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Assessment of landfill leachate in semi-arid climate and its impact on the groundwater quality case study: Hamedan, Iran

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Abstract To evaluate environmental impacts of solid waste landfilling, groundwater quality near the MSW landfill in a semi-arid climate of Iran (Hamedan) and its leachates were analyzed. To this aim, heavy metal concentrations, COD, BOD_5, TOC, EC, NO_3^-, Cl^-, TDS, and pH of two leachate ponds (active and closed sites) as the sources of contamination as well as the shallow groundwater of the area were measured. Monthly and seasonal monitoring program of 13 sampling points in the area were designed during the period of 2014–2016. Principal components analysis has been carried out using chemical data to deduce relationship between the samples. A special statistical approach including a main factor (age of leachate) and a subfactor (distance from the source of pollutant) was designed in order to identify the landfill role on the groundwater contamination. The physicochemical analysis of the leachate characteristics confirmed a high variation in the contaminants (i.e., organic compounds, salts, and heavy metals) related to leachate age. The BOD_5/COD ratio of the active (0.73) and closed (0.77) sites ponds indicated that the leachates were in a biodegradable and unstabilized condition. The seasonal physicochemical analysis of the leachates showed that rainfall events increase the decomposition rate of the waste and affect pollutant concentration of the leachate. The proposed statistical analysis illustrated a direct relationship between the groundwater quality parameters and the leachates physicochemical characteristics.

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Introduction

In Iran, such as other developing countries, approximately all produced solid waste is transported to the landfills sites. Open dumping solid wastes lead to environmental hazardous impacts. Penetrating precipitations into dumped solid waste and surface water passage through these areas result in chemical, organic, and inorganic compounds movement in the environment (Mor et al. 2006; Longe and Balogun 2010; Jhamnani and Singh 2009; Sabahi et al. 2009; Saarela 2003). Long-term impacts of landfills on the environment and human health linked to the knowledge of leachate composition (Mavakala et al. 2016). Moisture content of waste, rising water table, precipitation, and snowmelt are the principal components in leachate formation (Bhalla et al. 2013; Peng 2013). The solid waste liquid (leachate) generally spreads over surface ground and has an important environmental contamination potential (Bhalla et al. 2013).

One of the major causes of groundwater resources contamination is landfill (Fatta et al. 1999). Due to leachate percolation from landfill, the groundwater located near the landfills or dumpsites is highly polluted. Organic and inorganic constituents in leachate adversely affect the groundwater quality and make it unsuitable for domestic water supply and other uses. The leachate chemical constitution, its quantity and distance of contaminant from water sources can affect the scale of pollution (Slomczynska and Slomczynski 2004). A number of factors affect the leachate rate and its characteristics; these are inherent wastes water content and its composition, waste compaction degree, site hydrology condition, climate, and the waste age (Pantini et al. 2014). Landfill age and waste type may remarkably vary the leachate composition.

Tsarpali et al. (2012) analyzed temporal variations of the leachate composition and its toxic strength at a landfill site of Greece. The result showed the significant alterations between all of the physicochemical parameters with time. Further analysis also indicated that seasonal alterations of leachate composition were related to annual precipitation. Mavakala et al. (2016) studied leachate drained from MSW landfill in the Congo. The samples were collected during the wet and dry periods. The result demonstrated a significant temporal physicochemical variation in the leachate quality. Naveen et al. (2016) investigated the physical, chemical, and biological characteristics of a landfill leachate and water resources near the site in India. Their results indicated that the water quality was contaminated with the leachate and was not accepted for any use. Samadder et al. (2017) studied the physical and chemical parameters and heavy toxic metals of soil and groundwater in a waste dumping site of India. The result indicated the groundwater quality of the area was not suitable for potable water.

Depending on the landfill waste types (a combination of urban, industrial, and commercial waste) there are four types of pollutants in the leachate including: i) dissolved organic matters, ii) inorganic components, iii) heavy metals ions, and iv) xenobiotic organic compounds (Kjeldsen et al. 2002).

When the landfills are incorrectly secured and improperly operated, the leachate is free to flow directly from waste toward the groundwater. In these conditions, high concentrations of leachate leak into springs and wells. Hence, contaminants spread into the environment resulting in ecosystem pollution. However, this process does not stop in decommissioned landfills. Therefore, it is necessary to keep monitoring the surroundings of landfill sites.

