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ORIGINAL ARTICLE

Characteristics of landfill leachates and bio-solids of municipal solid waste (MSW) in Riyadh City, Saudi Arabia

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Abstract The liquid and bio-solids (landfill sediments) product from landfills has many toxic substances, which may adversely affect on the environmental health. Thus in order to have a better management of characteristics of Riyadh landfill leachates, 80 representative landfill leachate samples were collected and analyzed from February to May 2008. The analysis of landfill leachates includes pH, EC_w, concentrations of soluble ions, chemical oxygen demand (COD), total suspended solids (TSS), and heavy metals contents. The obtained results showed that the landfill leachates are characterized by high concentrations of COD (13,900–22,350) mg L^{-1}, TSS of (2280–8912) mg L^{-1}, EC_w values of (42.5–58.3) dS m^{-1} but the pH values ranged 5.49–6.32. Moreover, the leachates had higher concentrations of soluble Na^{+}, K^{+}, Ca^{2+}, Mg^{2+}, Cl^{-}, HCO_3^{-} and SO_4^{2-}. In addition, the leachates contained Fe, Mn, As, Ni, Cr, Zn and Cu in concentrations equivalent to: 104, 11.0, 1.4, 0.6, 0.25, 0.2 and 0.14 mg L^{-1}, respectively. While in the bio-solids (landfill sediments) the average content of Cd, Cr, Cu, Fe, Mn, Mo, Ni and V reached to 10, 242, 234, 48,608, 190, 18, 166 and 24 mg kg^{-1}. The relatively higher variations between the upper and lower limits (maximum and minimum values) of the studying parameters lead to conclude that it is essential to conduct a

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long-term monitoring program to obtain representative information and this fluctuation should be considered when operating the leachate treatment plant.

1. Introduction

The municipal solid waste (MSW) has been a major environmental problem in many countries. Increasing waste production as in Saudi Arabia has increased the problem of how to get rid of it without causing undesirable impact on the environment and human health. The production rate of municipal solid waste (MSW) is about 1.2–1.8 kg/person/day in Riyadh (Al-Mutairi, 2009). Traditionally, most of the municipal solid wastes (MSW) were disposed directly into a simple landfill in Riyadh. The landfill is the most common technology used to dispose municipal solid residues in developing countries. However, the landfill leachates contain a high concentration of organic matters and inorganic ions, including heavy metals (Baun et al., 2000). Thus it is well known from the literature that the landfill leachates may cause a serious environmental problem caused to discharge heavy metals continuously, if it is not under control (Poon and Chen, 1999; Abu-Rukah and Al-Kofahi, 2001; Nanny and Ratasuk, 2002; Huan-Jung et al., 2006 and Mor et al., 2006). On the other hand as groundwater and surface water pollution are concerned, leachate quality deserved a careful scrutiny and analysis to prevent further damage to the environment (Koerner and Soong, 2000 and Al-Yaqout and Hamoda, 2003). The presence of humic substance in leachate of landfill might enhance the transportation of heavy metals in addition the increase of ash content in landfill may increase the heavy metal and salts concentrations in leachates (Urase et al., 1997). In this respect, Huan-jung et al. (2006) analsized the liquid output of three types of landfills, they pointed out that the active landfill leachates had high concentrations of the COD, volatile suspended solids, total TS, total organic carbon TOC, electrical conductivity and had high contents of Fe, Cr and Ni. Furthermore Pivato and Gaspari (2006), pointed out that the liquid municipal solid waste of landfill is rich in minerals, organic compounds, ammonia and other toxic elements that can be a source of great concern to the aquatic environments. Also, Ozkaya et al. (2006) indicated that the degree of toxicity of the liquid leachates may vary from one candidate to another sample and this difference was probably linked to the mobilization of contamination or pollution load carrying or installation of solid waste. Moreover, Olivero-Verbel et al. (2007) found that the landfill leachates contained high concentrations of Cd, Hg, Ni, Mn, Cu and Pb where the toxicity of leachates depends on the concentration of such metals (especially Cd) associated with organic matter. On the other hand, Svensson et al. (2005), Oman and Junestedt (2008), studied the chemical properties of the liquid products from landfills of Sweden. They reported that such landfills could be dangerous and have a significant impact on the future of risk assessment of landfills. However there is a shortage in the information about the characteristics of landfill leachates under Saudi Arabian conditions. Therefore, the objective of the current research was to examine and evaluate the landfill leachates of the municipal solid waste of Riyadh to understand their characteristics. The data obtained can help in the strategic management of landfills for reducing the risk of these landfills in the environment of Saudi Arabia.

