/19/2010 11:25	OCT 10	16.4	23.6	1.8	58.2	0	0	39.7	200	16.4	23.6	1.8	0.69	999	-0.05	51.4
JALEEB19	11/8/2010 10:48	NOV 10	31.2	24.3	2	42.5	141	0	35.1	200	31.2	24.2	2.4	1.28	1004	-8.5	34.94
JALEEB19	12/20/2010 15:01	DEC 10	26.6	20	3.6	49.8	0	0	21.5	200	26.7	20	3.6	1.33	1008	-7.12	36.19

Table App. 5.20: LFG measurements in Borehole 20

Jleeb Al Shuyoukh Landfill, LF Gas Monitoring																	BH 20
ID	DATE	MONTH	CH4	CO2	O2	BAL	NH3	H2S	TEMP	CH4 %	PEAK	PEAK	MIN	CH4/	BARO	REL.	Res
			%	%	%	%	ppm	ppm	DegC	LEL%	CH4%	CO2%	O2%	CO2%	mb	PRESS.mb	Nitro%
JALEEB20	4/1/2008 9:53	MAR 08	20.9	22.9	1.2	55	0	0	30.6	200	22	22.5	1.2	0.91	998	0.03	50.46
JALEEB20	4/14/2008 11:34	APR 08	20.8	22	1.6	55.6	0	0	33.2	200	21.2	21.9	1.6	0.95	1004	0.16	49.55
JALEEB20	5/18/2008 11:03	MAY 08	20.2	23.4	1.1	55.3	0	0	38.1	200	21.5	23.3	1.1	0.86	998	-0.05	51.14
JALEEB20	6/1/2008 10:22	JUN 08	17	19.6	2.7	60.7	0	0	42.1	200	18.9	19.4	2.7	0.87	998	-15.89	50.49
JALEEB20	7/6/2008 9:02	JUL 08	18.9	19	4.1	58	2	0	42.2	200	22	19	2.5	0.99	991	-0.11	42.5
JALEEB20	8/9/2008 10:22	AUG 08	42.9	28.7	2.6	25.8	0	0	43.9	200	51.3	28.4	2.6	1.49	988	-0.33	15.97
JALEEB20	9/11/2008 10:20	SEP 08	40.5	26.9	0.4	32.2	2	0	43.8	200	46.1	26.8	0.4	1.51	1003	-5.29	30.69
JALEEB20	10/12/2008 13:12	OCT 08	48.7	30.9	0.6	19.8	0	0	35.9	200	54.3	30.7	0.6	1.58	1002	-0.02	17.53
JALEEB20	11/13/2008 11:34	NOV 08	35	28.5	23.4	13.1	140	12	20.6	200	35.2	28	22	1.23	1004	0.16	49.55
JALEEB20	12/15/2008 16:40	DEC 08	21.5	26	1	51.5	0	0		200	22	25.8	0.8	0.83	1007	0.45	47.72
JALEEB20	8/1/2009 10:14	JAN 09	20.8	22	1.6	55.6	0	0	18.2	200	21.2	21.9	1.6	0.95	1004	0.16	49.55
JALEEB20	11/2/2009 11:22	FEB 09	11.5	21.7	3.8	63	22	0	26.1	200	11.5	21.7	3.8	0.53	1003	-0.04	48.64
JALEEB20	17/3/2009 3:35	MAR 09	17.6	26.1	0.6	55.7	1	7	26.4	200	40.6	32.2	0.5	0.67	1005	0.42	53.43
JALEEB20	21/4/2009 10:03	APR 09	9.3	15.1	6.5	69.1	1	4	28.9	186	11.2	17.5	5.2	0.62	1006	-0.04	44.53
JALEEB20	26/5/2009 7:44	MAY 09	14.3	26	0.5	59.2	2	7	38.4	200	14.3	26	0.6	0.55	992	0.02	57.31
JALEEB20	8/6/2009 10:14	JUN 09	16.9	19.5	2.7	60.9	0	0	41.1	200	17	19.1	2.7	0.87	996	-0.12	50.69
JALEEB20	11/7/2009 11:22	JUL 09	18.9	19	4.1	58	2	0	42.2	200	22	19	2.5	0.99	1003	-0.11	42.5
JALEEB20	8/12/2009 9:50	AUG 09	18.7	21.6	2.2	57.5	0	0	50.4	200	19.5	21.2	2.2	0.87	1000	-0.12	49.18
JALEEB20	9/4/2009 9:27	SEP 09	0	2.4	18	79.6	0	15	35	0	0.1	7.8	15.5	0	1001	0.11	11.56
JALEEB20	10/11/2009 9:08	OCT 09	19	23.6	1.9	55.5	0	0	33.9	200	19.1	23.7	1.9	0.81	1003	0.01	48.32
JALEEB20	13/11/2009 11:18	NOV 09	21.5	26	1	51.5	0	0	23.6	200	22	25.8	0.8	0.83	1007	0.45	47.72
JALEEB20	26/12/2009 7:44	DEC 09	35	28.5	23.4	13.1	140	12	24.8	200	35.2	28	22	1.23	1004	0.16	49.55
JALEEB20	1/18/2010 10:14	JAN 10	4.3	8	14	73.7	0	0	21	86	4.2	7.9	14	0.54	1013	-0.04	20.78
JALEEB20	3/1/2010 10:40	FEB 10	21.5	26.9	0.3	51.3	0	0	25.8	200	21.6	27	0.3	0.8	1004	0.02	50.17
JALEEB20	3/18/2010 10:05	MAR 10	19	24.2	1.6	55.2	0	0	33.4	200	19.1	24.3	1.6	0.79	1001	-0.12	49.15
JALEEB20	4/22/2010 13:58	ARP 10	19.9	26.6	0.5	53	0	1	38.3	200	20	26.7	0.5	0.75	991	0.09	51.11
JALEEB20	5/20/2010 10:35	MAY 10	16.1	21	3	59.9	0	1	45.4	200	16.5	21.3	3	0.77	995	-0.14	48.56
JALEEB20	6/23/2010 10:09	JUN 10	11.1	18.4	5.4	65.1	0	0	48.7	200	11	18.4	5.4	0.6	990	-0.19	44.69
JALEEB20	7/21/2010 11:09	JUL 10	18.7	24.6	1.3	55.4	0	0	52.6	200	18.9	24.8	1.4	0.76	983	-0.15	50.49
JALEEB20	8/21/2010 9:44	AUG 10	37.2	27.8	3.3	31.7	22	0	48.4	200	55.6	32	2	1.34	989	-0.14	19.23
JALEEB20	9/20/2010 11:36	SEP 10	16.5	22.9	2.2	58.4	0	0	44.9	200	16.6	22.9	2.3	0.72	994	-0.08	50.08
JALEEB20	10/19/2010 11:28	OCT 10	16.4	23	2.6	58	0	0	35.1	200	16.4	23	2.6	0.71	999	-0.06	48.17
JALEEB20	11/8/2010 10:59	NOV 10	16.7	23.3	2.4	57.6	0	0	31.2	200	16.7	23.3	2.4	0.72	1004	-20.49	48.53
JALEEB20	12/21/2010 13:21	DEC 10	15.8	21.6	4.4	58.2	0	0	26.1	200	15.8	21.6	4.5	0.73	1010	0.15	41.57

Table App. 5.21: LFG measurements in Borehole 21

Jleeb Al Shuyoukh Landfill, LF Gas Monitoring																	BH 21
ID	DATE	MONTH	CH4	CO2	O2	BAL	NH3	H2S	TEMP	CH4 %	PEAK	PEAK	MIN	CH4/	BARO	REL.	Res
			%	%	%	%	ppm	ppm	DegC	LEL%	CH4%	CO2%	O2%	CO2%	mb	PRESS.mb	Nitro%
JALEEB21	4/2/2008 8:31	MAR 08	0	0.7	20.2	79.1	0	1	26.4	0	0	1	20.1	0	1006	-0.05	2.74
JALEEB21	4/15/2008 11:16	APR 08	12.9	8.4	11.4	67.3	0	0	36.9	200	13	8.1	5.5	1.54	1003	-0.29	24.21
JALEEB21	5/22/2008 8:17	MAY 08	47.2	32.6	0.7	19.5	0	0	39.9	200	51.2	32.5	0.7	1.45	997	-0.14	16.85
JALEEB21	6/2/2008 11:52	JUN 08	37.2	29.4	0.2	33.2	0	0	40.5	200	40	29.1	0.2	1.27	996	-23.43	32.44
JALEEB21	7/6/2008 9:04	JUL 08	36.5	27.4	1	35.1	0	0	42.9	200	38.1	27.4	1	1.33	991	-0.52	31.32
JALEEB21	8/9/2008 10:20	AUG 08	17.2	21	2	59.8	0	0	46.9	200	17.8	20.7	2	0.82	990	-0.14	52.24
JALEEB21	9/11/2008 9:08	SEP 08	19	23.6	1.9	55.5	0	0	43	200	19.1	23.7	1.9	0.81	1003	0.01	48.32
JALEEB21	10/12/2008 12:40	OCT 08	20.9	14.4	7.1	57.6	0	1	34	200	22	14.3	7.1	1.45	1001	-40.67	30.76
JALEEB21	11/15/2008 11:16	NOV 08	35.5	8.4	11.4	67.3	0	0	26.9	200	35.5	8.1	11.4	4.23	1004	-0.29	24.21
JALEEB21	12/15/2008 16:34	DEC 08	48	33.8	0.6	17.6	0	0		200	50	33.5	0.3	1.42	1007	0.16	15.33
JALEEB21	8/1/2009 10:20	JAN 09	23.6	15.8	7.6	53	0	0	17.9	200	25.3	15.5	7.6	1.49	1003	-0.17	24.27
JALEEB21	11/2/2009 11:25	FEB 09	18.8	20.8	4.7	55.7	12	12	29.9	200	19	21.1	4.7	0.9	1004	0.1	37.93
JALEEB21	17/3/2009 4:22	MAR 09	22.3	26.5	1.7	49.5	1	17	27	200	22.6	26.6	1.7	0.84	1005	0	43.07
JALEEB21	21/4/2009 10:08	APR 09	20	26.1	1.3	52.6	1	12	30.1	200	20	26.3	1.3	0.77	1006	-0.04	47.69
JALEEB21	26/5/2009 7:47	MAY 09	0	0	19.3	80.7	1	3	39.7	0	25.8	25.2	3.6	0	992	2.16	7.75
JALEEB21	8/6/2009 10:20	JUN 09	46	32.8	0.5	20.7	0	0	41.9	200	51.2	32.6	0.5	1.4	995	-0.42	18.81
JALEEB21	11/7/2009 11:26	JUL 09	36.5	27.4	1	35.1	0	0	42.9	200	38.1	27.4	1	1.33	1003	-0.52	31.32
JALEEB21	8/13/2009 9:44	AUG 09	56.8	33	0.8	9.4	0	0	50	200	65.6	32.8	0.8	1.72	1004	0.6	6.38
JALEEB21	9/6/2009 9:07	SEP 09	51.9	32.3	0.6	15.2	0	0	34.4	200	57.4	32.1	0.6	1.61	998	-0.35	12.93
JALEEB21	10/11/2009 10:20	OCT 09	20.6	16.4	8.2	54.8	0	0	37.4	200	20.7	16.2	8.2	1.26	1003	-0.24	23.8
JALEEB21	13/11/2009 11:34	NOV 09	48	33.8	0.6	17.6	0	0	24.7	200	50	33.5	0.3	1.42	1007	0.16	15.33
JALEEB21	26/12/2009 7:47	DEC 09	35.5	8.4	11.4	67.3	0	0	25.1	200	35.5	8.1	11.4	4.23	1004	-0.29	24.21
JALEEB21	1/18/2010 10:20	JAN 10	26.2	26.3	2.3	45.2	0	0	21.3	200	26.6	26.4	2.3	1	1013	-0.05	36.51
JALEEB21	3/2/2010 10:10	FEB 10	0.1	0.4	19	80.5	27	0	25.5	2	0.3	4.4	14.2	0.25	1007	-0.18	8.68
JALEEB21	3/18/2010 10:15	MAR 10	32.4	29.7	0.7	37.2	0	0	34.4	200	32.5	29.7	0.7	1.09	1002	0.81	34.55
JALEEB21	4/22/2010 14:01	ARP 10	6.6	21.4	1.1	70.9	0	1	40.9	132	6.6	21.4	1.1	0.31	992	0.04	66.74
JALEEB21	5/20/2010 10:39	MAY 10	27.9	22.8	5.3	44	0	0	46.2	200	29	23.3	5.3	1.22	996	-0.21	23.97
JALEEB21	6/23/2010 10:14	JUN 10	42	32.5	0.6	24.9	0	0	50.9	200	42	32.5	0.7	1.29	990	-0.17	22.63
JALEEB21	7/21/2010 11:13	JUL 10	42.9	31.7	1.5	23.9	0	0	53.9	200	42.9	31.7	1.5	1.35	983	-0.01	18.23
JALEEB21	8/21/2010 9:44	AUG 10	37.7	28.8	3	30.5	0	0	48.7	200				1.31	989	-12.99	19.16
JALEEB21	9/20/2010 11:40	SEP 10	34	27.5	2.8	35.7	0	0	45.9	200	34	27.5	2.8	1.24	994	0.28	25.12
JALEEB21	10/19/2010 11:32	OCT 10	18.9	13.6	11.3	56.2	0	0	36.1	200	18.9	13.6	11.3	1.39	999	0	13.49
JALEEB21	11/8/2010 11:03	NOV 10	35	28	2.9	34.1	0	0	34.3	200	35	28	3	1.25	1004	0.09	23.14
JALEEB21	12/21/2010 13:24	DEC 10	26.6	23.7	4.8	44.9	0	0	25	200	26.7	23.7	4.9	1.12	1010	0.24	26.76

Table App. 5.22: LFG measurements in Borehole 22

Jleeb Al Shuyoukh Landfill, LF Gas Monitoring																	BH 22
ID	DATE	MONTH	CH4	CO2	O2	BAL	NH3	H2S	TEMP	CH4 %	PEAK	PEAK	MIN	CH4/	BARO	REL.	Res
			%	%	%	%	ppm	ppm	DegC	LEL%	CH4%	CO2%	O2%	CO2%	mb	PRESS.mb	Nitro%
JALEEB22	4/2/2008 8:39	MAR 08	0	0.5	20.1	79.4	0	2	28.1	0	0	0.7	20	0	1006	-0.5	3.42
JALEEB22	4/15/2008 10:32	APR 08	58.1	35	0.5	6.4	0	2	32.4	200	66.2	34.7	0.6	1.66	1004	0.37	4.51
JALEEB22	5/22/2008 8:24	MAY 08	57.8	35.3	0.3	6.6	0	0	37	200	62.8	35.3	0.3	1.64	997	1.61	5.47
JALEEB22	6/2/2008 12:04	JUN 08	8.3	6.3	13.1	72.3	0	26	37.6	166	12.4	8.8	10.9	1.32	996	-25.08	22.78
JALEEB22	7/6/2008 9:06	JUL 08	9.8	5.9	9	75.3	1	0	41.5	196	9.8	5.6	9.1	1.66	991	-0.12	41.28
JALEEB22	8/9/2008 10:24	AUG 08	12.9	9.8	10.3	67	0	14	47.6	200	12.1	8.9	10.9	1.32	988	-0.19	28.07
JALEEB22	9/12/2008 9:01	SEP 08	2.1	17.9	0.2	79.8	0	0	43.9	42	2.2	17.9	0.2	0.12	1002	-34.89	79.04
JALEEB22	10/12/2008 13:17	OCT 08	5.4	6	14.9	73.7	0	4	36	108	5.4	10.8	14.2	0.9	997	-0.08	17.38
JALEEB22	11/15/2008 11:05	NOV 08	33.5	32.7	0.6	33.2	0	0	18.6	200	33.8	32.4	0.5	1.02	1003	0.37	4.51
JALEEB22	12/15/2008 12:03	DEC 08	58	36.7	0.5	4.8	1	0		200	61.2	36.3	0.2	1.58	1008	0.15	2.91
JALEEB22	8/1/2009 10:24	JAN 09	27.8	20.8	3.8	47.6	60	0	19.2	200	28.3	20.5	3.8	1.34	1005	0.66	33.24
JALEEB22	11/2/2009 11:28	FEB 09	26.6	18.5	5.1	49.8	0	0	26.4	200	28.3	18.2	5.1	1.44	1003	0.31	30.52
JALEEB22	17/3/2009 4:25	MAR 09	51.4	36.1	0.3	12.2	5	50	26.6	200	51.7	36.2	0.3	1.42	1006	0.44	11.07
JALEEB22	21/4/2009 10:12	APR 09	53.5	37.2	0.3	9	11	576	29.8	200	53.8	37.5	0.3	1.44	1006	-0.17	7.87
JALEEB22	26/5/2009 7:50	MAY 09	53	36.7	0.3	10	9	202	39.2	200	53.1	36.8	0.3	1.44	992	2.79	8.87
JALEEB22	8/6/2009 10:24	JUN 09	4	1.4	18.6	76	0	0	36.2	80	3.4	1.3	18.7	2.86	995	0.5	5.69
JALEEB22	11/7/2009 11:28	JUL 09	9.8	5.9	9	75.3	1	0	41.5	196	9.8	5.6	9.1	1.66	1002	-0.12	41.28
JALEEB22	8/13/2009 10:05	AUG 09	1.8	3	16.2	79	0	9	50.9	36	1.8	3.2	16.2	0.6	1005	-0.25	17.76
JALEEB22	9/6/2009 9:25	SEP 09	0	1.8	19.3	78.9	0	0	30.9	0	0	3.2	18.9	0	998	0	5.95
JALEEB22	10/12/2009 9:01	OCT 09	0.3	3.7	18.4	77.6	0	0	33.5	6	16.8	12.5	12.8	0.08	1003	0.23	8.05
JALEEB22	15/11/2009 11:16	NOV 09	6.1	2.4	18.1	73.4	1	0	24.8	128	6.3	2.6	17.8	2.54	1008	0.15	2.91
JALEEB22	26/12/2009 7:50	DEC 09	33.5	32.7	0.6	33.2	0	0	25.6	200	33.8	32.4	0.5	1.02	1003	0.37	4.51
JALEEB22	1/18/2010 10:24	JAN 10	33.3	22	7.4	37.3	0	0	21.3	200	33.3	21.9	7.4	1.51	1013	-0.01	9.33
JALEEB22	3/2/2010 10:15	FEB 10	0.8	0.5	18.8	79.9	4	0	24.5	16	1.9	1	18.5	1.6	1007	-0.04	8.84
JALEEB22	3/18/2010 10:19	MAR 10	62.4	38.4	0.2	0	0	0	33.1	200	62.6	38.5	0.2	1.63	1002	2.26	0
JALEEB22	4/22/2010 14:05	ARP 10	39.9	32	0.6	27.5	0	1	38.8	200	39.9	32	0.6	1.25	992	0	25.23
JALEEB22	5/20/2010 10:42	MAY 10	56.4	34.4	2	7.2	0	2	47.4	200	56.2	34.4	2.1	1.64	996	0.1	0
JALEEB22	6/23/2010 10:17	JUN 10	62.4	37.7	0.6	0	0	2	50.9	200	62.2	37.6	0.6	1.66	990	0.08	0
JALEEB22	7/21/2010 11:16	JUL 10	60	36.6	0.9	2.5	0	1	54.2	200	60	36.6	0.9	1.64	983	0.07	0
JALEEB22	8/21/2010 9:47	AUG 10	54.7	34.1	2.2	9	0	0	49.6	200	54.7	34.1	2.2	1.6	989	-0.05	0.68
JALEEB22	9/20/2010 11:43	SEP 10	48.8	31.8	2.1	17.3	0	0	47.2	200	48.8	31.8	2.1	1.53	994	0.12	9.36
JALEEB22	10/20/2010 10:20	OCT 10	59	34	1.2	5.8	0	0	37	200	59.8	34.8	1.1	1.74	1000	0.39	1.26
JALEEB22	11/8/2010 11:06	NOV 10	47.9	30.9	2.9	18.3	0	0	31.1	200	48	31	2.9	1.55	1004	0.69	7.34
JALEEB22	12/21/2010 13:27	DEC 10	34.6	22.5	7.5	35.4	0	0	25.1	200	39	25.5	6.3	1.54	1010	1.08	7.05

Table App. 5.23: LFG measurements in Borehole 23

Jleeb Al Shuyoukh Landfill, LF Gas Monitoring																	BH 23
ID	DATE	MONTH	CH4	CO2	O2	BAL	NH3	H2S	TEMP	CH4 %	PEAK	PEAK	MIN	CH4/	BARO	REL.	Res
			%	%	%	%	ppm	ppm	DegC	LEL%	CH4%	CO2%	O2%	CO2%	mb	PRESS.mb	Nitro%
JALEEB23	4/2/2008 8:47	MAR 08	29.7	20	1.9	48.4	0	0	28.4	200	32.6	19	1.9	1.49	1006	0.01	41.22
JALEEB23	4/15/2008 10:38	APR 08	34.3	25.7	0.3	39.7	0	0	33.8	200	35.8	25.3	0.3	1.33	1004	0	38.57
JALEEB23	5/22/2008 8:32	MAY 08	33.2	25.8	0.6	40.4	0	0	37.7	200	34.4	25.8	0.6	1.29	997	0.43	38.13
JALEEB23	6/2/2008 11:45	JUN 08	15.5	13.2	0.6	70.7	1	0	38.8	200	15.7	13	0.6	1.17	997	-0.1	68.43
JALEEB23	7/6/2008 9:08	JUL 08	13.9	8.7	12.8	64.6	0	0	42.1	200	19.1	9.8	11.1	1.6	990	-0.41	16.22
JALEEB23	8/9/2008 10:25	AUG 08	29.8	24.5	2.6	43.1	0	0	47.7	200	30.6	24.4	2.6	1.22	988	-0.12	33.27
JALEEB23	9/12/2008 9:07	SEP 08	29.9	19.3	1.8	49	0	0	43.4	200	29.6	18	2.2	1.55	1003	-0.1	42.2
JALEEB23	10/11/2008 16:09	OCT 08	31.9	24.4	0.6	43.1	0	0	34.3	200	32.5	24	0.6	1.31	997	-0.1	40.83
JALEEB23	11/15/2008 10:38	NOV 08	38.2	28.2	0.1	33.5	0	0	16.7	200	29	28.5	0.1	1.35	1003	0	38.57
JALEEB23	12/15/2008 11:59	DEC 08	37	27	0.5	35.5	0	0		200	38.2	26.9	0.2	1.37	1008	0.15	33.61
JALEEB23	8/1/2009 10:28	JAN 09	34.3	25.7	0.3	39.7	20	0	20.9	200	35.8	25.3	0.3	1.33	1004	0	38.57
JALEEB23	11/2/2009 11:31	FEB 09	25.6	17.4	9.7	47.3	0	0	27.4	200	25.7	17.4	9.6	1.47	1003	0.13	10.63
JALEEB23	17/3/2009 4:27	MAR 09	30.1	27.2	0.1	42.6	5	14	26.2	200	53.1	33.8	0.1	1.11	1005	0.37	42.22
JALEEB23	21/4/2009 10:16	APR 09	29.3	26.8	0.2	43.7	0	15	29	200	29.7	26.8	0.2	1.09	1006	-0.06	42.94
JALEEB23	26/5/2009 7:52	MAY 09	28.3	27	0.4	44.3	0	11	37.9	200	28.6	27.2	0.2	1.05	992	0.28	42.79
JALEEB23	8/6/2009 10:28	JUN 09	32.1	24.3	0.5	43.1	1	0	36.8	200	35.2	23.7	0.5	1.32	996	0.84	41.21
JALEEB23	11/7/2009 11:31	JUL 09	13.9	8.7	12.8	64.6	0	12	42.1	200	19.1	9.8	11.1	1.6	1002	-0.41	16.22
JALEEB23	8/13/2009 10:10	AUG 09	35.7	25.3	0.4	38.6	0	0	43.7	200	36.5	24.9	0.4	1.41	1005	-0.2	37.09
JALEEB23	9/6/2009 9:23	SEP 09	31.8	22.6	0.6	45	0	0	34.6	200	33.6	21.8	0.6	1.41	999	-0.09	42.73
JALEEB23	10/12/2009 9:07	OCT 09	29.9	19.3	1.8	49	0	0	33.8	200	29.6	18	2.2	1.55	1003	-0.1	42.2
JALEEB23	15/11/2009 11:05	NOV 09	37	27	0.5	35.5	0	0	23.6	200	38.2	26.9	0.2	1.37	1008	0.15	33.61
JALEEB23	26/12/2009 7:52	DEC 09	38.2	28.2	0.1	33.5	0	0	26.4	200	29	28.5	0.1	1.35	1003	0	38.57
JALEEB23	1/18/2010 10:28	JAN 10	34.6	26.2	0.4	38.8	0	0	21.4	200	34.6	26.2	0.4	1.32	1013	-0.05	37.29
JALEEB23	3/2/2010 10:19	FEB 10	31.2	25.2	1	42.6	0	0	24.6	200	31.3	25.2	1	1.24	1007	-0.07	38.82
JALEEB23	3/18/2010 10:22	MAR 10	36.5	27.9	0.2	35.4	0	0	32.6	200	36.7	28	0.2	1.31	1002	4.9	34.64
JALEEB23	4/22/2010 14:11	ARP 10	43.8	27.3	4.8	24.1	0	2	36.7	200	43.7	27.3	4.8	1.6	992	-0.27	5.96
JALEEB23	5/20/2010 10:45	MAY 10	22.9	20.6	4.6	51.9	0	4	45.7	200	22.9	20.6	4.6	1.11	996	-0.16	34.51
JALEEB23	6/23/2010 10:20	JUN 10	24.3	26	0.4	49.3	0	0	49.6	200	24.2	26	0.4	0.93	990	-0.18	47.79
JALEEB23	7/21/2010 11:19	JUL 10	20.7	24.5	0.9	53.9	0	0	53.2	200	20.7	24.6	0.9	0.84	983	-0.05	50.5
JALEEB23	8/21/2010 9:52	AUG 10	47.4	29.2	3.2	20.2	344	0	50.4	200	41.1	23.9	1.4	1.62	989	-0.09	8.1
JALEEB23	9/21/2010 10:59	SEP 10	21.1	25.2	0.8	52.9	0	9	45.3	200	21.1	25.2	0.9	0.84	995	1.51	49.88
JALEEB23	10/20/2010 10:25	OCT 10	47.3	31	2.7	19	0	0	28.6	200	58.1	33	1.7	1.53	1001	-19.87	8.79
JALEEB23	11/8/2010 11:08	NOV 10	22.8	24.4	1.7	51.1	0	5	30.1	200	22.8	24.5	1.7	0.93	1004	0.19	44.67
JALEEB23	12/21/2010 13:29	DEC 10	19	18.3	6.2	56.5	0	0	24.1	200	19	18.3	6.2	1.04	1010	0.23	33.06

Table App. 5.24: LFG measurements in Borehole 24

Jleeb Al Shuyoukh Landfill, LF Gas Monitoring																	BH 24
ID	DATE	MONTH	CH4	CO2	O2	BAL	NH3	H2S	TEMP	CH4 %	PEAK	PEAK	MIN	CH4/	BARO	REL.	Res
			%	%	%	%	ppm	ppm	DegC	LEL%	CH4%	CO2%	O2%	CO2%	mb	PRESS.mb	Nitro%
JALEEB24	4/2/2008 8:55	MAR 08	40.8	25.3	4.5	29.4	0	0	28.1	200	41.6	24.7	4.5	1.61	1006	-0.01	12.39
JALEEB24	4/15/2008 10:44	APR 08	52.2	32.7	0.3	14.8	0	0	33.1	200	57.6	32.5	0.3	1.6	1004	0.07	13.67
JALEEB24	5/22/2008 9:04	MAY 08	52.9	33.9	0.4	12.8	0	0	36.7	200	54.4	33.9	0.4	1.56	996	-5.07	11.29
JALEEB24	5/29/2008 8:50	JUN 08	52.2	32.4	0.3	15.1	1	0	36.6	200	55.6	32.3	0.3	1.61	995	0.48	13.97
JALEEB24	7/6/2008 9:10	JUL 08	49.1	30.3	1.1	19.5	0	0	45.3	200	49.9	30.2	1.1	1.62	990	-0.42	15.34
JALEEB24	8/9/2008 10:28	AUG 08	48.9	31.3	2.4	17.4	0	0	43.9	200	60.8	32.9	0.6	1.56	988	-0.11	8.33
JALEEB24	9/12/2008 9:15	SEP 08	46.2	29.4	2.2	22.2	0	0	41.4	200	49.2	29	2.3	1.57	1003	0.03	13.88
JALEEB24	10/11/2008 16:09	OCT 08	54	32.7	0.4	12.9	0	0	34.1	200	63.1	32.4	0.4	1.65	997	0.11	11.39
JALEEB24	11/15/2008 10:44	NOV 08	53.9	35.6	0	10.5	0	0	16.5	200	54	35.5	0	1.51	1004	0.07	13.67
JALEEB24	12/15/2008 11:55	DEC 08	53.4	33.8	0.6	12.2	1	0		200	58.1	33.5	0.2	1.58	1008	0.18	9.93
JALEEB24	8/1/2009 10:32	JAN 09	52.2	32.7	0.3	14.8	150	0	30.5	200	57.6	32.5	0.3	1.6	1004	0.07	13.67
JALEEB24	11/2/2009 11:34	FEB 09	45.3	30.9	0.3	23.5	0	10	30.1	200	46.7	30.3	0.3	1.47	1006	0.07	12.39
JALEEB24	17/3/2009 4:30	MAR 09	50.8	35.2	0.1	13.9	0	55	26.3	200	50.9	35.3	0.1	1.44	1005	0	13.52
JALEEB24	21/4/2009 10:21	APR 09	46.6	34.6	0.2	18.6	0	76	29.4	200	48.6	35.1	0.2	1.35	1006	-0.2	17.84
JALEEB24	26/5/2009 7:55	MAY 09	47.1	34.5	0.2	18.2	0	85	37.6	200	48.4	35	0.2	1.37	992	2.36	17.44
JALEEB24	8/6/2009 10:32	JUN 09	52.2	32.4	0.3	15.1	1	0	36.6	200	55.6	32.3	0.3	1.61	995	0.48	13.97
JALEEB24	11/7/2009 11:34	JUL 09	49.1	30.3	1.1	19.5	0	0	45.3	200	49.9	30.2	1.1	1.62	1003	-0.42	15.34
JALEEB24	8/13/2009 10:14	AUG 09	52.3	32.6	0.4	14.7	0	0	41.3	200	59	32.4	0.4	1.6	1004	1.05	13.19
JALEEB24	9/6/2009 9:29	SEP 09	57.7	32.3	1	9	2	0	33.8	200	61	31.9	1.1	1.79	1000	0.19	5.22
JALEEB24	10/12/2009 9:15	OCT 09	46.2	29.4	2.2	22.2	0	0	33.8	200	49.2	29	2.3	1.57	1003	0.03	13.88
JALEEB24	15/11/2009 10:38	NOV 09	53.4	33.8	0.6	12.2	1	0	24.6	200	58.1	33.5	0.2	1.58	1008	0.18	9.93
JALEEB24	26/12/2009 7:55	DEC 09	53.9	35.6	0	10.5	0	0	26	200	54	35.5	0	1.51	1004	0.07	13.67
JALEEB24	1/18/2010 10:32	JAN 10	44.8	29.9	2.7	22.6	0	0	20.8	200	44.7	29.9	2.7	1.5	1012	0.07	12.39
JALEEB24	3/2/2010 10:24	FEB 10	52.7	33.9	0.6	12.8	0	0	25.1	200	52.9	34	0.6	1.55	1006	-0.02	10.53
JALEEB24	3/18/2010 10:25	MAR 10	44.8	29.9	2.7	22.6	0	0	30.8	200	44.7	29.9	2.7	1.5	1002	0.07	12.39
JALEEB24	4/22/2010 14:14	ARP 10	28.5	22.7	3.7	45.1	0	7	37	200	28.4	22.7	3.6	1.26	992	0.02	31.11
JALEEB24	5/20/2010 10:48	MAY 10	45.3	29.4	3	22.3	0	0	42.7	200	45.4	29.3	3.3	1.54	995	-0.11	10.96
JALEEB24	6/23/2010 10:23	JUN 10	52.3	34.1	0.5	13.1	0	0	49	200	52.4	34.1	0.5	1.53	990	-0.06	11.21
JALEEB24	7/21/2010 11:22	JUL 10	51.3	33.9	0.8	14	0	0	52.5	200	51.3	33.9	0.8	1.51	983	0	10.98
JALEEB24	8/21/2010 9:52	AUG 10	48.8	32.5	1.3	17.4	0	0	49.7	200	49	32.7	1.3	1.5	988	-6.01	12.49
JALEEB24	9/21/2010 11:01	SEP 10	50.4	34.2	0.9	14.5	0	0	46.3	200	50.5	34.2	0.9	1.47	995	0.28	11.1
JALEEB24	10/20/2010 10:27	OCT 10	20.3	23.5	1.8	54.4	0	0	37.9	200	20.4	23.5	1.8	0.86	1001	0.08	47.6
JALEEB24	11/8/2010 11:11	NOV 10	46.9	31.8	2.2	19.1	0	0	28.1	200	46.9	31.8	2.2	1.47	1004	0.45	10.78
JALEEB24	12/21/2010 13:32	DEC 10	40.1	27.1	4.8	28	0	0	24.1	200	40.3	27.1	4.9	1.48	1010	0.36	9.86

