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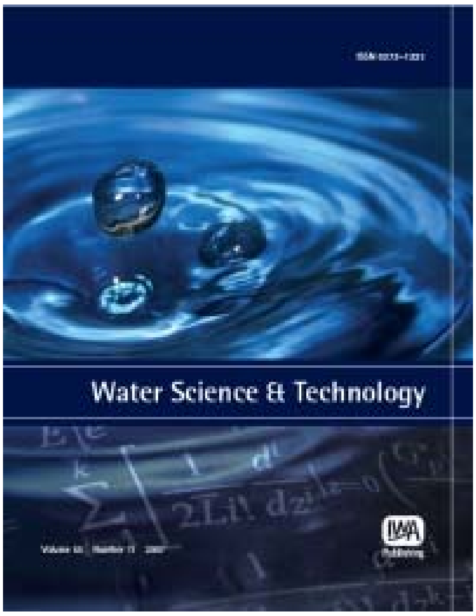
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Analysis of landfill components in estimating the percolated leachate to groundwater using the HELP model

Tamer M. Alslaibi, Yunes K. Mogheir and Samir Afifi

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 landfill is Gaza landfill which does not have a lining system. The main objective of the present study is to assess the effect of landfill components on percolated leachate to groundwater aquifer using the Hydrologic Evaluation of Landfill Performance (HELP) model. A comprehensive analysis of landfill components affecting the generated leachate was conducted. The results showed that the landfill components were ordered in priority according to their effects on percolated leachate through clay layer as follows: (1) existing of lining system enhances the percolation reduction up to 87%, (2) 30% reduction of rainfall level enhances the percolation reduction up to 50%, (3) 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% more than with the availability of recirculation system. The waste depth has no significant effect on the quantity of percolated leachate. Analysis suggested that changes in lining system type, rainfall level, landfill area, and recirculation ratio have the most significant impact on model outputs indicating that these parameters should be carefully selected when similar modeling studies are performed.

Key words | comprehensive analysis, groundwater, HELP, landfill, percolated leachate

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INTRODUCTION

Pollution occurs when a product added to our natural environment adversely affects nature's ability to dispose of it. A pollutant is something which adversely interferes with health, comfort, property or environment of the people (Sabahi *et al.* 2009). Solid waste includes all the discarded solid materials from commercial, municipal, industrial, and agricultural activities (Henry & Heinke 1989). In some countries landfilling is the preferred method of municipal solid waste (MSW) disposal due to its favorable economics. However, poorly designed landfills can create contamination of groundwater, soil, and air. The most commonly reported danger to the human health from these landfills is from the use of groundwater that has been contaminated by leachate (Chain & DeWalle 1976; Lo 1996). As water percolates through the landfill, contaminants are leached from the solid waste. Leachate is produced when moisture enters the refuse in a landfill, extracts contaminants into the liquid phase, and produces moisture content sufficiently high to initiate liquid flow. Leachate may contain dissolved or suspended material associated with wastes disposed off in the landfill, as well as many byproducts of chemical and biological reactions (Bharat & Singh 2009).

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,

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to protect the soil and groundwater from pollution originating in the landfill (Hughes *et al.* 2008).

The uses of HELP model to estimate the generated leachate quantity has given rise to a great number of studies in recent years. Globally, these include the research carried out by Klinck & Stuart (1999), Jagloo (2002) and Qrenawi (2006). Klinck & Stuart (1999) used the HELP model to estimate the quantity of leachate generated from the landfill. Jagloo (2002) in her study in the Mauritius region used the HELP model to estimate the generated leachate. In the study by Qrenawi (2006) of leachate discharged from the landfill, the HELP model was utilized to quantify the amount of leachate. Abu Qudais (1987) revealed that the maximum leaf area index (MLAI) and the evaporative zone depth (EZD) were the most significant parameters affecting leachate quantity in arid regions. It was noted that a small change in any of them will dramatically affect the modeled leachate quantity.

