Journal of Engg. Research **Vol. 5 No. (1) March 2017 pp.** *89-104*

التقييم الكمي للمخاطر البيئية للراشح الناتج من مردم نفايات مغلق –دراسة حالة

أنور فيصل الياقوت

قسم الهندسة المدنية – جامعة الكويت

من الملاحظ أن الوعي بين الجمهور تجاه حماية البيئة آخذ في الارتفاع. وكذلك الجهات المعنية لحماية البيئة في العالم وفي الكويت على وجه الخصوص مهتمة بتحديد المخاطر الناتجة من دفن النفايات في المرادم وخاصة المغلقة. في هذه الدراسة، تم إجراء التقييم الكمي لمخاطر العصارة الناتجة (الراشح) من دفن النفايات في المردم المغلق الواقع في الصليبية وذلك أثناء القيام بدراسة الوضع الراهن للموقع. وتستخدم دراسات التقييم الكمي للمخاطر على نطاق واسع لإدارة القضايا البيئية. وقد أجريت هذه الدراسة لتقييم تلوث المياه الجوفية نتيجة لتولد الراشح فى الموقع. وعليه تم حفر ثلاثة آبار جديدة ومراقبتها، بالإضافة إلى الآبار القديمة الموجودة في المردم. وتم جمع وتحليل عينات مياه الرشح من الآبار. وأشارت النتائج عن وجود تركيزات عالية من النترات والكبريتات والحديد والمعادن الأخرى في عينات مياه الرشح. وبينت دراسة التقييم الكمي للمخاطر أن عددا من عينات مياه الرشح قد تجاوز التراكيز المسموح فيها، مما يثير المخاوف من تلوث وتسمم موقع الردم في الصليبية.

Quantitative environmental risk assessment of leachate from a closed landfill – A case study

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ABSTRACT

Awareness of environmental protection among the public is on the rise. The regulatory bodies in the world and especially in Kuwait are concerned with identifying the risks posed by closed landfill sites. In this study, quantitative risk assessment for the leachate generated from Al-Sulaibiya closed landfill in Kuwait was carried out after conducting a site investigation. Risk assessments are widely used to manage environmental issues. This study was conducted to assess the groundwater contamination due to landfill leachate. Three boreholes were drilled, in addition to the existing old boreholes at the landfill site. Leachate samples were collected and were analyzed. The results of analyses indicated high concentrations of nitrate, sulfate, iron, and other metals in the leachate samples. The quantitative risk assessment indicates that a number of leachate samples exceeded the contamination limits, raising concerns about the contamination and toxicity at the landfill site.

Keywords: Contamination; environmental risk assessment; leachate; unlined landfill.

INTRODUCTION

Risk assessments are conducted for a number of reasons, including: to establish whether an ecological risk exists or not; to identify the need for additional data collection; to focus on the dangers of a specific pollutant or the risks posed to a specific site; and to help develop contingency plans and other responses to pollutant releases. Risk assessment studies are an important part of the US Environmental Protection Agency's (USEPA) Superfund program and play a key role in the development and implementation of new environmental regulations (USEPA, 2002).

Landfills have been the main part of waste management system in Kuwait since the 1970's. Currently, Kuwait Municipality is responsible to remediate 13 closed landfills to reduce their risk. A typical closed landfill in Kuwait is likely to be uncapped, have no lining and no leachate or gas collection system. The landfill may have been closed for a long period of time and local knowledge of the operation or characteristics of the landfill (e.g. depth, geology, and type of waste) is usually lacking. A closed landfill site that lacks proper monitoring plan to assess the potential for emissions of gas or leachate, will be difficult to evaluate its likely risk to the environment or human health. The regulatory bodies in the world and especially in Kuwait are concerned with identifying the risks posed by closed landfill sites.

Risk assessment provides a structured mechanism for deciding if contamination poses unacceptable risks to people, their property or the environment and making judgments about how best to manage these risks (Environmental Agency, UK, 2000). Risk assessments can be used to describe a wide range of procedures from a very simple statement about possible hazards and risks, to highly formalized, quantitative procedures. In the technical literature, risk assessment is usually considered as a systematic means of developing a scientific basis for regulatory decision-making

(Petts, 1998). To achieve maximum protection to the environment against the hazards associated with landfill sites, all potential hazards must be identified and risks associated with them be assessed. Therefore, risk assessment is increasingly being applied to landfill sites, at the planned, operational or completed stage (Environment Agency, 2003a).

In order to establish the risk assessment approach, in this study, Al-Sulaibyah closed landfill site was selected as a case study to develop a screening methodology for closed landfill sites in Kuwait. Al-Sulaibyah landfill site is located in Amghara area about 20 km north of Kuwait City and about 1.5 km from the Gulf shoreline. The site has an area of about 2.76 km^2, and is located next to the heavily populated Saad Al-Abdullah (residential), and Amghara (industrial) areas. The site was used for dumping different types of wastes such as municipal solid waste (MSW), construction and demolition waste, liquid waste, etc. Moreover, the landfill is unlined without any designed leachate and/or gas collection systems.

