Research Journal of

Environmental Sciences

ISSN 1819-3412

Academic
Journals Inc.

www.academicjournals.com

Research Journal of Environmental Sciences 4 (4): 359-370, 2010
ISSN 1819-3412

Assesment of HELP Model Performance in Arid Areas, Case Study: Landfill Test Cells in Kahrizak

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Abstract: This study investigated the applicability of the HELP model in arid areas, by construction of two 35×25 m test cells in Kahrizak landfill (longitude = 51°, 20', latitude = 35° 27' degrees) and monitoring the real leachate generation from each one. A set of field capacity and saturated water conductivity tests were also performed to determine basic hydrologic properties of municipal waste landfilled. A comparison was made between values calculated by HELP model and recorded values, shows that a prediction of leachate on annual basis can be done by HELP model with acceptable accuracy but when the infiltration of water to waste body increase due to leachate production, the model intents to underestimate water storage capacity of the landfill, which lead to deviation of calculated values from real ones.

Key words: Landfill, municipal solid waste, hydraulic conductivity, field capacity, leachate

INTRODUCTION

Hydrologic Evaluation of Landfill Performance (HELP) model is one of the most accepted tools to simulate the hydrological attributes of landfills (Berger, 2003). This model is developed as a layer model, in which, the landfill body is divided to different layers with certain hydrological properties which are constant in each concerned layer. Then the hydrologic balance between these layers is considered in a transient state.

The HELP model is mainly used for designing different cover layers and drainage from landfill. It has been applied in some places for determining the leachate production in landfills (Berger, 2003; Gisbert *et al*., 2003; Vlyssiddes *et al*., 2003). As stated in some of the technical documentation of the model (Schroeder *et al*., 1994a), it is recommended to compare liner alternatives performances by HELP rather than prediction of exact leachate amount by this model. Some of the references also report high error values in the output of the model comparing with real values (Richardson *et al*., 2000).

The HELP model is developed in United States and is mainly used in developed countries. In Tehran, there are two main differences concerning the water balance of the landfills:

- The evaporation rates in Tehran is higher than typical values in developing countries and hydro-climatological budget is negative (Evaporation exceeds the value of precipitation) which minimizes the precipitation role in leachate production in the landfills

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- The moisture content of municipal solid waste in Tehran is around 60-70% (Mahdipoor, 2003) and is higher than typical values in Europe and United States. Therefore, it is predicted that main part of leachate in Tehran city landfill will be generated by the excessive water content (Safari and Baronian, 2002)

In the performed research, it was intended to survey the suitability of this model for local conditions in Iran based on large scale field studies and to obtain a solid background on applicability of this model in the Iranian territory and also neighbor countries with similar attributes.

The research comprised of construction of two test cells and monitoring leachate production and also performing two other field tests to determine the field capacity and permeability of the waste.

MATERIALS AND METHODS

The research included three major activities:

- Developing two test cells as a model of big engineered landfills and recording the relevant data in a 1 year period. The data of concern in this article is the amount of leachate produced in these two cells with different hydrologic regime
- Performing a set of 5 tests to attain a value for field capacity of mixed compacted municipal waste
- Performing a set of 5 tests to obtain a value for saturated hydraulic permeability of the compacted municipal waste

The test cells are built in current operating landfill in Tehran city and the tests were performed using the received municipal waste in the same place. The monitoring of the cells started at January of 2006 up to January 2007 and filed capacity and permeability were performed during the first two seasons of 2008.

Test Cells

In order to investigate the field behavior of landfilled waste two separate cells were considered to be built and operated in the research in Kahrizak landfill (longitude = 51°, 20', latitude = 35° 27' degrees). The main idea behind designation of two different cells were to survey leachate recirculation effect on the performance of the landfill while maintaining the minimum dimensions for the cells to be comparable with real landfill dimensions.

Both cells have around 25 m width and 35 m length. In one of the cells (Cell B) leachate recirculation took place while the other one (Cell A) was operated without any recirculation. Height of each cell was around 5.5 m which was filled in 3 lifts (Fig. 1, 2).

Design of cells was made based on regulations and standards applied to sanitary landfills and mainly based on EPA guidelines (Richardson, 1994).

Base sealing system in test cells is comprised of a 1.5 mm thick geomembrane over a 60 cm compacted clay layer. The Clay layer was compacted in 4 separate 15 cm layers. To achieve the required impermeability, an optimum moisture content of 13% was used to compact the clay.

A geotextile layer is also implemented over the geomembrane layer for protection against geomembrane puncture. Additionally a 10 cm thick sand layer was also used to guarantee the soundness of liner in operation period.