Table App. 5.25: LFG measurements in Borehole 25

Jleeb Al Shuyoukh Landfill, LF Gas Monitoring																	BH 25
ID	DATE	MONTH	CH4	CO2	O2	BAL	NH3	H2S	TEMP	CH4 %	PEAK	PEAK	MIN	CH4/	BARO	REL.	Res
			%	%	%	%	ppm	ppm	DegC	LEL%	CH4%	CO2%	O2%	CO2%	mb	PRESS.mb	Nitro%
JALEEB25	4/2/2008 10:39	MAR 08	0	2.4	7.7	89.9	0	28	27.8	0	1.3	8.9	7.7	0	1006	-0.17	60.79
JALEEB25	4/15/2008 11:09	APR 08	0	1.7	5.1	93.2	24	0	33.8	0	0	2.9	5.1	0	1003	-0.14	73.92
JALEEB25	5/22/2008 10:32	MAY 08	0	1.6	2.4	96	1	0	37.6	0	0	1.6	2.4	0	996	2.06	86.93
JALEEB25	6/2/2008 11:50	JUN 08	0	1.5	17.9	80.6	0	37	39.5	0	1	3.2	16.9	0	990	-25.86	12.94
JALEEB25	7/7/2008 9:12	JUL 08	0	0.4	18.2	81.4	0	13	40.7	0	0	0.8	18	0	991	-0.42	12.6
JALEEB25	8/9/2008 10:30	AUG 08	0	2.7	2.9	94.4	0	173	45.8	0	2.9	4	2.7	0	989	0.13	83.44
JALEEB25	9/12/2008 8:33	SEP 08	0	1.5	14.5	84	1	0	40.5	0	0	1.8	14.5	0	1002	-10.52	29.19
JALEEB25	10/12/2008 10:00	OCT 08	0	3.5	9.1	87.4	0	10	33.8	0	1.5	9.6	9.2	0	997	0	53
JALEEB25	11/15/2008 11:09	NOV 08	0	1.7	5.1	93.2	24	0	23.8	0	0	2.9	5.1	0	1003	-0.14	73.92
JALEEB25	12/15/2008 12:07	DEC 08	0	2.7	2.9	94.4	0	173		0	0	4	2.7	0	1007	0.13	83.44
JALEEB25	8/1/2009 10:36	JAN 09	0	1.7	5.1	93.2	0	24	20.1	0	0	2.9	5.1	0	1003	-0.14	73.92
JALEEB25	11/2/2009 11:37	FEB 09	0	1.6	18.2	80.2	2	0	29.8	0	0	1.6	18.2	0	1005	-0.02	51.16
JALEEB25	17/3/2009 4:32	MAR 09	0	2.6	2.6	94.8	0	13	26	0	47.8	33.8	0.2	0	1005	1.01	84.97
JALEEB25	21/4/2009 10:25	APR 09	0	2.3	6.1	91.6	0	7	29.3	0	0	2.3	6.2	0	1006	-0.21	68.54
JALEEB25	26/5/2009 7:58	MAY 09	0	2.1	8	89.9	0	6	37	0	0	2.1	7.9	0	992	2.66	59.66
JALEEB25	8/6/2009 10:36	JUN 09	0	1.9	2	96.1	0	13	39.5	0	0	2.1	2.1	0	994	1.09	88.54
JALEEB25	11/7/2009 11:37	JUL 09	0	0.4	18.2	81.4	0	13	40.7	0	0	0.8	18	0	1003	-0.42	12.6
JALEEB25	8/13/2009 9:59	AUG 09	0	2.1	9.2	88.7	0	13	43.8	0	0	3.4	8.9	0	1005	0.44	53.92
JALEEB25	9/6/2009 9:31	SEP 09	0	3.9	7.9	88.2	0	2	33.8	0	1.8	11.4	7.8	0	1001	0.15	58.34
JALEEB25	10/12/2009 8:33	OCT 09	0	1.5	14.5	84	1	0	30.9	0	0	1.8	14.5	0	1002	-10.52	29.19
JALEEB25	15/11/2009 11:09	NOV 09	0	2.7	2.9	94.4	0	173	24.2	0	0	4	2.7	0	1007	0.13	83.44
JALEEB25	26/12/2009 7:58	DEC 09	0	1.7	5.1	93.2	24	0	29.2	0	0	2.9	5.1	0	1003	-0.14	73.92
JALEEB25	1/18/2010 10:36	JAN 10	0	2	9.8	88.2	67	0	20.2	0	0.3	2	9.7	0	1012	-0.02	51.16
JALEEB25	3/2/2010 10:28	FEB 10	0	2.1	8.9	89	91	0	23.1	0	1.1	2.1	8.9	0	1006	-0.05	55.36
JALEEB25	3/18/2010 10:29	MAR 10	0	2.5	6.3	91.2	230	0	32.9	0	0.7	2.4	6.5	0	1001	0.37	67.39
JALEEB25	4/22/2010 14:21	ARP 10	0	1.6	5.5	92.9	185	0	38.2	0	0.6	1.6	5.5	0	991	-0.14	72.11
JALEEB25	5/20/2010 10:52	MAY 10	0.1	2.3	8.1	89.5	220	0	45.2	2	0.6	2.3	8.1	0.04	995	-0.18	58.88
JALEEB25	6/23/2010 10:26	JUN 10	0	2.1	8.8	89.1	277	0	49.9	0	0.6	2.1	7.4	0	990	-0.26	55.84
JALEEB25	7/21/2010 11:24	JUL 10	0	1.9	9.1	89	321	0	51.8	0	0.5	1.9	9.2	0	983	-0.15	54.6
JALEEB25	8/21/2010 9:55	AUG 10	0	1.2	12.3	86.5	338	0	47.8	0	0.5	1.1	12.5	0	989	-0.1	40.01
JALEEB25	9/21/2010 11:04	SEP 10	0	2	10.3	87.7	256	0	48.4	0	0.6	2	10.4	0	995	-0.03	48.77
JALEEB25	10/20/2010 10:30	OCT 10	1.8	1.2	16.6	80.4	0	0	38.9	36	40.4	27.4	4.2	1.5	1000	0.13	17.65
JALEEB25	11/8/2010 11:14	NOV 10	0	2.6	6.7	90.7	116	0	25.1	0	1.4	2.6	6.8	0	1003	0.09	65.37
JALEEB25	12/21/2010 13:34	DEC 10	0.9	0.7	17.6	80.8	0	0	24.4	18	1.2	0.9	17.1	1.29	1010	0.26	14.27

Table App. 5.26: LFG measurements in Borehole 26

Jleeb Al Shuyoukh Landfill, LF Gas Monitoring																	BH 26
ID	DATE	MONTH	CH4	CO2	O2	BAL	NH3	H2S	TEMP	CH4 %	PEAK	PEAK	MIN	CH4/	BARO	REL.	Res
			%	%	%	%	ppm	ppm	DegC	LEL%	CH4%	CO2%	O2%	CO2%	mb	PRESS.mb	Nitro%
JALEEB26	4/2/2008 10:50	MAR 08	2.1	9.2	7.5	81.2	0	0	29.5	42	2.1	8.6	7.6	0.23	1006	-0.07	52.85
JALEEB26	4/15/2008 11:21	APR 08	6.1	17.2	1.8	74.9	0	0	35.6	122	6.1	17	1.9	0.35	1003	-0.35	68.1
JALEEB26	5/22/2008 8:11	MAY 08	2.8	15	5.7	76.5	0	0	35.9	56	2.8	14.9	5.7	0.19	997	-0.08	54.95
JALEEB26	5/29/2008 10:19	JUN 08	5.5	20.2	0.6	73.7	0	0	41	110	5.8	20.1	0.6	0.27	995	-0.28	71.43
JALEEB26	7/7/2008 9:14	JUL 08	4.4	13.8	2.9	78.9	0	0	44.4	88	4.3	13.5	3.2	0.32	991	0.56	67.94
JALEEB26	8/10/2008 9:13	AUG 08	4.2	14.8	2.9	78.1	0	0	44.4	78	4.3	15	2.7	0.28	991	0.56	67.94
JALEEB26	9/11/2008 10:16	SEP 08	4.4	13.8	2.9	78.9	0	0	42	88	4.3	13.5	3.2	0.32	1003	0.56	67.94
JALEEB26	10/12/2008 10:01	OCT 08	3.9	2.8	17.7	75.6	0	1	34.2	78	3.9	3.6	17.7	1.39	998	-0.28	8.69
JALEEB26	11/15/2008 11:21	NOV 08	0	2.4	19.6	78	129	0	18.6	0	6.1	17	1.9	0	1002	-0.35	68.1
JALEEB26	12/15/2008 16:30	DEC 08	7.1	22.5	0.6	69.8	0	0		142	7.2	22.2	0.4	0.32	1007	1.17	67.53
JALEEB26	8/1/2009 10:40	JAN 09	6.1	17.2	1.8	74.9	0	0	18.6	122	6.1	17	1.9	0.35	1003	-0.35	68.1
JALEEB26	11/2/2009 11:41	FEB 09	5.3	20.3	0.3	74.1	0	8	30.1	106	5.5	20.3	0.3	0.26	1005	-0.05	72.97
JALEEB26	17/3/2009 4:36	MAR 09	2.8	21.6	0.2	75.4	0	5	26.5	56	3.4	21.9	0.3	0.13	1005	0.93	74.64
JALEEB26	26/4/2009 8:25	APR 09	0.3	9.8	10.3	79.6	2	2	32.4	6	0.3	9.7	10.4	0.03	1001	0.19	40.67
JALEEB26	26/5/2009 8:01	MAY 09	0	6.9	12.5	80.6	0	2	38.3	0	0	6.8	12.7	0	992	1.27	33.35
JALEEB26	8/6/2009 10:40	JUN 09	2.8	15	5.7	76.5	0	0	35.9	56	2.8	14.9	5.7	0.19	997	-0.08	54.95
JALEEB26	11/7/2009 11:41	JUL 09	4.4	13.8	2.9	78.9	0	0	44.4	88	4.3	13.5	3.2	0.32	1004	0.56	67.94
JALEEB26	8/13/2009 9:49	AUG 09	0	2.5	15.5	82	0	6	46.5	0	0	2.5	15.5	0	1005	-0.19	23.41
JALEEB26	9/6/2009 9:11	SEP 09	2.3	12.7	1.7	83.3	0	0	35.1	46	2.4	12.4	1.7	0.18	1000	0.05	76.87
JALEEB26	10/11/2009 10:16	OCT 09	4.4	13.8	2.9	78.9	0	0	34.4	88	4.3	13.5	3.2	0.32	1003	0.56	67.94
JALEEB26	15/11/2009 11:21	NOV 09	7.1	22.5	0.6	69.8	0	0	26.2	142	7.2	22.2	0.4	0.32	1007	1.17	67.53
JALEEB26	26/12/2009 8:01	DEC 09	4.2	8.3	14.4	73.1	1	1	23.7	84	40	33.5	1.1	0.51	1006	0.02	18.67
JALEEB26	1/18/2010 10:40	JAN 10	5.2	18.4	5.1	71.3	0	0	22.6	104	5.2	18.1	5.6	0.28	1012	-0.08	52.02
JALEEB26	3/2/2010 10:32	FEB 10	5.1	20.6	0.9	73.4	0	0	25	102	5.1	20.6	0.9	0.25	1006	0.96	70
JALEEB26	3/18/2010 10:36	MAR 10	5.1	20.6	0.9	73.4	0	0	33.9	102	5.1	20.6	0.9	0.25	1001	-0.05	70
JALEEB26	4/22/2010 14:28	ARP 10	51.6	33.3	1	14.1	0	0	38.5	200	51.6	33.3	1.1	1.55	991	0.15	10.32
JALEEB26	5/20/2010 10:55	MAY 10	1.1	13	6.5	79.4	0	0	46.5	22	1	12.9	6.6	0.08	995	-0.17	54.83
JALEEB26	6/23/2010 10:29	JUN 10	3	20.9	1	75.1	0	0	48.8	60	3	20.9	1	0.14	989	-0.19	71.32
JALEEB26	7/21/2010 11:27	JUL 10	0.2	10.2	9.4	80.2	0	0	52.7	4	0.2	10.1	9.4	0.02	983	-0.2	44.67
JALEEB26	8/21/2010 10:00	AUG 10	21.4	24.7	3.7	50.2	0	0	50.2	200	21.2	24.4	4	0.87	988	-0.11	36.21
JALEEB26	9/21/2010 11:07	SEP 10	1.6	15.9	5.2	77.3	0	0	46.2	32	1.6	15.8	5.3	0.1	995	-0.13	57.64
JALEEB26	10/20/2010 10:35	OCT 10	1	14.8	5.9	78.3	39	0	35.8	20	1	14.8	5.9	0.07	1000	0	56
JALEEB26	11/8/2010 11:17	NOV 10	3.6	20.7	1.7	74	0	0	28.1	72	3.6	20.7	1.8	0.17	1003	0.04	67.57
JALEEB26	12/21/2010 13:37	DEC 10	2.7	18	3.5	75.8	0	0	24.7	54	2.7	18.1	3.5	0.15	1009	0.13	62.57

Table App. 5.27: LFG measurements in Borehole 27

Jleeb Al Shuyoukh Landfill, LF Gas Monitoring																	BH 27
ID	DATE	MONTH	CH4	CO2	O2	BAL	NH3	H2S	TEMP	CH4 %	PEAK	PEAK	MIN	CH4/	BARO	REL.	Res
			%	%	%	%	ppm	ppm	DegC	LEL%	CH4%	CO2%	O2%	CO2%	mb	PRESS.mb	Nitro%
JALEEB27	4/2/2008 10:56	MAR 08	8.1	8.4	8.7	74.8	0	0	30.6	162	8	8.3	8.8	0.96	1006	0	41.91
JALEEB27	4/15/2008 11:26	APR 08	18.4	20.5	1.8	59.3	0	0	36.5	200	20	20.4	1.1	0.9	1004	-0.37	52.5
JALEEB27	5/22/2008 8:05	MAY 08	27.7	28.1	0.7	43.5	0	1	35.6	200	30.8	27.9	0.7	0.99	996	-0.05	40.85
JALEEB27	5/29/2008 10:15	JUN 08	27.6	27.4	0.4	44.6	0	0	40.7	200	31.7	27.2	0.4	1.01	994	-0.21	43.09
JALEEB27	7/7/2008 9:15	JUL 08	25.2	23.4	0.9	50.5	0	0	42.7	200	26.2	23.1	0.9	1.08	990	-0.36	47.1
JALEEB27	8/10/2008 9:15	AUG 08	30.8	29	0.6	39.6	0	0	46.6	200	31.6	28.6	0.2	1.06	991	0.14	37.33
JALEEB27	9/11/2008 10:12	SEP 08	14.1	16.7	3.4	65.8	0	0	43.5	200	14.1	16.6	3.4	0.84	1002	1.22	52.95
JALEEB27	10/12/2008 10:04	OCT 08	32.8	23.4	3	40.8	0	0	34.4	200	33.1	23.2	3.1	1.4	999	0.06	29.46
JALEEB27	11/15/2008 11:26	NOV 08	0	1.2	19.9	78.9	145	0	17.6	0	20	20.4	1.1	0	1004	-0.37	52.5
JALEEB27	12/15/2008 16:27	DEC 08	30.8	29	0.6	39.6	0	0		200	31.6	28.6	0.2	1.06	1007	0.14	37.33
JALEEB27	8/1/2009 10:43	JAN 09	18.4	20.5	1.8	59.3	0	0	18.9	200	20	20.4	1.1	0.9	1004	-0.37	52.5
JALEEB27	11/2/2009 11:44	FEB 09	14.5	21.5	1.4	62.6	6	18	29.7	200	14.6	21.5	1.4	0.67	1005	-0.26	57.31
JALEEB27	17/3/2009 4:39	MAR 09	18.7	24.2	3.7	53.4	0	11	26.8	200	19.9	26.2	0.2	0.77	1006	-0.26	39.41
JALEEB27	26/4/2009 8:27	APR 09	12.5	21.2	5	61.3	2	0	32	200	14.5	23.4	3.8	0.59	1002	0.16	42.4
JALEEB27	26/5/2009 8:04	MAY 09	0	1.2	18.4	80.4	0	0	38.5	0	0	1.4	18.3	0	992	-0.39	10.85
JALEEB27	8/6/2009 10:43	JUN 09	27.7	28.1	0.7	43.5	1	0	35.6	200	30.8	27.9	0.7	0.99	996	-0.05	40.85
JALEEB27	11/7/2009 11:44	JUL 09	25.2	23.4	0.9	50.5	0	0	42.7	200	26.2	23.1	0.9	1.08	1004	-0.36	47.1
JALEEB27	8/13/2009 9:53	AUG 09	7.8	7.7	9.3	75.2	0	0	47	156	7.8	7.6	9.4	1.01	1005	-0.06	40.05
JALEEB27	9/6/2009 9:16	SEP 09	23.3	23.5	0.4	52.8	0	0	33.2	200	24.1	23.3	0.4	0.99	1001	-0.04	51.29
JALEEB27	10/11/2009 10:12	OCT 09	14.1	16.7	3.4	65.8	0	0	34.6	200	14.1	16.6	3.4	0.84	1002	1.22	52.95
JALEEB27	15/11/2009 11:26	NOV 09	30.8	29	0.6	39.6	0	0	25.3	200	31.6	28.6	0.2	1.06	1007	0.14	37.33
JALEEB27	26/12/2009 8:04	DEC 09	27.3	22.3	1.7	48.7	145	0	29.2	200	27.5	22.1	1.8	1.22	1003	1.71	32.09
JALEEB27	1/18/2010 10:43	JAN 10	5.8	9	11.6	73.6	0	0	20.6	116	5.8	9	11.6	0.64	1013	0.03	29.75
JALEEB27	3/2/2010 10:36	FEB 10	2.8	3.9	15.5	77.8	0	0	25.4	56	2.8	3.9	15.5	0.72	1007	3.15	19.21
JALEEB27	3/18/2010 10:39	MAR 10	16.5	21.8	2.7	59	0	0	33.8	200	16.5	21.8	2.7	0.76	1002	0	48.79
JALEEB27	4/22/2010 14:32	ARP 10	27.7	28.7	1.5	42.1	0	1	38.7	200	27.7	28.7	1.5	0.97	991	0.24	36.43
JALEEB27	5/20/2010 10:59	MAY 10	20.6	25.9	0.9	52.6	0	0	46.5	200	20.7	26.1	0.9	0.8	996	-0.06	49.2
JALEEB27	6/23/2010 10:32	JUN 10	27.1	30.3	1.2	41.4	0	0	50.5	200	27	30.2	1.3	0.89	990	-0.13	36.86
JALEEB27	7/21/2010 11:30	JUL 10	26.1	28.9	1.4	43.6	0	0	53.1	200	26	28.8	1.4	0.9	983	-0.04	38.31
JALEEB27	8/21/2010 10:01	AUG 10	24.5	27.8	2	45.7	0	0	48.6	200	24.6	27.9	1.8	0.88	989	-22.43	38.14
JALEEB27	9/21/2010 11:09	SEP 10	18.4	22.2	4.1	55.3	0	0	46.3	200	18.4	22.1	4.1	0.83	996	0.14	39.8
JALEEB27	10/20/2010 10:37	OCT 10	21.5	24.4	2.4	51.7	0	0	37.6	200	21.5	24.3	2.4	0.88	1001	0.23	42.63
JALEEB27	11/8/2010 11:19	NOV 10	19.9	22.5	2.8	54.8	0	0	29.7	200	19.8	22.5	2.8	0.88	1004	0.08	44.22
JALEEB27	12/21/2010 13:39	DEC 10	21.4	21.8	4.1	52.7	0	0	24.5	200	21.4	21.6	4.6	0.98	1010	0.37	37.2

Table App. 5.28: LFG measurements in Borehole 28

Jleeb Al Shuyoukh Landfill, LF Gas Monitoring																	BH 28
ID	DATE	MONTH	CH4	CO2	O2	BAL	NH3	H2S	TEMP	CH4 %	PEAK	PEAK	MIN	CH4/	BARO	REL.	Res
			%	%	%	%	ppm	ppm	DegC	LEL%	CH4%	CO2%	O2%	CO2%	mb	PRESS.mb	Nitro%
JALEEB28	4/3/2008 11:34	MAR 08	51.3	33.6	0.4	14.7	0	0	28.9	200	59.9	33.1	0.5	1.53	1008	2.36	13.19
JALEEB28	4/15/2008 10:52	APR 08	50.4	35.1	0.4	14.1	0	0	33.8	200	56.3	34.8	0.4	1.44	1003	0.05	12.59
JALEEB28	5/22/2008 9:16	MAY 08	50.7	35.6	0.4	13.3	0	0	37	200	55.2	35.5	0.4	1.42	997	0.43	11.79
JALEEB28	5/29/2008 9:00	JUN 08	43	32.6	0.7	23.7	0	0	36.4	200	43.9	32	0.7	1.32	996	-0.07	21.05
JALEEB28	7/7/2008 9:17	JUL 08	46.2	31.3	1.4	21.1	0	0	40.8	200	48.5	31.3	1.4	1.48	990	1.27	15.81
JALEEB28	8/10/2008 9:17	AUG 08	54.5	36.1	0.9	8.5	2	0	46.6	200	62.3	35.8	0.3	1.51	991	0.05	5.1
JALEEB28	9/12/2008 9:25	SEP 08	43.5	32.4	0.9	23.2	0	0	42.5	200	45.1	32.3	0.9	1.34	1003	0.07	19.8
JALEEB28	15/10/2008 10:52	OCT 08	49.2	30.9	0.5	19.4	0	0	37.6	200	55.6	30.8	0.5	1.59	997	0.26	17.51
JALEEB28	11/15/2008 10:52	NOV 08	54.6	37.6	0.3	7.5	0	0	16.2	200	56.3	34.8	0.4	1.45	1003	0.05	12.59
JALEEB28	12/14/2008 12:16	DEC 08	54.5	36.1	0.9	8.5	2	0		200	62.3	35.8	0.3	1.51	1009	0.05	5.1
JALEEB28	8/1/2009 10:50	JAN 09	50.4	35.1	0.4	14.1	0	0	20.3	200	56.3	34.8	0.4	1.44	1003	0.05	12.59
JALEEB28	11/2/2009 11:49	FEB 09	46.5	33.2	0.2	20.1	2	4	31.1	200	46.5	33.5	0.2	1.4	1005	0.19	19.34
JALEEB28	17/3/2009 4:43	MAR 09	46.6	37.3	0.1	16	7	12	26.1	200	47.6	37.5	0.1	1.25	1006	3.64	15.62
JALEEB28	26/4/2009 8:31	APR 09	47.7	37.1	0.2	15	14	17	27.5	200	47.7	37.2	0.1	1.29	1006	2.28	14.24
JALEEB28	26/5/2009 8:08	MAY 09	45	36.7	0.4	17.9	3	6	37.2	200	45	36.9	0.4	1.23	992	1.47	16.39
JALEEB28	8/6/2009 10:50	JUN 09	50.7	35.6	0.4	13.3	0	0	37	200	55.2	35.5	0.4	1.42	997	0.43	11.79
JALEEB28	11/7/2009 11:49	JUL 09	46.2	31.3	1.4	21.1	0	0	40.8	200	48.5	31.3	1.4	1.48	1004	1.27	15.81
JALEEB28	8/13/2009 10:21	AUG 09	49.7	34.2	0.4	15.7	0	0	39.5	200	53.3	33.9	0.4	1.45	1004	1.89	14.19
JALEEB28	9/6/2009 9:16	SEP 09	50	35.2	0.4	14.4	0	0	34.5	200	51.6	35.1	0.4	1.42	1001	0.07	12.89
JALEEB28	10/12/2009 9:25	OCT 09	43.5	32.4	0.9	23.2	0	0	33.2	200	45.1	32.3	0.9	1.34	1003	0.07	19.8
JALEEB28	15/11/2009 10:52	NOV 09	54.5	36.1	0.9	8.5	2	0	25.6	200	62.3	35.8	0.3	1.51	1009	0.05	5.1
JALEEB28	26/12/2009 8:08	DEC 09	54.6	37.6	0.3	7.5	0	0	29.3	200	56.3	34.8	0.4	1.45	1003	0.05	12.59
JALEEB28	1/18/2010 10:50	JAN 10	50.4	35.7	0.6	13.3	0	0	21.5	200	50.4	35.7	0.6	1.41	1012	-0.02	11.03
JALEEB28	3/2/2010 10:44	FEB 10	41.4	32.2	1	25.4	0	0	24.1	200	41.5	32.3	1	1.29	1006	-0.07	21.62
JALEEB28	3/18/2010 10:45	MAR 10	53.8	37.6	0.3	8.3	0	11	33.4	200	53.9	37.6	0.3	1.43	1001	0.62	7.17
JALEEB28	4/22/2010 14:37	ARP 10	51.2	35.7	1.6	11.5	0	9		200	51.1	35.6	1.7	1.43	991	0.12	5.45
JALEEB28	5/22/2010 10:21	MAY 10	49.5	36	0.5	14	0	0	40.3	200	49.5	36	0.5	1.38	997	0.05	12.11
JALEEB28	6/23/2010 10:37	JUN 10	53.2	37.4	0.5	8.9	0	16	49.8	200	53	37.4	0.5	1.42	990	-0.19	7.01
JALEEB28	7/21/2010 11:35	JUL 10	51.6	37	0.8	10.6	0	15	52.6	200	51.7	37	0.9	1.39	983	-0.04	7.58
JALEEB28	8/23/2010 10:14	AUG 10	49.7	36.7	0.8	12.8	0	1	49.1	200	49.8	36.8	0.8	1.35	981	-0.15	9.78
JALEEB28	9/21/2010 11:13	SEP 10	50.5	36.5	1.1	11.9	0	5	47.1	200	50.4	36.3	1.2	1.38	996	0.22	7.74
JALEEB28	10/20/2010 10:41	OCT 10	47.3	34	2.4	16.3	0	2	39.1	200	47.7	34.2	2.3	1.39	1001	0.18	7.23
JALEEB28	11/8/2010 11:23	NOV 10	40.7	29.2	4.7	25.4	0	5	28	200	40.8	29.2	4.8	1.39	1004	0.04	7.63
JALEEB28	12/21/2010 13:42	DEC 10	45.3	32.2	3.5	19	0	14	24	200	45.2	32.1	3.7	1.41	1010	0.76	5.77

Table App. 5.29: LFG measurements in Borehole 29

Jleeb Al Shuyoukh Landfill, LF Gas Monitoring																	BH 29
ID	DATE	MONTH	CH4	CO2	O2	BAL	NH3	H2S	TEMP	CH4 %	PEAK	PEAK	MIN	CH4/	BARO	REL.	Res
			%	%	%	%	ppm	ppm	DegC	LEL%	CH4%	CO2%	O2%	CO2%	mb	PRESS.mb	Nitro%
JALEEB29	4/3/2008 11:39	MAR 08	0	1.8	19	79.2	0	39	28.1	0	0	5.2	18.1	0	1008	0.05	7.38
JALEEB29	4/15/2008 10:59	APR 08	0	2.5	17.8	79.7	64	0	32.6	0	1.6	10.6	13.6	0	1003	-0.19	12.42
JALEEB29	5/22/2008 9:20	MAY 08	0	2.8	18.2	79	32	0	37.2	0	1.7	10.8	13.7	0	996	0.35	10.2
JALEEB29	5/29/2008 9:06	JUN 08	0	2.6	18.8	78.6	0	25	35	0	1.5	11.4	14.1	0	996	0.04	7.54
JALEEB29	7/7/2008 9:19	JUL 08	0.3	1.6	18.4	79.7	0	13	38.4	6	0.3	2.4	18.4	0.19	990	0.01	10.15
JALEEB29	8/10/2008 9:18	AUG 08	0	0.7	19.3	80	2	269	49.4	0	0	0.7	19.3	0	991	0	7.05
JALEEB29	9/12/2008 9:32	SEP 08	0	4.6	18.4	77	0	0	41.7	0	28.7	20.7	7.3	0	1002	2.05	7.45
JALEEB29	15/10/2008 10:59	OCT 08	0	0.2	19.8	80	0	3	31	0	0	0.2	19.7	0	1002	0.02	5.16
JALEEB29	11/15/2008 10:59	NOV 08	0	1	19.8	79.2	129	0	20.1	0	1.6	10.6	13.6	0	1003	-0.19	12.42
JALEEB29	12/14/2008 12:13	DEC 08	0	0.7	19.3	80	2	269	12.3	0	0	0.7	19.3	0	1009	0	7.05
JALEEB29	8/1/2009 10:54	JAN 09	0	2.5	17.8	79.7	0	0	16.5	0	1.6	10.6	13.6	0	1003	-0.19	12.42
JALEEB29	11/2/2009 11:53	FEB 09	0	1.3	18.5	80.2	8	0	27.7	0	0	1.5	18.3	0	1007	-0.1	10.27
JALEEB29	17/3/2009 4:46	MAR 09	0	0.1	19.7	80.2	0	3	25.8	0	15.8	13.7	5.4	0	1006	0.07	5.73
JALEEB29	26/4/2009 8:35	APR 09	0	0	19.7	80.3	2	1	32.5	0	0	0.1	19.5	0	1001	1.13	5.83
JALEEB29	26/5/2009 8:11	MAY 09	0	0	19.6	80.4	1	2	37	0	0	0.2	18.7	0	992	-0.17	6.31
JALEEB29	8/6/2009 10:54	JUN 09	0	2.8	18.2	79	0	32	37.2	0	1.7	10.8	13.7	0	996	0.35	10.2
JALEEB29	11/7/2009 11:53	JUL 09	0.3	1.6	18.4	79.7	0	13	38.4	6	0.3	2.4	18.4	0.19	1003	0.01	10.15
JALEEB29	8/13/2009 10:26	AUG 09	0	1.8	18.5	79.7	0	51	35.9	0	48.7	35.3	0.3	0	1004	-0.35	9.77
JALEEB29	9/5/2009 9:59	SEP 09	0	2.7	18.4	78.9	0	40	34.7	0	2.1	14.8	13.4	0	1000	-0.14	9.35
JALEEB29	10/12/2009 9:32	OCT 09	0	4.6	18.4	77	0	0	32.5	0	28.7	20.7	7.3	0	1002	2.05	7.45
JALEEB29	15/11/2009 10:59	NOV 09	0	0.7	19.3	80	2	269	24.8	0	0	0.7	19.3	0	1009	0	7.05
JALEEB29	26/12/2009 8:11	DEC 09	0	1	19.8	79.2	129	0	29.3	0	1.6	10.6	13.6	0	1003	-0.19	12.42
JALEEB29	1/18/2010 10:54	JAN 10	0	0.3	18.8	80.9	148	0	21	0	0.3	0.5	18.2	0	1012	-0.11	9.84
JALEEB29	3/2/2010 10:48	FEB 10	0	0.4	18.4	81.2	192	0	24.6	0	0.8	0.8	17.4	0	1006	-0.08	11.65
JALEEB29	3/18/2010 10:49	MAR 10	0	0.5	18.5	81	330	0	32.8	0	0.6	0.5	18	0	1001	0.45	11.07
JALEEB29	4/22/2010 14:40	ARP 10	0	0.9	18.1	81	260	0	37.9	0	0.4	1	18	0	991	-0.19	12.58
JALEEB29	5/22/2010 10:25	MAY 10	0.1	0.4	18.7	80.8	87	0	40	2	0.7	0.6	18.2	0.25	998	-0.05	10.11
JALEEB29	6/23/2010 10:40	JUN 10	0	0.6	18.3	81.1	339	0	49	0	0.6	0.6	17.7	0	989	-0.3	11.93
JALEEB29	7/21/2010 11:38	JUL 10	0	0.6	18.2	81.2	294	0	51.5	0	0.5	0.6	17.9	0	982	-0.15	12.4
JALEEB29	8/23/2010 10:17	AUG 10	0	0.3	18.7	81	357	0	46.6	0	1.1	0.9	17.2	0	988	-0.16	10.31
JALEEB29	9/21/2010 11:16	SEP 10	0	0.8	18.1	81.1	308	0	46.4	0	0.8	1.2	17.7	0	995	-0.07	12.68
JALEEB29	10/20/2010 10:43	OCT 10	0.9	0.9	18.2	80	154	0	39	18	1.3	1.1	17	1	1000	-0.02	11.2
JALEEB29	11/8/2010 11:26	NOV 10	0	0.5	19	80.5	147	0	23.7	0	0.9	0.8	17.6	0	1004	0.07	8.68
JALEEB29	12/21/2010 13:45	DEC 10	1.4	1.1	17.7	79.8	0	0	17.1	28	0.9	0.7	17.4	1.27	1009	0.17	12.89

Table App. 5.30: LFG measurements in Borehole 30

Jleeb Al Shuyoukh Landfill, LF Gas Monitoring																	BH 30
ID	DATE	MONTH	CH4	CO2	O2	BAL	NH3	H2S	TEMP	CH4 %	PEAK	PEAK	MIN	CH4/	BARO	REL.	Res
			%	%	%	%	ppm	ppm	DegC	LEL%	CH4%	CO2%	O2%	CO2%	mb	PRESS.mb	Nitro%
JALEEB30	4/3/2008 11:54	MAR 08	0	4.9	10.5	84.6	0	22	29.5	0	1.8	10.8	10.5	0	1007	-0.06	44.91
JALEEB30	4/15/2008 11:37	APR 08	0	1.3	14.3	84.4	26	0	33.9	0	0	2.1	14.3	0	1003	-0.4	30.35
JALEEB30	5/22/2008 10:26	MAY 08	0	2	10	88	6	0	37.5	0	0	1.9	10.1	0	996	0.53	50.2
JALEEB30	5/29/2008 10:06	JUN 08	0	2.9	8.6	88.5	0	11	39.9	0	0	2.8	8.6	0	994	1.3	55.99
JALEEB30	7/7/2008 11:30	JUL 08	0	1.8	18.6	79.6	0	3	42.4	0	0.2	4.8	17.9	0	991	-20.48	9.29
JALEEB30	8/10/2008 9:20	AUG 08	0	2.4	12.9	84.7	0	194	46.9	0	0	2.4	12.8	0	991	0.08	35.94
JALEEB30	9/12/2008 8:46	SEP 08	0	1.2	13.9	84.9	0	2	43.2	0	0	1.2	13.9	0	1003	0.47	32.36
JALEEB30	15/10/2008 11:37	OCT 08	0	1.9	13.5	84.6	0	15	34.9	0	0	2.9	13.5	0	996	-0.17	33.57
JALEEB30	11/15/2008 11:37	NOV 08	0	1	19.4	79.6	150	0	17.8	0	0	2.1	14.3	0	1003	-0.4	30.35
JALEEB30	12/15/2008 11:51	DEC 08	0	2.4	12.9	84.7	0	194		0	0	2.4	12.8	0	1008	0.08	35.94
JALEEB30	8/1/2009 11:01	JAN 09	0	1.3	14.3	84.4	0	26	19.9	0	0	2.1	14.3	0	1003	-0.4	30.35
JALEEB30	11/2/2009 12:00	FEB 09	0	4.4	10.9	84.7	3	4	31.5	0	0	4.4	10.8	0	1006	-0.13	43.5
JALEEB30	17/3/2009 4:51	MAR 09	0	4.4	11.2	84.4	2	2	N/A	0	0	4.4	11.2	0	1006	0.88	42.06
JALEEB30	26/4/2009 8:40	APR 09	0	0	19.7	80.3	2	0	32.2	0	0	0.9	18.1	0	1001	2.01	5.83
JALEEB30	26/5/2009 8:15	MAY 09	0	1.6	13.5	84.9	3	0	38.5	0	0	1.7	13.5	0	992	-0.25	33.87
JALEEB30	8/6/2009 11:01	JUN 09	0	2	10	88	0	6	37.5	0	0	1.9	10.1	0	996	0.53	50.2
JALEEB30	11/7/2009 12:00	JUL 09	0	1.8	18.6	79.6	0	3	42.4	0	0.2	4.8	17.9	0	1003	-20.48	9.29
JALEEB30	8/13/2009 11:15	AUG 09	0	0.8	13.2	86	1	5	35.6	0	0	0.8	13.2	0	1003	3.24	36.1
JALEEB30	9/5/2009 9:40	SEP 09	0	1.3	15.1	83.6	0	9	33.9	0	0	1.7	15	0	1000	-1.81	26.52
JALEEB30	10/12/2009 8:46	OCT 09	0	1.2	13.9	84.9	0	2	32.7	0	0	1.2	13.9	0	1003	0.47	32.36
JALEEB30	15/11/2009 11:37	NOV 09	0	2.4	12.9	84.7	0	194	25.1	0	0	2.4	12.8	0	1008	0.08	35.94
JALEEB30	26/12/2009 8:15	DEC 09	0	1	19.4	79.6	150	0	28.1	0	0	2.1	14.3	0	1003	-0.4	30.35
JALEEB30	1/18/2010 11:01	JAN 10	0	2	14.2	83.8	39	0	20.9	0	0	2	14.1	0	1012	-0.16	30.12
JALEEB30	3/2/2010 10:58	FEB 10	0	1.4	15	83.6	31	0	25.1	0	0.1	1.4	15	0	1006	0.8	26.9
JALEEB30	3/18/2010 10:57	MAR 10	0	2.8	13	84.2	12	0	32.4	0	0.2	2.8	13	0	1001	-0.09	35.06
JALEEB30	4/22/2010 14:46	ARP 10	0	4.5	10	85.5	0	0	38.7	0	0.1	4.5	9.9	0	991	-0.12	47.7
JALEEB30	5/22/2010 10:31	MAY 10	0	2.1	13.2	84.7	0	0	41.4	0	0.2	2.1	13.2	0	998	-0.09	34.8
JALEEB30	6/23/2010 10:45	JUN 10	0	1.8	13.5	84.7	75	0	51.4	0	0.2	1.9	13.6	0	989	-0.29	33.67
JALEEB30	7/21/2010 11:42	JUL 10	0.1	1.9	13.2	84.8	61	0	54.3	2	0.1	1.9	13.2	0.05	983	-0.21	34.9
JALEEB30	8/23/2010 10:21	AUG 10	0	0.1	19.1	80.8	191	0	47.6	0	0.1	0.4	18.2	0	988	0.89	8.6
JALEEB30	9/21/2010 11:24	SEP 10	0	0.9	16.1	83	195	0	46.1	0	0	0.9	16.2	0	995	-0.01	22.14
JALEEB30	10/20/2010 10:47	OCT 10	0	0.9	16.1	83	182	0	36.3	0	0.1	0.9	16.1	0	1000	-0.02	22.14
JALEEB30	11/8/2010 11:32	NOV 10	0.5	0.7	18.5	80.3	83	0	12.2	10	1	0.9	17.1	0.71	1004	-0.01	10.37
JALEEB30	12/21/2010 13:50	DEC 10	3	2.3	17	77.7	0	0	19.7	60	5.3	3.7	13.9	1.3	1010	0.21	13.44