RISK ASSESSMENT CONCEPTS

The potential pollutant linkages at a site are usually illustrated within a site conceptual model (DOE, 1995c). Figure 1 illustrates the source-pathway-target chain in relation to a landfill. Having established what pollutant linkages are present or are likely to be present at the site in question, further risk assessment is required to establish whether these pollutant linkages are significant. In developed countries like UK, New Zealand and Australia, a tiered approach to such risk assessments is usually adopted. This generally involves a qualitative risk assessment, followed, where necessary, by either a *generic quantitative risk assessment* or a *detailed quantitative risk assessment*.

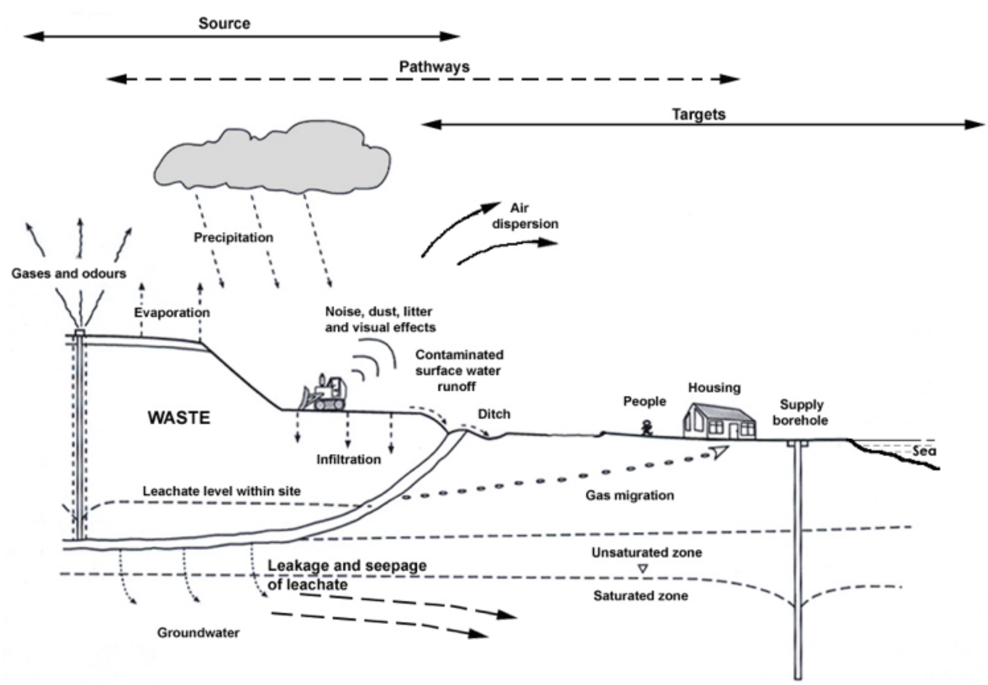

Fig. 1. Conceptual model of linkages between landfill exposure sources, environmental pathways and targets (modified after DOE, 1995c).

Quantitative risk assessment

Quantitative risk assessments are carried out in a sequence of ever-increasing data quality and ever-decreasing conservatism, focusing on potentially significant pollutant linkages remaining within the conceptual model.

This sequence may be described as a series of tiers:

- Comparison against conservative generic assessment criteria – Generic quantitative risk assessment.
- Comparison against less conservative assessment criteria derived specifically for that site - Detailed quantitative risk assessment.

A number of different ways of sub-dividing these tiers have been proposed in various documents, but the details are not as important as the principle of a step-wise approach.

Generic quantitative risk assessment (GQRA)

This involves the comparison of site concentrations of contaminants in soil, water or gas/vapour samples with generic assessment criteria, which are assumed to represent "safe limits". Historically, GQRA was typically restricted to comparing the concentration of contaminants in soils with values taken from sources such as the Iinterdepartmental Committee on Redevelopment of Contaminated Land (ICRCL) Guidance note 59/83. These generic assessment criteria can be replaced by the soil guideline values (SGVs) derived by DEFRA (2003), which are intended to be conservative values representing levels of contaminant in soils below which it can be assumed that no risk to human health exists. Initially, SGVs have been produced for a limited number of metallic contaminants, but it is anticipated that values will be derived for a much wide range of contaminants in the future. It should also be noted that, it is necessary to consider risks to other receptors, such as surface and ground waters, ecosystems and buildings/building materials. Generic assessment criteria designed to protect these receptors and guidance on their use have also been produced by a variety of sources.

Detailed quantitative risk assessment (DQRA)

Where the comparison of site concentrations with generic assessment criteria indicate that a pollutant linkage may still pose an unacceptable risk, or where no generic criteria exists, two courses of action are possible:

- Implement risk management measures to ensure that the risk is adequately mitigated.
- Undertake further detailed quantitative risk assessment to determine, if the risk is significant.

Detailed quantitative risk assessment involves the gathering of additional site data usually relating to soil and groundwater processes that affect contaminant fate and transport. This data can be used to reduce the level of conservatism in the generic assessment criteria used in GQRA. This allows site-specific assessment criteria to be derived to accurately represent the levels of contamination that pose a risk at that particular site. These can be compared with site concentrations of contaminants to identify, if they continue to represent a significant risk.