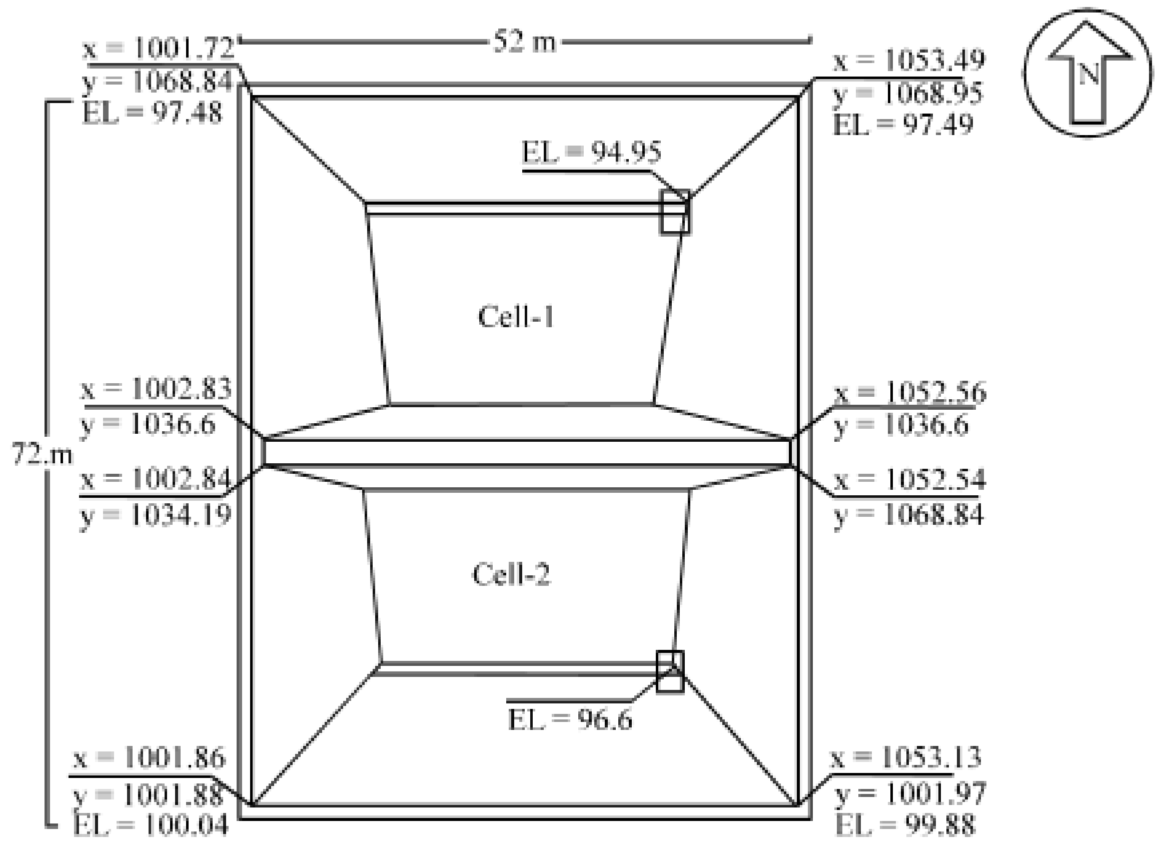

Fig. 1: The schematic presentation of test cells (plan-view)

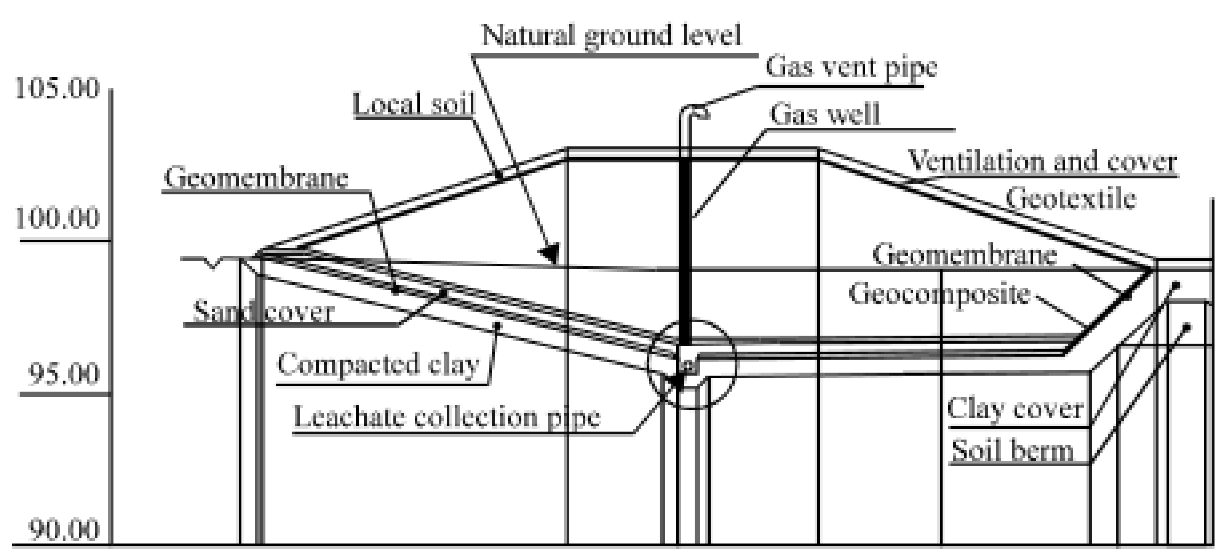

Fig. 2: The schematic presentation of test cells (section)

Leachate collection system in the cells is comprised of a gravel blanket (16-32 mm grain size) with one main pipe (perforated- made of High Density Polyethylene) which conveys the gathered leachate to the monitoring sump where the leachate is pumped out of landfill body. Thickness of gravel blanket was designed as 45 cm to avoid clogging. A general slope of 2% was also used in the bottom of the landfill for leachate drainage. The drain pipe with diameter of 200 mm was placed in a 60 cm wide trench with bottom slope of 1%. A great factor of safety applied for sizing the pipe to avoid any clogging in leachate pipes.

Collected leachate is conveyed to a sump with 1×1 m dimension. Access to the sump was provided by a concrete shaft and the leachate monitoring and pumping were taken place through this concrete shaft. There were two masonry basins lined with HDPE to store the leachate in the site temporarily. Each of these basins has the capacity of 70 m^3.

