The Islamic University – Gaza
Deanship of Graduate Studies
Faculty of Engineering
Water Resources Engineering

الجامعة الإسلامية – غزة
عمـادة الدراسـات العليـا
كـليـــة الهـندســـة
هندســة مصــادر الميــاه

Evaluating the Impact of Landfill Leachate on Groundwater Aquifer in Gaza Strip Using Modeling Approach

تقييم تأثير العصارة المتسربة من مكبات النفايات على خزان مياه غزة الجوفي باستخدام نهج النمذجة

Prepared By
Eng. Tamer Mousa Alslaibi

Supervised By
Prof. Samir Afifi and Dr. Yunes Mogheir

A Thesis Submitted in Partial Fulfillment of the Requirements for the Degree of Master of Science in Engineering - Water Resources Engineering

The Islamic University – Gaza - Palestine

1430هـ – 2009 م

DEDICATION

I would like to dedicate this thesis to my parents, wife, sons (Bara 'a and Sally), brothers and sisters

ACKNOWLEDGEMENTS

First, I would like to express my greatest gratitude to Dr. Yunes Moghier and Prof. Samir Afifi for their invaluable guidance.

I would like to acknowledge my lovely parents, wife, sons (Bara'a and Sally), brothers and sisters whose wisdom and love shaped me as I grew up.

I would like to extend my great appreciations to all water resources master program lectures and supporting staff in the Islamic University.

I would like to acknowledgment Eng. Luay Qrenawi for his support and help during my study.

Many thanks go to all my friends and colleagues in Environment Quality Authority especially; Eng. Bahaa Alagha and Eng. Ibrahim El-Aff for their support and help during my study.

Special thanks are directed to The Islamic University of Gaza and Heidelberg University of Germany for their financial support.

There have been numerous supports (big and small) that have helped me to complete my thesis.

Thus, I would like to thank everyone from the bottom of my heart.

Abstract

Landfills are one of the groundwater pollution sources in Gaza Strip. This study focuses on two landfills operating in Gaza Strip; the first is Dear Al Balah landfill which has a lining system and the second Gaza landfill which does not have lining system. The objectives of the present study are to assess the quantity and quality of the two landfills leachate percolated to the groundwater aquifer, to model the generated leachate quantity, to study the effects on groundwater aquifer quality around the two landfills and to propose mitigation measures.

Groundwater samples from 18 boreholes located downstream of landfills in addition to two leachate samples were collected during dry season in November 2008 to study possible impact of leachate percolation into groundwater. Several physical and chemical parameters were tested in groundwater and leachate samples, these include temperature, pH and EC, NO_3, NH_4, Cl, SO_4, BOD, COD, TOC, Pb, Fe, Cu, Cd, Zn. The Geographic Information System (GIS) was used as a tool to illustrate the analyzed result of the pollutant indicators around both landfills in the periods 1995, 1999, 2001 and 2008 respectively. Moreover, this study presents the application of the hydrologic evaluation of landfill performance (HELP) model and Water Balance Method (WBM) for the determination of the annual landfill leachate. Two scenarios were applied on Gaza landfill, using HELP model which are assuming lining system and current state of no lining system. Furthermore, landfill components were analyzed to study their influence on the quantity of percolated leachate to groundwater.

The results showed that most of boreholes were contaminated, where concentration of most physical and chemical parameters were above acceptable standard levels required by local and international standards for potable and irrigation water. It is quite evident that landfills present potential threats to the surrounding environment.

HELP model indicated that the average volume of leachate discharged from Dear Al Balah landfill in the period from 1997 to 2007 was about 6,800 m^3/year while the average volume of leachate percolated through clay layer was 550 m^3/year which represent about 8% of the generated leachate. The results for the first scenario of Gaza landfill showed that the average annual volume of leachate discharged and percolated

through clay layer were more than 34,000 m^3 and around 2,000 m^3 respectively which represents about 6.5% of generated leachate while this percentage increased to about 50% when applying the second scenario which represents the reality.

WBM indicated that the average volume of leachate discharged from Dear Al Balah landfill in the period from 1997 to 2007 was about 7,660 m^3/year. While the average annual generated leachate volume at Gaza landfill without recycle and with 40 % recycle were about 29,000 and 39,000 m^3 respectively. So that, the estimated quantity of leachate by the study methods was very closed.

The landfills components were ordered in priority according to their effect on percolated leachate through clay layer, (1) Existing of lining system enhances the percolation reduction up to 87%, (2) About 30% reduction of rainfall level enhances the percolation reduction up to 50%, (3) About 50% reduction of existing landfill area enhances the percolation reduction up to 50%, and (4) The absent of recirculation system slight enhances the percolation reduction up to 2.5% than with the availability of recirculation system. The waste depth has no significant effect on the quantity of percolated leachate.

The study recommend that new sanitary landfill sites should be designed as an engineering facility to minimize the adverse effects associated with solid waste disposal and to prevent further contamination to surface water, groundwater as well as soil. In case the local authorities decided to continue operating landfills, mitigation measures should be considered at Gaza and Dear Al Balah landfills to minimize the leachate accumulated and percolated to local aquifer such as installation of final cover (cap) and use of vertical expansion not lateral to minimize landfill area. Further studies should be carried out on the two landfills such as conducting contaminant transport model to study the pollutants transport through the soil layers.

الملخص

يعاني قطاع غزة من مشاكل تلوث المياه الجوفية ، وتعتبر مكابات النفايات واحدة من مصادر هذا التلوث. لقد ركزت هذه الدراسة على مكبين رئيسيين في قطاع غزة الأول مكب دير البلح المصمم بطريقة هندسية لمنع تسرب العصارة والثاني مكب غزة الذي لا يحتوي على نظام حماية . تهدف هذه الدراسة الى تقييم نوعية وكمية العصارة المتسربة الى المياه الجوفية من كلا المكبين ، ونمذجة كمية العصارة المتكونة ، بالاضافة الى دراسة تسرب العصارة على جودة المياه الجوفية حول المكبين واقتراح الاجراءات التخفيفية المناسبة.

لدراسة إمكانية تسرب العصارة الى المياه الجوفية تم أخذ عينتي عصارة و18 عينة مياه جوفية من الآبار المحيطة بمكبي النفايات والتي تقع بعد المكب (Downstream) وذلك في صيف عام 2008 ، وتم فحص عدة عناصر فيزيائية وكيميائية لهذه العينات وتشمل درجة الحرارة والحامضية ودرجة التوصيل الكهربائي والنترات والأمونيا والكلورايد والكبريتات وكمية الاكسجين المستهلكة عضوياً وكمية الأكسجين المستهلكة كيميائياً والكربون العضوي الكلي بالإضافة الى العناصر الثقيلة. وتم عرض النتائج من خلال برنامج نظم المعلومات الجغرافية (GIS) لعام 2008 ومقارنتها مع نتائج تحليل السنوات السابقة لعام 1995 و 1999 و 2001. وقد تم استخدام طريقتين لتقدير كمية العصارة المتكونة سنوياً في كلا المكبين وهي طريقة برنامج المحاكاة HELP Model وطريقة اتزان المياه (Water Balance Method). تم تطبيق سناريوهان على مكب غزة باستخدام برنامج HELP مرة بافتراض أنه مصمم بطريقة هندسية والأخرى بتطبيق الوضع القائم حيث أنه غير مصمم هندسياً. علاوة على ذلك تم دراسة تأثير مكونات مكب النفايات على كمية العصارة المتسربة الى الخزان الجوفي.

أوضحت الدراسة أن معظم الآبار التى تم فحصها تحتوي على مستوي عالي من الملوثات حيث أن تراكيز العناصر الفيزيائية والكيميائية كانت أعلى من المواصفات المحلية والعالمية لمياه الشرب وأغراض الزراعة ، و هذا مؤشر أن مكبات النفايات محل الدراسة تشكل خطر على البيئة المحيطة.

لقد أشارة نتائج استخدام برنامج HELP إلى أن متوسط كمية العصارة المتكونة في مكب دير البلح تقدر بحوالي 6,800 م^3 سنويا خلال فترة الدراسة من سنة 1997 الى 2007 بينما تقدر كمية العصارة المتسربة خلال طبقات الطين بحوالي 550 م^3 سنوياً والتي تشكل 8% من كمية العصارة المتكونة. أما بالنسبة لمكب غزة فتقدر متوسط كمية العصارة المتكونة بناءً على السيناريو الاول - و الذي يفترض وجود نظام عزل و جمع للعصارة - بحوالي 34,000 م^3 والمتسربة عبر طبقات الطين بحوالي 2,000 م^3 والتي تمثل 6 % من العصارة المتكونة ، وترتفع هذه النسبة إلى 50 % عند تطبيق السيناريو الثاني والذي يمثل الواقع. بينما أشارة نتائج طريقة اتزان المياه (WBM) الى أن متوسط كمية العصارة المتكونة في مكب دير البلح تقدر بحوالي 7,660 م^3 سنويا خلال فترة الدراسة من سنة 1997 الى 2007، أما بالنسبة لمكب غزة فتقدر متوسط كمية العصارة المتكونة بحوالي 39,000 م^3 على اعتبار أن 40 % منها راجع الى المكب وبحوالي 29,000 م^3 على اعتبار أنه لا توجد عصارة راجعة الى المكب. وبناءً على ذلك فإن كمية العصارة المقدرة بالطريقتين متقاربة بشكل كبير وهذا يدل على دقة الطريقتين في تقدير كمية العصارة.

تأثير مكونات مكبات النفايات على كمية العصارة المتسربة تم ترتيبها بناءً على درجة التأثير كالتالي: (1) وجود نظام الحماية في مكبات النفايات يؤدي الى خفض كمية العصارة المتسربة بنسبة 87 % ، (2) خفض كمية الامطار بنسبة 30 % يؤدي الى خفض كمية العصارة المتسربة بنسبة 50 % ، (3) خفض مساحة المكب بنسبة 50 % يؤدي الى خفض كمية العصارة المتسربة بنسبة 50 % ، (4) غياب نظام تدوير العصارة يؤدي إلى انخفاض طفيف في كمية العصارة المتسربة بنسبة 2.5% عنه في حالة وجود نظام التدوير ، لا يوجد تأثير ملموس لسمك طبقة النفايات على كمية العصارة المتسربة.

وقد أوصت الدراسة بضرورة إنشاء مكبات صحية مصممة بطريقة هندسية لتقليل التأثيرات السلبية على البيئة المحيطة ومنع حدوث تلوث إضافي للمياه السطحية والجوفية وكذلك التربة ، وفي حال قررت السلطات المحلية الاستمرار في التخلص من النفايات في مكبي غزة ودير البلح يجب أن تقوم باتخاذ الاجراءات الوقائية التالية للحد من كمية العصارة المتسربة من خلال تغطية مكبات النفايات للتقليل من كمية الأمطار المتسربة وكذلك بالتمدد الرأسي في المكب وعدم التمدد أفقياً للتقليل من المساحة السطحية. وقد أوصت الدراسة أيضاً بضرورة عمل دراسة اضافية حول نمذجة انتقال الملوثات خلال طبقات التربة.

Table of Contents

List of Figures

List of Tables

ACRONYMS AND ABBREVIATION

SYMBO	DESCRIPTION
BOD	Biochemical Oxygen Demand
C&DD	Construction and Demolition Debris
Cd	Cadmium
Cl	Chloride
COD	Chemical Oxygen Demand
Cu	Copper
DB	Drilled Boreholes
EC	Electrical Conductivity
ET	Evapotranspiration
EZD	Evaporative Zone Depth
Fe	Iron
GIS	Geographical Information System
GTZ	German Technical Cooperation
HDPE	High Density Polyethylene
HELP	Hydrologic Evaluation of Landfill Performance
IDW	Inverse Distance Weighting
IUG	Islamic University of Gaza
J	Joules
JSC	Joint Service Council
k	Hydraulic Conductivity
MCL	Maximum Contaminant Level
MEnA	Ministry of Environmental affairs
MLAI	Maximum Leaf Area Index
MSW	Municipal Solid Waste
NH_4	Ammonia
NO_3	Nitrite
P	Precipitation
Pb	Lead
PMO	Palestinian Meteorological Office
R	Correlation
RO	Runoff
SCS	Soil Conservation Service
SO_4	Sulfate
SWRRB	Simulator for Water Resources in Rural Basins
TOC	Total Organic Carbon
UNEP	United Nations Environment Programme
US EPA	United States Environmental Protection Agency
WBM	Water Balance Method
WHO	World Health Organization
Zn	Zinc

CHAPTER (1): INTRODUCTION

1.1 Introduction

Waste disposal has always been an important issue for human societies. Solid wastes are disposed on or below the land surface resulting in potential sources of groundwater contamination. One of the most common waste disposal methods is landfilling; a controlled method of disposing solid wastes on land with the dual purpose of eliminating public health and environmental hazards and minimizing nuisances without contaminating surface or subsurface water resources. A municipal solid waste (MSW) landfill is not a benign repository of discarded material; it is a biochemically active unit where toxic substances are leached or created from combinations of non-toxic precursors and gradually released into the surrounding environment over a period of decades (Papadopoulou et al., 2006). Biological, chemical and physical processes within the landfill promote the degradation of wastes and result in the production of leachate and gases.

In modern landfills, the waste is contained by a liner system. The primary purpose of the liner system is to isolate the landfill contents from the environment and, therefore, to protect the soil and groundwater from pollution originating in the landfill. The greatest threat to groundwater posed by modern landfills is leachate. Leachate consists of water and water- soluble compounds in the refuse that accumulate as water moves through the landfill. This water may be from rainfall or from the waste itself. Leachate may migrate from the landfill and contaminate soil and ground water, thus presenting a risk to human and environmental health (Hughes et al., 2008).

Incidents of groundwater contamination by landfill leachate have been widely reported since the early 1970s (Bou-Zeid and El-Fadel, 2004). This created the need to understand the mechanisms that control leachate formation, quality, quantity, and most importantly migration characteristics with associated spatial and temporal variations during landfill operations and after closure.

1.2 Problem Identification

A recent study was performed in the composition of municipal solid waste in the Gaza Strip and showed that they characterized by a high organic content (Jaber and Nassar, 2007). The composition of municipal solid waste in Gaza Strip is shown in Table 1.1, where food waste constitutes more than 60% of the total waste at source, as shown in figure 1.1. Most of this amount of household waste is buried in landfills or disposed without separation or treatment. Susceptible groundwater aquifer is under potential contamination by solid waste leachate. Important factors to prevent groundwater contamination by leachate are proper management of solid waste and landfill structure.

Table 1.1: Composition of Municipal Solid Waste in the Gaza Strip (UNEP, 2003)

Material	Percent Fraction
Organic material	60% - 70%
Paper and cardboard	7% - 10%
Plastics	5% - 10%
Glass	3% - 6%
Metals	2% - 3%
Others	3% - 7%

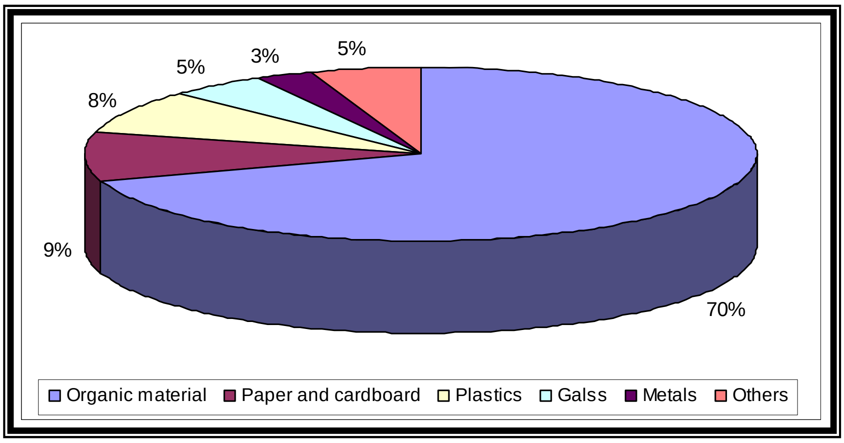

Figure 1.1: Composition of Municipal Solid Waste in the Gaza Strip (UNEP, 2003)

Factors affect leachate generations are: climate (rainfall), topography (run on/run-off), landfill cover, vegetation, and type of waste. In unlined landfills like Gaza and Rafah dumping sites, the leachate may be infiltrating into groundwater causes severe contaminations. The process depends on several factors; soil chemistry and mineralogy, leachate/soil interaction, groundwater aquifer system and water characteristics. Sanitary landfill like the one of Dear Al Balah requires meeting standards and regulations to prevent environmental contamination. Figure 1.2 summarizes the mechanism of leachate transport from landfill to groundwater and consequently to human beings.

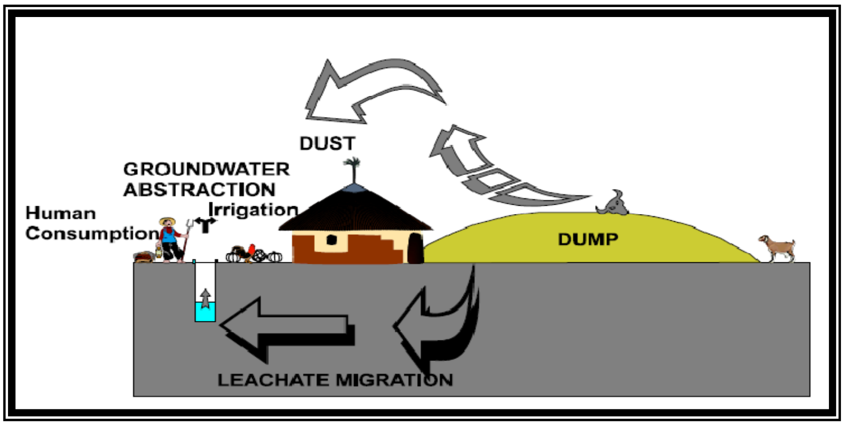

Figure 1.2: Schematic of Leachate Transport from Landfill to the Human Throw Pumping Wells (Klinck and Stuart, 1999)

Many studies investigated the health effects of contaminated groundwater due to landfill leachate. It contains a host of toxic and carcinogenic chemicals, which may cause harm to both humans and environment. Table 1.2 gives hints about the health effects of contaminants in leachates. Furthermore, leachate-contaminated groundwater can adversely affect industrial and agricultural activities that depend on groundwater. The use of contaminated water for irrigation can decrease soil productivity, contaminate crops, and move possibly toxic pollutants up the food chain as animals and humans consume crops grown in an area irrigated with contaminated water (Jagloo, 2002). Due to the health impacts caused by landfill leachate it is very important to estimate its quantity of leachate might reach the groundwater and study the effect of this leachate on groundwater.

Table 1.2: Health Effects of Landfill Leachate (EPA, 2003)

Contaminant	Potential Health Effects from Exposure Above The MCL
Arsenic	Skin damage; circulatory system problems; increased
Barium	Risk of cancer
Fluoride	Bone disease (fluorosis).
Mercury	Kidney damage
Nitrate	Methemoglobinemia (blue-baby syndrome).

** Maximum Contaminant Level (MCL)*

1.3 Objectives of the study

The main objectives of the intended research are:

1. Evaluation current situation of landfilling process in the two sites.
2. Assessment of the generated leachate quantities and percolated processes to groundwater aquifer in the specific sites.
3. Investigate the contaminants transport in groundwater and recommending mitigation measures.

1.4 Applied Methods

The methodology comprises of several stages, as follows:

1. Literature collection and review, which is aimed at having a clear understanding of the previous experiences and findings of previous researchers in the field. This stage assisted in the formulation of the theoretical bases of the current study.
2. Data collection approach has been based on field work where the researcher conducted several visits to the targeted landfill areas to collect the required samples and study the topography. Collected Data such as solid waste quantities, sources, rate of their generation, solid waste composition, final disposal options, and description of the middle and southern landfills (area, location, topography, groundwater table, quantity and type of waste deposited).
3. Collecting and testing of some groundwater samples from multilevel observation wells for studying the landfill leachate transport through aquifer.
4. Estimating quantities of accumulated leachate and percolated amounts to groundwater aquifer, using :
    a. The Hydrologic Evaluation of Landfill Performance (HELP) model.
    b. Water Balance Method.
    c. Field measured data.
5. Development of monitoring system of groundwater aquifer for the studied areas which were contaminated by landfill leachate transport and recommending mitigation measures.
6. Upon completion of the data and literature collection, assessment and analysis, the researcher started to compose the thesis study.

1.5 Thesis Structure

The thesis has been organized in seven chapters: Chapter One is a general introduction considering a brief background on landfills problems and impacts associated with landfilling processes; it also presents the objectives and overall research methodology. Chapter Two presents a brief literature review of landfill types, anatomy and their liner system, and the findings of previous researchers in the field. Chapter Three presents in details the study areas (Dear Al Balah and Gaza landfill) in terms of location, topography, climate, hydrology and geology. Chapter Four describes the detailed methods used in this study. Chapter Five is directed towards modeling of the landfill leachate quantified at the sites and its effects on groundwater quality. Furthermore, it also presents the results of the application of the two methods. Chapter Six presents the discussion of the results and the recommending mitigation measures to be taken in the to landfills areas. Chapter Seven highlights the conclusions and the recommendations.

CHAPTER (2): LITERATURE REVIEW

2.1 Introduction

Large quantities of wastes from urban, municipal, and industrial sectors are generated worldwide. Landfills have served for many decades as ultimate disposal sites for all types of these wastes. At present many of these find their way into the environment with little or no treatment especially in developing countries (Abu-Rukah and Al-Kofahi, 2001). Physical, chemical, and biological processes interact simultaneously to bring about the overall decomposition of the wastes. One of the byproducts of all these mechanisms is chemically laden leachates. The major environmental problem at landfills is the loss of leachates from the site and the subsequent contamination of groundwater (Jagloo, 2002). Modern landfills have liners at the base, which act as barriers to leachate migration. However, it is widely acknowledged that such liners deteriorate over time and ultimately fail to prevent the movement of leachates into an aquifer (Jagloo, 2002).

The impact of landfill leachates on the surface and groundwater has given rise to a great number of studies in recent years. Globally, these include the research carried out by (Abu Rukah & Al-Kofahi, 2001), (Jagloo, 2002) and (Qrenawi, 2006). (Abu Rukah & Al-Kofahi, 2001) studied the various metal ions migration in the El-Akader landfill site and concluded that all results presented show that the El-Akader dump site constitutes a serious threat to local aquifers. (Jagloo, 2002) in here study in the Mauritius region stated that the risk assessment performed using the Landsim simulation package reveals no detrimental short term or long term risk of groundwater contamination. In their study (Qrenawi, 2006) indicated the landfill leachate as well as the industrial wastewater discharged at the site is a major contributor to the groundwater contamination and the situation is expected to be worse in the near future.

There is no special researches done to study this environmental issue in the Gaza Strip, however, the Environment Quality Authority prepared a report on the environmental assessment of solid waste dump site in the Gaza Strip (Jaber and Nassar, 2007). The report concluded that leachate poses a serious threat of pollution to underlying groundwater resources. This is of particular importance within the context of the Gaza Strip where groundwater is the only source of drinking water (Jaber and Nassar, 2007).

2.1.1 Landfill leachate

According to Jagloo, 2002, there are three important attributes that distinguish any source of groundwater contamination: the degree of localization, the loading history, and the kinds of contaminants emanating from them. A sanitary landfill is a point source of groundwater pollution and produces a reasonably well defined plume in many instances.

The loading history describes how the concentration of a contaminant or its rate of production varies as a function of time at the source. Leachate rates at a landfill site are controlled by seasonal factors or by a decline in source strength as components of the waste such as organics, biodegrade.

Many factors influence leachate composition, these include the types of wastes deposited in the landfill, the amount of precipitation in the area and other site-specific conditions (Jagloo, 2002).

2.1.2 Leachate Effects

Leachate contains a host of toxic and carcinogenic chemicals, which may cause harm to both humans and environment. Table 1.2 gives details about the health effects of contaminants in leachates. Furthermore, leachate-contaminated groundwater can adversely affect industrial and agricultural activities that depend on well water. The use of contaminated water for irrigation can decrease soil productivity, contaminate crops, and move possibly toxic pollutants up the food chain as animals and humans consume crops grown in an area irrigated with contaminated water (Jagloo, 2002).

2.1.3 Landfill Sitting Considerations

While alternative waste disposal methods – incineration along with the advent of recycling, composting, and pollution prevention – are scaling back the number of active landfills, the engineering construction and operation of landfills are now more complex than ever. Driven by public pressure and subsequent regulatory requirements, landfill design and operation now have to conform to strict standards.

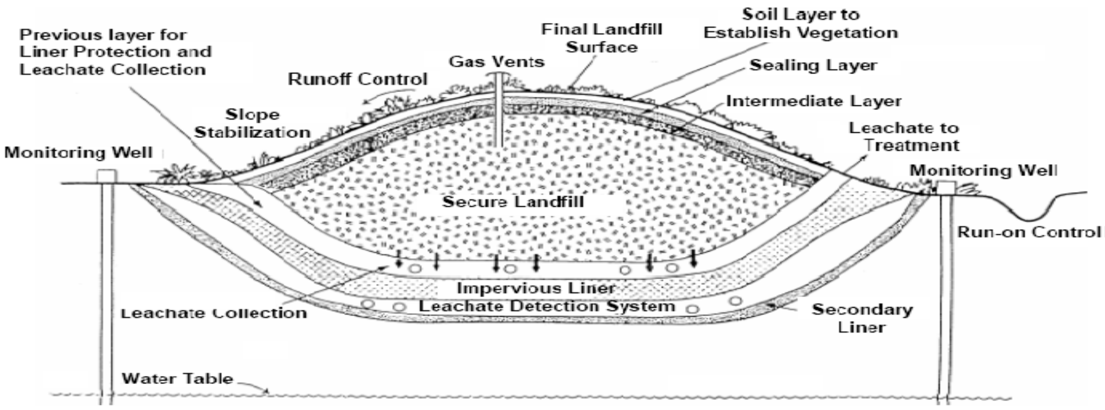

Figure 2.1: Schematic Cross Section in a Sanitary Landfill (Jaber & Nassar, 2007)

To achieve a successful sitting process, several significant political and environmental obstacles have to be overcome. Factors that must be considered in evaluating potential sites for the long term disposal of solid waste include (Jaber and Nassar, 2007):

1. Distance from waste generation source and waste type.
2. Depth to groundwater and groundwater quality from observation wells.
3. Distance from residential, religious and archaeological sites.
4. Site access and capacity.
5. Soil characteristics, clay content, topography and land slope.
6. Local environmental and climatic conditions.
7. Existing land use pattern and land cost.
8. Distance from airports.
9. Ease of access in any kind of weather to all vehicles expected to use it.
10. Seismic activity.

Final selection of a disposal site is usually based on the results of detailed site survey, engineering design, cost studies, the conducting of one or more environmental impact assessments, the outcome of public hearings and a sober analysis of presently operating landfills. The environmental impacts of new landfills must be as low as possible for as long period as possible. This means that; environmental impact assessment and safety analyses are therefore necessary in each and every case.

2.2 Typical Anatomy of a Sanitary Landfill

The design of a landfill will significantly affect its safety, cost, and effectiveness over the lifetime of the facility. Key items requiring attention in the design are listed in the following sections.

2.2.1 Protective Cover

1. Cover vegetation

As portions of the landfill are completed, native grasses and shrubs are planted and the areas are maintained as open spaces. The vegetation is visually pleasing and prevents erosion of the underlying soils as shown in figure 2.2.

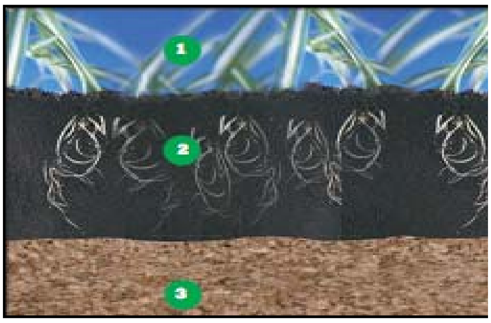

Figure 2.2: Protective Cover of landfill (www.wm.com)

2. Top Soil

Helps to support and maintain the growth of vegetation by retaining moisture and providing nutrients as shown in figure 2.2.

3. Protective cover soil

Protects the landfill cap system and provides additional moisture retention to help support the cover vegetation as shown in figure 2.2.

2.2.2 Composite Cap System

4. Drainage Layer

A layer of sand or gravel or a thick plastic mesh called a geonet drains excess precipitation from the protective cover soil to enhance stability and help prevent infiltration of water through the landfill cap system as shown in figure 2.3.

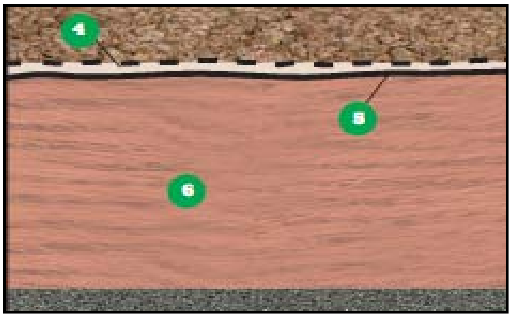

Figure 2.3: Composite Cap System of landfill (www.wm.com)

A geotextile fabric, similar in appearance to felt, may be located on top of the drainage layer to provide separation of solid particles from liquid. This prevents clogging of the drainage layer as shown in figure 2.3.

5. Geomembrane

A thick plastic layer forms a cap that prevents excess precipitation from entering the landfill and forming leachate. This layer also helps to prevent the escape of landfill gas, thereby reducing odors as shown in figure 2.3.

6. Compacted Clay

It is placed over the waste to form a cap when the landfill reaches the permitted height. This layer prevents excess precipitation from entering the landfill and forming leachate and helps to prevent the escape of landfill gas, thereby reducing odors as shown in figure 2.3.

2.2.3 Working Landfill

7. Daily Cover

At the end of each working period, waste is covered with six to twelve inches of soil or other approved material. Daily cover reduces odors, keeps litter from scattering and helps deter scavengers as shown in figure 2.4.

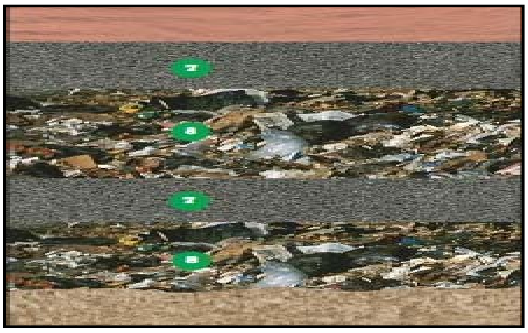

Figure 2.4: Working Landfill (www.wm.com)

8. Waste

As waste arrives, it is compacted in layers within a small area to reduce the volume consumed within the landfill. This practice also helps to reduce odors, keeps litter from scattering and deters scavengers as shown in figure 2.4.

2.2.4 Leachate Collection System

Leachate is a liquid that has filtered through the landfill. It consists primarily of precipitation with a small amount coming from the natural decomposition of the waste. The leachate collection system collects the leachate so that it can be removed from the landfill and properly treated or disposed of. The leachate collection system as shown in figure 2.5 has the following components:

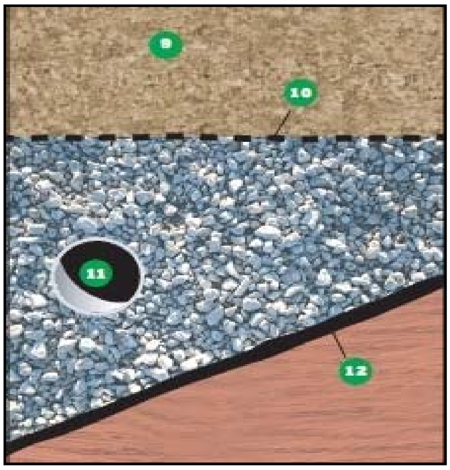

Figure 2.5: Leachate Collection System of landfill (www.wm.com)

9. Leachate Collection Layer

A layer of sand or gravel or a thick plastic mesh called a geonet collects leachate and allows it to drain by gravity to the leachate collection pipe system.

10. Filter Geotextile

A geotextile fabric, similar in appearance to felt, may be located on top of the leachate collection pipe system to provide separation of solid particles from liquid. This prevents clogging of the pipe system.

11. Leachate Collection Pipe System

Perforated pipes, surrounded by a bed of gravel, transport collected leachate to specially designed low points called sumps. Pumps, located within the sumps, automatically remove the leachate from the landfill and transport it to the leachate management facilities for treatment or another proper method of disposal.

2.2.5 Composite Liner System

12. Geomembrane

A thick plastic layer forms a liner that prevents leachate from leaving the landfill and entering the environment. This geomembrane is typically constructed of a special type of plastic called high-density polyethylene or HDPE as shown in figure 2.6.

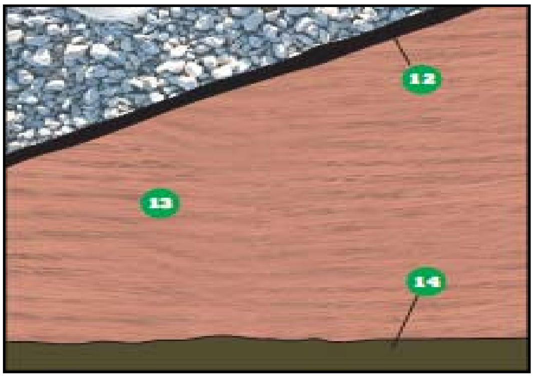

Figure 2.6: Composite Liner System of landfill (www.wm.com)

HDPE is tough, impermeable and extremely resistant to attack by the compounds that might be in the leachate. This layer also helps to prevent the escape of landfill gas.

13. Compacted Clay

Is located directly below the geomembrane and forms an additional barrier to prevent leachate from leaving the landfill and entering the environment. This layer also helps to prevent the escape of landfill gas as shown in figure 2.6.

14. Prepared Subgrade

The native soils beneath the landfill are prepared as needed prior to beginning landfill construction as shown in figure 2.6.

2.3 Landfill Types and Liner Systems

Society produces many different solid wastes that pose different threats to the environment and to community health. Different disposal sites are available for these different types of waste. The potential threat posed by the waste determines the type of liner system required for each type of landfill. Liners may be described as single (also referred to as simple), composite, or double liners (Hughes et al., 2008).

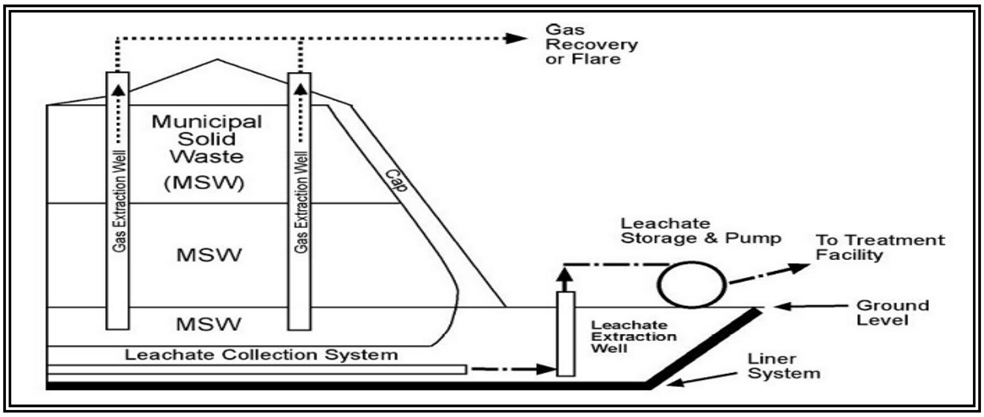

Figure 2.7: Modern landfill (http://ohioline.osu.edu)

2.3.1 Single-Liner Systems

Single liners as shown in figure 2.8 consist of a clay liner, a geosynthetic clay liner, or a geomembrane (specialized plastic sheeting). Single liners are sometimes used in landfills designed to hold construction and demolition debris (C&DD). Construction and demolition debris results from building and demolition activities and includes concrete, asphalt, shingles, wood, bricks, and glass. These landfills are not constructed to contain paint, liquid tar, municipal garbage, or treated lumber; consequently, single-liner systems are usually adequate to protect the environment. It is cheaper to dispose of construction materials in a C&DD landfill than in a municipal solid waste landfill because C&DD landfills use only a single liner and are therefore cheaper to build and maintain than other landfills.