A risk assessment tool or model is usually employed to derive site-specific assessment criteria. These use mathematical algorithms to predict the likely exposure of the receptor based on the data and assumptions input into the model. One such model is the Contaminated Land Assessment Model,, which has been developed by DEFRA (Department for Environment, Food and Rural Affairs) and the Environment agency in order to derive the UK soil guideline values.

SITE DESCRIPTION AND CHARACTERISTICS

Al-Sulaibyah landfill site is located upstream of wastewater-irrigated farms and near to the heavily populated Saad Al-Abdullah, Jahra and South Doha residential areas. The ground surface elevation varies between 16 and 26 m above mean sea level (AMSL). The landfill site is approximately 2.76 km^2 in area. The landfill was operated from 1982 to 2005. The site was used for dumping different types of wastes such as municipal solid waste (MSW), construction and demolition waste, and liquid waste, etc. It is an 'unlined' landfill and not designed with leachate or gas collection systems. According to Kuwait Municipality (KM, 2003), Al-Sulaibyah landfill site received 351,335 tons of municipal solid wastes; 84,000 tons of agricultural and commercial wastes; 521,490 tons of construction and demolition waste; and 264, 000 gallons of liquid waste. Al-Yaqout & Hamoda (2003) evaluated the leachate at Al-Sulaibyah landfill site and reported that considerable quantities of leachate are formed due to several reasons, despite the arid climatic conditions. Such leachate migrates to the water table beneath the landfill, thus contaminating the soil and the aquifer. The local environmental parameters like climate, soil and hydrology are important for the risk assessment of the landfill leachate.

General Characteristics: The ambient temperature, which ranges between 20^{o}C and 50^{o}C affects the generation of leachate and its characteristics. The annual average rainfall in Kuwait is 120 mm, which is considered not a significant factor in leachate generation. Al-Yaqout & Townsend (2001) reported that the calculated values of climatic water balance based on the precipitation and pan-evaporation data were negative even in the wettest seasons. The main characteristic of Kuwait's hydrologic state is the superiority of potential and actual evaporation compared with available precipitation. As a result, the total rainfall is neither sufficient for groundwater recharge, nor to support sustained flow of streams or rivers. There is barely any runoff of rainfall to the sea, and precipitation mostly evaporates or percolates into the ground. Therefore, the main natural water sources in Kuwait are limited to the brackish groundwater, which is located in the Kuwait Group and the Dammam limestone aquifers. The surface of Kuwait is formed of sedimentary rocks and sediments ranging from early Miocene to Recent (Fuchs et al., 1968). The surface topography of Kuwait is generally flat or gently undulating desert plain (sandy and gravelly), sloping toward the sea, with low isolated hills, escarpments, and shallow closed depressions. The mainland of Kuwait slopes gently towards the sea at an average gradient of 1 in 500 (Saeedy & Abu-Eid, 1984).

The upper aquifer sequence in Al-Sulaibyah landfill is composed of the undifferentiated, fluviatile, clastic sequence of the Kuwait Group. Two sediment types within the Al-Sulaibyah

Landfill were reported by Al-Senafy et al. (2003). These sediments are sand and gravelly sand, with sand being the most dominant deposit. These deposits were affected by the calcretization process in a heterogeneous manner (Al-Senafy & Al-Fahad, 2000). The precipitation of authigenic calcite within the pore spaces and its gradual replacement of the original framework minerals were responsible for the consolidation of the originally friable sediments and their alteration to hard calcareous rocks. Hard horizons of the deposit were encountered, generally at depths between 7 and 15 m below the ground surface. Clayey horizons were not encountered within the lithology of Al-Sulaibyah landfill (Al-Senafy et al., 2003; Al-Yaqout, 2003).

Groundwater flow and Quality: the depth to the water table from the ground surface at Al-Sulaibyah landfill, varied between 4 m in the northern edge to about 12 m at the southern edge. Flow direction was similar to the regional flow direction towards the northeast (Al-Senafy et al., 2003; Al-Yaqout, 2003; Al-Yaqout & Hamoda, 2003). Concentrations of most of the major groundwater constituents of Al-Sulaibyah landfill exceed the drinking water limits recommended by the World Health Organization (WHO), the US EPA and Kuwait's EPA. The pH values were around neutrality, ranging between 6.86 and 8.15. The total dissolved solids (TDS) concentrations ranged between 2,000 and 10,000 mg/l (Al-Senafy et al., 2003).

Leachate Study: Al-Yaqout (2012) investigated the subsurface conditions at Al-Sulaibyah landfill site by drilling 10 test boreholes and carried out tests on soil samples collected at different depths, in order to determine the chemical characteristics of solid waste. It was observed from site visits that only seven boreholes (designated as BH-C to BH-I) existed now in acceptable conditions, and the other three boreholes were missing or damaged. From these seven existing old boreholes, another two boreholes (BH-H and BH-I) were dried up.

In this study, leachate is considered the main source of groundwater contamination at Al-Sulaibiyah site, in which groundwater is the main receptor being contaminated through the soil (pathway). Thus, further site investigation was carried out by drilling three additional boreholes to monitor the leachate characteristics, as part of the objectives.