Table App. 5.31: LFG measurements in Borehole 31

Jleeb Al Shuyoukh Landfill, LF Gas Monitoring																	BH 31
ID	DATE	MONTH	CH4	CO2	O2	BAL	NH3	H2S	TEMP	CH4 %	PEAK	PEAK	MIN	CH4/	BARO	REL.	Res
			%	%	%	%	ppm	ppm	DegC	LEL%	CH4%	CO2%	O2%	CO2%	mb	PRESS.mb	Nitro%
JALEEB31	4/3/2008 11:48	MAR 08	49.3	31.8	0.4	18.5	0	0	29.7	200	60.8	31.2	0.5	1.55	1008	0.17	16.99
JALEEB31	4/15/2008 11:45	APR 08	49	30.1	0.7	20.2	0	0	34	200	54.3	29.8	0.7	1.63	1003	-0.28	17.55
JALEEB31	5/22/2008 9:10	MAY 08	48.4	32.4	0.3	18.9	0	0	38.2	200	51.2	32.3	0.3	1.49	997	-1.76	17.77
JALEEB31	5/29/2008 8:55	JUN 08	48.5	32.8	0.3	18.4	1	0	37.6	200	53.1	32.3	0.4	1.48	996	-5.41	17.27
JALEEB31	7/7/2008 11:33	JUL 08	44.8	29.9	0.5	24.8	0	0	43	200	46.6	29.4	0.5	1.5	991	-0.24	22.91
JALEEB31	8/10/2008 9:22	AUG 08	48	33.1	0.7	18.2	0	0	47	200	50.3	32.8	0.3	1.45	991	0.09	15.55
JALEEB31	9/12/2008 8:54	SEP 08	42.6	26	2.6	28.8	1	0	44.7	200	43.7	25.4	2.6	1.64	1003	1.06	18.97
JALEEB31	15/10/2008 11:45	OCT 08	48.7	30.9	0.6	19.8	0	0	34	200	54.3	30.7	0.6	1.58	1002	-0.02	17.53
JALEEB31	11/15/2008 11:45	NOV 08	47.4	30.4	0.8	21.4	0	0	17.2	200	54.3	29.8	0.7	1.56	1003	-0.28	17.55
JALEEB31	12/14/2008 12:22	DEC 08	48	33.1	0.7	18.2	0	0	11.8	200	50.3	32.8	0.3	1.45	1009	0.09	15.55
JALEEB31	8/1/2009 11:05	JAN 09	49	30.1	0.7	20.2	0	0	23.6	200	54.3	29.8	0.7	1.63	1003	-0.28	17.55
JALEEB31	11/2/2009 12:04	FEB 09	48.3	34.6	0.2	16.9	0	0	24.5	200	48.6	34.7	0.2	1.4	1007	0.19	16.14
JALEEB31	17/3/2009 4:54	MAR 09	41.8	33.3	0.2	24.7	4	8	25.5	200	42.8	33.6	0.1	1.26	1006	2.25	23.94
JALEEB31	26/4/2009 8:43	APR 09	50.2	30	0.4	19.4	0	0	33.3	200	54.6	29.7	0.4	1.67	1002	0.18	17.89
JALEEB31	26/5/2009 8:18	MAY 09	39.7	33.7	0.2	26.4	9	9	39	200	40.5	34	0.2	1.18	992	2.73	25.64
JALEEB31	8/6/2009 11:05	JUN 09	48.4	32.4	0.3	18.9	0	0	38.2	200	51.2	32.3	0.3	1.49	997	-1.76	17.77
JALEEB31	11/7/2009 12:04	JUL 09	44.8	29.9	0.5	24.8	0	0	43	200	46.6	29.4	0.5	1.5	1003	-0.24	22.91
JALEEB31	8/13/2009 10:50	AUG 09	49.5	30.2	0.6	19.7	0	0	37	200	51.9	30	0.6	1.64	1004	-0.21	17.43
JALEEB31	9/5/2009 9:46	SEP 09	48.2	31.7	0.4	19.7	0	0	35.1	200	58	31.5	0.4	1.52	1000	-0.07	18.19
JALEEB31	10/12/2009 8:54	OCT 09	42.6	26	2.6	28.8	1	0	34.1	200	43.7	25.4	2.6	1.64	1003	1.06	18.97
JALEEB31	15/11/2009 11:45	NOV 09	48	33.1	0.7	18.2	0	0	25.6	200	50.3	32.8	0.3	1.45	1009	0.09	15.55
JALEEB31	26/12/2009 8:18	DEC 09	47.4	30.4	0.8	21.4	0	0	28.9	200	54.3	29.8	0.7	1.56	1003	-0.28	17.55
JALEEB31	1/18/2010 11:05	JAN 10	45.2	32.4	0.4	22	0	0	21.9	200	45.3	32.5	0.4	1.4	1012	-0.06	20.49
JALEEB31	3/2/2010 11:02	FEB 10	44.1	31.9	0.4	23.6	0	0	22.7	200	44.4	32.1	0.4	1.38	1006	-0.11	22.09
JALEEB31	3/18/2010 11:00	MAR 10	44.6	32.3	0.4	22.7	0	0	33.6	200	44.6	32.3	0.4	1.38	1001	1.08	21.19
JALEEB31	4/22/2010 14:48	ARP 10	43	31.6	0.6	24.8	0	0	37.5	200	43	31.5	0.6	1.36	990	-0.01	22.53
JALEEB31	5/22/2010 10:36	MAY 10	39.7	29.3	2.2	28.8	0	0	41.1	200	39.7	29.3	2.2	1.35	997	-0.01	20.48
JALEEB31	6/23/2010 10:49	JUN 10	43.6	32.7	0.7	23	0	0	52.5	200	43.7	32.7	0.7	1.33	989	-0.23	20.35
JALEEB31	7/24/2010 11:18	JUL 10	35.2	26.3	4.3	34.2	0	0	49.6	200	41.5	26.3	4.3	1.34	984	-0.12	17.95
JALEEB31	8/23/2010 10:25	AUG 10	43.8	33.5	0.9	21.8	0	0		200	43.8	33.4	1	1.31	987	1.09	18.4
JALEEB31	9/21/2010 11:22	SEP 10	43.1	32.9	0.9	23.1	0	0	47.1	200	43	32.9	0.9	1.31	996	1.46	19.7
JALEEB31	10/20/2010 10:51	OCT 10	38.1	28.8	2.8	30.3	0	0	29.9	200	38.1	28.7	2.9	1.32	1000	0.05	19.72
JALEEB31	11/8/2010 11:29	NOV 10	37.1	28.1	3.3	31.5	0	0	25.8	200	37.9	28.4	3.1	1.32	1004	0.08	19.03
JALEEB31	12/21/2010 13:47	DEC 10	34.6	25.4	4.8	35.2	0	0	24.2	200	34.6	25.4	5.1	1.36	1010	0.93	17.06

Table App. 5.32: LFG measurements in Borehole 32

Jleeb Al Shuyoukh Landfill, LF Gas Monitoring																	BH 32
ID	DATE	MONTH	CH4	CO2	O2	BAL	NH3	H2S	TEMP	CH4 %	PEAK	PEAK	MIN	CH4/	BARO	REL.	Res
			%	%	%	%	ppm	ppm	DegC	LEL%	CH4%	CO2%	O2%	CO2%	mb	PRESS.mb	Nitro%
JALEEB32	4/3/2008 10:05	MAR 08	0	1.3	19.3	79.4	0	16	27.5	0	0	2.3	19.2	0	1002	0	6.45
JALEEB32	4/15/2008 11:58	APR 08	0	0.9	18.2	80.9	17	0	33.6	0	0	1.5	17.8	0	1003	-0.36	12.1
JALEEB32	5/22/2008 9:26	MAY 08	0	1.5	18.3	80.2	16	0	36.1	0	0	2.4	18.1	0	997	0.42	11.03
JALEEB32	5/29/2008 9:12	JUN 08	0	1.3	18.9	79.8	0	16	35.2	0	0	2	18.6	0	996	-0.03	8.36
JALEEB32	7/7/2008 8:03	JUL 08	0	1.5	18.3	80.2	0	16	40.1	0	0	2.4	18.1	0	994	0.42	11.03
JALEEB32	8/10/2008 9:24	AUG 08	0	0.8	19.2	80	1	246	44.9	0	0	0.8	19.1	0	991	-0.07	7.42
JALEEB32	9/12/2008 9:37	SEP 08	0	1.7	18.9	79.4	0	12	45.1	0	0	3.3	18.4	0	1003	-0.22	7.96
JALEEB32	15/10/2008 11:58	OCT 08	0	2.6	18.7	78.7	0	0	32.1	0	1.1	12.1	16.2	0	1002	0.15	8.01
JALEEB32	11/15/2008 11:58	NOV 08	0	1.6	19.4	79	117	0	18.2	0	0	1.5	17.8	0	1004	-0.36	12.1
JALEEB32	12/14/2008 12:07	DEC 08	0	0.8	19.2	80	1	246		0	0	0.8	19.1	0	1010	-0.07	7.42
JALEEB32	8/1/2009 11:08	JAN 09	0	0.9	18.2	80.9	0	17	12.1	0	0	1.5	17.8	0	1003	-0.36	12.1
JALEEB32	11/2/2009 12:07	FEB 09	0	0.6	19.3	80.1	3	5	26.7	0	0	0.6	18.6	0	1006	-0.13	7.15
JALEEB32	17/3/2009 4:58	MAR 09	0	0.7	19.3	80	2	1	N/A	0	4.6	4.6	11.8	0	1006	2.73	7.05
JALEEB32	26/4/2009 8:47	APR 09	0	0.3	19.4	80.3	2	0	31.7	0	0	0.3	19.4	0	1002	-0.11	6.97
JALEEB32	26/5/2009 8:21	MAY 09	0	0.6	19	80.4	3	3	36.8	0	0	0.6	18.8	0	992	0.92	8.58
JALEEB32	8/6/2009 11:08	JUN 09	0	1.5	18.3	80.2	0	16	36.1	0	0	2.4	18.1	0	997	0.42	11.03
JALEEB32	11/7/2009 12:07	JUL 09	0	1.5	18.3	80.2	0	16	40.1	0	0	2.4	18.1	0	1003	0.42	11.03
JALEEB32	8/13/2009 10:56	AUG 09	0	1.8	18.3	79.9	0	35	37.2	0	1.2	9.9	16	0	1004	-0.16	10.73
JALEEB32	9/5/2009 10:07	SEP 09	0	1.4	18.5	80.1	0	18	33.9	0	0	2.8	18.2	0	1000	-0.1	10.17
JALEEB32	10/12/2009 9:37	OCT 09	0	1.7	18.9	79.4	0	12	32.5	0	0	3.3	18.4	0	1003	-0.22	7.96
JALEEB32	15/11/2009 11:58	NOV 09	0	0.8	19.2	80	1	246	26.4	0	0	0.8	19.1	0	1010	-0.07	7.42
JALEEB32	26/12/2009 8:21	DEC 09	0	1.6	19.4	79	117	0	27.1	0	0	1.5	17.8	0	1004	-0.36	12.1
JALEEB32	1/18/2010 11:08	JAN 10	0	0.7	18.6	80.7	132	0	20.9	0	0.3	0.7	18.2	0	1012	-0.11	10.39
JALEEB32	3/2/2010 11:08	FEB 10	0	0.6	18.8	80.6	163	0	23.7	0	0.8	0.8	17.8	0	1006	-0.12	9.54
JALEEB32	3/18/2010 11:04	MAR 10	0	0.5	18.7	80.8	282	0	33.8	0	0.5	0.5	18.1	0	1001	0.21	10.11
JALEEB32	4/22/2010 14:51	ARP 10	0	0.5	18.4	81.1	224	0	37.3	0	0.3	0.5	18.1	0	991	-0.03	11.55
JALEEB32	5/22/2010 10:40	MAY 10	0	0.4	18.5	81.1	106	0	41.6	0	0.5	0.4	18	0	998	-0.13	11.17
JALEEB32	6/23/2010 10:52	JUN 10	0	0.5	18.5	81	201	0	50.8	0	0.5	0.5	17.9	0	989	-0.31	11.07
JALEEB32	7/24/2010 11:21	JUL 10	0	0.5	18.7	80.8	131	0	48.1	0	0.5	0.5	18.2	0	984	-0.11	10.11
JALEEB32	8/23/2010 10:28	AUG 10	0	0.4	18.9	80.7	232	0	50.3	0	0.4	0.4	18.4	0	988	0.6	9.26
JALEEB32	9/21/2010 11:19	SEP 10	0	0.4	18.9	80.7	164	0	48.6	0	0	0.4	18.9	0	996	-0.07	9.26
JALEEB32	10/20/2010 10:53	OCT 10	0	0.4	18.8	80.8	233	0	38.7	0	0.6	0.6	18	0	1001	0	9.74
JALEEB32	11/10/2010 10:49	NOV 10	0	0.4	18.6	81	166	0	25	0	0.2	1	18	0	1009	0.08	10.69
JALEEB32	12/21/2010 13:54	DEC 10	0	0.3	19	80.7	37	0	24.4	0	0.2	1.2	16.8	0	1010	0.26	8.88

Table App. 5.33: LFG measurements in Borehole 33

Jleeb Al Shuyoukh Landfill, LF Gas Monitoring																	BH 33
ID	DATE	MONTH	CH4	CO2	O2	BAL	NH3	H2S	TEMP	CH4 %	PEAK	PEAK	MIN	CH4/	BARO	REL.	Res
			%	%	%	%	ppm	ppm	DegC	LEL%	CH4%	CO2%	O2%	CO2%	mb	PRESS.mb	Nitro%
JALEEB33	4/2/2008 8:34	MAR 08	0	1.3	19.8	78.9	0	0	26	0	0	1.9	19.2	0	1004	0.02	4.06
JALEEB33	4/15/2008 11:52	APR 08	0	1.6	18.1	80.3	49	0	36.1	0	0	5.5	16.7	0	1003	-0.4	11.88
JALEEB33	5/22/2008 9:31	MAY 08	0	0.9	18.8	80.3	14	0	36.8	0	0	1.3	18.6	0	997	0.75	9.24
JALEEB33	5/29/2008 9:17	JUN 08	0	0.8	19.2	80	0	13	35.7	0	0	1.2	19	0	996	0.01	7.42
JALEEB33	7/7/2008 8:04	JUL 08	0	0.9	18.8	80.3	0	14	41	0	0	1.3	18.6	0	996	0.75	9.24
JALEEB33	8/10/2008 9:26	AUG 08	0	0.6	19.6	79.8	1	219	46.9	0	0	1.3	19.5	0	992	0.01	5.71
JALEEB33	9/12/2008 9:45	SEP 08	0	0.6	19.2	80.2	0	10	47.3	0	0	1.1	19	0	1003	0.49	7.62
JALEEB33	15/10/2008 11:52	OCT 08	0	4.1	18.5	77.4	0	0	32.6	0	12.3	14.8	13.5	0	1002	-0.09	7.47
JALEEB33	11/15/2008 11:52	NOV 08	0	1.1	20.1	78.8	113	0	19.2	0	0	5.5	16.7	0	1003	-0.4	11.88
JALEEB33	12/14/2008 12:03	DEC 08	0	0.6	19.6	79.8	1	219		0	0	1.3	19.5	0	1010	0.01	5.71
JALEEB33	8/1/2009 11:19	JAN 09	0	1.6	18.1	80.3	0	9	18	0	0	5.5	16.7	0	1003	-0.4	11.88
JALEEB33	11/2/2009 12:11	FEB 09	0	0.5	18	81.5	0	1	28.4	0	0	3.1	18.2	0	1008	0.04	13.46
JALEEB33	17/3/2009 5:01	MAR 09	0	0.1	19.9	80	3	2	N/A	0	0	0.2	19	0	1006	0.51	4.78
JALEEB33	26/4/2009 8:50	APR 09	0	0	19.8	80.2	2	0	31.9	0	0	0	19.6	0	1002	3.23	5.36
JALEEB33	26/5/2009 8:24	MAY 09	0	0	19.2	80.8	4	0	36.9	0	0	0	19.1	0	992	1.21	8.22
JALEEB33	8/6/2009 11:19	JUN 09	0	0.9	18.8	80.3	0	14	36.8	0	0	1.3	18.6	0	997	0.75	9.24
JALEEB33	11/7/2009 12:11	JUL 09	0	0.9	18.8	80.3	0	14	41	0	0	1.3	18.6	0	1003	0.75	9.24
JALEEB33	8/13/2009 11:01	AUG 09	0	0.9	18.8	80.3	1	16	37.5	0	0	1.6	18.2	0	1004	-0.26	9.24
JALEEB33	9/5/2009 10:12	SEP 09	0	0.9	19	80.1	0	11	34.8	0	0	1.3	18.8	0	1000	1.01	8.28
JALEEB33	10/12/2009 9:45	OCT 09	0	0.6	19.2	80.2	0	10	32.8	0	0	1.1	19	0	1003	0.49	7.62
JALEEB33	15/11/2009 11:52	NOV 09	0	0.6	19.6	79.8	1	219	26	0	0	1.3	19.5	0	1010	0.01	5.71
JALEEB33	26/12/2009 8:24	DEC 09	0	1.1	20.1	78.8	113	0	27.3	0	0	5.5	16.7	0	1003	-0.4	11.88
JALEEB33	1/18/2010 11:19	JAN 10	0	1.3	18.5	80.2	81	0	19.7	0	0	1.4	18.3	0	1011	-0.1	10.27
JALEEB33	3/2/2010 11:14	FEB 10	0	0.1	19.3	80.6	124	0	24.1	0	0	0.5	18.8	0	1006	-0.15	7.65
JALEEB33	3/18/2010 11:44	MAR 10	0	0.1	19.1	80.8	72	0	34.6	0	0.2	0.7	18.8	0	1001	-0.35	8.6
JALEEB33	4/22/2010 15:00	ARP 10	0	0.7	17.6	81.7	142	0	36.8	0	0	0.6	16.7	0	990	-20.57	15.17
JALEEB33	5/22/2010 10:45	MAY 10	0	0.9	17.9	81.2	117	0	39.7	0	0.1	0.5	18.1	0	998	-0.12	13.54
JALEEB33	6/23/2010 10:56	JUN 10	0	0.9	16.9	82.2	135	1	50.3	0	0.1	1.5	16.6	0	989	-0.33	18.32
JALEEB33	7/24/2010 11:24	JUL 10	0	0.5	18.1	81.4	74	0	50	0	0.1	0.7	17.6	0	984	-0.14	12.98
JALEEB33	8/23/2010 10:31	AUG 10	0	0.8	18.1	81.1	167	0		0	0	0.5	18.5	0	988	0.15	12.68
JALEEB33	9/25/2010 11:20	SEP 10	0	0.2	19.1	80.7	105	0	46.3	0	56.6	32.5	1.9	0	994	-0.22	8.5
JALEEB33	10/20/2010 10:56	OCT 10	0	0.9	18.4	80.7	181	0	35.1	0	0.1	1	18.7	0	1000	0.01	11.15
JALEEB33	11/10/2010 10:52	NOV 10	0	0.3	19	80.7	169	0	25.3	0	0	0.3	18.9	0	1009	-0.04	8.88
JALEEB33	12/21/2010 14:00	DEC 10	0	1	17.5	81.5	36	0	24	0	0	1	16.8	0	1010	0.66	15.35

Table App. 5.34: LFG measurements in Borehole 34

Jleeb Al Shuyoukh Landfill, LF Gas Monitoring																	BH 34
ID	DATE	MONTH	CH4	CO2	O2	BAL	NH3	H2S	TEMP	CH4 %	PEAK	PEAK	MIN	CH4/	BARO	REL.	Res
			%	%	%	%	ppm	ppm	DegC	LEL%	CH4%	CO2%	O2%	CO2%	mb	PRESS.mb	Nitro%
JALEEB34	4/3/2008 10:12	MAR 08	0	0.7	16.2	83.1	0	12	26.3	0	0	1.3	16.2	0	1004	-0.08	21.86
JALEEB34	4/15/2008 11:32	APR 08	0	2.2	14.4	83.4	71	0	33.7	0	1.3	11.8	12.5	0	1003	-0.36	28.97
JALEEB34	5/22/2008 10:22	MAY 08	0	1.3	14.5	84.2	19	0	37.8	0	0	7.7	14.5	0	996	-0.24	29.39
JALEEB34	5/29/2008 10:02	JUN 08	0	1.5	15	83.5	0	25	39.3	0	0	2.9	14.9	0	994	-9.09	26.8
JALEEB34	7/7/2008 8:08	JUL 08	0	1.3	14.5	84.2	0	19	43.4	0	0	7.7	14.5	0	996	-0.24	29.39
JALEEB34	8/10/2008 9:28	AUG 08	0	0.6	16.3	83.1	0	191	48.1	0	0	1.7	16.3	0	992	0.06	21.49
JALEEB34	9/12/2008 8:41	SEP 08	0	0.8	15.8	83.4	1	1	48.3	0	0	1.2	15.8	0	1003	-0.11	23.68
JALEEB34	15/10/2008 11:32	OCT 08	0	0.9	15.6	83.5	0	12	34	0	0	1.7	15.6	0	997	-0.07	24.53
JALEEB34	11/15/2008 11:32	NOV 08	0	7	18.6	74.4	170	0	18.4	0	1.3	11.8	12.5	0	1003	-0.36	28.97
JALEEB34	12/15/2008 11:48	DEC 08	0	0.6	16.3	83.1	0	191		0	0	1.7	16.3	0	1008	0.06	21.49
JALEEB34	8/1/2009 11:25	JAN 09	0	2.2	14.4	83.4	0	7	16.9	0	1.3	11.8	12.5	0	1003	-0.36	28.97
JALEEB34	11/2/2009 3:14	FEB 09	0	1.1	18.5	80.4	4	0	25	0	0	1.2	18.4	0	1009	-20.37	10.47
JALEEB34	17/3/2009 5:05	MAR 09	0	0	16.6	83.4	3	0	26.3	0	0	0.1	16.6	0	1006	-0.2	20.65
JALEEB34	26/4/2009 8:53	APR 09	0	0	16.6	83.4	2	0	32	0	0	0	16.6	0	1002	3.03	20.65
JALEEB34	26/5/2009 8:27	MAY 09	0	0	16.4	83.6	3	1	37.3	0	0	0	16.4	0	993	1.89	21.61
JALEEB34	8/6/2009 11:25	JUN 09	0	1.3	14.5	84.2	0	19	37.8	0	0	7.7	14.5	0	996	-0.24	29.39
JALEEB34	11/7/2009 3:14	JUL 09	0	1.3	14.5	84.2	0	19	43.4	0	0	7.7	14.5	0	1003	-0.24	29.39
JALEEB34	8/13/2009 11:11	AUG 09	0	0.4	15.4	84.2	1	9	38.2	0	0	0.5	15.4	0	1004	-0.27	25.99
JALEEB34	9/5/2009 9:36	SEP 09	0	1.4	15.4	83.2	0	11	33.9	0	0	2.7	15.4	0	1000	-13.34	24.99
JALEEB34	10/12/2009 8:41	OCT 09	0	0.8	15.8	83.4	1	1	30.8	0	0	1.2	15.8	0	1003	-0.11	23.68
JALEEB34	15/11/2009 11:32	NOV 09	0	0.6	16.3	83.1	0	191	27.5	0	0	1.7	16.3	0	1008	0.06	21.49
JALEEB34	26/12/2009 8:27	DEC 09	0	7	18.6	74.4	170	0	27.9	0	1.3	11.8	12.5	0	1003	-0.36	28.97
JALEEB34	1/18/2010 11:25	JAN 10	0	0.9	18.6	80.5	105	0	21.6	0	0	1.2	18.3	0	1011	-0.14	10.19
JALEEB34	3/2/2010 11:18	FEB 10	0	0.2	18	81.8	94	0	24.9	0	0	0.8	16.2	0	1007	-0.17	13.76
JALEEB34	3/23/2010 10:06	MAR 10	0	0.9	18	81.1	56	0	28.7	0	0	0.6	16.2	0	1004	0.1	13.06
JALEEB34	4/22/2010 15:01	ARP 10	0	0.3	17.8	81.9	128	0	35.8	0	0	0.2	16.9	0	990	-14.65	14.62
JALEEB34	5/22/2010 10:50	MAY 10	0	0.5	17.8	81.7	92	0	40.4	0	0	0.5	16.2	0	998	-0.15	14.42
JALEEB34	6/23/2010 11:00	JUN 10	0	0.2	17.9	81.9	69	1	48	0	0	0.7	16.3	0	989	-0.44	14.24
JALEEB34	7/24/2010 11:28	JUL 10	0	0.3	17.3	82.4	75	0	49.2	0	0	0.3	16.9	0	985	-0.14	17.01
JALEEB34	8/25/2010 9:17	AUG 10	0.2	0.2	16.8	82.8	0	0	47.1	4	49.3	28.5	4.1	1	986	-0.12	19.3
JALEEB34	9/25/2010 11:23	SEP 10	0	0.5	17.9	81.6	167	0	47.4	0	0	0.2	16.7	0	994	-0.19	13.94
JALEEB34	10/20/2010 11:00	OCT 10	0	0.6	18.2	81.2	148	0	32.5	0	0	0.6	16.9	0	1001	-0.02	12.4
JALEEB34	11/10/2010 10:56	NOV 10	0	0.4	17.5	82.1	155	0	21.7	0	0	0.4	16.7	0	1009	0.08	15.95
JALEEB34	12/21/2010 14:00	DEC 10	0	0.9	18.2	80.9	26	0	20.2	0	0	0.7	18.1	0	1009	-8.2	12.1

Table App. 5.35: LFG measurements in Borehole 35

Jleeb Al Shuyoukh Landfill, LF Gas Monitoring																	BH 35
ID	DATE	MONTH	CH4	CO2	O2	BAL	NH3	H2S	TEMP	CH4 %	PEAK	PEAK	MIN	CH4/	BARO	REL.	Res
			%	%	%	%	ppm	ppm	DegC	LEL%	CH4%	CO2%	O2%	CO2%	mb	PRESS.mb	Nitro%
JALEEB35	4/2/2008 8:45	MAR 08	0	0.7	19.7	79.6	0	0	25.5	0	0	1	19.7	0	1004	1.21	5.13
JALEEB35	4/15/2008 12:07	APR 08	0	0.7	18.4	80.9	6	0	34	0	0	1.1	18.1	0	1003	-0.47	11.35
JALEEB35	5/22/2008 9:36	MAY 08	0	0.7	18.6	80.7	11	0	36.9	0	0	1	18.6	0	997	-0.34	10.39
JALEEB35	5/29/2008 9:21	JUN 08	0	0.6	19	80.4	0	11	35.7	0	0	0.8	19	0	996	-0.2	8.58
JALEEB35	7/7/2008 8:11	JUL 08	0	0.7	18.6	80.7	0	11	40.8	0	0	1	18.6	0	995	-0.34	10.39
JALEEB35	8/10/2008 9:30	AUG 08	0	0.8	19.6	79.6	0	204	48.5	0	0	1.6	19.4	0	991	-0.01	5.51
JALEEB35	9/12/2008 9:50	SEP 08	0	0.6	19.2	80.2	0	4	43.7	0	0	0.8	19.1	0	1003	-0.24	7.62
JALEEB35	15/10/2008 12:07	OCT 08	0	1.2	19.1	79.7	0	11	32	0	0	3.1	18.5	0	1003	2.55	7.5
JALEEB35	11/15/2008 12:07	NOV 08	0	2.1	19.6	78.3	52	0	18.2	0	0	1.1	18.1	0	1003	-0.47	11.35
JALEEB35	12/14/2008 12:00	DEC 08	0	0.8	19.6	79.6	0	204		0	0	1.6	19.4	0	1010	-0.01	5.51
JALEEB35	8/1/2009 11:27	JAN 09	0	0.7	18.4	80.9	0	6	22.9	0	0	1.1	18.1	0	1003	-0.47	11.35
JALEEB35	11/2/2009 3:17	FEB 09	0	0.8	18.4	80.8	0	1	23.2	0	0	2.4	18.6	0	1006	0	6.47
JALEEB35	17/3/2009 5:08	MAR 09	0	0.1	20.1	79.8	3	0	26.3	0	0	0.2	17.4	0	1005	0.01	3.82
JALEEB35	12/4/2009 8:18	APR 09	0	0.9	19.3	79.8	1	0	26.1	0	0	3.2	19.1	0	1003	0.04	6.85
JALEEB35	26/5/2009 8:30	MAY 09	0	0	19.8	80.2	3	2	37	0	0	0.2	19.4	0	992	1.61	5.36
JALEEB35	8/6/2009 11:27	JUN 09	0	0.7	18.6	80.7	0	11	36.9	0	0	1	18.6	0	997	-0.34	10.39
JALEEB35	11/7/2009 3:17	JUL 09	0	0.7	18.6	80.7	0	11	40.8	0	0	1	18.6	0	1003	-0.34	10.39
JALEEB35	8/13/2009 11:06	AUG 09	0	0.5	18.8	80.7	1	14	36.1	0	0	1	18.5	0	1005	1.07	9.64
JALEEB35	9/5/2009 10:18	SEP 09	0	0.6	19	80.4	0	10	34.4	0	0	0.9	18.9	0	1000	0.95	8.58
JALEEB35	10/12/2009 9:50	OCT 09	0	0.6	19.2	80.2	0	4	32.7	0	0	0.8	19.1	0	1003	-0.24	7.62
JALEEB35	15/11/2009 12:07	NOV 09	0	0.8	19.6	79.6	0	204	28.4	0	0	1.6	19.4	0	1010	-0.01	5.51
JALEEB35	26/12/2009 8:30	DEC 09	0	2.1	19.6	78.3	52	0	26.5	0	0	1.1	18.1	0	1003	-0.47	11.35
JALEEB35	1/18/2010 11:27	JAN 10	0	1.1	18.5	80.4	64	0	22.3	0	0	1.2	18.3	0	1012	-20.37	10.47
JALEEB35	3/2/2010 11:21	FEB 10	0	0.3	18.7	81	73	0	23.8	0	0	0.7	18.6	0	1005	-0.13	10.31
JALEEB35	3/23/2010 10:09	MAR 10	0	0.5	18.6	80.9	36	0	27.1	0	0	0.7	18.6	0	1004	1.14	10.59
JALEEB35	4/22/2010 15:04	ARP 10	0	0.2	18.7	81.1	73	0	38.7	0	0	0.2	18.8	0	990	-0.19	10.41
JALEEB35	5/22/2010 10:54	MAY 10	0	0.1	18.8	81.1	34	0	41.4	0	0	0.3	18.6	0	997	-0.4	10.04
JALEEB35	6/24/2010 10:25	JUN 10	0	0.6	17.8	81.6	42	0	43.7	0	57.7	33.2	1.5	0	990	0.32	14.32
JALEEB35	7/24/2010 11:32	JUL 10	0	1.1	17.4	81.5	0	0	51	0	0	0.6	18.2	0	984	-0.17	15.73
JALEEB35	8/25/2010 9:20	AUG 10	0.5	0.5	18.3	80.7	338	0	48.6	10	0.7	0.4	17.9	1	985	-0.04	11.53
JALEEB35	9/25/2010 11:25	SEP 10	0	0.8	18.1	81.1	135	0	42.3	0	0	0.6	18.5	0	993	0.32	12.68
JALEEB35	10/20/2010 11:02	OCT 10	0	0.1	19.2	80.7	146	0	33.5	0	0	0.1	18.8	0	1000	0.24	8.12
JALEEB35	11/10/2010 10:59	NOV 10	0	0.3	18.9	80.8	135	0	27.2	0	0	0.3	18.9	0	1008	0.01	9.36
JALEEB35	12/21/2010 14:03	DEC 10	0	0.6	18.8	80.6	37	0	22.1	0	0	0.6	17	0	1009	-5.74	9.54

Table App. 5.36: LFG measurements in Borehole 36

Jleeb Al Shuyoukh Landfill, LF Gas Monitoring																	BH 36
ID	DATE	MONTH	CH4	CO2	O2	BAL	NH3	H2S	TEMP	CH4 %	PEAK	PEAK	MIN	CH4/	BARO	REL.	Res
			%	%	%	%	ppm	ppm	DegC	LEL%	CH4%	CO2%	O2%	CO2%	mb	PRESS.mb	Nitro%
JALEEB36	4/3/2008 10:06	MAR 08	0	1.3	19.8	78.9	0	19	26.3	0	0	2.7	18.6	0	1004	-0.13	4.06
JALEEB36	4/16/2008 11:55	APR 08	0	2.5	18.5	79	20	0	33.3	0	1.8	8	14.5	0	1003	-0.27	9.07
JALEEB36	5/20/2008 10:57	MAY 08	0	2.3	18.7	79	21	0	37.2	0	1.4	10.7	14.3	0	1000	-0.11	8.31
JALEEB36	6/2/2008 9:58	JUN 08	0	2	17.9	80.1	0	33	41.6	0	0.1	5.6	15.8	0	995	-0.4	>>>>
JALEEB36	7/7/2008 8:14	JUL 08	0	2.8	18.2	79	0	32	40.2	0	1.7	10.8	13.7	0	996	0.35	10.2
JALEEB36	8/10/2008 9:32	AUG 08	0	1	20.1	78.9	0	92	43.9	0	0	4	18.5	0	992	1.88	2.92
JALEEB36	9/15/2008 10:40	SEP 08	0	4.6	17.8	77.6	0	0	43.2	0	32.1	20.8	6.3	0	1002	-0.01	10.32
JALEEB36	16/10/2008 11:55	OCT 08	0	1.6	19	79.4	0	1	32.9	0	0	3.7	17.8	0	1001	0.89	7.58
JALEEB36	11/15/2008 11:55	NOV 08	0	1.7	19.6	78.7	39	1	16.9	0	1.8	8	14.5	0	1003	-0.27	9.07
JALEEB36	12/13/2008 17:04	DEC 08	0	1	20.1	78.9	0	92	14.1	0	0	4	18.5	0	1009	1.88	2.92
JALEEB36	9/1/2009 10:09	JAN 09	0	2.5	18.5	79	0	20	18.6	0	1.8	8	14.5	0	1003	-0.27	9.07
JALEEB36	11/2/2009 3:22	FEB 09	0	2.2	17.8	80	3	0	24	0	0	2.4	17.6	0	1006	0.36	13.47
JALEEB36	17/3/2009 5:12	MAR 09	0	0.1	20	79.9	4	0	25.6	0	0	0.1	19.7	0	1006	1.93	4.3
JALEEB36	12/4/2009 8:22	APR 09	0	0.5	19.2	80.3	0	0	26.6	0	0	1.2	19.2	0	1004	-0.01	7.72
JALEEB36	26/5/2009 8:34	MAY 09	0	0	19.5	80.5	4	1	37.9	0	0	0	19.4	0	992	1.85	6.79
JALEEB36	9/6/2009 10:09	JUN 09	0	3.2	18	78.8	0	42	39.2	0	1.8	8.7	13.7	0	996	-0.53	10.76
JALEEB36	11/7/2009 3:22	JUL 09	0	2.8	18.2	79	0	32	40.2	0	1.7	10.8	13.7	0	1002	0.35	10.2
JALEEB36	8/13/2009 11:23	AUG 09	0	0.4	19	80.6	1	3	36.8	0	0	0.6	17.8	0	1004	-0.28	8.78
JALEEB36	9/4/2009 10:53	SEP 09	0	2	18.7	79.3	0	26	33.4	0	0.4	5.6	17.2	0	1001	-73.89	8.61
JALEEB36	15/10/2009 10:40	OCT 09	0	4.6	17.8	77.6	0	0	34.6	0	32.1	20.8	6.3	0	1002	-0.01	10.32
JALEEB36	15/11/2009 11:55	NOV 09	0	1	20.1	78.9	0	92	28.6	0	0	4	18.5	0	1009	1.88	2.92
JALEEB36	26/12/2009 8:34	DEC 09	0	1.7	19.6	78.7	39	1	26.1	0	1.8	8	14.5	0	1003	-0.27	9.07
JALEEB36	1/19/2010 10:09	JAN 10	0	0.9	19	80.1	74	0	19.9	0	0	0.4	19.2	0	1009	0.02	8.28
JALEEB36	3/2/2010 11:30	FEB 10	0	0.4	18.6	81	44	0	25.6	0	0	0.7	18.6	0	1006	-0.14	10.69
JALEEB36	3/23/2010 10:12	MAR 10	0	1	18.2	80.8	28	0	27.7	0	0	1	18.2	0	1005	-0.03	12
JALEEB36	4/22/2010 15:08	ARP 10	0	1.2	17.5	81.3	57	0	39.5	0	0	1.1	17.5	0	991	-0.07	15.15
JALEEB36	5/22/2010 10:59	MAY 10	0	0.1	18.8	81.1	44	0	42	0	0	0.1	18.8	0	998	-0.23	10.04
JALEEB36	6/24/2010 10:29	JUN 10	0	0.1	18.7	81.2	66	0	45.4	0	0	0.1	18.7	0	990	-0.2	10.51
JALEEB36	7/24/2010 11:35	JUL 10	0	0.8	17.9	81.3	18	0	53.7	0	0	0.9	17.9	0	984	-0.13	13.64
JALEEB36	8/25/2010 9:23	AUG 10	0	0.6	17.8	81.6	305	0	46.8	0	0.2	0.6	18	0	986	0.98	14.32
JALEEB36	9/25/2010 11:28	SEP 10	0	0.2	18.7	81.1	146	0	47.3	0	0	0.2	18.8	0	994	0.55	10.41
JALEEB36	10/20/2010 11:06	OCT 10	0	0.5	18.8	80.7	98	0	29.8	0	0	0.4	18.9	0	1000	0.59	9.64
JALEEB36	11/10/2010 11:04	NOV 10	0	0.5	19	80.5	109	0	25.7	0	0	0.3	18.2	0	1009	0.17	8.68
JALEEB36	12/21/2010 14:06	DEC 10	0	0.7	18.7	80.6	31	0	24.7	0	0	0.7	18.7	0	1010	0.53	9.91