The method of landfilling in test cells was a combination of trench and area method. The ground was excavated to 2.5 m depth in the first place. The side slope of 1:4 (1 horizontal to 4 vertical) was used to provide the accessibility of the cell for waste handling equipment and trucks. After installation of liner and leachate collection system in the excavated cell, waste filling started and it continues to 3 m height above the earth level.

Table 1: Geometrical characteristics and filling pattern for each test cell

Layer	Characteristics	Cell B	Cell A
	Landfilled waste (ton)	1759	1559
1st	Height (m)	1.8	1.5
	Duration (day)	30	30
	Covering duration and instrument installation (day)	13	13
	Landfilled waste (ton)	1508	1463
2nd	Height (m)	1.9	2
	Duration (day)	19	19
	Covering duration and instrument installation (day)	6	6
	Landfilled waste (ton)	1491	1547
3rd	Height (m)	1.8	1.7
	Duration (day)	17	17
	Covering duration and instrument installation (day)	16	16
Total	Landfilled waste (ton)	4758	4569
	Height (m)	5.5	5.2

The landfill was filled in three steps each of them placed approximately 1600 tons of waste. Twenty five centimeters of coarse soil is used as the intermediate cover for the cells. In Table 1 the main geometrical characteristics of each cell is shown.

In one of the cells (Cell B) 9 branches of perforated pipes were put in the cover that can be attached to a pump in the times of leachate recirculation.

The pipes used for recirculation of leachate have a diameter of 4 cm with 8 mm diameter holes and 50 cm spacing. These pipes were put in a trench dug in the cover and backfilled with gravel. The leachate then was re-circulated over expanse of the landfill cap through these pipes placed under the test cell final cover.

During the operation, the leachate infiltrated to the drainage system, was removed from the sump and measured. The application of robust sophisticated bottom liner and effective drainage system made it possible to assume that the monitored volume in the sump is identical to the quantity of leachate produced in the cell.

The waste compaction was done with a waste placed in the landfills with 826C caterpillar waste compactor and was compacted to around 900 kg m^{-3} density. This was to ensure that the properties of waste would be identical to current engineered landfill in practice. The number of passes to achieve such density was 6 compactor passes for 0.5 m high waste pile.

Field Capacity and Permeability Tests

To determine field capacity and permeability of the soil, standards and well accepted method are commonly used in practice (ASTM D2980-04, 2004; ASTM D2434, 2006; ASTM D6836, 2008), but due to non homogenous nature of municipal solid waste, these methods cannot be applied to determine waste characteristics.

A modified method was designed then to determine field capacity and permeability of the municipal solid waste.

As described by United States environmental Protection Agency (Schroeder *et al*., 1994b), that the field capacity is the volumetric water content at a soil water suction of 0.33 bars or remaining after prolonged period of gravity drainage without water supply. Based on this definition using the concept of gravity drainage, a cylinder container with 60 cm diameter and 80 cm depth is chosen to determine field capacity, this container then filled with compacted municipal waste with density of 900 kg m^{-3} (Fig. 3).

A valve is fabricated at the bottom of the container and a galvanized mesh was welded a few centimeters above the valve to prevent clogging the valve by waste.

This valve was closed during compaction process. After filling the container the weight of container was recorded and the valve was opened. The excessive water then flow out the