SITE INVESTIGATION AND TESTING

Drilling boreholes

In this study, three new boreholes were drilled (designated as BH-1, BH-2 and BH-3), in a direction approximately perpendicular to the previously drilled boreholes (Figure 2). From each test borehole, solid waste samples were collected at regular depth intervals of one meter through the entire depth. BH-1 and BH-2 were drilled up to a depth of 20 m, whereas BH-3 was drilled up to a depth of 15 m. The samples were extracted using standard split spoon sampler according to ASTM D 1586-67 (ASTM, 2000), which is used to obtain disturbed samples in connection with the standard penetration test (SPT). The SPT was performed by driving the split spoon sampler with a 63.5 kg hammer and a drop height of 76 cm. Samples were also obtained from the boreholes to be analyzed chemically in the lab. The soil and ground water conditions encountered in the test boreholes were evaluated and are presented in the form of logs of boring. A representative bore log is shown in Figures 3a and 3b (BH-2). The depth to the water table from the ground surface varied between 4.9 and 6.5 meters. The pH values of ground water ranged between 7.27 and 8.42.

Leachate samples were collected from the five existing (old) boreholes (BH-C to BH-G) and the three new boreholes (BH-1 to BH-3), and were transported to the laboratories at Kuwait University. The environmental investigations were carried out to determine the leachate quality in the landfill. The investigations included determining physical and chemical parameters of soil and leachate samples collected from the boreholes. The aim of sampling and testing was to identify the properties of soil and leachate, so as to determine the levels of contamination.

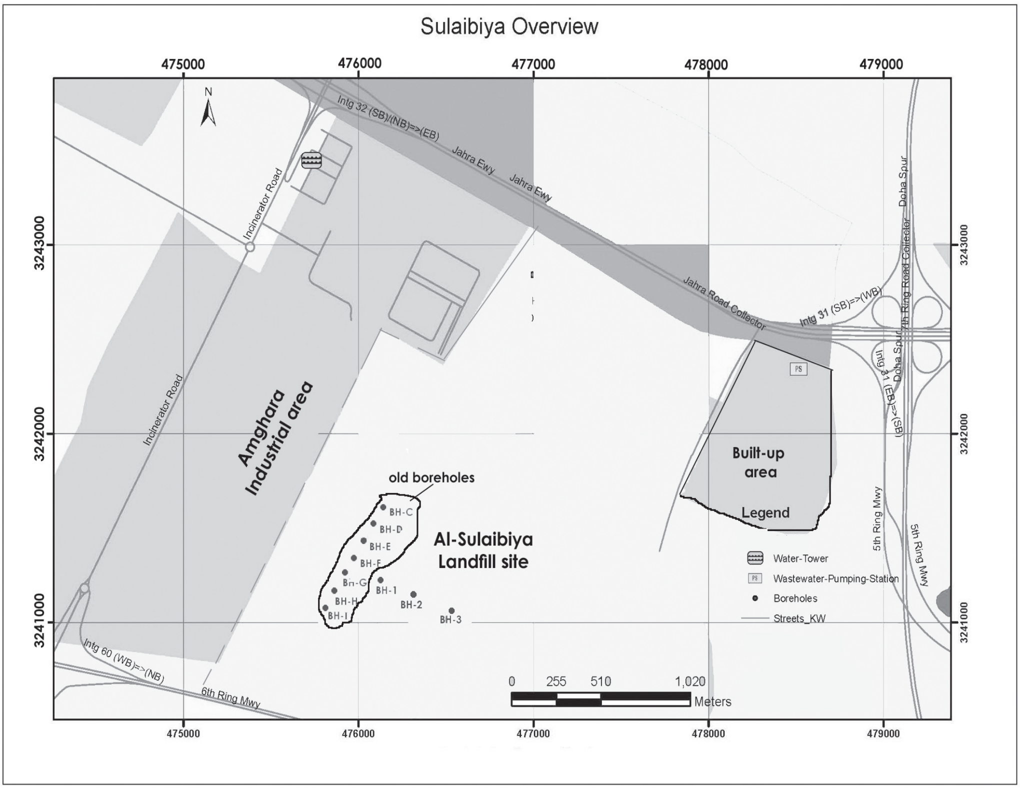

Fig. 2. Location of old and new boreholes drilled at Al-Sulaibyah landfill site.