Table App. 5.37: LFG measurements in Borehole 37

Jleeb Al Shuyoukh Landfill, LF Gas Monitoring																	BH 37
ID	DATE	MONTH	CH4	CO2	O2	BAL	NH3	H2S	TEMP	CH4 %	PEAK	PEAK	MIN	CH4/	BARO	REL.	Res
			%	%	%	%	ppm	ppm	DegC	LEL%	CH4%	CO2%	O2%	CO2%	mb	PRESS.mb	Nitro%
JALEEB37	4/3/2008 8:51	MAR 08	10	10.4	8.4	71.2	0	0	33.9	200	10	10.2	8.4	0.96	1002	-0.16	39.45
JALEEB37	4/16/2008 11:07	APR 08	9.3	13.3	6.3	71.1	0	1	33.7	186	9.7	13	6.4	0.7	1004	0.19	47.29
JALEEB37	5/22/2008 10:17	MAY 08	10.6	18.5	1.7	69.2	0	0	37.9	200	11	18.1	1.7	0.57	996	-0.31	62.77
JALEEB37	6/2/2008 9:00	JUN 08	6.8	9.9	10.7	72.6	1	0	40.1	136	6.8	9.9	10.7	0.69	995	0.08	32.15
JALEEB37	7/7/2008 10:56	JUL 08	8.2	10.5	8.6	72.7	0	15	39.1	164	8.2	10.4	8.6	0.78	992	1.77	40.19
JALEEB37	8/10/2008 9:34	AUG 08	10.7	19.9	2.2	67.2	0	0	48.4	200	10.9	19.7	2	0.54	992	0.01	58.88
JALEEB37	9/12/2008 9:56	SEP 08	9.9	10	8	72.1	0	0	39.4	198	10	9.6	8	0.99	1003	0.53	41.86
JALEEB37	16/10/2008 11:07	OCT 08	10	10.4	8.4	71.2	0	0	33.9	200	10	10.2	8.4	0.96	1002	-0.16	39.45
JALEEB37	11/15/2008 11:07	NOV 08	9.3	13.3	6.3	71.1	0	1	23.7	186	9.7	13	6.4	0.7	1004	0.19	47.29
JALEEB37	12/15/2008 11:41	DEC 08	10.7	19.9	2.2	67.2	0	0		200	10.9	19.7	2	0.54	1009	0.01	58.88
JALEEB37	9/1/2009 10:14	JAN 09	9.3	13.3	6.3	71.1	1	0	19.1	186	9.7	13	6.4	0.7	1004	0.19	47.29
JALEEB37	11/2/2009 3:28	FEB 09	8.2	10.5	8.6	72.7	15	0	26.8	164	8.2	10.4	8.6	0.78	1003	1.77	40.19
JALEEB37	17/3/2009 5:17	MAR 09	9.6	20.7	2	67.7	4	2	26.1	192	9.5	21	1.9	0.46	1006	-0.13	60.14
JALEEB37	12/4/2009 8:26	APR 09	0	0.4	19.2	80.4	0	0	27.7	0	0.8	2.6	16.8	0	1004	-0.14	7.82
JALEEB37	26/5/2009 8:38	MAY 09	9.7	18.1	4.4	67.8	4	1	39.3	194	9.6	18	4.4	0.54	992	-0.38	51.17
JALEEB37	9/6/2009 10:14	JUN 09	9	15.2	3.9	71.9	0	0	40.7	180	9	15	3.9	0.59	995	0.93	57.16
JALEEB37	11/7/2009 3:28	JUL 09	8.2	10.5	8.6	72.7	0	15	39.1	164	8.2	10.4	8.6	0.78	1002	1.77	40.19
JALEEB37	8/14/2009 8:59	AUG 09	9.3	13.3	6.3	71.1	0	1	33.7	186	9.7	13	6.4	0.7	1004	0.19	47.29
JALEEB37	9/4/2009 11:45	SEP 09	6.5	6.4	12.1	75	1	0	34.4	130	6.5	6.2	12.1	1.02	1001	0	29.26
JALEEB37	10/12/2009 9:56	OCT 09	9.9	10	8	72.1	0	0	33.6	198	10	9.6	8	0.99	1003	0.53	41.86
JALEEB37	15/11/2009 11:07	NOV 09	10.7	19.9	2.2	67.2	0	0	28.3	200	10.9	19.7	2	0.54	1009	0.01	58.88
JALEEB37	26/12/2009 8:38	DEC 09	9.3	13.3	6.3	71.1	0	1	25.4	186	9.7	13	6.4	0.7	1004	0.19	47.29
JALEEB37	1/19/2010 10:14	JAN 10	12.1	14.2	7.7	66	0	0	20.3	200	12	14.1	7.8	0.85	1009	0.1	36.89
JALEEB37	3/2/2010 11:35	FEB 10	15.9	18.8	4.3	61	0	0	22.7	200	16	18.8	4.3	0.85	1006	-0.3	44.75
JALEEB37	3/23/2010 10:17	MAR 10	12.4	17.6	4.9	65.1	0	0	27.9	200	12.5	17.6	4.9	0.7	1005	-0.33	46.58
JALEEB37	4/22/2010 15:11	ARP 10	10.8	21.2	1.3	66.7	0	0	39.3	200	10.8	21.2	1.3	0.51	991	0	61.79
JALEEB37	5/22/2010 11:04	MAY 10	12.6	19	3.4	65	0	0	41.6	200	12.7	19.1	3.4	0.66	998	-0.12	52.15
JALEEB37	6/24/2010 10:33	JUN 10	16.1	21.8	2.3	59.8	0	0	46.9	200	16.3	21.8	2.4	0.74	990	-0.36	51.11
JALEEB37	7/24/2010 11:39	JUL 10	14.1	18.3	5	62.6	0	0	50.7	200	14.2	18.1	5.1	0.77	984	-0.14	43.7
JALEEB37	8/25/2010 9:28	AUG 10	16.8	18.1	5.5	59.6	0	0	47.9	200	16.8	18.1	5.5	0.93	982	-0.07	38.81
JALEEB37	9/25/2010 11:32	SEP 10	13	19.4	3.6	64	0	0	47.1	200	13	19.4	3.6	0.67	994	-0.06	50.39
JALEEB37	10/20/2010 11:09	OCT 10	12	17.8	4.6	65.6	0	0	34.7	200	12.1	17.9	4.6	0.67	1000	0.15	48.21
JALEEB37	11/10/2010 11:07	NOV 10	12.2	14.7	7.6	65.5	10	0	23.7	200	12.2	14.6	7.6	0.83	1009	0.25	36.77
JALEEB37	12/22/2010 14:10	DEC 10	9.2	16.3	5.6	68.9	0	0	20.5	184	9.7	16.7	5.6	0.56	1006	0	47.73

Table App. 5.38: LFG measurements in Borehole 38

Jleeb Al Shuyoukh Landfill, LF Gas Monitoring																	BH 38
ID	DATE	MONTH	CH4	CO2	O2	BAL	NH3	H2S	TEMP	CH4 %	PEAK	PEAK	MIN	CH4/	BARO	REL.	Res
			%	%	%	%	ppm	ppm	DegC	LEL%	CH4%	CO2%	O2%	CO2%	mb	PRESS.mb	Nitro%
JALEEB38	4/3/2008 8:56	MAR 08	0	2.7	17.6	79.7	0	0	32.2	0	6.4	7.1	12.5	0	1003	-0.27	13.17
JALEEB38	4/16/2008 11:13	APR 08	0	2.4	18.1	79.5	3	1	34.2	0	0.1	7.1	15.9	0	1004	0	11.08
JALEEB38	5/22/2008 10:13	MAY 08	0	5.7	13.5	80.8	0	0	36.6	0	1.1	9.5	13.5	0	996	-0.33	29.77
JALEEB38	6/2/2008 9:04	JUN 08	0	1.9	18.1	80	1	4	40.7	0	0	5.7	16.6	0	996	0.66	11.58
JALEEB38	7/7/2008 10:59	JUL 08	0	1.8	18.7	79.5	0	5	41.2	0	2.5	10.2	14.7	0	995	-0.12	8.81
JALEEB38	8/10/2008 9:36	AUG 08	0	3.7	16.2	80.1	0	148	44.3	0	0	3.6	16.4	0	991	0.2	18.86
JALEEB38	9/12/2008 10:00	SEP 08	0	2.7	17.6	79.7	0	0	36.5	0	6.4	7.1	12.5	0	1003	-0.27	13.17
JALEEB38	16/10/2008 11:13	OCT 08	0	2.1	18.7	79.2	8	0	34	0	0.2	6.7	17.7	0	1001	2.18	8.51
JALEEB38	11/15/2008 11:13	NOV 08	0	1.4	19.7	78.9	0	0	19.9	0	0.1	7.1	15.9	0	1004	0	11.08
JALEEB38	12/15/2008 11:44	DEC 08	0	3.7	16.2	80.1	0	148		0	0	3.6	16.4	0	1009	0.2	18.86
JALEEB38	9/1/2009 10:18	JAN 09	0	2.4	18.1	79.5	1	3	20.6	0	0.1	7.1	15.9	0	1004	0	11.08
JALEEB38	11/2/2009 3:31	FEB 09	0	5	15.7	79.3	0	1	28.1	0	0	10.1	8.4	0	1005	-0.01	19.95
JALEEB38	17/3/2009 5:21	MAR 09	0	0.3	20	79.7	3	34	25.6	0	0	8.4	12.3	0	1006	5.23	4.1
JALEEB38	12/4/2009 8:29	APR 09	0.7	0.2	19.2	79.9	0	0	27.6	14	0.7	0.6	18.8	3.5	1004	1.54	7.32
JALEEB38	26/5/2009 8:40	MAY 09	0	5.4	14	80.6	3	4	37.5	0	0	5.9	13.6	0	992	2.67	27.68
JALEEB38	9/6/2009 10:18	JUN 09	0	7.1	10.9	82	0	13	38.7	0	0.7	9.9	11	0	994	0	40.8
JALEEB38	11/7/2009 3:31	JUL 09	0	1.8	18.7	79.5	0	5	41.2	0	2.5	10.2	14.7	0	1003	-0.12	8.81
JALEEB38	8/14/2009 9:03	AUG 09	0	2.4	18.1	79.5	3	1	34.2	0	0.1	7.1	15.9	0	1004	0	11.08
JALEEB38	9/4/2009 11:40	SEP 09	0	2.1	18.7	79.2	0	8	34	0	0.2	6.7	17.7	0	1001	2.18	8.51
JALEEB38	10/12/2009 10:00	OCT 09	0	2.7	17.6	79.7	0	0	32.2	0	6.4	7.1	12.5	0	1003	-0.27	13.17
JALEEB38	15/11/2009 11:13	NOV 09	0	3.7	16.2	80.1	0	148	27.6	0	0	3.6	16.4	0	1009	0.2	18.86
JALEEB38	26/12/2009 8:40	DEC 09	0	1.4	19.7	78.9	0	0	26.2	0	0.1	7.1	15.9	0	1004	0	11.08
JALEEB38	1/19/2010 10:18	JAN 10	0	5.7	13.6	80.7	0	0	20.3	0	0	5.8	13.5	0	1008	0.01	29.29
JALEEB38	3/2/2010 11:38	FEB 10	0	0.4	18.7	80.9	113	0	25.6	0	0.1	0.6	18.4	0	1006	-0.1	10.21
JALEEB38	3/23/2010 10:20	MAR 10	0	3.5	15.7	80.8	0	0	27.1	0	0	3.5	15.7	0	1005	0.01	21.45
JALEEB38	4/22/2010 15:14	ARP 10	0	10	8.9	81.1	0	0	37.8	0	0	10	8.9	0	991	-0.11	47.46
JALEEB38	5/22/2010 11:07	MAY 10	0	4.1	14.9	81	0	0	40.1	0	0.1	4	15	0	997	-0.09	24.68
JALEEB38	6/24/2010 10:36	JUN 10	0	5.2	13.8	81	0	0	44.5	0	0.1	5.3	13.7	0	990	-0.39	28.84
JALEEB38	7/24/2010 11:41	JUL 10	0	1.5	17.5	81	0	0	51.1	0	0.2	1.5	17.5	0	984	-0.12	14.85
JALEEB38	8/25/2010 9:30	AUG 10	0	1.8	17.2	81	110	0	47.8	0	0.1	1.8	17.3	0	985	-0.11	15.98
JALEEB38	9/25/2010 11:34	SEP 10	0	1.6	17.7	80.7	64	0	46.8	0	0.1	1.6	17.7	0	994	-0.19	13.79
JALEEB38	10/20/2010 11:12	OCT 10	0	0.5	18.8	80.7	125	0	37.4	0	0	0.5	18.5	0	1000	0.03	9.64
JALEEB38	11/10/2010 11:11	NOV 10	10.8	9	12.6	67.6	94	0	25.7	200	0.7	1.5	18.4	1.2	1008	0.11	19.97
JALEEB38	12/22/2010 14:15	DEC 10	24.6	19.8	10.4	45.2	0	0	24.1	200	23.3	16.5	12.5	1.24	1007	0.38	5.89

Table App. 5.39: LFG measurements in Borehole 39

Jleeb Al Shuyoukh Landfill, LF Gas Monitoring																BH 39
ID	DATE	MONTH	CH4	CO2	O2	BAL	NH3	H2S	TEMP	CH4 %	PEAK	PEAK	MIN	CH4/	BARO	REL.	Res
			%	%	%	%	ppm	ppm	DegC	LEL%	CH4%	CO2%	O2%	CO2%	mb	PRESS.mb	Nitro%
JALEEB39	4/3/2008 9:02	MAR 08	26.6	18.5	5.1	49.8	0	0	36.2	200	28.3	18.2	5.1	1.44	1003	0.31	30.52
JALEEB39	4/16/2008 11:19	APR 08	22	16	5.9	56.1	0	1	35.5	200	23	15.4	6	1.38	1004	0.57	33.8
JALEEB39	5/22/2008 10:08	MAY 08	40.9	27	0.6	31.5	0	0	39.8	200	47.1	26.6	0.6	1.51	996	-0.44	29.23
JALEEB39	6/2/2008 9:08	JUN 08	31.1	22.5	2.7	43.7	2	0	41.4	200	34.7	22.3	2.7	1.38	996	1.02	33.49
JALEEB39	7/7/2008 11:00	JUL 08	32.3	23.5	2.3	41.9	1	0	47.3	200	33.4	23.1	2.2	1.37	992	-0.35	33.21
JALEEB39	8/10/2008 9:38	AUG 08	33.5	26.6	1.3	38.6	1	0	43.7	200	35	26.2	1	1.26	991	0.08	33.69
JALEEB39	9/12/2008 10:04	SEP 08	26.6	18.5	5.1	49.8	0	0	42.3	200	28.3	18.2	5.1	1.44	1003	0.31	30.52
JALEEB39	16/10/2008 11:19	OCT 08	39.1	26.6	1.9	32.4	0	0	32.9	200	42.3	25.9	1.9	1.47	1002	0	25.22
JALEEB39	11/15/2008 11:19	NOV 08	24.4	21	5.9	48.7	0	0	39	200	23	15.4	6	1.16	1005	0.57	33.8
JALEEB39	12/15/2008 12:11	DEC 08	33.5	26.6	1.3	38.6	1	0		200	35	26.2	1	1.26	1008	0.08	33.69
JALEEB39	9/1/2009 10:22	JAN 09	31.8	27.8	0.2	40.2	4	11	17.9	200	31.7	27.6	0.2	1.14	1006	4.71	39.44
JALEEB39	11/2/2009 3:35	FEB 09	34.3	27	4.5	34.2	4	3	22.8	200	46.1	32.7	1.7	1.27	1005	0.05	17.19
JALEEB39	17/3/2009 5:23	MAR 09	0	0.1	19.9	80	4	9	28.5	0	32.9	27.5	1.8	0	1006	4.52	4.78
JALEEB39	12/4/2009 8:31	APR 09	11.5	21.7	3.8	63	2	14	29.3	200	11.5	21.7	3.8	0.53	1003	-0.04	48.64
JALEEB39	26/5/2009 8:43	MAY 09	29.9	28	1.1	41	4	25	39.4	200	29.7	28	1.1	1.07	992	1.33	36.84
JALEEB39	9/6/2009 10:22	JUN 09	37.6	27.6	0.8	34	1	0	41	200	39.3	27.5	0.8	1.36	995	0.09	30.98
JALEEB39	11/7/2009 3:35	JUL 09	32.3	23.5	2.3	41.9	1	0	47.3	200	33.4	23.1	2.2	1.37	1001	-0.35	33.21
JALEEB39	8/14/2009 9:09	AUG 09	22	16	5.9	56.1	0	1	35.5	200	23	15.4	6	1.38	1004	0.57	33.8
JALEEB39	9/4/2009 11:27	SEP 09	22	16	5.9	56.1	0	1	35.5	200	23	15.4	6	1.38	1002	0.57	33.8
JALEEB39	10/12/2009 10:04	OCT 09	26.6	18.5	5.1	49.8	0	0	36.2	200	28.3	18.2	5.1	1.44	1003	0.31	30.52
JALEEB39	15/11/2009 11:19	NOV 09	33.5	26.6	1.3	38.6	1	0	32.7	200	35	26.2	1	1.26	1008	0.08	33.69
JALEEB39	26/12/2009 8:43	DEC 09	24.4	21	5.9	48.7	0	0	29.5	200	23	15.4	6	1.16	1005	0.57	33.8
JALEEB39	1/19/2010 10:22	JAN 10	37.5	29.3	0.3	32.9	0	0	34	200	37.4	29.3	0.4	1.28	1008	1.26	31.77
JALEEB39	3/2/2010 11:41	FEB 10	14	12.9	8.5	64.6	0	0	29.5	200	14.1	13	8.5	1.09	1006	1.72	32.47
JALEEB39	3/23/2010 10:23	MAR 10	28.6	22.4	4	45	0	0	33.6	200	28.5	22.4	4	1.28	1005	0.05	29.88
JALEEB39	4/22/2010 15:17	ARP 10	35.1	26.5	2.1	36.3	0	0	42.1	200	35.2	26.5	2.1	1.32	991	-0.13	28.36
JALEEB39	5/22/2010 11:10	MAY 10	27	20.6	4.9	47.5	0	0	42.9	200	27.2	20.7	4.9	1.31	997	-0.23	28.98
JALEEB39	6/24/2010 10:39	JUN 10	17.4	11.5	11.7	59.4	0	0	47.5	200	17.4	11.5	11.7	1.51	991	-0.3	15.17
JALEEB39	7/24/2010 11:44	JUL 10	34.6	26	2.5	36.9	0	0	51.1	200	35.2	26.1	2.5	1.33	984	-0.17	27.45
JALEEB39	8/25/2010 9:33	AUG 10	30.6	23.4	4.3	41.7	0	0	49.5	200	30.7	23.4	4.3	1.31	986	-0.05	25.45
JALEEB39	9/25/2010 11:36	SEP 10	31.9	25.1	3.2	39.8	0	0	49.7	200	32	25.1	3.2	1.27	994	-0.23	27.7
JALEEB39	10/20/2010 11:15	OCT 10	29.4	24	3.6	43	0	0	31.7	200	29.4	24	3.6	1.23	1000	0	29.39
JALEEB39	11/10/2010 11:12	NOV 10	16.3	14.8	8.1	60.8	0	0	25.7	200	16.4	14.8	8.1	1.1	1008	-7.78	30.18
JALEEB39	12/22/2010 14:16	DEC 10	26.2	21.6	5.5	46.7	0	0	26.2	200	26.2	21.6	5.5	1.21	1006	-20.19	25.91

Table App. 5.40: LFG measurements in Borehole 40

Jleeb Al Shuyoukh Landfill, LF Gas Monitoring																BH 40
ID	DATE	MONTH	CH4	CO2	O2	BAL	NH3	H2S	TEMP	CH4 %	PEAK	PEAK	MIN	CH4/	BARO	REL.	Res
			%	%	%	%	ppm	ppm	DegC	LEL%	CH4%	CO2%	O2%	CO2%	mb	PRESS.mb	Nitro%
JALEEB40	4/3/2008 9:07	MAR 08	41.3	26.5	1.9	30.3	0	0	34.8	200	42.3	26.4	2	1.56	1002	-0.1	23.12
JALEEB40	4/16/2008 11:26	APR 08	48.4	28.8	1.2	21.6	0	0	35.1	200	52.4	28.6	1.3	1.68	1004	-0.01	17.06
JALEEB40	5/19/2008 12:00	MAY 08	50.4	30.6	1	18	0	1	39.6	200	55.8	30.4	1	1.65	997	-0.27	14.22
JALEEB40	6/2/2008 9:20	JUN 08	45.2	28.1	1.3	25.4	0	0	42.2	200	47.4	27.8	1.3	1.61	995	-0.05	20.49
JALEEB40	7/7/2008 11:02	JUL 08	48.4	32.4	0.3	18.9	0	0	45.8	200	51.2	32.3	0.3	1.49	997	-1.76	17.77
JALEEB40	8/10/2008 9:40	AUG 08	55.9	34.5	0.4	9.2	0	0	45.3	200	59	34.3	0.2	1.62	991	0.25	7.69
JALEEB40	9/12/2008 10:13	SEP 08	41.3	26.5	1.9	30.3	0	0	43.5	200	42.3	26.4	2	1.56	1002	-0.1	23.12
JALEEB40	16/10/2008 11:26	OCT 08	48.2	31.7	0.4	19.7	0	0	35.1	200	58	31.5	0.4	1.52	1000	-0.07	18.19
JALEEB40	11/15/2008 11:26	NOV 08	21.5	30.2	7.8	40.5	0	0	18	200	52.4	28.6	1.3	0.71	1004	-0.01	17.06
JALEEB40	12/15/2008 16:23	DEC 08	55.9	34.5	0.4	9.2	0	0		200	59	34.3	0.2	1.62	1007	0.25	7.69
JALEEB40	9/1/2009 10:26	JAN 09	48.4	28.8	1.2	21.6	0	0	18.6	200	52.4	28.6	1.3	1.68	1004	-0.01	17.06
JALEEB40	11/2/2009 3:38	FEB 09	46.9	33.4	0.3	19.4	0	16	26.3	200	47.6	33.4	0.3	1.4	1006	-0.05	18.27
JALEEB40	17/3/2009 5:26	MAR 09	34.3	27	4.5	34.2	4	3	25.6	200	46.1	32.7	1.7	1.27	1005	0.05	17.19
JALEEB40	12/4/2009 8:34	APR 09	0	1.4	19	79.6	0	0	27	0	0.7	4.7	17.8	0	1003	-0.08	7.78
JALEEB40	26/5/2009 8:45	MAY 09	39.6	29.4	1.8	29.2	3	10	38.9	200	39.6	29.4	1.8	1.35	991	-0.15	22.4
JALEEB40	9/6/2009 10:26	JUN 09	50.5	31.1	1	17.4	0	0	39.7	200	60.5	31	1	1.62	997	-0.3	13.62
JALEEB40	11/7/2009 3:38	JUL 09	48.4	32.4	0.3	18.9	0	0	45.8	200	51.2	32.3	0.3	1.49	1001	-1.76	17.77
JALEEB40	8/14/2009 9:15	AUG 09	48.4	28.8	1.2	21.6	0	0	35.1	200	52.4	28.6	1.3	1.68	1004	-0.01	17.06
JALEEB40	9/4/2009 11:35	SEP 09	48.4	28.8	1.2	21.6	0	0	35.1	200	52.4	28.6	1.3	1.68	1002	-0.01	17.06
JALEEB40	10/12/2009 10:13	OCT 09	41.3	26.5	1.9	30.3	0	0	34.8	200	42.3	26.4	2	1.56	1002	-0.1	23.12
JALEEB40	15/11/2009 11:26	NOV 09	55.9	34.5	0.4	9.2	0	0	27.9	200	59	34.3	0.2	1.62	1007	0.25	7.69
JALEEB40	26/12/2009 8:45	DEC 09	21.5	30.2	7.8	40.5	0	0	29.9	200	52.4	28.6	1.3	0.71	1004	-0.01	17.06
JALEEB40	1/19/2010 10:26	JAN 10	51.4	32.5	1	15.1	0	0	21.2	200	51.6	32.6	1	1.58	1007	-0.05	11.32
JALEEB40	3/2/2010 11:45	FEB 10	44.5	28.6	1.8	25.1	0	0	26.4	200	44.5	28.7	1.9	1.56	1005	-0.18	18.3
JALEEB40	3/23/2010 10:28	MAR 10	50.4	31.7	0.9	17	0	0	29.5	200	50.5	31.7	0.9	1.59	1004	-0.13	13.6
JALEEB40	4/22/2010 15:21	ARP 10	50.1	30.7	2.3	16.9	0	0		200	50.1	30.6	2.4	1.63	990	0.08	8.21
JALEEB40	5/22/2010 11:14	MAY 10	35.1	21.5	6.3	37.1	0	0	42.1	200	35.1	21.5	6.3	1.63	997	-0.06	13.29
JALEEB40	6/24/2010 10:42	JUN 10	24	14.1	10.9	51	0	0	48.3	200	24	14.1	10.9	1.7	990	-0.17	9.8
JALEEB40	7/24/2010 11:47	JUL 10	51.7	32.1	1.8	14.4	0	0	53	200	52	32.1	1.8	1.61	983	-0.02	7.6
JALEEB40	8/25/2010 9:36	AUG 10	44.3	27.6	4.3	23.8	0	0	48.5	200	44.4	27.6	4.3	1.61	985	-0.08	7.55
JALEEB40	9/25/2010 11:39	SEP 10	51.7	32.4	1.8	14.1	0	0	48.6	200	51.9	32.4	1.8	1.6	994	0.48	7.3
JALEEB40	10/20/2010 11:17	OCT 10	48.6	30.8	2.4	18.2	0	0	34.1	200	48.7	30.8	2.4	1.58	1000	0.33	9.13
JALEEB40	11/10/2010 11:15	NOV 10	46.9	30.4	2.3	20.4	0	0	25.3	200	46.9	30.4	2.3	1.54	1008	0.35	11.71
JALEEB40	12/22/2010 14:19	DEC 10	30.3	19.1	9	41.6	0	0	25.1	200	30.3	19	9	1.59	1006	0.16	7.58

Table App. 5.41: LFG measurements in Borehole 41

Jleeb Al Shuyoukh Landfill, LF Gas Monitoring																	BH 41
ID	DATE	MONTH	CH4	CO2	O2	BAL	NH3	H2S	TEMP	CH4 %	PEAK	PEAK	MIN	CH4/	BARO	REL.	Res
			%	%	%	%	ppm	ppm	DegC	LEL%	CH4%	CO2%	O2%	CO2%	mb	PRESS.mb	Nitro%
JALEEB41	4/3/2008 9:13	MAR 08	55.8	32.2	0.9	11.1	0	0	33.3	200	58.3	32.1	0.9	1.73	1002	-17.66	7.7
JALEEB41	4/16/2008 11:33	APR 08	53.5	31.4	1.4	13.7	0	0	35	200	58	31	1.1	1.7	1004	0.27	8.41
JALEEB41	5/19/2008 12:06	MAY 08	54.9	32.1	0.9	12.1	0	0	37.8	200	58.8	31.9	0.9	1.71	998	0.08	8.7
JALEEB41	6/2/2008 9:25	JUN 08	55.5	32.8	0.5	11.2	0	0	40.6	200	65.2	32.7	0.5	1.69	995	0.6	9.31
JALEEB41	7/7/2008 11:06	JUL 08	57.8	35.3	0.3	6.6	0	0	43.5	200	62.8	35.3	0.3	1.64	997	1.61	5.47
JALEEB41	8/10/2008 9:42	AUG 08	57.6	34.4	0.8	7.2	0	0	45.8	200	60.6	34.1	0.4	1.67	991	1.48	4.18
JALEEB41	9/12/2008 10:09	SEP 08	55.8	32.2	0.9	11.1	0	0	39.3	200	58.3	32.1	0.9	1.73	1002	-17.66	7.7
JALEEB41	16/10/2008 11:33	OCT 08	54.5	31.9	1	12.6	0	0	35.4	200	62.7	31.8	1	1.71	1001	0.35	8.82
JALEEB41	11/15/2008 11:33	NOV 08	34.3	18.4	22.7	39.5	120	0	20.5	200	58	31	1.1	1.86	1004	0.27	8.41
JALEEB41	12/15/2008 12:15	DEC 08	57.6	34.4	0.8	7.2	0	0		200	60.6	34.1	0.4	1.67	1008	1.48	4.18
JALEEB41	9/1/2009 10:30	JAN 09	53.5	31.4	1.4	13.7	0	0	19.5	200	58	31	1.1	1.7	1004	0.27	8.41
JALEEB41	11/2/2009 3:42	FEB 09	56.7	35.4	0.1	7.8	4	32	27.8	200	56.5	35.3	0.2	1.6	1006	0.2	7.42
JALEEB41	17/3/2009 6:08	MAR 09	55.7	36.4	0.1	7.8	4	32	25.2	200	55.5	36.3	0.2	1.53	1006	0.2	7.42
JALEEB41	12/4/2009 8:37	APR 09	2.9	0.8	19.1	77.2	1	0	27.1	58	2.8	1.6	18.9	3.63	1003	0.19	5
JALEEB41	26/5/2009 8:48	MAY 09	53.1	35.8	0.5	10.6	6	79	36.5	200	53.2	35.9	0.4	1.48	992	1.04	8.71
JALEEB41	9/6/2009 10:30	JUN 09	55.5	33.1	0.6	10.8	0	0	38.5	200	62.9	33.1	0.6	1.68	997	-0.04	8.53
JALEEB41	11/7/2009 3:42	JUL 09	57.8	35.3	0.3	6.6	0	0	43.5	200	62.8	35.3	0.3	1.64	1002	1.61	5.47
JALEEB41	8/14/2009 9:19	AUG 09	53.5	31.4	1.4	13.7	0	0	37.1	200	58	31	1.1	1.7	1004	0.27	8.41
JALEEB41	9/4/2009 11:31	SEP 09	53.5	31.4	1.4	13.7	0	0	35	200	58	31	1.1	1.7	1002	0.27	8.41
JALEEB41	10/12/2009 10:09	OCT 09	55.8	32.2	0.9	11.1	0	0	33.3	200	58.3	32.1	0.9	1.73	1002	-17.66	7.7
JALEEB41	15/11/2009 11:33	NOV 09	57.6	34.4	0.8	7.2	0	0	29.3	200	60.6	34.1	0.4	1.67	1008	1.48	4.18
JALEEB41	26/12/2009 8:48	DEC 09	34.3	18.4	22.7	39.5	120	0	30.3	200	58	31	1.1	1.86	1004	0.27	8.41
JALEEB41	1/19/2010 10:30	JAN 10	60.9	36.2	0.3	2.6	0	0	20.8	200	61.1	36.4	0.3	1.68	1007	0.17	1.47
JALEEB41	3/2/2010 11:49	FEB 10	59.6	35.3	0.7	4.4	0	0	25.2	200	60	35.5	0.7	1.69	1005	1.48	1.75
JALEEB41	3/23/2010 10:31	MAR 10	62.4	36.2	0.4	1	0	0	27.6	200	62.3	36.1	0.4	1.72	1004	0.14	0
JALEEB41	4/22/2010 15:29	ARP 10	61.1	36.3	0.5	2.1	0	0	35.1	200	61.2	36.4	0.5	1.68	990	0.29	0.21
JALEEB41	5/23/2010 10:05	MAY 10	60.8	35.4	1	2.8	0	0	39.9	200	60.8	35.4	1	1.72	997	-0.14	0
JALEEB41	6/24/2010 10:46	JUN 10	28.3	16.1	10.4	45.2	0	0	45.8	200	28.4	16.1	10.4	1.76	990	-0.26	5.89
JALEEB41	7/25/2010 11:10	JUL 10	60.1	35.4	0.9	3.6	0	0	46.3	200	60	35.3	1	1.7	983	-20.73	0.2
JALEEB41	8/25/2010 9:38	AUG 10	50.5	30.6	3.2	15.7	0	0	48.5	200	50.5	30.6	3.2	1.65	985	0.04	3.6
JALEEB41	9/25/2010 11:41	SEP 10	45.6	27.8	4.7	21.9	0	0	46.7	200	45.6	27.8	4.7	1.64	994	-0.18	4.13
JALEEB41	10/20/2010 11:20	OCT 10	51.3	31.6	2.8	14.3	0	0	38	200	51.5	31.6	2.9	1.62	1000	0.49	3.72
JALEEB41	11/10/2010 11:17	NOV 10	37.1	23.2	6.9	32.8	0	0	26.5	200	37.1	23.2	6.9	1.6	1008	0.19	6.72
JALEEB41	12/22/2010 14:21	DEC 10	36.7	22.9	7.3	33.1	0	0	30.9	200	36.8	23	7.3	1.6	1006	0.07	5.51

