Journal of Environmental Science and Technology

ISSN 1994-7887

Journal of Environmental Science and Technology 4 (4): 419-436, 2011
ISSN 1994-7887 / DOI: 10.3923/jest.2011.419.436

Assessment of Groundwater Quality Due to Municipal Solid Waste Landfills Leachate

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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 objective of this study was assessment degree of groundwater pollution around the two landfills due to percolated leachate from the two landfills. Groundwater samples from 18 water wells 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 spatial distribution of the pollutant indicators around both landfills in the periods 1995, 1999, 2001 and 2008, respectively. The results showed that most of wells were contaminated, where concentration of most physical and chemical parameters were above acceptable standard levels for potable or irrigation water. It is quite evident that landfills present potential threats to the surrounding environment.

Key words: Landfills, groundwater pollution, percolated leachate, groundwater samples, pollutant indicators

INTRODUCTION

Pollution occurs when a product added to our natural environment adversely affects nature's ability to dispose it off. A pollutant is something which adversely interferes with health, comfort, property or environment of the people. There are many types of pollution such as air pollution, soil pollution, water pollution, nuclear pollution and oil pollution (Sabahi *et al*., 2009).

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 (Abu Rukah and Al-Kofahi, 2001). Landfill is an engineered waste disposal site facility with specific pollution control technologies designed to minimize potential impacts. Landfills are usually either placed above ground or contained within quarries, pits. Landfills are sources of groundwater and soil pollution due to the production of leachate and its migration through refuse (Misra and Mani, 1991). 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 leachate 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 and Al-Kofahi (2001), Jagloo (2002), Qrenawi (2006), Adeyemi *et al.* (2007), Soltani *et al.* (2007), Ogbonna *et al.* (2006), Nouri *et al.* (2006) and Shahidullah *et al.* (2000). In their study Adeyemi *et al.* (2007) the biochemical effect of leachate (using Odo Iya Alaro landfill located in Ojota, Kosofe local government of Lagos State as a case study), on the quality of surrounding groundwater was assessed. Water samples were collected from two hand dug wells and two boreholes at about 2 km radius to the landfill. The physicochemical and microbial characteristics of the leachate contaminated groundwater samples were determined. Compared to the tapwater, the leachate-contaminated groundwater samples and the simulated leachate showed significantly ($p<0.05$) higher concentrations of heavy metals such as Pb, Cd and Cr. Coliform bacteria such as *E. coli*, *Shigella* sp. and *Salmonella* sp. were present in the leachate contaminated groundwater samples and simulated leachate. Overall, the data revealed that consumption of leachate-contaminated groundwater may lead to, among other things, heavy metal toxicity such as impaired renal function and possibly cancer. The evidences from this study, therefore, suggest that consumption of leachate-contaminated groundwater is hazardous and therefore should be discouraged. Soltani *et al.* (2007) study in their research industrial wastes generated at Tabriz Petrochemical Complex (TPC) which were shown to contain significant concentration of lead. Environmentally sound landfilling of these waste streams was studied in terms of potential risk of associated groundwater contamination. The waste was to be disposed of in a landfill overlying an aquifer of fine sand texture and a water table depth of about 9 m. A modeling approach was employed for estimating the concentration of lead in groundwater downstream of the landfill site. The Industrial Waste Evaluation Model (IWEM) developed by US Environmental Protection Agency was used which estimates the receptor dose of lead, calculates the associated human health risk and recommends protective measures (i.e., liner type). Accordingly the appropriate liner being of composite type was selected as the required protective measure to minimize the transport of lead to the underlying aquifer which is a major source of drinking water for the downstream residential communities.

Ogbonna *et al.* (2006) in their study eight stations of the waste collection sites in Port Harcourt city were sampled for a period of one year to determine the level of inorganic chemicals and microbial contaminants in the environment. Temperature ranged from 24.5 to 28°C while pH values recorded between 3.3 to 7.3. Organic matter content recorded 2.03%, which was found to be conducive for chelate formation as well as exchange infiltration of surface water to cause flooding. The mean textural class for the soils was predominantly sandy loam. The values for the metal concentrations in the soils revealed that they were above recommended permissible limits in all the stations high enough to cause severe pollution to the environment. Thus, the presence of pathogenic microorganisms especially the fecal coliforms and fungi species in the boreholes from the various stations is a major concern for consumers because of their effect on the health of the populace. Adequate treatment of waste is required before discharge into the environment (Nouri *et al.*, 2006).