Important factors to prevent groundwater contamination by leachate are proper management of solid waste and landfill structure. The main objective of this article is to assess the effect of landfill components on percolated leachate to groundwater aquifer using the Hydrologic Evaluation of Landfill Performance (HELP) model.

STUDY AREA

Gaza Strip is situated on the south west of Palestine. It is bordered by Egypt from the south, Negev desert from east and the Green Line from the north. There are three controlled landfills constructed 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. Both landfills are located in the eastern direction of Gaza Strip of about 500 m from the Green Line as plotted in Figure 1.

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, which reflects that the area is highly populated due to the high birth rate.

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) (Alslaibi & Mogheir 2007). The highest mean annual temperature is 30.85°C, while the lowest mean annual temperature is 14.16°C. The average annual wind speed in Gaza Strip is about 10.92 km/hr (PMO 2008).

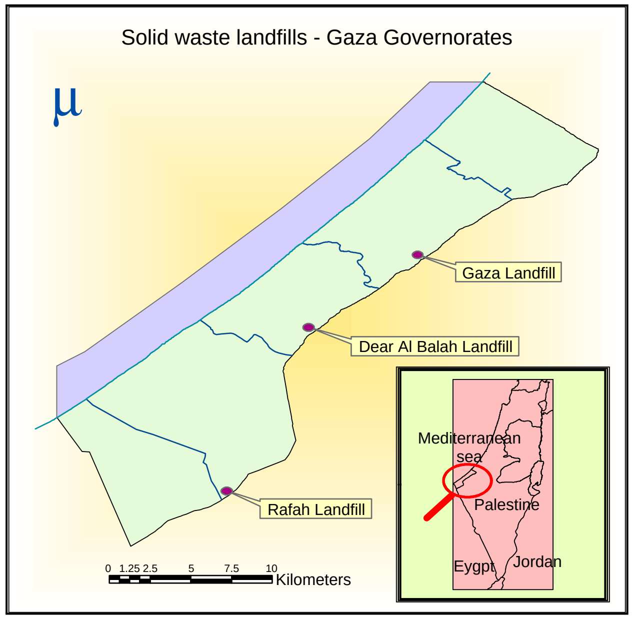

Figure 1 | Landfills location of the study area.

The Dear Al Balah and Gaza landfills have an area of 6 and 20 hectares respectively. The nearest residential area is about 4 km from the landfills. The Dear Al Balah and Gaza landfills received about 90,000 and 450,000 ton of solid wastes yearly respectively and more than 60% of the total wastes are food waste (UNEP 2003). The texture of the soils under the landfills is sandy and silty clay. The average thickness of main clay layer was about 17 m and the hydraulic conductivity was about 1.7×10^{-5} cm/s. Layout of Dear Al Balah and Gaza landfill are shown in Figures 2 and 3 respectively. The lining system of Dear Al Balah landfill consists of four layers which are clay layer, base coarse layer, asphalt layer and aggregate layer as shows in Figure 4.

MODELING METHODOLOGY

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 (Schroeder *et al.* 1994). It is a quasi two dimensional hydrologic model of water movement across,

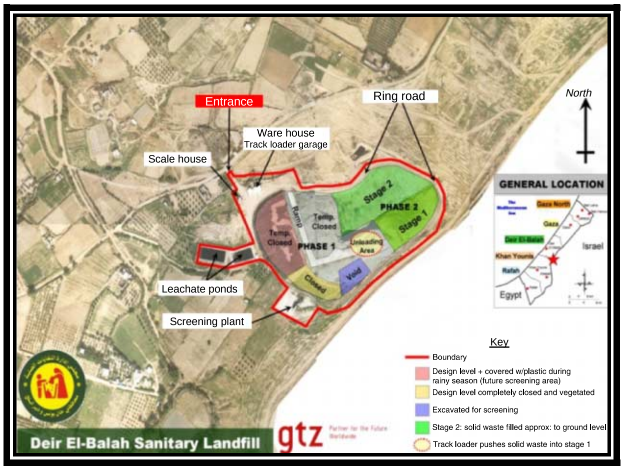

Figure 2 | Plan of Dear Al Balah landfill location (GTZ 2002).