2. Materials and methods

2.1. In-place landfill leachate samples

An active landfill located at Riyadh city, Saudi Arabia (24°37′39.8″ N, 46°53′13.7″ E) had been selected for investigation of leachate properties (Fig. 1). This site (about 500,000 m^2) was in operation since 2006 to receive mainly municipal solid wastes from different areas of Riyadh. Eighty representative landfill leachate samples were collected and analsized during the period from February to May 2008.

2.2. Analysis of leachates samples

The collected samples were filtered through a 0.2 μm membrane and stored for the chemical analysis of pH, EC and soluble ions concentrations of (Na^+, K^+, Ca^+, Mg^{2+}, NO_3^-, HCO_3^-, CO_3^{2-} and Cl^-) as well as the concentrations of As, Pb, Cd, Cr, Co, Cu, Fe, Mn, Ni, Zn and V in the landfill. The chemical composition of the studied samples were determined according to Rainwater and Thatcher (1979) for the determination of soluble SO_4^{2-}, Page et al. (1982) for the determinations of pH, EC, the concentration of soluble (Na^+, K^+, Ca^{2+}, Mg^{2+}, NO_3^-, HCO_3^- CO_3^{2-} and Cl^-). The sodium adsorption ratio (SAR) values of the landfill leachates were calculated from the following formula:

$$\text{Sodium Adsorption Ratio (SAR)} = \frac{\text{Na}}{\sqrt{\frac{\text{Ca}+\text{Mg}}{2}}}$$

where Na^+, Ca^{2+} and Mg^{2+} are expressed as meq L^{-1}, as described by Page et al. (1982).

The concentration NO_3^-, was determined using phenol disulphonic acid, according to Maiti (2004). The chemical oxygen demand COD was determined using Closed Reflux, Colorimetric according to the Standard methods for the examination of water and waste water (APHA, AWWA and WEF, 2005). Heavy metals were measured in samples from the landfill Leachate after filtration using, ICP-AES instruments (Perkin Elmer, Model 4300 DV). Also, heavy metals were determined in the bio-solids (landfill sediments) after digestion of the sediments with HNO_3 acid according to the methods of APHA, AWWA and WEF (2005). The total suspended solids (TSS) were determined also according to APHA, AWWA and WEF (2005).

2.3. Quality control

Care was considered to avoid metal contamination in the process of sampling, extracting and analysis. All equipments and

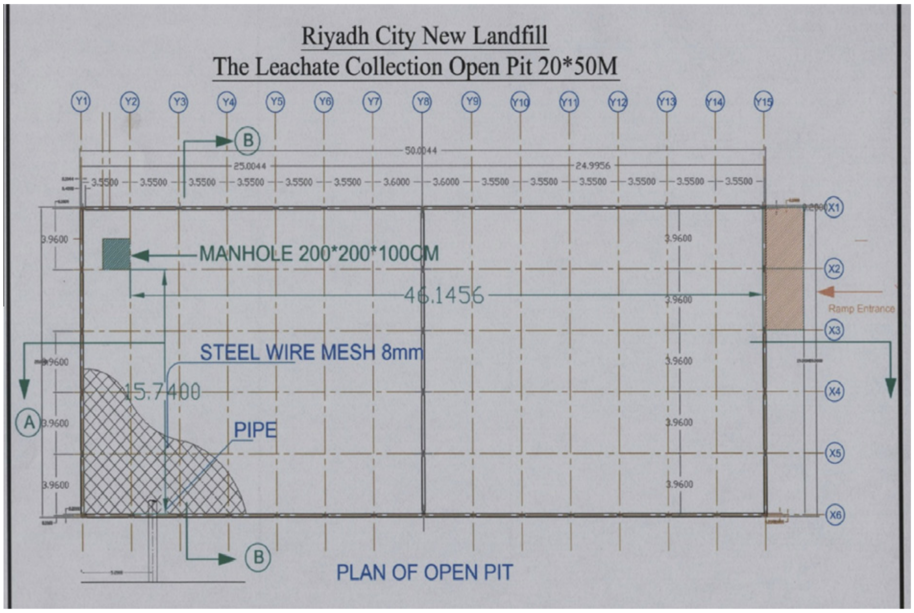

Figure 1 Schematic diagram of the new landfill at Riyadh city.

containers were soaked in 10% HNO_3 for 24 h then rinsed thoroughly in de-ionized water before use. Also, quality control was assured by performing duplicate analyses on all samples and by using reagent blanks and standards. The values of the studying metals below the detection limits of the ICP were rejected.