The objective of this study was to evaluate and map regional patterns of heavy metals (Cu, Cd, Ni and Zn) occurrence in south of Iran. The study was performed in Shush and Andimeshk plains in the south part of Iran, with high agricultural activities that cover an area of 1100 km2 between the Dez and Karkhe rivers. This region was divided into four sub-regions A, B, C and D. Additionally 168 groundwater samples were collected from 42 water wells during the months April, May, August and September of 2004. The Flame Atomic Absorption Spectrometry (AAS-Flame) was used to measure the heavy metals concentration in water samples. The results demonstrated that all of the samples, Cu, Zn and Ni concentrations have been shown below the EPA MCLG, EPA secondary standard and EPA MCL, respectively, but Cd, contents of 4.8% of all samples was higher than EPA MCL. The heavy metals concentration is more pronounced in south part than northern part of the studied area. Absent confining layers, proximity to land surface, excess agricultural and industrial activities in south part and groundwater flow direction that is generally from north to south parts in this area makes south region of Shush plain especially vulnerable to heavy metals pollution and other contaminants.

A study was conducted to evaluate the groundwater quality at Phulpur thana of Mymensingh district in Bangladesh (Shahidullah *et al*., 2000). Water samples from 14 deep tubewells were analyzed for pH, EC, TDS, Na^+, K^+, Ca^{++}, Mg^{++}, Fe, P, B, NO_3-N, $SO_4^=$, Cl^-, $CO_3^=$ and HCO_3. In addition SAR, SSP and RSC were calculated following standard equations. The range of EC was 180-380 S cm^{-1} and SAR 0.22-0.80 and these two parameters indicated that three samples were in low salinity-low alkali` and 11 were in medium salinity-low alkali` hazard class. There was no chloride toxicity in the area. The presence of $SO4^=$, NO_3^- and P were negligible. As regards boron and SSP, all waters were of good` to excellent` class. In respect of TDS all were fresh water`. On the basis of RSC values all samples were of suitable` class. As a whole, groundwater of the area can safely be used for long-term irrigation. But some of those may not be suitable for drinking and industrial uses in consideration of Fe concentration, TDS and pH values. Among the quality determining factors SSP and SAR were highly correlated where correlation coefficient was 0.97.

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). The Objective of this study was significant to assess degree of groundwater pollution around both Dear Al Balah landfill which has a lining system and Gaza landfill which does not have lining system, due to percolated leachate.

MATERIALS AND METHODS

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.

