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A comparative study of the characterization of landfill leachate at the dumping sites in Kuwait

Saleh M. Al-Muzaini
Environmental Sciences Department, Kuwait Institute for Scientific Research, P.O. Box 24885, 13109 - Safat, State of Kuwait.
e-mail: smuzaini@safat.kisr.edu.kw, smuzaini@live.com

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Abstract

The paper reports the results of a laboratory investigation aimed at evaluating the effectiveness of age of landfill and the degree of stabilization effects on the composition and characteristics of leachates of three different landfills at ages of 10, 20 and 23 years. Landfill leachates at Qurain, Sulaibiya and Jaleeb Al Shoukh solid waste disposal sites were studied by periodically collecting samples through boreholes installed at these sites. The analysis of samples showed high values in all the parameters, however, the levels of heavy metals were low. The presence of heavy metals such as As, Ca, Cd, Co, Cu, Fe, Hg, Mg, Mn, Mo, Na, Ni, Pb, Se, Sn, V and Zn was attributed to the type of solid waste materials dumped at these sites. Leachate values of Cu, Ni and V were high indicating the disposal of predominantly petroleum-related waste at the sites. Yet, the results suggest that a monitoring system such as monitoring wells could be established and treatment facilities should be built to avoid surface and groundwater contamination. Geophysical studies could be conducted to know more about the path of groundwater flow from these landfill sites to the surrounding areas in order to implement effective control systems in the future.

Key words: Environment effect, groundwater, physicochemical composition, waste disposal, water flow, water pollution, water quality.

Introduction

The observation that sanitary landfill leachate may pollute adjacent surface and groundwater has led to a number of studies in order to understand the effect of domestic solid waste disposal on the underground water quality in Kuwait and other regions [7, 30]. Studies have shown that even small landfills can adversely impact the groundwater quality if sites are not properly selected and landfills are not properly designed [11, 25, 36].

Therefore, protecting and preventing groundwater system from contamination have got significant importance for groundwater resources management. Assessment of landfill leachate characteristics is one of the major task for protecting groundwater. As a result of that, intensive monitoring and contamination prevention programs could be applied to delineate the sites that are already contaminated.

In Kuwait, three main landfill sites are operated by municipality for solid waste disposal. These landfills are Jaleeb Al-Shoukh, Sulaibiya and Qurain. The first site at Jaleeb was in operation from 1970 until 2000 and received waste about 2500 tons of waste per day. The site at Sulaibiya received 500 tons of waste per day and was in operation from 1982 until 1995, and the Qurain landfill site received about 1400 tons of waste per day from 1975 until 1985. Presently, the dumping sites were closed due to improper disposal operations and the discomfort faced by the residents from offensive odors being omitted at the landfill sites [3, 8, 9]. Migration of leachate from the sites beyond the site boundaries was noticed and confirmed by local authorities [4, 19]. In Kuwait, the problem of landfill leachate has received attention mainly because groundwater occurs at shallow depths. In fact, a groundwater contamination due to landfill leachate is recognized as a serious problem in Kuwait and worldwide [4, 5, 23]. Local authorities have estimated that in spite of increasing waste reduction policy and recycling processes by local companies, 90% of domestic waste is being disposed to landfill. This means that more landfill sites will be needed and expected that municipal landfills will result in pollution adjacent surface and groundwater.

This has led the environmental authorities to conduct a number of studies on landfill leachate in order to understand its effect on groundwater quality [4, 5, 19]. Several studies have shown potential problems with leachate generation [27, 28, 32, 35]. These studies have also pointed out the concern that the contents of landfill leachate may present a risk to both human and the environment. Parameters such as biological oxygen demand (BOD), chemical oxygen demand (COD), heavy metals and volatile acid concentrations have been measured in landfill leachate with their presence being dependent on the landfill's stage of stabilization [20, 22]. The composition of the leachate depends on the heterogeneity and composition of the waste, the degree of biodegradation, moisture content and operational procedures. Lin and Sah [29] showed that leachates contain toxic constituents and are extremely hazardous to groundwater quality.