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

Figure 3 | Plan of Gaza landfill location (Google Earth 2008).

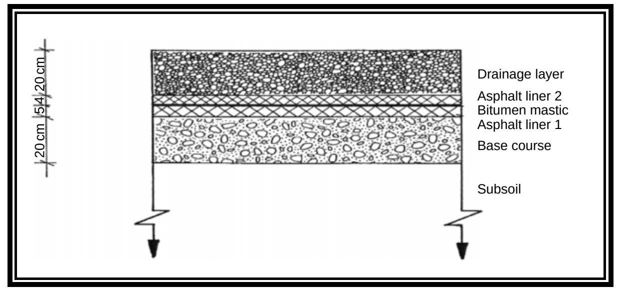

Figure 4 | Asphalt lining system cross section at Dear Al Balah landfill (GTZ 1996).

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 (Sabahi *et al.* 2009).

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).

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).

The model accepts three types of data which are weather, soil and design data as shown in Table 1.

The weather 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 runoff curve number, as shown in Table 2.

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 3; 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.

The values for the soil layers parameters are presented in Table 4.

Table 1 | 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/s	–
	Porosity, moisture content	vol./vol.	–
	Field capacity and wilting point	vol./vol.	–
	Recycling ratio	%	–

MODEL OUTPUT

Figure 5 presents the estimated cumulative leachate quantity by HELP model and the measured leachate quantity in the site. It was noticed that there were missing measurements of the leachate quantities in the first four years. From Figure 5 it can be recognized that the measured leachate volume is less than 50% of the estimated leachate volume by the study method in the years from 2001 to 2004.

Table 2 | HELP model input parameters

Parameter	Range	Typical value: Dear Al Balah	Typical value: Gaza
Evaporative zone depth	4–60 in	23.62 in	23.62 in
Maximum leaf area index	0–5	3.5	3.5
Wind speed	1.7–17.1 km/hr	10.92 km/hr	10.92 km/hr
Relative humidity	69–73%	–	–
Annual rainfall	–	322.58 mm	405.72 mm
Temperature	12–27°C	–	–
Solar radiation	–	18.58 MJ/m^2/day	18.58 MJ/m^2/day
Runoff curve number	75–85	81.3	78.9
Recycling ratio	0–100%	40%	40%

Table 3 | Type 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

However, in the last three years of the study period (2005 to 2007), the estimated quantity by the study method and measured leachate volume become very close quantities.

According to the results shown in Figure 5, there is a gap between estimated and measured leachate volumes in Dear Al Balah site. This gap might relate to the following factors.

- There is a quantity of leachate percolates throw the lining system to the groundwater which has been estimated using the HELP model.
- 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.
- 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 decreased as the landfill reached stabilization level in 2007 (end year of expected life span) by 7% and this deference can be acceptable in this year.

There is no measured leachate volume at Gaza site because the absence of leachate measuring device and lining system.

ANALYSIS OF LANDFILL COMPONENTS

The analyzed landfill components were: weather conditions, waste depth, landfill area, lining system and re-circulation system. Weather conditions included several