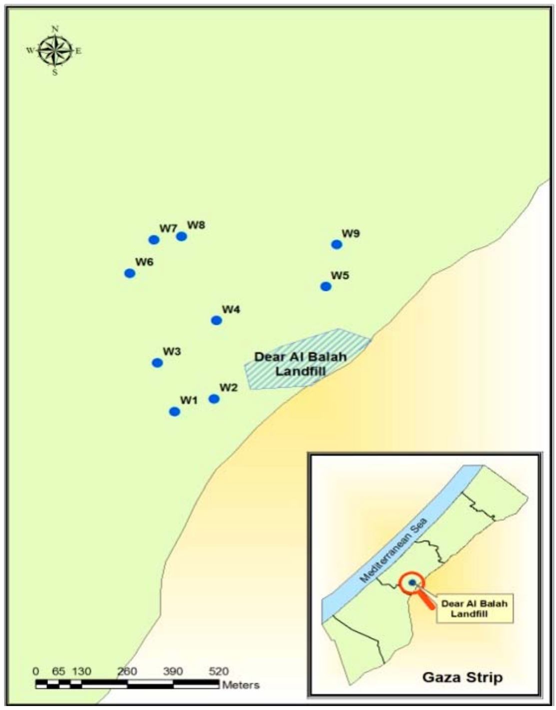

Fig. 1: Sampled wells locations around Dear Al Balah Landfill

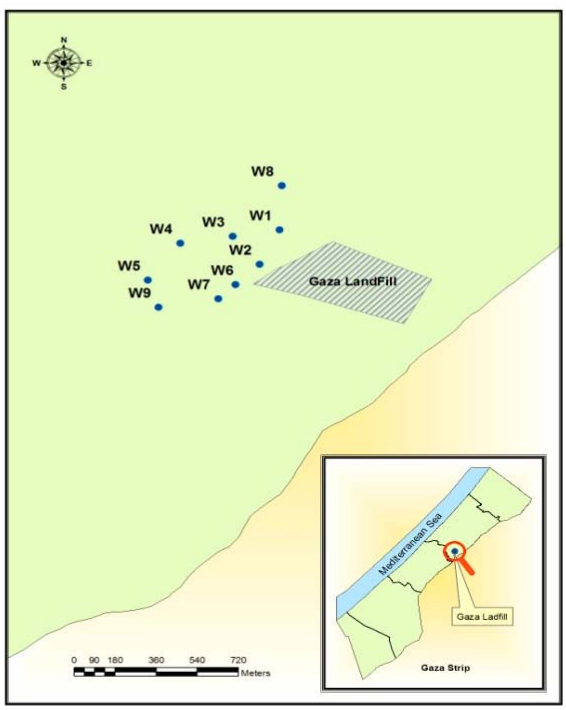

Fig. 2: Sampled wells locations around Gaza Landfill

Table 1: Sampled wells distance from Dear Al Balah and Gaza landfills

	Distance from landfill site in (m)	
Well No.	Dear Al Balah	Gaza
W1	200	160
W2	85	56
W3	245	240
W4	157	385
W5	150	473
W6	442	90
W7	500	187
W8	458	335
W9	289	443

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 Fig. 1 and 2. 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 Table 1. Due to security considerations there are no wells in upstream side of landfills.

Tested parameters and sampling period: 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 Islamic University of Gaza (IUG) laboratories after summer specifically in November 2008.

RESULTS

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.

Leachate characterization: A group of physical and chemical parameters were tested in leachate samples collected from Dear Al Balah and Gaza landfill. The experimental results obtained for the leachate at Dear Al Balah and Gaza landfills are summarized in Table 2.

The following points summarize the main findings of the sampling program of leachate:

- 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

Table 2: Physical-chemical characteristics of leachate (MOH, 2001)

	Concentration						
	Gaza		Dear Al Balah				
Parameter	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) (mg L^{-1}) (μ.s cm^{-1})	52000	45100	37200	35500	55400	35500	32200
Nitrate (NO_3) (mg L^{-1})	40	325	-	-	-	-	440
Chloride (Cl) (mg L^{-1})	8050	12200	7350	6900	10500	8000	9440
Ammonia (NH_4) (mg L^{-1})	2210	2045	4233	1864	5052	2320	3473
COD (mg L^{-1})	40000	45500	39750	12840	28350	25280	46500
BOD_5 (mg L^{-1})	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^{-1})	-	1352	7430	3500	10000	3000	1560
Sulfate (SO_4) (mg L^{-1})	20	1337	357.5	210	380	200	926
Lead (Pb) (mg L^{-1})	0.11	BDL	-	-	-	0.004	BDL
Iron (Fe) (mg L^{-1})	57	BDL	-	-	-	-	BDL
Cadmium (Cd) (mg L^{-1})	3.2	BDL	-	-	-	0.01	22.5
Zinc (Zn) (mg L^{-1})	5.6	65.5	-	-	-	0.01	64
Copper (Cu) (mg L^{-1})	-	6	-	-	-	0.01	BDL

BDL: Below detected limit

- 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, as shown in Fig. 3

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:

Monitoring program: The water samples were taken from wells located around Dear Al Balah and Gaza landfill as presented in Fig. 1 and 2, 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 Table 3 and 4, respectively.

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

- 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
- The EC of all the sampling wells around Gaza landfill was ranged between 1060 and 2350 μs cm^{-1}. 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^{-1} in W_9 and 4180 μs cm^{-1} 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
- COD values for Gaza landfill have a range between Below Detection Limit (BDL) and 325 mg L^{-1} The highest COD values measured at wells W_2, W_4, W_5, W_8 and W_9. COD values for