Al-Muzaini and Musalamani [7] investigated environmental pollution from landfill sites in north of Kuwait City receiving solid wastes. Field sampling and analysis were carried out and determined that temperature, pH, BOD, ammonia and total organic

carbon (TOC) levels were high. Heavy metals such as Cd, Fe, Ni, Pb, V, Zn and Fe were found in lower concentration in upstream wells than in downstream wells. Al-Yaqout *et al.* [8] reported that solid waste landfills leachate contained high contents of organic matter, heavy metals and nutrients. Keating and Thiem [24] evaluated groundwater contamination due to landfill leachate. Evaluation of the potential impact of such contamination on potable wells could be a difficult task; however, using a numerical computer model, the extent of pollution can be easily evaluated, and contamination from a landfill can be investigated. Landfill leachate contains considerable amounts of dissolved organics and heavy metals, has intense color, and polycyclic aromatic hydrocarbons (PAH) are also present. The quantity and quality of such features could fluctuate to levels that can contaminate groundwater. Analysis of leachate samples for major cations and anions together with trace heavy metals (i.e., Cd, Cu, Fe, Mn, Ni, Pb, and Zn) from four southern Ontario municipal solid waste landfills led to the determination that the leachate samples contained high concentrations of alkali and alkaline earth metals as well as chloride ions. Also, the elemental composition and speciation of landfill leachates is affected by high concentrations of inorganic ligands, primarily chlorine and dissolved organic compounds (DOC) [13]. The composition of the landfill leachate from the same source as well as from different sources is extremely variable. Landfill leachates often contain high concentrations of toxic heavy metals and many of these metals can form strong bimolecular complexes. The leachates from the same sites were found to have genotoxic effect in test systems [12].

The physical and chemical properties of soil and subsurface geologic materials were discussed by Lapauve *et al.* [26], who indicated that knowledge of subsurface geologic and soil properties such as humic materials and type of clay minerals are the most important factors. Murray *et al.* [34] demonstrated from their study and field investigation that groundwater contamination was dominated by a sanitary landfill leachate. Yet, leachate quantities and qualities must be known before a flexible design can be incorporated [33]. Zamora *et al.* [37] and Campbell [14] stressed that many protective measures can be applied to prevent pollution from landfill sites including the design and operation of leachate sites.

The purpose of this article was to present the characteristics of the landfill leachate at the Jaleeb Al-Shoukh, Sulaibiya and Qurain dumping sites, to address the issues related to leachate contamination and to develop recommendations to improve the present situation at these three sites.

Material and Methods

Description of landfill: The Qurain landfill site is located about 15 km southeast of Kuwait City, about 1 km from the shoreline (Fig. 1). The total area of the site is approximately 1 km^2. The site was used for dumping of municipal solid waste and demolition and construction materials from 1975 until 1985. The total volume of the waste dumped is 5 million m^3 of non-homogenous waste.

The Sulaibiya landfill site is located near Sulaibiya industrial area in the west, south of Kuwait City. It receives 500 tons of waste per day. The site was used for dumping of domestic waste and demolition materials from 1980 to 2000. The total area of the site is approximately 3 km^2.

The other site at Jaleeb Al-Shoukh was used from 1970 to 1993 and received about 2500 tons of waste per day. The waste consists of mixture of house refuse and viscous industrial waste. The total area of the site is approximately 6 km^2 [19].

These sites are located on quarries of natural low-permeability soil. Most of the landfill sites were used as a quarry for sand and gravels. They have not been properly selected and have no engineering design or planning. The disposal practice was simply dump the refuse and spread over the land, compacted by landfill compactors into 3 m high layers and then covered the waste with a 0.5 m layer of soil. As soon as the number of refuse layers were in place, a 0.15 m thick layer of clean soil was compacted on the top of the refuse layers. When the site is filled with waste, the operation moves on to another site [6].