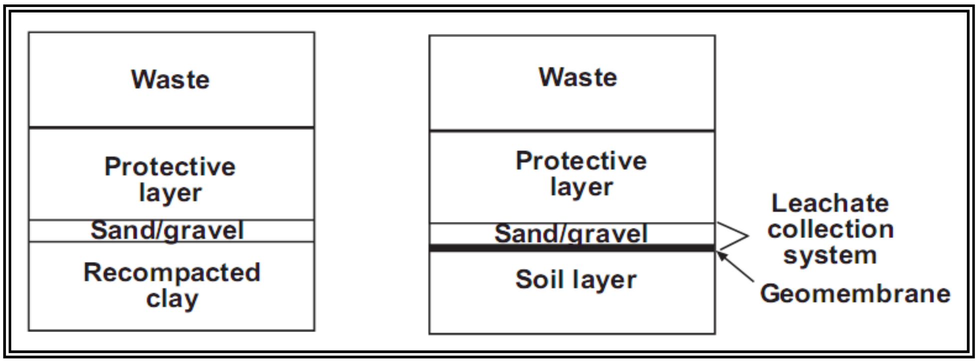

Figure 2.8: Examples of single liner system (http://ohioline.osu.edu)

2.3.2 Composite-Liner Systems

A composite liner consists of a geomembrane in combination with a clay liner as shown in figure 2.9. Composite-liner systems are more effective at limiting leachate migration into the subsoil than either a clay liner or a single geomembrane layer (Hughes et al., 2008). Composite liners are required in municipal solid waste (MSW) landfills. Municipal solid waste landfills contain waste collected from residential, commercial, and industrial sources. These landfills may also accept C&DD debris, but not hazardous waste. The minimum requirement for MSW landfills is a composite liner. Frequently, landfill designers and operators will install a double liner system in MSW landfills to provide additional monitoring capabilities for the environment and the community.

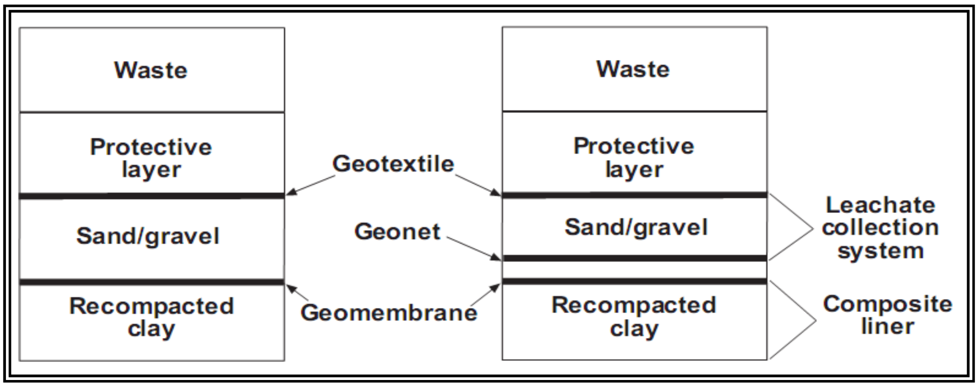

Figure 2.9: Examples of composite liner system (http://ohioline.osu.edu)

2.3.3 Double-Liner Systems

A double liner consists of either two single liners, two composite liners, or a single and a composite liner as shown in figure 2.10. The upper (primary) liner usually functions to collect the leachate, while the lower (secondary) liner acts as a leak-detection system and backup to the primary liner. Double-liner systems are used in some municipal solid waste landfills and in all hazardous waste landfills. Hazardous waste landfills (also referred to as secure landfills) are constructed for the disposal of wastes that once were ignitable, corrosive, reactive, toxic, or are designated as hazardous by the U.S. Environmental Protection Agency (U.S. EPA) (Hughes et al., 2008). These wastes can have an adverse effect on human health and the environment, if improperly managed. Hazardous wastes are produced by industrial, commercial, and agricultural activities. Hazardous wastes must be disposed of in hazardous waste landfills. Hazardous waste landfills must have a double liner system with a leachate collection system above the primary composite liner and a leak detection system above the secondary composite liner.

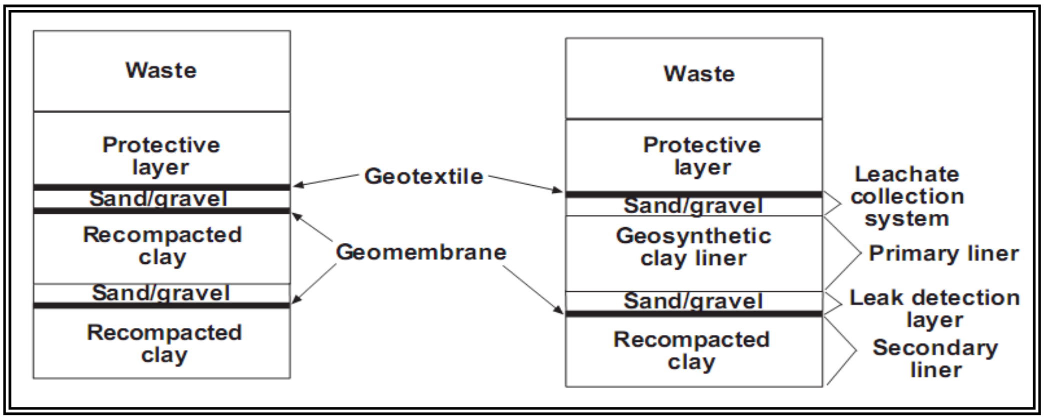

Figure 2.10: Examples of double liner system (http://ohioline.osu.edu)

2.4 Leachate Recirculation

Leachate is composed of liquid that can enters the landfill from external sources, such as surface drainage, rainfall, groundwater and liquid produced from the decomposition of solid waste within the landfill. The liquids migrating through the waste dissolve salt, pick up organic constituents and leach heavy metals. The organic strength of landfill leachate can be 20 to 100 times greater than the strength of raw sewage, making this "landfill liquor" a potentially potent polluter of soil and water. In open dumps, the material that leached would be absorbed into the ground and percolated move into groundwater, surface water, or aquifer system. In sanitary landfill, it is required that leachate collection systems be designed to pump and collect the leachate for treatment (Heimlich, 2000).

Leachate recirculation is defined in Agency guidance LFTGN03 as: "the practice of returning leachate to the landfill from which it has been abstracted" (Waste Management Research Group, 2008). Leachate recirculation is one of many techniques used to manage leachate from landfills. The main goal of leachate control is to prevent uncontrolled dispersion. Leachate should always be collected, treated or contained before it is released into the environment. During leachate recirculation, the leachate is returned to a lined landfill for re-infiltration into the municipal solid waste (MSW). This is considered a method of leachate control because as the leachate continues to flow through the landfill it is treated through biological processes, precipitation, and sorption. This process also benefits the landfill by increasing the moisture content which in turn increases the rate of biological degradation in the landfill, the biological stability of the landfill, and the rate of methane recovery from the landfill (Nora, 2007). Leachate recirculation can be applied to all types of landfills from the current "EU Waste Regulations Compliant" MSW landfills to the most basic (with little engineering and management) seen in the developing nations (Nora, 2007).

2.4.1 Benefits of leachate recirculation

Leachate recirculation in MSW landfills offers these key benefits: (1) reduction in leachate treatment and disposal costs; (2) accelerated decomposition and settlement of waste resulting in gain in airspace; (3) acceleration in gas production; and (4) Accelerating stabilization of organic waste. (5) Potential reduction in post-closure care period and associated costs. (Khire, 2006).

2.4.2 Landfill age and leachate quality

Leachate quality is greatly influenced by the length of time which has elapsed since waste placement. The quantity of chemicals in the waste is finite and, therefore, leachate quality reaches a peak after approximately two to three years followed by a gradual decline in ensuing years (McBean et al., 1995). Table 2.1 summaries the concentration changes of the most common of leachate pollutants with time after landfill closed.

Table 2.1: Leachate characteristics with time (Koliopoulos and Koliopoulou, 2003)

Parameter	0-5 yr	5-10 yr	10-20 yr	>20 yr
BOD_5 (mg/l)	4,000-30,000	1,000-4,000	50-1,000	<50
COD (mg/l)	10,000-60,000	10,000-20,000	1,000-5,000	<100
Ammonia (mg/l)	100-1,500	300-500	50-200	<30
pH	3-6	6-7	7-7.5	6.5-7.5
Chloride (mg/l)	500-3,000	500-2,000	100-500	<100
Sulphate (mg/l)	50-2,000	200-1,000	50-200	<50

1- PH

pH increases with time, which reflects the decrease in concentration of the partially ionized free volatile fatty acids, figure 2.11 (Chian and DeWalle, 1977). Variations in leachate quality with age should be expected throughout most of the landfill life because organic matter will continue to undergo stabilization (Qasim and Chiang, 1994).

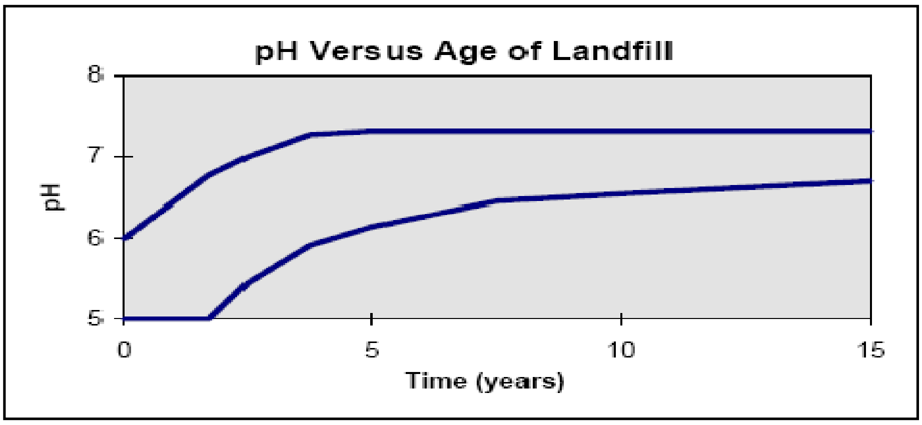

Figure 2.11: Changes in pH with increasing age of the landfill (Reinhart and Grosh, 1998)

2- BOD and COD

BOD and COD are used to measure the organic content in leachate. Generally, leachate from new landfills will be high in BOD and COD and will then steadily decline, leveling off after about 10 years (Akyurek, 1995). All contaminants do not peak at the same time. Due to their initially biodegradable nature, organic compounds decrease more rapidly than inorganics with increasing age of the landfill (Chian and DeWalle, 1977). Inorganics are only removed as a result of washout by infiltrating rainwater (Qasim and Chiang, 1994). Organic compounds, however, decrease in concentration through decomposition as well as washout.

Chian and DeWalle (1977) reported COD and BOD values in the range of 31.1 to 71,680 mg/L and 3.9 to 57,000 mg/L, respectively. A BOD range between 20 to 40,000 mg/L was observed by Ehrig (1989). This researcher also reported COD values in the range of 500 to 60,000 mg/l. A decrease in the concentrations of BOD and COD occurs over time. A decline in BOD concentrations can be attributed to a combination of reduction in organic contaminants available for leaching and the increased biodegradation of organic compounds (Krug and Ham, 1995). A constant decrease in COD is also expected as degradation of organic matter continues (Ehrig, 1989). Figure 2.12 illustrates COD concentrations from some 35 landfills over time after landfill closed. McBean et al. (1995) report COD values ranging from 30,000 to 50,000 mg/l in young leachate. Leachates from old, extensively leached refuse have CODs generally less than 2000 mg/L (McBean et al., 1995).

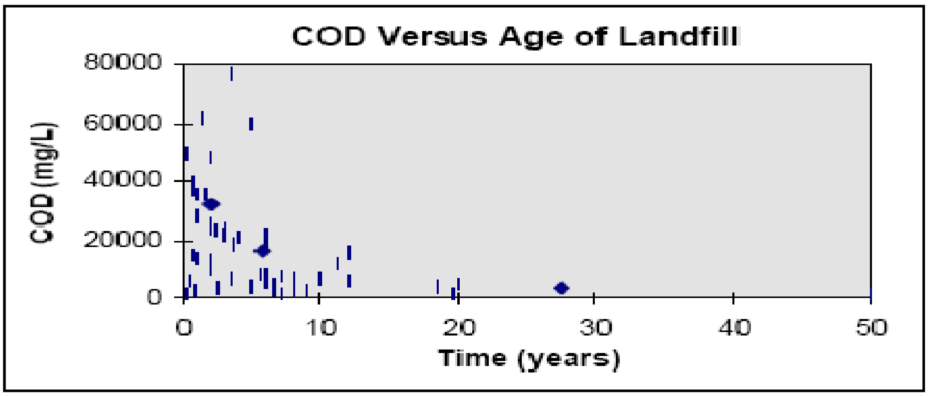

Figure 2.12: Change in COD concentrations with increasing age of the landfill (Reinhart and Grosh, 1998)

Figure 2.13 provides a plot of fitted BOD (mg/l) concentrations over time since closure where GC stands for gas collection system and year represents age of the waste at closure time.

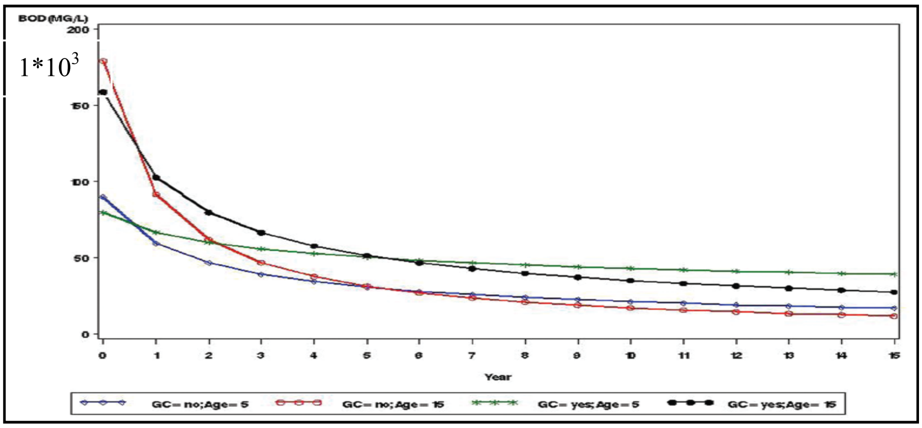

Figure 2.13: Change in BOD concentrations with increasing age of the landfill (Repa, 2008)

Since the BOD test is predominately a biological test, it generally reflects the biodegradability of the organic matter in leachate. Like the COD/TOC, the BOD to

COD ratio, an indicator of the proportion of biologically degradable organic matter to total organic matter, decreases as the landfill ages and more degradation products are leached from deposited residues (Copa et al., 1995; Westlake, 1995). Similar results were obtained in studies conducted by (Reinhart and Grosh, 1998). The calculated ratio of BOD to COD based on Reinhart and Grosh's data showed a decrease from 0.47 to 0.07 within a period of 23 years. (Chian and DeWalle, 1977) found the ratio decreased from 0.49 to 0.05, as shown in figure 2.14.

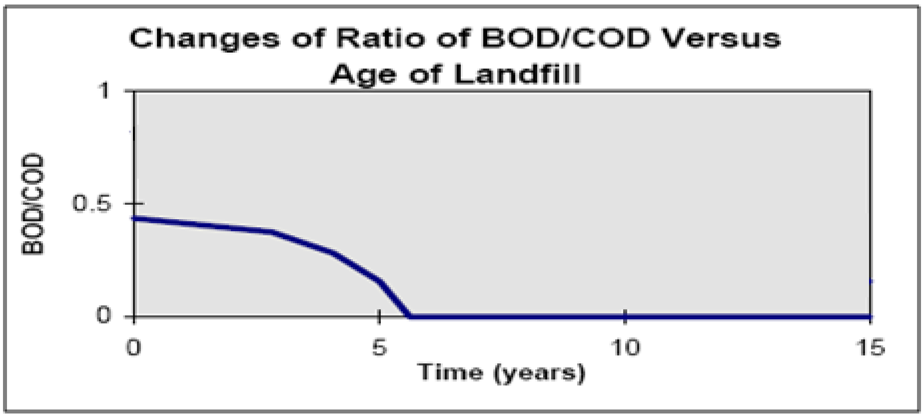

Figure 2.14: Changes of the ratio of BOD /COD with increasing age of the landfill (Reinhart and Grosh, 1998)

2.5 Formation of leachate plume

Gravity causes leachate to move through the landfill, to the bottom and sides, and through the underlying soil until it reaches the groundwater zone or aquifer as plotted in figure 2.15. As leachates move down the subsurface, they mix with groundwater held in the soil spaces and this mixture moves along the groundwater's flow path as a plume of contaminated groundwater

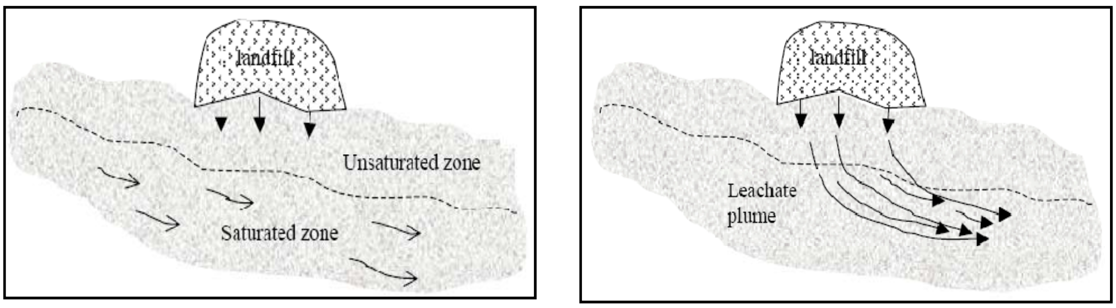

Figure 2.15: Movement of leachate from landfill and formation of leachate plume to groundwater (Jagloo, 2002)

The leachate contaminants first enter the unsaturated zone and eventually are transported to the groundwater table in the saturated zone. Figure 2.16 gives an overview of the zones that exist underground in general.

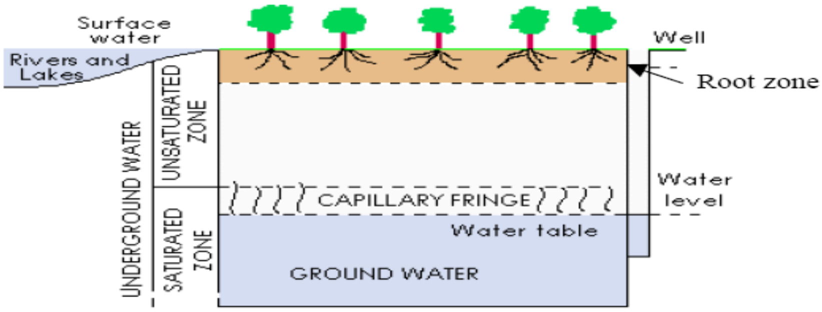

Figure 2.16: Subsurface vertical stratigraphy (Jagloo, 2002)

2.6 Previous Related Studies

The estimation of leachate quantity and potential percolation into the subsurface by using the Hydrologic Evaluation of Landfill Performance (HELP) model has given rise to a great number of studies in recent years. (Bou-Zeid & El-Fadel, 2004) presented a case study in simulating leachate generation and transport at a 2000 ton/day landfill facility and assesses leachate migration away from the landfill in order to control associated environmental impacts. Leachate quantity and potential percolation into the subsurface are estimated using the Hydrologic Evaluation of Landfill Performance (HELP) model. A three dimensional subsurface model (PORFLOW) was adopted to simulate groundwater flow and contaminant transport away from the site. A comprehensive sensitivity analysis to leachate transport control parameters was also conducted and concluded that changes in partition coefficient, source strength, aquifer hydraulic conductivity, and dispersivity have the most significant impact on model output indicating that these parameters should be carefully selected when similar modeling studies are performed.

The objectives of (Qrenawi, 2006) study was to review the situation of the current landfilling practices at Al-Akaider landfill, identify and assess the environmental and health risks associated with Al-Akaider landfill and to recommend management options to minimize such risks. The work throughout this study is divided into two major categories; risk assessment of industrial wastewater ponds and leachate at Al-

Akaider landfill site and risk assessment of gaseous emissions released from the landfill and their impacts on the neighboring communities and the surrounding environment.

For leachate discharged from the landfill; HELP 3 model was utilized to quantify the amount of leachate. The model indicated that the average volume of leachate discharged from Al-Akaider landfill in the period from 1981 to 2002 was about 5500 m^3/year. To study the transport of nitrate from landfill leachate to the groundwater at the site the SE-SOIL model was utilized. The output of HELP 3 and the results of leachate sample analysis were fed into the SE-SOIL model. The arrival time of nitrate from leachate to the groundwater at the site was about 23 years indicating that the contamination of groundwater by leachate has already occurred.

To verify these results; groundwater samples from two wells at the area (one from upstream and the other from downstream) were obtained and analyzed. The results of analysis supported the notion that groundwater contamination at Al-Akaider landfill region has already occurred. The risk associated with the contamination of groundwater was acceptable for adults while it was unacceptable for children and it value is expected to increase in the future.

(Rojas, 2007) study aimed to evaluate the groundwater contamination potential due to the leachate from the Payatas dumpsite using a FEMWATER (3D finite element unsaturated-saturated flow and solute transport model) and HELP (quasi-2D hydrologic model for landfill). Based on the results of the simulations using different flux rates and 300 mg/l concentration of a non-reactive, no-decay contaminant, the following conclusions are arrived at:

- Firstly, the leachate from Payatas will contaminate the subsurface layers over time. As long as this leakage pervades, the contaminant plume will increase in area and depth.
- Second, the infiltration of water due to rainfall dilutes the contaminant plume such that the concentration becomes lower as the distance from the point of contamination increases and as time progresses.

- Third, the simulations indicate that the contaminant plume has a greater tendency to move towards the Marikina River but also progresses toward the reservoir and the wells.
- Finally, the pump and treat remediation require more than 75 lps/well to be more effective in reducing contamination. Then, it may not be viable because of the high operating cost of pumping and water treatment.

(Smith, et al., 2000) study used The HELP model to evaluate landfill performance in terms of the volume of leachate that potentially could leak from the base of the landfill each year. A series of runs were made to determine how this volume was affected by the quality of both the clay cap and the liner system at the base of the landfill. Predictably, the results indicated that potential leakage through the bottom of the landfill increased with increasing hydraulic conductivity of the clay cap and decreasing quality or absence of the geomembrane liners.

(Jagloo, 2002) study aimed to conduct a groundwater risk analysis in the vicinity of a landfill in Mauritius. The study involved three aspects: First, the groundwater chemistry was evaluated using records of chemical analyses. The outcome shows that there is a noticeable change in the values of some parameters (Cl^-, $SO4^{-2}$, nitrates, etc.) when compared to their background levels, before the sitting of the landfill. This may signify leachates migration, but it should be noted that further investigation is necessary to determine if other sources might also be held accountable. Second, a water balance was performed so as to predict the amount of leachate generated at the landfill site. A rough estimation, due to the lack of data, reveals that 45% of rainfall is evaporated, 17% flows as surface run-off while 40% gets absorbed in the waste mass. In a third step, a risk assessment was performed using Landsim software. The simulation, which predicts the performance of the landfill in the future, reveals no detrimental short term or long-term risk of groundwater contamination.

(Sabahi et al., 2009) research performing sampling the leachate at three different locations of the landfill, at the landfill itself and 15 and 20 m downstream of this landfill. Groundwater samples collected from 5 boreholes to study possible impact of leachate percolation into groundwater. Leachate and groundwater samples were collected during dry season only, due to the excessive generation of leachate during this season. Objective of this study was significant to assess degree of groundwater pollution due to Ibb landfill leachate at Al-Sahool area. Parameters measured were pH, temperature, Electrical Conductivity (EC), Total Dissolved Solids (TDS), Dissolved Oxygen (DO), Fluoride (F), Chloride (Cl), Sulphate (SO4), Nitrites (NO2), Nitrates (NO3), ammonia-N (NH3-N), heavy metals (Pb, Zn, Ni, Cr, Cd, Cu), major cations (Na, Mg, Ca, K, Fe) and biological parameters (COD, BOD5 and coliform group bacteria). The results showed that, leachate at landfill most likely in methanogenic phase, based on the alkaline pH value recorded (pH = 8.46). The results also showed that 4 out of 5 boreholes were contaminated, where concentration of physico-chemical parameters are above the standard acceptable levels which required for drinking water adapted by Yemen's ministry of water and environment and by word standard. Therefore, landfill is dangerous for environment so it should do sanitary landfill to prevent further contamination to surface water, groundwater as well as soil.

(Tricys, 2002) studied the composition of the deposited waste which has changed significantly from the beginning of Siauliai landfill exploitation up to now. The leachate contains a lot of materials including harmful to the environment. The results indicate that the surface and groundwater pollution around the landfill has a tendency to increase. The number of chlorides, nitrogen compounds, and heavy metal ions in the leachate increased during the last five years. The research demonstrated that the leachate on the different sides of the landfill varies in its composition the leachate of the northern and eastern sides is polluted more than that of the western side.

CHAPTER (3): STUDY AREA

3.1 Location and Site Description

Gaza Strip is situated on the south west of Palestine. It is bordered by Egypt from the south, Negev desert from east and green line from the north. There are three controlled landfills constructed after Oslo Agreement in Gaza Strip; first one is Gaza landfill which locates in Gaza Governorate. The second is Dear Al Balah landfill which locates in Medal Area Governorate and the third is Rafah landfill in Rafah Governorat. The research will concentrate on Gaza and Dear Al Balah landfills because Rafah landfill has the same conditions of Gaza landfill. Both landfills are located in the eastern direction of Gaza Strip of about 500 m from the Green Line as plotted in figure 3.1.

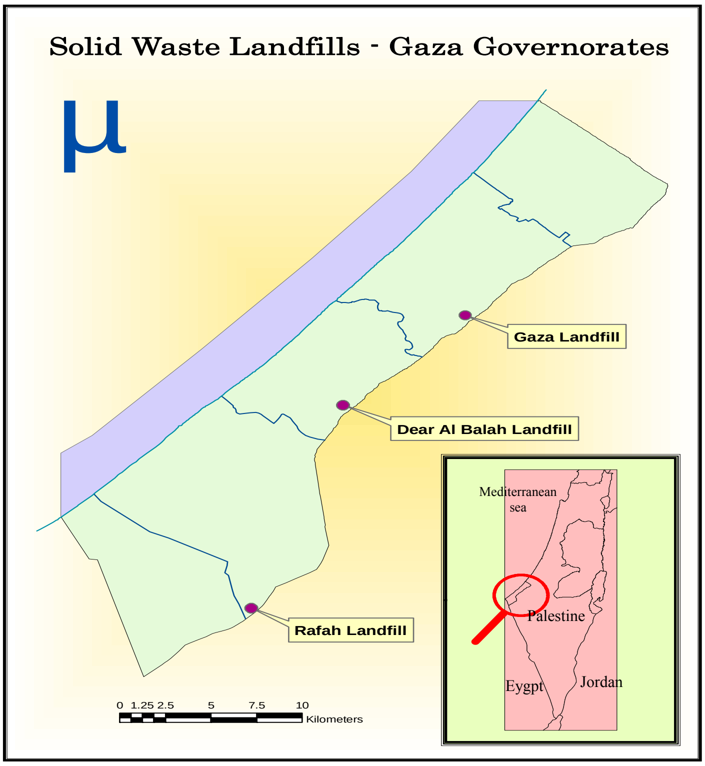

Figure 3.1: Landfills location of the Study Area

The total area of Gaza Governorates is 365 (km^2), 40 km long and an average of 7 –12 km wide. The estimated population is around 1.5 million inhabitants that mean the area is highly populated due to the high birth rate and Palestinians are returning to their homeland.

Gaza Strip is located in the semi-arid zone, consists of 5 Governorates, the North Governorate, Gaza Governorate, Dear Al Balah Governorate, Khanyunis Governorate, and Rafah Governorate. The area has very limited water resources, the main source of water in Gaza is the shallow aquifer that underlies the whole Gaza Strip and extends north into Israel. This aquifer is highly vulnerable to pollution, because the aquifer is underlying sandstone, sands and gravel that cannot trap the organic and non-organic pollutants.

3.2 Climatic Conditions

3.2.1 Rainfall

Generally; the climate of Palestine is of East Mediterranean type; identified as being hot and humid in summer and cold in winter. The US Environmental Agency has classified regions into arid and non-arid regions based on rainfall of 12.5 in/yr (312.5 mm/yr) to be the reference (Qrenawi, 2006). The Gaza Strip area is classified as a semiarid region since the average annual rainfall is about 13.83 in/yr (351.4 mm/yr), as shown in figure 3.2. The nearest meteorological station to Gaza landfill is Gaza south (Mogragah) station at a coordinate of 31° 27.54' N & 34° 27.03' E while Dear Al Balah landfill is Dear Al Balah station at a coordinate of 31° 23.50' N & 34° 22.77' E. as shown in figure 3.3 (PMO, 2008).

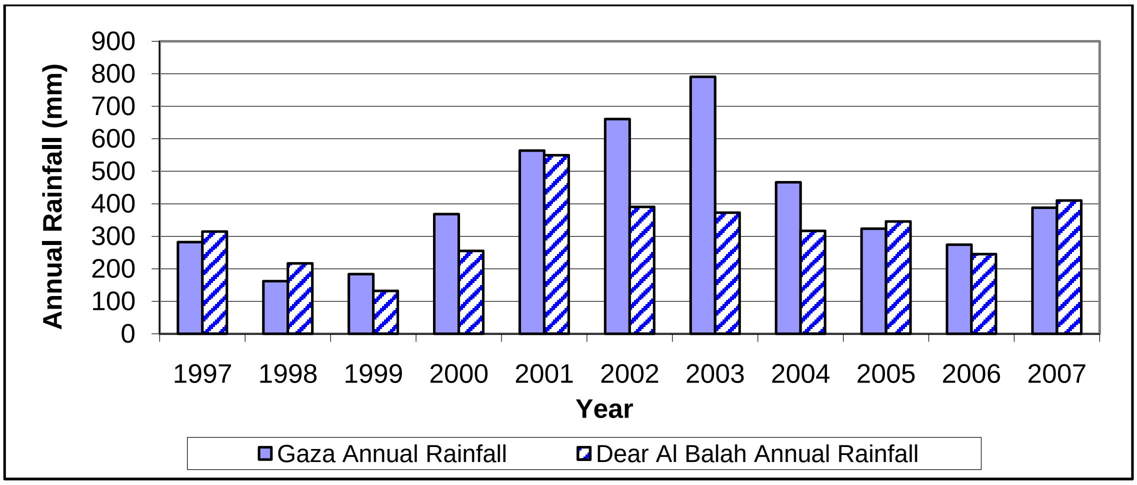

Figure 3.2: Total Annual Rainfall of the Study Area (PMO, 2008)

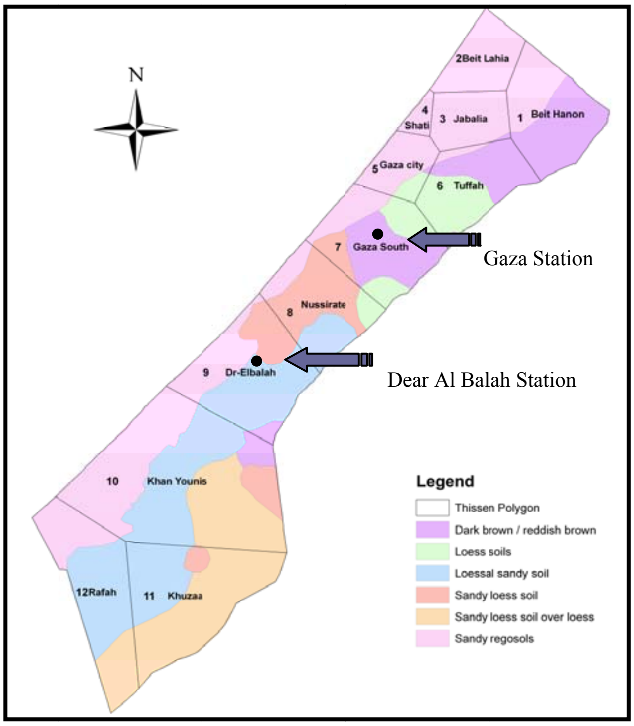

Figure 3.3: Location of the Nearest Meteorological Stations to Gaza and Dear Al Balah Landfills (Alslaibi & Mogheir, 2007)

3.2.2 Temperature

The highest mean annual temperature is 30.85 °C, while the lowest mean annual temperature is 14.16 C°, as shown in figures 3.4 and 3.5 (PMO, 2008)

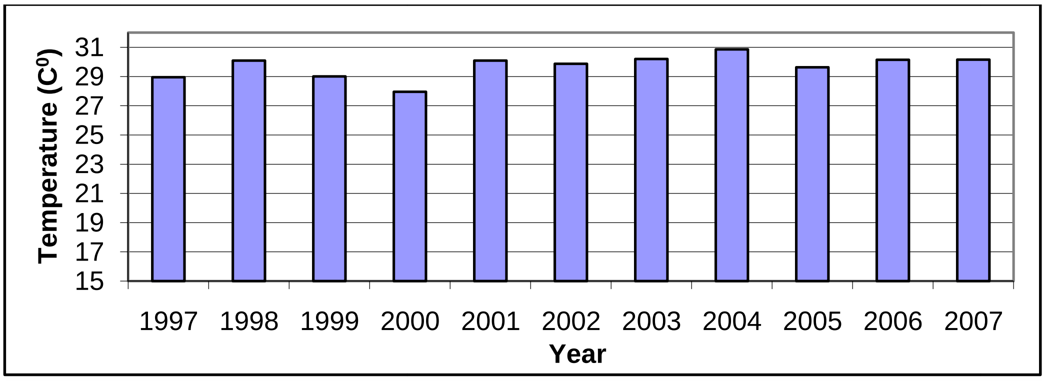

Figure 3.4: Average Annual Maximum Temperature of the Study Area (PMO, 2008)

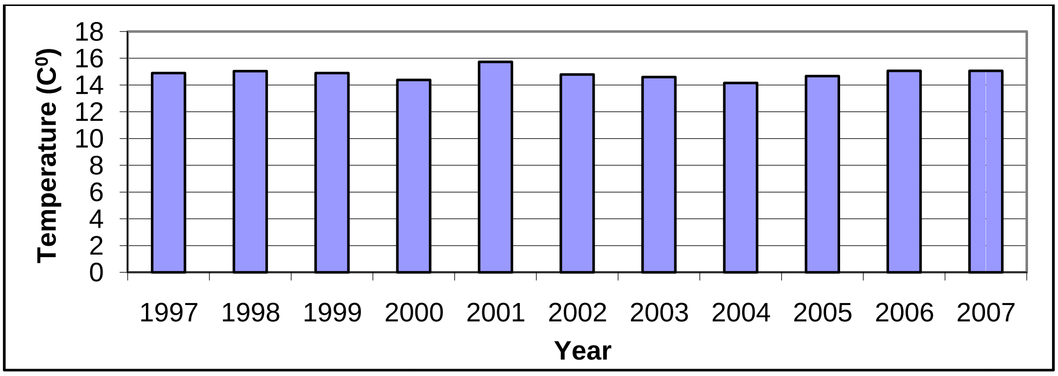

Figure 3.5: Average Annual Minimum Temperature of the Study Area (PMO, 2008)

3.2.3 Solar Radiation

The average annual solar radiation for the study area is about 18.58 MJ / m^2 / day, as shown in figure 3.6 (PMO, 2008).