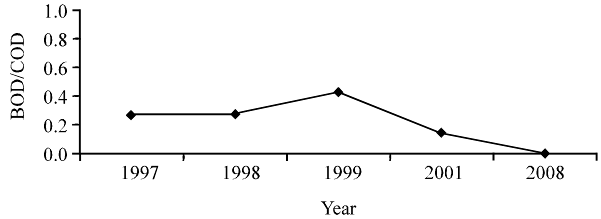

Fig. 3: Change of (BOD/COD) quality with time

Table 3: Groundwater characteristics for sampling wells at Dear Al Balah in 2008

	Well ID								
Parameter	W_1	W_2	W_3	W_4	W_5	W_6	W_7	W_8	W_9
Agricultural No.	Mid.110	Illegal	Illegal	Illegal	Illegal	Illegal	Illegal	Illegal	Illegal
X GPS	90870	90982	90821	90989	91298	90743	90811	90890	91329
Y GPS	89115	89157	89276	89415	89527	89571	89681	89692	89665
ZM (Water depth) (m)	-	-	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^{-1})	3430	1840	3490	4160	1770	4180	1990	2420	1600
Nitrate (NO_3) (mg L^{-1})	44	39.6	66	88	101.2	66	110	83.6	118.8
Chloride (Cl) (mg L^{-1})	841	370	809.5	778.5	355	1004	368.5	499	323.5
Ammonia (NH_4) (mg L^{-1})	7.56	11.2	4.48	4.48	6.44	7.28	6.44	10.92	7.28
COD (mg L^{-1})	326	150	273	345	442	448	218	234	186
BOD_5 (mg L^{-1})	10	BDL	BDL	BDL	BDL	BDL	BDL	BDL	10
TOC (mg L^{-1})	6.22	8.92	9.46	12.17	10.82	10.28	10.28	12.71	4.87
Sulfate (SO_4) (mg L^{-1})	22.06	4.78	23.49	25.32	6.03	25.41	1.5	10.15	1.25
Lead (Pb) (mg L^{-1})	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
Iron (Fe) (mg L^{-1})	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
Cadmium (Cd) (mg L^{-1})	0.011	0.043	0.023	0.022	0.018	0.002	0.014	0.02	0.021
Zinc (Zn) (mg L^{-1})	0.111	0.122	0.185	0.107	0.109	0.107	0.108	0.111	0.124
Copper (Cu) (mg L^{-1})	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	0.19

BDL: Below detected lmit

Dear Al Balah landfill have a range between BDL and 448 mg L^{-1}. The highest COD values measured at wells W_1, W_4, W_5 and W_6

- 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^{-1}. The highest Cl values measured at wells W_1, W_3 W_4 and W_6
- Nitrate concentrations (NO_3) fluctuated between relatively normal levels to high levels (40-119 mg L^{-1}) 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 for drinking water (PS) except of W_1, W_2, W_3 and W_6, as shown in Fig. 4

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 Environmental Quality Authority (EQA, 2010) except W_2 , as shown in Fig. 5.

Table 4: Groundwater characteristics for sampling wells at Gaza in 2008

	Well ID								
Parameter	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) (m)	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^{-1})	1630	1870	1190	2150	2350	1390	1080	3290	1060
Nitrate (NO_3) (mg L^{-1})	28.16	92.4	61.6	61.6	35.2	52.8	66	30.8	57.2
Chloride (Cl) (mg L^{-1})	229	341	176.5	452	477	188.5	204	720	193
Ammonia (NH_4) (mg L^{-1})	3.64	4.2	6.16	3.92	5.88	3.64	4.48	5.6	8.12
COD (mg L^{-1})	4	113	BDL	147	251	30	BDL	325	248
BOD_5 (mg L^{-1})	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
TOC (mg L^{-1})	6.21	BDL	BDL	3.51	7.3	8.92	9.73	9.19	6.76
Sulfate (SO_4) (mg L^{-1})	BDL	BDL	BDL	11.78	15.01	BDL	BDL	17.85	BDL
Lead (Pb) (mg L^{-1})	BDL	BDL	BDL	BDL	BDL	BDL	0.042	BDL	BDL
Iron (Fe) (mg L^{-1})	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
Cadmium (Cd) (mg L^{-1})	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
Zinc (Zn) (mg L^{-1})	0.118	0.104	0.103	0.229	0.105	0.091	BDL	0.114	0.099
Copper (Cu) (mg L^{-1})	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL

BDL: Below Detected Limit

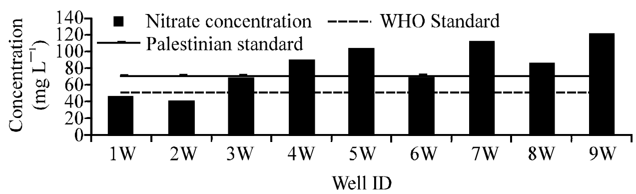

Fig. 4: Comparison between nitrate concentration of wells and maximum allowable concentration at Dear Al Balah Landfill