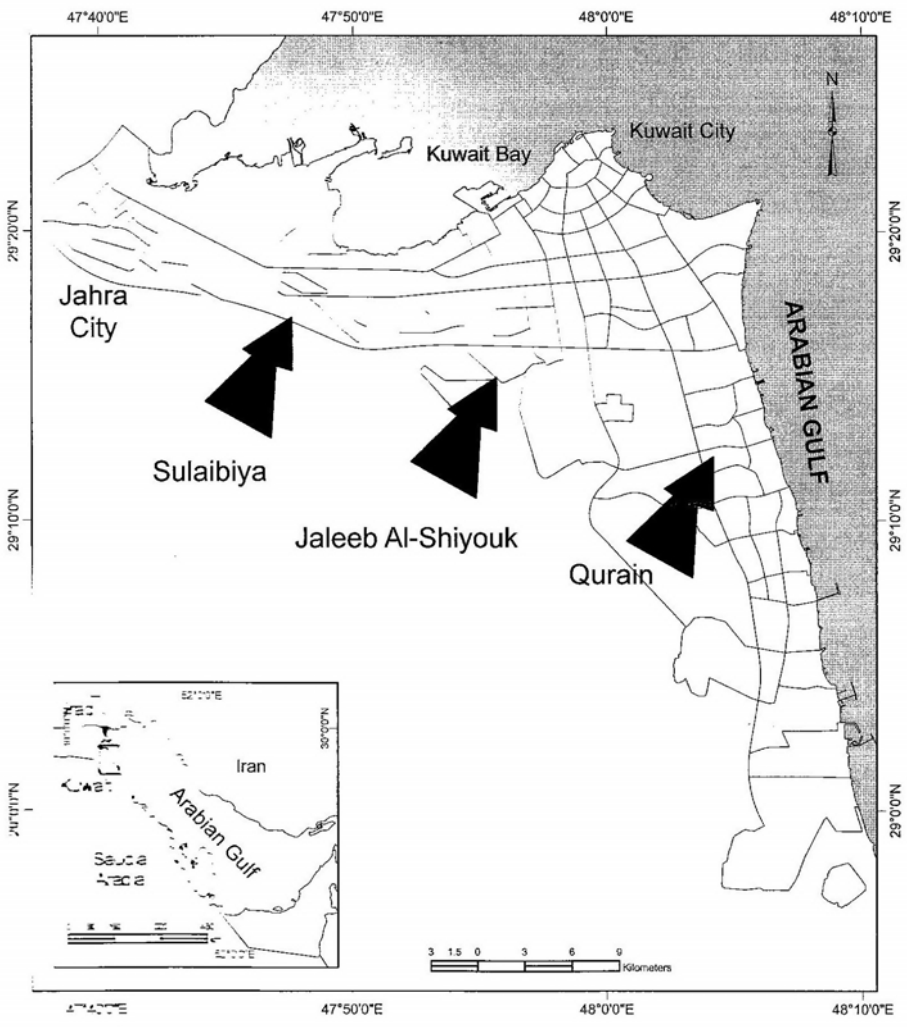

Figure 1. Sampling Sites: Map of the Qurain, Sulaibiya and Jaleeb Al-Shiyouk.

Analytical methods: During the phase of this study, a network of observation wells was established in the landfill sites. Boreholes were installed at three sites for landfill leachate sampling. The pipes used were polyvinyl chloride (PVC) materials and a cemented platform was built at each site. The sampling unit was fabricated using Teflon and stainless-steel rope with PVC pockets. Leachate samples were collected from each site in clean 1-L capacity glass bottles. The duration of sampling was 12 months.

The total dissolved solids (TDS), temperature, pH and conductivity were measured immediately after the collection of samples. In the laboratory, the collected samples were mixed thoroughly and divided in two parts, one for characterizations of landfill leachate and the other for determination of heavy metals. Heavy metal concentrations were determined by ICP- OES Spectrometers, Varian (Varian Australia Pty. Ltd, Australia).