There are very few studies on landfill leachate characteristics and its impact on groundwater quality in Iran. Thus, aim of the present study is the investigation of several physicochemical parameters along with the heavy metals in the solid waste dumping site leachate and nearby groundwater. In this study, impacts of the leachate on groundwater quality were explored at the Hamedan uncontrolled landfill site of Iran, using multivariate data analysis and an especial statistical testing. Therefore, various physicochemical parameters analyzed in the leachates (as the source of pollutant) and groundwater samples. The analysis focused on the leachate age (from active and closed sites of the landfill), distance from source of pollution and monthly meteorological condition.

Materials and methods

Study area

Hamedan municipal landfill is located in the Hamedan-Bahar plain, at a distance of 20 km from north of the city. Area of the landfill is about 2.3 km^2 at latitude 34°58′17″N and longitude 48°35′50″E, located at an altitude of 1790 m from the sea level. Hamedan and its urban areas, with a population more than 0.6 million are estimated to produce about 300 ton of household garbage daily. Previous study conducted in the area shows a low thickness (in average about 5 m) of alluvial (sandy gravel with silt and clay) in the soil. The main clay minerals of the soil samples were found to be kaolinite (85%), illite (10%), and montmorillonite (5%). The alluvium deposit thickness increased (near to 30 m) toward west of the area. A shallow groundwater (about 2 m from the ground surface) with conglomerate–sandstone bedrock is located under the landfill area. In downstream of the landfill (northern and western sides), the Hamedan-Bahar aquifer depth varies from 20 to 50 m. The study area climate was semi-arid with an extremely dry condition associated with semi-hot summers and cold winters. The mean minimum and maximum air temperature are − 1.9 °C and 24.6 °C, respectively with an average rainfall of 330 mm.

The landfill construction was started in 2000 and spread over an area of about 10 ha. In 2007, it was closed (decommissioned) and a new site (active) was started over an area of about 20 ha (Fig. 1). Distance between the closed and active sites is about 750 m. As shown in Fig. 1, the closed and active sites provide leachate ponds. Absence of an appropriate engineering design and/or manipulation brought about uncontrolled leachates in these sites. These leachates are sources of contaminants such as organic compounds, microorganisms, and heavy metals, which have a large potential pollution in the environment. Nine borewells (BW1–BW9) of distance from 300 to 700 m drilled for collection of groundwater samples and its quality analysis. According to standard methods (APHA 2012) one-litter sterilized sampling bottles were used. Before sampling, the bottles were firstly washed with a detergent liquid and rinsed with distilled water. Thereafter, it was rinsed with the water samples prior to collection, to avoid any interference that may arise from using contaminated sample containers. The sample preserved using 2 ml concentrated HNO_3 acid to avoid metal precipitation and brought to the laboratory for further analysis.

Groundwater and leachates monitoring program

A monitoring program of 13 sampling points of the groundwater and leachates was designed, including borewells (BW1–BW9), springs (S1 and S2), and leachates which were selected within an area about 12 km^2. Distance between leachates and the sampling points ranged 0.3–1.7 km. Monthly water sampling was preceded in 2014–2016. June–October and January–May considered as dry and rainy seasons of the area in order to analyze a relatively long temporal variation of the contaminants.

Water table fluctuation was also observed using BW1–BW9 as well as the springs (S1–S2) during 2014 and 2016. Because of topographical condition of the area, borewells BW2 and BW3 and springs S1 and S2 were under subsurface flow of the active site leachate. BW4 and BW5 are also under influence of the closed site leachate flow. BW1 is located in the upstream area, out of the landfill influence. BW6, BW7, BW8, and BW9 are located in the downstream area of the landfill site. After each sampling, the samples were immediately transported to the laboratory and stored in cold room (4 °C). The methods used for the various determinations were based on the priority to analyze parameters as prescribed by APHA (2012). All the samples were analyzed according to the internationally accepted procedures and standard methods (APHA 2012).

Water quality parameters

The groundwater samples analyses included pH, electrical conductivity (EC), total dissolved solids (TDS), chemical oxygen demand (COD), biochemical oxygen demand (BOD_5), potassium (K^+), chloride (Cl^-), nitrate (NO_3^-), total organic carbon (TOC), and heavy metals. K^+ were estimated by flame photometric method. Al, As, Fe, Mn, Cu, Cr, Hg, Ni, Pb, and Zn concentrations were determined by atomic absorption spectrometry. NO_3^- analysis was performed by Brucine method using UV spectrophotometer. Cl^- was determined by titration method (silver nitrate). COD was measured by reflux titrimetric method, while BOD_5 was calculated by oxygen determination and Winkler titration method. TOC was measured with infrared spectrophotometry method. Based on the recorded water table level in the sampling points (BW1–BW9) and the springs (S1 and S2), the shallow groundwater flow of landfill area was evaluated using Surfer software (version 14) and a GIS-based map.