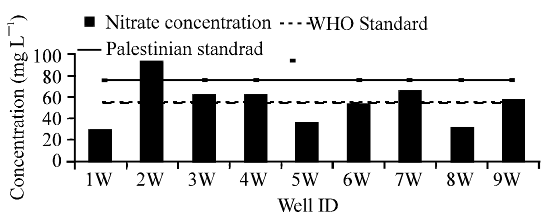

Fig. 5: Comparison between nitrate concentration of wells and maximum allowable concentration at Gaza Landfill

The Ammonia (NH_4) at Dear Al Balah landfill site was considered too high and ranged between 4.48 and 11.2 mg L^{-1}. 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^{-1}. 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 for drinking water (PS), as shown in Fig. 6 and 7, respectively.

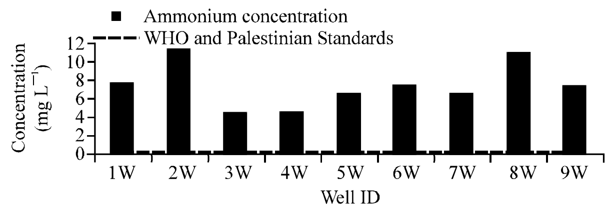

Fig. 6: Comparison between ammonium concentration of wells in Dear Al Balah Landfill and WHO and palestinian standards ration

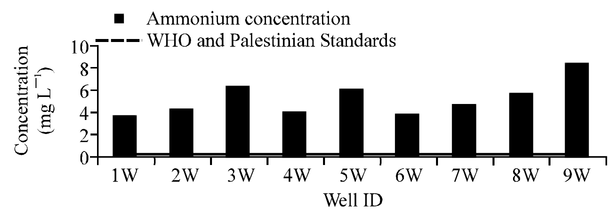

Fig. 7: Comparison between ammonium concentration of wells in Gaza Landfill and WHO and palestinian standards

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).

The range of Zinc concentration around Gaza site was between 0.091 and 0.229 mg L^{-1} while it was between 0.107 and 0.185 mg L^{-1} around Dear Al Balah site.

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).

At Gaza site, Fig. 8 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 (NH_4), Chemical Oxygen Demand (COD) and Electric conductivity (EC) are other indicators of pollutants were also plotted 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