The acidified samples were used for the analysis of heavy metals. The acidification was made by putting 50 ml of sample in a digestion tube, and then 10 ml of HNO_3 (69%) was added. The sample was cooled to room temperature before filtration. After filtration, the sample was collected for heavy metal contents in the solution. Unpreserved samples were immediately used for the analysis employing DR 2800 spectrophotometer [21]. The methods were approved as described in its manual (method numbers identified in parenthesis) for chemical oxygen demand (COD 8000), total suspended solids (TSS 8005), nitrate (8172, 8153), NH_3 (8038), phosphorus (8048), potassium (8049), sulfate (8051), sulfide (8131), bromine (8016), chlorine (8107), chloride (8113), calcium (8030), magnesium (8030), iodine (8031) and turbidity (8232). The instruments were calibrated using reference standards and suitable blanks in order to produce high quality.

Results and Discussion

Data for landfill leachate quality are presented in Tables 1 and 2. The data presents reported average values of 2, 4 and 14 monitoring wells (boreholes) at Jaleeb Al-Shoukh, Sulaibiya and Qurain landfill sites, respectively. The temperature ranged between 20 and 20.7°C, highest average value being 20.7°C at Jaleeb Al-Shoukh. The pH ranged between 8 and 8.9 being higher at Qurain. The observed high pH at Qurain may be due to the high salinity, the decreases in accumulation of short-chain fatty acids and/or increase in the utilization of practically ionized free, volatile-fatty acids by methane bacteria [15, 16]. The conductivity ranged between 3.04 and 23.59 mS cm^{-1}, the highest average value being at Sulaibiya. This indicated a high concentration of ionic solutes in Sulaibiya's boreholes. The concentration of turbidity ranged between 200 and 345 mg/l, while the values of TDS were extremely high at Jaleeb Al-Shoukh landfill site. BOD and COD levels were high as was the COD at Jaleeb Al-Shoukh site, whereas the BOD at this site was high compared to the Sulaibiya site, indicating that a high proportion of readily biodegradable organic materials in solution were present. Other factors that contribute to the variation in quality are solid waste characteristics, composition of waste size of fill and degree of compaction [36]. Nitrate concentrations ranged between 19.61 and 77.5 mg/l. The highest concentration (77.5 mg/l) was recorded at Jaleeb Al-Shoukh site. The concentration of NH_3 (9.03 to 52.7 mg/l) was high at Sulaibiya site. This may cause toxicity effect and odor when wastewater is being discharged [10]. The concentration of phosphorus was almost the same in three landfill sites. Sulfide concentrations ranged between 0.20 and 0.31 mg/l. The concentration of potassium and sulfate were at Jaleeb Al-Shoukh landfill 468 and 165 mg/l. Data was not determined for both Sulaibiya and Qurain landfill sites. The chlorine was present in small amounts at all the three sites. Calcium, magnesium and iodine were found only in Jaleeb Al-Shoukh landfill site. The concentrations were 6.75, 3.02 and 2.23 mg/l.

The data for metal analysis showed high values for calcium, iron, lead and zinc compared to other metals. This is due to the materials dumped there and landfill site contents. Nickel, zinc, cadmium and magnesium were found higher in samples from Sulaibiya site. The levels were comparable at Jaleeb Al-Shoukh and Qurain. Preference two sites the level of mercury was higher in Jaleeb Al-Shoukh than Qurain. Other heavy metals, such as arsenic, cobalt, copper, manganese, selenium, tin and vanadium, were found at low concentrations, possibly due to the age of landfill [31] and solid waste stabilization [36].

In general, the samples from Sulaibiya site contained high leachate concentrations as evident by the values of different parameters, which may be attributed to the contents of the materials dumped at the site. Therefore a comparison of some of the parameters was made with the available data of the brackish water, seawater and groundwater in Kuwait as shown in Table 3.