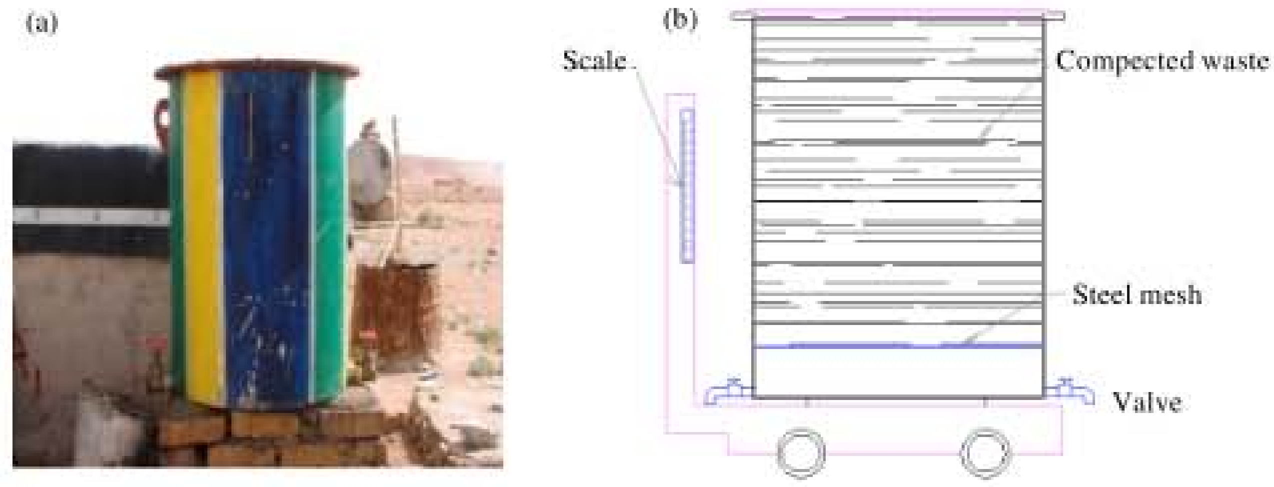

Fig. 3: (a) Field capacity test container and (b) schematic drawing

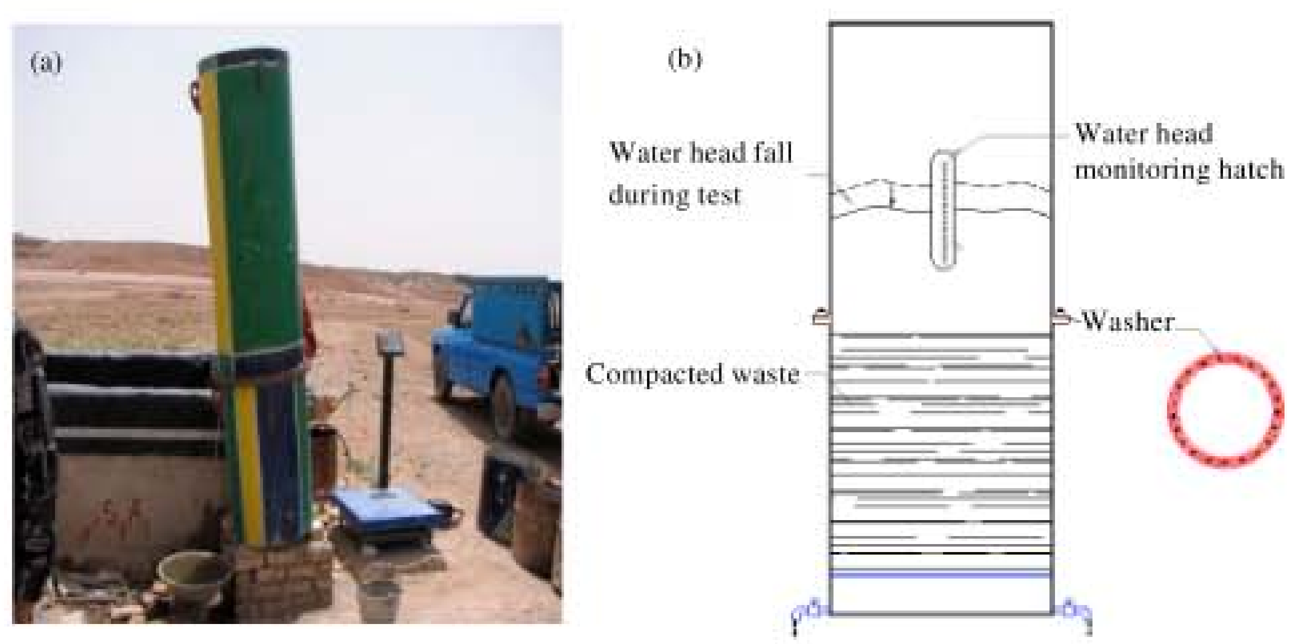

Fig. 4: (a) Apparatus for saturated hydraulic conductivity and (b) schematic drawing

container during time. In time the flow stops (which takes 2-3 days), the weight of the container was measured and the difference between two measurements was deduced as the weight of excessive water to field capacity. By drying the sample waste the dry weight and field capacity of the waste was determined.

Before emptying the container, the saturated hydraulic conductivity test was performed. This test is designed in a way that it can be the continuation of field capacity test. Another cylinder, which has a water level indicator, was fabricated over the field capacity container. A plastic washer was used for sealing the joint between containers (Fig. 4). After fabrication of apparatus, it was filled with water while the bottom valves were closed. Then two valves were opened simultaneously and the rate of water drop was recorded. This rate reached a constant value after some seconds that could be considered as the waste permeability. A secondary valve was predicted for this test to let the water discharge from the vessels take place with minimum orifice discharge limitations and to be sure that the rate of water discharge is merely dependant on the waste conductivity. The results of both tests is shown in Table 2.

Modeling Leachate Production with HELP

Hydrological Evaluation of Landfill Performance (HELP) model is a layer model developed based on Water Balance equation for each individual layer. This model is

Table 2: The result of field tests for hydrological properties of municipal waste in Tehran

Sample No.	Saturated hydraulic conductivity (cm sec^{-1})	Field capacity (V/V)
1	0.0937	33.60
2	0.0842	29.05
3	0.0833	25.76
4	0.1123	22.76
5	0.0473	27.00

Table 3: Material properties used in HELP model as input parameters

Layer No.	Layer type	Porosity	Field capacity	Wilting point	Effective saturated hydraulic conductivity (cm sec^{-1})
		------------------------	(V/V)	------------------------	
1	Final cover	0.42	0.31	0.18	0.19×10^{-4}
2	Compacted waste	0.35	0.27	0.19	0.25×10^{-1}
3	Intermediate cover	0.32	0.05	0.02	0.2
4	Drainage material	0.40	0.03	0.01	0.3
5	Protection sand	0.40	0.24	0.14	0.11×10^{-3}
6	Geomembrane liner	----	----	----	0.2×10^{-12}

developed by team of experts supported by United States Environmental Protection Agency Funds (Schroeder *et al*., 1994a, b). The HELP Model is one the most elaborated models developed for predication of landfill hydrological performance. The Models incorporates a large set of assumptions and equations based on approved references. A comprehensive description of technical background and formulation used in HELP model is gathered and available in engineering documentation of the model (Schroeder *et al*., 1994a, b).

After determining the two main hydrological characteristics of the waste, modeling for prediction of leachate generation in both cells were performed to provide a set of data for further comparison with real monitored leachate generation in the cells.