Drill Rig No.: **CME45**	Boring Method: **Augering**	Boring Diameter: **125 mm**	Location: **Sulaibiya**
Date Started: **15/07/2009**	**Date Completed: 15/07/2009**	Operator: **J.J.P.**	Job Order No.: **05874**

Scale (m)	Samples: Type	Number	Symbol	Depth (m)	SPT Records – Field Records: 0-150 mm	150-300 mm	300-450 mm	N Blows	SYMBOLS: Legend	USCS	Description	Elevation (m)	Ground Water Level (m)
0												4	
1	SPT	1		1 - 1.45	2	8	7	15			Medium dense, grey, fine **silty SAND**, with waste debris, strong reaction with dilute hydrochloric acid, dry, with tiles & concrete fragments.	3	
2	SPT	2		2 - 2.45	18	21	17	38			Becomes dense, greyish brown with gravel fragments, moist.	2	
3	SPT	3		3 - 3.15	25	50/0	-	50/0			Becomes very dense, encountered hard possible debris material (no recovery).	1	
4	SPT	4		4 - 4.35	24	22	28/5	50/20			(No recovery).	0	G.W.L. **4.60** (m)
5	SPT	5		5 - 5.45	25	18	16	34			Becomes dense.	-1	
6	SPT	6		6 - 6.45	5	3	7	10			Becomes loose, dark grey with debris of waste material, wet.	-2	
7	SPT	7		7 - 7.45	7	9	11	20			Becomes medium dense with wood, concrete, aggregate, roots, plastic and tile fragments.	-3	
8	SPT	8		8 - 8.45	8	12	13	25			Becomes pale brown, fine to medium grained **SAND with silt**, weak reaction with dilute hydrochloric acid, moist, with foul odor.	-4	
9	SPT	9		9 - 9.45	11	12	14	26				-5	
10													

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Note:
The measured G.W.L. is approximate and has been recorded immediately after completion of drilling.
For more accurate determination of G.W.L., installation of piezometer(s) is highly recommended.
Dilute HCL Testing Per ASTM D2488, Clauses 10.6 &14.2.5 for checking the presence of CaCO3 which may indicate false soil strength

SAMPLE KEY
- SPT : Standard Penetration Test
- D & M : Dames & Moore Sampler
- B : Bulk Sample
- CORE : Core Sample

- ▼ Ground Water Table
- G.W.L.: Ground Water Level
- E.G.L.: Existing Ground Level
- E.E.L.: Existing Excavation Level

Logged By : S.A.A. — Checked By : R.Q.V.

PLATE A3.2.0

Date: 16/07/2009	Boring Method: Augering	Dia: 125 mm	Ground level (m): 4.349
Risk Assessment Study in Closed Unlined Landfill in Kuwait		KTM Coordinates: N 3,242,462.195 E 477,220.307	
College of Engineering, Kuwait University		Location: Al-Sulaibyah Landfill.	
		Log of Boring	**BH-2** Page: 1/2

Fig. 3a. Log of borehole 2 (BH-2)

Scale (m)	Type	Number	Symbol	Depth (m)	0-150 mm	150-300 mm	300-450 mm	N Blows	USCS	Description	Elevation (m)	Ground Water Level (m)
10	SPT	10		10 - 10.45	10	13	15	28	SP-SM	Medium dense, pale brown, fine to medium grained **SAND with silt**, strong reaction with dilute hydrochloric acid, moist with foul odor.	-5.7	
11	SPT	11		11 - 11.45	10	14	20	34	SW-SM	Dense, greyish brown, fine medium grained **well graded SAND**, strong reaction with dilute hydrochloric acid, moist with foul odor.	-6.7	
12	SPT	12		12 - 12.45	8	12	21	33				
13	SPT	13		13 - 13.45	14	20	22	42				
14	SPT	14		14 - 14.22	25	50/7	-	50/7	SP-SM	Very dense, greyish brown, fine to medium grained **SAND with silt**, strong reaction with dilute hydrochloric acid, moist.	-9.7	
15	SPT	15		15 - 15.21	25	50/6	-	50/6		Becomes pale brown.		
16	SPT	16		16 - 16.32	25	40	10/2	50/17				
17	SPT	17		17 - 17.37	10	26	24/7	50/22		Becomes weak reaction with dilute hydrochloric acid.		
18	SPT	18		18 - 18.33	12	31	19/3	50/18				
19	SPT	19		19 - 19.32	20	39	11/2	50/17				
20												

Note:
The measured G.W.L. is approximate and has been recorded immediately after completion of drilling.
For more accurate determination of G.W.L., installation of piezometer(s) is highly recommended.
Dilute HCL Testing Per ASTM D2488, Clauses 10.6 &14.2.5 for checking the presence of CaCO3 which may indicate false soil strength

SAMPLE KEY
SPT : Standard Penetration Test
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Logged By : S.A.A. | Checked By : R.Q.V.

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PLATE A3.2.1

Date: 16/07/2009	Boring Method: Augering	Dia: 125 mm	Ground level (m): 4.349	
Risk Assessment Study in Closed Unlined Landfill in Kuwait		KTM Coordinates: N 3,242,462.195 E 477,220.307		
College of Engineering, Kuwait University		Location: Al-Sulaibyah Landfill.		
		Log of Boring	**BH-2**	Page: 2/2

Fig. 3b. Log of borehole 2 (BH-2). (contd…)

The laboratory testing program covered the range of contaminants following the British Standards (BS) and ASTM standards. After preparation of soil and leachate samples, analytical methods followed those procedures specified in the Standard methods (APHA, 1998). A total of 30 chemical parameters for the leachate samples, and 26 parameters for the soil samples were determined. The chemical parameters included pH, conductivity, TDS, BOD, COD, TOC, Cl, SO_4, NO_3, Al, Ca, Fe, K, Mg, Na, Sr, Boron, V, Cr, Co, Ni, Cu, Zn, As, Mo, Cd, Ba, Hg, and Pb.