Water Quality Index

Water Quality Index (WQI) was used in order to get an overall idea of groundwater quality in the area. WQI is one of the most effective methods to evaluate the composite influence of water quality parameters on the overall quality of water. The WHO drinking water standard was used for the calculation of WQI. Its values are classified into five categories: excellent water (WQI < 50), good water (WQI = 50–100), poor water (WQI = 100–200), very poor water (WQI = 200–300), and water unsuitable for drinking (WQI > 300) (Batabyal and Chakraborty 2015).

The WQI was calculated through three steps: i) each chemical water quality parameters (pH, TDS, K^+, Cl^-, NO_3^-, TOC, Pb, Ni, Hg, Fe, Mn, and Zn) was weighted (w_i) according to its relative importance in the overall quality of water for drinking purposes. ii) A relative weight (W_i) of each chemical parameter was calculated using Eq. 1. iii) For each chemical parameter, a quality rating scale (q_i) calculated using Eq. 2.

$$W_i = \frac{w_i}{\sum_{i=1}^{n} w_i} \quad (1)$$

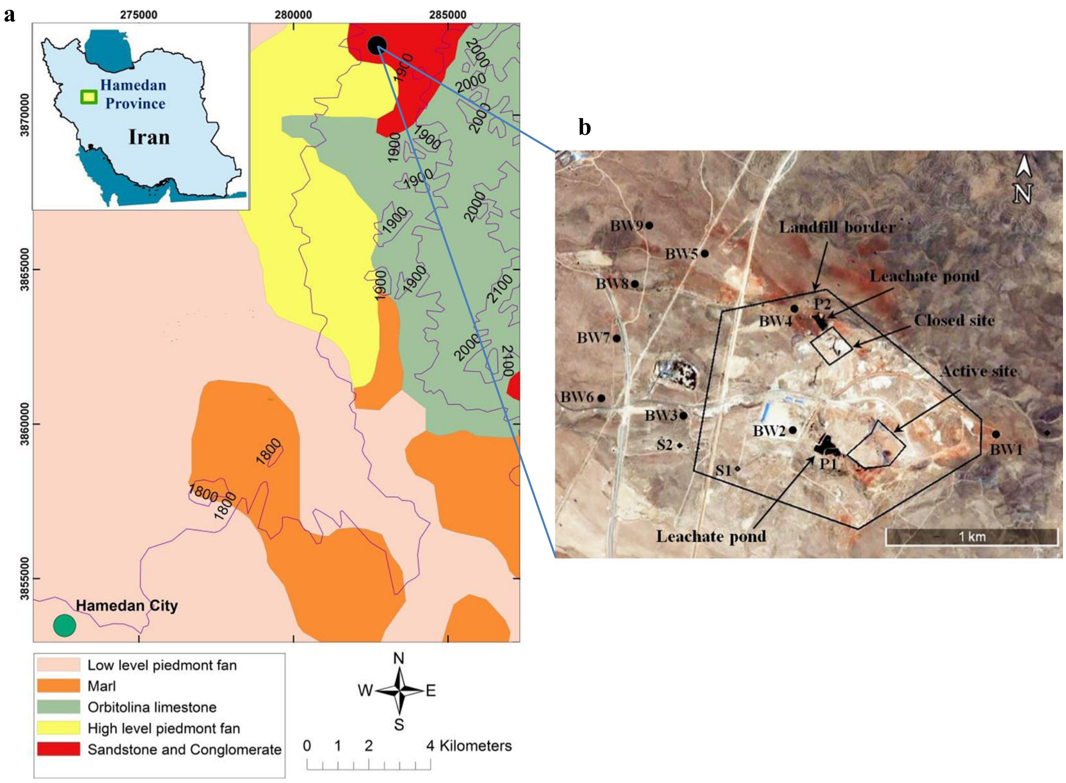

Fig. 1 **a** Location and geological units of the study area, **b** Locations of the active and closed sites, leachate ponds, borewells, and the springs

where, W_i is the relative weight; w_i is the weight of each parameter; and n is the number of parameters.

$$q_i = (C_i/S_i) \times 100 \quad (2)$$

where, q_i is the quality rating; C_i is the concentration of each chemical parameter in each water sample in mg/l; and S_i is the WHO drinking water standard for each chemical parameter in mg/l.