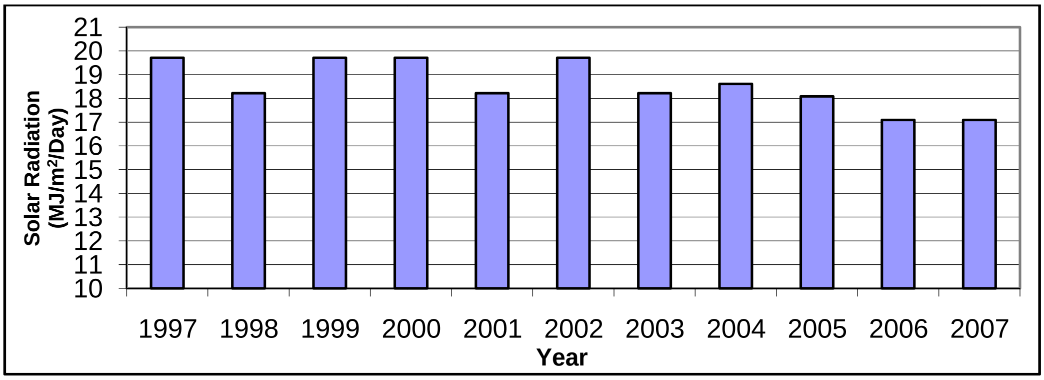

Figure 3.6: Average Annual Solar Radiation of the Study Area (PMO, 2008)

3.2.4 Relative Humidity

The relative humidity is defined as the ratio of the actual vapor pressure at a given point to its saturation value at a given air temperature. When the relative humidity is unity, this means that the atmosphere is fully saturated with water vapor. In a semiarid country like Gaza Strip, it is expected that the relative humidity is high in the wet summer and low in winter. Figure 3.7 summarizes the seasonally relative humidity data for the study area. As shown in figure 3.7; it is recognized that relative humidity values in summer are higher than those in the winter. This may be due to the evaporation rate in summer is higher than that in the winter and hence the relative humidity values are expected to be higher.

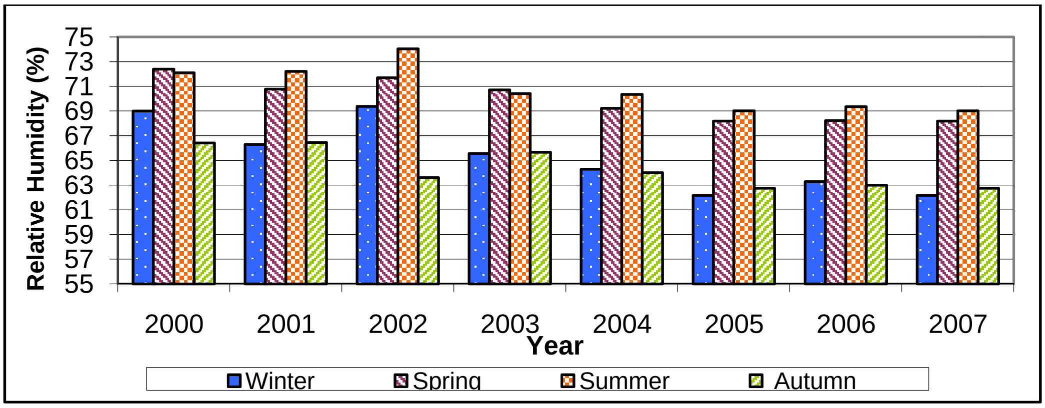

Figure 3.7: Seasonally Relative Humidity for the Study Area (PMO, 2008)

3.2.5 Wind Speed

The average annual wind speed in Gaza Strip is about 10.92 Km / hr. as shown in figure 3.8 (PMO, 2008)

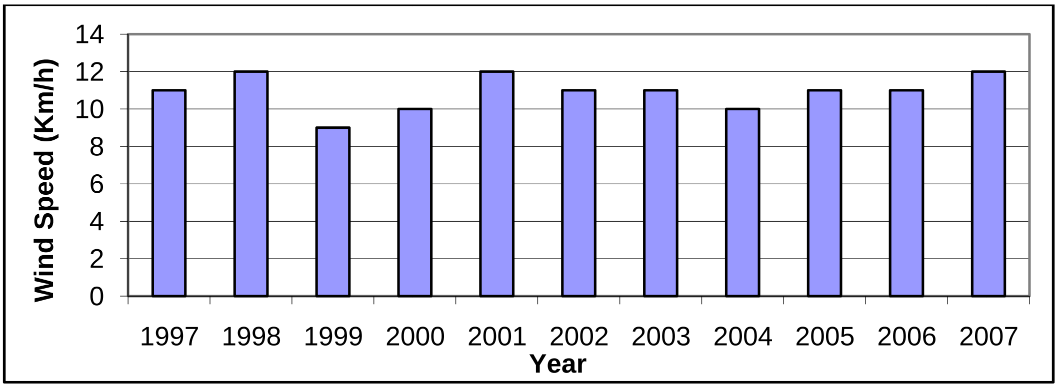

Figure 3.8: Average Annual Wind Speed of the Study Area (PMO, 2008)

3.3 Landfills in Gaza Strip

Currently, there are three landfills in the Gaza Strip; in south, middle, and Gaza city. All landfills were established through donor-funded projects and have basic infrastructure and equipments, including weighbridges to measure the weight of trucks. In Gaza Governorate, a disposal site was established in 1987 and covers at least 30 hectares directly east of Gaza City and adjoining the Green Line with Israel. This site receives wastes from both Gaza Governorate and Northern Governorate under agreement. Groundwater is about 80 meters below surface, with sand and clay layers forming the sub-surface (Jaber and Nassar, 2007). The landfill of Gaza Governorate is unlined. There is a special cell constructed and designed for the disposal of hazardous waste and it is double lined by polyethylene; it is used for the moment for the disposal of expired medical wastes only.

In the Middle Governorate, the landfill is located east of Dear Al Balah city and was established in 1996 and covers approximately seven hectares and also adjoins on the Green Line with Israel. This landfill receives wastes from both Middle Governorate and Khan Younis Governorate under Joint Service Council (JSC) agreement. The landfill is lined with asphalt and equipped to re-circulate leachate. Groundwater is about 60 meters below surface (Jaber and Nassar, 2007). The surface layer (approximately 15 meters deep) is sand, below which there is a clay layer of about 20 meters that in turn is underlain by a mixture of sand and clay to the groundwater level.

In Rafah Governorate a waste disposal site of approximately four hectares is located near to Sofa crossing border and was established in 1998. This site receives waste from different communities of Rafah Governorate including different municipalities. The site is not lined but has leachate recirculation abilities and a weighbridge and for the moment it is over loaded and needs to be extended very soon (Jaber and Nassar, 2007).

According to the Environment Quality Authority, these landfills are located on impermeable ground outside the recharge area for the coastal aquifers, and thus do not have liners or leachate collection systems. The landfill in middle governorate has a liner, leachate collection and treatment system. According to the Palestinian Environment Quality Authority, all of locations were selected on the basis of appropriate studies.

The study will include two sites located in Gaza Governorate and Middle Regions of the Gaza Strip, as shown in figure 3.1.

3.3.1 Gaza Municipality landfill

The essential information about Gaza landfill are summarized as follows:

- Has an area of 120 dunums and it is recently extended by an area of 80 dunums.
- 4 km a way from nearest residential area.
- Height of waste is 25 meters.

- Quantity of received solid waste is 450,000 ton/year.
- Type of waste are 80 % Municipal Solid Waste (MWS), 5% Slurry, 5 % construction waste, 3 % industrial and 7 % medical and hazardous waste.
- Types of soil are sandy and silty clay.
- Expected lifespan is 10 years.
- There no lining system and no management of the waste (EQA, 2002).
- Layout of Gaza landfill location and view of solid waste are plotted in Figures 3.9 and 3.10 respectively.

Figure 3.9: Plan of Gaza Landfill location (Google Earth, 2008)

Figure 3.10: Solid Waste in Gaza Landfill in Year 2008

3.3.2 Dear Al Balah Municipality landfill

The essential information about Dear Al Balah landfill are summarized as follows:

- Has an area of 60 dunums.
- 13 municipalities and village councils share the usage of the landfill.
- 4 km away from nearest residential area.
- Height of waste is 17 meters.
- Quantity of received solid waste is 90,000 ton/year.
- Type of waste is 95 % MSW and 5 % other waste.
- The soil under the landfill is sandy and silty clay.
- Expected lifespan is 5 years.
- Some management problems are encountered such as proper management through recirculation at the top of waste and asphalt lining (EQA, 2002).
- Layout of Dear Al Balah landfill and view of solid waste are plotted in Figures 3.11 and 3.12 respectively.

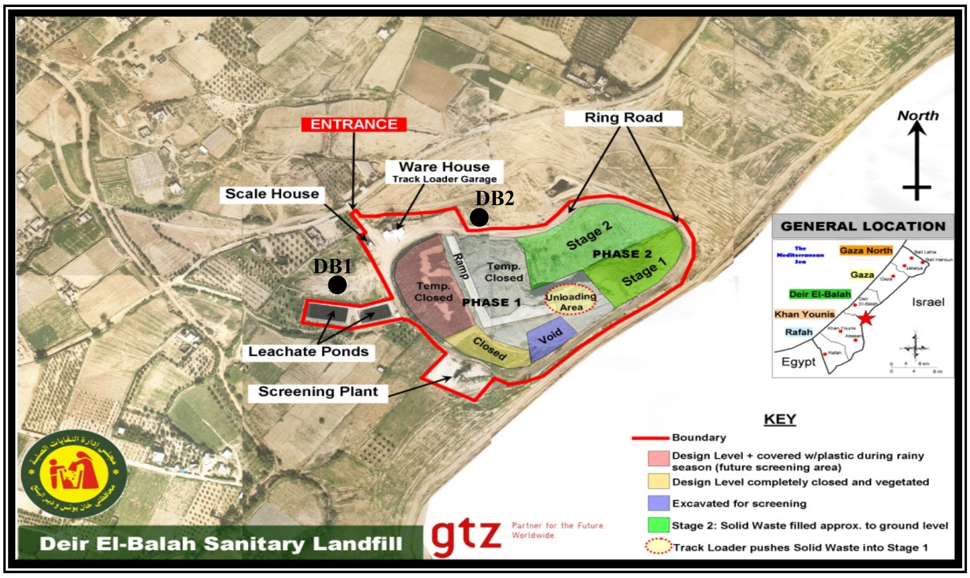

Figure 3.11: Plan of Dear Al Balah Landfill Location (GTZ, 2002)

Figure 3.12: Solid Waste of Dear Al Balah Landfill in Year 2008

3.3.3 Rafah Municipality landfill

The essential information about Rafah landfill are summarized as follows:

- Has an area of 25 dunums.
- 8 km away from nearest residential area.
- Height of waste is 12 meters.
- Quantity of received solid waste is 63,000 ton/year.
- Type of waste is 90 % MSW and 10 % of other waste.
- Type of soil is almost clay.
- Expected lifespan is 10 years.
- In the landfill there are no management and no lining under the landfill (EQA, 2002).
- Layout of Rafah landfill and view of solid waste are plotted in Figures 3.13 and 3.14 respectively.

Figure 3.13: Plan of Rafah Landfill location (Google Earth, 2008)

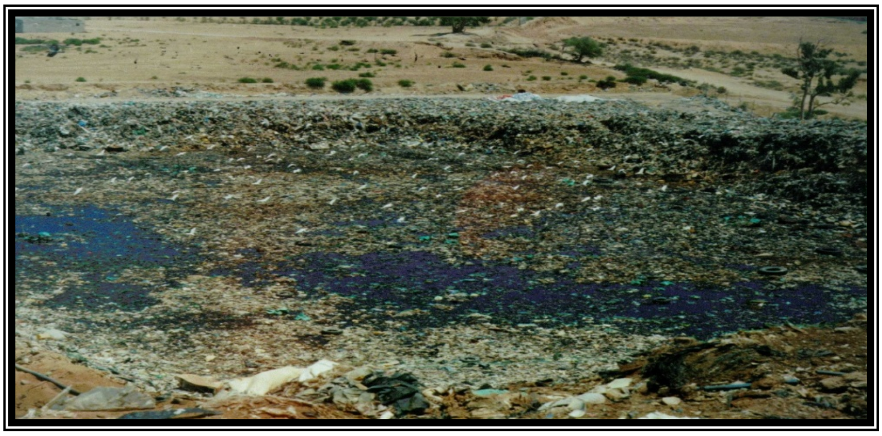

Figure 3.14: Solid Waste of Rafah Landfill (EQA, 2002)

3.4 Soil Profiles

Two boreholes were drilled by GTZ around Dear Al Balah landfill DB1 and DB2 as shown in figure 3.11. The soil profile of DB1 borehole shows that the thickness of main clay layer was about 19 m while the thickness of main clay layer of DB2 borehole was about 12.5 m. So that, the average thickness of main clay layer was about 17 m. as shown in figure 3.15.

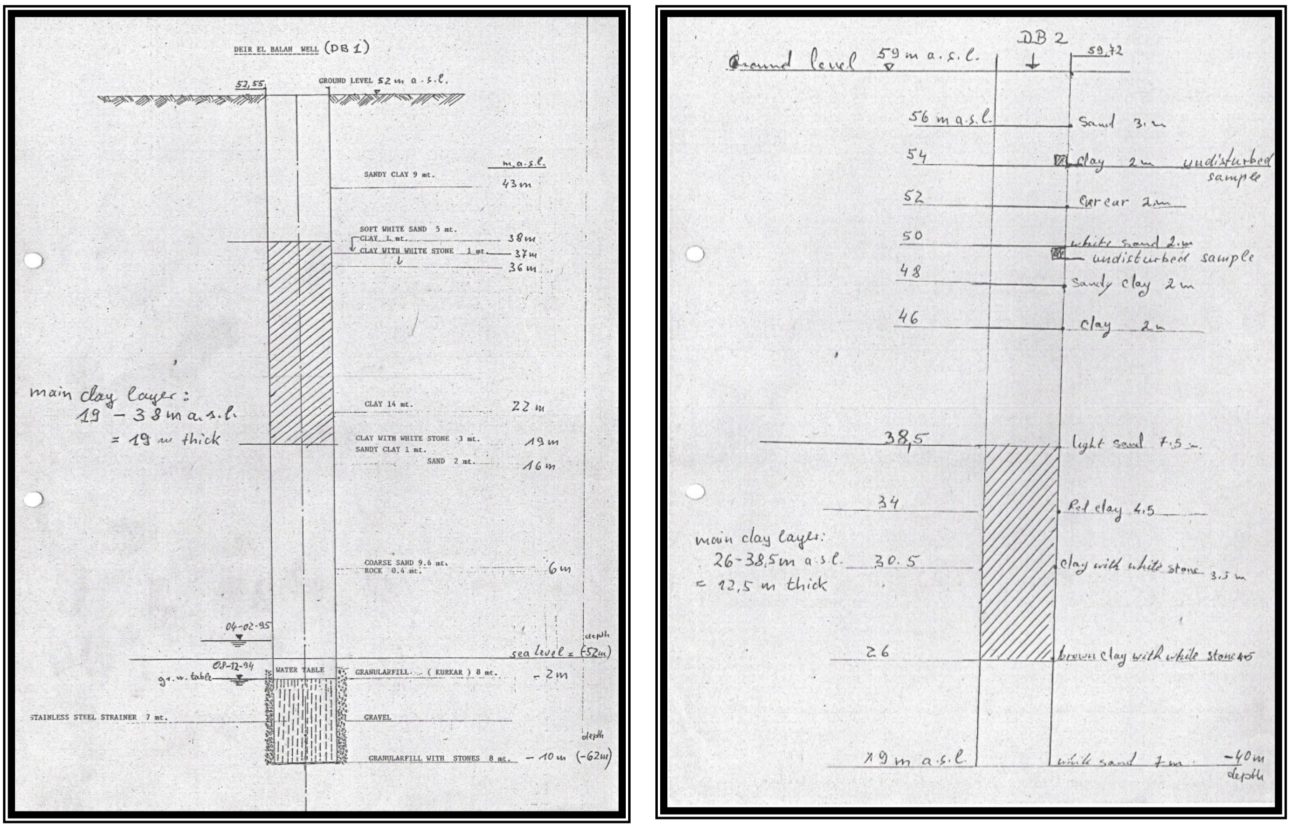

Figure 3.15: Soil Profiles of Two Boreholes around Dear Al Balah Landfill (GTZ, 1996)

3.5 Lining System Construction

Figure 3.16 shows the cross section of asphalt lining system at Dear Al Balah landfill that consists of the following layers:

- Base course.
- Bitumen spraying (1,5 Kg/m^2).
- Asphalt linier 1.
- Bitumen spraying.
- Asphalt linier 2.
- Bitumen spraying (1,5 Kg/m^2) at the drainage pipes.

It is important to note that there is no lining system, neither in Gaza landfill nor in Rafah landfill.

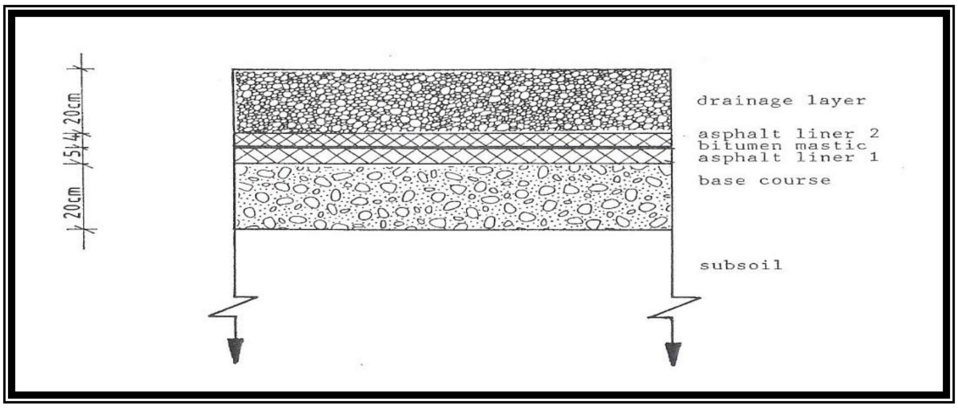

Figure 3.16: Asphalt Lining System Cross Section at Dear Al Balah Landfill (GTZ, 1996)

Figure 3.17: Asphalt Lining System view at Dear Al Balah Landfill (GTZ, 1996)

CHAPTER (4): METHODOLOGY

4.1 Introduction

The purpose of this study was to evaluate the lining system effectiveness of landfills in Gaza Strip. The study covered two landfills operating in Gaza Strip; the first is Dear Al Balah landfill which has a lining system and the second Gaza landfill which does not have lining system. Due to this difference it will help to make a comparison between the two systems. Monitoring program was carried out to obtain field and laboratory data needed for determining the leachate water and groundwater in surrounding monitoring wells. To attain historical perspective about landfills condition, historical operating data and result from previous monitoring programs were collected to deduce the trend of past and current system operation and groundwater quality. All methods and techniques used will be presented in the following sections.

4.2 Method of Study

The data and information used in this thesis have been collected from both a literature review and actual field investigation. The literature review consists of:

1. Review of relevant books, reports, journals, and internet websites as well as consulting professionals. The topics were solid waste quantities, sources, rate of their generation, solid waste composition, final disposal options, and description of the middle and northern landfills (area, location, topography, groundwater table, quantity and type of waste deposited).
2. The sampling program was conducted at landfills of Dear Al Balah and Gaza City. The groundwater samples from multilevel observation wells and leachate water was collected in November 2008. Chemical and biochemical analysis were conducted in the laboratories of Environment and Earth Sciences Department at the Islamic University.
3. The Geographic information system (GIS) was used as a tool to simplify the presentation of the analyzed result of the pollutant indicators within 500 m radius circle area around both Dear Al Balah and Gaza landfills in the periods 1995, 1999, 2001 and 2008 respectively. The Inverse Distance Weighting (IDW) was used to interpolate the unknown points.

4. Estimating the quantity of landfill leachate accumulated and percolated to groundwater aquifer was calculated, based on:
   a. The Hydrologic Evaluation of Landfill Performance (HELP) model.
   b. Water Balance Method.
   c. Field measured data.
5. Developing a monitoring program of groundwater aquifer for the landfills areas which were contaminated by landfill leachate and recommending mitigation measures.

It is important to understand the mechanisms that control leachate formation, quality, quantity, and most important the migration characteristics with associated spatial and temporal variations during landfill operations and after closure. Thus, two approaches have been used in the study to quantify the leachate water as shown in figure 4.1.

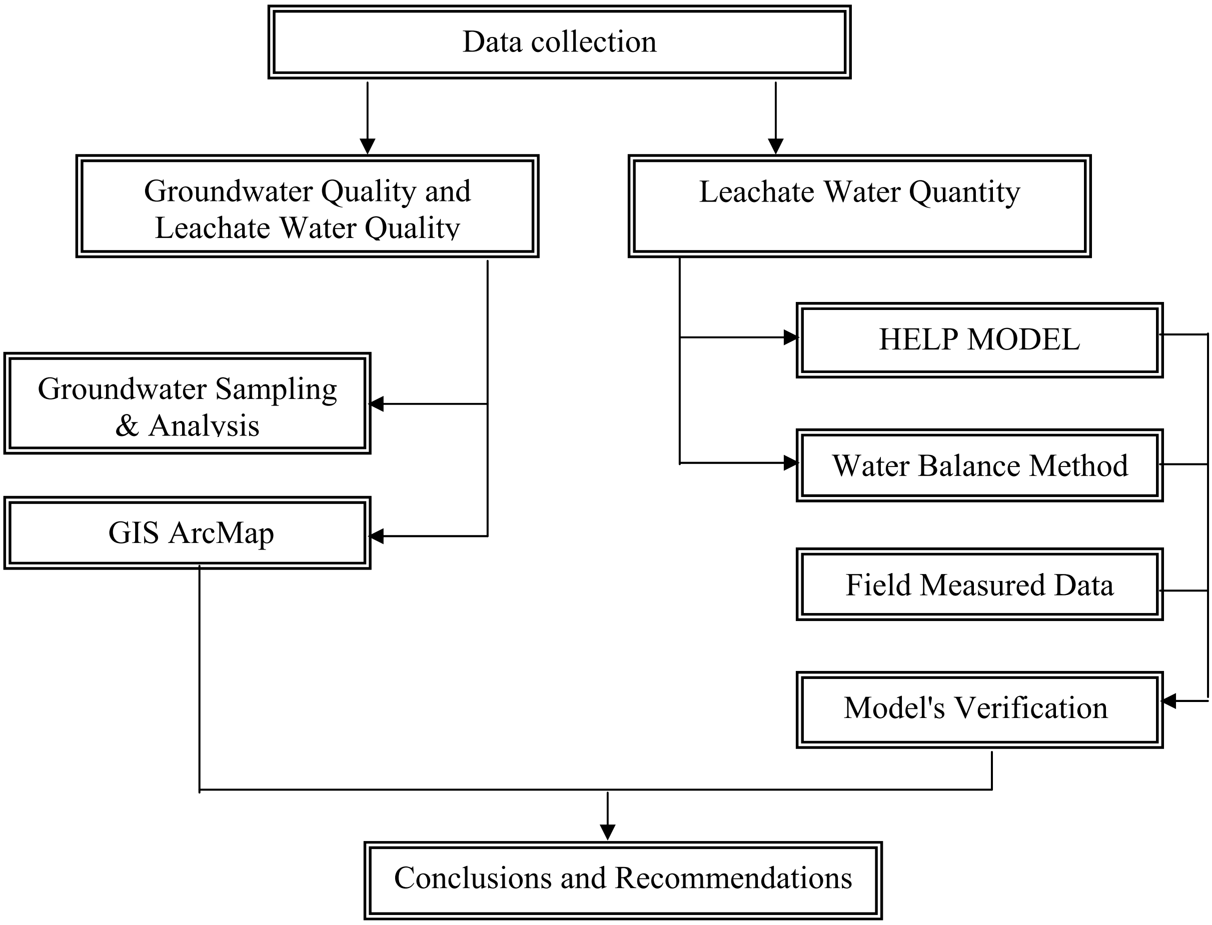

Figure 4.1: Procedure of the Assessment of Landfill Leachate

4.3 Monitoring Program

4.3.1 Wells Location

Groundwater and leachate samples were collected from 20 selected wells surrounding Dear Al Balah and Gaza landfills (10 locations for each). The exact location of the wells presented in figures 4.2 & 4.3. The wells located in the west side of the landfills represented the downstream side as the lateral flow direction of Gaza Strip is from east to west. The shape of these wells makes two circles around landfill with different radius from 100 m to less than 500 m to study the pollutant transport. As presented in tables 4.1 & 4.2. Due to security considerations there are no wells in upstream side of landfills.

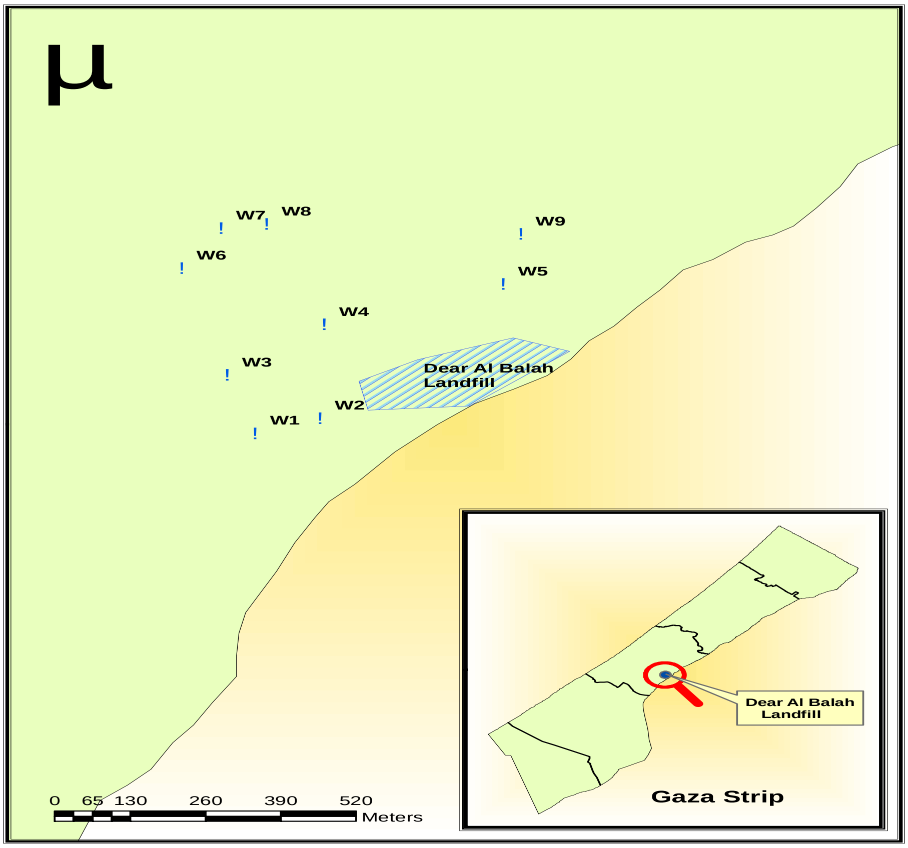

Figure 4.2: Sampled Wells Locations around Dear Al Balah Landfill

Table 4.1: Sampled Wells Distance from Dear Al Balah Landfill

Well No.	Distance (m)	Well No.	Distance (m)
W1	200	**W6**	442
W2	85	**W7**	500
W3	245	**W8**	458
W4	157	**W9**	289
W5	150	-	-

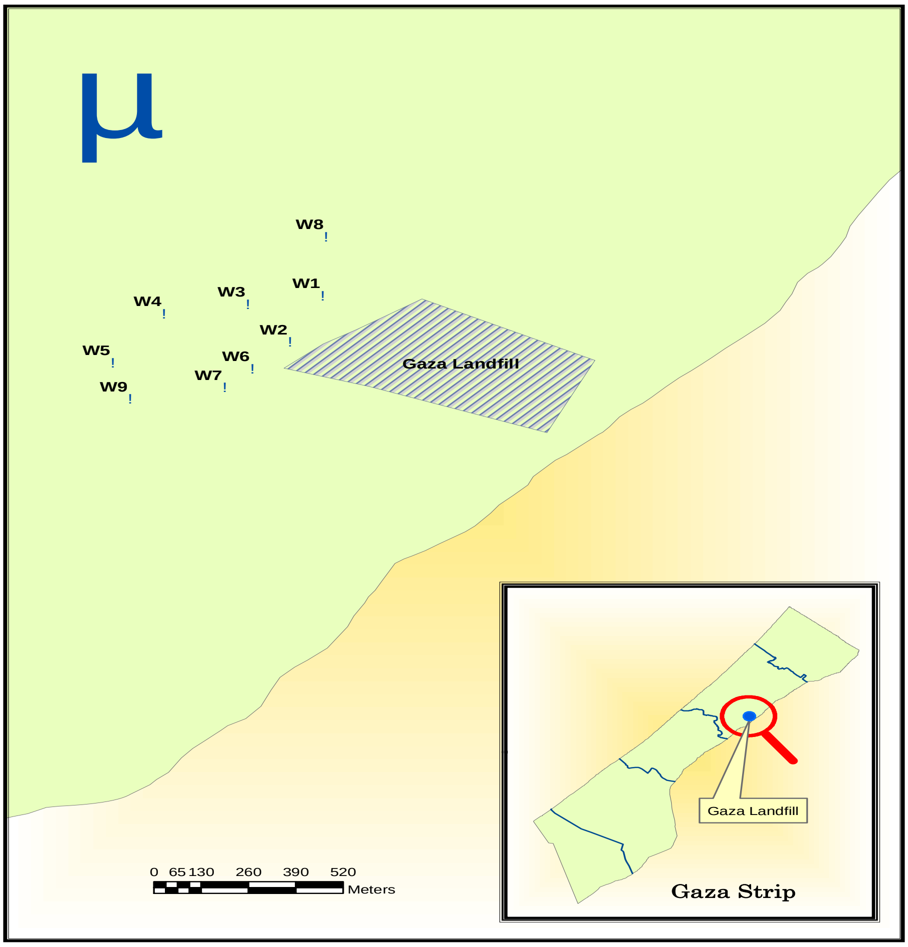

Figure 4.3: Sampled Wells Locations around Gaza Landfill

Table 4.2: Sampled Wells Distance from Gaza Landfill

Well No.	Distance (m)	Well No.	Distance (m)
W1	160	**W6**	90
W2	56	**W7**	187
W3	240	**W8**	335
W4	385	**W9**	443
W5	473	-	-

4.3.2 Tested Parameters

A group of physical and chemical parameters were tested in groundwater and leachate samples. The Physical parameters include temperature, pH and electrical conductivity (EC). The chemical parameters include: Nitrite (NO_3), Ammonia (NH_4), Chloride (Cl), Sulfate (SO_4), Lead (Pb), Iron (Fe), Cadmium (Cd), Zinc (Zn), Copper (Cu), Biological Oxygen Demand (BOD), Chemical Oxygen Demand (COD) and Total Organic Carbon (TOC). These parameters were tested in the IUG laboratories.

4.3.3 Sampling Period

Due to seasonal variation two phases for testing the parameters were proposed in both summer and winter. Because of the unexpected local constrains (IUG laboratories facilities and equipment were destroyed in the Israeli bombardment) only one phase was accomplished after summer specifically in November 2008.

4.3.4 Chemical and Biochemical Analysis

1- Temperature

Temperature was taken synchronously with pH value using the device (Hanna 8424) by selection of their modes.

2- pH

Combined portable meter (Hanna 8424) was used for measuring pH and temperature. Before each sample collection process, the meter was calibrated and verified to insure the good working conditions. To determine the pH value, probes were immersed into the sample and the mode of pH was selected by pressing the range key until the display changes to pH. Electrode was stirred gently and stands a few minutes to adjust and stabilize. The display of the pH value automatically compensated for temperature.

3- Electrical Conductivity

Measuring conductivity was carried out using EC meter (Hanna, TH-2400). The device measures the resistance occurring in an area of the test solution defined by the probe's physical design. Voltage is applied between the two electrodes immersed in the solution, and the voltage drop caused by the resistance of the solution is used to calculate conductivity per centimeter. The display of the EC value is also automatically compensated for temperature. The basic unit of measuring conductivity is the Siemen (or mho), the reciprocal of the ohm in the resistance measurement. Because ranges normally found in aqueous solutions are small, micro Siemens/cm (µS/cm) are commonly used.

4- Biochemical Oxygen Demand (BOD)

BOD was measured with OxiTop measuring system. The quantity of samples was taken after well mixing according to corresponding measuring range recommended in the manufacturer manual. The samples discharged into OxiTop bottles followed by placing a magnetic stirring rod. Rubber quiver inserted in the neck of the bottle. Three sodium hydroxide tablets were placed into the rubber quiver with a tweezers. OxiTop bottle was directly tightly closed and pressed on S and M buttons simultaneously for two second until the display shows 00. The bottles were placed in the stirring tray and incubated for 5 days at 20 ºC. Readings of stored values was registered after 5 days by pressing on M until values displayed for 1 second (Modified from OxiTop Manual).

5- Chemical Oxygen Demand (COD)

The Chemical Oxygen Demand (COD) is used as a measure of the oxygen equivalent of the organic matter content of a sample that is susceptible to oxidation by a strong chemical oxidant. The closed dichromate reflux method (colorimetric method) was used to determine COD. Two ml of the sample is refluxed in strongly acid solution vessel. After digestion in COD reactor at 160C^{o} for 2 hrs, oxygen consumed is measured against standard at 620 nm with a spectrophotometer.

6- Nitrate (NO_3)

Nitrate (NO_3) was measured with Spectrophotometer device. Scientists found that Nitrate absorbs the light of wavelength 220 nanometer, but the presence of the organic particles also do obstacle because they also absorbs the light of same wavelength but the clear absorption is completed at 275 nanometer. Therefore, subtraction the readings at 220 and 275, the nitrates quantities in the drinking water can be measured. Nitrate measuring process is achieved by taking samples of known concentrations and using the resulted calibration curve, and then by matching technique, the nitrate in the sample is measured.

7- Chloride (Cl)

In a neutral or slightly alkaline solution, potassium chromate can indicate the end point of the silver nitrate titration of chloride. Silver chloride is precipitated quantitatively before red silver chromate is formed. 10 ml of sample or a suitable portion diluted to 100 ml is placed into an Erlenmeyer flask and 1ml potassium chromate solution added. The mixture is then titrated against a white back ground with silver nitrate solution until the color changes from greenish yellow to reddish brown. Blank sample with distilled water is treated in the same way as the sample.

8- Ammonia (NH_4)

Ammonia was tested by using distillation method which was followed by titration step to determine the concentration of Ammonia. Ammonia was distilled into a solution of boric acid and the ammonia in the distillate was determined titrimetrically with standard HCl^-. (APHA, 1995).

9- Sulfate (SO_4)

Sulfate was measured using Turbidimetric Method. Sulfate ion (SO_4^{-2}) is precipitated in an acetic acid medium with barium chloride ($BaCl_2$) so as to form barium sulfate ($BaSO_4$) crystals of uniform size. Light absorbance of the $BaSO_4$ suspension is measured by a turbidimeter and the SO_4^{-2} concentration is determined by comparison of the reading with a standard curve (APHA, 1995).