Data analysis

Subsurface conditions: Subsurface conditions at the site are somewhat variable, but in general the subsurface consists of top soil underlain by a mixture of waste material and granular soils. The top soil layer consists of dense to medium dense, pale brown, medium grained sand with silt, with waste debris, of a strong reaction with dilute hydrochloric acid, and brick/tile fragments. Top soil depth encountered in the three boreholes is about 0.5 to 2 m. As the depth increases, the soil exhibits a foul odor in all the three boreholes. Below the surficial material, the random fill consists of dense to medium dense grey to dark grey/black sand mixed with silt and waste materials. The refuse was found to contain different types of materials like cloth, rubber, construction debris, plastic and metals. Most of the material exhibited strong odor, even in otherwise refuse-free materials. Based on the borehole logs, the refuse materials extend from 0.5 to 8 m. The water content of the soil samples collected from the three boreholes at 1 m depth was 7 to 8%, and it increased with depth.

Subsurface penetration blows (N) ranged from 4 to 50. The strata with 4 to 6 blows (N) was described as loose, sand mixed with waste materials and gravel fragments. N values ranging from 7 to 10 were described as loose with dark grey colour, irregular waste, and wet material. N values ranging from 15 to 28, the strata was described as contaminated soil with waste, medium dense, odorous and grey colour. In general, for the N values more than 30, the strata was described as dense, fine to medium grained, with brown colour.

Native calcareous deposits underlying the refuse fill were encountered in the three boreholes. These deposits consist of dense, calcareous clayey, fine to medium grained with traces of fine gravel, silty fine to medium sand, irregular cementation with variable hardness, reddish brown. Groundwater observations were made at each of the three boreholes during and upon completion of drilling operations. Groundwater level was encountered during drilling in the three bore holes at depths ranging from 4.9 to 6.5 m below ground surface. Based on water level data (Table 1), Al-Sulaibyah site appears to be a wet landfill in which the leachate quantities are increasing and is likely indicative of perched conditions whereby groundwater is retained in upper soils overlying materials of lower permeability.

Table 1. Water level in boreholes

BH #	Depth of water level from ground surface			
	20/07/2009	07/10/2009	08/11/2009	06/01/2010
New Boreholes				
BH-1	5.82	5.84	5.84	5.75
BH-2	4.94	5.03	5.09	4.95
BH-3	6.44	6.45	6.46	6.37
Old Boreholes				
BH-C	5.32	5.35	5.36	5.35
BH-D	5.07	5.09	5.15	5.05
BH-E	5.10	5.12	5.13	5.01
BH-F	5.71	5.73	5.77	5.74
BH-G	5.65	5.68	5.74	5.68

Leachate chemical characteristics

The landfill leachate is generated as a product of waste decomposition, the water added to the landfill from percolation of waste through the landfill surface, and from upward flow of water through the bottom. Kuwait being an arid country, rainfall is scarce. Therefore, the percolation of water through the landfill is minimal and the leachate is formed primarily by upward flow of rising subsurface water and the high quantity of liquid waste dumped with MSW. The leachate quantity and quality varies widely depending on the age of the landfill and the location of the sampling, due to lack of homogeneity especially in the absence of a leachate collection system as in the case of Al-Sulaibyah landfill.

Leachate samples were collected from five old boreholes and three new boreholes (a total of 8 boreholes), and were immediately sent to Kuwait University laboratories for testing. The summary of the chemical characteristics from leachate samples collected during the six months monitoring period (July 2009 to January 2010) are presented in Table 2.

The pH values of the leachate samples ranged from 7.30 to 8.56, which indicates the alkaline nature of the leachate. The pH of the leachate depends not only on the concentration of acids that are present, but also on the partial pressure of CO_2 in the landfill gas that is in contact with the leachate (Banar et al., 2006). The TDS values were found to be in the range of 2540 – 13270 mg/l in the leachate samples. The electrical conductivity (EC) values show a high range from 5080 to 26,530 µS/cm. Conductivity is used as an indicator of the abundance of dissolved inorganic species or total concentration of ions (Banar et al., 2006). As shown in Table 2, analysis of leachate samples shows high organic strength of leachate as expressed by its BOD and COD. The high quantity of organic material in MSW leachate is reflected by its very high oxygen demand (Kmet & McGinley, 1984). The concentration of BOD for the eight boreholes.