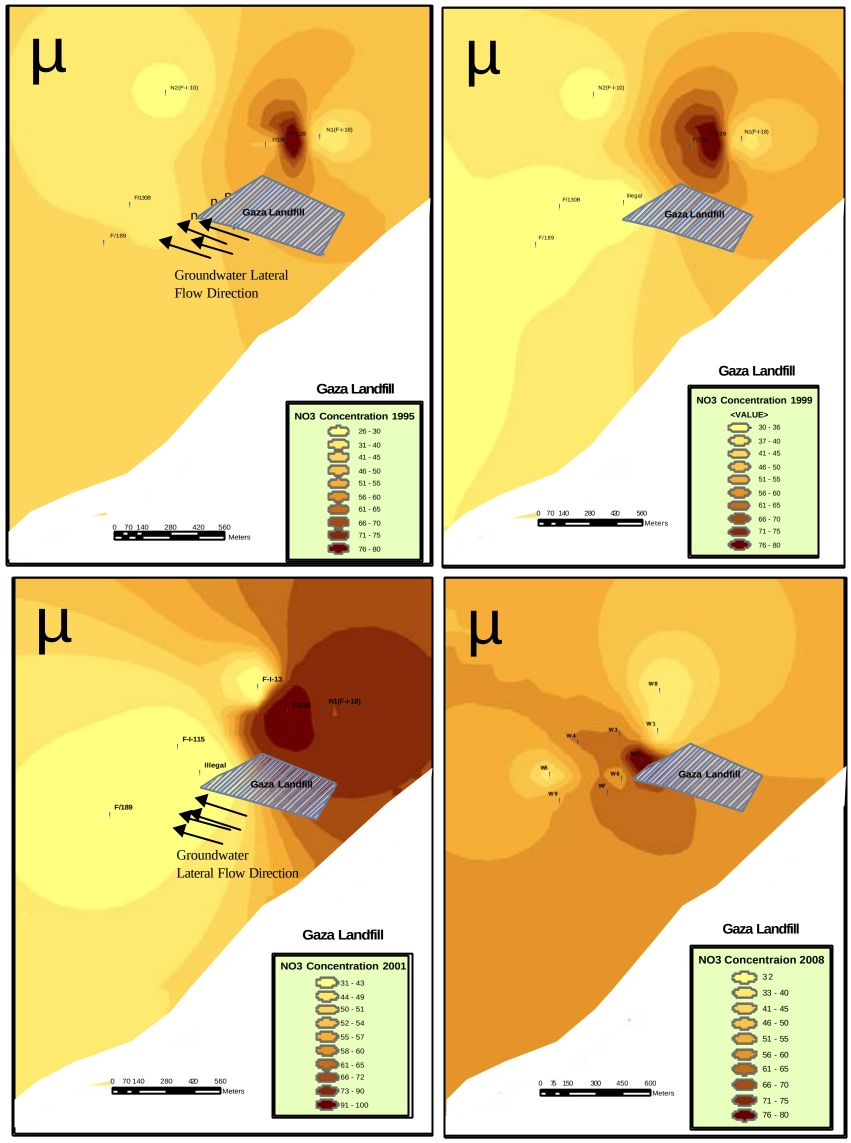

Fig. 8: Nitrate concentration of groundwater wells near the landfill of selected year during Lifespan of Gaza site

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 Fig. 9. 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 Fig. 10.

High concentrations of Cl and EC in groundwater were found close to landfill in southwest direction, as shown in Fig. 11 and 12, respectively.