In cell 1 (Northern cell) where no leachate recirculation took place, the following configuration was applied in the model in 9 layers:

- **First layer:** The final cover layer with low penetration (ML soil type) with 40 cm thickness
- **Second layer:** Compacted waste with 150 cm thickness
- **Third layer:** Intermediate cover layer comprised of gravel with 20 cm thickness
- **Fourth layer:** Compacted municipal layer with 200 cm thickness
- **Fifth layer:** Intermediate cover layer comprised of gravel with 20 cm thickness
- **Sixth layer:** Compacted municipal layer with 170 cm thickness
- **Seventh layer:** Gravel drainage layer with 30 cm thickness and 2% slope
- **Eighth layer:** Sand protection layer for geomembrane with 10 cm thickness
- **Ninth layer:** Flexible membrane Liner (geomembrane)

The properties of material used in model are included in Table 3.

Although, a clay layer was constructed under the geomembrane, but as the geomembrane surface was considered highly impermeable and with no holes in it (Due to high quality control practice during installation) no leachate penetration through geomembrane was considered, therefore the clay layer was not modeled.

The leachate output from layer 7 and 8 used to determine the amount of leachate discharged from the cell. Dimension of the cell was considered 25×350 m.

The simulated time was one year and starts 6 months after beginning the operation (waste dumping) of the cells when the final cover was installed and leachate output from the cells reaches a stable regime (It is when the moisture excessive to field capacity during the waste dumping, drained out of the landfill). Therefore, the starting simulation period was in January as set to month-1 for all of the charts.

Table 4: Temperature and precipitation values used in input parameters for the model

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Precipitation (mm)	4.5	15.4	16.4	45.8	22.6	46.3	1.8	0	0.0	0.0	9.0	43.2
Temperature (°C)	1.8	6.6	8.6	13.8	20.8	28.0	29.8	30	27.4	20.4	15.1	7.2

Climatological data statistics from the nearest weather station (Imam Khomeini Airport Station) were used such as precipitation and temperature was used as input values for the model. In Table 4 the average monthly temperature and precipitation is shown.

For modeling cell 2 (Southern cell) where leachate recirculation took place, as the HELP model could not simulate recirculation of leachate, the following methodology was chosen to model the landfill hydrological performance:

- At first a model is developed without considering any leachate reticulation and the amount of leachate generation was determined
- In the second step, in a different model, the leachate recirculation was represented as precipitation when no other precipitation of evaporation or runoff was introduced to the predefined configuration of the landfill. This will lead to a new leachate generation rates which are caused by leachate recirculation
- The leachate generated from step 1 and 2 are then accumulated as the total discharge of the leachate generated from precipitation and also leachate recirculation
- The model outputs from amount of generated leachate then was compared to real values monitored on site

RESULTS AND DISCUSSION

Based on monitored values total amount of 94.9 m^3 leachate is produced in the modeling period in cell-1 while in cell-2 the this value reach the sum of 105 m^3 while 164 m^3 of leachate was recirculated over the cell. In the same period the amount of precipitation over the cells amounts to around 334 m^3 based on the precipitation data gathered from nearest station.

The maximum monthly value for leachate discharge in cell-1 is 12.1 m^3 in December, while the maximum value for cell-2 took place in November when 12.7 m^3 leachate was recorded in the drainage system outlet.

The model results for cell-1 show production of 99.7 m^3 in modeling period in cell-1 and 201.9 m^3 in cell-2. The detailed discussion over the comparison of model results recorded values will be presented in following text. What is obvious from the first point is that there is negligible difference in cell outputs in recorded values while the modeling results show a great difference between them.

In Fig. 5 a plot of monthly precipitation versus real leachate discharge and modeling results for discharge for cell-1 is presented (The calculation and monitoring started from January 2006 as the first month in the chart).

As it is understood from Fig. 5, calculated values have a considerable deviation from monitored values and show moderate conformance to precipitation (rain) pattern with 1 month delay.

In Fig. 6 an accumulative plot of monitored and calculated leachate shows that in one hydrological cycle, the calculated values conform very well with monitored values while both model results and recorded values show leachate discharge equivalent to 100 mm in modeling period. Therefore, even we have not get a satisfactory result from the model in monthly basis values but usable results have been produced in annual basis.