A sub index (SI) also determined for each chemical parameter, using Eq. 3, and finally, the WQI calculated based on Eq. 4.

$$SI_i = W_i \times q_i \quad (3)$$

$$WQI = \sum SI_{i-n} \quad (4)$$

where, SI_i is the sub index of ith parameter; W_i is relative weight of ith parameter; q_i is the rating based on concentration of ith parameter; and n is the number of the chemical parameters.

Statistical analysis

In order to assess possible relationship between data, a multivariate data analysis including the correlation matrix (CM) and principal component analysis (PCA) applied using SPSS software (Vasanthavigar et al. 2013). The statistical test (nested designs) that composed of a main factor (age of leachate) and a subfactor (distance from contaminate source) designed in order to identify the role of landfill on groundwater contamination (Marofi et al. 2015). To this aim, leachates of the closed and active sites and borewells BW2, BW3, BW4, and BW5 were used. BW2–BW3 and BW4–BW5 were under effects of active and closed site leachates, respectively. BW2, BW4 and BW3, BW5 were considered as the points with short distance ($\leq$ 300 m) and long distance ($\geq$ 1000 m) from the leachate ponds locations (as the contaminate sources), respectively.

Results and discussion

The characteristics of the samples from leachate ponds of the closed and active sites are presented in Tables 1 and 2. The pH values of the active and closed sites leachate ponds were 7.73 and 8 respectively. It was higher in the samples of the closed site, due to alkalinity condition and suitability of the methanogenic bacteria in older leachate pond. Similar results were obtained by Samadder et al. (2017), Abd El-Salam and Abu-Zuid (2015), Tränkler et al. (2005), Al-Yaqout and Hamoda (2003). They found that leachate samples had a slightly high pH (from normal) and remained in the range of 7–8 during the operations which indicate the short acidic phase and early methanogenic phase. The relationship between pH and decomposition stages has been stated by several authors (Bahaa-eldin et al. 2010; Olaniya et al. 1998; USEPA 2003; Vasanthi et al. 2008; Salem et al. 2008).

Average values of BOD_5 in active and closed site leachates were 8634 and 9217 mg/l, respectively; when COD values were 11,774 and 11,920 mg/l, respectively. The higher COD value of the closed site leachate could be related to the old waste compression and consolidation, which retarded the solid wastes degradation. The high BOD_5 value indicated that the process of stabilization in the both sites was in the initial stage with a very slow rate of decomposition. These BOD_5 and COD values clearly indicated severe contamination of the site. The BOD_5/COD ratio showed that the leachate were in an unstabilized and biodegradable conditions, thus require more time and favorable situations for anaerobic biodegradation. Abd El-Salam and Abu-Zuid (2015) studied the leachate originating from sanitary landfills in Alexandria (Egypt). They concluded that the leachate had BOD_5 value from 9620 to 11,700 mg/l with an average rate of 10,824 mg/l. The COD values also varied between 12,850 and 16,350 mg/l with a mean of 15,629 mg/l. The BOD_5/COD ratio of about 0.69 showed the leachate had a high capacity for degradation through the anaerobic phase. These results are in agreement with the current study results. Al-Yaqout and Hamoda (2003) also focused on the leachate chemical characteristics from both active and old landfills in Kuwait. The results showed that BOD_5 concentrations in active site leachate ranged from 30 to 600 mg/l and in closed site leachate ranged from 210 to 345 mg/l. The BOD_5/COD ratio for active site leachate ranged from 0.004 to 0.38 and for closed site leachate ranged from 0.02 to 0.04. Regadío et al. (2015) studied a 14 years old landfill in Spain and indicated that the BOD_5/COD ratio of their study was 0.1, indicating a relatively stabilized leachate condition. Chofqi et al. (2004) also investigated the leachate resulting from the El Jadida municipal landfill (Morocco). They reported the leachate had the mean values of COD and BOD_5 of 1000 and 60 mg/l, respectively. The result showed that the leachate was stabilized and the landfill was in the methanic phase of anaerobic degradation, based on the BOD_5/COD ratio that was about 0.06. Lower BOD_5/COD ratio was recorded in another study in Colombia (Olivero-Verbel et al. 2008). Results of our study were in contradiction with Monje-Ramirez and Orta de Velasquez (2004) research that was reported about a well-stabilized Mexican sanitary landfill (BOD_5/COD < 0.01, COD = 5000 mg/l and BOD_5 = 20 mg/l). Hassan and