2.4. Data analysis

Descriptive statistics (range, median, standard deviation (SD), max, min, etc.) were calculated using SPSS (2000), and STATGRAPHIC (2000).

Table 1 Statistical summaries for the major chemical compositions of the landfill leachates of Riyadh.

Parameter	Maximum	Minimum	Average	Standard error	Standard deviation	Confidence level (95.0%)
PH	6.32	5.94	6.21	0.02	0.11	0.05
EC (dS m^{-1})	58.30	42.50	52.83	1.22	5.98	2.52
SAR	18.8	14.2	16.3	3.2	7.2	4.7
COD (mg L^{-1})	22,350	13,900	17,003	592	2841	1228
TSS (mg L^{-1})	8912	2280	5604	360	1726	746.2
Na^+ (mg L^{-1})	7769.0	4136.0	6109.3	225.7	1105.6	466.9
K^+ (mg L^{-1})	4622.0	2408.0	3684.3	145.0	710.4	300.0
Ca^{2+} (mg L^{-1})	8600.0	5300.0	7412.5	195.9	959.6	405.2
Mg^{2+} (mg L^{-1})	2612.0	693.0	1962.5	103.6	507.4	214.3
HCO_3^- (mg L^{-1})	61000.0	36600.0	50795.2	1471.9	7210.9	3044.9
Cl^- (mg L^{-1})	11538.0	5503.0	8971.5	334.0	1636.2	690.9
SO_4^{2-} (mg L^{-1})	1944.1	980.6	1504.1	47.1	230.7	97.4
NO_3^- (mg L^{-1})	nd	nd	nd	nd	nd	nd
As (mg L^{-1})	1.682	1.09	1.328	0.043	0.207	0.01
Co (mg L^{-1})	0.096	0.064	0.077	0.002	0.012	0.01
Cr (mg L^{-1})	0.336	0.21	0.26	0.011	0.051	0.02
Cu (mg L^{-1})	0.246	0.124	0.176	0.009	0.043	0.23
Fe (mg L^{-1})	190.22	134.44	167.61	4.724	22.91	468.4
Mn (mg L^{-1})	13.14	9.25	10.843	0.287	1.394	11.9
Ni (mg L^{-1})	0.718	0.384	0.505	0.024	0.115	14.8
V (mg L^{-1})	0.152	0.024	0.079	0.011	0.051	0.04
Zn (mg L^{-1})	0.226	0.11	0.182	0.006	0.031	0.05
Cd (mg L^{-1})	nd	nd	nd	nd	nd	nd
Pb (mg L^{-1})	nd	nd	nd	nd	nd	nd

nd = not detected.

Table 2 Comparison between the results of Riyadh landfill leachates with the leachates of other counters.

Parameter (mg L^{-1})[a]	SA, Taiwan[b]	SC, Taiwan[b]	JB, HK[c]	GDB, HK[c]	Kuwait[d]	USA[e]	Italy[e]	Germany[e]	This study
Age	10–16	11	3.5	11	–	–	–	–	2–3
pH	7.03–8.50	6.82–8.37	7.2–8.0	7.2–8.4	6.9–8.2	5.1–6.9	6.0–8.5	5.7–8.1	5.94–6.32
EC	3.58–14.16	5.0–29.60	8.5–12.0	2.5–11.8	1.2–16.9	–	–	–	42.5–6.32
COD	320–1340	840–4210	489–1670	147–1590	157.9–9400	1340–18,100	7750–38,520	1630–63,700	13,900–22,350
K	198–778	312–2243	270–632	78–416	–	–	–	–	2408–4622
Na	320–1342	431–3142	484–1190	132–743	–	–	–	–	4136–7770
Ca	47.2–137.5	15.9–61	–	–	5.6–122	254.1–2300	0–175	70–290	5300–8600
Mg	27.8–103	15.7–157	35–63	8–26	5.2–268	233–410	827–1469	100–270	693–2612
Cd	< 0.15	< 0.01	< 0.01	< 0.02	–	–	–	–	< 0.002
Cr	0.01–0.18	004–1.26	0.03–0.15	0.02–0.23	–	–	–	–	0.21–0.336
Cu	0.01–4.38	0.02–0.9	< 0.05	0.01–0.13	0–0.2	0–0.1	–	–	0.124–0.246
Fe	0.26–5.44	0.39–28	1.14–3.25	1.26–5.0	0.35–54.1	4.2–1185	47–330	8–1979	134.44–190.22
Mn	0.18–5.27	0.02–0.75	0.05–0.24	0.05–1.30	–	–	–	–	9.25–13.16
Ni	0.04–0.14	0.01–0.28	0.07–0.18	0.04–0.17	–	–	–	–	0.384–0.718
Pb	< 0.02	0.02–0.18	0.03–0.12	< 0.10	0–0.2	0–0.46	–	–	< 0.04
Zn	0.04–1.61	0.03–0.66	0.24–2.55	0.13–0.39	0–4.8	18.8–67	5.0–10	–	0.108–0.226
V	–	–	–	–	–	–	–	–	0.024–0.152
As	–	–	–	–	–	–	–	–	1.09–1.682
Co	–	–	–	–	–	–	–	–	0.064–0.096