Table 4 | Properties of layer no. 1, 2, 3, 4, 5 & 6

	Typical value											
	Layer 1		Layer 2		Layer 3		Layer 4		Layer 5		Layer 6	
Parameter	Dear Al Balah	Gaza	Dear Al Balah	Gaza	Dear Al Balah	Gaza	Dear Al Balah	Gaza	Dear Al Balah	Gaza	Dear Al Balah	Gaza
Thickness (in)	20	984	670	670	7.88	–	3.54	–	7.88	–	670	–
Porosity (vol./vol.)	0.437	0.671	0.671	0.475	0.397	–	0.427	–	0.397	–	0.475	–
Field capacity (vol./vol.)	0.062	0.292	0.292	0.378	0.032	–	0.418	–	0.032	–	0.378	–
Wilting point (vol./vol.)	0.024	0.077	0.077	0.265	0.013	–	0.367	–	0.013	–	0.265	–
Initial moisture (vol./vol.)	0.0835	0.294	0.294	0.475	0.033	–	0.427	–	0.032	–	0.475	–
Hydraulic conductivity (cm/s)	5.8×10^{-2}	10^{-3}	10^{-3}	1.7×10^{-5}	0.30	–	1×10^{-7}	–	0.3	–	1.7×10^{-5}	–

parameters such as rainfall, temperature, solar radiation, relative humidity and wind speed. Since both landfills locations are 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. Therefore, only the rainfall parameter has such impact.

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 were 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 the existing of lining system causes 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 the lining system, the percolated leachate volume was 6.5% of the total cumulative quantities as shown in Figure 6. To this end, it is assumed that the existing of a suitable lining system will enhance the reduction of percolation of the leachate volume up to 87%, as shown in Figure 7.

Rainfall level

Rainfall level component was studied for Gaza landfill based on two scenarios. First, by applying the actual rainfall

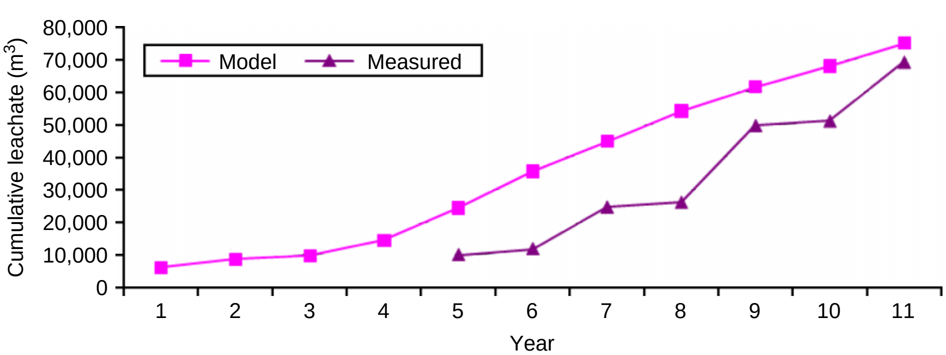

Figure 5 | Measured and estimated cumulative annual leachate volume generated at Dear Al Balah landfill.

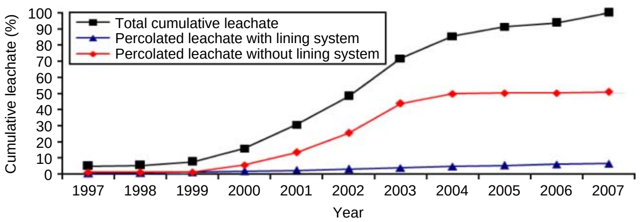

Figure 6 | Effect of lining system on cumulative annual leachate volume accumulated & percolated at Gaza landfill.

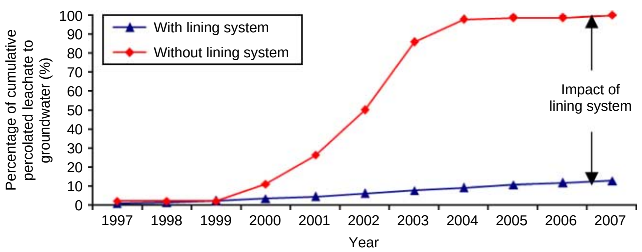

Figure 7 | Percentage of cumulative annual leachate volume percolated at Gaza landfill.

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 8, the 30% reduction of existing rainfall level resulted in 50% reduction of the percolated leachate to groundwater. In addition, Figure 8 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%.