10-Heavy Metals

Metal concentrations in ground water and leached solutions were measured by using a Perkin-Elmer AAnalyst-100, Spectrometer. The standard solutions of Copper, Lead, Cadmium, Iron and Zinc were also prepared from their pure salts. The appropriate concentrations were prepared by dissolving the metal chlorides (in case of Iron, Copper, Cadmium and Zinc) and metal nitrate (in case of Lead) in distilled water. Dilutions were made by 0.1 M HCl to achieve the proper concentrations of the standard solutions. The appropriate absorbance reading for each metal ion was obtained by the dilution of samples with 0.1 M HCl to the optimum -analytical range for each metal.

The recommended wavelengths and slit widths for the metal ions determined are given in table 4.3.

Table 4.3: The Recommended Wavelengths and Slit Widths for the Metal Ions (Jarad, 2006)

Metal	Selected wavelength
Zinc (Ze)	213.8 nm.
Copper (Cu)	324.8 nm.
Iron (Fe)	248.3 nm.
Cadmium (Cu)	228.8 nm.
Lead (Pb)	283.3 nm.
All slit width were 0.7 µm	

4.4 Presentation of the spatial distribution of the pollutants

The Geographic Information System (GIS) was used as a tool to illustrate the analyzed result of the pollutant indicators within 500 m radius circle area around both Dear Al Balah and Gaza landfills in the periods 1995, 1999, 2001 and 2008 respectively. There are several methods used in GIS ArcMap to interpolate the pollutants in the unknown areas which are Inverse Distance Weighting, Spline and Kriging methods. The study used the "Inverse Distance Weighting" (IDW), which is the most common method used to interpolate the unknown points.

IDW is a method of interpolation that estimates cell values by averaging the values of sample data points in the neighborhood of each processing cell. The closer a point is to the center of the cell being estimated, the more influence, or weight; it has in the averaging process, as shown figure 4.4 (ArcGIS Desktop Help, 2006).

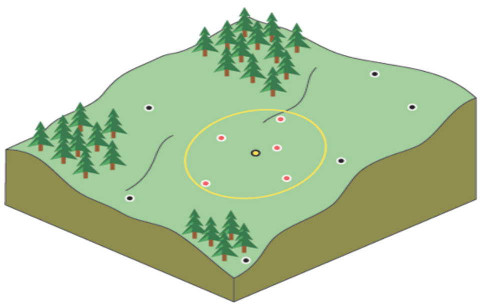

Figure 4.4: Search Radius of Inverse Distance Weighting (IDW) method (ArcGIS Desktop Help, 2006)

IDW method assumes that the variable being mapped decreases in influence with distance from its sampled location. The characteristics of the interpolated surface can also be controlled by applying a search radius (fixed or variable), which limits the number of input points that can be used for calculating each interpolated cell.

A fixed search radius requires a neighborhood distance and a minimum number of points. The distance dictates the radius of the circle of the neighborhood (in map units). The distance of the radius is constant, so for each interpolated cell, the radius of the circle used to find input points is the same. All the measured points that fall within the radius will be used in the calculation of each interpolated cell. When there are fewer measured points in the neighborhood than the specified minimum, the search radius will increase until it can encompass the minimum number of points.

While with a variable search radius, the number of points used in calculating the value of the interpolated cell is specified, which makes the radius distance vary for each interpolated cell, depending on how far it has to search around each interpolated cell to reach the specified number of input points. Thus, some neighborhoods will be small and others will be large, depending on the density of the measured points near the interpolated cell. If the radius for a particular neighborhood reaches the maximum distance before obtaining the specified number of points, the prediction for that location will be performed on the number of measured points within the maximum distance. (ArcGIS Desktop Help, 2006).

Accordingly, The Inverse Distance Weighting (IDW) with variable search radius was used to interpolate the unknown points to calculating the value of the interpolated cell to create a continuous surface or map of the predictions are made for locations in the study area because it is more sophisticated than fixed search radius.

4.5 Leachate Water Quantity

The quantity of leachate generated at Dear Al Balah & Gaza landfills was estimated using the following methods:

1. The Hydrologic Evaluation of Landfill Performance (HELP) model.
2. Water Balance Method.
3. Field measured data.

4.5.1 Models Description and Concepts

1- HELP Model

Model Description: HELP model is the most widely used tool to predict leachate quantity and analyze water balance in landfill lining and capping systems by United State Environmental Protection Agency (US EPA). It is a quasi two dimensional hydrologic model of water movement across, into, through and out of landfills. HELP generates estimations of runoff amounts, evapotranspiration, drainage, leachate production and leakage from liners. HELP model was developed to help hazardous waste landfill designers and regulators to evaluate the hydrologic performance of proposed landfill designs

The model accepts weather, soil and design data and uses solution techniques that account for the effects of surface storage, snowmelt, runoff, infiltration, evapotranspiration, vegetative growth, soil moisture storage, lateral subsurface drainage, leachate recirculation, unsaturated vertical drainage, and leakage through soil, geo-membrane or composite liners. Landfill systems including various combinations of vegetation, cover soils, waste cells, lateral drain layers, low permeability barrier soils and synthetic geo-membrane liners may be modeled. The program was developed to conduct water balance analyses of landfills, cover systems and solid waste disposal and containment facilities (Schroeder et al., 1994).

The primary purpose of the model is to assist in the comparison between design alternatives as judged by their water balances. The model, applicable to open, partially closed and fully closed sites, is a tool for both designers and permit writers (Schroeder et al., 1994).

Concepts behind HELP Model: HELP model uses many process descriptions that were previously developed and reported in the literature and used in other hydrologic models. For example: Runoff modeling is based on the Soil Conservation Service (SCS) curve number method. Potential evapotranspiration is modeled by the modified Penman method. Evaporation of interception and surface water is based on the energy balance method. Interception is modeled by the method proposed by Horton. Vertical drainage is modeled by Darcy's law. Saturated lateral drainage is modeled by an analytical approximation to the steady state solution of the Boussinesq equation. Evaporation from soil, plant transpiration and vegetative growth were extracted and modeled using the methods included in Simulator for Water Resources in Rural Basins (SWRRB) model

These processes are linked together in a sequential order starting at the surface with a surface water balance; then evapotranspiration from the soil profile and finally drainage and water routing, starting at the surface with infiltration and then proceeding downward through the landfill profile to the bottom. The solution procedure is applied repetitively for each day as it simulates the water routing throughout the simulation period (Schroeder et al., 1994).

HELP model input data: The model accepts three types of data which are weather, soil and design data as shown in table 4.4.

Table 4.4: Input Data Required by HELP Model

Data Type	Parameter	Unit	Time Step
Weather Data	Evaporative Zone Depth	cm	-
	Maximum Leaf Area Index	-	-
	Relative Humidity	%	Seasonally
	Average Wind Speed	km / hr	-
	Rainfall Data	mm	Daily
	Temperature Data	°C	Daily
	Solar Radiation	MJ/m^2	Daily
Landfill Characteristics	Landfill Area	Acres	-
	% of Landfill where Runoff is Possible	%	-
	Runoff Curve Number	-	-
Soil and Solid Waste Data	Layer Type and Texture	-	-
	Layer Thickness	in	-
	Hydraulic Conductivity	cm / sec	-
	Porosity, Moisture Content, Field Capacity and Wilting Point	vol. / vol.	-
	Recycling Ratio	%	-

The weathered data of HELP model, which are evaporative zone depth, maximum leaf area index, wind speed, relative humidity, temperature and solar radiation, were identical in the two sites. The exceptions were annual rainfall and run of curve number, as shown in table 4.5

Table 4.5: HELP Model Input Parameters

<table>
<tr><th rowspan="2">Parameter</th><th rowspan="2">Range</th><th colspan="3">Typical Value</th></tr>
<tr><th>Dear Al Balah</th><th colspan="2">Gaza</th></tr>
<tr><td>Evaporative Zone Depth</td><td>4 - 60 in</td><td>23.62 in</td><td colspan="2">23.62 in</td></tr>
<tr><td>Maximum Leaf Area Index</td><td>0 - 5</td><td>3.5</td><td colspan="2">3.5</td></tr>
<tr><td>Wind Speed</td><td>1.7 - 17.1 km/hr</td><td>10.92 km/hr</td><td colspan="2">10.92 km/hr</td></tr>
<tr><td>Relative Humidity</td><td>69 - 73 %</td><td>-</td><td colspan="2">-</td></tr>
<tr><td>Annual Rainfall</td><td>-</td><td>322.58 mm</td><td colspan="2">405.72 mm</td></tr>
<tr><td>Temperature</td><td>12-27°C</td><td>-</td><td colspan="2">-</td></tr>
<tr><td>Solar Radiation</td><td>-</td><td>18.58</td><td colspan="2">18.58</td></tr>
<tr><td>Runoff Curve Number</td><td>75 - 85</td><td>81.3</td><td colspan="2">78.9</td></tr>
<tr><td>Recycling Ratio</td><td>0-100 %</td><td>40 %</td><td>40 %</td><td>0 %</td></tr>
</table>

The soil data of HELP model were identical in both Dear Al Balah site and Gaza for the first scenario using six layers (from bottom to top) as shown in table 4. 6; clay layer, base coarse layer, asphalt layer, aggregate layer, compacted solid waste layer and soil cover layer (sandy soil). But when applied the second scenario on Gaza site the model used two layers which are waste and clay layers.

Table 4.6: Properties of Layers at Dear Al Balah & Gaza Landfills

Layer Name	Layer No.		
	Dear Al Balah	Gaza First Scenario	Gaza Second Scenario
Sandy Soil	1	1	-
Waste	2	2	1
Aggregate	3	3	-
Asphalt	4	4	-
Base course	5	5	-
Clay	6	6	2

Typical soil layers used in HELP model are Thickness (in), Porosity (vol. / vol.), Field Capacity (vol. / vol.), Wilting Point (vol. / vol.), Initial Moisture (vol. / vol.), and Hydraulic Conductivity (cm/sec). The values for the soil layers are presented in tables 4.7, 4.8, and 4.9.

Table 4.7: Properties of Layer No. 1 & 2 at Dear Al Balah & Gaza Landfills

Parameter	Typical Value For layer 1		Typical Value For layer 2	
	Dear Al Balah	Gaza	Dear Al Balah	Gaza
Thickness (in)	20	984	670	670
Porosity (vol. / vol.)	0.437	0.671	0.671	0.475
Field Capacity (vol. / vol.)	0.062	0.292	0.292	0.378
Wilting Point (vol. / vol.)	0.024	0.077	0.077	0.265
Initial Moisture (vol. / vol.)	0.0835	0.294	0.294	0.475
Hydraulic Conductivity (cm/sec)	$5.8*10^{-2}$	10^{-3}	10^{-3}	$1.7*10^{-5}$

Table 4.8: Properties of Layer No. 3 & 4 at Dear Al Balah & Gaza Landfills

Parameter	Typical Value For layer 3		Typical Value For layer 4	
	Dear Al Balah	Gaza	Dear Al Balah	Gaza
Thickness (in)	7.88	-	3.54	-
Porosity (vol. / vol.)	0.397	-	0.427	-
Field Capacity (vol. / vol.)	0.032	-	0.418	-
Wilting Point (vol. / vol.)	0.013	-	0.367	-
Initial Moisture (vol. / vol.)	0.033	-	0.427	-
Hydraulic Conductivity (cm/sec)	0.30	-	$1*10^{-7}$	-

Table 4.9: Properties of Layer No. 5 & 6 at Dear Al Balah & Gaza Landfills

Parameter	Typical Value For layer 5		Typical Value For layer 6	
	Dear Al Balah	Gaza	Dear Al Balah	Gaza
Thickness (in)	7.88	-	670	-
Porosity (vol. / vol.)	0.397	-	0.475	-
Field Capacity (vol. / vol.)	0.032	-	0.378	-
Wilting Point (vol. / vol.)	0.013	-	0.265	-
Initial Moisture (vol. / vol.)	0.032	-	0.475	-
Hydraulic Conductivity (cm/sec)	0.3	-	$1.7*10^{-5}$	-

2- Water Balance Method

The method is simple which has been used to predict moisture movement within the landfill. The basic configuration that is assumed for the method is that the landfill consists of a covered surface, a compacted waste compartment and a lining system as shown in figure 4.5.

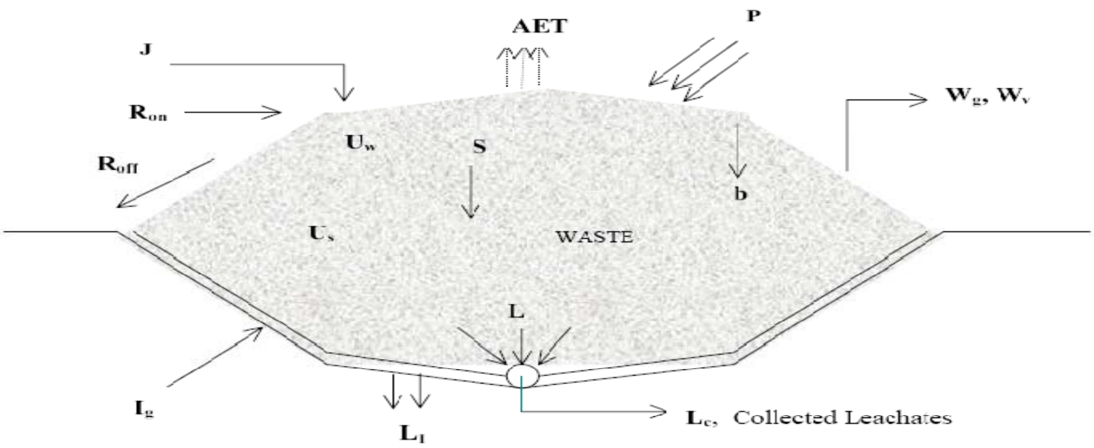

Figure 4.5: Hydrologic Balance of Landfill (Jagloo, 2002)

Where,

L	Leachate generated	U_w	Water content in wastes
L_I	Leachate infiltration in clay liner	U_s	Water content in soil cover
L_c	Collected leachate	S	Water in sludge
I_g	Water from underground	W_v	Water lost as water vapor
B	Water production by biodegradation of waste	W_g	Water consumed in the formation of landfill gas
J	Leachate recirculation	R_{off}	Runoff
R_{on}	Run on	P	Precipitation
AET	Actual evapotranspiration		

The water balance of landfill was derived; making use of assumptions in instances where it is applicable the infiltration through the top of the waste pile is calculated using Equation 1.

$$I = P + J + R_{on} - R_{off} - AET \pm U_s \quad (1)$$

Where,

I: Infiltration (mm\year)

P: precipitation (mm\year)

J: leachate recirculation (mm\year)

R_{off}: runoff (mm\year)

R_{on}: runon (mm\year)

AET: actual evapotranspiration (mm\year)

U_s : water content in soil cover (mm\year)

Assuming that,

1. The final soil cover is existent and the moisture content of the daily thin layers of soil is assumed to be at field capacity and is assumed not to contribute significantly in total moisture content of the cells (U_s=0).
2. The landfill has been designed so that water outside the site does not enter the site (R_{on} = 0).

Therefore, the infiltration (I) through the top part section of the waste pile becomes

$$I = P + J - R_{off} - AET \qquad (2)$$

Where, the change in water volume of the waste due to external sources (P_L) is computed as,

$$P_L = I + I_g \qquad (3)$$

Where,

I_g: the water from aquifers entering the landfill (mm\year)

Assuming water from aquifers entering the landfill is negligible (I_g = 0), the change in water volume of the waste due to external sources (P_L) is computed as,

$$P_L = I \qquad (4)$$

Then, the total leachate production is computed as,

$$L = P_L \pm U_w + b \qquad (5)$$

Where,

B: water production by biodegradation of waste (m^3\year)

U_w: the water content in wastes (at field capacity) (m^3\year)

The water produced due to the biodegradation of waste is assumed to be very small and negligible (b=0), then,

$$L = P_L \pm U_w \qquad (6)$$

It is worth noting that water percolating through from the surface of a landfill, tends to be absorbed by the waste until the field capacity is reached. It is only when the infiltration of water exceeds this value that movement of water through the waste occurs, initially under unsaturated conditions and, finally, if sufficient water is present, under saturated conditions.

The water balance method steps are summarized in table 4.10. Appendix A-1 shows the collected data and the testing of water balance method.

Table 4.10: Steps of Water Balance Method

Step 1	Input values for evapotranspiration and precipitation
Step 2	Calculate Runoff $R_{off} = C_{RO}$ x P where, C_{RO}= runoff coefficient
Step 3	Calculate Flux – movement of water Flux = P – R_{off} – AET If flux has a negative value (-ve up): water evaporating from wastes If flux has a positive value (+ve down): water infiltrating in the wastes
Step 4	Calculate STORE = AW + Flux, where AW = actual water content in the wastes
Step 5	Determine AW: If STORE > Max Storage Capacity (FC), Then AW = Maximum Storage Capacity Otherwise, AW = STORE or AW = 0 (if STORE = δ 0)
Step 6	Determine PERC IF STORE > Max Storage Capacity PERC = STORE – Max Storage Capacity Otherwise PERC = 0 Note If PERC has a positive value (+ve) : Leachate formed If PERC has a negative (-ve) : Moisture deficit

4.5.2 Model Calibration

The HELP model and water balance method were calibrated in case of Dear Al Balah landfill as this site has a measured data of generated leachate quantities from the landfill. After calibration, the modal was used to estimate the leachate quantity from Gaza landfill by considering two scenarios:

- First, assuming the Gaza landfill has a lining system and,
- Second, applying the actual situation where the lining is not available.

CHAPTER (5): RESULTS

The results of the study focus on analysis of carried out monitoring program and historical data analysis of the studied landfills. Two methods for analysis were used: Hydrologic Evaluation of Landfill Performance (HELP) model and Water Balance Method (WBM) to present the finding results. The results will be presented in two groups: leachate water quantity and the quality of leachate and the groundwater.

5.1. Leachate Water Quantity

Leachate water quantity was quantified using HELP and WBM in both landfills. In addition, the analysis considered two scenarios in Gaza landfill.

5.1.1. Dear Al Balah Landfill

HELP Model was run using 11 years duration (1997 - 2007) of daily climatic data for Dear Al Balah site. The landfill was simulated using six layers (from bottom to top) as shown in figure 3.16; clay layer, base coarse layer, asphalt layer, aggregate layer, compacted solid waste layer and soil cover layer (sandy soil). Around 40 % of the collected leachate recycled to the soil cover layer and was used in the simulation.

The volumes of leachate accumulated at the barrier layer (Asphalt Layer) and percolated through clay layer are presented in table 5.1. Figure 5.1 presents the annual rate of precipitation and the annual leachate volume generated at asphalt layer and percolated throw clay layer at Dear Al Balah landfill as estimated by HELP Model in the period (1997-2007). The average annual leachate volume generated at Dear Al Balah landfill for the simulation period (1997 – 2007) was 6,800 m^3 while the average annual leachate volume percolated through clay layer was 550 m^3 which represents about 8% of the generated leachate.

Table 5.1: Available Leachate accumulated at the Barrier Layer for Dear Al Balah Landfill as Estimated by HELP Model

Year	Precipitation (mm)	40% Recycle (m^3)			
		Leachate Accumulate at Asphalt Layer		Leachate percolate Through Clay Layer	
		Annual	Total Cumulative	Annual	Total Cumulative
1997	314.6	6,110.73	6,110.73	403.5	403.5
1998	216.5	2,397.68	8,508.40	318.3	721.8
1999	132	1,076.49	9,584.89	203.9	925.7
2000	255	4,861.91	14,446.81	364.3	1,289.9
2001	549.5	9,906.91	24,353.72	492.8	1,782.7
2002	390.6	11,197.86	35,551.57	674.6	2,457.3
2003	372.6	9,254.17	44,805.74	732.0	3,189.3
2004	316.6	9,299.26	54,105.00	827.1	4,016.4
2005	345.7	7,343.34	61,448.34	639.5	4,655.9
2006	245	6,348.31	67,796.65	779.5	5,435.4
2007	410.3	7,003.26	74,799.91	614.8	6,050.1
Avg.	322.58	6,800.00	-	550.0	-

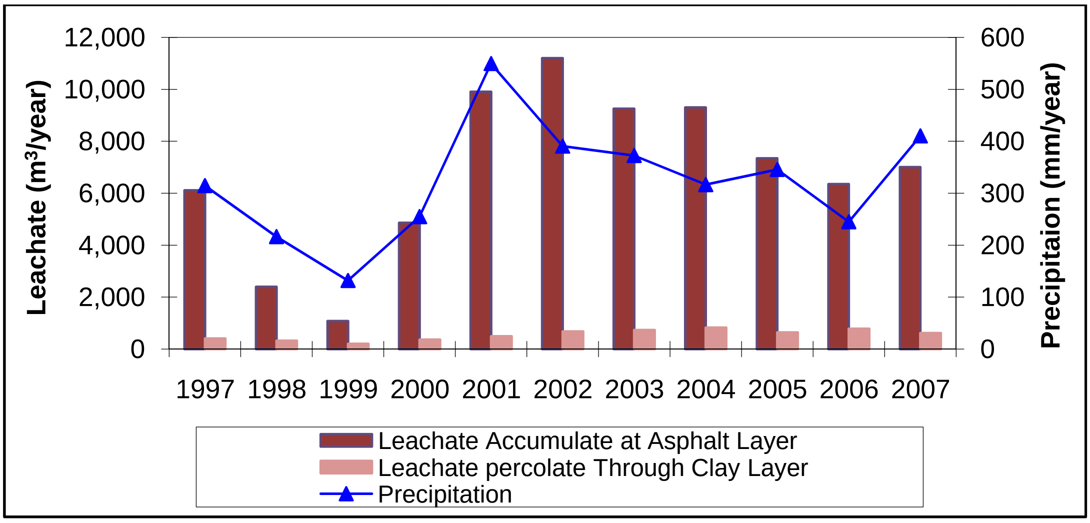

Figure 5.1: Annual Leachate Volume Generated and Percolated at Dear Al Balah Landfill Estimated by HELP Model

Figure 5.2 shows the cumulative annual leachate volume generated at the barrier layer and the cumulative quantity of percolated leachate through clay layer in the study period of simulation. The cumulative annual leachate volume generated was 74,800 m^3 while the cumulative annual leachate volume percolated through clay layer was 6,050 m^3.

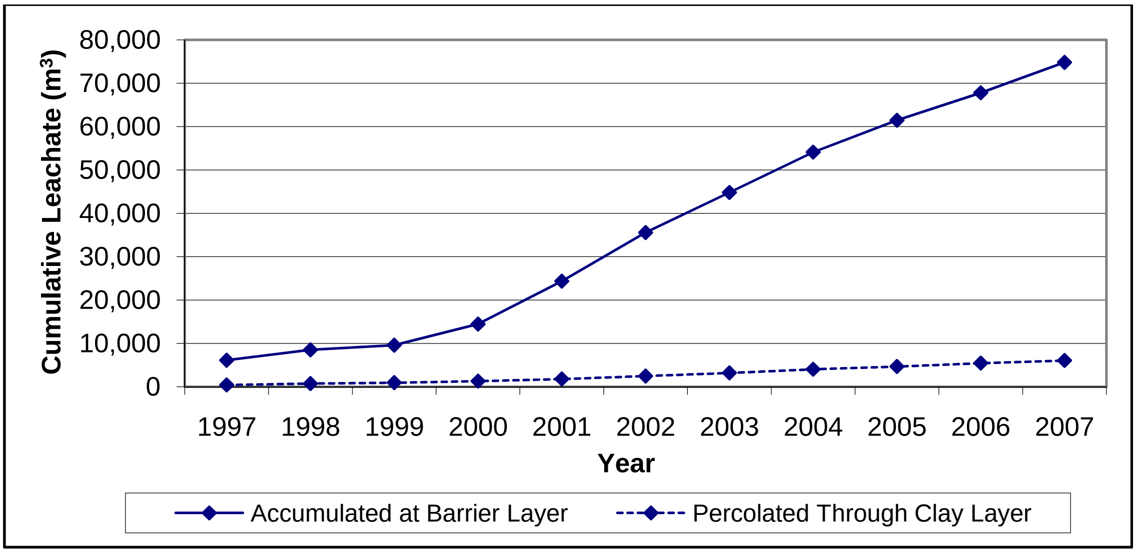

Figure 5.2: Cumulative Annual Leachate Volume Generated at Dear Al Balah Landfill Estimated by HELP Model

The Water Balance Method was used to estimate the leachate water quantity in the same study period (1997-2007). Table 5.2 shows the annual rate of precipitation and the annual quantity of leachate accumulated at the barrier layer by Water Balance method without recycle, with 40 % recycle and the cumulative leachate volume generated in the study period. Annual leachate volume generated at the barrier layer is plotted in figure 5.3 for Dear Al Balah landfill. The average annual leachate volume generated at Dear Al Balah landfill without recycle and with 40 % recycle for the simulation period (1997 – 2007) was very close and have the following values 7,360 and 7,663 m^3 respectively. The cumulative annual leachate volume was 73,345 m^3.

Table 5.2: Available Leachate accumulated at the Barrier Layer for Dear Al Balah Landfill as Estimated by Water Balance Method

Year	Precipitation (mm)	Accumulated Leachate (m^3) By		
		Water Balance without Recycle	Water Balance with 40% Recycle	Cumulative Water Balance with 40% Recycle
1997	314.6	5,062.0	5,062.0	5,062.0
1998	216.5	4,883.9	4,883.9	9,945.9
1999	132	4,351.6	4,351.6	14,297.5
2000	255	5,406.5	5,406.5	19,704.0
2001	549.5	7,089.9	7,089.9	26,793.9
2002	390.6	7,738.5	7,738.5	34,532.4
2003	372.6	7,384.1	7,384.1	41,916.4
2004	316.6	6,699.3	6,699.3	48,615.7
2005	345.7	7,373.6	7,373.6	55,989.3
2006	245	6,846.0	6,846.0	62,835.3
2007	410.3	8,391.2	10,509.4	73,344.7
Avg.	322.58	7,360.4	7,663.0	-

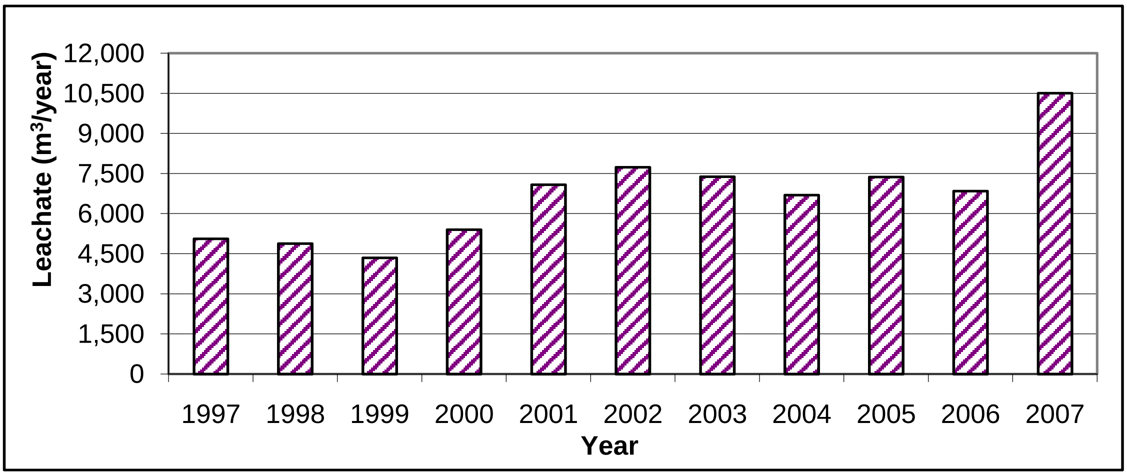

Figure 5.3: Annual Leachate Volume Generated at Dear Al Balah Landfill Estimated by Water Balance Method

The cumulative annual leachate quantity comes from three sources: precipitation, moisture content of the waste and re-circulated leachate. This classification of leachate sources are plotted in figure 5.4 for Dear Al Balah landfill. Figure 5.4 shows that about half of leachate quantity comes from moisture content of the waste while the remaining comes from the infiltration of precipitation and re-circulated leachate.

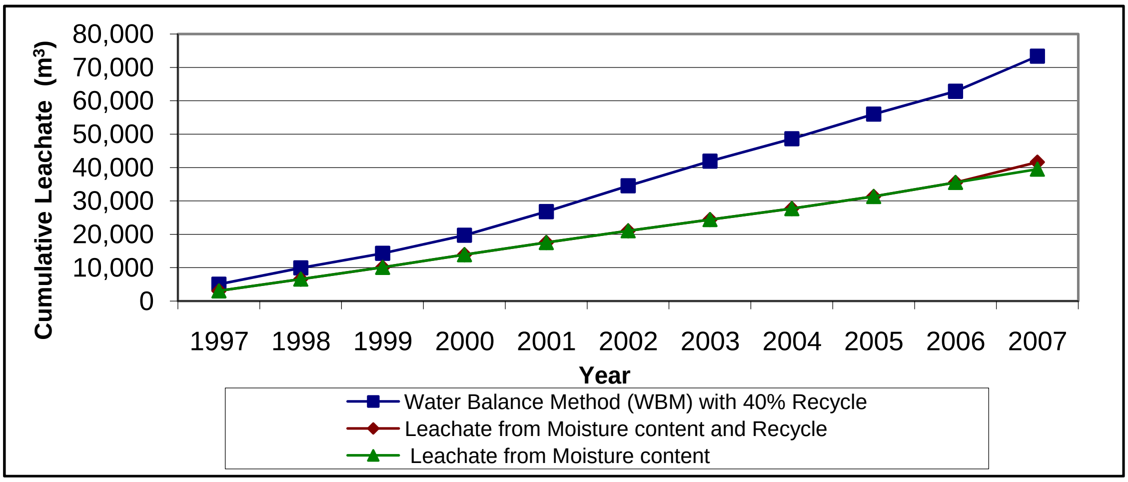

Figure 5.4: Cumulative Annual Leachate Volume Generated at Dear Al Balah Landfill Estimated by Water Balance Method

Table 5.3 presents the estimated cumulative leachate quantity by WBM with 40 % recycle and HELP model and the measured leachate quantity in the site. The used two methods showed close results during the study period. It was noticed that there were missing measurements of the leachate quantities in the first four years. From table 5.3 it can be recognized that the measured leachate volume is less than 50% of the estimated leachate volume by the study methods in the years from 2001 to 2004. However, in the last three years of the study period (2005 to 2007), the estimated quantity by the study methods and measured leachate volume become very close quantities as shown also in figure 5.5.

Table 5.3: Cumulative Leachate / Leakage through the Barrier Soil Layer for Dear Al Balah Landfill

Year	Precipitation (mm)	Leachate Quantity (m3) By		
		Water Balance with 40% Recycle	HELP Model with 40% Recycle	Measured Leachate (m^3)
1997	314.6	5,062.0	6,110.7	-
1998	216.5	9,945.9	8,508.4	-
1999	132	14,297.5	9,584.9	-
2000	255	19,704.0	14,446.8	-
2001	549.5	26,793.9	24,353.7	9,982.0
2002	390.6	34,532.4	35,551.6	11,853.0
2003	372.6	41,916.4	44,805.7	24,651.0
2004	316.6	48,615.7	54,105.0	26,134.0
2005	345.7	55,989.3	61,448.3	49,765.0
2006	245	62,835.3	67,796.7	51,194.0
2007	410.3	73,344.7	74,799.9	69,296.0

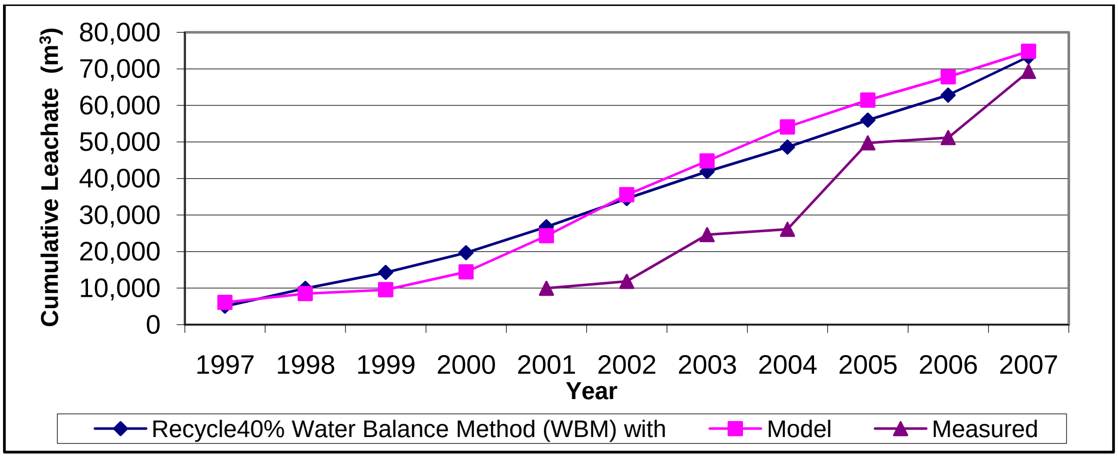

Figure 5.5: Cumulative Annual Leachate Volume Generated at Dear Al Balah Landfill

5.1.2. Gaza Landfill

The results present the calculated data in the last years (from 1997 to 2007) of Gaza landfill. Due to the absence of leachate collection system in Gaza landfill, there was no measured data record.

HELP Model was run using 11 years duration (1997 - 2007) of daily climatic data for Gaza landfill with two scenarios.

1. First scenario: calculation the leachate volume assuming that Gaza landfill has a lining system similar to Dear Al Balah landfill as presented in figure 3.16 and table 4.6.
2. Second scenario: applying the actual situation landfill as presented in table 4.6.

Annual and accumulated leachate volumes generated by HELP model at the barrier layer (Asphalt Layer - first scenario) in the period of simulation (1997-2007) are presented in table 5.4. Annual and cumulative leachate volumes generated at the barrier layer are plotted in figure 5.6 & 5.7 respectively. For first scenario, it was shown that the average annual volume of leachate accumulated at the barrier layer (Asphalt Layer) and percolated through clay layer in the period (1997-2007) were more than 34,000 m^3 and around 2,200 m^3 respectively. Accordingly, the estimate percolated leachate represents about 6.5% of generated leachate volume. The total cumulative leachate volume was 377,746 m3 while the total cumulative leachate volume percolated through clay layer was 24,413 m^3.