[a] Except pH, age (year), EC (ds m^{-1}).
[b] Huan-jung et al. (2006).
[c] Chu et al. (1994).
[d] Al-Yaqout and Hamoda (2003).
[e] Rowe et al. (1995).

3. Results and discussions

3.1. Chemical compositions of landfill leachates

Data in Table 1 show a descriptive statistics for the chemical compositions of the studying landfill leachates of Riyadh city. Apparently, the EC, COD and SAR values as well as the concentrations of soluble ions were remarkably higher in all leachate samples. For example the EC_w values ranged from 42.5 to 58.3 dS m^{-1}. Also the COD concentrations ranged between 13,900 and 22,350 mg L^{-1}, while total suspended solids ranged between 2280 and 8912 mg L^{-1}. It is interesting to note that such values were extremely higher than the respective values detected by Chu et al. (1994) and Al-Yaqout and Hamoda (2003) as shown in Table 2. On the other hand the descriptive statistics of the concentrations of soluble Na^+, K^+, Ca^{2+}, Mg^{2+}, HCO_3^-, Cl^-, SO_4^{2-}, As, Co, Cr, Cu, Fe, Ni, Mn, V and Zn in leachates are listed in Table 1. Generally the concentrations of Na^+, K^+, Ca^{2+} and Mg^{2+} were the highest among the studied metals as they ranged from (4136–7769), (2408–4622), (5300–8600) and (693–2613) mg L^{-1}, respectively. While the respective concentrations of soluble Cl^-, SO_4^{2-} and HCO_3^- ranged between (5503–11,538), (981–1944), and (36,600–61,000) mg L^{-1}, respectively. The abovementioned findings could be explained as follows: during the process of municipal waste decompositions, more soluble salts became prone to be leached out. This is reflected in increasing the EC_w values and the concentrations of soluble ions in leachates. In addition, the relatively higher concentrations of soluble Na^+ compared to (Ca^{2+} + Mg^{2+}) reflected in increasing the SAR values of leachates to be more than 16 in average. On the contrary, the pH values of the leachates were lower as it ranged from 5.94 to 6.32 with an average of 6.12. This may be

Table 3 Comparison between the present results with results of Ehring (1988).

Parameter [a]	Acid phase[b]		Methanogenic phase[b]		The present study	
	Average	Range	Average	Range	Average	Range
pH	6.1	4.5–7.5	8	7.5–9	6.21	5.94–6.32
COD	22,000	6000–60,000	3000	500–4500	16,874	13,900–22,350
SO_4^{2-}	500	70–1750	80	10–420	1504	981–1944
Ca^{2+}	1200	10–2500	60	20–600	7412	5300–8600
Mg^{2+}	470	50–1150	180	40–350	1962	693–2612
Fe	780	20–2100	15	3–280	103.6	134.44–190.22
Mn	25	0.3–65	0.7	0.03–45	10.899	9.25–13.16

[a] All values in mg L^{-1} except pH.
[b] Ehring (1988).

Table 4 Comparison of heavy metals in the leachate sediments (mg kg^{-1}) with those reported by Oman and Junestedt (2008).

Elements	Heavy metals content in sediments (mg/kg) (Oman and Junestedt, 2008)				Heavy metals content in sediments of Riyadh landfill (mg/kg)			
	Min.	Max.	Median	Average	Min.	Max.	Median	Average
Cd	0.13	11	0.686	2.2	3.53	15.87	10.18	9.98
Cr	4	124	43	55	181.43	349.21	218.9	241.61
Cu	1.9	1890	46	242	130.34	409.17	207.9	234.06
Fe	13,500	285,000	62,400	105,825	38,937	62927.93	46,771	48607.63
Mn	954	3000	1720	1850	148.99	231.83	181.5	190.14
Mo	0.08	83	37	41	0.05	42.86	15.05	18.06
Ni	2.9	68	15	22	100.51	331.51	141.6	165.91
V	28	102	69	65	13.76	34.7	23.37	24.08

attributed to the acidic nature of leachates as well as the organic and inorganic acids formed during the decomposition of the municipal wastes.