Table 1. Chemical and physical analysis of the landfill leachate.

	Landfill site		
Parameter	Jaleeb Al-Shoukh	Sulaibiya	Qurain
Age of landfill (years)	23	20	10
Temperature (°C)	20.7	20	20.0
pH (unit)	8.00	8.0	8.9
Conductivity (mS/cm)	13.04	23.59	18.99
BOD (mg/l)	401	93.10	ND
COD (mg/l)	789	334.7	ND
Nitrate (HR) (mg/l)	77.5	19.61	ND
Nitrogen (NH_3) (mg/l)	9.03	52.70	6.71
Phosphorus (mg/l)	1.93	2.0	ND
Potassium (K) (mg/l)	465	ND	2.10
Sulfate (mg/l)	165	ND	ND
Sulfide (mg/l)	0.24	0.20	ND
Bromine (mg/l)	1.47	ND	0.31
Chlorine (T) (mg/l)	0.69	1.20	ND
Chloride (mg/l)	2.38	ND	2.34
Iodine (mg/l)	2.23	ND	ND
Turbidity (mg/l)	345	230	200
TDS (mg/l)	537	15300	1129

Note: BOD Biological Oxygen Demand; COD Chemical Oxygen Demand; TDS Total Dissolved Solids; ND Not Determined; T Total; HR High Rate.

Table 2. Heavy metal concentration in landfill leachate.

	Landfill site		
Constituent	Jaleeb Al-Shoukh	Sulaibiya	Qurain
As	0.01	ND	ND
Ca	6.25	1185	276
Cd	0.01	27	0.05
Cr	0.01	ND	0.15
Co	0.02	ND	0.05
Cu	0.05	ND	0.05
Fe	0.68	4467	2.4
Hg	0.73	ND	0.25
Mg	2.75	1250	0.06
Mn	0.11	ND	0.05
Mo	0.01	ND	ND
Na	ND	ND	2070
Ni	0.03	135	0.05
Pb	0.01	48.3	0.05
Se	0.01	ND	ND
Sn	0.01	ND	ND
V	0.01	ND	ND
Zn	0.03	321	0.20

Note: All amounts are given in mg/l. ND Not Determined.

Table 3. Comparison of brackish water, seawater, portable water and groundwater with landfill leachate at Kuwait.

Parameter	Range in Kuwait	** Brackish water	** Seawater (Doha)	** Groundwater (Rawdatain)
TDS	11000 –53700	3800	4700 ± 2000	239
pH (unit)	8 – 9	7.7	8.2 ±0.1	-
Conductivity(mS/cm)	3 – 24	5000	-	-
NH_3	9 – 53	0.02	-	-
Potassium (K)	0 – 468	14	470 ± 20	4
Sodium (Na)	0 – 2070	540	12300 ± 20	9
Chloride	0 – 2	1100	2400 ± 700	9
Sulfate (SO_2)	0 – 165	1170	3400 ± 300	22
Magnesium (Mg)	0.06 – 1250	150	1700 ± 150	7
Calcium (Ca)	6 – 1185	430	570 ± 45	45
Iron (Fe)	1 – 4467	0.6	0.08 ± 0.08	-

* This study **Al-Awadi (1998) - No reading All amounts are given in mg/l.

Table 4. Comparison of some parameters of grounwater in a residential area of Kuwait (Al-Rawda) with leachate at landfill sites.