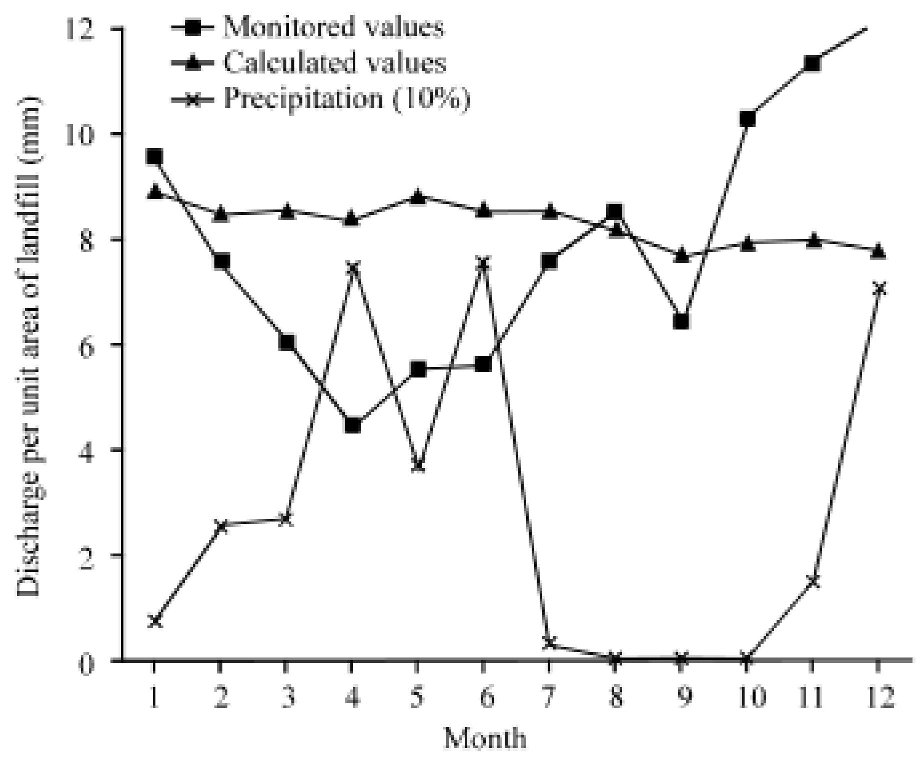

Fig. 5: Calculated values by HELP versus monitored values in cell-1

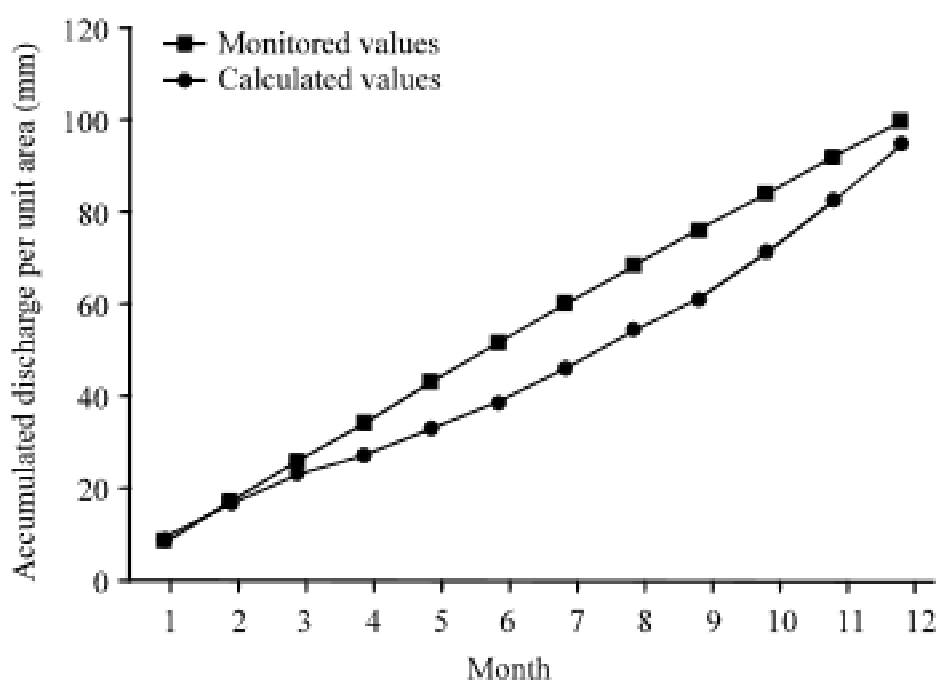

Fig. 6: Accumulated calculated values by HELP versus monitored values in cell-1

In Fig. 7 a plot of calculated and monitored values in the Cell-2 where the leachate recirculation took place, is shown. As it is understood from the figure, calculated values are mainly higher than the monitored values in every month when maximum difference took place in April and the difference tend to decrease in subsequent months. Accumulated values also show around 150% deviation from real values on site measurements (Fig. 8).

As it was understood from the comparison of the model results and recorded values there are some contradictions in monthly values.

The reasons behind these differences could be figured out as follows:

- The HELP model is developed based on water transfer between waste layers and does not have the capability to model drain channels (Ramke, 1991). The drain channels are formed in the waste body because of non-homogeneity of void dispersion in the waste body. The water will flow easier in the parts with more voids in them. These parts will be attached together and form preferential drain channels which transfer the water in waste body. Since, HELP model cannot recognize this phenomenon a retention effect