Table 1 Statistics of the samples collected from leachate pond of the closed site

Parameters	Units	Min	Max	$\bar{x} \pm SD$
pH	–	7.59	8.19	8 ± 0.243
EC	µS/cm	58,100	245,550	156,348 ± 81,175
TDS	mg/l	38,900	176,800	109,572 ± 58,020
COD	mg/l	7600	18,080	11,920 ± 4118
BOD_5	mg/l	5550	14,200	9217 ± 3352
Cl^-	mg/l	14,200	59,000	31,240 ± 16,848
NO_3^-	mg/l	82.61	129	109.06 ± 17.26
K^+	mg/l	4500	15,000	9833 ± 5251
TOC	mg/l	1450	2300	1883 ± 425

Table 2 Statistics of the samples collected from leachate pond of the active site

Parameters	Units	Min	Max	$\bar{x} \pm SD$
pH	–	7.3	7.89	7.73 ± 0.136
EC	µS/cm	26,520	42,400	34,491 ± 5810
TDS	mg/l	17,500	28,100	23,050 ± 3731
COD	mg/l	6240	17,940	11,774 ± 3809
BOD_5	mg/l	4742	12,110	8634 ± 2575
Cl^-	mg/l	1640	4200	3456 ± 1036
NO_3^-	mg/l	59.2	525	289 ± 191
K^+	mg/l	4500	6000	5166 ± 763
TOC	mg/l	1300	2100	1783 ± 301

Ramadan (2005) noted the higher values of BOD_5 (28,833 mg/l), COD (45,240 mg/l), and BOD_5/COD ratio (0.63), that are similar to our research results. Chen (1996) also researched on the effect of landfill age and rainfall on the landfill leachate value in Taiwan. Concentrations of BOD_5 (296 mg/l) and COD (3340 mg/l) from the study were lower than the values of the present study, that indicate the maturity condition of the leachate.

Based on the study of Bashir et al. (2009), the young leachates can be more polluted than the mature ones where BOD_5 of the young and mature samples reach up to 81,000 and 4200 mg/l, respectively. Chofqi et al. (2004) revealed that the BOD_5/COD ratio of young leachate reaches to a value equal to 0.85, where biological activity corresponds to the acid phase of anaerobic degradation. On the basis of Bashir et al. (2009) study, stabilized leachate of old landfills produce a relatively low COD as well as a low BOD_5/COD ratio (< 0.1).

In the present study, Cl^- in the active site leachate ranged from 1640 to 4200 mg/l with a mean value of 3456 mg/l. In the closed site, it also widely ranged between 14,200 and 59,000 mg/l with an average value of 31,240 mg/l. Cl^- values from the reports of Regadío et al. (2015), Monje-Ramirez and Orta de Velasquez (2004), Abd El-Salam and Abu-Zuid (2015), and Bahaa-eldin et al. (2010), were 7000, 11,378, 2050, and 5680 mg/l, respectively. This vast variation in the Cl^- values may be resulting from the waste type and its characteristics.

NO_3^- in active site leachate pond ranged from 59.2 to 525 mg/l with a mean value of 289 mg/l. In closed site leachate, it ranged from 82.61 to 129 mg/l with a mean value of 109.06 mg/l. High nitrate values indicate oxidized condition of the environment. Hassan and Ramadan (2005) indicated that anaerobic condition of landfills could be affected by rainfall and the heterogeneous mixture of waste materials. Oxidizing conditions in the landfill may cause volatilization and nitrification reactions. Enriched free ammonia-NH_3 (by volatilization of the wastes material) transformed to nitrate by nitrification process and therefore, increases concentrations of nitrate. They reported that the more prevalent-reducing conditions in the landfill, resulting in nitrate reduction to ammonia and N_2.

In the active site leachate pond, EC extended from 26,520 to 42,400 μS/cm with a mean value of 34,491 μS/cm. In the leachate pond of the closed site, it ranged from 58,100 to 245,550 μS/cm with a mean value of 156,348 μS/cm. Al-Yaqout and Hamoda (2003) found that EC in active site ranged from 1200 to 16,900 μS/cm and in closed landfill ranged from 6210 to 21,900 μS/cm. The mean value of TDS in the active site was 23,050 mg/l and in the closed site was 109,572 mg/l. The result of the current study is in contradiction with Abu-Daabes et al. (2013) report that indicated the old landfill site shows less EC compared with the active sites.