Table 5.4: Available Leachate Accumulated / Percolated through the Barrier Layer for Gaza Landfill as Estimated by HELP Model (First Scenario)

Year	Precipitation (mm)	40% Recycle (m^3)			
		Leachate Accumulate at Asphalt Layer		Leachate percolate Through Clay Layer	
		Total	Total Cumulative	Total	Total Cumulative
1997	282.1	18,640.41	18,640.41	1,514.03	1,514.03
1998	162	1,279.24	19,919.65	946.96	2,461.00
1999	183.5	8,370.29	28,289.94	1,840.47	4,301.47
2000	368.3	31,555.78	59,845.71	2,030.86	6,332.33
2001	563.6	55,828.67	115,674.38	2,103.46	8,435.78
2002	660.5	66,705.03	182,379.41	3,129.90	11,565.68
2003	790.7	88,438.35	270,817.77	3,158.87	14,724.55
2004	466.1	52,475.38	323,293.14	2,865.60	17,590.15
2005	323.6	21,871.39	345,164.54	2,792.70	20,382.85
2006	274.4	8,775.12	353,939.66	1,965.89	22,348.74
2007	388.2	23,806.61	377,746.26	2,064.55	24,413.29
Avg.	405.72	34,340.57	-	2,219.39	-

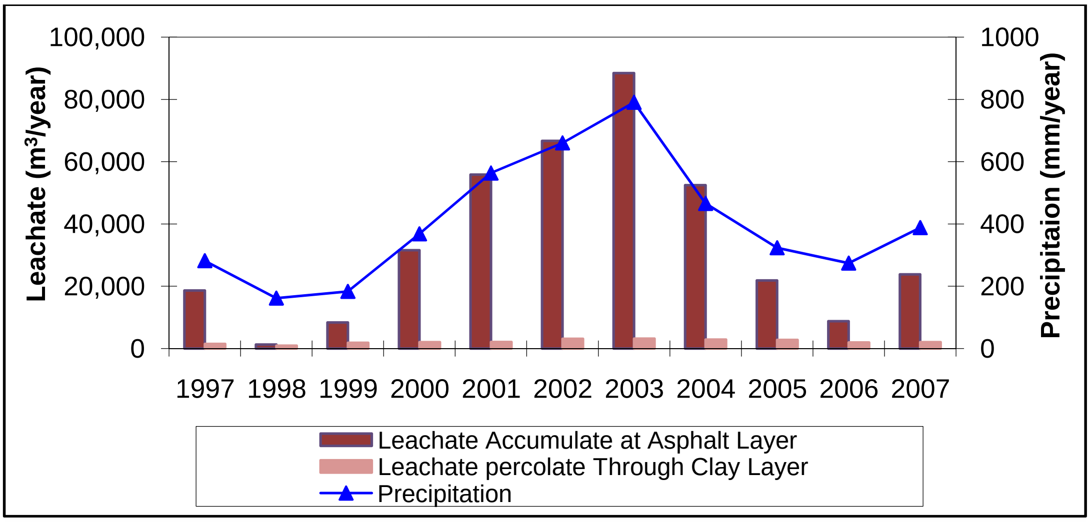

Figure 5.6: Annual Leachate Volume Generated and Percolated at Gaza Landfill as Estimated by HELP Model (First Scenario)

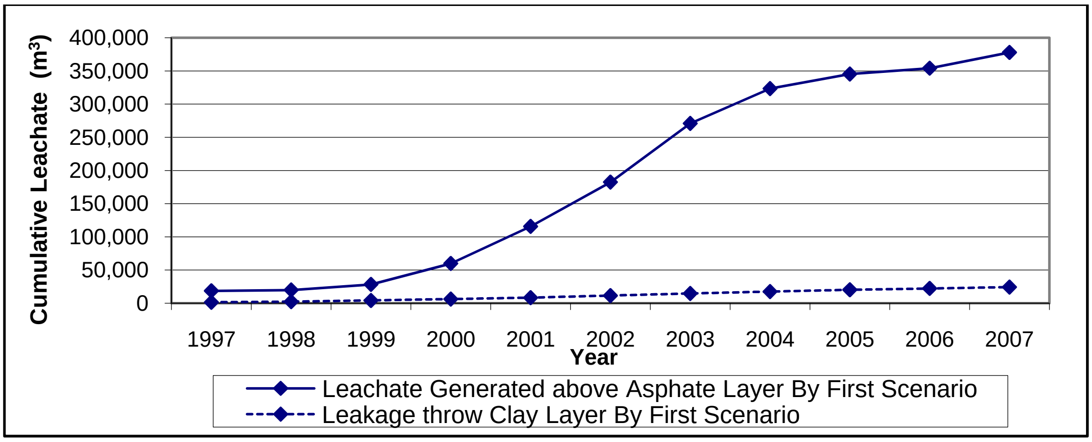

Figure 5.7: Cumulative Annual Leachate Volume Generated at Gaza Landfill as Estimated by HELP Model (First Scenario)

Table 5.5 presents the available leachate percolated through the Clay Layer for Gaza landfill as estimated by HELP Model for the actual status of the land fill (Second Scenario). The results showed that the average annual leachate volume percolated at Gaza landfill for the simulation period (1997 – 2007) is 17,487 m^3/year while the total cumulative percolated leachate volume in the period from 1997 to 2007 was 192,358 m^3.

Table 5.5: Available Leachate Percolated through the Clay Layer for Gaza Landfill as Estimated by HELP Model (Second Scenario)

Year	Precipitation (mm)	Percolated Leachate Volume without Recycle (m^3)	
		Total	Total Cumulative
1997	282.1	4,120.48	4,120.48
1998	162	22.44	4,142.93
1999	183.5	0.93	4,143.86
2000	368.3	17,019.88	21,163.73
2001	563.6	29,291.53	50,455.27
2002	660.5	45,589.99	96,045.26
2003	790.7	69,099.06	165,144.32
2004	466.1	22,758.56	187,902.88
2005	323.6	1,715.15	189,618.04
2006	274.4	128.09	189,746.12
2007	388.2	2,612.54	192,358.67
Avg.	405.72	17,487.15	-

The annual percolated leachate volume through clay layer computed by HELP model is plotted in figure 5.8 for the second scenario of Gaza landfill in the period of simulation (1997-2007). Figure 5.9 shows the cumulative annual leachate volume at the barrier layer and the cumulative quantity of percolated leachate through clay layer for first and second scenarios in the period of simulation of Gaza landfill. The results showed about 6.5% of generated leachate at Gaza landfill was percolated through clay layer when applying first scenario while this percentage increased to about 50% when applying the second scenario which represent the reality.

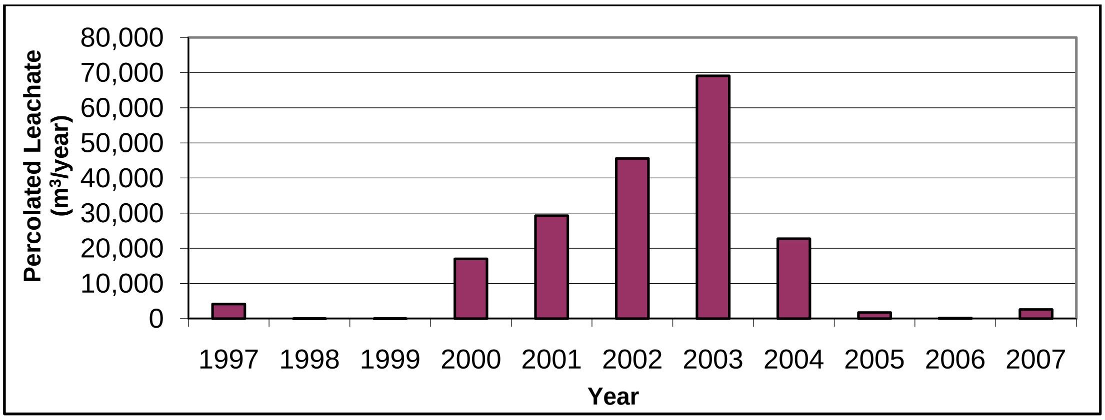

Figure 5.8: Annual Leachate Volume Percolated at Gaza Landfill as Estimated by HELP Model (Second Scenario)

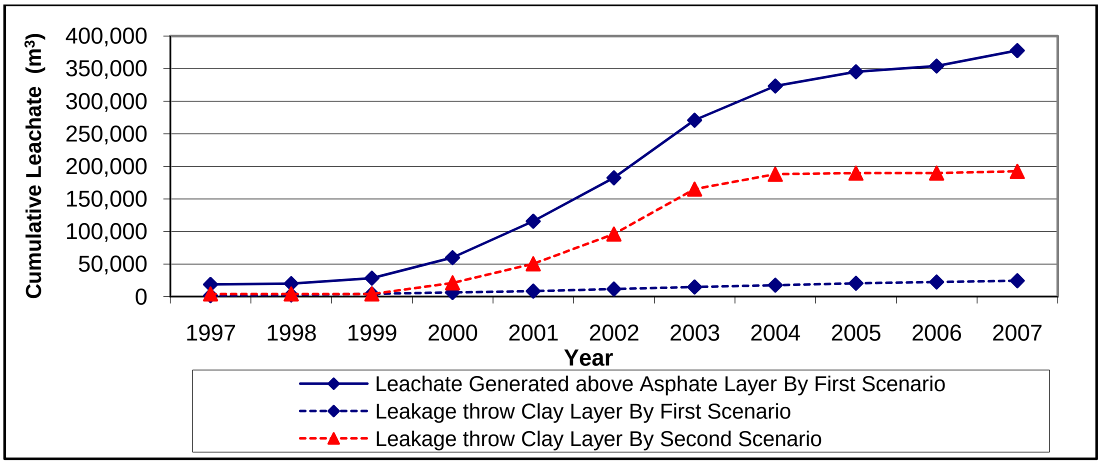

Figure 5.9: Cumulative Annual Leachate Volume Generated at Gaza Landfill as Estimated by HELP Model (First & Second Scenario)

The results obtained from **Water Balance Method** showed the same trend found by HELP model**.** Table 5.6 showed the annual rate of precipitation and the quantities of leachate accumulated at the barrier layer (first scenario- Asphalt layer) by Water Balance Method without recycle, with 40% recycle and the cumulative annual leachate volumes generated in the period of simulation from 1997 to 2007 with 40% recycle. The results showed that the average annual generated leachate volume at Gaza landfill without recycle and with 40 % recycle were 29,678 and 39,582 m^3

respectively. From table 5.6 it can be noticed that there is no significant change for the first four years, however the generated leachate starts to increase in 2001. The total cumulative generated leachate volume was 374,506 m^3.

Table 5.6: Available Leachate accumulated at the Barrier Layer for Gaza Landfill as Estimated by Water Balance Method (First Scenario)

Year	Precipitation (mm)	Accumulated Leachate (m3) By		
		Water Balance without Recycle	Water Balance with 40% Recycle	Cumulative Water Balance with 40% Recycle
1997	282.1	25,073.4	25,073.4	25,073.4
1998	162	22,479.2	22,479.2	47,552.6
1999	183.5	22,943.6	22,943.6	70,496.2
2000	368.3	26,935.3	26,935.3	97,431.4
2001	563.6	31,153.8	31,268.6	128,700.1
2002	660.5	33,246.8	46,409.9	175,110.0
2003	790.7	36,059.1	52,860.0	227,970.0
2004	466.1	29,047.8	37,684.9	265,654.8
2005	323.6	25,968.7	36,668.2	302,323.0
2006	274.4	24,907.0	33,776.7	336,099.6
2007	388.2	27,365.1	38,407.2	374,506.8
Avg.	405.72	29,678.3	39,582.2	-

Annual generated leachate volumes at the barrier layer (Asphalt layer) are plotted in figure 5.10 for Gaza landfill. The classification of leachate sources: precipitation, moisture content of the waste and re-circulated leachate are plotted in figure 5.11. The results showed that about half of leachate quantity comes from moisture content of the waste while the remaining comes from the infiltration of precipitation and re-circulated leachate.

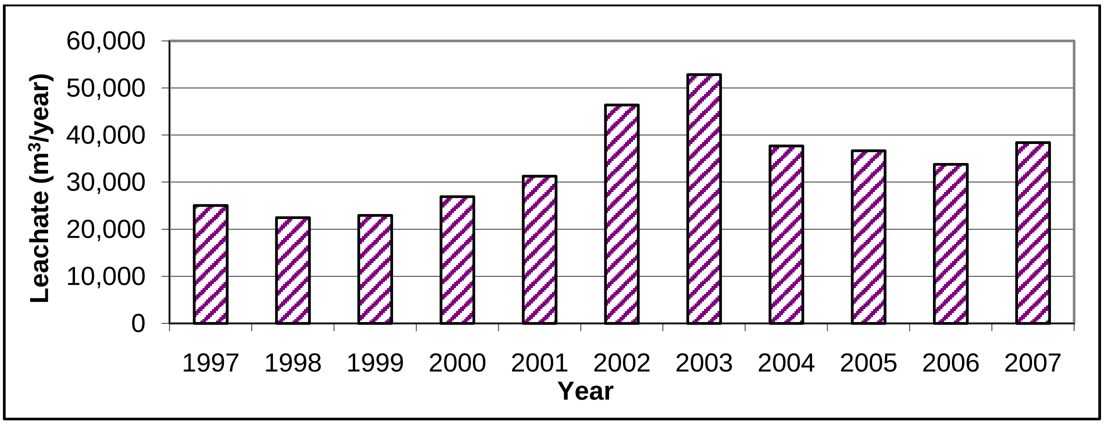

Figure 5.10: Annual Leachate Volume Generated at Gaza Landfill as Estimated by Water Balance Method (First Scenario)

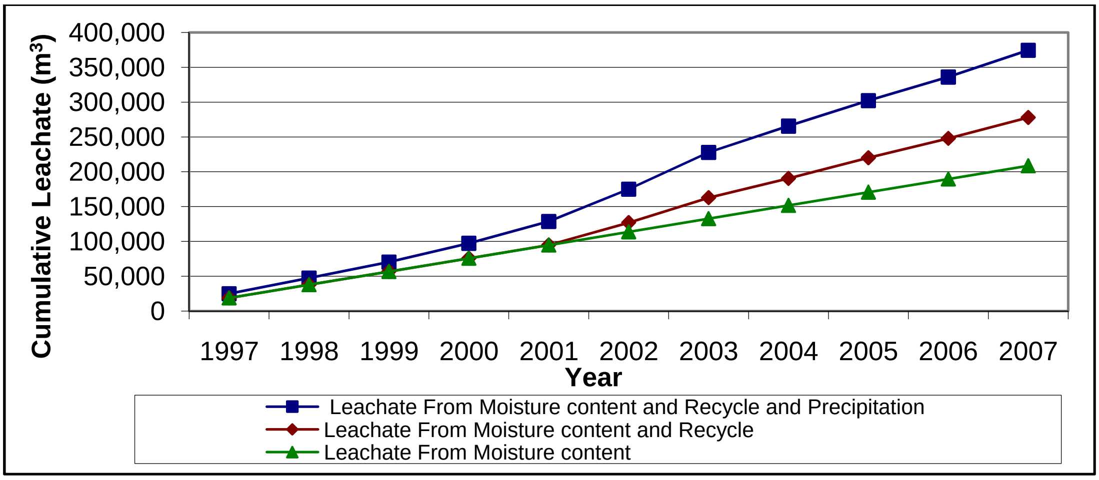

Figure 5.11: Cumulative Annual Leachate Volume Generated at Gaza Landfill Estimated by Water Balance Method (First Scenario)

Table 5.7 showed the average annual generated leachate volume and the cumulative generated leachate volume by Water Balance Method without recycle in the period of simulation from 1997 to 2007 for the second scenario. The total cumulative leachate was more than 305,000 m^3 in the investigated period and the average annual quantities were around 29,000 m^3. From table 5.7 it can be seen that, the annual quantities were strongly connected with level of annual precipitation.

Table 5.7: Available Leachate accumulated at the Barrier Soil Layer for Gaza Landfill as Estimated by Water Balance Method (Second Scenario)

Year	Precipitation (mm)	Accumulated Leachate (m^3)	
		Water Balance without Recycle	Cumulative Water Balance without Recycle
1997	282.1	25,073.4	25,073.4
1998	162	22,479.2	47,552.6
1999	183.5	22,943.6	70,496.2
2000	368.3	26,935.3	97,431.4
2001	563.6	31,153.8	128,585.2
2002	660.5	33,246.8	161,832.0
2003	790.7	36,059.1	197,891.1
2004	466.1	29,047.8	226,938.9
2005	323.6	25,968.7	252,907.6
2006	274.4	24,907.0	277,814.6
2007	388.2	27,365.1	305,179.7
Avg.	405.72	29,678.3	-

Annual generated leachate volumes are plotted in figure 5.12 for Gaza landfill. The classification of leachate sources: precipitation and moisture content of the waste are plotted in figure 5.13 for the second scenario of Gaza landfill. The total cumulative leachate from moisture source of solid waste is around the two third of the total leachate.

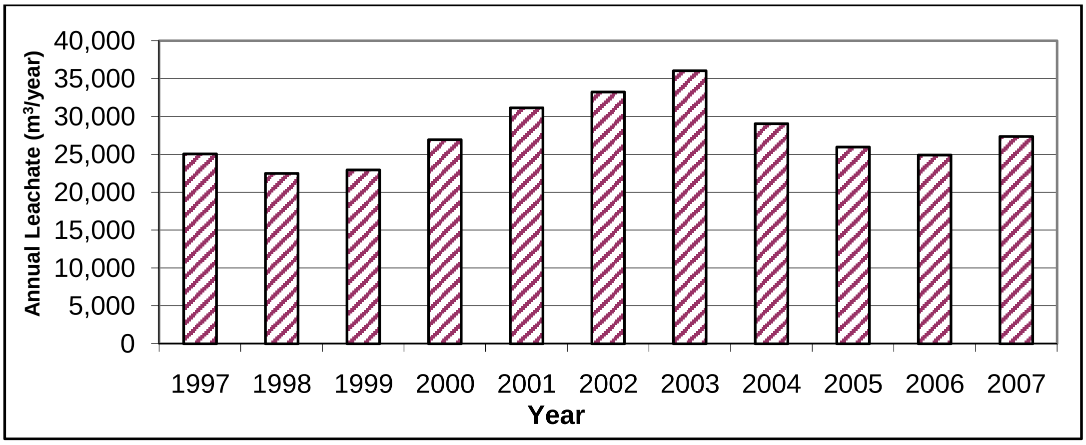

Figure 5.12: Annual Leachate Volume Generated at Gaza Landfill as Estimated by Water Balance Method (Second Scenario)

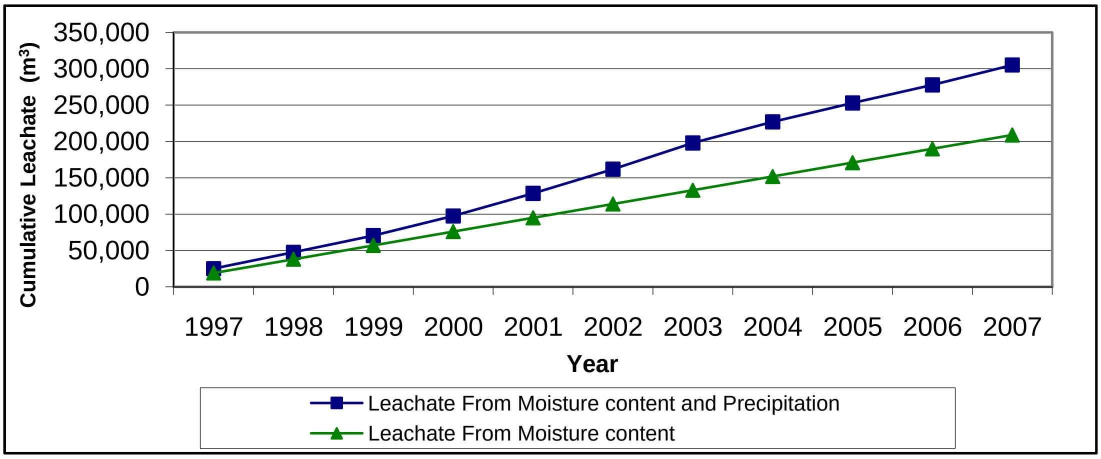

Figure 5.13: Cumulative Annual Leachate Volume Generated at Gaza Landfill as Estimated by Water Balance Method (Second Scenario)

5.2. Leachate Water and Groundwater Quality

The leachate and groundwater quality results were presented in the light of the outputs of sampling programs for leachate gathered from landfills, in Dear Al Balah and Gaza City areas and the groundwater samples collected from multilevel observation wells around both sites. The Geographic Information System (GIS) was used as a tool to simplify the presentation of the analyzed results of the pollutant indicators around both Dear Al Balah and Gaza landfills in the periods 1995, 1999, 2001 and 2008 respectively.

5.2.1. Leachate Characterization

A group of physical and chemical parameters were tested in leachate samples collected from Dear Al Balah and Gaza landfill. The Physical parameters included pH and Electrical Conductivity (EC). While the chemical parameters included: NO_3, NH_4, Cl, SO_4, Pb, Fe, Mn, Cd, Zn, BOD, COD and TOC. These parameters were tested in the IUG laboratories in Oct. 2008. The experimental results obtained for the leachate at Dear Al Balah and Gaza landfills are summarized in table 5.8.

Table 5.8: Physical–Chemical Characteristics of Leachate

Parameter	Concentration						
	Gaza		Dear Al Balah				
	2001	**2008**	**1997**	**1998**	**1999**	**2001**	**2008**
PH	8.2	8.4	8.22	8.7	8.2	8.2	8.3
Electric Conductivity (EC)	52000	45100	37200	35500	55400	35500	32200
Nitrate (NO_3) (mg/l)	40	325	-	-	-	-	440
Chloride (Cl) (mg/l)	8050	12200	7350	6900	10500	8000	9440
Ammonia (NH_4) (mg/l)	2210	2045	4233	1864	5052	2320	3473
COD (mg/l)	40000	45500	39750	12840	28350	25280	46500
BOD_5 (mg/l)	28500	887.5	11200	3700	12500	4000	800
BOD_5/COD (%)	0.713	0.02	0.282	0.288	0.441	0.158	0.017
TOC (mg/l)	-	1352	7430	3500	10000	3000	1560
Sulfate (SO_4) (mg/l)	20	1337	357.5	210	380	200	926
Lead (Pb) (mg/l)	0.11	BDL	-	-	-	0.004	BDL
Iron (Fe) (mg/l)	57	BDL	-	-	-	-	BDL
Cadmium (Cd) (mg/l)	3.2	BDL	-	-	-	0.01	22.5
Zinc (Zn) (mg/l)	5.6	65.5	-	-	-	0.01	64
Copper (Cu) (mg/l)	-	6	-	-	-	0.01	BDL

BDL: Below Detected Limit

The variation of COD and Ammonia concentration with time have the same behavior which decrease in years 1998 and 2001 and start to increase after 2001 while the BOD concentration decrease after 1999, as shown in figures 5.14 and 5.15.

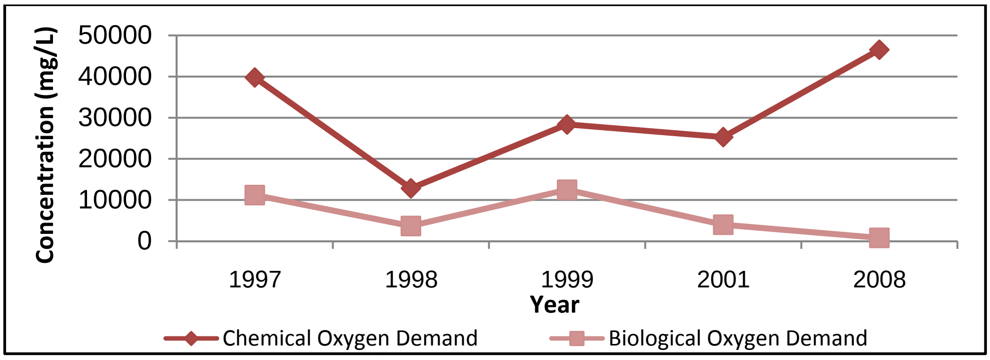

Figure 5.14: Change of Chemical Oxygen Demand (COD) Quality with Time

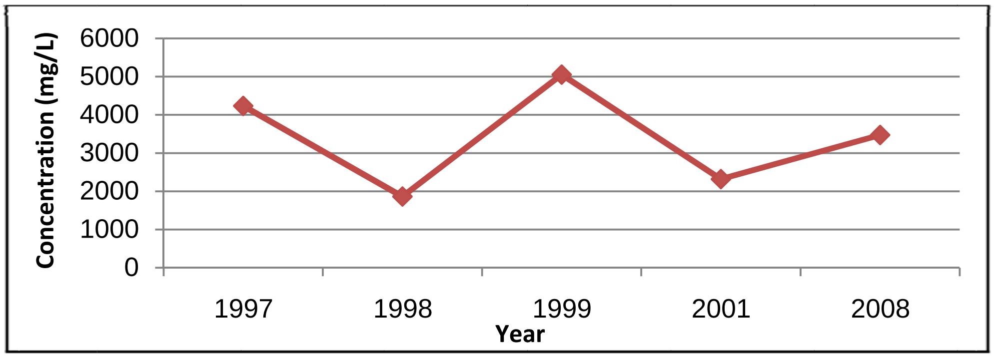

Figure 5.15: Change of Ammonium (NH4) Quality with Time

The BOD/COD ratio was around 0.28 in years 1997 and 1998 and reach to maximum ratio 0.44 at year 1999 after that the ratio of BOD/COD was decreased to 0.017 in 2008.

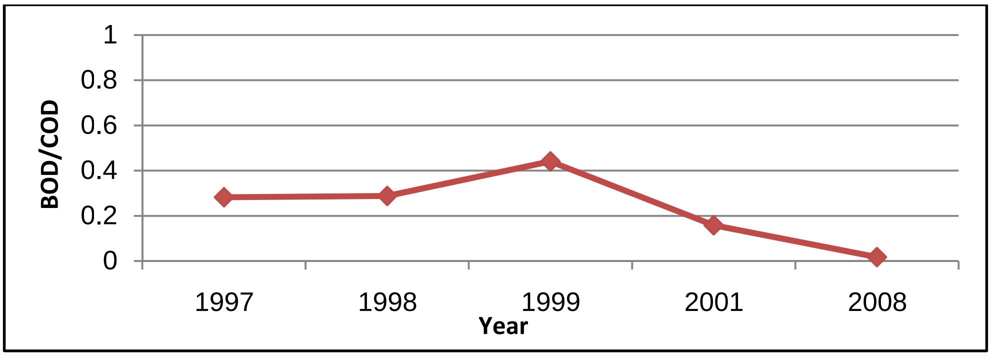

Figure 5.16: Change of (BOD/COD) Quality with Time

5.2.2. Groundwater Quality

Sampling program and geographic information system (GIS) were used to study the groundwater quality for both Dear Al Balah and Gaza landfills as follows:

5.2.2.1. Monitoring Program

The water samples were taken from wells located around Dear Al Balah and Gaza landfill as presented in figure 4.2 and 4.3 respectively. Based on the local constrains (IUG laboratories facilities and equipment were destroyed in the Israeli bombardment) only the first phase was carried out after summer (November 2008). The second phase of tested parameters after winter couldn't be measured. The monitoring program results for the selected wells for the groundwater in Dear Al Balah and Gaza are shown in tables 5.9 and 5.10 respectively.

Table 5.9: Groundwater Characteristics for Sampling Wells at Dear Al Balah in 2008

Parameter	Well ID								
	W_1	**W_2**	**W_3**	**W_4**	**W_5**	**W_6**	**W_7**	**W_8**	**W_9**
Agricultural No.	Mid.1	Illega	Illega	Illega	Illega	Illega	Illega	Illega	Illega
X GPS	9087	90982	90821	90989	91298	90743	90811	90890	9132
Y GPS	8911	89157	89276	89415	89527	89571	89681	89692	8966
ZM (Water depth)	-	-	65	75	85	47	11	-	67
PH	7.95	7.75	7.68	7.69	7.82	7.86	7.78	7.91	7.94
EC (µ.s/cm)	3430	1840	3490	4160	1770	4180	1990	2420	1600
Nitrate (NO_3) (mg/L)	44	39.6	66	88	101.2	66	110	83.6	118.8
Chloride (Cl) (mg/L)	841	370	809.5	778.5	355	1004	368.5	499	323.5
Ammonia (NH_4) (mg/L)	7.56	11.2	4.48	4.48	6.44	7.28	6.44	10.92	7.28
COD (mg/L)	326	150	273	345	442	448	218	234	186
BOD_5 (mg/L)	10	BDL	BDL	BDL	BDL	BDL	BDL	BDL	10
TOC (mg/L)	6.22	8.92	9.46	12.17	10.82	10.28	10.28	12.71	4.87
Sulfate (SO_4) (mg/L)	22.06	4.78	23.49	25.32	6.03	25.41	1.5	10.15	1.25
Lead (Pb) (mg/L)	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
Iron (Fe) (mg/L)	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
Cadmium (Cd) (mg/L)	0.011	0.043	0.023	0.022	0.018	0.002	0.014	0.02	0.021
Zinc (Zn) (mg/L)	0.111	0.122	0.185	0.107	0.109	0.107	0.108	0.111	0.124
Copper (Cu) (mg/L)	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	0.19

BDL: Below Detected Limit

Table 5.10: Groundwater Characteristics for Sampling Wells at Gaza in 2008

Parameter	Well ID								
	W_1	**W_2**	**W_3**	**W_4**	**W_5**	**W_6**	**W_7**	**W_8**	**W_9**
Agricultural No.	F-I-16	Illegal	F-I-115	Illegal	Illegal	Illegal	Illegal	Illegal	Illegal
X GPS	97796	97707	97590	97360	97219	97602	97527	97805	97266
Y GPS	96762	96589	96730	96695	96511	96488	96417	96983	96374
ZM (Water depth)	63	63	63	63	63	63	63	70	70
PH	7.86	7.55	7.61	7.46	7.6	7.8	7.61	7.68	7.74
EC (µ.s/cm)	1630	1870	1190	2150	2350	1390	1080	3290	1060
Nitrate (NO_3) (mg/L)	28.16	92.4	61.6	61.6	35.2	52.8	66	30.8	57.2
Chloride (Cl) (mg/L)	229	341	176.5	452	477	188.5	204	720	193
Ammonia (NH_4) (mg/L)	3.64	4.2	6.16	3.92	5.88	3.64	4.48	5.6	8.12
COD (mg/L)	4	113	BDL	147	251	30	BDL	325	248
BOD_5 (mg/L)	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
TOC (mg/L)	6.21	BDL	BDL	3.51	7.3	8.92	9.73	9.19	6.76
Sulfate (SO_4) (mg/L)	BDL	BDL	BDL	11.78	15.01	BDL	BDL	17.85	BDL
Lead (Pb) (mg/L)	BDL	BDL	BDL	BDL	BDL	BDL	0.042	BDL	BDL
Iron (Fe) (mg/L)	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
Cadmium (Cd) (mg/L)	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
Zinc (Zn) (mg/L)	0.118	0.104	0.103	0.229	0.105	0.091	BDL	0.114	0.099
Copper (Cu) (mg/L)	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL

BDL: Below Detected Limit

The following points summarize the main findings of the sampling program of the groundwater wells:

1. The pH of all the sampling wells around Gaza and Dear Al Balah landfill was about neutral, the range was 7·55–7·95 at Gaza while the range was 7.68–7.95 at Dear Al Balah.
2. The EC of all the sampling wells around Gaza landfill was ranged between 1060 and 2350 µs/cm. EC was high, especially in wells 2, 4, 5, and 8 which are about 50 to 470 m from the landfill. The EC values of all wells around Dear Al Balah landfill have a range between 1600 µs/cm in W_9 and 4180 µs/cm in W_6. EC was high, especially in wells 1, 3, 4, and 6 which are about 160 to 440 m from the landfill at the downstream side.
3. COD values for Gaza landfill have a range between below detection limit (BDL) and 325 mg/l The highest COD values measured at wells W_2, W_4, W_5, W_8 and W_9**.** COD values for Dear Al Balah landfill have a range between BDL and 448 mg/L. The highest COD values measured at wells W_1, W_4, W_5 and W_6**.**
4. The highest concentration of Cl in the groundwater at Gaza landfill site was measured at well W_8 while Cl values around Dear Al Balah landfill have arrange between 355 and 1004 mg/L. The highest Cl values measured at wells W_1, W_3 W_4 and $W_{6.}$
5. Nitrate concentrations (NO_3) fluctuated between relatively normal levels to high levels (40–119 mg/l) for Dear Al Balah Landfill. The highest NO_3 values of nitrate concentration were recorded in wells W_4, W_5, $W_{7,}$ W_8 and W_9. While at Gaza landfill the highest NO_3 value was recorded in well W_2. NO_3 concentration of all wells at Dear Al Balah landfill are above WHO standard except of W_1, W_2 and above Palestinian standards except of W_1, W_2, W_3 and W_6, as shown in figure 5.17.

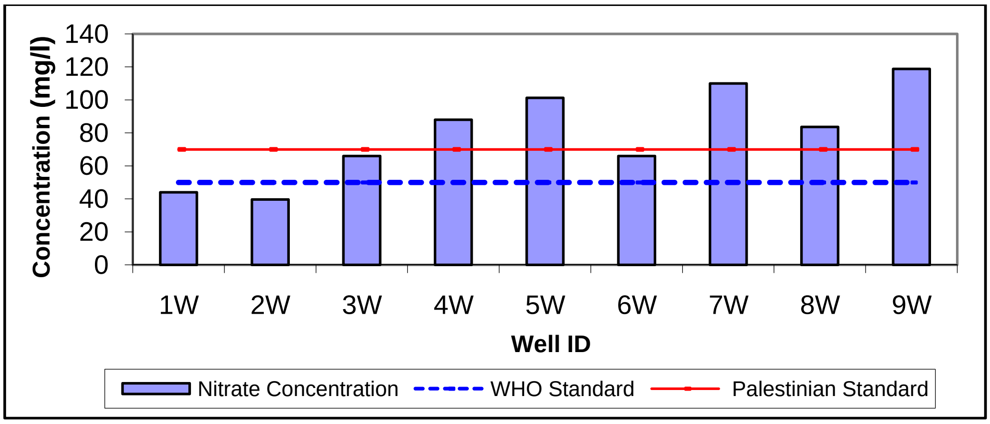

Figure 5.17: Comparison between Nitrate Concentration of wells and Maximum allowable Concentration at Dear Al Balah Landfill

NO_3 concentration of all wells at Gaza landfill are above WHO standard except of W_1, W_5 and W_8 while the Nitrate concentration of all wells are below Palestinian standard except W_2 , as shown in Figure 5.18.

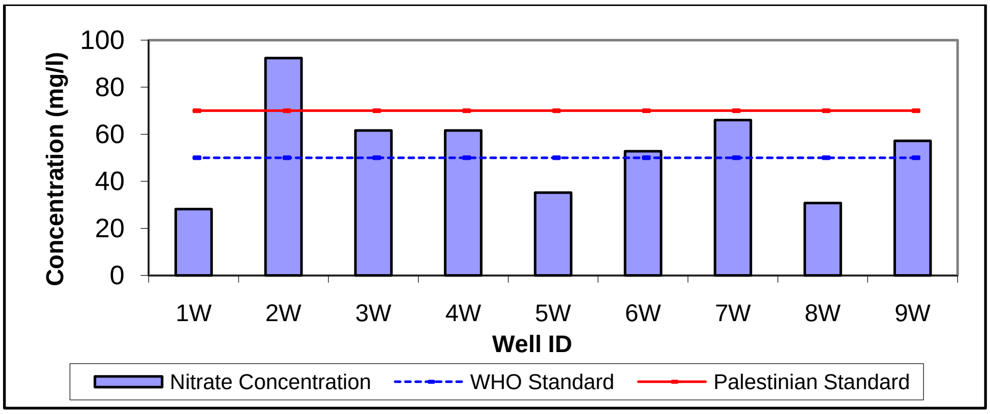

Figure 5.18: Comparison between Nitrate Concentration of wells and Maximum allowable Concentration at Gaza Landfill

6. The Ammonia (NH_4) at Dear Al Balah landfill site was considered too high and ranged between 4.48 and 11.2 mg/l. It was noticed that wells W_1 and W_2 were more polluted than wells W_3, W_4, W_5, W_6 and W_9.at Gaza landfill site NH_4 was considered to be in high concentration and ranged between 3.54 and 8.12 mg/L. It was noticed that wells W_1, W_2, W_6 and W_7 were less polluted than wells W_3, W_5, W_8 and W_9. NH_4 concentration of all wells at Dear Al Balah and Gaza landfills are above WHO and Palestinian standards, as shown in figure 5.19 and 5.20 respectively.