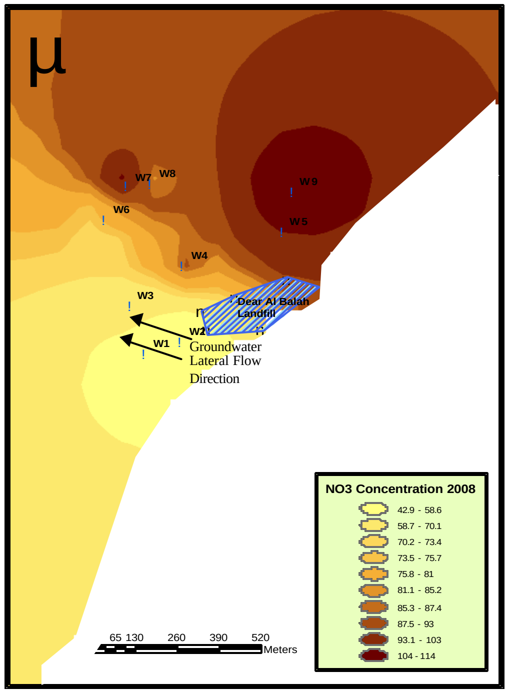

Fig. 9: Nitrate concentration of groundwater wells near the Dear Al Balah Site

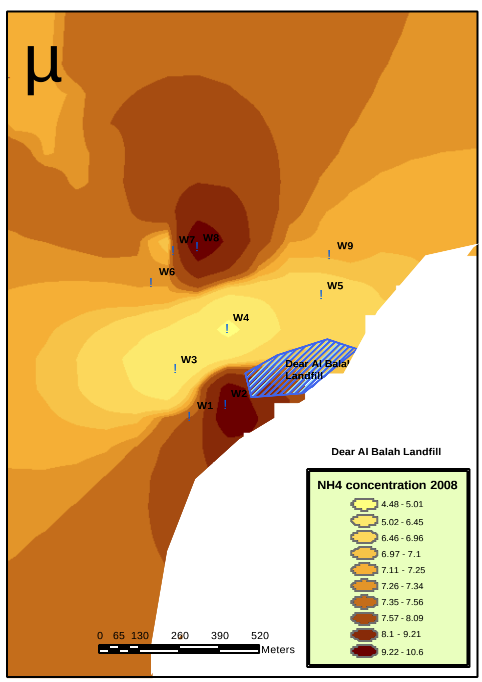

Fig. 10: Ammonium concentration of groundwater wells near the Dear Al Balah Site

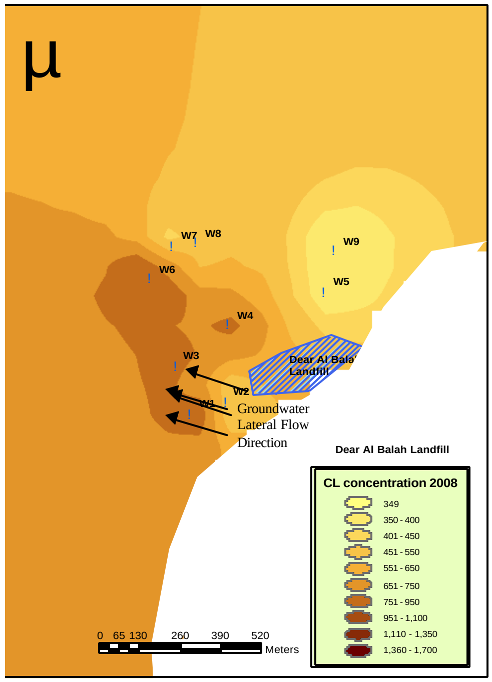

Fig. 11: Chloride concentration of groundwater wells near the Dear Al Balah Site

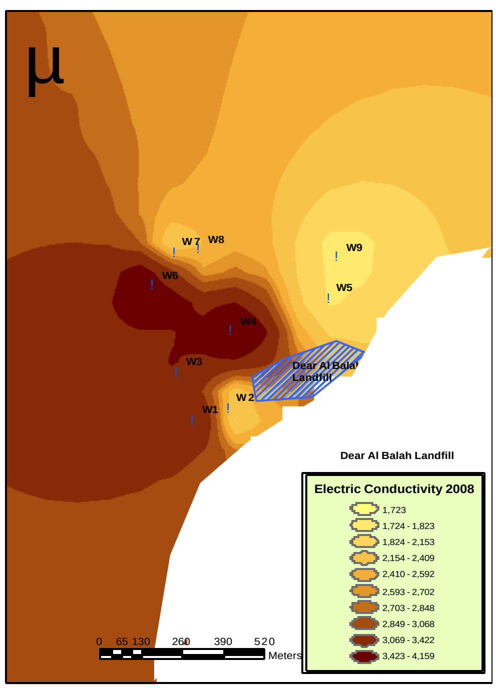

Fig. 12: Electric conductivity level of groundwater wells near the Dear Al Balah Site4

DISCUSSION

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. 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^{-1}. 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 2decreased 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*., 2004: 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_5/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^{-1} at Gaza landfill and 800 mg L^{-1} at Dear Al Balah landfill. The concentrations of COD exhibited a range of values between 45,500 and 46,500 mg L^{-1}. 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^{-1} at Gaza landfill and 440 mg L^{-1} 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^{-1} at Gaza landfill and 3473 mg L^{-1} 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^{-1}) were not detected at Gaza leachate while (except Cd, 22.5 and Zn, 64 mg L^{-1}) 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.

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 Wittmann, 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.

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 (400 µs cm^{-1}). According to (Abu Rukah and Al-Kofahi, 2001) water conductivity within 1000 µs cm^{-1} 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. 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^{-1}. According to Greek legislation the water are suitable for irrigation, since the BOD_5 values are below the suggested limit of 40 mg L^{-1}. COD values for Gaza landfill which closed to landfill site and located in the downstream of lateral flow direction 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 3. 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^{-1}, while about 400 mg L^{-1} 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^{-1}) except W_8 which is 720 mg L^{-1}. The concentration values approached levels above those permitted by US Environmental Protection Agency (EPA, 2003) standards, i.e. 250 mg L^{-1}. High concentration of Chloride in the groundwater at W_8. Since this well is far from the Gaza landfill, the identified Chloride levels may be caused by other source. While Chloride values around Dear Al Balah landfill ranged between 355 and 1004 mg L^{-1}, 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. 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^{-1}) for Gaza Landfill. The average permissible concentrate is 70 mg L^{-1} for Palestinian Standards whiles the average permissible concentrate is 50 mg L^{-1} by WHO (1970) 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 Fig. 10. 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. 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^{-1} 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. While at Dear Al Balah ammonia was considered to be in high concentration and ranged between 4.48 and 11.2 mg L^{-1} 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.

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^{-1} 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^{-1} according to EPA standards. The range of zinc concentration around Gaza site was between 0.091 and 0.229 mg L^{-1} while was between 0.107 and 0.185 mg L^{-1} around Dear Al Balah site.

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 8 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 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 Fig. 9. 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 Fig. 10. 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 Fig. 11 and 12, 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.

CONCLUSION

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.

ACKNOWLEDGMENT

My deep grateful to the Islamic University of Gaza, Particularly the Water Resources Engineering Department and the Center for Environmental and rural Studies for giving me the real and appreciated opportunity to carry out the research.

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