Table App. 5.42: LFG measurements in Borehole 42

Jleeb Al Shuyoukh Landfill, LF Gas Monitoring																	BH 42
ID	DATE	MONTH	CH4	CO2	O2	BAL	NH3	H2S	TEMP	CH4 %	PEAK	PEAK	MIN	CH4/	BARO	REL.	Res
			%	%	%	%	ppm	ppm	DegC	LEL%	CH4%	CO2%	O2%	CO2%	mb	PRESS.mb	Nitro%
JALEEB42	4/3/2008 9:18	MAR 08	12.3	13.2	2.8	71.7	0	1	34.9	200	12.3	12.8	2.8	0.93	1002	0.13	61.12
JALEEB42	4/16/2008 11:38	APR 08	15.2	15.2	0.8	68.8	0	0	34	200	15.4	15	0.9	1	1003	-0.21	65.78
JALEEB42	5/19/2008 12:14	MAY 08	14.9	16.4	0.6	68.1	0	0	40.1	200	15.2	16.3	0.6	0.91	997	-0.24	65.83
JALEEB42	6/2/2008 9:29	JUN 08	10.3	10.7	4.6	74.4	0	25	41.5	200	10.1	11.2	4.8	0.96	995	-0.25	57.01
JALEEB42	7/7/2008 11:08	JUL 08	9.9	10	8	72.1	0	0	43.7	198	10	9.6	8	0.99	994	0.53	41.86
JALEEB42	8/10/2008 9:44	AUG 08	12.7	16.1	2.1	69.1	0	0	46.6	200	12.9	16.1	0.6	0.79	991	-0.01	61.16
JALEEB42	9/15/2008 10:09	SEP 08	12.3	13.2	2.8	71.7	1	0	43.5	200	12.3	12.8	2.8	0.93	1002	0.13	61.12
JALEEB42	16/10/2008 11:38	OCT 08	13.7	11.6	10	64.7	0	0	34.3	200	13.7	11.3	10	1.18	1001	-0.26	26.9
JALEEB42	11/15/2008 11:38	NOV 08	33.8	12.8	20.9	30.7	120	0	16.7	200	15.4	15	0.9	2.64	1003	-0.21	65.78
JALEEB42	12/14/2008 11:50	DEC 08	12.7	16.1	2.1	69.1	0	0		200	12.9	16.1	0.6	0.79	1010	-0.01	61.16
JALEEB42	9/1/2009 10:34	JAN 09	15.2	15.2	0.8	68.8	0	0	20.6	200	15.4	15	0.9	1	1003	-0.21	65.78
JALEEB42	11/2/2009 3:45	FEB 09	6.8	9.9	10.7	72.6	1	0	24.1	136	6.8	9.9	10.7	0.69	1003	0.08	32.15
JALEEB42	17/3/2009 6:13	MAR 09	8.9	0.4	19.2	71.5	2	0	27.5	178	8.8	1.1	18.4	22.25	1003	-0.03	0
JALEEB42	12/4/2009 8:39	APR 09	8.9	0.4	19.2	71.5	2	0	27.5	178	8.8	1.1	18.4	22.25	1003	-0.03	0
JALEEB42	26/5/2009 8:50	MAY 09	1	6.1	12.3	80.6	0	8	38.2	20	1.2	6.1	12.3	0.16	991	-0.08	34.11
JALEEB42	9/6/2009 10:34	JUN 09	14.3	16.7	0.5	68.5	0	0	39.7	200	14.7	16.6	0.5	0.86	997	-0.17	66.61
JALEEB42	11/7/2009 3:45	JUL 09	9.9	10	8	72.1	0	0	43.7	198	10	9.6	8	0.99	1002	0.53	41.86
JALEEB42	8/14/2009 9:27	AUG 09	15.2	15.2	0.8	68.8	0	0	36.1	200	15.4	15	0.9	1	1003	-0.21	65.78
JALEEB42	9/4/2009 11:13	SEP 09	15.2	15.2	0.8	68.8	0	0	34	200	15.4	15	0.9	1	1003	-0.21	65.78
JALEEB42	15/10/2009 10:09	OCT 09	12.3	13.2	2.8	71.7	1	0	34.9	200	12.3	12.8	2.8	0.93	1002	0.13	61.12
JALEEB42	15/11/2009 11:38	NOV 09	12.7	16.1	2.1	69.1	0	0	28.1	200	12.9	16.1	0.6	0.79	1010	-0.01	61.16
JALEEB42	26/12/2009 8:50	DEC 09	33.8	12.8	20.9	30.7	120	0	31.5	200	15.4	15	0.9	2.64	1003	-0.21	65.78
JALEEB42	1/19/2010 10:34	JAN 10	6.7	15.7	2	75.6	0	0	20.9	134	6.7	15.7	2	0.43	1007	0.1	68.04
JALEEB42	3/2/2010 11:52	FEB 10	5.5	15.6	1	77.9	0	0	25.2	110	5.5	15.6	1	0.35	1005	-0.05	74.12
JALEEB42	3/23/2010 10:34	MAR 10	3	8.1	7	81.9	0	0	28	60	4.5	12.8	5.1	0.37	1004	-0.03	55.44
JALEEB42	4/22/2010 15:34	ARP 10	5.9	17.4	0.3	76.4	0	3	33.7	118	5.9	17.4	0.3	0.34	990	-0.38	75.27
JALEEB42	5/23/2010 10:08	MAY 10	5.1	15.1	3.7	76.1	0	0	40.4	102	5.1	15.1	3.7	0.34	997	-0.1	62.11
JALEEB42	6/24/2010 10:48	JUN 10	2.8	7.7	11	78.5	0	0	39.9	56	2.8	7.7	11	0.36	990	-0.32	36.92
JALEEB42	7/25/2010 11:13	JUL 10	6	14.8	5	74.2	0	0	47.9	120	6	14.7	5.1	0.41	983	0.15	55.3
JALEEB42	8/25/2010 9:42	AUG 10	1.7	4.7	14.2	79.4	5	0	48.7	34	1.7	4.9	14.1	0.36	985	-0.14	25.72
JALEEB42	9/25/2010 11:43	SEP 10	6.2	15.1	4.7	74	0	0	47	124	6.2	15.1	4.8	0.41	993	-0.07	56.23
JALEEB42	10/20/2010 11:22	OCT 10	6.4	17.5	2.3	73.8	48	0	38.3	128	6.4	17.4	2.3	0.37	999	0.02	65.11
JALEEB42	11/10/2010 11:20	NOV 10	5.1	14.4	4.8	75.7	0	0	22.5	102	5.1	14.4	4.8	0.35	1008	0.25	57.56
JALEEB42	12/22/2010 14:24	DEC 10	4.9	15.1	4.6	75.4	0	1	22.6	98	5.1	15.7	4	0.32	1006	0.17	58.01

Table App. 5.43: LFG measurements in Borehole 43

Jleeb Al Shuyoukh Landfill, LF Gas Monitoring																	BH 43
ID	DATE	MONTH	CH4	CO2	O2	BAL	NH3	H2S	TEMP	CH4 %	PEAK	PEAK	MIN	CH4/	BARO	REL.	Res
			%	%	%	%	ppm	ppm	DegC	LEL%	CH4%	CO2%	O2%	CO2%	mb	PRESS.mb	Nitro%
JALEEB43	4/3/2008 9:24	MAR 08	20.9	14.4	7.1	57.6	0	1	34	200	22	14.3	7.1	1.45	1001	-40.67	30.76
JALEEB43	4/16/2008 11:43	APR 08	25.2	23.6	0.4	50.8	0	0	33.3	200	25.8	23.1	0.4	1.07	1003	1.67	49.29
JALEEB43	5/19/2008 12:20	MAY 08	24.7	25.2	0.4	49.7	0	0	38.6	200	26.4	24.8	0.4	0.98	997	-0.34	48.19
JALEEB43	6/2/2008 9:34	JUN 08	31.5	26.2	0.3	42	0	0	41.5	200	34.2	26.1	0.3	1.2	995	-0.31	40.87
JALEEB43	7/7/2008 11:10	JUL 08	33.7	29.1	0.2	37	0	0	45.1	200	34.1	28.9	0.2	1.16	992	-0.28	36.24
JALEEB43	8/10/2008 9:46	AUG 08	27.4	27.1	0.1	45.4	0	0	47	200	28.9	27.5	0.1	1.01	991	1.83	45.02
JALEEB43	9/15/2008 10:14	SEP 08	31.1	25.5	0.3	43.1	1	0	40.6	200	32	25.2	0.4	1.22	1002	0.24	41.97
JALEEB43	16/10/2008 11:43	OCT 08	26.9	15	8	50.1	0	1	34.8	200	27.1	14.9	8	1.79	1000	-0.26	19.86
JALEEB43	11/15/2008 11:43	NOV 08	28.6	27.4	0	23.1	0	0	18.1	200	25.8	23.1	0.4	1.04	1005	1.67	49.29
JALEEB43	12/15/2008 11:38	DEC 08	27.4	27.1	0.1	45.4	0	0		200	28.9	27.5	0.1	1.01	1008	1.83	45.02
JALEEB43	9/1/2009 10:38	JAN 09	25.2	23.6	0.4	50.8	0	0	19.8	200	25.8	23.1	0.4	1.07	1003	1.67	49.29
JALEEB43	11/2/2009 3:49	FEB 09	31.8	27.8	0.2	40.2	4	11	21.7	200	31.7	27.6	0.2	1.14	1006	4.71	39.44
JALEEB43	17/3/2009 6:16	MAR 09	25	27.7	0.1	47.2	1	0	23.7	200	24.9	27.7	0.1	0.9	1006	1.25	46.82
JALEEB43	12/4/2009 8:42	APR 09	10.9	0.3	19.2	69.6	0	0	29.9	200	22.2	2	17.2	36.33	1003	-0.13	0
JALEEB43	26/5/2009 8:53	MAY 09	23.5	27.5	0.3	48.7	5	11	38	200	24.9	27.7	0.3	0.85	991	-0.12	47.57
JALEEB43	9/6/2009 10:38	JUN 09	26.9	25.7	0.4	47	0	0	39.7	200	29.5	25.6	0.4	1.05	996	-0.21	45.49
JALEEB43	11/7/2009 3:49	JUL 09	33.7	29.1	0.2	37	0	0	45.1	200	34.1	28.9	0.2	1.16	1002	-0.28	36.24
JALEEB43	8/14/2009 9:32	AUG 09	25.2	23.6	0.4	50.8	0	0	38.2	200	25.8	23.1	0.4	1.07	1003	1.67	49.29
JALEEB43	9/4/2009 11:22	SEP 09	25.2	23.6	0.4	50.8	0	0	33.3	200	25.8	23.1	0.4	1.07	1003	1.67	49.29
JALEEB43	15/10/2009 10:14	OCT 09	31.1	25.5	0.3	43.1	1	0	35.5	200	32	25.2	0.4	1.22	1002	0.24	41.97
JALEEB43	15/11/2009 11:43	NOV 09	27.4	27.1	0.1	45.4	0	0	28.9	200	28.9	27.5	0.1	1.01	1008	1.83	45.02
JALEEB43	26/12/2009 8:53	DEC 09	28.6	27.4	0	23.1	0	0	29.2	200	25.8	23.1	0.4	1.04	1005	1.67	49.29
JALEEB43	1/19/2010 10:38	JAN 10	27.8	27	0.2	45	0	0	20.4	200	27.8	27	0.2	1.03	1007	0.24	44.24
JALEEB43	3/2/2010 11:55	FEB 10	28	26.5	0.4	45.1	0	0	24.9	200	28	26.6	0.4	1.06	1005	2.68	43.59
JALEEB43	3/23/2010 10:38	MAR 10	29.8	26.9	0.5	42.8	0	0	28.1	200	29.9	26.9	0.5	1.11	1004	0.02	40.91
JALEEB43	4/22/2010 15:37	ARP 10	18.7	21.6	3.4	56.3	0	0	37.3	200	18.7	21.6	3.4	0.87	990	-0.42	43.45
JALEEB43	5/23/2010 10:12	MAY 10	32.7	28.3	0.6	38.4	0	0	41.9	200	32.8	28.3	0.6	1.16	997	-0.13	36.13
JALEEB43	6/24/2010 10:54	JUN 10	15	12.5	10.8	61.7	0	0	45.6	200	15.1	12.6	10.8	1.2	990	-0.24	20.88
JALEEB43	7/25/2010 11:15	JUL 10	36	30.3	0.7	33	0	0	48.8	200	36.2	30.3	0.7	1.19	984	1.14	30.35
JALEEB43	8/29/2010 9:50	AUG 10	25.6	20.4	6.6	47.4	0	0	49.1	200	25.7	20.4	6.6	1.25	990	-0.12	22.45
JALEEB43	9/25/2010 11:46	SEP 10	27.2	26.8	1.4	44.6	0	0	45.7	200	27.2	26.7	1.4	1.01	994	0.59	39.31
JALEEB43	10/20/2010 11:25	OCT 10	28.6	26.4	1.8	43.2	0	0	34.1	200	29.4	26.5	1.8	1.08	999	0.14	36.4
JALEEB43	11/10/2010 11:23	NOV 10	27.2	25	2.6	45.2	0	0	27.9	200	27.2	24.9	2.6	1.09	1008	0.47	35.37
JALEEB43	12/22/2010 14:27	DEC 10	20.7	21.8	3.9	53.6	0	0	22.8	200	20.7	21.8	3.9	0.95	1006	0.35	38.86

Table App. 5.44: LFG measurements in Borehole 44

Jleeb Al Shuyoukh Landfill, LF Gas Monitoring																	BH 44
ID	DATE	MONTH	CH4	CO2	O2	BAL	NH3	H2S	TEMP	CH4 %	PEAK	PEAK	MIN	CH4/	BARO	REL.	Res
			%	%	%	%	ppm	ppm	DegC	LEL%	CH4%	CO2%	O2%	CO2%	mb	PRESS.mb	Nitro%
JALEEB44	4/3/2008 9:28	MAR 08	45.2	30	0.7	24.1	0	1	36.1	200	45.3	30	0.7	1.51	1002	0.8	21.45
JALEEB44	4/16/2008 11:48	APR 08	39.6	24.8	1.9	33.7	0	0	33.9	200	41.8	24.6	1.9	1.6	1003	1.62	26.52
JALEEB44	5/19/2008 12:25	MAY 08	39.3	26.4	1.1	33.2	0	0	39.5	200	41.7	26.1	1	1.49	998	-0.31	29.04
JALEEB44	6/2/2008 9:38	JUN 08	43.1	27	0.9	29	0	0	41.4	200	44.5	26.7	0.9	1.6	995	-0.3	25.6
JALEEB44	7/7/2008 11:14	JUL 08	41.2	25	1.5	32.3	0	0	44.1	200	41.9	24.9	1.5	1.65	991	-0.29	26.63
JALEEB44	8/10/2008 9:51	AUG 08	41.2	27.3	1.9	29.6	0	0	47.6	200	43.3	27.3	0.9	1.51	991	0.2	22.42
JALEEB44	9/15/2008 10:19	SEP 08	45.2	30	0.7	24.1	1	0	39.7	200	45.3	30	0.7	1.51	1002	0.8	21.45
JALEEB44	16/10/2008 11:48	OCT 08	39.8	20.5	4	35.7	0	0	35.9	200	41.9	20.3	4	1.94	999	0.8	20.58
JALEEB44	11/15/2008 11:48	NOV 08	41.5	39.4	0.1	19.1	0	0	18.7	200	41.8	24.6	1.9	1.05	1003	1.62	26.52
JALEEB44	12/14/2008 11:54	DEC 08	41.2	27.3	1.9	29.6	0	0		200	43.3	27.3	0.9	1.51	1009	0.2	22.42
JALEEB44	9/1/2009 10:41	JAN 09	39.6	24.8	1.9	33.7	0	0	22.9	200	41.8	24.6	1.9	1.6	1003	1.62	26.52
JALEEB44	11/2/2009 3:51	FEB 09	42.1	28.6	3.8	25.5	3	8	23.2	200	42.5	29.7	3.8	1.47	1004	-0.03	9.14
JALEEB44	17/3/2009 6:18	MAR 09	41.8	30.6	0.1	27.5	1	10	23.4	200	41.6	30.6	0.2	1.37	1006	0.17	27.12
JALEEB44	12/4/2009 8:44	APR 09	15.6	0.3	19.2	64.9	0	1	30	200	34.7	2.5	16.2	52	1003	0.05	0
JALEEB44	26/5/2009 8:55	MAY 09	38.8	30.9	0.2	30.1	1	11	38	200	40.6	31.5	0.2	1.26	992	2.26	29.34
JALEEB44	9/6/2009 10:41	JUN 09	41.2	27.1	0.5	31.2	0	0	40.2	200	43.2	26.9	0.5	1.52	997	-0.45	29.31
JALEEB44	11/7/2009 3:51	JUL 09	41.2	25	1.5	32.3	0	0	44.1	200	41.9	24.9	1.5	1.65	1002	-0.29	26.63
JALEEB44	8/14/2009 9:36	AUG 09	42.2	20.9	3.6	33.3	0	0	40.6	200	46.5	20.5	3.6	2.02	1006	0.76	19.69
JALEEB44	9/4/2009 11:18	SEP 09	39.6	24.8	1.9	33.7	0	0	33.9	200	41.8	24.6	1.9	1.6	1003	1.62	26.52
JALEEB44	15/10/2009 10:19	OCT 09	45.2	30	0.7	24.1	1	0	36.1	200	45.3	30	0.7	1.51	1002	0.8	21.45
JALEEB44	15/11/2009 11:48	NOV 09	41.2	27.3	1.9	29.6	0	0	27.1	200	43.3	27.3	0.9	1.51	1009	0.2	22.42
JALEEB44	26/12/2009 8:55	DEC 09	41.5	39.4	0.1	19.1	0	0	28.5	200	41.8	24.6	1.9	1.05	1003	1.62	26.52
JALEEB44	1/19/2010 10:41	JAN 10	41.3	28.5	0.7	29.5	0	0	20.6	200	41.9	28.5	0.7	1.45	1007	-0.07	26.85
JALEEB44	3/2/2010 11:58	FEB 10	42.1	27.3	1.2	29.4	0	0	24.7	200	43.9	27.4	1.2	1.54	1005	2.3	24.86
JALEEB44	3/23/2010 10:40	MAR 10	42.4	27	1.8	28.8	0	0	27.8	200	42.6	27	1.8	1.57	1004	4.28	22
JALEEB44	4/22/2010 15:39	ARP 10	40.5	28.9	0.6	30	0	0	37.3	200	40.5	28.8	0.6	1.4	990	-0.19	27.73
JALEEB44	5/23/2010 10:14	MAY 10	51.4	32.1	0.6	15.9	0	1	41.7	200	51.3	32	0.6	1.6	997	-0.1	13.63
JALEEB44	6/24/2010 10:55	JUN 10	46.3	31.3	1.1	21.3	0	0	46	200	46.5	31.3	1.1	1.48	990	-0.44	17.14
JALEEB44	7/25/2010 11:17	JUL 10	43	29	2.9	25.1	0	0	49.1	200	42.8	29	3	1.48	984	-0.14	14.14
JALEEB44	8/29/2010 9:52	AUG 10	33.7	22.5	6.6	37.2	0	0	50.4	200	33.8	22.5	6.5	1.5	990	-0.13	12.25
JALEEB44	9/25/2010 11:48	SEP 10	35	25.3	3.2	36.5	0	0	46.5	200	37	26.6	2.6	1.38	994	-0.25	24.4
JALEEB44	10/20/2010 11:28	OCT 10	41.2	28.8	1.7	28.3	0	0	35.1	200	41.4	28.8	1.7	1.43	1000	-0.11	21.87
JALEEB44	11/10/2010 11:27	NOV 10	19	12.1	11.7	57.2	0	0	25.8	200	19.6	12.1	11.7	1.57	1008	0.02	12.97
JALEEB44	12/22/2010 14:29	DEC 10	34.6	25.1	3.2	37.1	0	0	22	200	34.5	25.1	3.2	1.38	1006	0.56	25

Table App. 5.45: LFG measurements in Borehole 45

Jleeb Al Shuyoukh Landfill, LF Gas Monitoring																	BH 45
ID	DATE	MONTH	CH4	CO2	O2	BAL	NH3	H2S	TEMP	CH4 %	PEAK	PEAK	MIN	CH4/	BARO	REL.	Res
			%	%	%	%	ppm	ppm	DegC	LEL%	CH4%	CO2%	O2%	CO2%	mb	PRESS.mb	Nitro%
JALEEB45	4/3/2008 9:33	MAR 08	2	18.7	0.3	79	12	0	36.4	40	33.9	23.4	0.3	0.11	1002	0.78	77.87
JALEEB45	4/16/2008 12:21	APR 08	3.6	15.5	0.8	80.1	0	0	33.3	72	3.6	15.3	0.8	0.23	1002	-0.39	77.08
JALEEB45	5/19/2008 12:30	MAY 08	3.4	16.8	0.7	79.1	0	0	39.3	68	3.6	16.6	0.7	0.2	997	-0.42	76.45
JALEEB45	6/2/2008 9:43	JUN 08	0.5	13.2	1.8	84.5	0	0	41.6	10	0.5	12.5	1.8	0.04	995	-0.38	77.7
JALEEB45	7/7/2008 11:17	JUL 08	2	16.7	0.3	81	0	0	46.1	40	33.9	23.4	0.3	0.11	995	0.78	77.87
JALEEB45	8/10/2008 9:53	AUG 08	2.4	16.6	1.2	79.8	1	88	47.2	48	2.6	16.3	0.9	0.14	991	0.14	75.26
JALEEB45	9/15/2008 10:23	SEP 08	2	18.7	0.3	79	0	0	42.2	40	33.9	23.4	0.3	0.11	1002	0.78	77.87
JALEEB45	16/10/2008 12:21	OCT 08	6.2	6	14.7	73.1	0	1	33.8	124	6.2	7.8	14.7	1.03	1000	-3.68	17.53
JALEEB45	11/15/2008 12:21	NOV 08	3.2	18.1	0.3	78.6	0	1	18.8	72	3.6	15.3	0.8	0.18	1003	-0.39	77.08
JALEEB45	12/14/2008 11:45	DEC 08	2.4	16.6	1.2	79.8	1	88		48	2.6	16.3	0.9	0.14	1009	0.14	75.26
JALEEB45	9/1/2009 10:44	JAN 09	1.4	15.5	0.8	82.3	0	0	23.1	72	3.6	15.3	0.8	0.09	1002	-0.39	77.08
JALEEB45	11/2/2009 3:54	FEB 09	2.1	17.9	0.2	79.8	0	0	28.7	42	2.2	17.9	0.2	0.12	1003	-34.89	79.04
JALEEB45	17/3/2009 6:22	MAR 09	0.7	18.3	0.1	80.9	0	5	24.4	14	41.1	30.5	0.1	0.04	1006	1.89	80.52
JALEEB45	12/4/2009 8:48	APR 09	14.5	0.2	19.2	66.1	0	0	27.7	200	14.7	0.3	18.9	72.5	1003	-0.09	0
JALEEB45	26/5/2009 8:57	MAY 09	0	0	19.9	80.1	1	6	38.6	0	0	12.9	6.7	0	991	0.09	4.88
JALEEB45	9/6/2009 10:44	JUN 09	2.3	17.4	0.5	79.8	0	0	39.9	46	2.4	17.1	0.5	0.13	996	0	77.91
JALEEB45	11/7/2009 3:54	JUL 09	2	16.7	0.3	81	0	0	46.1	40	33.9	23.4	0.3	0.11	1003	0.78	77.87
JALEEB45	8/14/2009 9:41	AUG 09	3.6	15.5	0.8	80.1	0	0	41.5	72	3.6	15.3	0.8	0.23	1002	-0.39	77.08
JALEEB45	9/4/2009 11:08	SEP 09	3.6	15.5	0.8	80.1	0	0	33.3	72	3.6	15.3	0.8	0.23	1002	-0.39	77.08
JALEEB45	15/10/2009 10:26	OCT 09	2.1	17.9	0.2	79.8	0	0	35.3	42	2.2	17.9	0.2	0.12	1002	-34.89	79.04
JALEEB45	15/11/2009 12:21	NOV 09	2.4	16.6	1.2	79.8	1	88	27.3	48	2.6	16.3	0.9	0.14	1009	0.14	75.26
JALEEB45	26/12/2009 8:57	DEC 09	3.2	18.1	0.3	78.6	0	1	23.6	72	3.6	15.3	0.8	0.18	1003	-0.39	77.08
JALEEB45	1/19/2010 10:44	JAN 10	1.6	18.8	0.2	79.4	0	0	21.1	32	1.6	18.8	0.2	0.09	1007	-0.06	78.64
JALEEB45	3/2/2010 12:03	FEB 10	0.8	18	0.5	80.7	0	0	24	16	0.8	18	0.5	0.04	1005	-0.17	78.81
JALEEB45	3/23/2010 10:43	MAR 10	0.4	6.4	10.5	82.7	0	0	28.8	8	0.9	15.4	3.7	0.06	1004	-0.04	43.01
JALEEB45	4/22/2010 15:43	ARP 10	2.4	19.5	0.4	77.7	0	0	36	48	2.4	19.6	0.4	0.12	990	0.12	76.19
JALEEB45	5/23/2010 10:17	MAY 10	1.2	19.5	1.1	78.2	0	0	41	24	1.2	19.5	1.1	0.06	997	-0.14	74.04
JALEEB45	6/24/2010 10:58	JUN 10	1.3	21.4	0.5	76.8	0	0	45.5	26	1.3	21.5	0.5	0.06	990	0.55	74.91
JALEEB45	7/25/2010 11:21	JUL 10	1.2	19.9	1.9	77	0	0	48.2	24	11.7	19.9	2	0.06	984	0.34	69.82
JALEEB45	8/29/2010 9:59	AUG 10	17.8	14.8	10.1	57.3	0	0		200	29.4	19.5	7.7	1.2	990	-0.15	19.12
JALEEB45	9/25/2010 11:50	SEP 10	1.4	19	2.5	77.1	0	0	47	28	1.4	19.1	2.5	0.07	994	0.04	67.65
JALEEB45	10/20/2010 11:30	OCT 10	1.2	18.8	2.5	77.5	0	0	37.4	24	1.3	18.9	2.5	0.06	999	0.02	68.05
JALEEB45	11/10/2010 11:29	NOV 10	0.4	9.7	9.9	80	0	0	29.4	8	0.4	9.7	9.9	0.04	1008	0.07	42.58
JALEEB45	12/22/2010 14:31	DEC 10	1.7	17	3.5	77.8	0	0	23.2	34	1.7	16.9	3.5	0.1	1006	0.12	64.57

Table App. 5.46: LFG measurements in Borehole 46

Jleeb Al Shuyoukh Landfill, LF Gas Monitoring																	BH 46
ID	DATE	MONTH	CH4	CO2	O2	BAL	NH3	H2S	TEMP	CH4 %	PEAK	PEAK	MIN	CH4/	BARO	REL.	Res
			%	%	%	%	ppm	ppm	DegC	LEL%	CH4%	CO2%	O2%	CO2%	mb	PRESS.mb	Nitro%
JALEEB46	4/3/2008 10:00	MAR 08	21.1	23.5	1.6	53.8	1	0	36.6	200	21.8	23.5	1.7	0.9	1002	0.2	47.75
JALEEB46	4/16/2008 12:26	APR 08	21.1	21.5	2.8	54.6	0	0	37.3	200	21.8	20.9	2.3	0.98	1002	-0.12	44.02
JALEEB46	5/19/2008 12:34	MAY 08	24.5	24.2	1	50.3	0	0	39.9	200	25.5	24	1	1.01	997	-0.3	46.52
JALEEB46	6/2/2008 9:48	JUN 08	17.6	18.7	4.2	59.5	0	0	42.5	200	18	18.5	4.2	0.94	995	-0.27	43.62
JALEEB46	7/7/2008 11:18	JUL 08	18.5	18.7	4.3	58.5	0	0	44.8	200	19.9	18.5	4.3	0.99	996	2.13	42.25
JALEEB46	8/10/2008 9:55	AUG 08	24.6	25.4	2	48	0	0	46.3	200	25.1	25.2	1.7	0.97	991	0.82	40.44
JALEEB46	9/15/2008 10:30	SEP 08	21.1	23.5	1.6	53.8	0	0	45.4	200	21.8	23.5	1.7	0.9	1002	0.2	47.75
JALEEB46	16/10/2008 12:26	OCT 08	26.9	15	8	50.1	1	0	34.8	200	27.1	14.9	8	1.79	1000	-0.26	19.86
JALEEB46	11/15/2008 12:26	NOV 08	22.6	28.6	12.7	48.5	118	0	17.5	200	21.8	20.9	2.3	0.79	1003	-0.12	44.02
JALEEB46	12/13/2008 16:56	DEC 08	24.6	25.4	2	48	0	0	17	200	25.1	25.2	1.7	0.97	1008	0.82	40.44
JALEEB46	9/1/2009 10:49	JAN 09	21.1	21.5	2.8	54.6	0	0	30.2	200	21.8	20.9	2.3	0.98	1002	-0.12	44.02
JALEEB46	11/2/2009 5:07	FEB 09	18.8	20.8	4.7	55.7	0	12	26.2	200	19	21.1	4.7	0.9	1004	0	37.93
JALEEB46	17/3/2009 6:26	MAR 09	21.3	25.8	0.5	52.4	0	0	25.4	200	23	25.7	0.5	0.83	1003	0.06	50.51
JALEEB46	12/4/2009 8:51	APR 09	18.9	0.1	19.3	61.7	0	0	26.1	200	18.8	0.2	19	189	1002	-0.03	0
JALEEB46	26/5/2009 8:59	MAY 09	17.8	25.9	1	55.3	4	27	40.2	200	17.9	26	1.1	0.69	991	0.3	51.52
JALEEB46	9/6/2009 10:49	JUN 09	25	25.9	0.9	48.2	0	0	41.3	200	27.1	25.8	0.9	0.97	996	-0.12	44.8
JALEEB46	11/7/2009 5:07	JUL 09	18.5	18.7	4.3	58.5	0	0	44.8	200	19.9	18.5	4.3	0.99	1004	2.13	42.25
JALEEB46	8/14/2009 9:50	AUG 09	21.1	21.5	2.8	54.6	0	0	41.5	200	21.8	20.9	2.3	0.98	1002	-0.12	44.02
JALEEB46	9/4/2009 10:59	SEP 09	21.1	21.5	2.8	54.6	0	0	37.3	200	21.8	20.9	2.3	0.98	1002	-0.12	44.02
JALEEB46	15/10/2009 10:30	OCT 09	21.1	23.5	1.6	53.8	0	0	36.6	200	21.8	23.5	1.7	0.9	1002	0.2	47.75
JALEEB46	15/11/2009 12:26	NOV 09	24.6	25.4	2	48	0	0	27.9	200	25.1	25.2	1.7	0.97	1008	0.82	40.44
JALEEB46	26/12/2009 8:59	DEC 09	22.6	28.6	12.7	48.5	118	0	24.7	200	21.8	20.9	2.3	0.79	1003	-0.12	44.02
JALEEB46	1/19/2010 10:49	JAN 10	26.7	27.2	0.8	45.3	0	0	26.3	200	26.8	27.2	0.8	0.98	1007	0.27	42.28
JALEEB46	3/2/2010 12:07	FEB 10	11.2	13.8	7.1	67.9	0	0	26.9	200	11.2	13.8	7.1	0.81	1005	-0.01	41.06
JALEEB46	3/23/2010 10:46	MAR 10	17.6	19.7	4.5	58.2	0	0	30.1	200	17.6	19.7	4.5	0.89	1004	0.17	41.19
JALEEB46	4/22/2010 15:46	ARP 10	25.7	28.1	0.4	45.8	0	0	39.7	200	25.9	28.3	0.4	0.91	990	-0.14	44.29
JALEEB46	5/23/2010 10:21	MAY 10	14.5	17.7	5.4	62.4	0	0		200	14.6	17.7	5.4	0.82	997	-0.2	41.99
JALEEB46	6/24/2010 11:02	JUN 10	20.3	24.4	1.8	53.5	0	0	47.5	200	20.3	24.4	0.5	0.83	989	-18.86	46.7
JALEEB46	7/25/2010 11:24	JUL 10	16.7	19.6	4.5	59.2	0	0	50.7	200	16.7	19.6	4.5	0.85	984	-0.07	42.19
JALEEB46	8/29/2010 10:04	AUG 10	40.5	26.5	6.2	26.8	0	0	50	200	38.1	24.6	7.3	1.53	990	-11.82	3.36
JALEEB46	9/25/2010 11:52	SEP 10	22.1	24.1	3.3	50.5	0	0	51.2	200	22.3	24.2	3.3	0.92	993	-0.24	38.03
JALEEB46	10/20/2010 11:33	OCT 10	20.4	22	4.6	53	0	0	46.9	200	20.5	22.1	4.6	0.93	999	-0.08	35.61
JALEEB46	11/10/2010 11:32	NOV 10	11.3	13.8	8.4	66.5	0	0	33.9	200	11.9	14.3	8.2	0.82	1008	0.2	34.75
JALEEB46	12/22/2010 14:33	DEC 10	22	24.5	3.2	50.3	0	0	27.6	200	22	24.5	3.3	0.9	1006	0.27	38.2

Table App. 5.47: LFG measurements in Borehole 47

Jleeb Al Shuyoukh Landfill, LF Gas Monitoring																	BH 47
ID	DATE	MONTH	CH4	CO2	O2	BAL	NH3	H2S	TEMP	CH4 %	PEAK	PEAK	MIN	CH4/	BARO	REL.	Res
			%	%	%	%	ppm	ppm	DegC	LEL%	CH4%	CO2%	O2%	CO2%	mb	PRESS.mb	Nitro%
JALEEB47	4/3/2008 9:39	MAR 08	45.3	31.5	0.3	22.9	0	0	36.2	200	46.9	31.5	0.3	1.44	1002	0.16	21.77
JALEEB47	4/16/2008 12:16	APR 08	44	30.8	0.4	24.8	0	0	34	200	48.5	30.6	0.4	1.43	1002	-0.15	23.29
JALEEB47	5/20/2008 10:50	MAY 08	44.6	31.4	0.5	23.5	0	0	37.6	200	48.8	31.3	0.5	1.42	1000	-0.01	21.61
JALEEB47	6/2/2008 9:53	JUN 08	43.2	28.7	0.4	27.7	0	0	41.6	200	44.2	28.6	0.4	1.51	994	-0.32	26.19
JALEEB47	7/7/2008 11:20	JUL 08	43.4	29.6	1.9	25.1	1	0	42.9	200	49.3	29.5	1.9	1.47	994	0.05	17.92
JALEEB47	8/10/2008 9:57	AUG 08	48.6	34.6	0.6	16.2	0	0	46.6	200	50.6	34.5	0.3	1.4	991	0.11	13.93
JALEEB47	9/15/2008 10:35	SEP 08	45.3	31.5	0.3	22.9	0	0	40.5	200	46.9	31.5	0.3	1.44	1002	0.16	21.77
JALEEB47	16/10/2008 12:16	OCT 08	41.4	24	0.4	34.2	0	0	34.5	200	43.4	23.7	0.5	1.73	996	3.9	32.69
JALEEB47	11/15/2008 12:16	NOV 08	48.6	33.8	0.4	4.9	0	3	17.1	200	48.5	30.6	0.4	1.44	1003	-0.15	23.29
JALEEB47	12/13/2008 17:00	DEC 08	48.6	34.6	0.6	16.2	0	0	15.2	200	50.6	34.5	0.3	1.4	1008	0.11	13.93
JALEEB47	9/1/2009 10:53	JAN 09	44	30.8	0.4	24.8	0	0	17.2	200	48.5	30.6	0.4	1.43	1002	-0.15	23.29
JALEEB47	11/2/2009 5:11	FEB 09	44.9	28.7	1	25.4	0	0	22.9	200	52.7	28.4	1	1.56	1005	-0.37	21.62
JALEEB47	17/3/2009 6:29	MAR 09	39.7	33.7	0.2	26.4	2	0	25.2	200	39.7	33.8	0.2	1.18	1006	0.07	25.64
JALEEB47	12/4/2009 8:54	APR 09	34.8	29.5	2.5	33.2	2	3	31.2	200	34.6	29.5	2.5	1.18	1002	0.39	23.75
JALEEB47	26/5/2009 9:02	MAY 09	39.4	34.2	0.3	26.1	4	20	38.3	200	41.1	34.3	0.2	1.15	991	1.67	24.97
JALEEB47	9/6/2009 10:53	JUN 09	45.5	31.2	0.4	22.9	0	0	39.8	200	47	31.1	0.4	1.46	996	-0.47	21.39
JALEEB47	11/7/2009 5:11	JUL 09	43.4	29.6	1.9	25.1	1	0	42.9	200	49.3	29.5	1.9	1.47	1004	0.05	17.92
JALEEB47	8/14/2009 9:55	AUG 09	44	30.8	0.4	24.8	0	0	41.4	200	48.5	30.6	0.4	1.43	1002	-0.15	23.29
JALEEB47	9/4/2009 11:04	SEP 09	44	30.8	0.4	24.8	0	0	34	200	48.5	30.6	0.4	1.43	1002	-0.15	23.29
JALEEB47	15/10/2009 10:35	OCT 09	45.3	31.5	0.3	22.9	0	0	36.2	200	46.9	31.5	0.3	1.44	1002	0.16	21.77
JALEEB47	15/11/2009 12:16	NOV 09	48.6	34.6	0.6	16.2	0	0	26.5	200	50.6	34.5	0.3	1.4	1008	0.11	13.93
JALEEB47	26/12/2009 9:02	DEC 09	48.6	33.8	0.4	4.9	0	3	24.8	200	48.5	30.6	0.4	1.44	1003	-0.15	23.29
JALEEB47	1/19/2010 10:53	JAN 10	48.3	34.6	0.2	16.9	0	0	21.6	200	48.6	34.7	0.2	1.4	1007	0.19	16.14
JALEEB47	3/2/2010 12:10	FEB 10	47	33.4	0.2	19.4	0	0	25.9	200	47.3	33.6	0.2	1.41	1005	-0.1	18.64
JALEEB47	3/23/2010 10:49	MAR 10	45.2	32.6	0.7	21.5	0	0	28.4	200	45.2	32.7	0.7	1.39	1004	0.01	18.85
JALEEB47	4/22/2010 15:48	ARP 10	46.7	33.8	0.4	19.1	0	0	36	200	46.7	33.8	0.4	1.38	990	0.26	17.59
JALEEB47	5/23/2010 10:24	MAY 10	40.8	30.7	1.6	26.9	0	0	42.2	200	41	30.8	1.5	1.33	997	-0.15	20.85
JALEEB47	6/24/2010 11:04	JUN 10	47.9	34.6	0.5	17	0	0	47.2	200	48	34.6	0.5	1.38	989	0.84	15.11
JALEEB47	7/25/2010 11:27	JUL 10	46.8	34.5	0.7	18	0	0	50.7	200	46.9	34.5	0.7	1.36	984	0.72	15.35
JALEEB47	8/29/2010 10:04	AUG 10	41.2	27.5	5.1	26.2	0	0	49.7	200	41	27.4	5.1	1.5	990	-13.18	6.92
JALEEB47	9/25/2010 11:55	SEP 10	43.2	31.8	2.3	22.7	0	0	47.4	200	43.2	31.8	2.4	1.36	993	-0.26	14.01
JALEEB47	10/20/2010 11:35	OCT 10	41.4	30.5	3	25.1	0	0	39.8	200	41.5	30.5	3.1	1.36	999	0.05	13.76
JALEEB47	11/10/2010 11:34	NOV 10	38.1	28.4	3.8	29.7	0	0	28.1	200	38.1	28.4	3.8	1.34	1008	0	15.34
JALEEB47	12/22/2010 14:35	DEC 10	42.2	30.9	2.7	24.2	0	0	29.3	200	42.2	30.9	2.8	1.37	1006	0.57	13.99