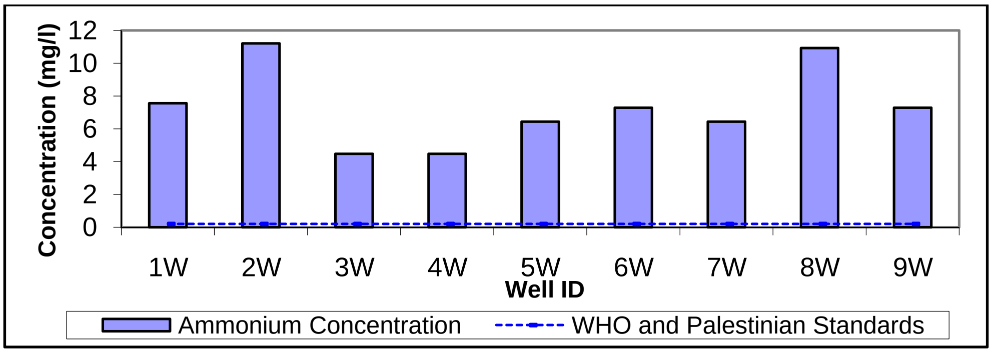

Figure 5.19: Comparison between Ammonium Concentration of wells in Dear Al Balah Landfill and WHO and Palestinian Standards ration

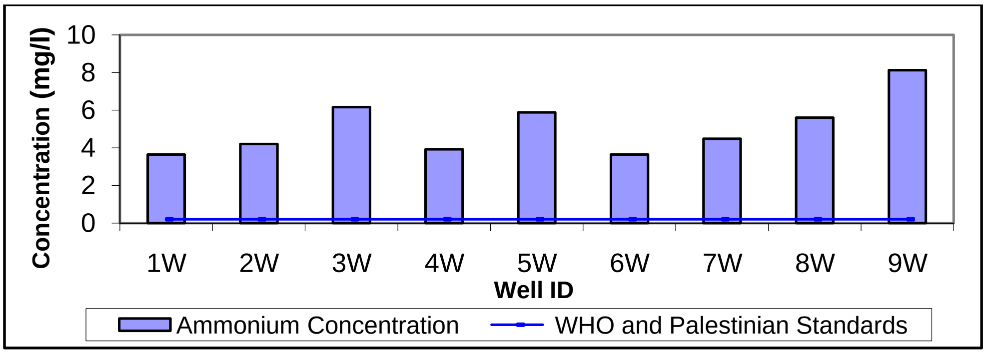

Figure 5.20: Comparison between Ammonium Concentration of wells in Gaza Landfill and WHO and Palestinian Standards

7. At Gaza landfill, Cadmium and Lead were below detection limit (BDL). At Dear Al Balah landfill, Lead were below detection limit (BDL) but Cadmium has high concentration in sampling sites (wells 2, 3 and 4) and has low concentration in sampling sites (wells 6 and 7).
8. The range of Zinc concentration around Gaza site was between 0.091 and 0.229 mg/l while it was between 0.107 and 0.185 mg/l around Dear Al Balah site.

5.2.2.2.Geographic Information System (GIS ArcMap)

The results of groundwater quality monitoring conducted by this study and the historical groundwater monitoring of selected wells was used by Geographic information system (GIS) as a tool to simplify the presentation of finding result of the pollutant indicators. The investigations were focused within 500 m radius circle area around both Dear Al Balah and Gaza landfills in the years 1995, 1999, 2001 and 2008 respectively. The Inverse Distance Weighting (IDW) was used to present the spatial distribution of the indicators.

The most common pollutants indicators which used to study the contaminants transport were Nitrate (NO_3), Chloride (Cl), Ammonium (NH_4), Chemical Oxygen Demand (COD) and Electric conductivity (EC). Figures 5.21, 5.22, 5.23, 5.24 and 5.25 represented the groundwater changes finding closed to Gaza landfill in the periods 1995, 1999, 2001 and 2008 while figures 5.26, 5.27, 5.28 and 5.29 plotted the results near the Dear Al Balah landfill only in the year 2008.

At Gaza site, figure 5.21 shows that the level of NO_3 in groundwater under the landfill was relatively low and a small plume area located in the north direction of the landfill. The plumed area was growing gradually through years 1999 and 2001. In year 2008, the plumed area was become in the west side of landfill and it is in the direction of groundwater flow.

Chloride (Cl), Ammonium (NH4), Chemical Oxygen Demand (COD) and Electric conductivity (EC) are other indicators of pollutants which were plotted in figures 5.22, 5.23, 5.24 and 5.25 for Gaza landfill. These indicators follow the same behavior of Nitrate in the case the plumed area direction which was mentioned in the Nitrate. The interpretation of these figures insures the fact that, the groundwater is affected by Gaza landfill leachate.

At Dear Al Balah landfill there is no historical data of groundwater samples in years 1995, 1999 and 2001. Therefore, there are no developed maps for these years. However, at year 2008, high concentrations of Nitrate in the groundwater found far away from the landfill in the north direction of landfill and not in the lateral flow direction, as shown in figure 5.26. The Ammonia concentration level is a very important indicator to study the effects of landfill leachate on groundwater. High concentrations of Ammonia in the groundwater were found in two locations, one close to landfill in southwest direction and the other one was far away from the landfill, as shown in figure 5.27.

High concentrations of Cl and EC in groundwater were found close to landfill in southwest direction, as shown in figures 5.28 and 5.29 respectively.

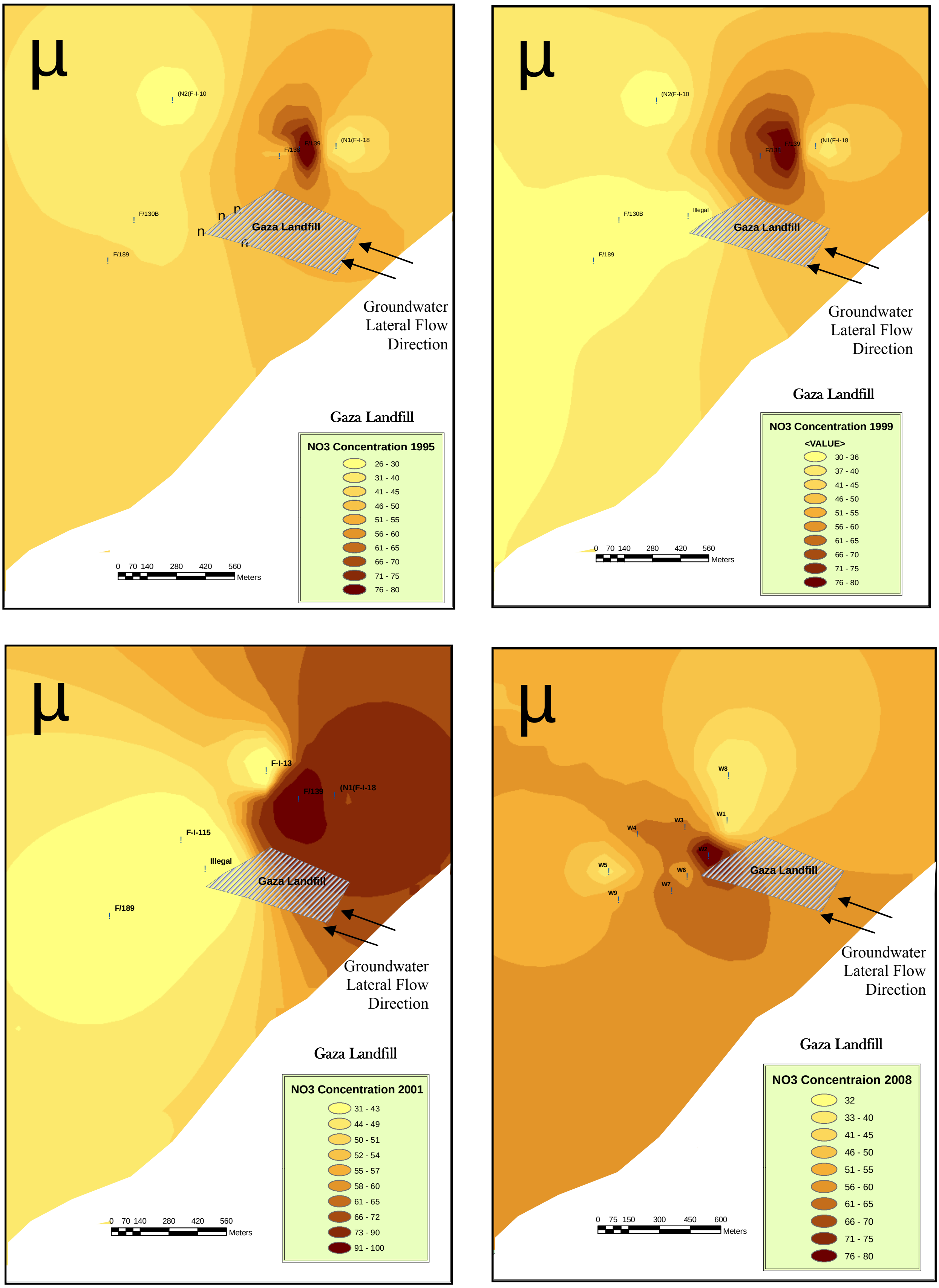

Figure 5.21: Nitrate Concentration of Groundwater Wells near the Landfill of Selected Year during Lifespan of Gaza Site

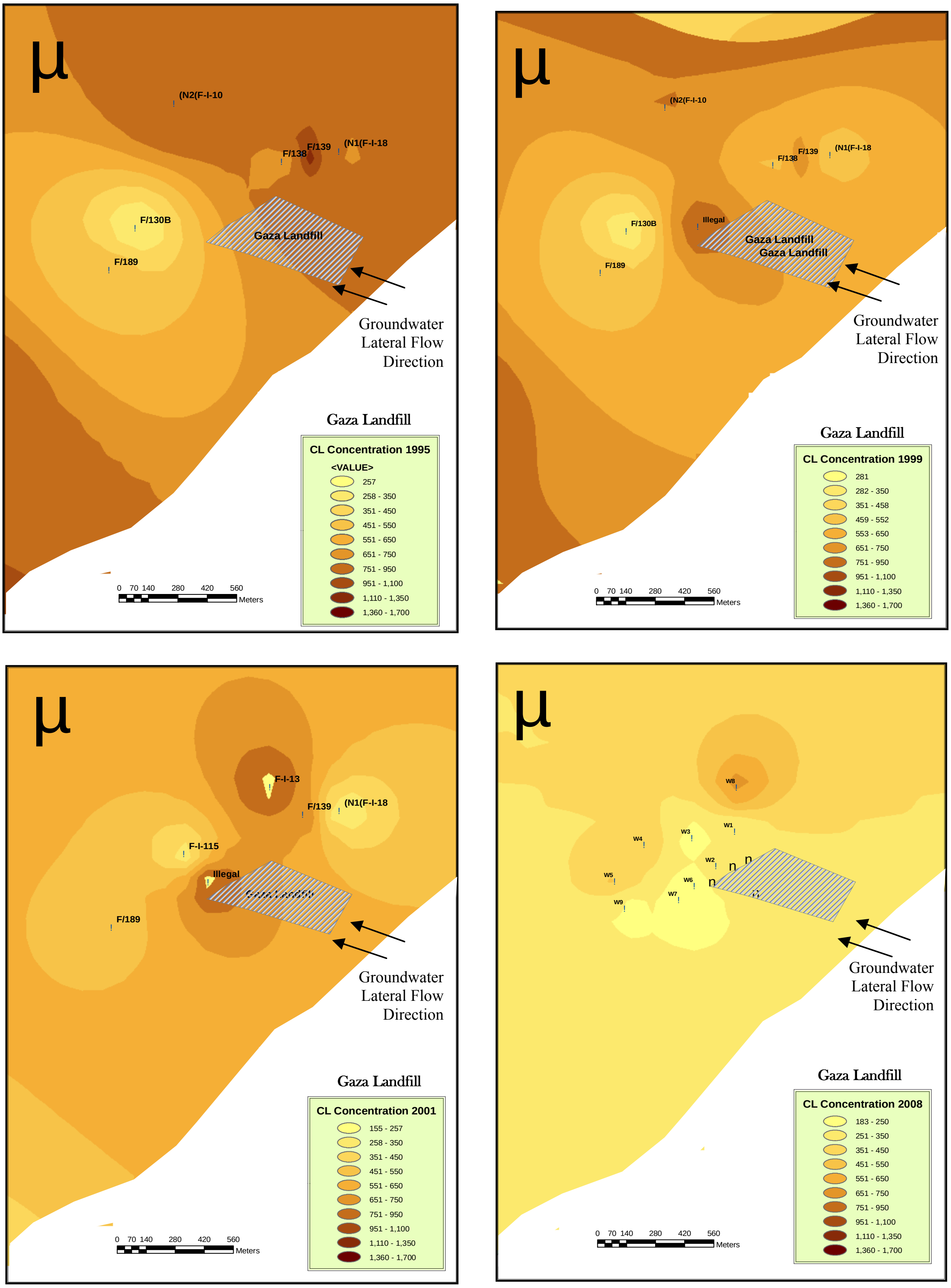

Figure 5.22: Chloride Concentration of Groundwater Wells near the Landfill of Selected Year during Lifespan of Gaza Site

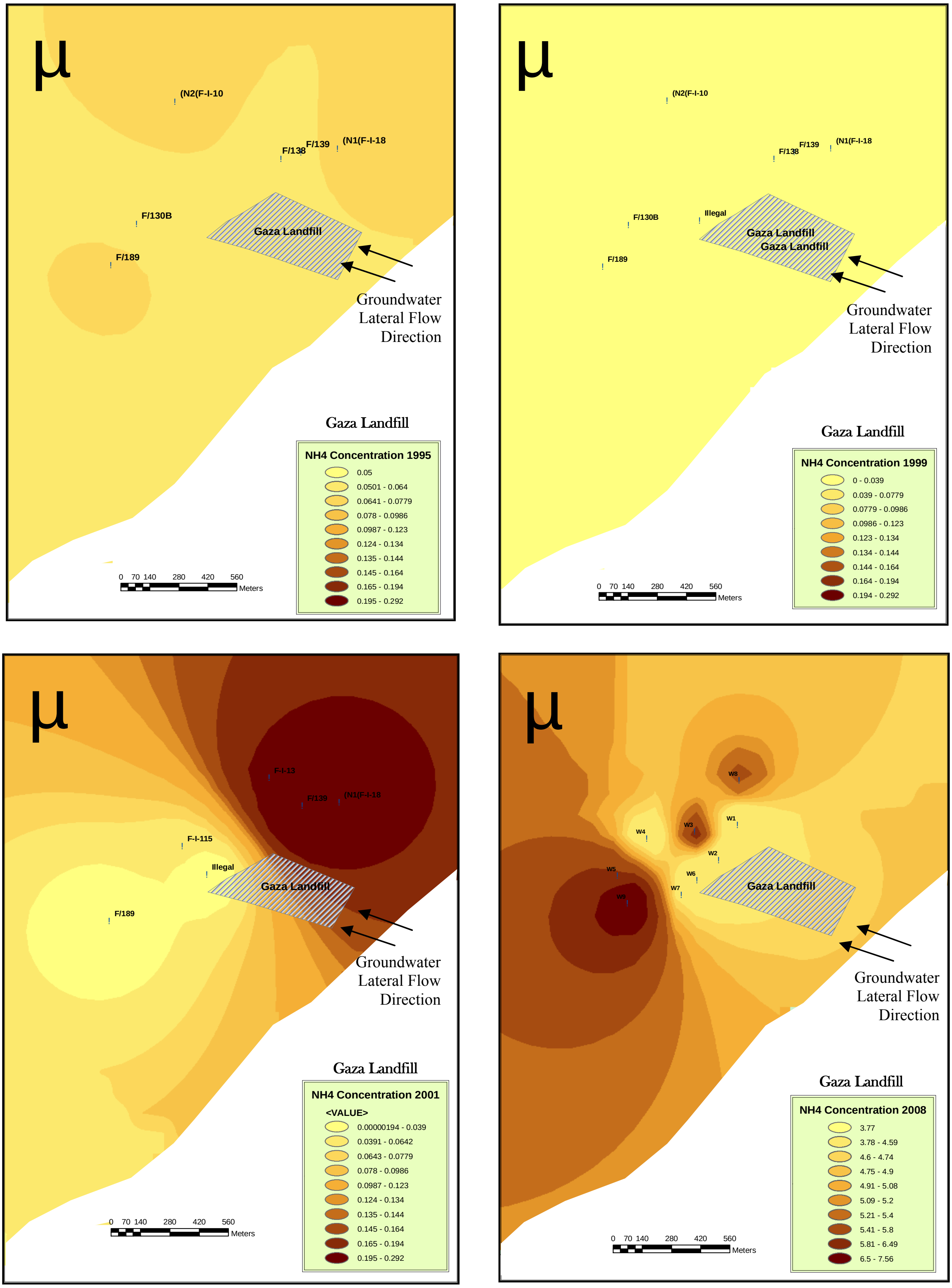

Figure 5.23: Ammonium Concentration of Groundwater Wells near the Landfill of Selected Year during Lifespan of Gaza Site

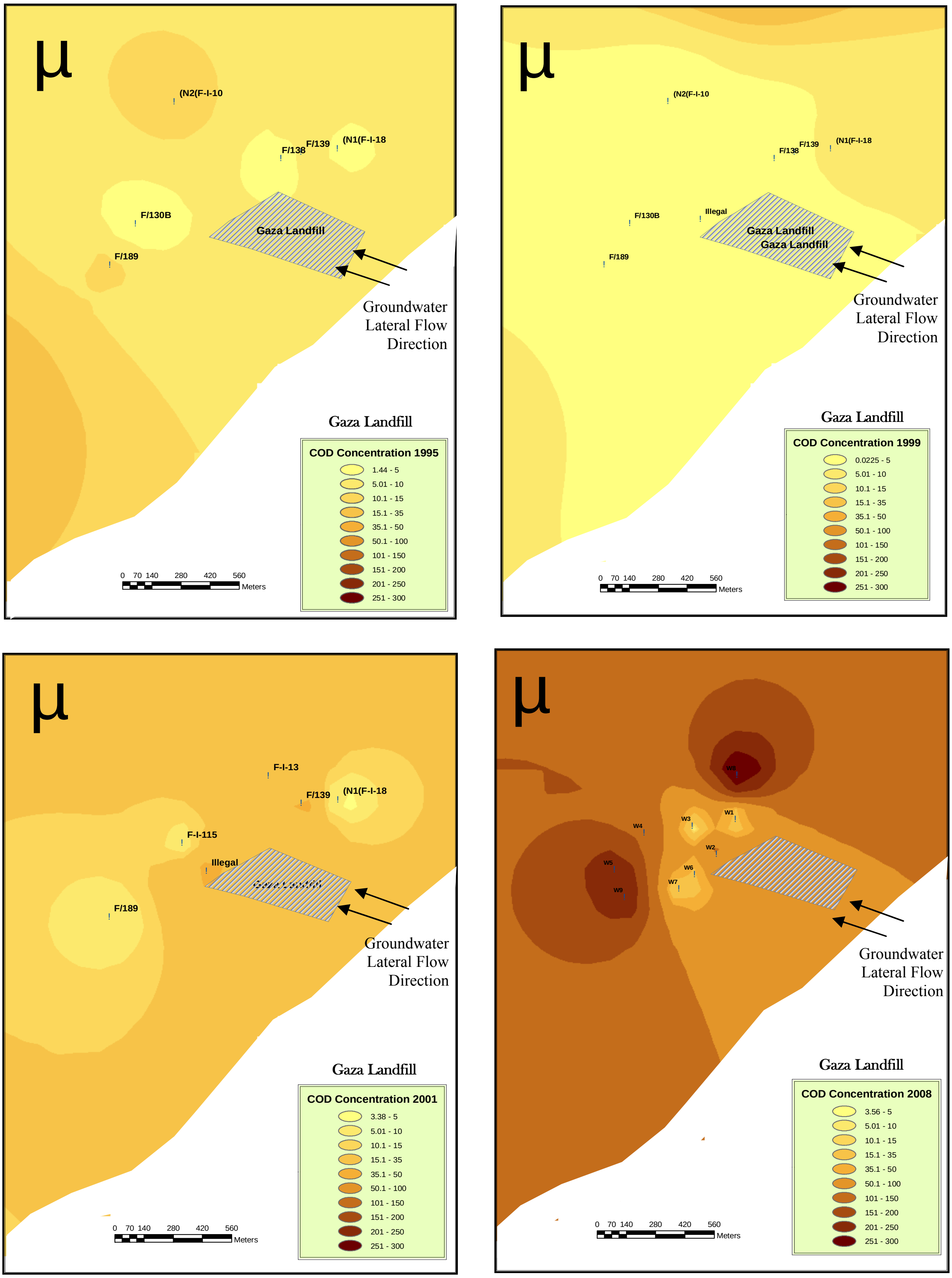

Figure 5.24: Chemical Oxygen Demand Concentration of Groundwater Wells near the Landfill of Selected Year during Lifespan of Gaza Site

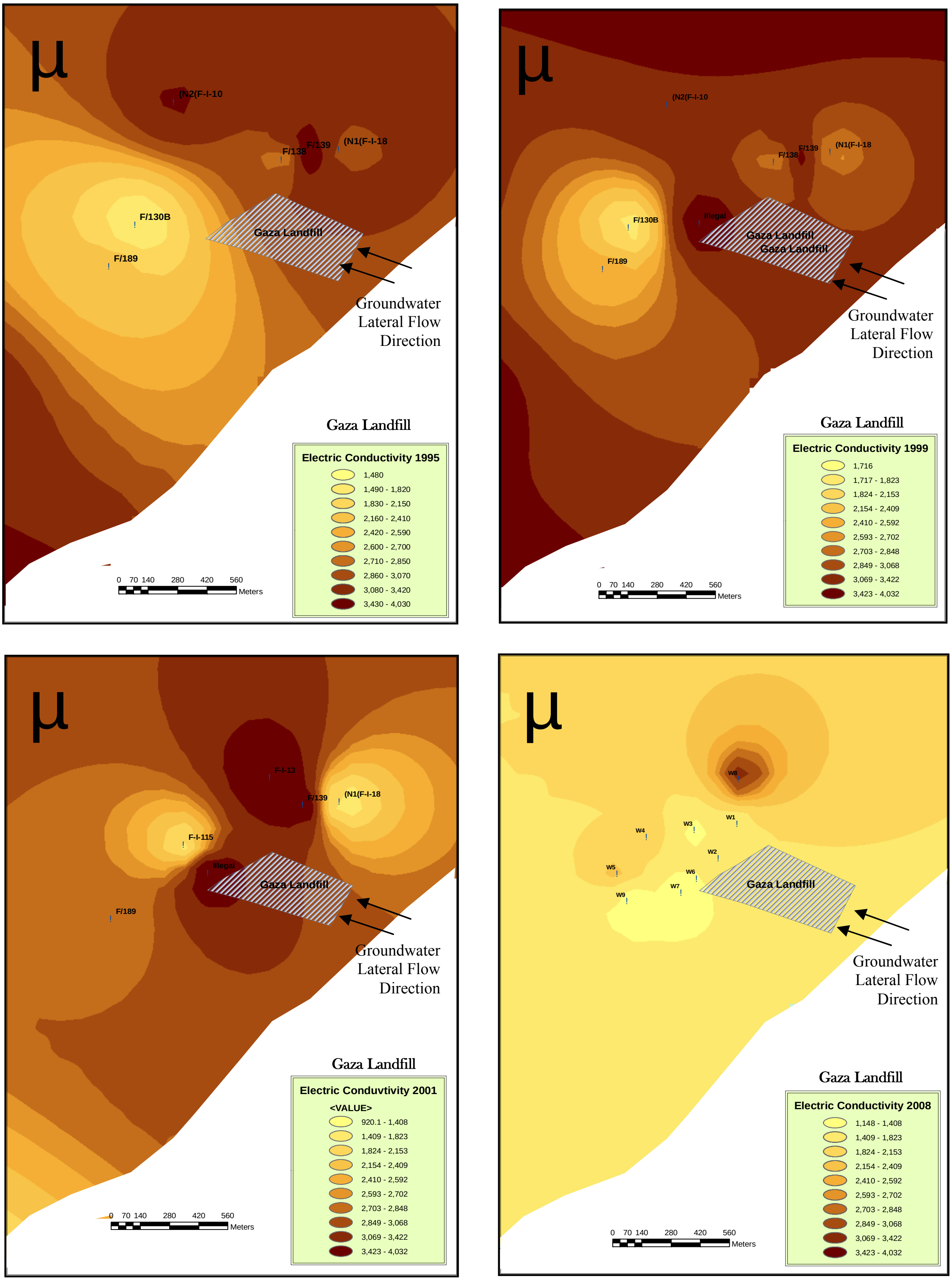

Figure 5.25: Electric Conductivity Concentration of Groundwater Wells near the Landfill of Selected Year during Lifespan of Gaza Site

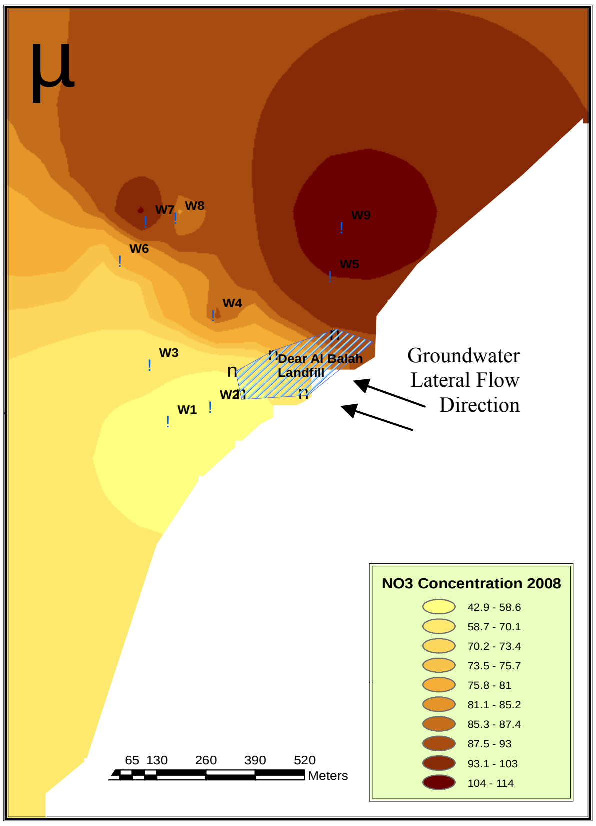

Figure 5.26: Nitrate Concentration of Groundwater Wells near the Dear Al Balah Site

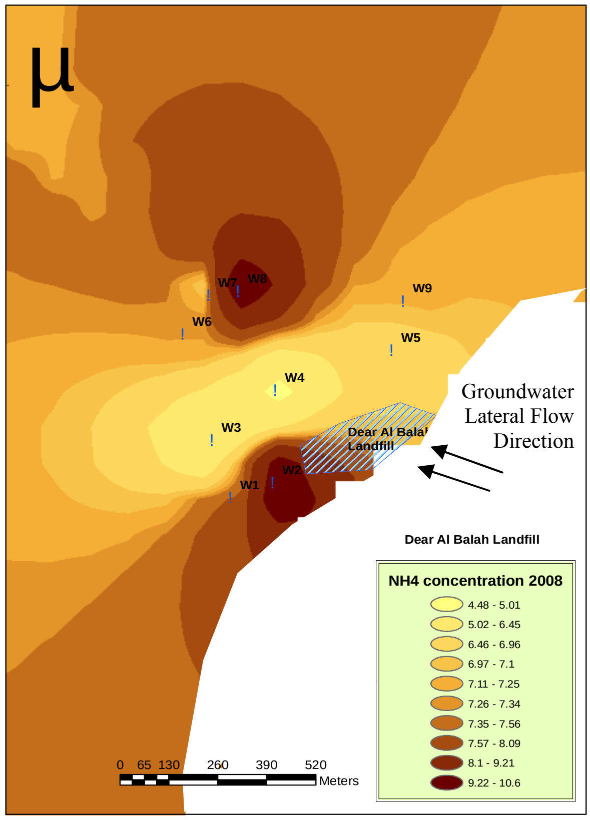

Figure 5.27: Ammonium Concentration of Groundwater Wells near the Dear Al Balah Site

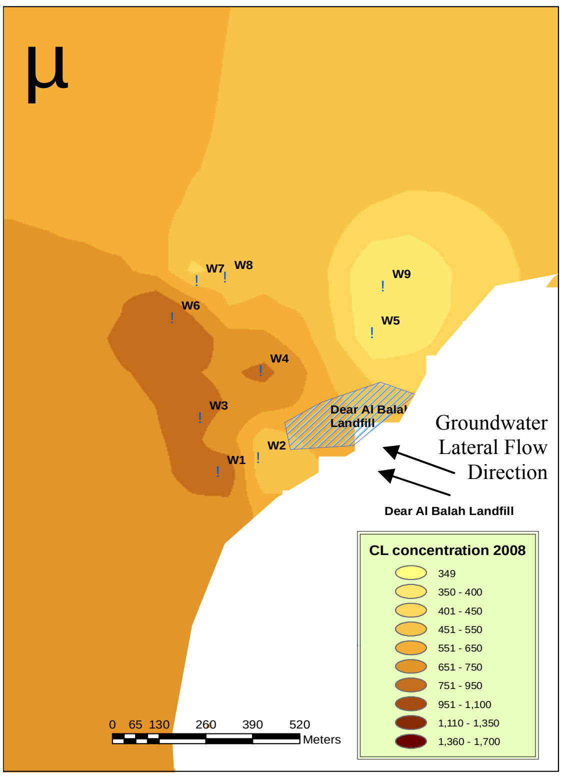

Figure 5.28: Chloride concentration of Groundwater Wells near the Dear Al Balah Site

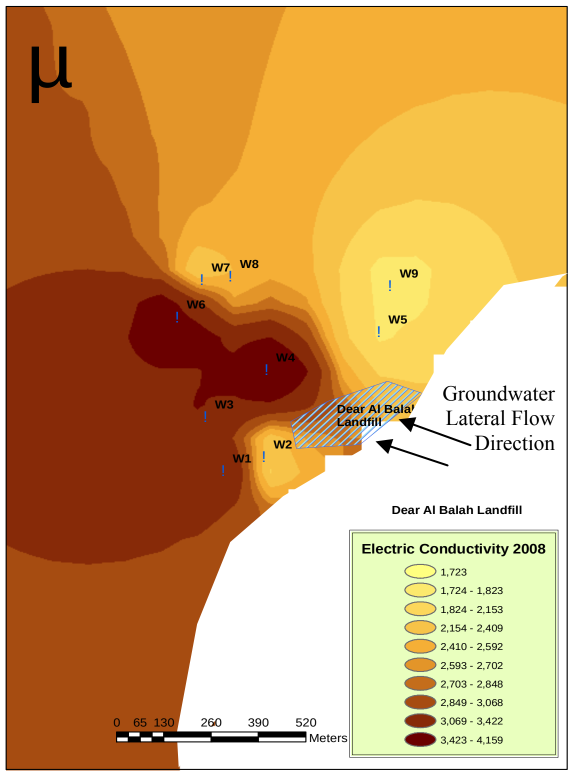

Figure 5.29: Electric Conductivity level of Groundwater Wells near the Dear Al Balah Site

CHAPTER (6): DISCUSSION

Chapter 6 discusses the finding results where main factors affecting leachate quantity and quality are evaluated. In addition, impacts of leachate on groundwater quality in the two investigated sites, Gaza and Dear Al Balah are assessed.

6.1 Evaluation of Leachate Water Quantity

The measured and estimated quantities of leachate are compared in the light of the used methods, metrological conditions, and site preparation and operation aspects of Gaza and Dear Al Balah landfills. Statistical analysis of the results of the used methods is a helpful tool to compare and evaluate the degree of relationship between the results of the two methods. Correlation coefficient R is used to describe the relation.

6.1.1 Comparison between HELP Model and Water Balance Method

HELP model and Water Balance method shows a strong correlation for estimating the annual and cumulative annual leachates where R ranges between 0.868 to 0.994. Table 6.1 summarizes the main statistical correlation values between both methods in Dear Al-Balah and Gaza Sties for the two scenarios.

Table 6.1: Correlation between HELP Model & Water Balance Method for Annual / Cumulative Leachate Volume Generated

	Dear Al Balah		Gaza			
			First scenario		Second scenario	
	Annual Leachate	Cumulative Leachate	Annual Leachate	Cumulative Leachate	Annual Leachate	Cumulative Leachate
Correlation R	0.896	0.994	0.868	0.986	0.977	0.981

Figure 6.1 shows that there is a strong correlation between results of the cumulative annual leachate estimated by HELP model and Water Balance Method of Dear Al Balah. The correlation coefficient for this case is computed as R=0.994.

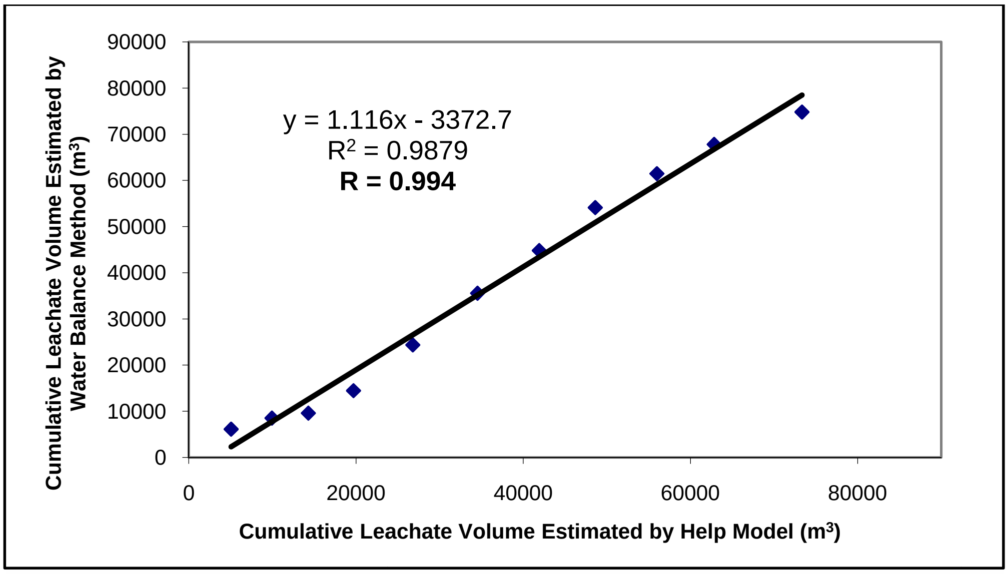

Figure 6.1: Regression between HELP Model & Water Balance Method for Cumulative Leachate Volume Generated at Dear Al Balah Landfill

The first scenario of Gaza landfill shows a strong correlation between the two methods for estimating the cumulative annual leachate (R= 0.986) and it is also shown in figure 6.2. In addition, figure 6.3 shows the strong correlation for the second scenario of Gaza landfill for cumulative annual leachate generated.