Parameter	A Range in Kuwait	B Al-Rawda well No. RW 01	B Al-Rawda well No. RW 02	B Al-Rawda well No. RW 04	B Al-Rawda well No. RQ 05
Depth (m)	15 – 30	0 – 100	0 – 105	0 – 100	0 – 100
TDS (mg/l)	537 – 15300	6218 – 6948	3968 – 4178	5446 – 6634	6889 – 7090
pH (unit)	8 – 8.9	7.07 – 7.60	6.86 – 7.38	6.96 – 7.76	7.10 – 7.45
Conductivity (mS/cm)	13 – 23.59	ND	ND	ND	ND
Potassium K (mg/l)	2 – 465	41 – 42	105 – 107	682 – 927	1625 – 1712
Sodium Na (mg/l)	0 – 2070	1649 – 1757	605 – 640	682 – 927	1625 – 1712
Magnesium Mg (mg/l)	0 – 1250	67 – 79	207 – 212	174 – 188	166 – 174
Calcium Ca (mg/l)	6.25 – 1185	173 – 1145	552 – 559	578 – 769	383 – 405
Chlorine Cl	0.69 – 1.20	751 – 797	401 – 435	1003 – 1403	1279 – 1364

Note (A) This study, (B) Al-Barak *et al.*, 2008, ND - Not Determined.

Table 5. Comparison of some parameters of groundwater in a few residential areas of Kuwait with leachate at landfill sites.

Parameter	Site (A) Range in Kuwait	(B,C) Jahra well No. JH-19E	(B) Kuwait city well No. KC-IC	(B,C) Salmiya well No. SL-2E
Depth (m)	3 – 30	20.7 – 40.7	12.7 – 16.7	24.6 – 39.6
pH (unit)	8 – 9	7.70	7.06	7.60
TDS (mg/l)	11000 – 53700	5198	7864	58742
NH_3 (mg/l)	9 – 53	14.40	0.18	11.90
NO_3 (mg/l)	1 – 78	62.40	1.60	78.00
Ca (mg/l)	6 – 1185	542	600	3737
Mg (mg/l)	0.06 – 1250	165	329	1386

Note: (A) - This Study (B) - Senay 1987 (C) - Saeedy *et al.*, 1990.

The total dissolved solid (TDS) in the leachate was less than in brackish water and more than in groundwater. Groundwater such as brackish water usually has higher TDS concentrations than other water sources because of mineral pickup from soil and rocks.

The sulfate, potassium and sodium levels in the leachate were much higher than those in groundwater and less than in brackish water and seawater. However, the level of calcium and iron in the leachate was higher compared to the brackish water, seawater and groundwater. Magnesium and chloride levels were less in seawater and brackish water but higher than in groundwater. In general, the quality of landfill leachate was better compared to sewater and brackish water.

A comparison was made between landfill leachate with groundwater wells in a residential area of Kuwait as shown in Tables 4 and 5. The TDS values of leachate are much higher compared to other groundwater wells, and values of other parameters were also high, except for chlorine. The high concentration of chlorine in groundwater wells is attributed to drinking water discharges. The TDS level of Sulaibiya landfill site is extremely high compared to the amount of TDS of landfill leachates at Jaleeb Al-Shoukh and Qurain, and this is due to the presence of clays and other high-scattering colloidal particles from soil and rocks. In fact, the leachate at landfill sites has no collection and treatment systems; they may create non-desirable ecological effects but also can cause mammalian toxicity. It could be demonstrated that the leachate finds its way to the shallow groundwater at the landfill sites and may contaminate the groundwater quality. Diffusion and dispersion of the plume probably could cause dilution of the leachate to background concentration at a very short distance [18]. Detectable levels of leachate were not found in samples of wells nearby the landfill sites. Thus it appears that the Kuwait's groundwater wells could

not be affected by the landfill leachate at the present time.

However, leachate collection and treatment facilities are better often to avoid environmental contamination and consequent risk to human health [17]. Since projected land use of disposal site is to make a park with recreational facilities, Kuwait experiences heavy rains, construction of ditches around the landfill sites could appear to be an excellent idea to capture all water-flow to contain landfill leachate and avoid contamination of nearby land. Some of this water may then flow as surface water to be used as a water source. Studies should be undertaken to examine the level of contamination in groundwater. Installing and monitoring several shallow wells around the landfill in the path of the leachate plume are recommended. Water samples should be collected for chemical analysis from the landfill boreholes on a long-term basis to know more about the quality changes of leachate due to the waste age.

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