Table App. 5.48: LFG measurements in Borehole 48

Jleeb Al Shuyoukh Landfill, LF Gas Monitoring																	BH 48
ID	DATE	MONTH	CH4	CO2	O2	BAL	NH3	H2S	TEMP	CH4 %	PEAK	PEAK	MIN	CH4/	BARO	REL.	Res
			%	%	%	%	ppm	ppm	DegC	LEL%	CH4%	CO2%	O2%	CO2%	mb	PRESS.mb	Nitro%
JALEEB48	4/3/2008 9:45	MAR 08	8.2	10.5	8.6	72.7	15	0	34.7	164	8.2	10.4	8.6	0.78	1000	1.77	40.19
JALEEB48	4/16/2008 12:11	APR 08	23.5	20.9	1.8	53.8	0	0	34.8	200	23.8	20.9	1.9	1.12	1002	-0.13	47
JALEEB48	5/20/2008 11:03	MAY 08	16.5	14.6	5.2	63.7	0	0	38.5	200	17.1	14.3	5.2	1.13	1000	-0.06	44.04
JALEEB48	6/2/2008 10:04	JUN 08	21.4	18.2	1.6	58.8	0	0	42.4	200	21.6	17.5	1.6	1.18	995	-0.75	52.75
JALEEB48	7/7/2008 11:22	JUL 08	21.5	17.9	6.5	54.1	1	0	44.2	200	22.7	17.9	6.5	1.2	995	-0.32	29.53
JALEEB48	8/10/2008 9:59	AUG 08	18.6	22.7	2.4	56.3	0	0	47.4	200	19.1	22.5	2.2	0.82	991	0.12	47.23
JALEEB48	9/15/2008 10:44	SEP 08	20.9	19.7	2.5	56.9	0	0	43.2	200	21.9	19.2	2.5	1.06	1003	0.03	47.45
JALEEB48	16/10/2008 12:11	OCT 08	20.9	14.4	7.1	57.6	0	1	34	200	22	14.3	7.1	1.45	1001	-40.67	30.76
JALEEB48	11/15/2008 12:11	NOV 08	23.5	20.9	1.8	53.8	0	0	24.8	200	23.8	20.9	1.9	1.12	1002	-0.13	47
JALEEB48	12/13/2008 16:52	DEC 08	18.6	22.7	2.4	56.3	0	0	14.8	200	19.1	22.5	2.2	0.82	1008	0.12	47.23
JALEEB48	9/1/2009 10:56	JAN 09	23.5	20.9	1.8	53.8	0	0	25.3	200	23.8	20.9	1.9	1.12	1002	-0.13	47
JALEEB48	11/2/2009 5:15	FEB 09	22.3	16	0.7	61	0	10	23.2	200	29.5	17.8	0.6	1.39	1004	0.1	15.33
JALEEB48	17/3/2009 6:32	MAR 09	21.3	17.3	1.4	60	0	0	23.1	200	21.9	17.1	1.3	1.23	1002	-11.35	35.59
JALEEB48	12/4/2009 8:56	APR 09	37.3	0.9	19.1	42.7	0	2	28	200	37.2	3.6	17.9	41.44	1003	-0.03	0
JALEEB48	26/5/2009 9:04	MAY 09	16.5	24.3	0.8	58.4	2	10	39.2	200	17	24.5	0.8	0.68	991	0.34	55.38
JALEEB48	9/6/2009 10:56	JUN 09	23.8	23.1	1.1	52	0	0	40.4	200	26.7	22.9	1.1	1.03	997	-0.53	47.84
JALEEB48	11/7/2009 5:15	JUL 09	21.5	17.9	6.5	54.1	1	0	44.2	200	22.7	17.9	6.5	1.2	1004	-0.32	29.53
JALEEB48	8/14/2009 10:00	AUG 09	23.5	20.9	1.8	53.8	0	0	41.6	200	23.8	20.9	1.9	1.12	1002	-0.13	47
JALEEB48	9/4/2009 10:49	SEP 09	23.5	20.9	1.8	53.8	0	0	34.8	200	23.8	20.9	1.9	1.12	1002	-0.13	47
JALEEB48	15/10/2009 10:44	OCT 09	20.9	19.7	2.5	56.9	0	0	35.5	200	21.9	19.2	2.5	1.06	1003	0.03	47.45
JALEEB48	15/11/2009 12:11	NOV 09	18.6	22.7	2.4	56.3	0	0	26.1	200	19.1	22.5	2.2	0.82	1008	0.12	47.23
JALEEB48	26/12/2009 9:04	DEC 09	23.5	20.9	1.8	53.8	0	0	23.6	200	23.8	20.9	1.9	1.12	1002	-0.13	47
JALEEB48	1/19/2010 10:56	JAN 10	21.3	25	0.6	53.1	0	0	21	200	21.3	25	0.6	0.85	1007	0.06	50.83
JALEEB48	3/2/2010 12:13	FEB 10	15.9	17.6	3.8	62.7	0	0	25.7	200	16	17.6	3.8	0.9	1005	-0.2	48.34
JALEEB48	3/23/2010 10:52	MAR 10	16.7	19.2	2.8	61.3	0	0	29.1	200	16.7	19.2	2.8	0.87	1004	1.57	50.72
JALEEB48	4/22/2010 15:52	ARP 10	23	25.6	0.7	50.7	0	0	36.7	200	23	25.5	0.8	0.9	990	0.03	48.05
JALEEB48	5/23/2010 10:27	MAY 10	15.8	19.2	2.9	62.1	0	0	43.2	200	16.2	19.2	3.1	0.82	997	-0.2	51.14
JALEEB48	6/24/2010 11:07	JUN 10	19	21.6	2.2	57.2	0	0	47.2	200	19.3	21.7	2.2	0.88	989	-0.29	48.88
JALEEB48	7/25/2010 11:29	JUL 10	15.8	18.3	3.5	62.4	0	0	49.6	200	16	18.4	3.5	0.86	984	-0.14	49.17
JALEEB48	8/29/2010 10:05	AUG 10	41.9	27.3	4.9	25.9	0	0	49.5	200	41.8	27.4	4.9	1.53	990	-13.25	7.38
JALEEB48	9/25/2010 11:57	SEP 10	20.3	22.4	3.2	54.1	0	0	47.8	200	20.4	22.4	3.2	0.91	993	1.17	42
JALEEB48	10/20/2010 11:37	OCT 10	19.3	21.4	3.9	55.4	0	0	39.2	200	19.4	21.4	3.9	0.9	999	0.03	40.66
JALEEB48	11/10/2010 11:36	NOV 10	13.6	14.9	7.3	64.2	0	0	27.1	200	13.6	14.9	7.3	0.91	1008	0.03	36.61
JALEEB48	12/22/2010 14:37	DEC 10	18.5	20.1	4.7	56.7	0	0	22.7	200	18.6	20.2	4.7	0.92	1006	0.26	38.93

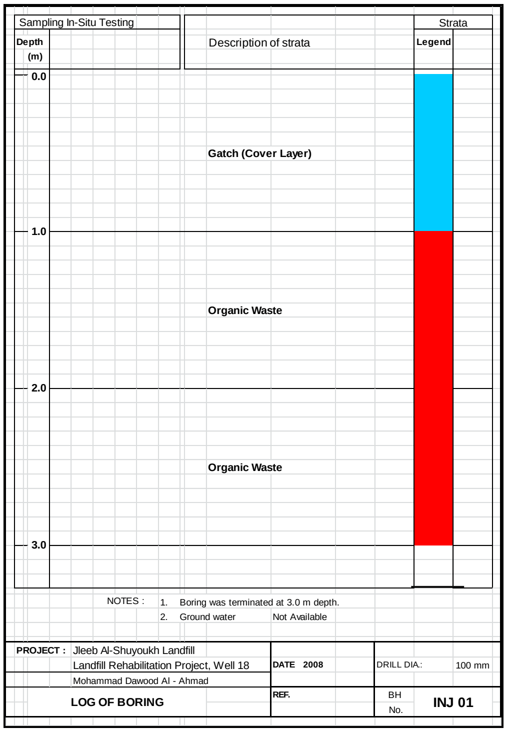
Table App. 5.49: LFG measurements in Borehole 49

Jleeb Al Shuyoukh Landfill, LF Gas Monitoring																	BH 49
ID	DATE	MONTH	CH4	CO2	O2	BAL	NH3	H2S	TEMP	CH4 %	PEAK	PEAK	MIN	CH4/	BARO	REL.	Res
			%	%	%	%	ppm	ppm	DegC	LEL%	CH4%	CO2%	O2%	CO2%	mb	PRESS.mb	Nitro%
JALEEB49	4/3/2008 9:50	MAR 08	37	20	5.7	37.3	0	0	28	200	38	19.8	5.7	1.85	1004	-0.13	15.75
JALEEB49	4/16/2008 12:06	APR 08	47.4	30.1	2.2	20.3	0	0	40	200	51	29.8	1.2	1.57	1002	-0.01	11.98
JALEEB49	5/20/2008 11:08	MAY 08	50.3	32.4	0.6	16.7	0	0	37.5	200	56.8	32.3	0.6	1.55	999	-0.19	14.43
JALEEB49	6/2/2008 10:12	JUN 08	50	33.4	0.4	16.2	0	0	41.7	200	57.8	33	0.4	1.5	994	-0.42	14.69
JALEEB49	7/7/2008 11:25	JUL 08	52.9	33.9	0.4	12.8	0	0	46.7	200	54.4	33.9	0.4	1.56	996	-5.07	11.29
JALEEB49	8/10/2008 10:01	AUG 08	51.8	35	0.7	12.5	0	0	47.8	200	53.1	34.8	0.3	1.48	991	0.11	9.85
JALEEB49	9/15/2008 10:51	SEP 08	51.8	33.4	0.4	14.4	0	0	45.8	200	56.7	33.4	0.4	1.55	1002	0.16	12.89
JALEEB49	16/10/2008 12:06	OCT 08	52.6	32.8	0.5	14.1	0	0	34.2	200	55.8	32.7	0.5	1.6	1000	0.28	12.21
JALEEB49	11/15/2008 12:06	NOV 08	42.7	32.3	1.9	23.2	0	0	20	200	51	29.8	1.2	1.32	1002	-0.01	11.98
JALEEB49	12/13/2008 16:48	DEC 08	51.8	35	0.7	12.5	0	0	12.6	200	53.1	34.8	0.3	1.48	1008	0.11	9.85
JALEEB49	9/1/2009 11:00	JAN 09	47.4	30.1	2.2	20.3	0	0	18.1	200	51	29.8	1.2	1.57	1002	-0.01	11.98
JALEEB49	11/2/2009 5:17	FEB 09	51.4	35.7	0.4	12.5	6	37	21.8	200	51.4	35.7	0.4	1.44	1006	-0.05	10.99
JALEEB49	17/3/2009 6:35	MAR 09	13.4	9.9	16.5	60.2	2	6	23	200	7.3	8.2	12.5	1.35	1006	0	0
JALEEB49	12/4/2009 8:59	APR 09	47	33.9	0.6	18.5	6	132	30.5	200	48.4	34.2	0.6	1.39	1001	0.97	16.23
JALEEB49	26/5/2009 9:06	MAY 09	50.3	35.5	0.2	14	6	205	38.1	200	50.8	36.1	0.2	1.42	991	0.18	13.24
JALEEB49	9/6/2009 11:00	JUN 09	49.5	32.5	0.6	17.4	0	0	39.5	200	54.5	32.3	0.7	1.52	996	0.48	15.13
JALEEB49	11/7/2009 5:17	JUL 09	52.9	33.9	0.4	12.8	0	0	46.7	200	54.4	33.9	0.4	1.56	1003	-5.07	11.29
JALEEB49	8/14/2009 10:05	AUG 09	47.4	30.1	2.2	20.3	0	0	41.3	200	51	29.8	1.2	1.57	1002	-0.01	11.98
JALEEB49	9/4/2009 10:45	SEP 09	52.6	32.8	0.5	14.1	0	0	34.2	200	55.8	32.7	0.5	1.6	1000	0.28	12.21
JALEEB49	15/10/2009 10:51	OCT 09	51.8	33.4	0.4	14.4	0	0	35.5	200	56.7	33.4	0.4	1.55	1002	0.16	12.89
JALEEB49	15/11/2009 12:06	NOV 09	51.8	35	0.7	12.5	0	0	25.4	200	53.1	34.8	0.3	1.48	1008	0.11	9.85
JALEEB49	26/12/2009 9:06	DEC 09	42.7	32.3	1.9	23.2	0	0	24.6	200	51	29.8	1.2	1.32	1002	-0.01	11.98
JALEEB49	1/19/2010 11:00	JAN 10	54.3	34.9	0.2	10.6	0	0	20.7	200	54.2	34.9	0.3	1.56	1007	0.4	9.84
JALEEB49	3/2/2010 12:17	FEB 10	51.7	32.8	1.1	14.4	0	0	26.3	200	51.6	32.8	1.1	1.58	1005	-0.03	10.24
JALEEB49	3/23/2010 10:55	MAR 10	55	34.7	0.4	9.9	0	0	28.2	200	55	34.7	0.4	1.59	1004	0.02	8.39
JALEEB49	4/22/2010 15:55	ARP 10	46	32.3	2	19.7	0	0	36.7	200	46	32.2	2	1.42	990	0.04	12.14
JALEEB49	5/23/2010 10:30	MAY 10	54.8	34.2	0.9	10.1	0	1	43.5	200	54.9	34.2	0.9	1.6	997	-0.12	6.7
JALEEB49	6/24/2010 11:09	JUN 10	56.1	36.4	0.6	6.9	0	1	45.9	200	56.4	36.6	0.6	1.54	989	-0.31	4.63
JALEEB49	7/25/2010 11:31	JUL 10	56	36	1.1	6.9	0	3	50	200	56.1	36.2	1.1	1.56	984	0.19	2.74
JALEEB49	8/29/2010 10:09	AUG 10	29.6	20.7	7.7	42	0	0	51.3	200	29.4	20.5	7.8	1.43	990	-0.23	12.89
JALEEB49	9/25/2010 11:59	SEP 10	53.1	35.5	1.2	10.2	0	0	46.7	200	53.3	35.6	1.2	1.5	993	0.68	5.66
JALEEB49	10/20/2010 11:39	OCT 10	47	32.8	2.5	17.7	0	0	39.9	200	47	32.9	2.5	1.43	999	0.18	8.25
JALEEB49	11/10/2010 11:38	NOV 10	48.4	32.7	2.3	16.6	0	0	25	200	48.5	32.8	2.3	1.48	1008	0.08	7.91
JALEEB49	12/22/2010 14:39	DEC 10	40.3	28.5	4.2	27	0	0	22.6	200	40.3	28.5	4.3	1.41	1006	0.24	11.12

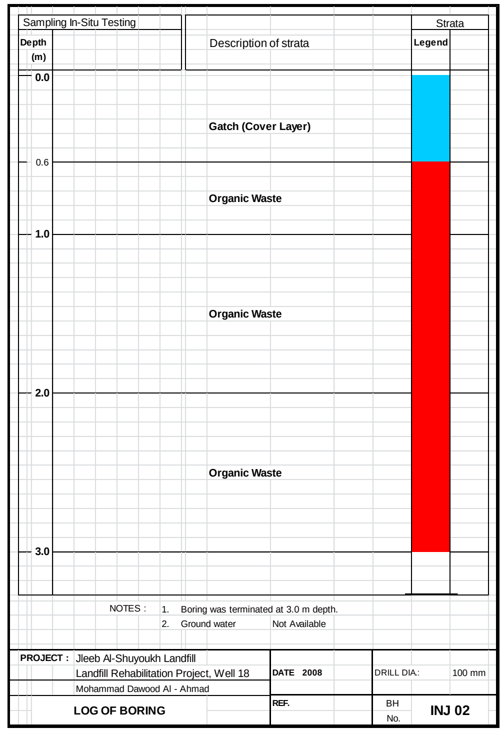
Table App. 5.50: LFG measurements in Borehole 50

Jleeb Al Shuyoukh Landfill, LF Gas Monitoring																	BH 50
ID	DATE	MONTH	CH4	CO2	O2	BAL	NH3	H2S	TEMP	CH4 %	PEAK	PEAK	MIN	CH4/	BARO	REL.	Res
			%	%	%	%	ppm	ppm	DegC	LEL%	CH4%	CO2%	O2%	CO2%	mb	PRESS.mb	Nitro%
JALEEB50	4/3/2008 9:54	MAR 08	29.6	23.4	4	43	0	0	27.2	200	30.7	23.1	4	1.26	1004	-0.08	27.88
JALEEB50	4/16/2008 12:01	APR 08	35.4	27.2	0.7	36.7	0	0	33.3	200	39.4	26.4	0.8	1.3	1002	-0.04	34.05
JALEEB50	5/20/2008 11:13	MAY 08	33.2	29	0.6	37.2	0	0	37.9	200	35.8	28.9	0.6	1.14	999	0.01	34.93
JALEEB50	6/2/2008 10:16	JUN 08	33.4	29.8	0.4	36.4	0	0	42.2	200	37.5	29.6	0.4	1.12	994	-0.44	34.89
JALEEB50	7/7/2008 11:28	JUL 08	33.2	29	0.6	37.2	0	0	47.1	200	35.8	28.9	0.6	1.14	996	0.01	34.93
JALEEB50	8/10/2008 10:03	AUG 08	36.4	30.9	1.7	31	0	0	46.5	200	36.9	30.9	0.6	1.18	991	0.22	24.57
JALEEB50	9/15/2008 10:55	SEP 08	33.9	30.2	0.4	35.5	0	0	41.2	200	34.4	30.1	0.4	1.12	1002	0.41	33.99
JALEEB50	16/10/2008 12:01	OCT 08	33.6	29.7	0.6	36.1	0	0	34.5	200	36	29.7	0.6	1.13	1000	-0.09	33.83
JALEEB50	11/15/2008 12:01	NOV 08	30.4	28.2	3	38.4	0	0	19	200	39.4	26.4	0.8	1.08	1003	-0.04	34.05
JALEEB50	12/13/2008 16:40	DEC 08	36.4	30.9	1.7	31	0	0	15.6	200	36.9	30.9	0.6	1.18	1008	0.22	24.57
JALEEB50	9/1/2009 11:03	JAN 09	35.4	27.2	0.7	36.7	0	0	21.7	200	39.4	26.4	0.8	1.3	1002	-0.04	34.05
JALEEB50	11/2/2009 5:20	FEB 09	31.8	27.8	0.2	40.2	4	11	23.6	200	31.7	27.6	0.2	1.14	1006	4.71	39.44
JALEEB50	17/3/2009 6:39	MAR 09	30.6	30.8	1.1	37.5	0	6	24.2	200	30.8	30.9	1	0.99	1006	0.11	33.34
JALEEB50	12/4/2009 9:02	APR 09	28.7	29.8	1.1	40.4	0	14	31	200	28.6	29.8	1.1	0.96	1001	0.32	36.24
JALEEB50	26/5/2009 9:09	MAY 09	29	31.2	0.3	39.5	0	32	37.7	200	29	31.3	0.2	0.93	991	0.04	38.37
JALEEB50	9/6/2009 11:03	JUN 09	34.3	29.1	0.5	36.1	0	0	39.7	200	35.7	28.9	0.5	1.18	996	0.22	34.21
JALEEB50	11/7/2009 5:20	JUL 09	33.2	29	0.6	37.2	0	0	47.1	200	35.8	28.9	0.6	1.14	1003	0.01	34.93
JALEEB50	8/14/2009 10:10	AUG 09	35.4	27.2	0.7	36.7	0	0	39.8	200	39.4	26.4	0.8	1.3	1002	-0.04	34.05
JALEEB50	9/4/2009 10:41	SEP 09	33.6	29.7	0.6	36.1	0	0	34.5	200	36	29.7	0.6	1.13	1000	-0.09	33.83
JALEEB50	15/10/2009 10:55	OCT 09	33.9	30.2	0.4	35.5	0	0	35.5	200	34.4	30.1	0.4	1.12	1002	0.41	33.99
JALEEB50	15/11/2009 12:01	NOV 09	36.4	30.9	1.7	31	0	0	26.2	200	36.9	30.9	0.6	1.18	1008	0.22	24.57
JALEEB50	26/12/2009 9:09	DEC 09	30.4	28.2	3	38.4	0	0	24.2	200	39.4	26.4	0.8	1.08	1003	-0.04	34.05
JALEEB50	1/19/2010 11:03	JAN 10	39.6	32.4	0.2	27.8	0	0	20.8	200	39.7	32.4	0.2	1.22	1006	0.15	27.04
JALEEB50	3/2/2010 12:20	FEB 10	38.5	31.8	0.3	29.4	0	0	24.8	200	38.7	31.8	0.3	1.21	1005	-0.16	28.27
JALEEB50	3/23/2010 10:58	MAR 10	38.1	31.7	0.4	29.8	0	0	28.6	200	38.3	31.7	0.5	1.2	1003	-0.25	28.29
JALEEB50	4/22/2010 15:58	ARP 10	31.8	27	3.1	38.1	0	0	35.1	200	31.9	27	3	1.18	990	0.09	26.38
JALEEB50	5/23/2010 10:32	MAY 10	37.2	31.6	0.7	30.5	0	0	43.3	200	37.3	31.6	0.7	1.18	996	-0.18	27.85
JALEEB50	6/24/2010 11:12	JUN 10	37.3	32.5	0.6	29.6	0	0	45.1	200	37.3	32.5	0.6	1.15	989	1.07	27.33
JALEEB50	7/25/2010 11:34	JUL 10	37	31.9	1.1	30	0	0	50.8	200	37	31.9	1.1	1.16	983	-0.06	25.84
JALEEB50	8/29/2010 10:10	AUG 10	29.9	21.3	7.2	41.6	0	0	50.1	200	29.9	21.2	7.2	1.4	990	-11.02	14.38
JALEEB50	9/25/2010 12:02	SEP 10	36.4	31.1	1.3	31.2	0	0	47.3	200	36.9	31.1	1.3	1.17	993	0.13	26.29
JALEEB50	10/20/2010 11:42	OCT 10	31.2	26.5	3.8	38.5	0	0	40	200	31.3	26.5	3.8	1.18	999	0.6	24.14
JALEEB50	11/10/2010 11:41	NOV 10	33.1	28	2.9	36	0	0	27.1	200	33.2	28	2.9	1.18	1007	0.52	25.04
JALEEB50	12/22/2010 14:42	DEC 10	32.8	27.5	3.3	36.4	0	0	23.1	200	32.8	27.5	3.3	1.19	1005	0.85	23.93

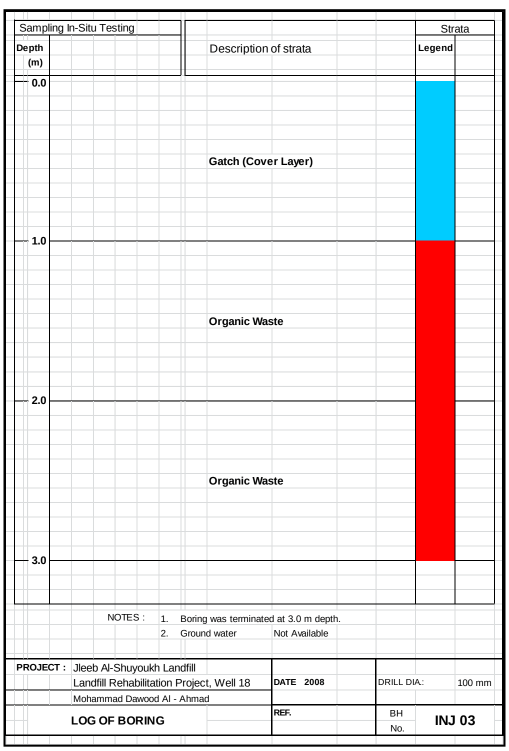
Appendix (6): Boreholes Logs in the Project Area



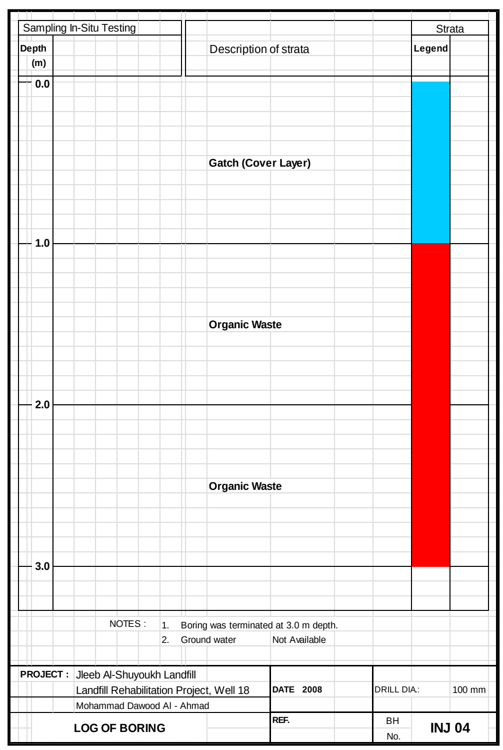
Borehole (INJ01)



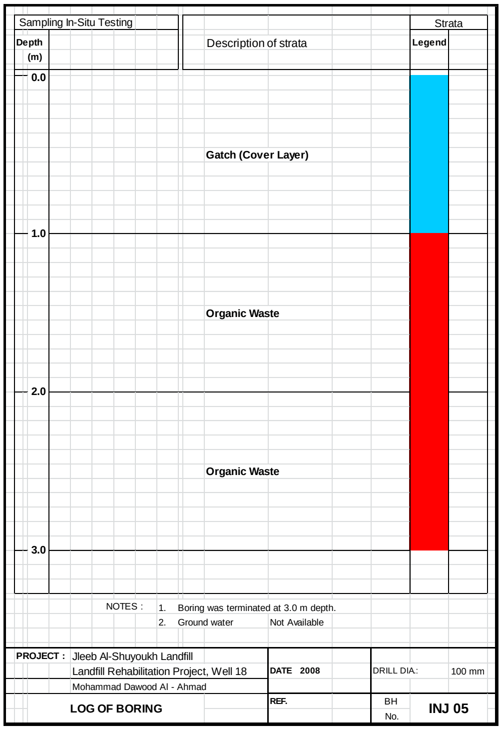
Borehole (INJ02)



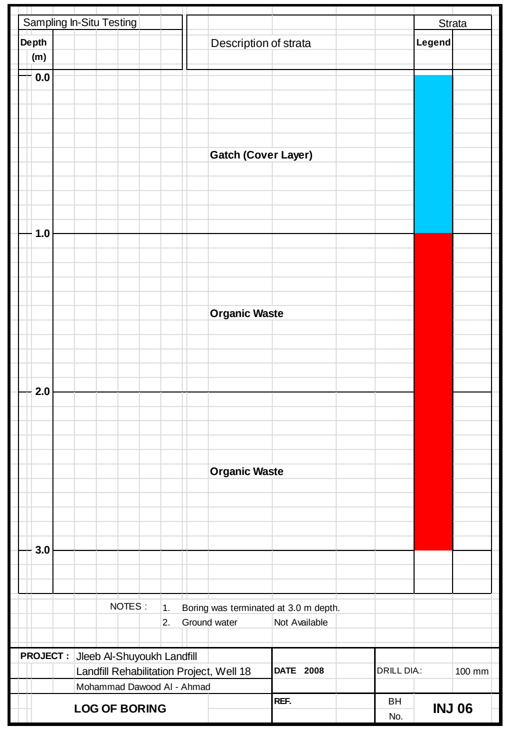
Borehole (INJ03)



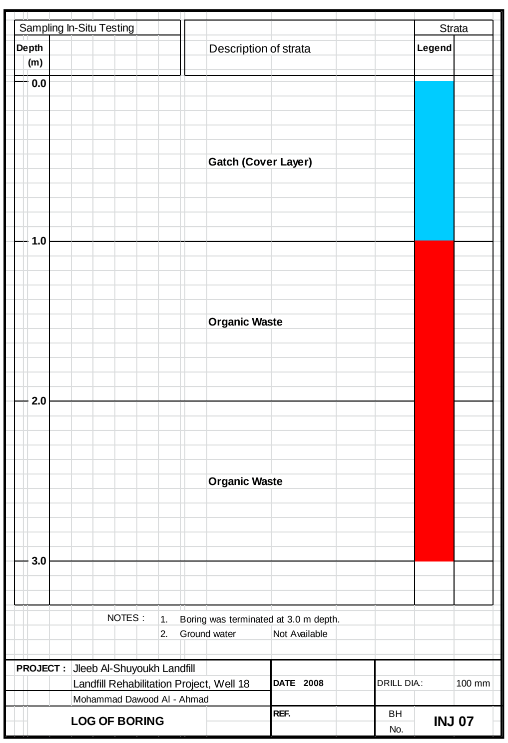
Borehole (INJ04)



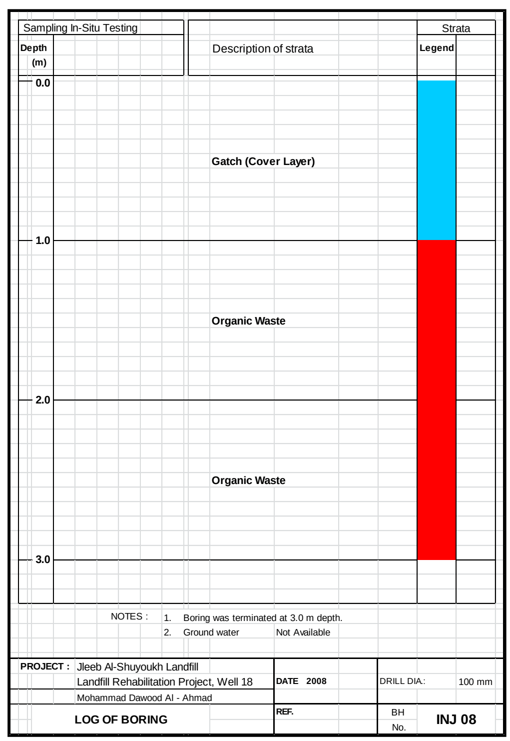
Borehole (INJ05)



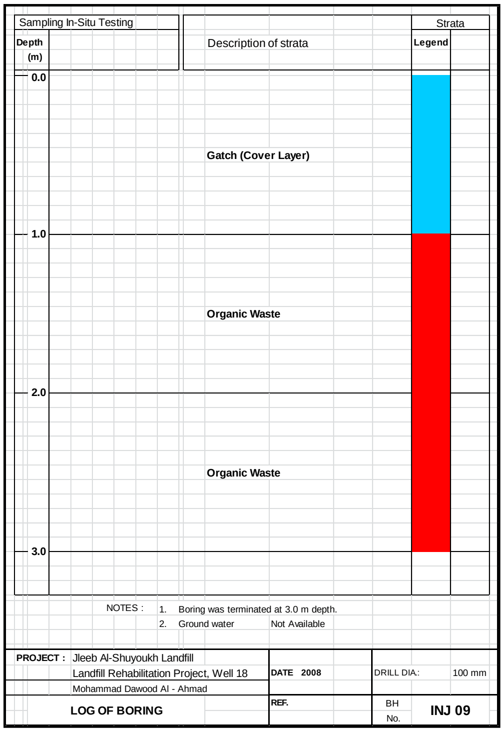
Borehole (INJ06)



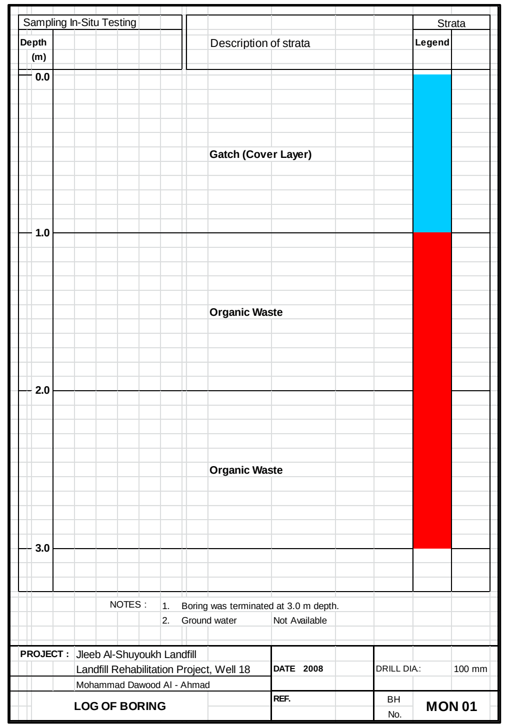
Borehole (INJ07)



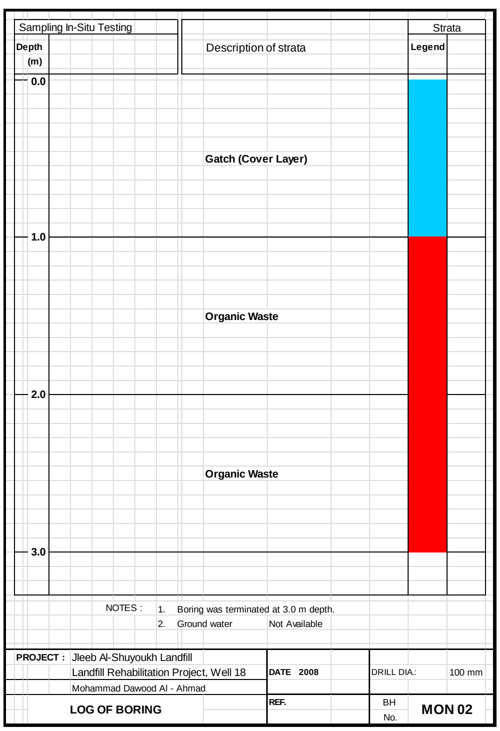
Borehole (INJ08)



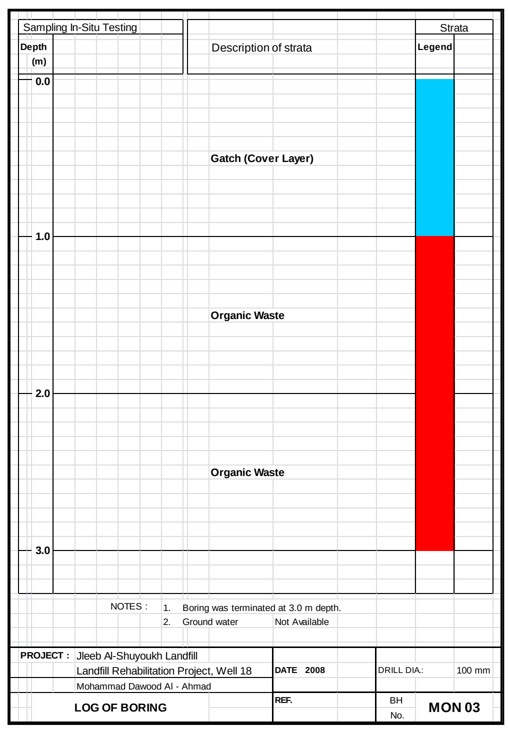
Borehole (INJ09)