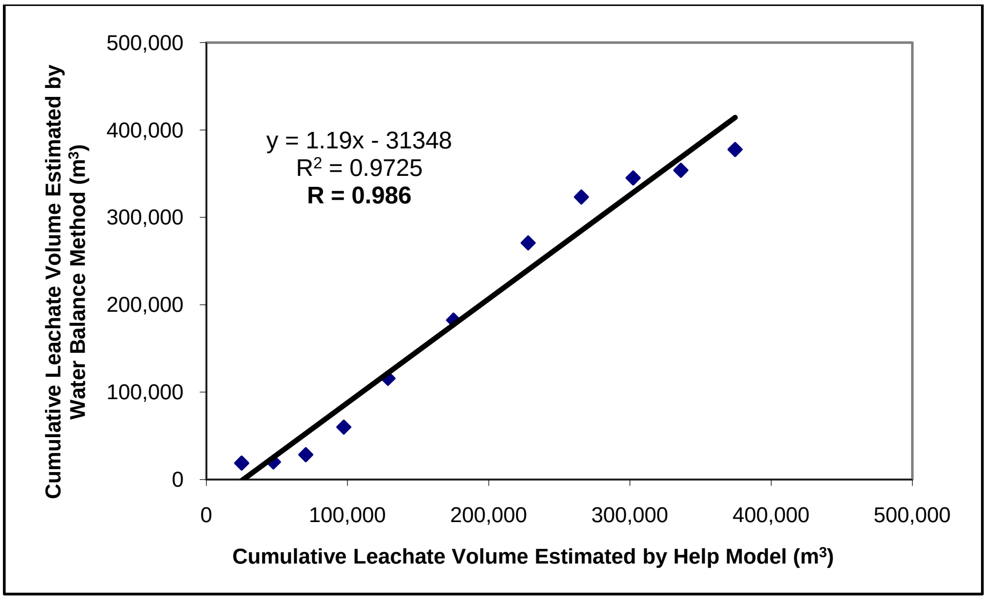

Figure 6.2: Regression between HELP Model & Water Balance Method for Cumulative Leachate Volume Generated at Gaza Landfill (First Scenario)

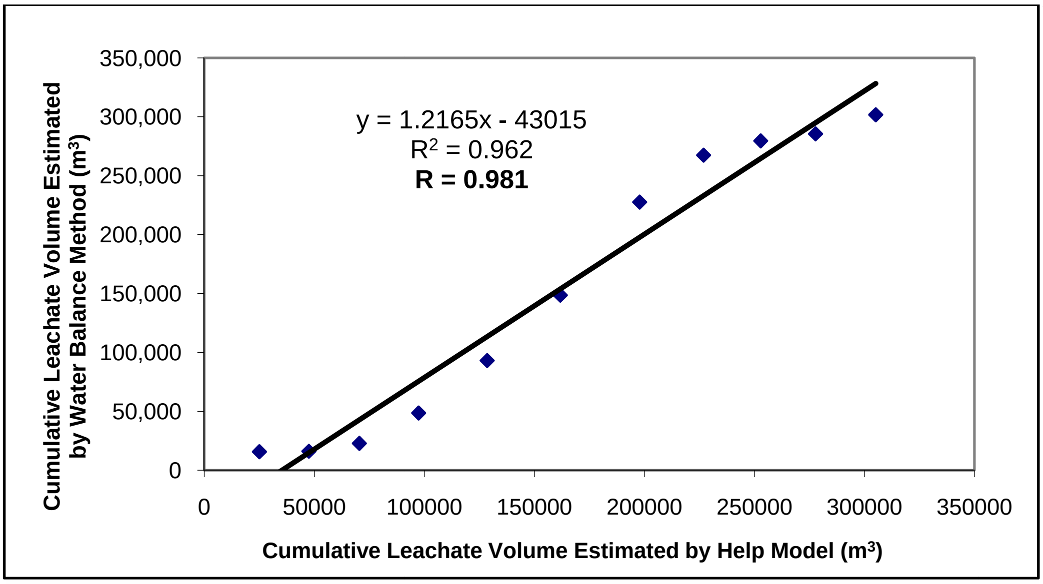

Figure 6.3: Regression between Model & Water Balance Method for Cumulative Annual Leachate Volume Generated at Gaza Landfill (Second Scenario)

The sensitivity analysis is another tool which studies the variation (uncertainty) in the output of a mathematical model and be apportioned, qualitatively or quantitatively to different sources of variation in the input of a model (Breierova and Choudhari, 1996). The aim of the sensitivity analysis is to present the sensitive parameters which influence the results of the simulation process. Figure 6.4 shows that the relation between precipitation and generated annual leachate volume by HELP model and Water Balance method during the period of simulation from 1997 to 2007 at Dear Al Balah landfill is very close. In addition, figure 6.4 reflects that the behavior of the generated quantity of annual leachate follows the same trend of annual rate of precipitation.

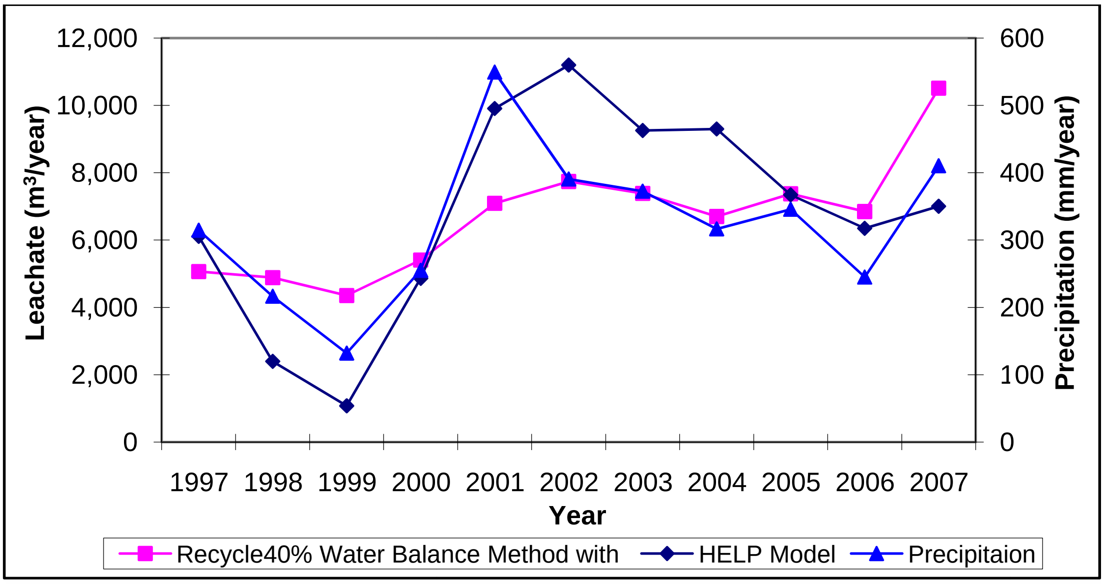

Figure 6.4: Relation between Annual Leachate Volume Generated and precipitation during the period of Simulation at Dear Al Balah Landfill

Comparison between the findings by HELP model and Water Balance Method at Gaza Landfill for the first and second scenarios were presented in figure 6.5 and 6.6 respectively. The two figures illustrates that both methods for quantifying the leachate quantity shows close results in the studied landfills.

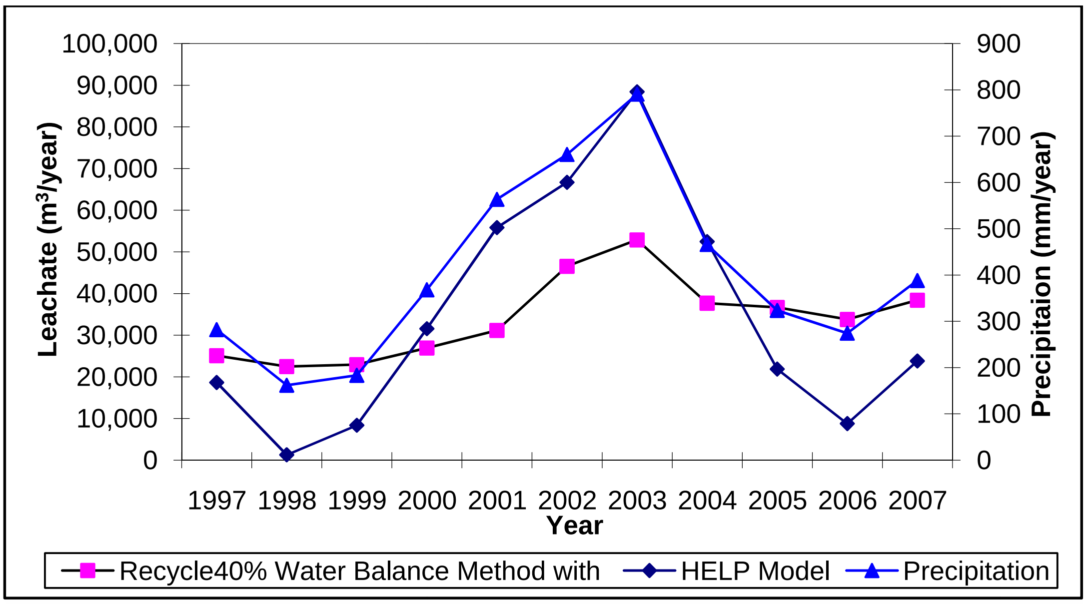

Figure 6.5: Relation between Annual Leachate Volume Generated and precipitation during the period of Simulation at Gaza Landfill (First Scenario)

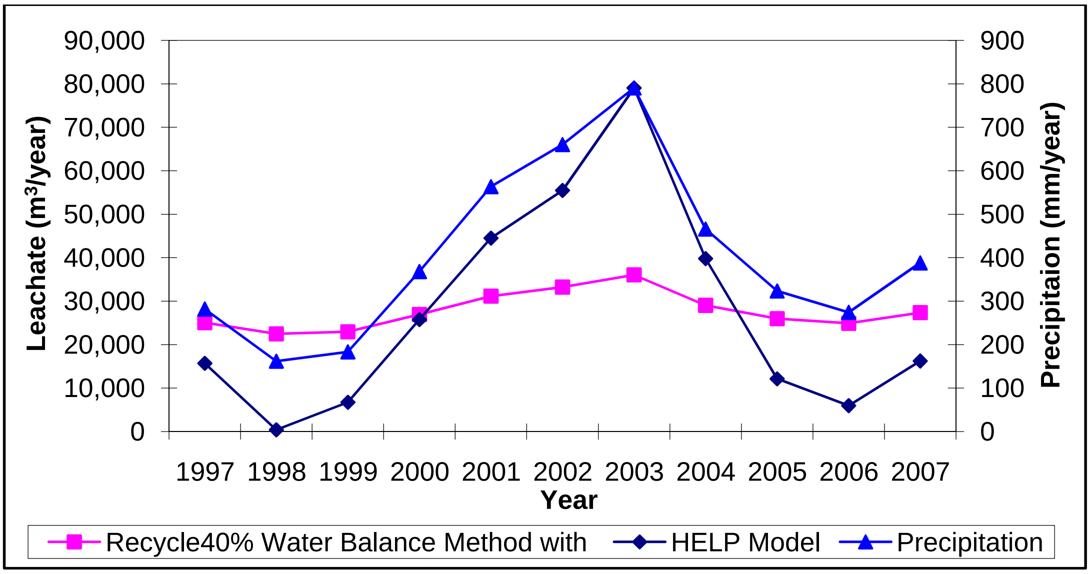

Figure 6.6: Relation between Annual Leachate Volume Generated and precipitation during the period of Simulation at Gaza Landfill (**Second Scenario**)

6.1.2 Comparison between the Estimated and the Measured Leachate Volume

According to the results shown in chapter 5, there is a gap between estimated and measured leachate volumes in Dear Al Balah site as shown in figure 5.5. This gab might refer to:

1. There is a quantity of leachate percolates throw the lining system to the groundwater. This has been estimated using the HELP model and shown in figure 5.2.
2. There is an error in the measured leachate volume. This error is caused by the absence of leachate measuring device. Accordingly, landfill administration in Dear Al Balah reverted to quantify the leachate volume using primitive techniques and re-circulation.
3. There is accumulated quantity of leachate absorbed inside the landfill.

Therefore, leachate volume data attained from landfill administration is lower than actual. However, the gap between leachate volume measured and the estimated by HELP model and Water Balance method decreased as the landfill reached stabilization level in 2007 (end year of expected life span) and the deference became irrelevant in this year.

In Gaza landfill, there were no field measurements. According to the results obtained from estimated tools, the average annual leachate volume generated in Gaza landfill is around three times of that from Dear Al Balah landfill. This large difference is due to:

1. The area of Gaza landfill is three times as large Dear Al Balah landfill area.
2. Average annual rainfall level in Gaza landfill is approximately exceeds the rainfall in Dear Al Balah with an amount of 83.14 mm.
3. The average annual solid waste accumulated in Gaza landfill was about 474,500 ton while it is about 89,790 ton accumulated at Dear Al Balah landfill. Thus, Gaza landfill has five times more annual solid waste accumulation than that Dear Al Balah landfill has.

6.1.3 Analysis of landfill components

The analysis of landfill components of each landfill was. For example, weather conditions, soil profile, waste depth, landfill area, lining system and re-circulation system was carried out to study their effects on the quantity of leachate percolated to the groundwater. Weather conditions include several parameters such as precipitation, temperature, solar radiation, relative humidity and wind speed. Since both landfills locations are of very close, approximately most of weather conditions (temperature, solar radiation, relative humidity and wind speed) are identical, thus these parameters do not have real effects on the estimated leachate volume. The only exception was rainfall level. Since soil profile in two sites are identical, it effect can be neutralize.

1. Lining system

To study the effects of lining system, it is necessary to fix other components such as rainfall level, landfill area and waste depth. Two scenarios are applied at Gaza landfill to study the effect of lining system on the cumulative quantity of percolated leachate to groundwater. First, assuming it has a lining system similar to Dear Al Balah landfill and the second, by applying the existing situation without lining system.

It was estimated that a reduction of about 87% of percolated leachate to the groundwater (from about 192,000 m^3 as per current status to about 24,000 m^3 assuming lining system). It is important to stress that in the absence of lining system, about 51% of the total cumulative leachate percolated to the groundwater while in the presence of lining system, the percolated leachate volume was 6.5% of the total cumulative quantities as shown in figure 6.7. To this end, it is assumed that the existing of suitable lining system will enhance the reduction of percolation of the leachate volume up to 87 %, as shown in figure 6.8.

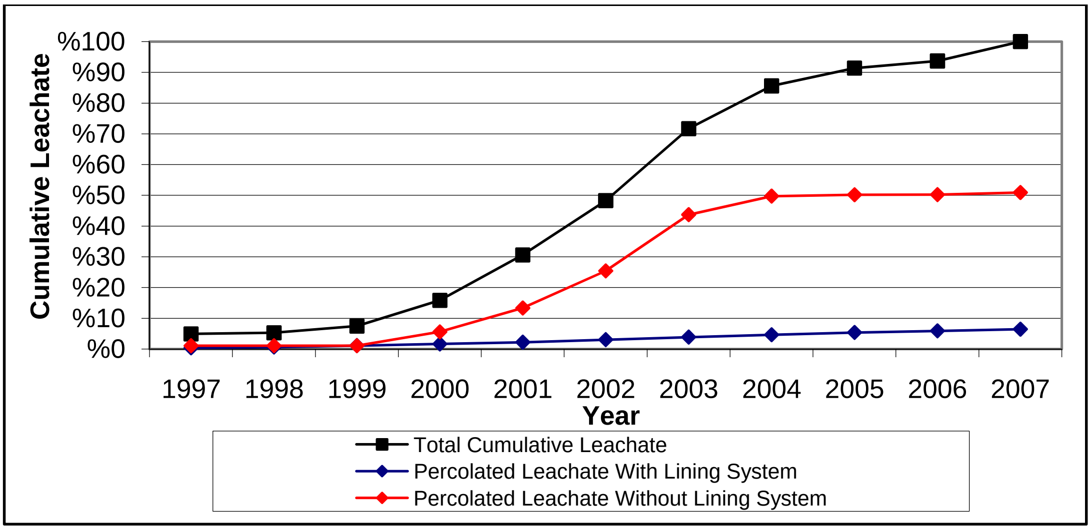

Figure 6.7: Effect of Lining System on Cumulative Annual Leachate Volume Accumulated & Percolated at Gaza Landfill

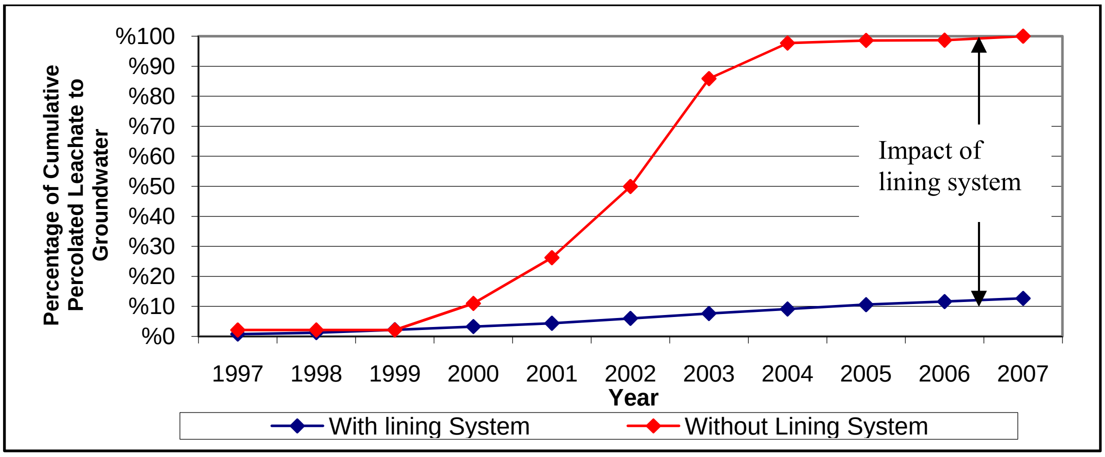

Figure 6.8: Percentage of Cumulative Annual Leachate Volume Percolated at Gaza Landfill

2. Rainfall Level

Rainfall level component was studied for Gaza landfill based on two scenarios. First, by applying the actual rainfall level at Gaza landfill (405 mm/year) and keeping other components unchanged. The second scenario, by assuming a set of rainfall levels (322 mm/year as an average of Dear Al Balah site). This imposed a reduction of rainfall by 30%.

The rainfall level is a major component that affects the quantity of percolated leachate to groundwater. As presented in figure 6.9, the 30% reduction of existing rainfall level resulted in 50% reduction of the percolated leachate to groundwater. In addition, figure 6.9 shows that the increase of rainfall results in increasing the percolated leachate to groundwater, for example, the average rainfall levels in the period 1997-1999 was higher than the actual by 5.4% and accordingly, the cumulative percolated leachate was higher by 4.3%. In the last six years of the simulation period (2001-2007) the average actual rainfall level was higher than the assumed level by 28 % and accordingly, the cumulative percolated leachate was higher by 49.5%.

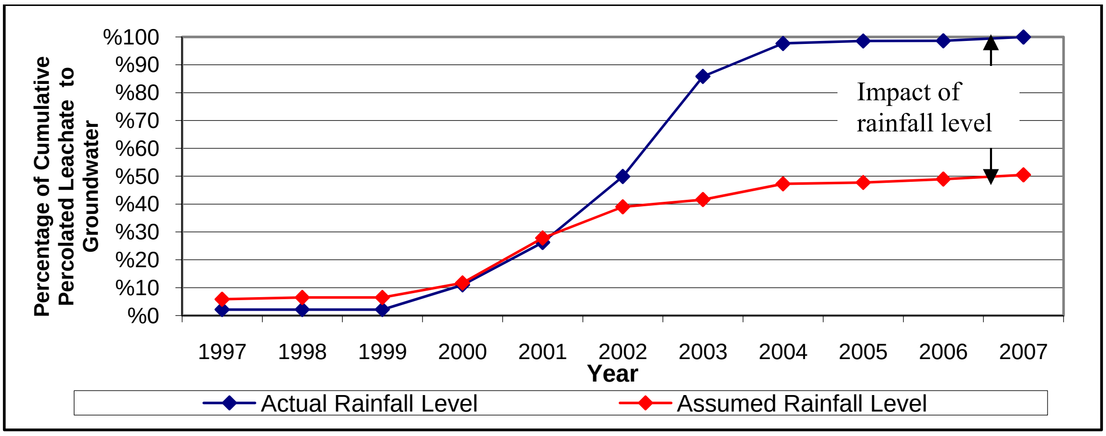

Figure 6.9: Effects of Rainfall level on Percentage of Cumulative Annual Leachate Volume Percolated

3. Landfill Area

The landfill area is an important component that affects the quantity of accumulated leachate and percolated to groundwater. Two scenarios applied for Gaza landfill to study the effect of landfill area on the cumulative quantity of leachate percolated to groundwater. First, by applying the actual area of Gaza landfill (200,000 m^2). The second scenario assumed that Gaza landfill area is the same area of Dear Al Balah that has a total area of 60,000 m^2. The other components were kept unchanged during the simulation.

The cumulative annual quantity of percolated leachate to the groundwater of the assumed area was about 30 % of the quantity of percolated leachate of the actual area. This yields that any reduction in area will reduce percolated leachate volume by similar percentage, as shown in figure 6.10, for instance, about 50% reduction of existing landfill area results in reduction of the percolated leachate by 50%.

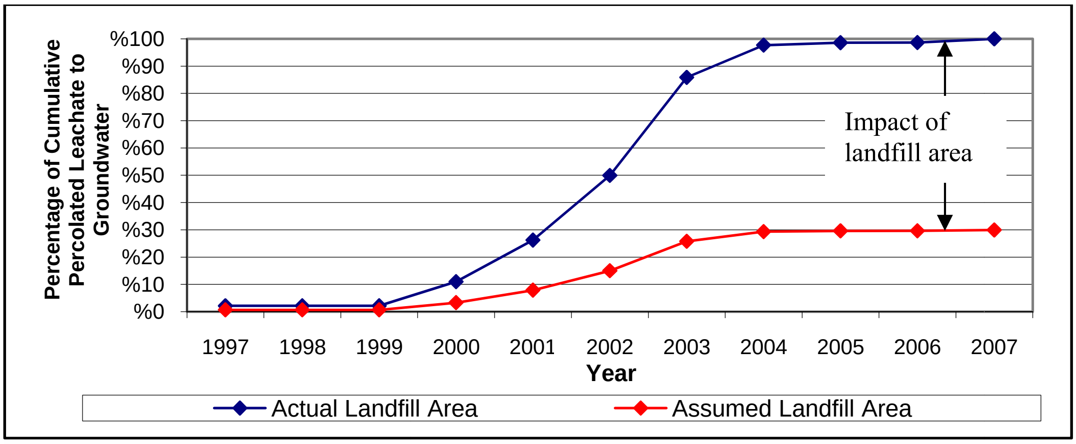

Figure 6.10: Effect of Landfill Area on Percentage of Cumulative Annual Leachate Volume Percolated.

4. Waste Depth

Waste depth component was studied for Gaza landfill based on two scenarios. First by applying the actual depth of waste at Gaza landfill (26 m) and the second by assuming the depth of waste in Dear Al Balah site (6 m). The other components were kept unchanged as given by Gaza site without lining.

As shown in figure 6.11, it was found that the results were almost identical and there was no significant change of the cumulative percolated leachate by variation of waste depth from 26 m in the actual (6,524,375 m^3 / 200 $\times 10^3$ m^2) to the assumed 6 m as in Dear Al Balah site (1,234,625 m^3 / 200 $\times 10^3$ m^2) .

Therefore, the results show that the waste depth has no significant effect on the quantity of cumulative percolated leachate.

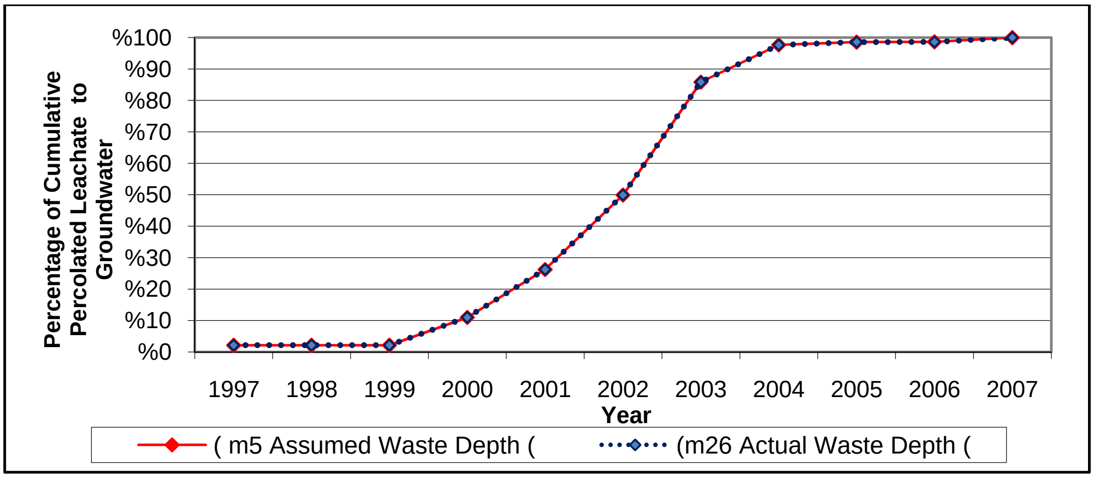

Figure 6.11: Effects of Waste Depth on Percentage of Cumulative Annual Leachate Volume Percolated.

5. Leachate Recirculation System

The results of leachate quantities estimated by the study methods in Dear Al Balah site showed, with 40% leachate recirculation and without recirculation, resulted in a slight increase of annual average leachate was observed . This can be explained and connected to the climate condition of the area (semiarid) with high evaporation rate. For Gaza landfill, with 40% recirculation and without recirculation showed the same trend as shown in figure 6.12. However, the effect of estimated recirculation of 40% in Gaza site with high quantities of leached showed relatively higher effects than that in Dear Al Balah site.

Therefore, the total quantity and the recirculation percentage should carefully be weighted in selection of leachate treatment. The potential evaporation area should also be considered. A previous experience in USA showed that recalculating leachate over waste in landfills led to increase the quantity (by nearly a factor of 10) and quality of methane gas for recovery as well as possibly reduce the concentration of contaminants in leachate and enhance the settling of the waste (Jaber and Nassar, 2007).

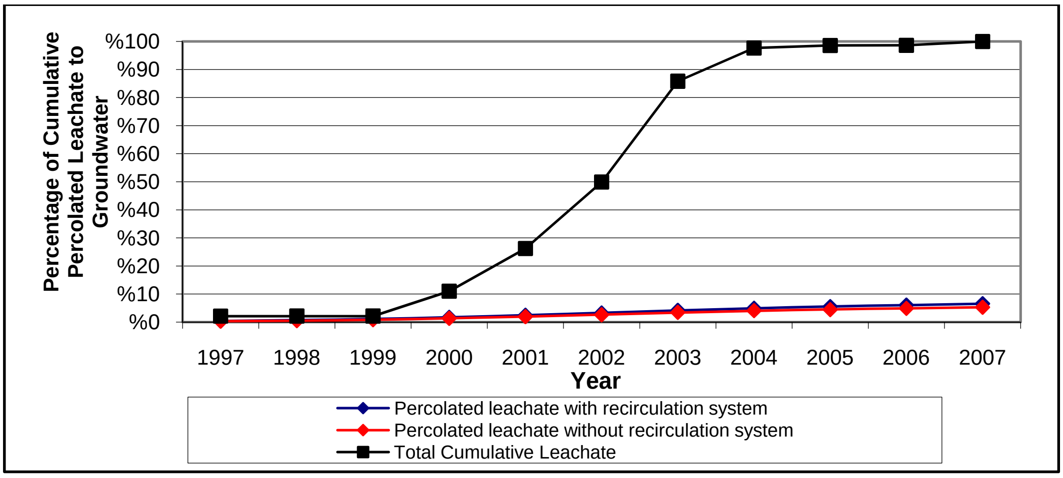

Figure 6.12: Effects of Recirculation of leachate on Cumulative Annual Leachate Volume Percolated at Gaza Landfill

6.2 Evaluation of Leachate Water Quality

Leachate is generated by the degradation of waste and the process of water coming into contact with, and filtering through, waste materials. Leachate varies in its chemical composition from site to site, and is dependent upon numerous factors such as waste composition, ambient temperatures and rainfall characteristics. However, leachate may have elevated concentrations of numerous organic and inorganic pollutants (Jaber and Nassar, 2007).

The pH values of the leachate ranged between 8.3 and 8.4. These alkaline values were expected since the landfill is an old one. The pH of the leachate is increasing with the landfill age (Abu-Rukah and Al-Kofahi, 2001). These values indicated that the biochemical activity in the Gaza and Dear Al Balah landfills body was as in its final stage and the organic load was biologically stabilized. During the initial stage the pH values were quite low due to acid formation but during the methanogenic stage the pH was mainly in the alkaline region. The conductivity values ranged within levels that are reported in the previous years with the values being in the range of 32,200 - 45,500 µs/cm. These high values can be attributed to the high levels of the various anions.

The BOD_5/COD ratio decreased from 0.71 to 0.02 from 1997 to 2008 at Gaza landfill, while it decreased from 0.28 to 0.017 from 1997 to 2008 at Dear Al Balah landfill, in good agreement with the ratio obtained by others (Frascari et al., 2003: from 0.5 to 0.18

in 9 years; a Chen and Bowerman, 1974: from 0.47 to 0.04 in 23 years; Lo, 1996: from 0.3 to 0.1 in 22 years); the decrease of the BOD/COD ratio reflects a decrease in biodegradability of the leachate and can be ascribed to the biodegradation processes occurring in the landfill. The BOD_5 value of the leachate was 887 mg/l at Gaza landfill and 800 mg/l at Dear Al Balah landfill. The concentrations of COD exhibited a range of values between 45,500 and 46,500 mg/l. A very interesting observation was the low BOD_5/COD ratio (0.017–0.02) which indicated that the majority of the present organic compounds are not biodegradable. This is in agreement with Fatta, that usually for landfills older than 10–15 years the BOD_5/COD ratio is lower than 0.1 (Fatta et al., 1999). The differentiation that was observed for the landfills under study, which have been operating since 1987, is mainly due to the high quantities of organic material that are disposed since municipal waste contains about 60-70% organics (Jaber and Nassar, 2007). Another important parameter that contributes to this differentiation is the time hysteresis of the initiation of the biological processes in the landfill body due to the high concentration of cadmium (Cd) which consider a toxic material to microorganisms and cause degradation and low concentration of BOD_5.

The nitrate was considered to be in high concentration 325 mg/l at Gaza landfill and 440 mg/l at Dear Al Balah landfill. The nitrate concentration in Dear Al Balah leachate was higher than in Gaza this may be due to leachate recirculation at Dear Al Balah landfill. These high concentrations could be considered a very danger source of pollution due to nitrate is a conservative contaminant and is not affected either by the biochemical processes taking place in the landfill body or by the natural decontamination reactions in which the leachate is involved during their penetration in the vadose zone (Fatta et al., 1999).

The ammonia was considered to be in high concentration 2045 mg/l at Gaza landfill and 3473 mg/L at Dear Al Balah landfill, due to the anaerobic conditions that prevailed in the landfill which in return contributed to nitrate reduction towards ammonia gas phase. These high concentrations are very toxic to the microorganisms that are responsible for the anaerobic processes. Consequently, the high level ammonia inhibits their growth and activity.

The metals examined in this study were cadmium (Cd), copper (Cu), iron (Fe), lead (Pb) and zinc (Zn). Generally, the concentrations of the metals (except Zn, 65.5 mg/L) were not detected at Gaza leachate while (except Cd, 22.5 and Zn, 64 mg/L) at Dear Al Balah leachate, which were at high levels. This is due to the fact that the landfills received mainly municipal solid waste and very low quantities of industrial waste including batteries, radios and TV sets.

6.3 Effects on Groundwater Quality

The importance of determining adverse effects of various elements reach groundwater through leachate upon human health has gained momentum during the past decade. The different approaches presume that, a sound scientific data base exists to define the maximum exposure levels for a specific chemical compound (Forstner and Wittman, 1983). In this study, the pollutant indicators results obtained from groundwater monitoring program of the observation wells around both Dear Al Balah and Gaza landfills and the GIS were used to study the effects of landfills on groundwater.

6.3.1 Results of Monitoring Wells

The high electrical conductivity (EC) measurements values in the underground water near the landfills are indications of its effect on groundwater. At all sites EC values were above the WHO suggested levels (400µs/cm). According to (Abu-Rukah and Al-Kofahi, 2001) water conductivity within 1000 µs/cm is suitable for irrigation purpose. It is important to note that the electric conductivity of the groundwater under Gaza landfill in year 2008 was lower than in years 1995, 1999 and 2001 but remaining above suggested levels, as shown in figure 5.25. This could be connected with low abstraction water quantity near the green line borders in the last two years due to security reason In addition; the east west groundwater lateral flow direction will have positive effect on groundwater quality.

For all wells located around Gaza and Dear Al Balah landfills BOD_5 values were not detected except at wells W_1 and W_9 which were 10 mg/l. According to Greek legislation the water are suitable for irrigation, since the BOD_5 values are below the suggested limit of 40 mg/l. COD values for Gaza landfill which closed to landfill site and located in the downstream of lateral flow direction, as shown in figure 5.24 were high. It is quite evident that the groundwater is affected by the Gaza landfill leachate. COD values for Dear Al Balah landfill showed the same trend, as shown in table 5.9. It is quite evident that the groundwater is affected by the Dear Al Balah landfill leachate.

The major anions tested in the present study are Chloride (Cl^-), Ammonia (NH_4), and Nitrate (NO_3^{-2}). (Faust and Aly, 1983) illustrated that Chloride in reasonable concentration is not harmful, but it causes corrosion in concentrations above 250 mg/l, while about 400 mg/l it causes a salty taste in water. Chloride concentration was measured, and the range is acceptable according to those permissible by Palestinian Standards (500 mg/L) except W_8 which is 720 mg/L. The concentration values approached levels above those permitted by US Environmental Protection Agency (EPA) standards, i.e. 250 mg/L. High concentration of Chloride in the groundwater at W_8. Since this well is far from the Gaza landfill, the identified Chloride levels, as shown in figure 5.22, may be caused by other source. While Chloride values around Dear Al Balah landfill ranged between 355 and 1004 mg/l, with the highest values measured at wells W_1, W_3 W_4 and W_6 which are closed to Dear Al Balah landfill and located in the downstream of lateral flow direction, as shown in figure 5.28. While wells $W_{5,}$ $W_{7,}$ W_8 and W_9 which are located in the northwest direction of the landfill gave lower Chloride level values. It is quite evident that the groundwater is affected by the Dear Al Balah landfill leachate.

Nitrate is a conservative contaminant and is not affected either by the biochemical processes taking place in the landfill body or by the natural decontamination reactions in which the leachate is involved during their penetration in the vadose zone. Therefore the Nitrate constitutes is a serious threat for the aquifer of the area, since their concentrations fluctuated between relatively normal levels to high levels (28–92 mg/L) for Gaza Landfill. The average permissible concentrate is 70 mg/l for Palestinian Standards whiles the average permissible concentrate is 50 mg/l by WHO standard. The highest values of Nitrate concentration were found at the wells W_2, W_3, W_4, W_6, W_7 and W_9 which closed to Gaza landfill at the downstream side, as plotted in figure 5.21. While at Dear Al Balah landfill the highest values of Nitrate concentration were found at the wells W_5, W_7, and W_9 which are located far away from the landfill and in the northwest direction, as plotted in figure 5.26. These high Nitrate values measured in the underground water relatively remote from the Dear Al Balah landfill. The agriculture practice in the Dear Al Balah area could be the source of Nitrate pollution.

Natural levels in groundwater are usually below 0.2 mg of Ammonia per liter according to EPA standard. The Ammonia was considered to be in high concentration and ranged between 3.54 and 8.12 mg/L in groundwater wells near Gaza landfill. Sampling wells W_1 ,W_2 ,W_6 and W_7, though more closer, were less polluted than wells W_3, W_5, W_8 and W_9 which is remote from the landfill. This could be connected with Ammonia transfer to Nitrate and the leachate movement, as plotted in figure 5.23. While at Dear Al Balah ammonia was considered to be in high concentration and ranged between 4.48 and 11.2 mg/l in water wells near Dear Al Balah landfill. Sampling wells W_1 and W_2, which are closed to Gaza landfill at the downstream side, were more polluted than wells W_3, W_4, W_5, W_6 and W_9 which is remote from the landfill. It is important to note that, the concentration of Ammonia in year 2008 was higher than that in years 1995, 1999 and 2001. Thus, it is quite evident that the groundwater is affected by the landfill leachate. Agricultural source is not excluded to be other important source for high ammonia values measured in the monitored wells. The wells W_7 and W_8 which remote from the landfill is an indication of possible effect by other source of Ammonia like fertilizers, as plotted in figure 5.27.