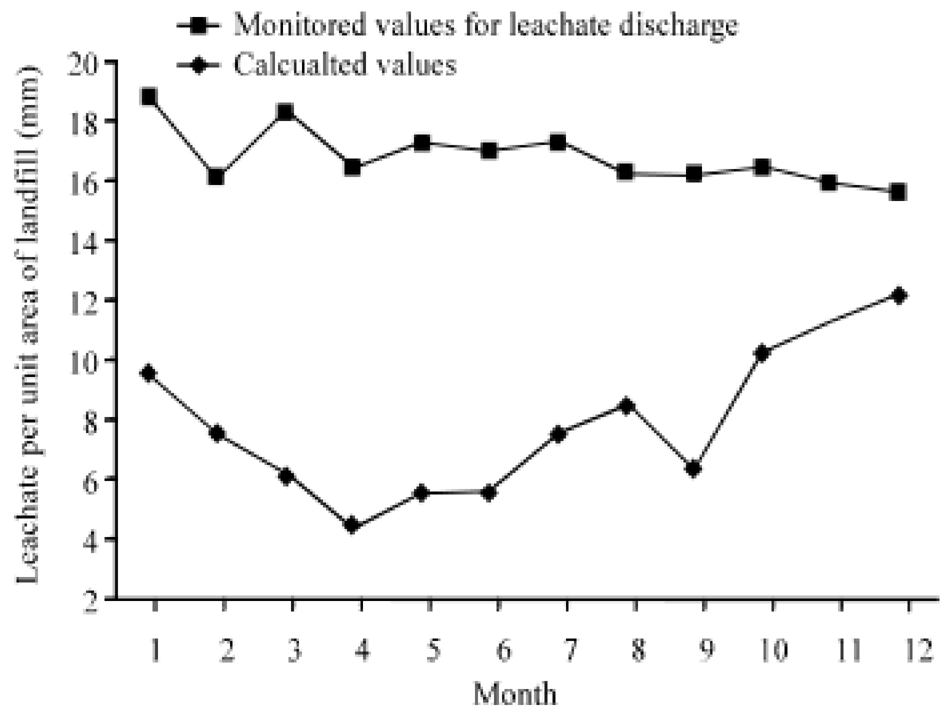

Fig. 7: Calculated values by HELP versus monitored values in cell-2

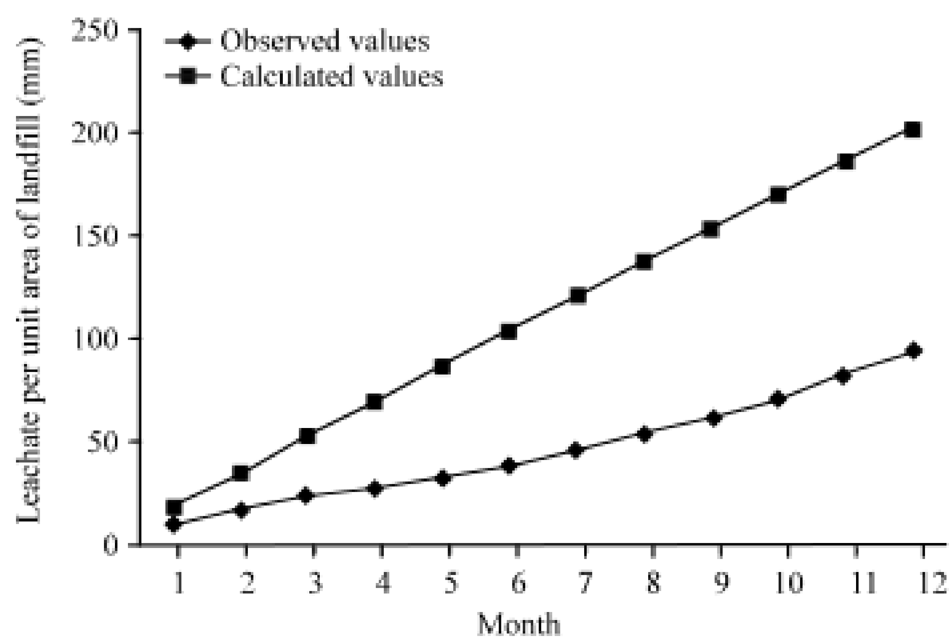

Fig. 8: Accumulated calculated values by HELP versus monitored values in cell-2

will be considered by this program which does not exist in reality, so the leachate will flow out much faster in reality than modeled in the HELP

- The weather station has 30 km distance to the landfill cells that may cause some deviations in calculated results, especially in monthly and daily basis. That is similar to the situation in practice when one may only use the nearest weather station in Iran or other developing countries when designing leachate treatment facilities

An ongoing research is now being implemented for solving above-mentioned problems by using an on-site weather station and also application a balance method instead of layer model (such as HELP).

An important issue that could lead us to better understanding of this contradiction is to investigate the remained moisture content after one year of simulation. The moisture content should be at minimum equal to field capacity based on field capacity definition, unless a suction force exists on the layer beneath. The calculated values were in the range 0.15 to 0.19 (v/v) (while the field capacity assigned to the waste was 27%) and the value of the residual moisture content decreased with depth which is contradictory to definition of field capacity. This will be discussed later in the text when we focus on the cell with leachate recirculation.

Although, we can confirm that in one annual hydrological cycle the total leachate discharge is predicted with acceptable precision in cell-1.

In cell-2, however more contradictions in the results can be noticed.

Based on the HELP analysis made for cell-2 the landfill does not store any water in itself and simply transfers the water from recirculation or precipitation to leachate drainage system. But in real test cells the water is stored in the landfill rather than being transferred to the leachate drainage system; therefore the leachate discharged values observed in the test site are much lower than what is calculated by HELP.

Again we come back to monitor the residual moisture content of the waste at the end of 1 year modeling period. This was surprising to see the moisture contents were much less than field capacity and in the same range of values calculated in the first cell without leachate recirculation that was in contrast to our definition of field capacity.

An effort was performed to see if the residual moisture content can be changed by increasing the field capacity, but this had a minor effect on the output values. When we decreased the hydraulic conductivity of bottom drainage system the residual moisture content increased so our primary assumption that suction from bottom layer caused this deviation was confirmed. To make sure that such assumption is correct a review on the engineering documentation of the HELP was carried out and the following text cleared the real reason behind deviations.

Drainage downward by soil suction exerted by dry soils lower in landfill profile is modeled as Darcian flow for any soil having relative moisture content greater than lower soils. The drainage rate is equal to unsaturated hydraulic conductivity computed as function of soil moisture content. As such the rate is assumed to be independent of pressure gradient.

This can explain what is happening in the bottom drainage layer when there is a considerable storage capacity in landfill. The HELP model calculates water balance parameters on daily basis. In a day when there is no water in waste layer excessive to field capacity the drainage layer goes dry and immediately develops suction because it is dryer than the waste layer above. That will cause the water going out of the waste layer although no considerable inflow exists or storage capacity overran. This does not happen in reality when a layer of sand is dryer than the waste layer above the moisture will not come down until the time that both have same moisture content and that is a reason why the residual moisture calculated are not correct and consequently the amount of leachate discharge is not accurate.