Table 2. Summary of the chemical analyses for the leachate samples

Parameter	New Boreholes				Old Boreholes			
	Min	Max	Mean	S.D.	Min	Max	Mean	S.D.
pH	7.27	8.42	8.06	1.07	7.30	8.56	7.99	0.43
Conductivity	5080	12700	6759.2	3332.2	6860	26530	14541.3	5465.5
TDS	2540	6350	3710	1401.3	3420	13270	7268.5	2734.7
BOD	30	120	70	34.64	60	145	96.33	26.01
COD	227	575	414.4	151.1	758	995	852.9	75.1
TOC	113.2	715.3	393.6	227.4	435.8	2560	1283.94	774.89
Cl	462.30	3571.5	2418.02	1022.84	1807.01	5739.18	3867.5	1217.22
SO_4	812.35	4171.9	2178.9	1243.1	465.24	11950.4	2057.1	2847.1
NO_3	31.0	1985.4	482.6	649.4	0.32	396.78	112.9	118.1
Al	0.03	11.4	1.13	3.4	0.02	0.72	0.22	0.21
Ca	80.26	1800.44	596.42	631.89	29.80	741.13	276.1	236.5
Fe	0.16	1.0	0.45	0.3	0.07	6.21	1.78	2.04
K	124.9	432.42	10.77.9	1646.5	186.49	1307.72	468.64	410.8
Mg	155.2	4519.1	3649.81	1092.8	192.08	939.54	429.85	279.4
Na	297.8	1886.68	9045.1	13859.3	1327.6	5239.9	3137.93	1020.0
Sr	1.5	378.5	151.9	160.0	3.15	14.23	8.11	2.45
B	0.43	14.14	37.3	59.1	3.67	13.86	8.14	3.34
V	0.0	0.39	0.05	0.12	0.01	0.37	0.11	0.11
Cr	0.02	0.05	0.03	0.01	0.01	0.38	0.14	0.12
Co	0.0	0.25	0.04	0.08	0.0	0.06	0.02	0.02
Ni	0.03	1.5	0.36	0.53	0.04	0.31	0.15	0.09
Cu	0.01	0.3	0.07	0.12	0.01	0.05	0.02	0.01
Zn	0.01	1.9	0.28	0.61	0.01	0.1	0.04	0.03
As	0.01	3.14	0.58	1.05	0.07	0.41	0.16	0.11
Mo	0.01	10.8	1.49	3.16	0.01	0.04	0.02	0.01
Cd	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Ba	0.04	1.29	0.3	0.42	0.03	0.58	0.24	0.2
Hg	0.0	0.04	0.01	0.02	0.0	0.01	0.01	0.0
Pb	0.0	0.01	0.01	0.01	0.0	0.03	0.01	0.01

* All units are in mg/l except pH (unit less) and Conductivity (µS/sec) ; S.D. = Standard Deviation.

ranged from 30 to 145 mg/l, with an average value of 86.5 mg/l. Typical BOD concentrations ranged from 50 to 100 mg/l for 15 years old landfill (McBean et al., 1995).

Statistical summary of BOD and COD is presented in Table 3. Further, the concentration of COD for the eight boreholes ranged from 207 to 995 mg/l, with an average of 688.5 mg/l. Typical concentrations for older leachate range between 500 to 3000 mg/l (McBean et al., 1995). Nitrogen, and a wide variety of trace metals were also found in the leachate (Table 2).

The biodegradability of leachate varies with time, as monitored by the BOD/COD ratio. In old, mature landfills, the BOD/COD ratio is often in the range of 0.05 to 0.2 (Tchobanoglous et al., 1993). This was observed at Al-Sulaibyah landfill site where the BOD/COD ratio ranged from 0.08 to 0.30 (Table 3), with most of the samples exhibiting a ratio between 0.08 and 0.20. This shows that the leachate is hardly biodegradable and has a high potential of environmental risk. The values of major cations (Na, K, Mg, Ca and Fe) for leachate are found in significant concentrations. High values of total organic Carbon (TOC) were observed in the leachate samples. TOC detection is an important measurement because of the effects it may have on the environment and human health, as it is a highly sensitive non-specific measurement of all organics present in a sample.

Table 3. Statistical summary of BOD and COD of leachate

Parameter	BOD	COD	BOD/COD ratio
Minimum (mg/l)	30	227	0.08
Maximum (mg/l)	145	995	0.30
Mean (mg/l)	86.46	688.5	0.14
Standard Deviation	31.6	241.67	0.055

GENERIC QUANTITATIVE RISK ASSESSMENT (GQRA)

This section makes use of the site investigation results as described in the previous section to evaluate further the potential pollutant linkages. In GQRA, the concentrations of the parameters measured in soil, water or soil gas are compared with generic assessment criteria (GAC). GAC are typically conservative to ensure that they are applicable to the majority of sites and normally apply to only a limited number of pollutant linkages.

Assessment of leachate

Landfill leachate is the main hazard that affects the quality of groundwater. The Al-Sulaibyah closed landfill is unlined and without any leachate collection system, which means that the leachate is contaminating the groundwater. Although, groundwater is not the main source of fresh water in Kuwait, it is being used for irrigation and other domestic purposes. The assessment criteria used for the screening of leachate parameters are the maximum contaminant level (MCL) values of USEPA for Drinking water, and the environmental quality standards (EQS) released by the Environmental Agency of UK. As per USEPA, the main contaminants in water are arsenic, cadmium, chromium, lead, nickel, zinc, nitrate and boron. Further, elevated levels of chloride and sulfate in water also cause health problems. As shown in Table 4, the concentrations of chloride, sulfate and copper exceeded the criteria in all the leachate samples of Al-Sulaibyah field. Further, nitrate and arsenic in 24 samples, nickel in 26 samples, mercury in 20 samples, chromium in 23 samples, and boron in 15 samples were found to be above the assessment criteria. Figure 4 shows the percentage of respective samples exceeding the screening criteria. Thus the QRA of the Al-Sulaibyah landfill site indicates that the landfill is contaminating the soil and groundwater posing environmental concerns to the authorities.