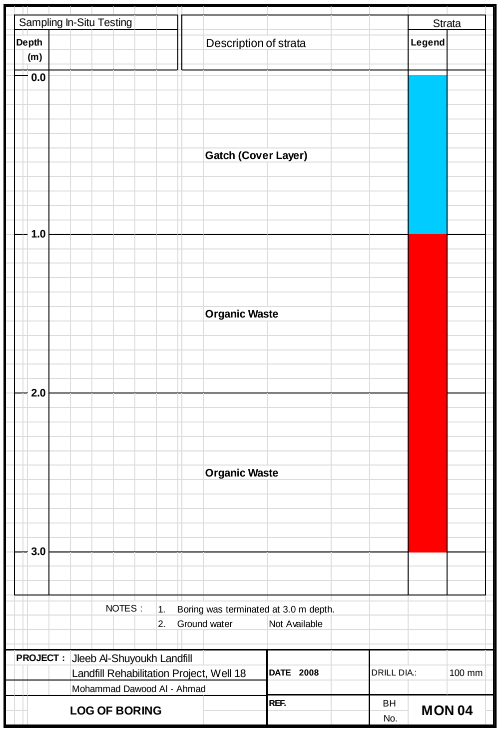
Borehole (MON01)



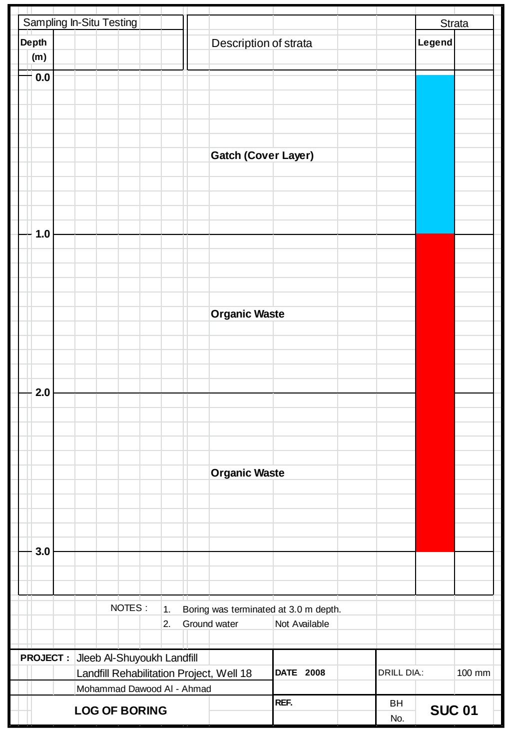
Borehole (MON02)



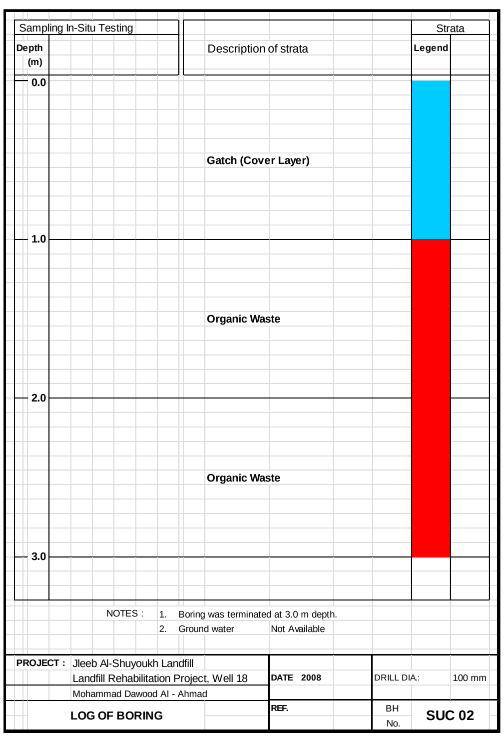
Borehole (MON03)



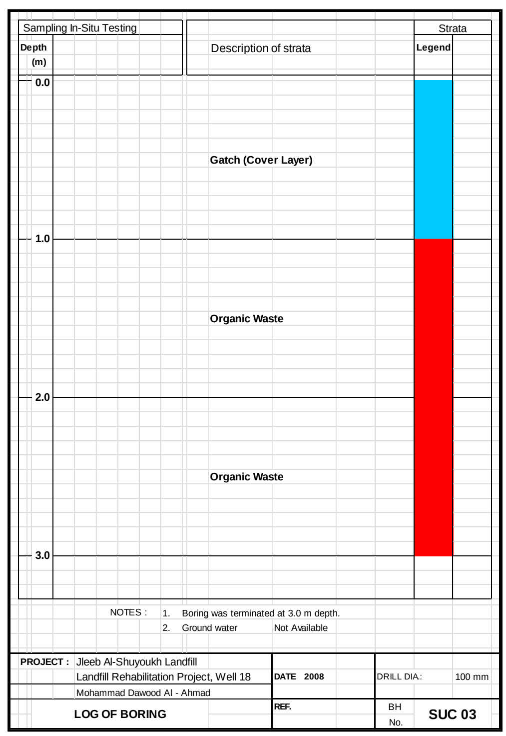
Borehole (MON04)



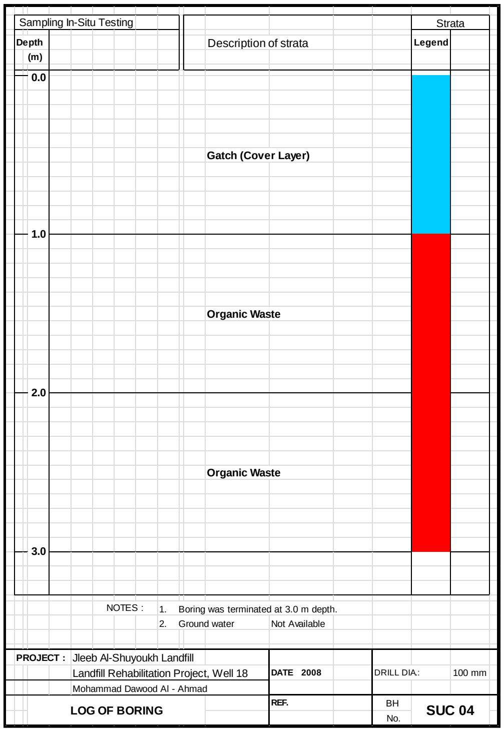
Borehole (SUC01)



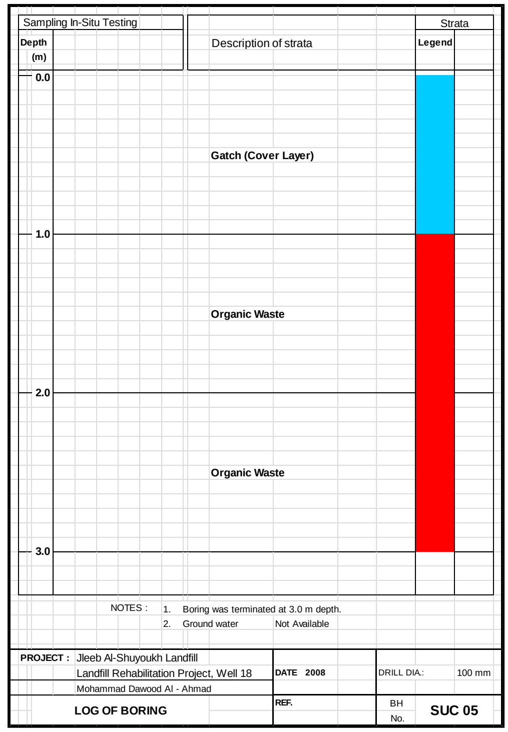
Borehole (SUC02)



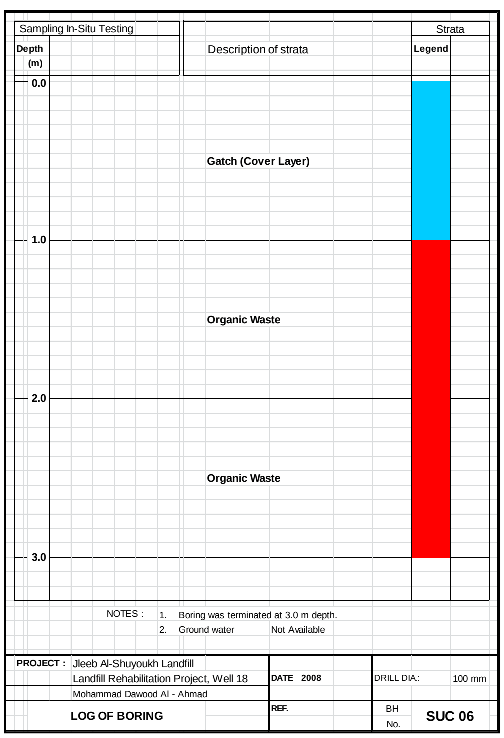
Borehole (SUC03)



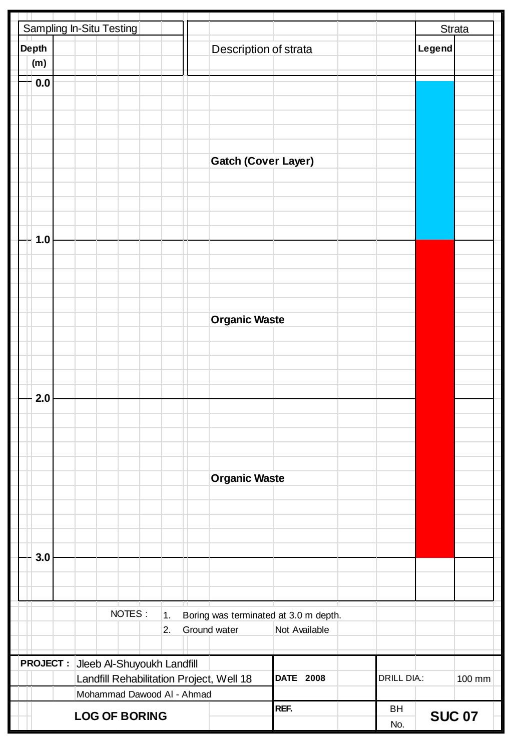
Borehole (SUC04)



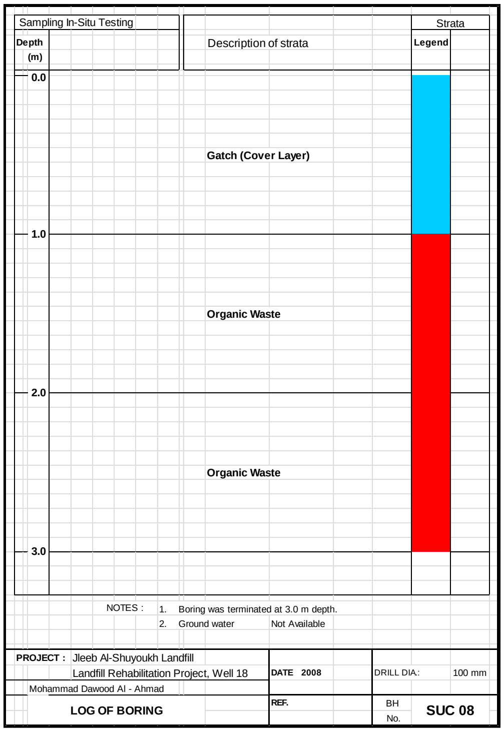
Borehole (SUC05)



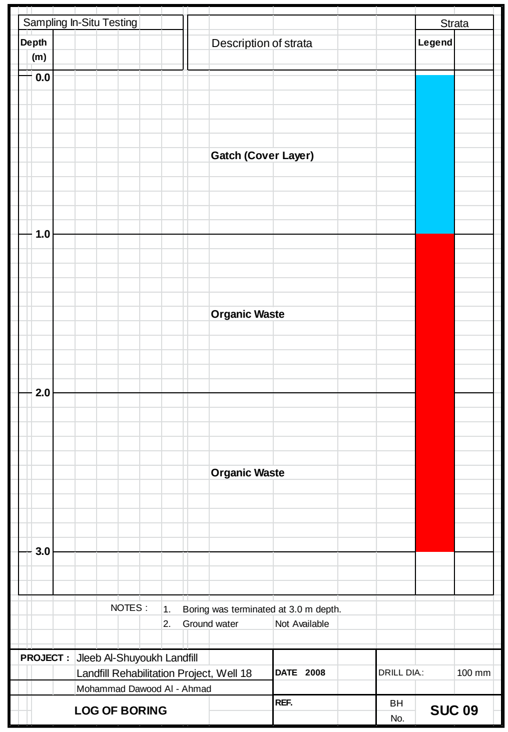
Borehole (SUC06)



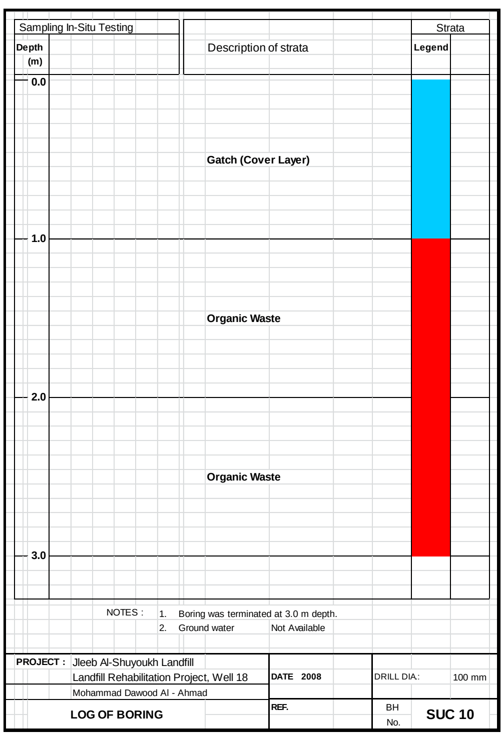
Borehole (SUC07)



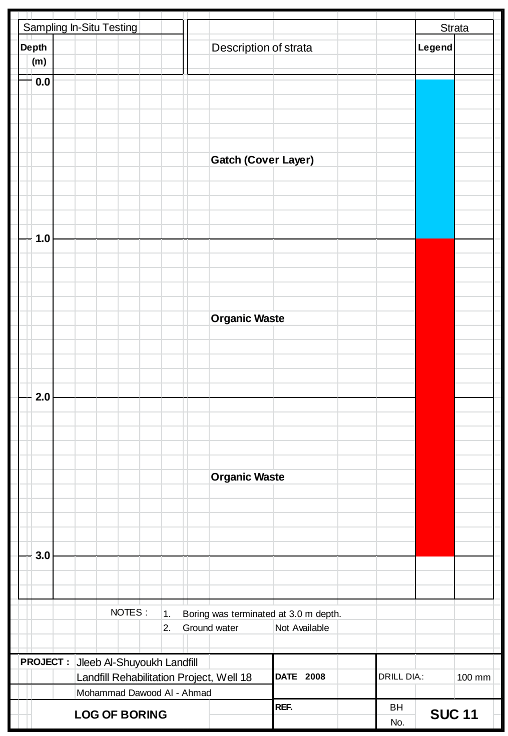
Borehole (SUC08)



Borehole (SUC09)



Borehole (SUC10)



Borehole (SUC11)

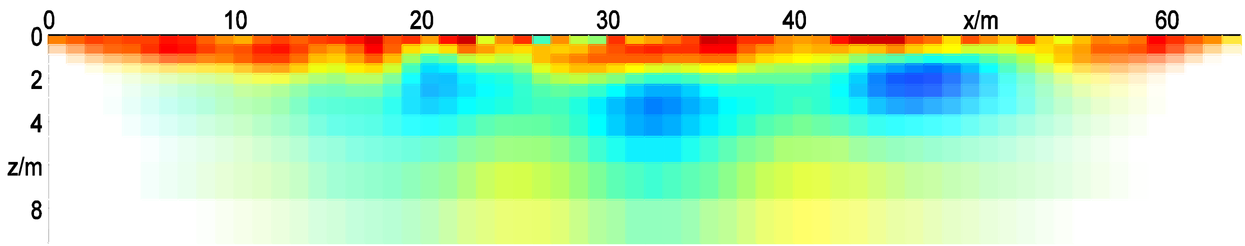
Sampling In-Situ Testing Depth (m)	Description of strata	Strata Legend
0.0	Gatch (Cover Layer)	
1.0	Organic Waste	
2.0	Organic Waste	
3.0		

NOTES :
1. Boring was terminated at 3.0 m depth.
2. Ground water Not Available

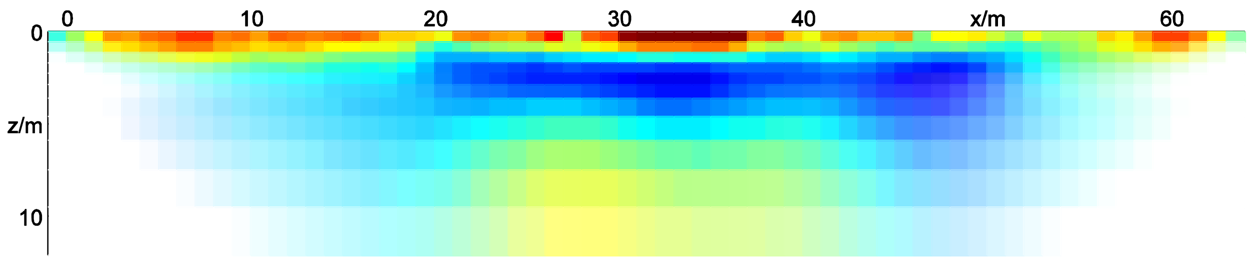
PROJECT : Jleeb Al-Shuyoukh Landfill Landfill Rehabilitation Project, Well 18 Mohammad Dawood Al - Ahmad	DATE 2008	DRILL DIA:	100 mm
LOG OF BORING	REF.	BH No.	SUC 12

Borehole (SUC14)

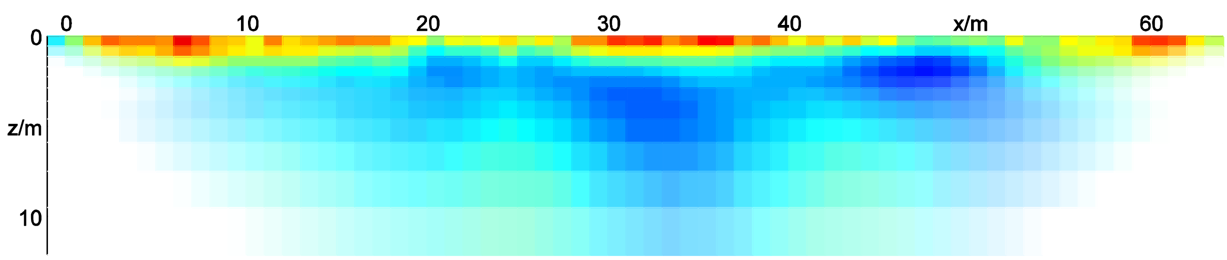
Appendix (7): 2D measured diagonal profiles (27 months)