Landfill area

The landfill area is an important component that affects the quantity of accumulated and percolated leachate 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 is due to any decrease of landfill area means decrease of the chatchment area. This yields that any reduction in area will reduce percolated leachate volume by similar percentage, as shown in Figure 9, for instance, about 50% reduction of existing landfill area results in reduction of the percolated leachate by 50%.

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 10, it was found that the results were almost identical and there was no significant change of the cumulative percolated leachate by variation of waste

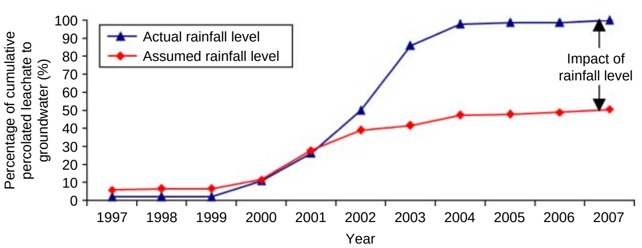

Figure 8 | Effects of rainfall level on percentage of cumulative annual leachate volume percolated at Gaza landfill.

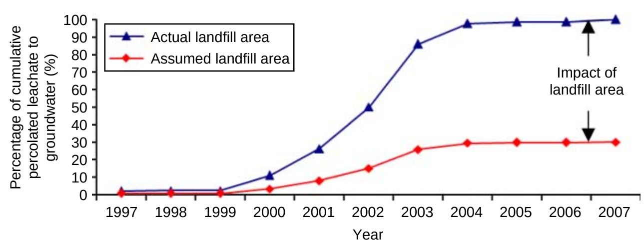

Figure 9 | Effect of landfill area on percentage of cumulative annual leachate volume percolated at Gaza landfill.

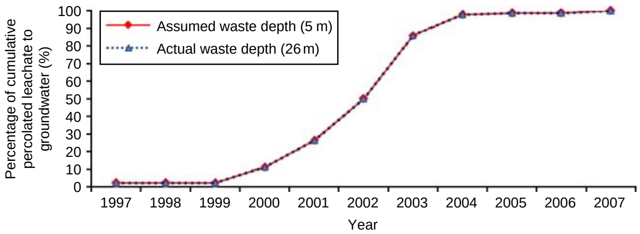

Figure 10 | Effects of waste depth on percentage of cumulative annual leachate volume percolated at Gaza landfill.

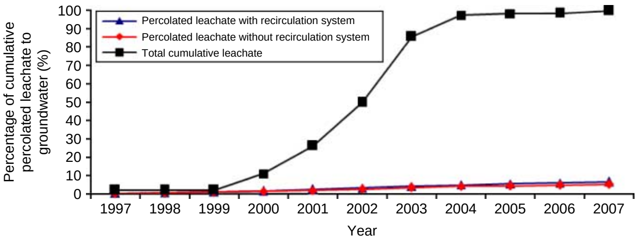

Figure 11 | Effects of recirculation of leachate on cumulative annual leachate volume percolated at Gaza landfill.

depth from 26 m in the actual (6,524,375 m^3/200 × 103 m^2) to the assumed 6 m as in Dear Al Balah site (1,234,625 m^3/ 200 × 103 m^2). Therefore, the results show that the waste depth has no significant effect on the quantity of cumulative percolated leachate.

Leachate recirculation system

The results of leachate quantities estimated by the study methods in Gaza site showed, with 40% leachate recirculation and without recirculation, resulted in a slight increase of annual average leachate (see Figure 11). This can be explained and connected to the climate condition of the area (semiarid) with high evaporation rate.

Landfill components such as existing of lining system, landfill area and rainfall level are the most major components that affect the quantity of generated leachate. Therefore, these parameters should be considered in the design of new sanitary landfills.

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.

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 absence of recirculation system reduces slightly the percolation up to 2.5% more than with the availability of recirculation system.
e. The waste depth has no significant effect on the quantity of percolated leachate.

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.

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