Table 4. Comparison of leachate quality with the assessment criteria.

Parameter	No. of samples	Screening value	Screening criteria	Min	Max	No. of samples exceeding the criteria
Chloride	27	250	MCL	462.30	5739.18	27
Sulphate	27	250	MCL	465.2	4171.9	27
Nitrate	27	10	MCL	0.32	1985.4	24
Arsenic	27	0.05	EQS	0.01	3.14	24
Cadmium	27	0.005	MCL	-	-	-
Chromium	27	0.015	EQS	0.01	0.38	23
Lead	27	0.025	EQS	0	0.03	1
Mercury	27	0.002	MCL	0	0.04	20
Nickel	27	0.1	EQS	0.03	1.5	26
Copper	27	0.005	EQS	0.01	0.3	27
Zinc	27	5	MCL	0.01	1.9	-
Boron	27	7	EQS	0.43	14.14	15

All concentrations in mg/l.

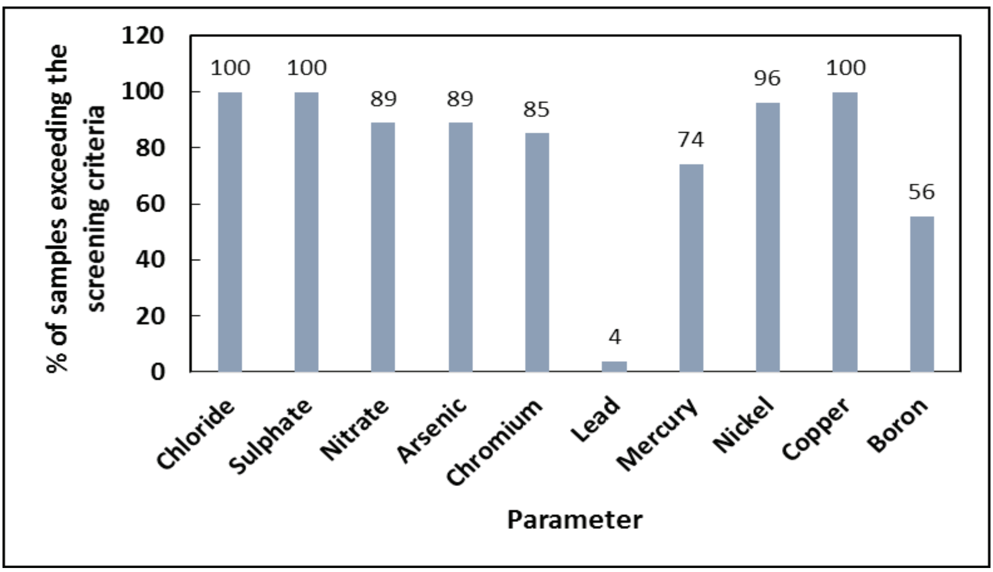

Fig. 4. Percentage of samples exceeding the screening criteria

SUMMARY AND CONCLUSIONS

Closed landfills present a growing risk to the environment and health in general. The risk of each hazard is a function of the contaminated source, containment, transport pathway, and the receptor. An effective approach to assess environmental risk at closed landfills was developed by using a screening analysis based on the inputs that can be observed and determined from existing information.

Site investigations were carried out by drilling three boreholes at the site to assess the groundwater contamination. Leachate samples were collected and were analyzed. Chemical analysis of leachate indicated pH values in the range of 7.30 to 8.56, suggesting the alkaline nature of leachate. The TDS and EC values were found to be in the range of 2540 – 13270 mg/l and 5080 – 26530 μS/cm, respectively in the leachate samples. Further, the chemical analysis showed high organic strength of leachate as expressed by its BOD and COD. The BOD/COD ratio was from 0.08 to 0.30, which indicates the variation of biodegradability of leachate with time. Moreover, high values of TOC were observed in the leachate samples.

A quntitative risk assessment (QRA) was carried out in the third stage. The assessment of leachate indicated that the concentrations of chloride, sulfate and copper exceeded the criteria in all the leachate samples of Al-Sulaibyah field. Further, nitrate, arsenic, nickel, mercury, chromium, and boron concentrations were found to be above the assessment criteria. Thus the QRA of the Al-Sulaibyah landfill site indicates that the landfill is contaminating the soil and groundwater posing environmental concerns to the authorities.

The screening methodology can be applied to any landfill in Kuwait or elsewhere, to assess the risk due to each hazard and can be ranked high, medium or low.

ACKNOWLEDGEMENTS

This study was a part of the research Project EV 04/06, sponsored by Kuwait University. I would like to thank Engineer Pattan Bazieth Khan for his assistance in research activities. Special thanks to the staff of Kuwait Municipality for their cooperation in carrying out the field works at Al-Sulaibyah closed landfill site.

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