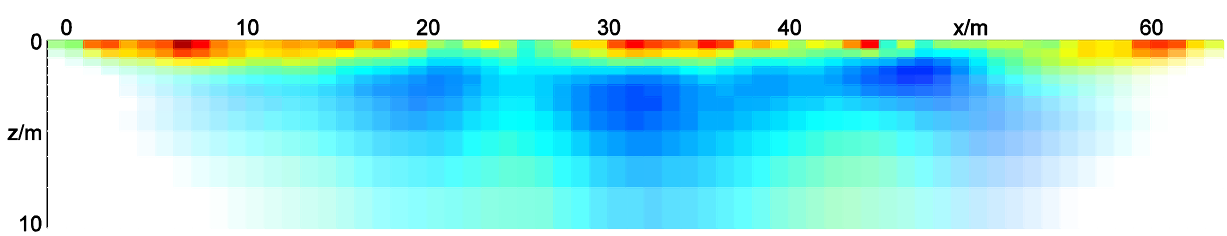
Diagonal profile,01



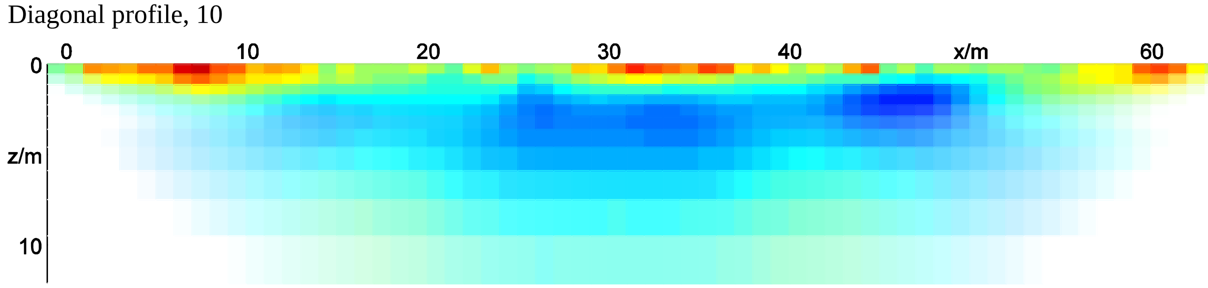
Diagonal profile, 02



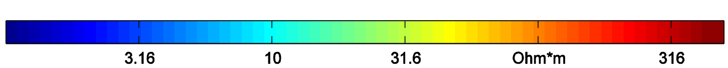
Diagonal profile, 06

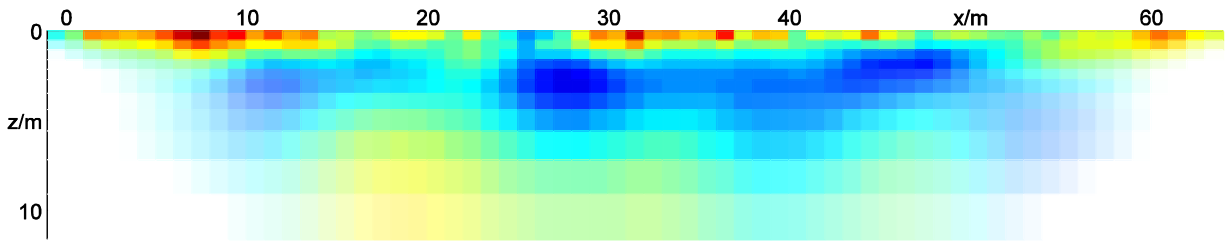


Diagonal profile, 10

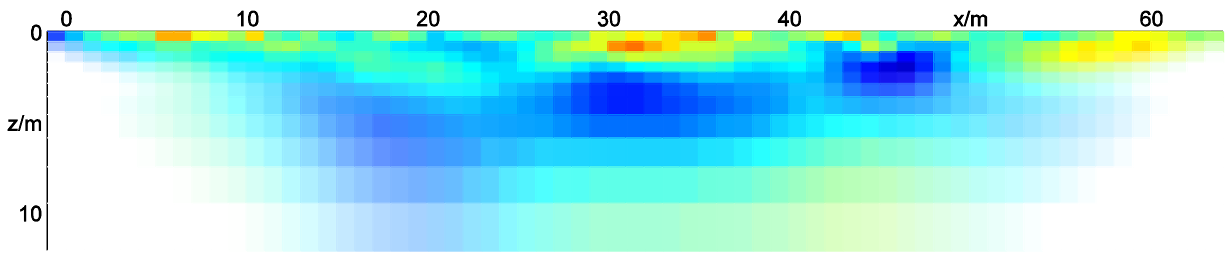


Diagonal profile, 014

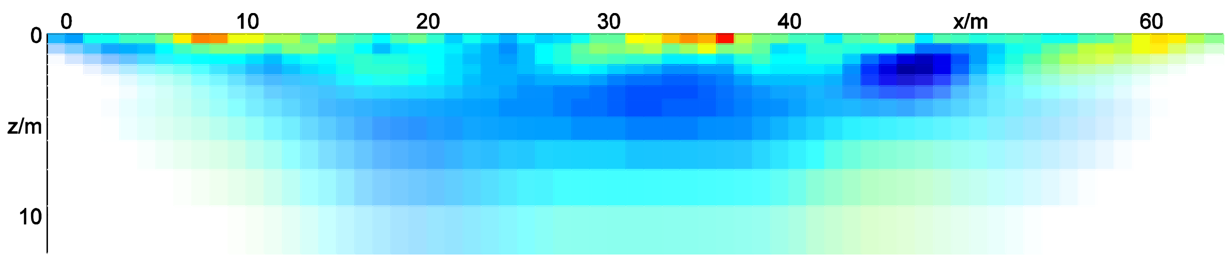




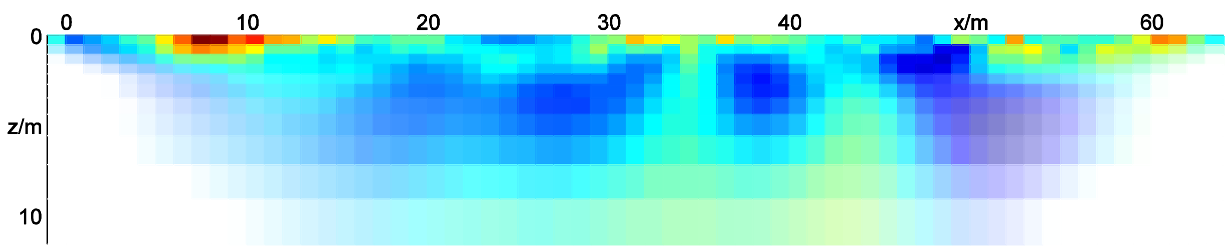
Diagonal profile,18



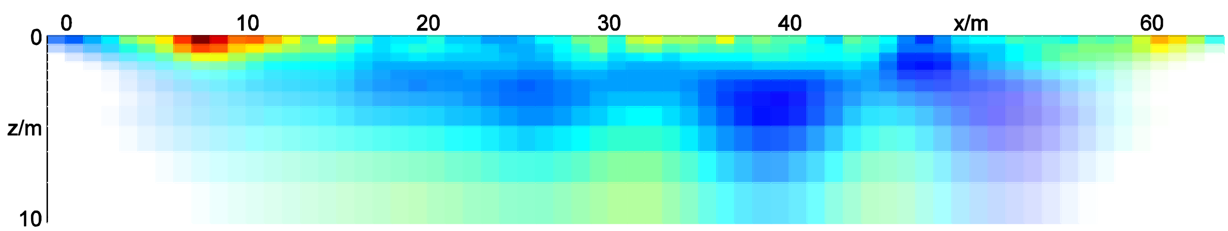
Diagonal profile, 22



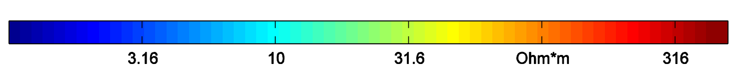
Diagonal profile, 26

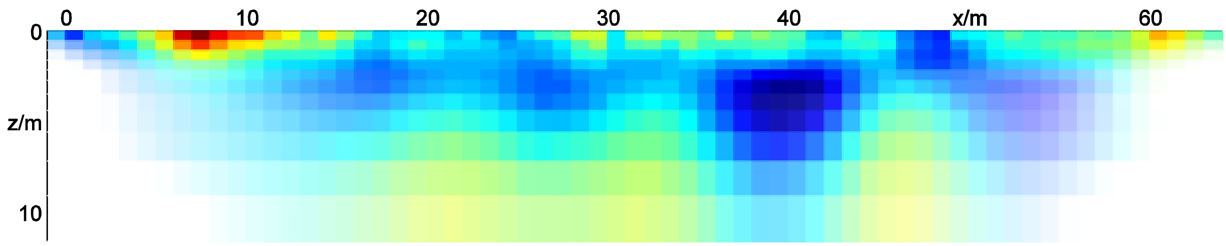


Diagonal profile, 34

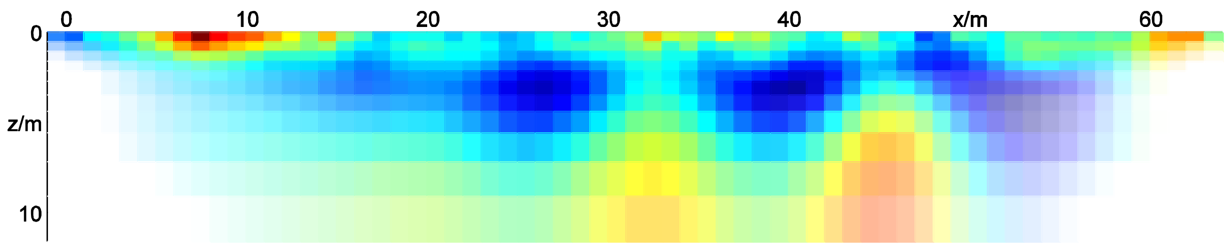


Diagonal profile, 38

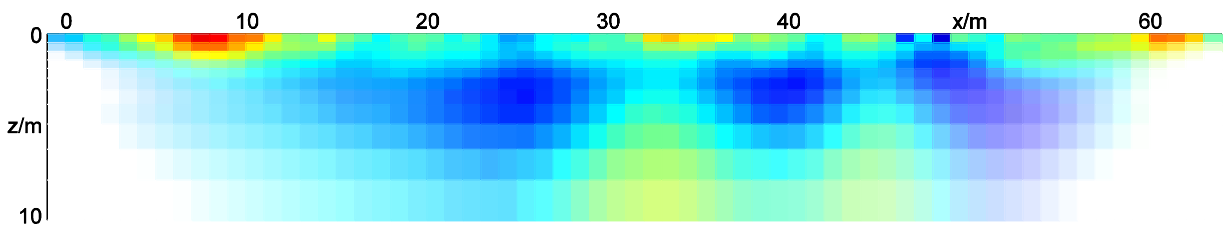




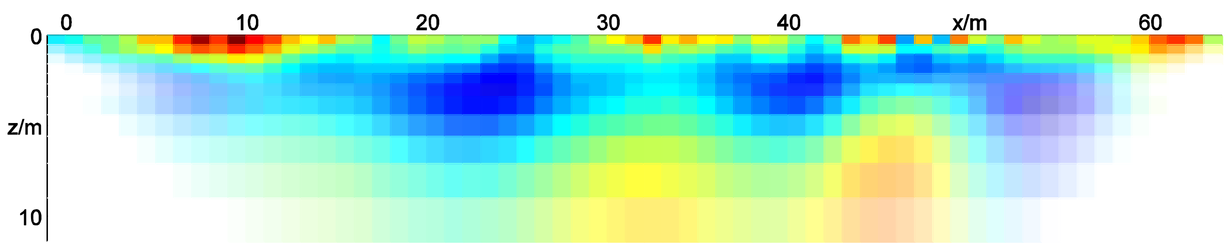
Diagonal profile,42



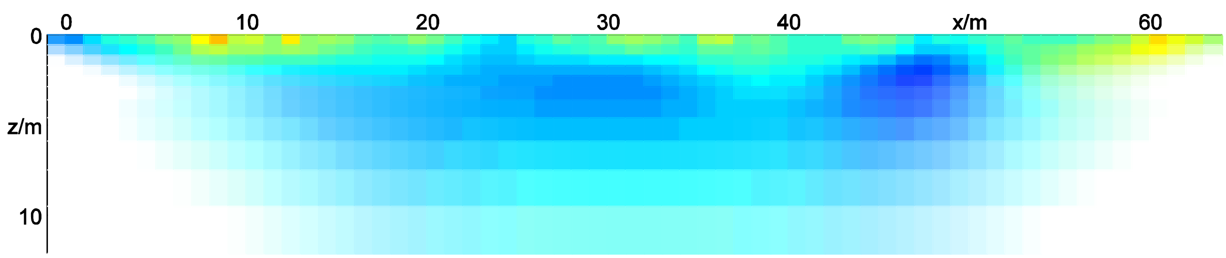
Diagonal profile, 46



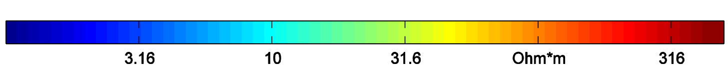
Diagonal profile, 50

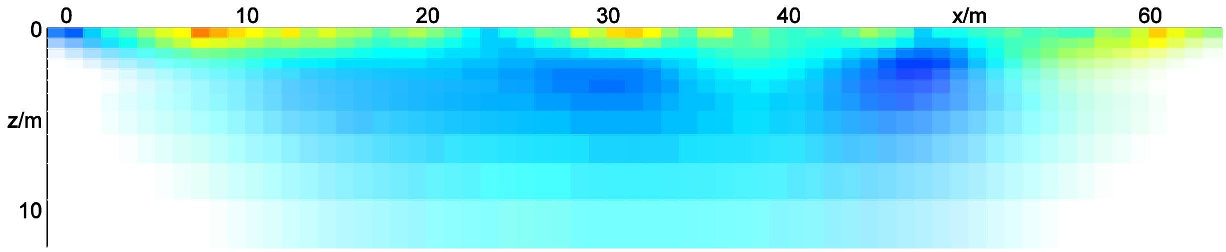


Diagonal profile, 54

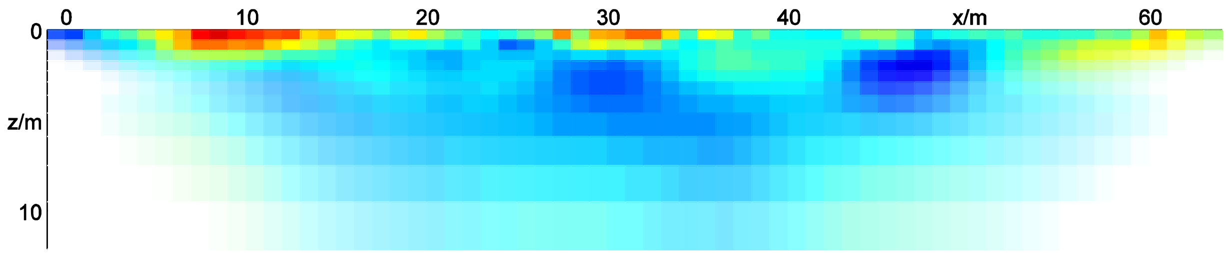


Diagonal profile, 58

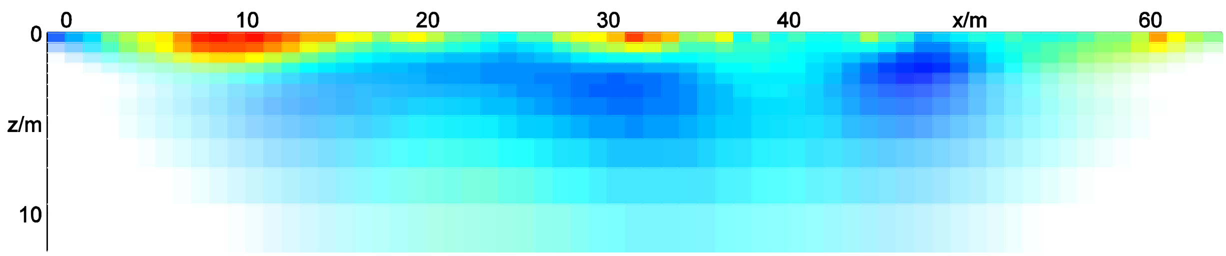




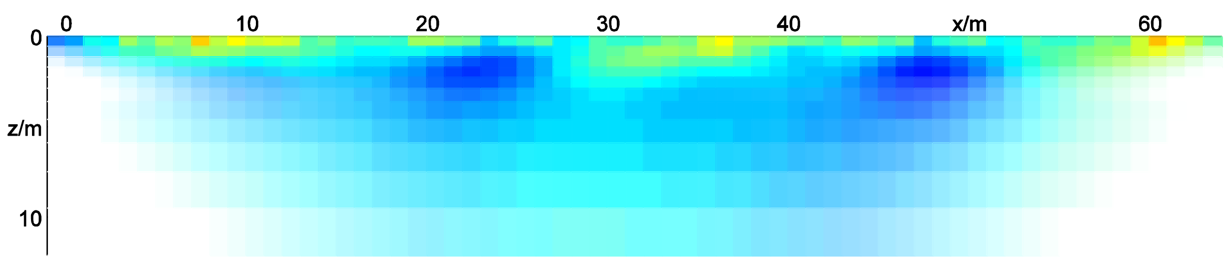
Diagonal profile,62



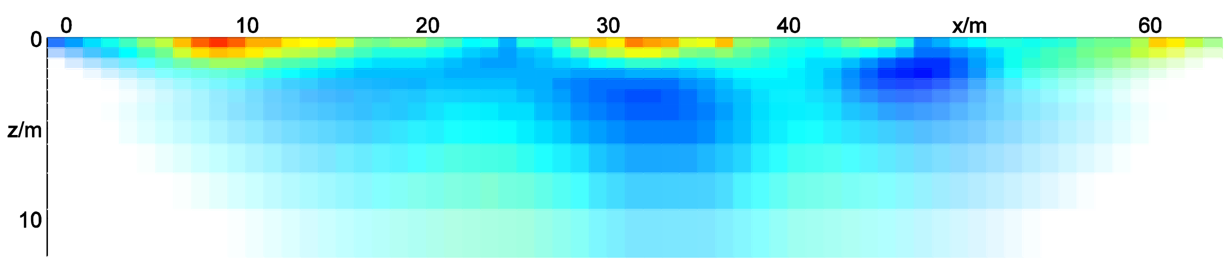
Diagonal profile, 66



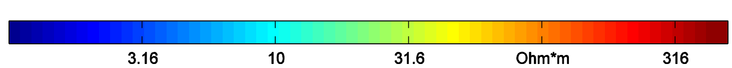
Diagonal profile, 70

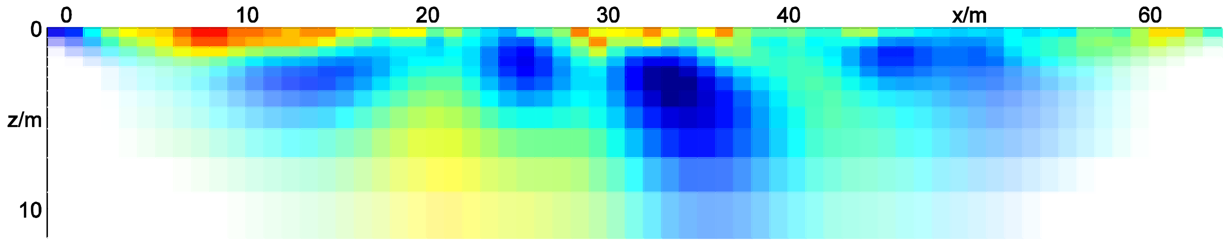


Diagonal profile, 74

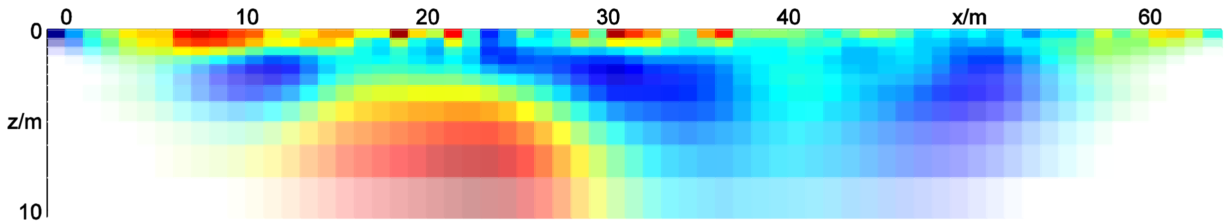


Diagonal profile, 78

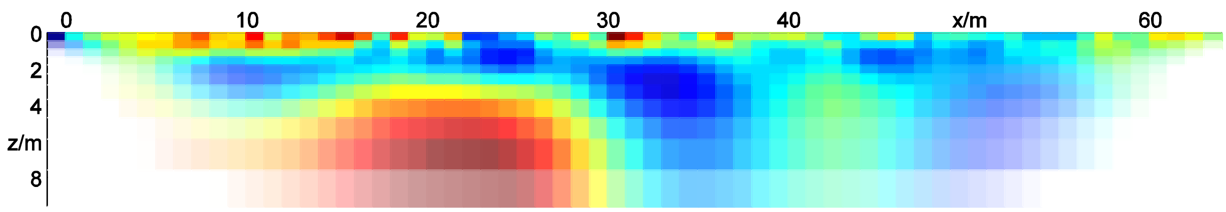




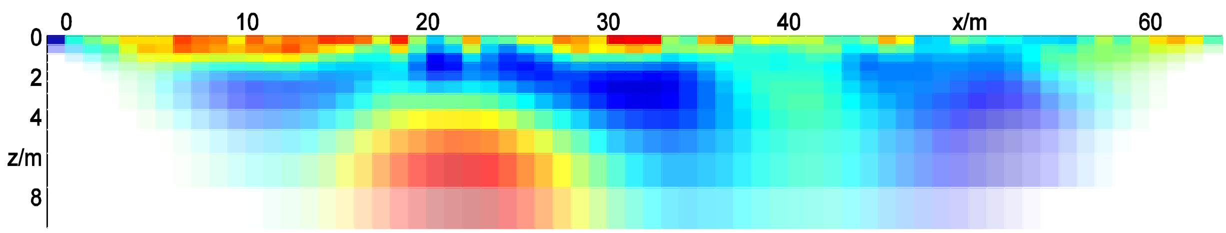
Diagonal profile,82



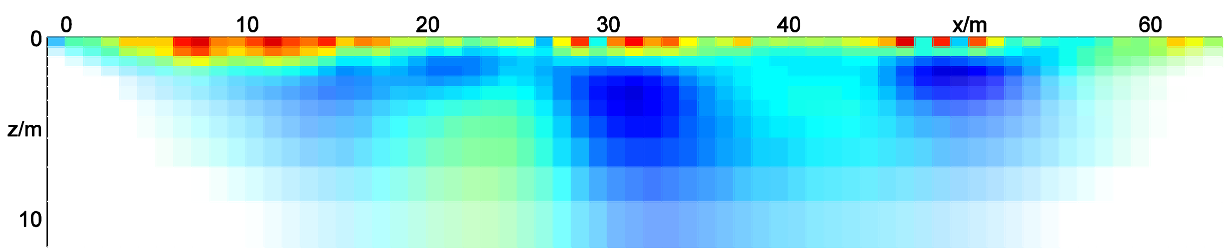
Diagonal profile, 86



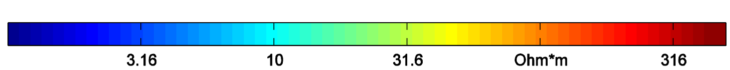
Diagonal profile, 90



Diagonal profile, 94



Diagonal profile, 104



Appendix (8): Publication

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Characterization, Concentrations and Emission Rates of Volatile Organic Compounds from Two Major Landfill Sites in Kuwait

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Abstract: Problem statement: The emission of pollutants from landfill sites in Kuwait is of major concern due to the associated adverse environmental and health impacts. There are 18 landfill sites in Kuwait which are contributing to the emission of atmospheric pollutants including; methane, carbon dioxide and Volatile Organic Compounds (VOCs). **Approach:** Determine the concentration and composition of VOCs in LFG emissions from two major landfill sites in Kuwait and to investigate the influence of the "*In-Situ Aerobic Stabilization*" on the reduction of VOCs emission. VOCs samples were collected during an intensive, short-term field sampling campaign conducted in 2010 where 50 individual volatile organic compounds were identified and quantified in landfill gas samples collected from the two landfill sites and the Project Area. **Results:** The concentration levels of VOCs were found to be significantly different within the same landfill site; however, the average total VOCs emissions were comparable between the two landfill sites. Concentration of total VOCs (i.e., sum of 50 compounds) in LFG emissions varied between 9.4-67.2 ppm in Jleeb Al-Shuyoukh landfill site and from 15.4-57.7 ppm in Al-Qurain landfill site. Annual emissions of the well-known five VOCs (i.e., benzene, toluene, ethylbenzene, m-, o- and p-xylenes and styrene) were also computed for each vent pipe from Jleeb Al-Shuyoukh landfill using the measured average concentrations and LFG flow rates. The results, if calculated in terms of the average ΣBTEX+S quantity emitted per vent pipe per year, showed that the magnitude of ΣBTEX+S emissions ranged between 0.108 -11.686 g y^{-1}. **Conclusion:** The results of this pilot project demonstrated that the "*In-situ aerobic stabilization method*" applied on old solid waste deposits in the project area of Jleeb Al-Shuyoukh landfill can significantly reduce the average VOCs concentration in LFG emissions from high-productivity wells in the project area down to (6.3±1.6 ppm), whereas VOCs concentration in LFG emissions from high-productivity wells in Jleeb Al-Shuyoukh landfill and Al-Qurain landfill sites remained relatively high, 57.1±6.95 and 49.8±11.2 ppm, respectively.

Key words: VOCs, NMOCs, BTEX, Municipal Solid Waste, Landfills, LFG, emissions

INTRODUCTION

After placement of Municipal Solid Wastes (MSW) in landfills; many biological, chemical and physical processes start to take place which would gradually lead to the emission of Landfill Gas (LFG) to air and leachates through ground (Awomeso *et al*., 2010; Williams, 2005). A significant fraction of the biodegradable portion of MSW is ultimately converted to gaseous end-products during the anaerobic stabilization of solid waste organic fractions (Abushammala *et al*., 2009). Usually, gas production begins within a year of waste placement and may continue for as long as 50 years after landfill closure. Landfill Gas (LFG) consists usually of 50-60% CH_4, 30-40 vol. %CO_2 and other trace gases (Wang-Yao *et al*., 2006). Non-Methane Organic Compounds (NMOCs) usually make up also less than 1% of landfill gas. Various trace gases such as hydrogen sulfide, water vapor, ammonia and a variety of volatile Organic Compounds (VOCs) are also present in LFG. European research has identified that landfill gas is composed of 140 trace components of which 90 were common to all studied landfill sites (Parker *et al*., 2002).

The emission of LFG is of major concern to local communities because of the bad smell and offensive

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odour as well as due to the various potential health hazards associated with toxic organic and inorganic compounds present in LFG. On the regional scale, LFG emissions are considered as a source of VOCs which contribute to the formation of photochemical oxidants including ground-level ozone (O_3). On the global scale, the emission of methane in LFG contributes to greenhouse effects. The waste sector is considered a significant contributor to Greenhouse Gas (GHG) emissions accountable for approximately 5% of the global greenhouse budget (IPCC, 2006). Atmospheric methane gas (CH_4) has more than doubled in concentration over the last 150 years (Stern et al., 2007).

Numerous investigations have been conducted with the objective of characterizing landfill gas emissions. More than fifty different VOCs have been identified in landfill gases (Kim et al., 2006). The list includes simple alkanes, olefins, aromatics and a wide array of chlorinated compounds. These VOCs include a number of known or suspected carcinogens (such as benzene, styrene and vinyl chloride). The concentrations of VOCs found in LFG typically range from a few parts per billion (ppb) to tens of thousands of ppb. Benzene, Toluene, Ethyl Benzene and Xylene (BTEX) compounds as well as methylated-and alkylated benzenes are frequently observed as trace contaminants in landfill gas.

The primary objective of the current study was to characterize VOCs emissions in LFG and to compare the composition and emission rates of VOCs between two major landfill sites in the State of Kuwait. The study also investigated the influence of in-situ aerobic stabilization of old solid waste deposits on the composition and concentration of VOCs in LFG emission.

MATERIALS AND METHODS

Landfill sites: The most common practised disposal method in the State of Kuwait for Municipal Solid Waste (MSW) is burial in landfills (UNDP, 2002; AlAhmad et al., 2003). Today, there are 18 landfills in Kuwait of which 14 sites are closed and 4 sites are still in operation (AlAhmad, 2009). Detailed information and data about these landfills, their waste input and composition or emissions measurements and characterization of VOCs in LFG do not exist. Due to the rapid development and the expansion in urban and residential areas in Kuwait, some of these landfills became on the boarders of residential and urban areas, as is the case of Jleeb Al-Shuyoukh and Al-Qurain landfill sites (Fig. 1).

Jleeb Al-Shuyoukh landfill: The landfill of Jleeb Al-Shuyoukh is located in the south of Kuwait City close to the International Airport of Kuwait and adjacent to the south-eastern boarder of Abdullah Al-Mubarak residential area. This landfill site was licensed by Kuwait Municipality to receive MSW from 1970-1993. The site is considered to be the largest MSW landfill in Kuwait where it encompasses approximately 6 square kilometres and the waste vertical profile varies in depth from 4-23 m. Approximately, about 20 million cubic meters of municipal solid waste and 3 million cubic meters of demolition waste were dumped during the operation period of the landfill. After a major burning incident of the landfill in 2002, a surface capping system with 1m-soil layer was installed. In 2006, 50 boreholes (depth up to 29 m) were drilled for measurement of landfill gas emissions. Measurements of LFG emission was started in March 2008 by the Environment Public Authority of Kuwait (KEPA).

In November 2008, a small area of Jleeb Al-Shuyoukh (576 m^2) was used to conduct this research project in collaboration with the Department of Waste Management at Rostock University in Germany. Aerobic in-situ stabilization of old solid waste deposits (Heyer et al., 2003; 2005; Cossu et al., 2006; Zanetti, 2008) was applied in the "Project Area" of Jleeb Al-Shuyoukh landfill to examine how this method would improve the emission behaviour and composition of landfill gas under the local conditions of Kuwait (AlAhamd, 2009). In-situ aerobic stabilization of MSW aims to achieve accelerated reduction of the emission and settlement potentials, reduction of the technical and financial expenditures during the aftercare phase and a reduction of the aftercare period. Extensive scientific research have shown that a sustained improvement of the emission and settlement behaviour of the landfill through aerobic in-situ stabilization measures can be achieved when the process technology is adapted to the local conditions of the landfill body and operated in a qualified manner (Spillmann et al., 2001; Heyer et al., 2003; 2005).

Al-Qurain landfill site: As shown in Fig. 1 above, this site has become over the past years entirely surrounded by residential areas from all sides due to the expansion of nearby residential areas. The area of Al-Qurain landfill was originally used for dumping of municipal and construction waste from 1970-1985. The volume of the landfill is approximately 5 million m^3 and the maximum depth of waste is 24 m. The surface is capped with a 1m soil layer. The landfill is equipped with an active LFG venting and collection system, a flare for burning-off LFG and a pre-treatment plant for leachate. The gas venting system has been in operation since 2005.

Sample collection: During the period May-August 2010, twenty eight samples were collected from selected monitoring wells (boreholes) in Jleeb landfill, the "Project Area" in Jleeb landfill and from Al-Qurain landfill site (Fig. 2 and 3 for the locations of boreholes used for sampling of VOCs).

Fig. 1: Satellite image of Kuwait City (SPOT, April 2010) showing the location of the two landfill sites (areas coloured in dark green)

Fig. 2: Location of boreholes used for the collection of VOCs samples from Jleeb landfill site

Fig. 3: Location of boreholes used for the collection of VOCs samples from Al-Qurain landfill

Table 1 gives short descriptions of the boreholes used for sampling. Boreholes 4 and 35 in Jleeb landfill were chosen to represent the native soils in the area with no waste buried underneath.

Boreholes 21 and 46 in Jleeb Al-Shuyoukh landfill and borehole S17 in Al-Qurain landfill were chosen to represent wells of low methane productivity, whereas boreholes 16 and 49 in Jleeb landfill and borehole S12 in Al-Qurain landfill were chosen to represent wells of high methane productivity (i.e., reaching a mature methanization stage). Borehole No 18 in Jleeb landfill was chosen following the aeration experiment (i.e., in-situ aerobic stabilization of buried wastes) applied in the in the "Project Area".

Prior to the sampling of VOCs, the borehole valve was opened and connected to a hand-held portable device (GA 2000 Plus infrared gas analyser, Geotechnical Instruments-UK) for the in-situ measurement of CH_4, CO_2, CO, O_2 and temperature in LFG. Sampling of VOCs was achieved using a clean Tedlar bag (1 L) and a small vacuum pump.

Sample analysis: Collected samples were brought to the analytical laboratory for the analysis of Volatile Organic Compounds (VOCs) in landfill gas. Fifty individual VOCs were identified and quantified in this study, ranging from simple aliphatic and aromatic hydrocarbons to di-and tri-methylated benzenes. The target volatile organic compounds identified and quantified in this study are listed in Table 2.

Analysis of VOCs in the collected gas samples was accomplished by following USEPA Method PAMS (Photochemical Assessment Monitoring Stations). The analytical system included a gas chromatography system (Perkin Elmer) equipped with flame ionization detector (GC/FID). The Gas Chromatography system (GC) was also equipped with a perkin elmer Automatic Thermal Desorber (ATD 400). The VOC samples contained in Tedlar bags were analyzed by introducing them into the GC/FID system with the aid of Peltier Cooling (PC) and the Thermal Desorption (TD) method (PC/TD system). Using this PC/TD system, the target VOC in LFG samples were then pre-concentrated in a liquid N_2-free cold trap (packed with both Carbosil adsorbent) at-15°C. Trapped VOC were then released thermally by heating the cold trap for 2 min at 320°C.

A 30 m GC capillary column (BP1) was used for the chromatographic separation of the different VOCs. After elution from the capillary column, identification of individual VOCs compounds was achieved by the Flame Ionization Detector (GC/FID) connected at the end of the capillary column.

Figure 4 and 5 show the GC/FID chromatograms recorded during the identification of light and heavy molecular weight VOCs in LFG samples, respectively. Appropriate calibration procedures were employed to ensure GC/FID reliability and accuracy. The GC/FID system was calibrated using a standard calibration cylinder (Spectra Gases, UK) containing all light and heavy molecular weight VOCs at a concentration of 100 ppb each. Detection limits for all VOCs was about 5 ppb.

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Table 1: Description of VOCs sampling locations in Jleeb and Al-Qurian Landfill sites

Landfill site	Borehole no.	Type	Max CH4 productivity during sampling	No. of samples
Jleeb Al-Shuyoukh	BH 4 and 35	Native soil No buried waste underneath	CH_4<2% Zero-productivity	4
	BH 21 and 46	Waste buried under 1m-soil layer	CH_4 = 20-30% Low-productivity	4
	BH36 and 49	Waste buried under1m-soil layer	CH_4 = 50-60% High-productivity	4
	BH 18 Project area "In-situ aerobic stabilization"	Waste buried under 1m-soil layer	CH_4= <3.3% After aeration	8
Al-Qurain	BH S17 Under 1m-soil layer (LFG collection)	Waste buried Low-productivity	CH_4 = 20-30%	4
	BH S12	Waste buried under 1m-soil layer (LFG collection)	CH_4 = 50-60% High-productivity	4

Table 2: VOCs identified and quantified in LFG samples

1	Ethylene	18	N-Hexane	35	M/P Xylene
2	Propane	19	MethylCyclopentane	36	Styrene
3	Propylene	20	2,4 DimethylPentane	37	O-Xylene
4	Iso-Butane	21	Benzene	38	N-Nonane
5	N-Butane	22	CycloHexane	39	IsoPropylBenzene
6	Acetylene	23	2-MethylHexane	40	N-PropylBenzene
7	1-Butene	24	2,3DimethylPentane	41	M-EthylToluene
8	Trans-2Butene	25	3-MethylHexane	42	P-EthylToluene
9	N-Pentane	26	2,2,4TrimethylPentane	43	1,3,5TriMethylBenzene
10	Trans-2Pentene	27	N-Heptane	44	O-EthylToluene
11	1-Pentene	28	MethylCycloHexane	45	1,2,4TriMethylBenzene
12	Cis-2Pentene	29	2,3,4TriMethylPentane	46	N-Decane
13	2,2 DiMethylButane	30	Toluene	47	1,2,3TriMethylBenzene
14	2,3 DimethylButane	31	2-MethylHeptane	48	M-DiethylBenzene
15	2 MethylPentane	32	3-MethylHeptane	49	P-DiethylBenzene
16	Isoprene	33	N-Octane	50	N-Undecane
17	1-Hexene	34	EthylBenzene		

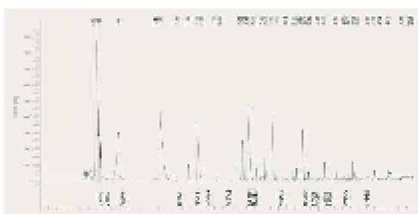

Fig. 4: GC/FID chromatogram of light VOCs identified in LFG samples

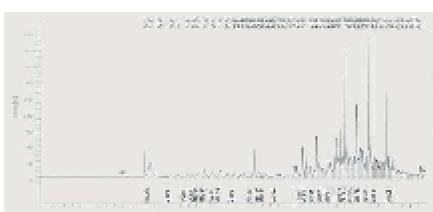

Fig. 5: GC/FID chromatogram of heavy VOCs identified in LFG samples

RESULTS AND DISCUSSION

Composition and concentrations of VOCs in LFG: Figure 6 and 7 compare the average concentrations of individual VOCs (50 compounds) measured in LFG samples collected from the different boreholes in the two landfill sites. It is evident from Fig. 7 and 8 that the composition of VOCs and the magnitude of measured concentrations are very much comparable between the high-productivity wells in the two landfill sites in Al-Jleeb and Al-Qurain where the correlation factor is relatively high (R^2 = 0.7966). The highest concentrations of VOCs in all sampling sites were observed for; styrene, m-methyltoluene and diethylatedbenzenes.

Table 3 summarizes the results of total VOCs concentrations (sum of 50 compounds) measured in LFG emissions from the monitoring wells in Jleeb Al-Shuyoukh and Al-Qurain landfill sites. Concentrations of total VOCs ranged from as low as 1.3±0.5 ppm in wells located in native soil areas up to 57.1±6.9 ppm and 49.8±11.2 in wells of high-productivity areas in both of Jleeb Al-Shuyoukh and Al-Qurain landfill sites, respectively.

The result show that the total VOCs emission from the project area (i.e., borehole No 18) is about one-half of the emission from the low-productivity wells in Jleeb landfill and about one-tenth of total VOCs emission from high-productivity wells. This significant reduction in VOCs emissions from the project area can be attributed to the high and rapid biological aerobic reactivity taking place in the project area. If this significant difference is converted into percent reduction in total VOCs emission relative to the emission from the high-productivity wells, then the in-situ aerobic stabilization can speed up the decomposition of the biodegradable organic wastes and significantly reduce VOCs emissions by about 89% in comparison with the slow anaerobic biological reactions which usually needs several tens of years to decompose the buried wastes.

The distribution of major aromatic VOCs in LFG emissions: Table 4 represents a statistical summary of major aromatic VOCs concentrations measured in this study (i.e., benzene; toluene; ethylbenzene; m-, p- and o-xylenes and styrene). Benzene concentrations ranged from as low as 5 ppb in LFG emissions from low-productivity wells and up to 252.1 ppb in LFG emissions from high-productivity wells. Xylene isomers (metha, para and ortho) and styrene were present in LFG emissions at much higher concentrations than benzene, toluene and ethylbenzene. The concentration of styrene reached as high as 4718.0 and 4057.8 ppb in high-productivity wells in Jleeb Al-Shuyoukh landfill and Al-Qurain landfill, respectively. Schrapp and Al-Mutairi (2010) reported the concentrations of 13 VOCs including BTEX and styrene in LFG emissions from Jleeb Al-Shuyoukh landfill. Table 4 compares the results of BTEX and styrene measurements obtained in this study with those reported in the literature (Schrapp and Al-Mutairi, 2010; Al-Mutairi, 2004; Kim et al., 2006).

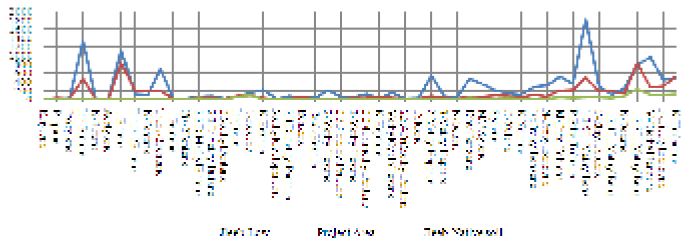

Fig. 6: Comparison of VOCs concentrations between low-productivity wells, native soil wells and the Project Area wells in Jleeb Al-Shuyoukh landfill (units are in ppb)

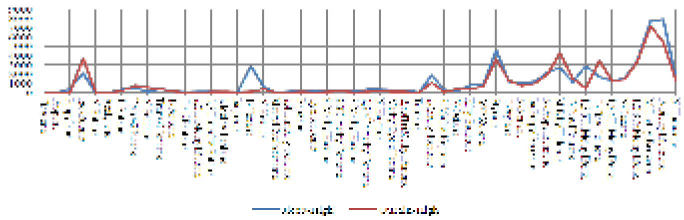

Fig. 7: Comparison of VOCs concentrations between Jleeb Al-Shuyoukh and Al-Qurain high-productivity wells (units are in ppb)

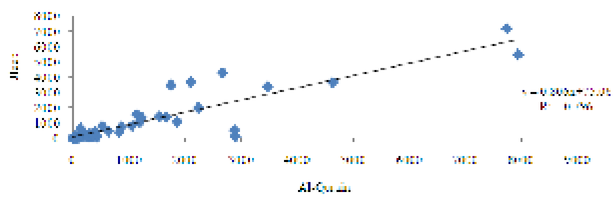

Fig. 8: Correlation of VOCs concentrations between Jleeb Al-Shuyoukh and Al-Qurain high-productivity wells (units in ppb)

Table 3: A statistical summary of VOCs concentrations measured in LFG emissions

			Total* VOCs concentration (ppm)	
Landfill Site	Borehole No.	Productivity	Mean ± STD	Range (Min-Max)
Jleeb Al-Shuyoukh	BH 4 and 35	CH_4 <2% Zero-productivity	1.3±0.5	(0.78-1.7)
	BH 21 and 46	CH_4 = 20-30% low-productivity	13.1±2.9	(9.4-15.7)
	BH16 and 49	CH_4 = 50-60% high-productivity	57.1±6.9	(51.9-67.2)
	BH 18, project area "In-situ aerobic stabilization"	CH_4 = < 3.3% after aeration	6.3±1.6	(4.7-9.1)
Al-Qurain	BH S17	CH_4 = 20-30% low-productivity	18.8±4.8	(15.4-22.1)
	BH S12	CH_4 = 50-60% high-productivity	49.8±11.2	(41.2- 57.7)

*; Sum of 50 VOCs

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Table 4: A statistical summary of major aromatic VOCs concentrations measured in Jleeb Al-Shuyoukh and Al-Qurain landfills

Landfill site/ sampling well	Concentration of Major Aromatic VOCs (in ppb) Benzene	Toluene	Ethyl Benzene	m&p-Xylene	o-Xylene	Styrene	ΣBTEX+S[1]	Ratio B/T
Jleeb Al-Shuyoukh	3.9±7.8[2]	15.7±10.9	30.5±20.2	20.5±8.1	31.7±13.0	17.7±6.3	125.1±53.3	0.6±0.4
(Native soil well)	(5.0-15.7)[3]	(5.0- 23.8)	(11.4-48.0)	(12.2-31.2)	(18.2-47.7)	(11.0-25.6)	(66.1-181.2)	(0.2-1.0)
Jleeb Al-Shuyoukh	21.8±36.2	24.3±8.4	462.2±374.3	339.0±292.7	124.1±59.3	195.8±45.9	1169.6±706.7	0.8±1.0
(Low-productivity wells)	(5.0-75.5)	(16.2-32.4)	(125.4-824.5)	(76.8-621.0)	(86.7-212.1)	(154.6-260.2)	(504.6-1939.4)	(0.3-2.3)
Jleeb Al-Shuyoukh	160.0±78.2	35.3±17.1	836.6±324.4	874.0±140.0	1213.1±484.5	4633.2±103.2	7752.3±935.5	5.6±3.7
(High-productivity wells)	(72.1-252.1)	(18.3-50.6)	(495.2-1178.8)	(683.4-1010.2)	(598.9-1659.2)	(4488.2-4718.0)	(6557.5-8565.3)	(1.4-10.5)
Jleeb Al-Shuyoukh	53.0±14.7	8.9±2.9	57.8±13.1	56.4±19.5	67.3±29.6	82.9±47.2	326.5±78.0	6.1±1.1
(Project Area)	(33.2-76.3)	(6.3-15.0)	(38.1-74.2)	(37.3-87.5)	(36.3-117.3)	(43.9-161.0)	(239.8-445.3)	(5.0-8.2)
Al-Qurain	9.5±6.3	6.0±1.4	296.1±106.4	430.0±127.9	478.7±245.8	117.4±40.8	1337.3±525.8	1.8±1.5
(Low-productivity well)	(5.0-14.0)	(5.0 – 7.0)	(220.9-371.3)	(339.6-520.2)	(304.9-652.5)	(88.6-146.3)	(966.0-1709.6)	(0.7-2.8)
Al-Qurain	94.5±62.6	29.0±6.9	391.4±21.5	732.7±129.4	1320.9±271.2	3661.0±561.5	6229.4±1038.9	3.6±3.0
(High-productivity well)	(50.2-138.7)	(24.1-33.8)	(376.2-406.6)	(641.2-824.2)	(1129.1-1512.7)	(3264.2-4057.8)	(5494.8-6964.0)	(1.5-5.8)
Jleeb Al-Shuyoukh[4]								
Summer (2004)	767	17333	821	NM[5]	NM	519	19440	0.04
Winter (2004)	490	12000	420	NM	NM	282	13192	0.04
Korea[6]								
Site A (NJ)	31.8	259.0	NM	10.4	45	NM	346.2	0.12
Site B (WJ)	924.0	2610.0	982.0	1045.0	NM	91.5	5652.5	0.35
Site D (HC)	828.0	1808.0	1264.0	946.0	1269.0	66.0	6181.0	0.46
Site E (NH)	117.0	21.9	53.7	43.2	48.9	248.0	532.7	5.30

[1]; ΣBTEX+S: Sum of benzene; toluene; ethylbenzene; m, p and o-xylenes and styrene. [2]: Mean ± standard deviation. [3]Concentration range (min-max). [4]: Schrapp and Al-Mutairi (2010): Only mean values were reported. [5]: NM: not measured. [6]: (Kim et al., 2006)

Table 5: A statistical summary of major aromatic VOCs fluxes calculated for each vent pipe in Jleeb Al-Shuyoukh landfill

Landfill site/sampling well	VOCs fluxes (g/year) Benzene	Toluene	EthylBenzene	m and p-Xylene	o-Xylene	Styrene	ΣBTEX+S[1]
Jleeb Al-Shuyoukh	0.016±0.023[2]	0.019±0.007	0.432±0.354	0.308±0.266	0.113±0.054	0.175±0.041	1.062±0.645
(Low-productivity wells)	(0.003-0.051)[3]	(0.013-0.026)	(0.117- 0.770)	(0.070-0.564)	(0.079-0.193)	(0.138-0.232)	(0.455-1.758)
Jleeb Al-Shuyoukh	0.163±0.080	0.042±0.021	1.192±0.462	1.210±0.194	1.682±0.671	6.294±0.140	10.58±1.299
(High-productivity wells)	(0.074-0.257)	(0.022-0.061)	(0.705-1.678)	(0.946-1.399)	(0.829-2.297)	(6.097-6.409)	(8.927-11.686)
Jleeb Al-Shuyoukh	0.019±0.005	0.004±0.001	0.029±0.006	0.027±0.009	0.032±0.014	0.039±0.022	0.150±0.038
(Project Area)	(0.012-0.027)	(0.003-0.006)	(0.019-0.037)	(0.018-0.042)	(0.017-0.056)	(0.021-0.076)	(0.108-0.206)

[1] ΣBTEX+S: Sum of benzene, toluene; ethylbenzene; m,p,o-xylenes and styrene. [2]Mean ± standard deviation. [3]Concentration range (min- max)

As shown in Table 4 and Fig. 9 that the sum of BTEX and styrene emissions (ΣBTEX+S) was comparable between Jleeb Al-Shuyoukh high-productivity wells (7752.3 ppb) and Al-Qurain high-productivity wells (6229.4 ppb) and also with those reported for sites B and D in Korea, 5652.5 ppb and 6181 ppb, respectively.

ΣBTEX+S emission from high-productivity wells in Jleeb Al-Shuyoukh are almost half of those calculated for BTEX and styrene measured in 2004 (Schrapp and Al-Mutairi, 2010). ΣBTEX+S emission from Jleeb Al-Shuyoukh low-productivity wells (1169.6 ppb) was also comparable with ΣBTEX+S emission from Al-Qurain low-productivity wells (1337.3 ppb). Interestingly, the average emission of ΣBTEX+S from monitoring wells in the project area was significantly reduced down to 326.5 ppb which is only 200 ppb higher than the measured ΣBTEX+S emissions from the native soil boreholes in the background of Jleeb Al-Shuyoukh landfill site.

The Benzene-to-Toluene ratio (B/T) is widely used in source apportionment studies to evaluate VOC emission characteristics from different sources. It has been reported that the B/T ratio was between 0.015 and 0.11 for landfill gas, 0.5 for vehicle exhaust gas and between 0.27 and 0.5 for typical urban atmospheric environment (Dincer et al., 2006). Other studies have also reported B/T ratios between 0.01 and 0.2 for landfill gas (Kim et al., 2006). Kim et al. (2006) measured VOCs emissions from five landfill sites in Korea and reported that B/T ratios varied significantly between 0.12 and 5.3. Urase et al. (2008) reported B/T ratio as high as 8 at a location in a landfill site in Tokyo-Japan.

As shown in Table 4, in the present study we observed low B/T ratios in the native soil wells and also in low-productivity wells in Jleeb Al-Shuyoukh landfill site of 0.6 and 0.8, respectively; whereas, higher B/T ratios of 6.1 and 5.6 were observed in the project area "In-situ aerobic stabilization" and in high-productivity wells in Jleeb Al-Shuyoukh and AlQurain landfill, respectively. These high B/T ratios in the project area and in the high-productivity wells can be attributed to the higher biological reactivity and reactions taking place in the vicinity of these. The temperature inside the waste layer is known to go up to 80°C occasionally. The exposure of the plastics in solid waste layer to such high temperature is probably one of the reasons for the release of VOCs from solid waste disposal sites. Figure 10 also shows that there was a good correlation ($R^2 = 0.9242$) between B/T ratios and ΣBTEX+S emissions for Jleeb Al-Shuyoukh and Al-Qurain high-productivity wells which further demonstrates the similarity in the chemical and biological processes, types and age of buried wastes as well as other local conditions between the two landfills leading to similar composition and concentrations of VOCs in LFG emissions.

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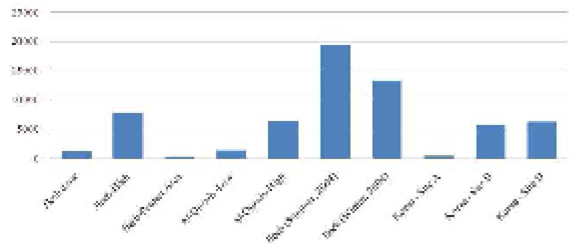

Fig. 9: Comparison of ΣBTEX+Styrene measured in this study with those reported in the literature (in ppb)

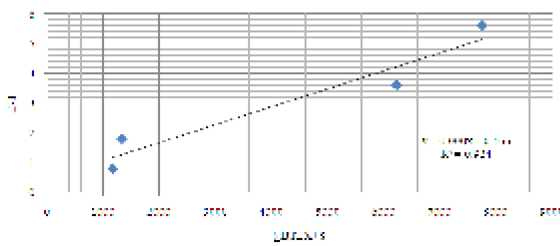

Fig. 10: Correlation between B/T and ΣBTEX+S in Jleeb Al-Shuyoukh and Al-Qurain

Estimation of VOCs annual emission rates: One of the objectives of the present study includes accurate identification and quantification of VOCs emissions from the two major landfill sites in Kuwait (i.e., Jleeb Al-Shuyoukh and Al-Qurain). The availability of this kind of information can help in evaluating the emission potential of a given landfill environment. For this purpose, the major five VOCs (i.e., benzene; toluene; ethylbenzene; m-, p- and o-xylenes and styrene) were computed for each sampled monitoring well in Jleeb Al-Shuyoukh landfill using their concentrations and the concurrently determined flow rates of LFG.

However, as our estimation is based on a relatively limited quantity of data sets such results may only be used at this stage as rough estimates for the extent of VOC emissions from landfill sites in Kuwait. Table 5 lists the results calculated in terms of the average ΣBTEX+S quantity emitted per vent pipe per year which showed that the magnitude of their annual emission rates can vary substantially, with the values ranging between 0.108-11.686 g y^{-1}.

CONCLUSION

During this study it was possible for the first time in Kuwait to identify and quantify 50 Volatile Organic Compounds (VOCs) in LFG emissions from two old landfill sites in Kuwait. The compounds identified included the well-known four aromatic VOCs; Benzene, Toluene, Ethylbenzene and o-, m and p-Xylenes (BTEX). Styrene was also identified and its concentration level was the highest amongst aromatic VOCs. Concentrations of total VOCs (i.e., sum of 50 compounds) in LFG emissions varied between 9.4-67.2 ppm in Jleeb Al-Shuyoukh landfill site and from 15.4-57.7 ppm in Al-Qurain landfill site.

The results obtained in this study demonstrated that the concentration levels of VOCs were found to be significantly different within the same landfill site depending on the reactivity and productivity of the biological decomposition processes of buried wastes. In addition, the results also demonstrated that total VOCs emissions were comparable between the two landfill sites.

This study demonstrated that the "in-situ aerobic stabilization method" applied in the project area of Jleeb Al-Shuyoukh landfill for the treatment of old waste deposits in landfills can significantly reduce the emission of VOCs in LFG by as much as 89%.

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