Respecting heavy metals, data in Table 1 show that the concentrations of Fe ranged between 134.44 and 190.2 mg L^{-1} with an average of 176.6 mg L^{-1}. The Fe concentrations were relatively higher in samples downstream of the basin samples. Meanwhile the concentration of Mn, Zn, Ni, As, Cr, and Cu ranged between (9.25–13.14), (0.11–0.23), (0.384–0.718), (1.09–1.682), (0.0.21–0.336) and (0.124–0.246) mg L^{-1}, respectively. It is worth to mention that the concentrations of Cd and Pb in the leachates were below the detection limit of the ICP.

Evaluating the previously data as a whole, it has to be mentioned that, except pH, and salinity, the possible risk derived from heavy metals in leachate should not be negligible. In this respect Urase et al. (1997) stated that, even if the effluent from landfill leachate met the effluent standard, landfill leachate was still one of the major sources of heavy metals discharged to the surrounding environment.

The previously chemical compositions of the Riyadh landfill leachates were compared with other landfills of Taiwan, Hong Kong, Kuwait, USA, Italy and Germany, and the data are summarized in Table 2. Obviously the leachates generated from Riyadh landfill had the highest EC and COD values as well as the highest concentrations of (Na^{+}, K^{+}, Ca^{2+} and Mg^{2+}, Cl^{-}, SO_4^{2-} and HCO_3^{-}) than the other landfills of Hong Kong (JB and GDB), Kuwait, USA, Germany and Taiwan. The leachate from USA landfills had a relatively lower pH values compared to other countries, which might be due to its young landfill age at the time of sampling. On the contrary, Cr and Mn concentrations in Riyadh leachates were higher than those of other countries cited mentioned above. It is interesting to note that the V, As and Co were detected only in Riyadh landfill leachates in concentrations ranged between (0.024–0.152), (1.09–1.682) and (0.064–0.094) mg L^{-1}, respectively. This result indicated that the biological treatment methods might not be suitable for the landfill of Riyadh. Consequently, the relatively higher contents of Cr, Ni, Cu, As, Mn, Co, V and Fe in Riyadh landfill leachates should be monitored in the future to prevent contamination of surrounding soil and groundwater. On the other hand when comparing the obtained data with those reported by Ehring (1988), it can be concluded that the landfill of Riyadh is still in the acidic phase due to lower pH values as well as the higher values of COD, SO_4^{2-}, Ca^{2+}, Mg^{2+}, Fe and Mn (Table 3).

3.2. Heavy metals in the bio-solids (landfill sediments)

Data in Table 4 clearly appear that the digested sediments of Riyadh landfill yielded Cd, Cr, Cu, Fe, Mn, Mo, Ni and V in amounts average of 10, 242, 234, 48,608, 190, 18, 166 and 24 mg kg^{-1}, respectively. The respective contents of such metals reached 22, 55, 242, 105,825, 1850, 41, 22 and 65 mg kg^{-1} in the study of Oman and Junestedt (2008). It is clear that the contents of Cd, Cr and Ni were relatively too high in Riyadh landfill sediments compared to the relatively values founded by Oman and Junestedt (2008).

4. Conclusions

From the above-mentioned results it could be concluded that, except pH, the EC_w, COD and SAR values as well as the concentrations of soluble ions were so much higher in Riyadh landfill leachates when comparing with the leachates of some other countries. Furthermore, the concentrations of soluble (Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, Cl^{-}, HCO_3^{-} and SO_4^{2-}) were exceeding the upper limits detected in the other landfills of Taiwan, Hong Kong, Kuwait, USA, Italy and Germany. Also, the concentrations Fe, Mn and Ni found to be in higher limits in Riyadh landfill compared to the landfills of the above cited countries. Therefore, there is a need to develop a system to prevent leakage and contamination of surrounding soil and groundwater. Finally, the quantity of municipal solid waste by burying a day is considered high in a continuous increase in Saudi Arabia. Therefore, it is necessary to activate new technology for the use of solid waste to be more attractive for the private sector for engage in the field of recycling such wastes. This will serve several objectives, such as; reducing the amount of waste produced to the landfill and consequently reduces their negatively environmental impacts. The most new technology that may be applied in this respect, using such wastes as a source of raw materials for industrial purposes or to be a source for energy production, or as a conditioners used for soil improvement and or in organic agricultural.

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