In our situation two main local features aggravated above-mentioned deviation:

- The large amount of leachate recirculation mobilized the storage capacity of the landfill, thus the suction which nullifies the effect of field capacity demonstrates a greater influence
- The depth of the test cell was not high therefore the suction of the leachate drainage layer could affect main waste body of the landfill

Regarding cell-2 where the large difference exists between the accumulated discharges calculated by HELP and observed values, the reason seems to be more severe than artificial suction considered by model. The difference can only be explained assuming different concept of field capacity from what is assumed in HELP model.

The results gained by study in cell-1 without any recirculation shows that the leachate prediction in arid areas can be predicted with a good accuracy in annual basis but for the monthly values a factor of 1.7 should be applied as safety factor. This factor of safety can be resulted from Fig. 5 where the maximum difference between calculated values and observed values is around 70% of the real value.

But when the infiltration to the landfill increases due to leachate recirculation, HELP model tends to underestimate the storage capacity of landfills and long deviations will happen from real values. The main reason for this deviation is the development of the suction in leachate drainage layer in the bottom of landfill, in turn when it turned dry the decrease in water content of the waste is lower than predicted field capacity.

The researchers believe by removing such malfunction, the deviation in the values calculated by HELP model, will decrease drastically although other limitations like neglecting channeling phenomena will also cause some error in leachate prediction.

Although, some major deviations from real values has been reported about the calculated results by HELP model but other researchers and/or people in field practice have used it in some places. This study confirms these deviations in model output and also delineates some causes for them.

It should be noticed that the conclusion of this research came from limited number of field test which cannot be representative for heterogeneous nature of municipal solid waste and further investigation in this regard is advised to get better understanding of landfill hydrologic performance.

ACKNOWLEDGMENT

This research was financially supported by President Deputy for Strategic Planning and Control (former Iranian Management and Planning Organization) and Organization of Material Recycling and Composting of Tehran city.

REFERENCES

ASTM D2980-04, 2004. Standard test method for volume weights, water-holding capacity and air capacity of water-saturated peat materials. http://www.astm.org/Standards/D2980.htm.

ASTM D2434, 2006. Standard test method for permeability of granular soils (Constant Head). http://www.astm.org/Standards/D2434.htm.

ASTM D6836, 2008. Standard test methods for determination of the soil water characteristic curve for desorption using a hanging column, pressure extractor, chilled mirror hygrometer and/or centrifuge. http://www.astm.org/Standards/D6836.htm.

Berger, K., 2003. Validation and enhancement of the HELP model to simulate the water balance of the surface covers. Proceeding Sardinia 2003, 9th International Waste Management and Landfill Symposium, Oct. 6-10, CISA, Environmental Sanitary Engineering Center, Italy.

Gisbert, T., C. Bloquet, G. Barina and C. Pettitpas, 2003. Assessing the quantity of leachate: A simple tool for short and long term prediction and evaluation on real size landfill sites. Proceeding Sardinia 2003, 9th International Waste Management and Landfill Symposium, CISA, Environmental Sanitary Engineering Center, Italy.

Mahdipoor, A., 2003. Seasonal Statistical Report for Tehran Waste Management System. Organization of Waste Recycling and Composting (OWRC) of Tehran, Iran, Tehran, pp: 8-15.

Ramke, H.G., 1991. Hyraulische beurteilung und dimensionierung der basisentwasserung von deponien fester siedlungsabfalle-wasserhaushalt, hydraulischenennwerte, berechnungsverfahren. Doctoral Thesis, Technical University of Carlo-Wilhelmina in Braunschweig.

Richardson, G., 1994. Design, Operation and Closure of Municipal Solid Waste Landfills. Diane Publishing Co., New York, ISBN-10: 0788114190.

Richardson, G.N., J.P. Giroud and A. Zhao, 2000. Design of lateral drainage systems for Landfills, Published article on the web. pp: 22. http://www.tenaxus.com/landfills/designinformation/designinfo/technicalpapers/designman.pdf.

Safari, E. and C. Baronian, 2002. Modeling temporal variations in leachate quantity generated at Kahrizak Landfill. Proceedings of International Environmental Modeling Software Society, (IEMSS'02), Faculty of Environmental Engineering, University of Tehran, Tehran, Iran, pp: 482-487.

Schroeder, P.R., C.M. Lloyd, P.A. Zappi and N.M. Aziz, 1994a. Hydraulic evaluation of landfill performance (HELP) model partial users guide for version 3. EPA/600/R-94/168a, September 1994, U.S. Environmental Protection Agency Office of Research and Development, Washington, DC. http://el.erdc.usace.army.mil/elmodels/pdf/help3use.pdf.

Schroeder, P.R., T.S. Dozier, P.A. Zappi, B.M. McEnroe, J.W. Sjostrom and R.L. Peyton, 1994b. The hydrologic evaluation of landfill performance (HELP) model: Engineering documentation for version 3. EPA/600/R-94/168b, September 1994, U.S. Environmental Protection Agency Office of Research and Development, Washington, DC. http://el.erdc.usace.army.mil/elmodels/pdf/help3doc.pdf.

Vlyssiddes, G., C. Israilidies, M. Loizidou, D. Fatta, sP.K. Karlis, D. Arapoglou and A. Papadopoulos, 2003. Quantification of water balance parameters and characterization of leachates for two municipal Landfills sites in Athens, Greece. Proceeding of the Sardinia 2003, 9th International Waste Management and Landfill Symposium, Published by CISA, Environmental Sanitary Engineering Center, Italy.