The metals examined in this study were Cadmium (Cd), Copper (Cu), Iron (Fe), Lead (Pb) and Zinc (Zn). Generally, the metals concentrations in the examined wells were not detected except Zn at Gaza landfill while Cd and Zn at Dear Al Balah landfill which were at low levels. This is due to the fact that the landfill receives mainly municipal solid waste and very low quantities of industrial waste.

The metals Lead, Cadmium, Chromium and Nickel are characterized as toxic according to EPA standards. At Gaza landfill, Cadmium and Lead were not detected. While at Dear Al Balah landfill, Lead were not detected although Cadmium has higher concentrations than the limiting value of 0.005 mg/l according to EPA standards in sampling wells 2, 3 and 4, which are located closer to the landfill. The wells 6 and 7, which are more remote, were less polluted. This could be connected with infiltration of leachate. Zinc concentration of all the sampling wells around Gaza and Dear Al Balah landfill were at acceptable levels and the average values less than the limiting value of 5 mg/l according to EPA standards. The range of zinc concentration around Gaza site was between 0.091 and 0.229 mg/l while was between 0.107 and 0.185 mg/l around Dear Al Balah site.

6.3.2 Later Flow and GIS

GIS was used as a tool to simplify the presentation of collected results. It helps to study the groundwater flow and transfer direction under the landfill surrounding area. Defining the groundwater flow direction made it possible to interpret the geochemical characteristics of the leachate plume as it moved down-gradient from the landfill source. The initial moisture content of the unsaturated zone is below the field capacity, so that during the early stages drainage and potential leakage is limited to localized channeling. Water from infiltration gradually builds up the moisture content of the unsaturated zone, until the general effects of gravity are felt. Eventually, leachate builds up until an approximate hydrologic balance is reached in which average outflow equals average infiltration, and leachate levels stabilize.

Generally, lateral flow direction in Gaza Strip is from east to west but local flow direction affected by the number of wells and its location in the area and the quantity of water consumption. Figure 5.21 shows that, at Gaza site in 1995 the groundwater under the landfill was polluted with Nitrate in a small plume area located in the north direction of landfill and the plumed area was grow gradually through years 1999 and 2001. The local lateral flow direction was to the north direction of the landfill. According to site investigations in that time, there was a group of agricultural wells found in the north side of landfill until 2001with high abstraction level. During Al Aqsa intifada, Israel destroyed the wells in that area and this cause a change in local lateral flow direction from north to west. Thus, in year 2008 the plumed area was became in the west side of landfill. It is important to note that the GIS interpolation of the plumed area showed that it was not speared exactly under the landfill. This is due to the fact that no accessible information is available from east side of landfill since there are no monitoring wells as the landfill located at the boundary line with Israeli side. Accordingly, it is quite evident that the groundwater is affected by Gaza landfill leachate.

Chloride (Cl), Ammonium (NH_4), Chemical Oxygen Demand (COD) and Electric conductivity (EC) are other indicators of pollutants transport which were plotted in figures 5.22, 5.23, 5.24 and 5.25 above for Gaza landfill. These indicators follow up the same behavior of Nitrate indicator for the plumed area direction which mentioned above and that insures the fact, the groundwater is affected by Gaza landfill leachate.

At Dear Al Balah landfill there is no historical data of groundwater samples in years 1995, 1999 and 2001. So, there are no maps generated for these years. However, at year 2008 high concentrations of Nitrate in the groundwater found far away from the landfill in the north direction of landfill and not in the lateral flow direction, as shown in figure 5.26. This could be caused by fertilizers and manure which used intensely in this agricultural area. High concentrations of ammonia in the groundwater found at two points near Dear Al Balah landfill. One of these locations is closed to landfill in southwest direction and the other is far away from the landfill, as shown in figure 5.27. The closed plumed area could be connected with Ammonia leachate from the landfill as it located in the downstream of lateral flow direction. Other source is not excluded as the remote plumed area may be caused by fertilizers and manure. Additional and sufficient investigation using isotopes or markers methods are need to have better conclusions.

High concentrations of Chloride and Electric Conductivity in the groundwater found closed to landfill in southwest direction, as shown in figures 5.28 and 5.29 respectively. Accordingly, it is quite evident that the groundwater is affected by Dear Al Balah landfill leachate but in levels lower than Gaza landfill. This could be due to the fact that the lining and leachate collection system in Dear Al Balah site is better designed.

CHAPTER (7): CONCLUSIONS AND RECOMMENDATIONS

This Chapter is concluding in the first section the main impact findings of landfill leachate on groundwater aquifer in Gaza Strip using modeling approach. The second section summarizes viable recommendation for future landfills planning and operation in the Gaza Strip.

7.1 Conclusions

Solid waste disposal is considered as one of the main environmental problem in Gaza Strip. The appropriate design and operation aspects of landfill in Gaza Strip, such as Dear Al Balah and Gaza landfills, are not well considered to protect the aquifer from contamination by leachate. Estimated annual solid waste generated in Gaza Strip is around 603,000 ton/year. Most of the generated solid waste amount is household waste and is buried in Dear Al Balah and Gaza landfills (about 90,000 ton/year and about 450,000 ton/year respectively). The damped solid waste produce large amount of leachate which contains a host of toxic and carcinogenic chemicals, which is a potential harm to both humans and environment and likely contaminate groundwater. This would adversely affect industrial and agricultural activities that depend on groundwater. The study covered the assessment of two landfills: Dear Al Balah and Gaza landfills located in Gaza and Middle Governorates.

Globally, a great number of researches in recent years were carried out to study the impact of landfill leachate on the surrounding environment but there are limited researches study the impacts of the solid waste landfills on groundwater aquifer in the Gaza Strip. This research used dual-approach in studying landfill leachate water. First approach is groundwater and leachate water quality which consisted of (1) monitoring program which was conducted at landfills of Dear Al Balah and Gaza City. Groundwater samples from multilevel observation wells and leachate water were collected in November 2008, and (2) Geographic Information System (GIS) was used as a tool to simplify the presentation of the analyzed result of the pollutant indicators within 500 m radius around both Dear Al Balah and Gaza landfills in the periods 1995, 1999, 2001 and 2008 respectively. Inverse Distance Weighting (IDW) was used to interpolate unknown points. Second approach is leachate water quantity which consisted of (1) Applying Hydrologic Evaluation of Landfill Performance (HELP) model (2) Applying Water Balance Method and (3) Field measured data to estimate quantity of accumulated landfill leachate and percolated to groundwater aquifer.

The study has considerable results with important outcome which can be summarized in following points:

1- Assessment of Dear Al Balah Landfill

- Application of Hydrologic Evaluation of Landfill Performance (HELP) model showed that yearly leachate from the base of the Dear Al Balah landfill is 35.2% of total precipitation (322 mm).
- Average annual leachate volume percolated through clay layer was 550 m^3 which represents about 8% of generated leachate (6,800.00 m^3).
- COD appeared to be quite high with low BOD_5/COD ratio confirmed the fact that existing landfill is in their last phase. Furthermore, majority of organic matter is not easily biodegradable.

2- Assessment of Gaza landfill

- Yearly leachate volume from the base of the Gaza landfill is 42.4% of total precipitation (405 mm).
- Average annual leachate volume percolated through clay layer was 17,487 m^3 which represents about 50% of generated leachate (34,340.00m^3).
- Clay layer is not efficient to prevent leachate percolation to groundwater aquifer.
- COD appeared to be quite high with low BOD_5/COD ratio confirmed the fact that existing landfill is in their last phase. Furthermore, majority of organic matter is not easily biodegradable.

3- Assessment of groundwater quality status

- Landfill leachate discharged at the sites is a major contributor to the groundwater contamination. The situation is currently bad and is expected to become worse in the near future.
- The increase of the main indicators concentrations; nitrate (NO_3), ammonia (NH_4), chloride (CL), chemical oxygen demand (COD) and electric conductivity (EC) in the downstream side are an evidence of groundwater contamination at the two sites.
- The groundwater under the two landfills is non-potable as most of the examined physical and chemical parameters exceed the permissible limits. In addition, it is not suitable for irrigation since EC is high and the increment concentrations of Chloride. Ultimately all results presented showed that the Dear Al Balah and Gaza landfill constitutes a serious threat to local aquifers.
- The current research showed that the pollution moves towards the southwestern side of both landfills. Furthermore, the study confirmed the fact that the Gaza landfill leachate constitutes a serious threat to the local aquifer more than Dear Al Balah due to the fact that leachate quantity at Gaza landfill was three times greater than Dear Al Balah leachate and the lining system is poorer.

4- The differences between the used methods (advantages and limitations)

- HELP Model and Water Balance Method are useful tools in predicting the leachate discharged from landfills if precise input data are used.
- The results of the water balance obtained were at normal and expected levels.
- Based on the analysis of landfill components using HELP model, the components would be ordered in priority according to their effects on percolated leachate volume through clay layer under the two landfills as follows:
    a. Existence of lining system enhances the reduction of the percolated leachate to 87%.

b. About 30% reduction of rainfall level enhances the percolation reduction up to 50%.
c. About 50% reduction of existing landfill area enhances the percolation reduction up to 50%.
d. The absent of recirculation system slight enhances the percolation reduction up to 2.5% than with the availability of recirculation system.
e. The waste depth has no significant effect on the quantity of percolated leachate.

- HELP Model and Water Balance Method are used huge amount of data such as weather data, waste generation data and filed data to estimate the leachate quantity.
- Precise input data of rainfall level should be used to estimate the amount of leachate by HELP Model because the model is very sensitive to rainfall data.

7.2 Recommendations

Based on the results of this research the recommendations are:

1. Gaza and Dear Al Balah landfills are approaching their capacity and plans should be urgently prepared for future disposal of waste. In absence of such plans and their subsequent implementation, it is likely that existing sites will continue to be used in ways that are unsuitable from both public health and environmental perspectives.

2. Since BOD_5/COD ratio decreased from 0.28 to 0.017 from 1997 to 2008 at Dear Al Balah landfill, which indicates that leachate recycling has become redundant because biodegradation process of leachate is low. Accordingly, it is recommended to stop leachate recycling. However, the absence of proper leachate other treatment facility, recycling stills the only available option to reduce the volume of leachate quantity.

3. New sanitary landfill sites should be designed using proper approved environmental specifications to minimize adverse effects associated with solid waste disposal. Design must include lining system, final cover (cap) and vertical expansion not lateral to minimize water infiltration into the landfill and gas emissions into the environment.

4. In case operating authorities decided to continue operating landfills, mitigation measures should be considered at Gaza and Dear Al Balah landfills to minimize the leachate accumulated and percolated to local aquifer such as final cover (cap) and vertical expansion not lateral to minimize landfill area.

5. Upstream as well as downstream monitoring wells surrounding Dear Al Balah and Gaza landfills should be used to regularly monitor quality of groundwater and to suggest the possible uses of such waters.

6. Further investigation should be made on studied landfills like contaminant transport model to study the pollutant transport through soil layers.

7. In dealing with an unacceptable landfill leachate impact there are limited management options available. They basically come down to the following approaches:
   - *Removal of source term.*
     Source term removal is possible by reduce the amount of leachate being generated. This option is technically more feasible and requires the landfill to be capped with a suitable, low permeability cover in order to reduce infiltration and hence leachate production. There are knock-on engineering effects from this approach which include need for a landfill gas management system, and a system to manage surface runoff from the cap.
   - *Leachate plume management.*
     This could be achieved by defining limit of unacceptable leachate impact through a groundwater monitoring network and definition of a

hazard zone around landfill using appropriate impact and risk assessment models. This zone would be then defined where groundwater abstraction and consumption is unsafe.

- *Waste reduction*

  Recycling and composting of solid waste are often adopted as effected tools in the integrated solid waste management approach. This will enhance reducing amount of waste going to landfill and/or incineration. These technologies in conjunction with waste minimization measures are seen as sustainable option and have been placed in the following hierarchy:

  - Waste reduction
  - Re-use
  - Recycling, composting and energy recovery
  - Disposal to landfill and incineration with no energy recovery.

References

1. Abu Rukah Y., and Al-Kofahi, O. (2001). The assessment of the effect of landfill leachate on ground water quality, a case study El-Akader landfill site – north Jordan. *Journal of Arid Environments*, 49**:** 615 - 630.

2. Akyurek M. (1995). Trends in landfill leachate characteristics. Presented at the Eighteenth International Madison Waste Conference, Department of Engineering Professional Development, Madison.

3. Al Sabahi E., Abdul Rahim S., et al. (2009). The characteristics of leachate and groundwater pollution at municipal solid waste landfill of Ibb City. Yemen. *Science Publications, American Journal of Environmental Sciences*, 5 (3): 256-266.

4. Alslaibi T. and Mogheir Y. (2007). Recent estimations of hydrologic cycle components in Gaza Strip catchment. International conference: sustainable development and management of water in Palestine. Editor: Dr. Amjad Aliewi. Jordan.

5. APHA (1995). Standard methods for the examination of water and wastewater, 20^{th} ed. Washington D.C, *American Public Health Assoc*.

6. ArcGIS Desktop Help (2006). ArcMap version 9.2. ESRI.

7. Bharat J. and Singh S. (2009). Groundwater contamination due to bhalaswa landfill site in New Delhi. International Conference on energy and environment. India, March 19-21, ISSN: 2070-3740.

8. Bou-Zeid E. and El-Fadel M. (2004). Parametric sensitivity analysis of leachate transport simulations at landfills. *Science Direct, Waste Management*, 24: 681–689.

9. Breierova L. and Choudhari M. (1996). An introduction to sensitivity analysis. The Massachusetts Institute of Technology, D-4526-2.

10. Chian E. and DeWalle (1977). Stability of organic matter in landfill leachates. Water Research, 11(2): 159.

11. Debra R. and Caroline J. (1998). Analysis of Florida MSW landfill leachate quality. University of central Florida. Report #97-3, Gainesville, FL 32609.

12. Ehrig H. (1989). Leachate quality in Sanitary Landfilling: Process, Technology, and Environmental Impact. Academic Press, New York. Available online: http://www.leachate.co.uk/html/left_leachate-recirculation.html.

13. Enviros (2006). Leachate recirculation. [Accessed in May. 2009], Available online: http://www.leachate.co.uk/html/left_leachate-recirculation.html.

14. EQA (2002). Office visit.

15. European standards for drinking water (1970). Second edition, *World Health Organization (WHO)*, Geneva.

16. Fatta D., Papadopoulos A. and Loizidou M. (1999). A study on the landfill leachate and its impact on the groundwater quality of the greater area. Athens, Greece. *Kluwer Academic Publishers*, 21**:** 175–190.

17. Faust S. and Aly O. (1983). Chemistry of Water Treatment. *Butterworth Publisher*: Woburn MA, 723p.

18. Forstner U. and Wittman, G. (1983). Metal pollution in the aquatic environment. Heidelberg. *Springer Verlag Berlin*, 486pp.

19. Foth and Van Dyke (2004). Updated research report on bioreactor landfills, landfill leachate recirculation and landfills with methane recovery. Scope ID: 04R004, Ramsey Washington County Resource Recovery Project.

20. Frascari et al., (2004). Long-term characterization, lagoon treatment and migration potential of landfill leachate: a case study in an active Italian landfill. Chemosphere, 54: 335-343.

21. Google earth (2009).

22. GTZ (1996). Solid waste management – Gaza middle area – Landfill design.

23. Heimlich J. (2000). Landfills. [Accessed in May. 2008], Available online: http://ohioline.osu.edu/cd-fact/0111.html.

24. Hughes K., Christy A., and Heimlich J. (2008) Landfill Types and Liner Systems. Ohio State University Extension Fact Sheet CDFS-138-05. Avaiable online: http://ohioline.osu.edu.

25. Jaber A. and Nassar A. (2007). Assessment of solid waste dumpsites in Gaza Strip. Gaza Strip. JICA & EQA.

26. Jagloo K. (2002). Groundwater risk analysis in the vicinity of a landfill, a case study in Mauritius, Royal institute of technology, Stockholm.

27. Jamous K. and Magdalawi M. (2002). Annual report of year 2002. Solid Waste Management Council for Kanunes and Dear Al Balah. Gaza Strip.

28. Jamous K. and Magdalawi M. (2003). Annual report of year 2003. Solid Waste Management Council for Kanunes and Dear Al Balah. Gaza Strip.

29. Jamous K. and Magdalawi M. (2004). Annual report of year 2004. Solid Waste Management Council for Kanunes and Dear Al Balah. Gaza Strip.

30. Jamous K. and Magdalawi M. (2005). Annual report of year 2005. Solid Waste Management Council for Kanunes and Dear Al Balah. Gaza Strip.

31. Jamous K. and Magdalawi M. (2006). Annual report of year 2006. Solid Waste Management Council for Kanunes and Dear Al Balah. Gaza Strip.

32. Jamous K. and Magdalawi M. (2007). Annual report of year 2007. Solid Waste Management Council for Kanunes and Dear Al Balah. Gaza Strip.

33. Jarad A. (2006). Significance of some trace elements in seminal plasma of infertile men in Gaza Strip. Msc Thesis, Islamic University of Gaza.

34. Kerry L., Ann D., and Joe E. Landfill types and liner systems. Ohio State University Extension Fact Sheet CDFS-138-05. Available online: http://ohioline.osu.edu.

35. Khire P. (2006). Field-scale testing og leachate recirculation blankets made up of recycletires. [Accessed in July. 2008], Available online: http://www.egr.msu.edu/cee/research/environmental/.

36. Klinck B. and Stuart M. (1999). Human health risk in relation to landfill leachate quality. Technical report WC/99/17.

37. McBean E., Rovers F. and Farquhar G. (1995). Solid waste landfill engineering and design. Prentice Hall PTR, Englewood Cliffs.

38. National Primary Drinking Water Standards (2003). Office of Water (4606M), EPA 816-F-03-016, [Accessed in Dec. 2007]. Available online: http://www.epa.gov/safewater/contaminants/index.html.

39. National Primary Drinking Water Standards (2008). EPA, Water on Tap, [Accessed in March. 2009]. Available online: http://www.sciencefaircenter.com.

40. Nora K. (2007). Assessment of aeration and leachate recirculation in open cell landfill operation with leachate management strategies. Msc Thesis, Asian Institute of Technology, School of Environment Resources and Development, Thailand.

41. Palestinian Meteorological Office (PMO) (2008). Software data, Gaza, Palestine.

42. Palestinian Standard for Drinking Water (PS) (2000). Gaza, Palestine.

43. Papadopoulou M. and Karatzas G. & Bougioukou G. (2006). Numerical modelling of the environmental impact of landfill leachate leakage on groundwater quality – a field application. Greece.

44. Qasim S. and Chiang W. (1994). Sanitary Landfill Leachate. *Technomic Publishing Company*, Lancaster.

45. Qrenawi I. (2006). Environmental and health risk assessment of Al-akaider landfill. Msc Thesis, Jordan University of Science and Technology.

46. Repa .E (2008). Characterizing municipal solid waste landfill leachate. *A publication of the environmental research and education foundation*. Volume 6, Issue 2.

47. Rojas J. and David S. (2007). Modeling of potential leachate contamination and pump-and-treat remediation of the Payatas dumpsite. Msc Thesis, Payatas.

48. Schroeder P., Lloyd C., Zappi P. (1994). The Hydrologic Evaluation of Landfill Performance (Help) Model, User's Guide for Version 3. Environmental Laboratory, U.S. Army Corps of Engineers.

49. Smith, Blunt, et al. (2000). Assessing the disposal of wastes containing NORM in nonhazardous waste landfills. United States.

50. Sabahi S. et al. (2009). The characteristics of leachate and groundwater pollution at municipal solid waste landfill of Ibb City, Yemen .Science Publications. American Journal of Environmental Sciences 5 (3): 256-266, 2009.

51. Telemachus K. and Georgia K. (2002). Evaluation of leachate emission – mid auchencarroch experimental project. Department of Topography - Surveying Engineering, Greece.

52. Thornton S., Tellam J., and Lerner D. (2005). Experimental and modeling approaches for the assessment of chemical impacts of leachate migration from landfills, A case study of a site on the Triassic sandstone aquifer in the UK East Midlands. *Geotechnical and Geological Engineering* 23: 811–829.

53. Tricys V. (2002), Research of leachate surface and groundwater pollution near Siauliai landfill. Environmental research, engineering and management. No.1 (19), P.30-33.

54. Typical Anatomy of a Landfill. [Accessed in July. 2008]. Available online: http://www.wm.com.

55. United Nations Environmental Program (UNEP) (2003). Desk Study on the Environment in the Occupied Palestinian Territories.

56. Waste Management Research Group (2008). Assessment of issues relating to leachate recirculation. University of Southampton. *School of Civil Engineering and the Environment*, Report ref: P1-516/3b.

List of Appendices

Appendix A

Calculations of Water Balance Method

Table A-1: Steps of Water Balance Method

W	Waste deposited (Kg)
CW	Cumulative weight of waste deposited (kg)
MC	Moisture content of waste (m^3) 20% by mass and ρ_{H2O}=1000 kg/m3- (value obtained from site)
V	Volume of waste deposited (m3) [1] ρ_{waste}=800 kg/m^3
CV	Cumulative volume of waste deposited (m^3)
V_C	[2]Volume of waste deposited + cover volume (m^3)
A	[3]Area covered by waste (m^2)
P	[4]Precipitation (mm)
R	[5]Runoff (mm)
EL_1	[6]Evaporation loss in rain days (mm)
I	[7]Infiltration (mm)
I	[8]Infiltration (m^3)
Rec.	[9]Recirculation
EL_2	[10]Evaporation loss Throughout the year (mm)
I_{Rec}	[11]Infiltration from recirculation
TMC	[12]Total moisture content (m^3)
AWC	[13]Actual water content of solid waste
AWS	[14]Amount of water that can be held in solid waste
MD	Moisture deficit
L	Leachate
CL	[15]Cumulative leachate

1. Data obtained from the annual Reports of Solid Waste Management Council.
2. Volume excludes final capping layer but includes 10% daily cover
3. Data obtained from literature search and sites visit.
4. Data obtained from Palestinian Meteorological Office.
5. Runoff = C_{RO} x P and C_{RO} = 17% (obtained from previous calculation)
6. Evaporation loss in rain days about 65% of Precipitation. (obtained from previous calculation)
7. I (mm) = P - R_{off} – EL_1
8. I (m^3) = I (mm) x A

Note: -ve value of infiltration indicates that there is a moisture deficit. Water is loss as evaporation from waste.

9. Rec. = CL x Recirculation ratio

   Where, Recirculation ratio = 40% (obtained from site visit)

10. Data obtained from previous calculation.
11. $I_{Rec.}$ (m^3) = Rec. – EL_2
12. Total moisture content of solid waste = moisture content of current lift + moisture content of previous lifts (MC+AWC)
13. Actual water content of solid waste = I+TMC
14. Amount of water that can be held in solid waste = field capacity x dry weight of solid waste, where field capacity is defined as the maximum amount of moisture that a soil can hold against gravity. Assuming a field capacity of 0.2, then P = 0.2 x CW x 0.8 (based on dry weight).
15. CL = AWC – AWS + I_{Rec}

Table A-2: Water Balance Method Calculations of Dear Al Balah Landfill

Year	W (Kg) * 10^3	CW (Kg)	MC (m3)	V (m3)	CV (m3)	V c (m3)	A (m2)	P (mm)	R (mm)	EL1 (mm)	I (mm)	I (m3)	Rec. (m3)	ET_2 (mm)
1997	77,000	77,000	15,400	96,250	96,250	105,875	35,000	315	53	204	57	1,982	2,025	428
1998	88,000	165,000	17,600	110,000	206,250	226,875	35,000	217	37	141	39	1,364	3,978	429
1999	88,000	253,000	17,600	110,000	316,250	347,875	35,000	132	22	86	24	832	5,719	409
2000	95,000	348,000	19,000	118,750	435,000	478,500	35,000	255	43	166	46	1,607	7,882	424
2001	90,700	438,700	18,140	113,375	548,375	603,213	35,000	550	93	357	99	3,462	10,718	428
2002	88,000	526,700	17,600	110,000	658,375	724,213	60,000	391	66	254	70	4,218	13,813	429
2003	84,000	610,700	16,800	105,000	763,375	839,713	60,000	373	63	242	67	4,024	16,767	409
2004	82,000	692,700	16,400	102,500	865,875	952,463	60,000	317	54	206	57	3,419	19,446	434
2005	91,000	783,700	18,200	113,750	979,625	1,077,588	60,000	346	59	225	62	3,734	22,396	431
2006	105,000	888,700	21,000	131,250	1,110,875	1,221,963	60,000	245	42	159	44	2,646	25,134	440
2007	99,000	987,700	19,800	123,750	1,234,625	1,358,088	60,000	410	70	267	74	4,431	28,491	440

Year	ET_2 (m^3)	$Rec._{net}$ (m^3)	TMC (m^3)	AWC (m^3)	AWS (m^3)	MD (m^3)	C L (m^3)	L (m^3)
1997	14,968	0	15,400	17,382	12,320	-	5,062	5,062
1998	15,008	0	34,982	36,346	26,400	-	9,946	4,884
1999	14,314	0	53,946	54,778	40,480	-	14,298	4,352
2000	14,832	0	73,778	75,384	55,680	-	19,704	5,407
2001	14,968	0	93,524	96,986	70,192	-	26,794	7,090
2002	25,727	0	114,586	118,804	84,272	-	34,532	7,738
2003	24,539	0	135,604	139,628	97,712	-	41,916	7,384
2004	26,030	0	156,028	159,448	110,832	-	48,616	6,699
2005	25,874	0	177,648	181,381	125,392	-	55,989	7,374
2006	26,420	0	202,381	205,027	142,192	-	62,835	6,846
2007	26,372	2,118	224,827	229,259	158,032	-	73,345	10,509

Table A-3: Water Balance Method Calculations of Gaza Landfill

Year	W (Kg) * 10^3	CW (Kg)	MC (m3)	V (m3)	CV (m3)	V c (m3)	A (m2)	P (mm)	R (mm)	EL1 (mm)	I (mm)	I (m3)	Rec. (m3)	ET_2 (mm)
1997	474,500	474,500	94,900	593,125	593,125	652,438	120,000	282	48	183	51	6,093	10,029	428
1998	474,500	949,000	94,900	593,125	1,186,250	1,304,875	120,000	162	28	105	29	3,499	19,021	429
1999	474,500	1,423,500	94,900	593,125	1,779,375	1,957,313	120,000	184	31	119	33	3,964	28,198	409
2000	474,500	1,898,000	94,900	593,125	2,372,500	2,609,750	120,000	368	63	239	66	7,955	38,973	424
2001	474,500	2,372,500	94,900	593,125	2,965,625	3,262,188	120,000	564	96	366	101	12,174	51,434	428
2002	474,500	2,847,000	94,900	593,125	3,558,750	3,914,625	120,000	661	112	429	119	14,267	64,733	429
2003	474,500	3,321,50	94,900	593,125	4,151,875	4,567,063	120,000	791	134	514	142	17,079	79,156	409
2004	474,500	3,796,000	94,900	593,125	4,745,000	5,219,500	120,000	466	79	303	84	10,068	90,776	434
2005	474,500	4,270,500	94,900	593,125	5,338,125	6,524,375	120,000	324	55	210	58	6,989	101,163	431
2006	474,500	4,745,000	94,900	593,125	5,931,250	6,524,375	120,000	274	47	178	49	5,927	111,126	440
2007	474,500	5,219,500	94,900	593,125	6,524,375	7,176,813	120,000	388	66	252	70	8,385	12,072	440

Year	ET_2 (m^3)	$Rec._{net}$ (m^3)	TMC (m^3)	AWC (m^3)	AWS (m^3)	MD (m^3)	C L (m^3)	L (m^3)
1997	51,318	0	94,900	100,993	75,920	-	25,073	25,073
1998	51,455	0	195,893	199,393	151,840	-	47,553	22,479
1999	49,078	0	294,293	298,256	227,760	-	70,496	22,944
2000	50,851	0	393,156	401,111	303,680	-	97,431	26,935
2001	51,319	115	496,011	508,185	379,600	-	128,700	26,935
2002	51,319	13,278	603,085	617,352	455,520	-	175,110	31,269
2003	49,078	30,079	712,252	729,331	531,440	-	227,970	46,410
2004	52,060	38,716	824,231	834,299	607,360	-	265,655	52,860
2005	51,748	49,415	929,199	936,188	683,280	-	302,323	36,668
2006	52,841	58,285	1,031,088	1,037,015	759,200	-	336,100	33,777
2007	52,745	69,327	1,131,915	1,140,300	835,120	-	374,507	38,407

Appendix B

Groundwater Background Concentrations

Table B-1: Background Concentration of Groundwater at Dear Al Balah Landfill

Parameter	2003		2005	
	W_2	W_4	W_2	W_4
Agricultural No.	Illegal	Illegal	Illegal	Illegal
X GPS	90982	90989	90982	90989
Y GPS	89157	89415	89157	89415
ZM (Water depth)	-	75	-	75
PH	7.53	7.53	7.8	7.89
EC µ.s/cm	3370	4310	3320	4110
Nitrate (NO_3) mg/L	40.5	43.8	38.91	52.73
Chloride (Cl) mg/L	772.6	988.3	821.7	1006
Ammonia (NH_4) mg/L	BDL	BDL	BDL	BDL
COD mg/L	-	-	-	-
BOD5 mg/L	-	-	-	-
TOC mg/L	-	-	-	-
Sulfate (SO_4) mg/L	357.0	462.8	275.8	410.0
Lead (Pb) mg/L	-	-	-	-
Iron (Fe) mg/L	-	-	-	
Cadmium (Cd) mg/L	-	-	-	-
Zinc (Zn) mg/L	-	-	-	-
Copper (Cu) mg/L	-	-	-	-

BDL: Below Detected Limit

Table B-2: Background Concentration of Groundwater at Gaza Landfill in 1995

Parameter	1995							
Agricultural No.	F/137	F/189	F/130B	F-I-10	F/138	F/139	F-I-18	F/160
Well ID	-	W_9	W_4	-	-	-	-	-
X GPS	96568	97241	97365	97551	98065	98162	98338	96096
Y GPS	95728	96360	96568	97184	96896	96929	96947	94110
ZM (Water depth)	-	-	-	-	-	-	-	-
PH	7.56	7.7	7.9	7.5	7.97	7.6	8.03	7.4
EC µ.s/cm	3340	2340	1420	3480	2530	4120	2910	5450
Nitrate (NO_3) mg/L	42	42.5	31.5	25	40.8	102	27.6	42.6
Chloride (Cl) mg/L	908	517	237	948	589	1248	700	1463
Ammonia (NH_4) mg/L	0.06	0.07	0.05	0.07	0.06	0.06	0.07	0.05
COD mg/L	23.5	11	1	13	1	10	4	15
BOD5 mg/L	9.5	7.2	0.3	4.8	0.2	4.8	3	7.45
TOC mg/L	-	-	-	-	-	-	-	-
Sulfate (SO_4) mg/L	262	178	65	323	134	254	141	295
Lead (Pb) mg/L	BDL	BDL	0.05	0.01	BDL	BDL	BDL	BDL
Iron (Fe) mg/L	BDL	BDL	BDL	0.02	BDL	BDL	0.01	BDL
Cadmium (Cd) mg/L	BDL	BDL	BDL	BDL	BDL	0.2	BDL	BDL
Zinc (Zn) mg/L	0.18	0.12	0.05	0.18	0.05	0.08	0.05	0.35
Copper (Cu) mg/L	-	-	-	-	-	-	-	-

BDL: Below Detected Limit

Table B-3: Background Concentration of Groundwater at Gaza Landfill in 1999

Parameter	1999										
Agricultural No.	F/137	F/189	F/130B	F-I-10	F/138	F/139	F-I-18	Illegal	F/160	F-I-32	F/165
Well ID	-	W_9	W_4	-	-	-	-	W_2	-	-	-
X GPS	96568	97241	97365	97551	98065	98161	98337	97707	96096	96395	97953
Y GPS	95728	96360	96568	97184	96895	96928	96946	96589	94110	96742	98039
ZM (Water depth)	-	-	-	-	-	-	-	-	-	-	-
PH	7.7	7.9	8	7.8	7.95	7.9	8.3	7.6	8.75	7.8	7.5
EC µ.s/cm	3680	2500	1600	3400	2600	3680	2600	3818	5500	3400	7000
Nitrate (NO_3) mg/L	31	33	32	32	62	100	31	30	32	32	37
Chloride (Cl) mg/L	850	500	250	755	500	750	470	854	1300	755	1700
Ammonia (NH_4) mg/L	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
COD mg/L	10	BDL	BDL	BDL	BDL	BDL	10	-	10	BDL	50
BOD5 mg/L	BDL	BDL	BDL	BDL	BDL	BDL	BDL	-	BDL	BDL	5
TOC mg/L	-	-	-	-	-	-	-	-	-	-	-
Sulfate (SO_4) mg/L	360	175	53	320	80	180	40	399	670	320	750
Lead (Pb) mg/L	BDL	BDL	BDL	BDL	0.004	BDL	BDL	-	BDL	BDL	0.006
Iron (Fe) mg/L	0.014	0.025	0.013	0.015	0.006	0.002	0.187	-	0.033	0.015	0.018
Cadmium (Cd) mg/L	BDL	BDL	BDL	BDL	BDL	BDL	0.005	-	BDL	BDL	BDL
Zinc (Zn) mg/L	0.025	0.016	0.009	0.017	0.014	0.01	0.008	-	0.026	0.017	0.04
Copper (Cu) mg/L	-	-	-	-	-	-	-	-	-	-	-

BDL: Below Detected Limit

Table B-4: Background Concentration of Groundwater at Gaza Landfill in 2001

Parameter	2001						
Agricultural No.	F/189	F-I-115	F/139	F-I-18	Illegal	F/160	F-I-13
Well ID	W_9	W_3	-	-	W_2	-	-
X GPS	97241	97590	98162	98338	97707	96096	98004
Y GPS	96360	96730	96929	96947	96589	94110	97067
ZM (Water depth)	-	-	-	-	-	-	-
PH	7.2	7.15	7.3	7	7.15	6.7	7.3
EC µ.s/cm	2700	1700	3800	1380	4000	920	4100
Nitrate (NO_3) mg/L	36	36	145	67	30	46	28
Chloride (Cl) mg/L	515	285	730	230	900	155	890
Ammonia (NH_4) mg/L	BDL	0.05	0.3	0.2	BDL	BDL	0.2
COD mg/L	5	5	40	BDL	40	10	20
BOD5 mg/L	BDL	20	5	BDL	6	3	2
TOC mg/L	-	-	-	-	-	-	-
Sulfate (SO_4) mg/L	247	90	210	64	400	28	400
Lead (Pb) mg/L	BDL	BDL	BDL	BDL	BDL	BDL	BDL
Iron (Fe) mg/L	0.1	0.015	0.04	0.05	0.1	0.03	0.4
Cadmium (Cd) mg/L	BDL	BDL	BDL	BDL	BDL	BDL	BDL
Zinc (Zn) mg/L	0.01	0.01	0.01	0.015	0.3	0.05	0.015
Copper (Cu) mg/L	-	-	-	-	-	-	-

BDL: Below Detected Limit