Heavy metals concentrations in landfill leachates

Tables 3 and 4 shows heavy metal concentration of the closed and active site leachates. It is clear that Cr had a low concentration in the both sites while Fe and Zn had high concentrations. The elevated Zn concentrations can be due to disposal of large quantities of industrial wastes (such as synthetic paints, lighting bulbs, television screen, and electrical batteries) in the landfill. Abd El-Salam and Abu-Zuid (2015) founded similar results. Lower values were reported in another study in active landfill in Kuwait, where Zn values were 0.1–0.2 mg/l and in closed landfill ranged 0.2–4.8 mg/l. High Mg^{2+} levels was recorded in leachates of active and closed sites (Al-Yaqout and Hamoda 2003). Waste age role on leachate characteristic was also investigated in this study. Description of chemical reactions at landfills in arid and semi-arid countries such as Iran is difficult because of different decomposition stages of wastes. Based on this result, the chemical properties of the leachate indicated a various stage of decomposition of the waste sites. In this uncontrolled landfill, the dumping sites including several layers of different age, where the older layers buried with younger wastes. This condition resulted in continuous percolation flow of young leachate through the older wastes. Therefore, characteristics of the landfill leachate may be influenced by different stabilized stages. As such, age analysis of landfill sites may not be exactly obtained by the leachates characteristics. Al-Yaqout and Hamoda (2003) obtained similar results.

The characteristics of the leachate samples collected from the active and closed sites are presented in Fig. 2. Comparison of the leachates shows that the concentration of heavy metals (except for Al and Hg) in the closed site leachate was greater than the active site leachate. Concentrations of TDS, TOC, K^+, and Cl^- in the active site leachate were lower than the closed site leachate except for NO_3^-.

Table 3 Heavy metal concentrations (mg/l) of the samples from leachate pond of the closed site

Parameters	Leachate samples		
$n = 24$	Min	Max	$\bar{x} \pm SD$
Al	0.37	1.55	1.029 ± 0.505
As	0.038	5.7	1.48 ± 2.375
Cu	0.01	3.56	0.722 ± 1.589
Fe	13.09	88.34	41.803 ± 32.501
Hg	0.008	1.58	0.452 ± 0.657
Mn	0.66	5.25	2.246 ± 2.108
Ni	1.47	5.06	3.465 ± 1.384
Pb	0.001	0.386	0.213 ± 0.144
Zn	0.25	13.84	5.599 ± 5.854
Cr	0.104	0.264	0.176 ± 0.081

Monthly rainfall distribution of the sampling period is presented in Fig. 3. The seasonal physicochemical variation of the leachates is also shown in Table 5. During dry season (June–October 2014), average values of pH in the leachate ponds of the active and closed sites were 7.6 and 7.88 while during rainy season (January–May 2015) it was 7.75 and 8.06, respectively. In the rainy seasons, specifically during the first rainy event, values of all the measured parameters in the leachates were higher than other periods that may be because of rainfall percolation into dumpsites of the landfill.

Table 4 Heavy metal concentrations (mg/l) of the samples from leachate pond of the active site

Parameters	Leachate samples		
$n = 24$	Min	Max	$\bar{x} \pm SD$
Al	0.35	3.04	1.278 ± 1.031
As	0.025	0.926	0.256 ± 0.294
Cu	0.01	4.58	0.647 ± 1.592
Fe	9.204	59.4	27.483 ± 16.31
Hg	0.004	3.286	0.562 ± 1.117
Mn	0.32	1.29	0.705 ± 0.342
Ni	0.608	1.08	0.786 ± 0.157
Pb	0.001	0.42	0.189 ± 0.171
Zn	0.092	8.25	2.39 ± 3.61
Cr	0.13	0.248	0.175 ± 0.064

A few studies focused on seasonal variation of landfill leachate characteristics, especially on metal concentrations. During the rainy season, some metal concentrations were approximately from 10 to 40 times higher than the dry period (Mavakala et al. 2016; Tsarpali et al. 2012). Based on the research reports, percolating rainwater through the waste layers is a major factor in the landfill leachate generation (Kjeldsen et al. 2002). Therefore, landfill leachate characteristics vary according to waste composition, waste age, landfilling technology, and climatic conditions (temperature and precipitation) (Kjeldsen et al. 2002). Consequently, monitoring the landfill leachate requires several samplings program, according to seasonal variation.

The characteristic of landfill leachates that were reported by some studies is given in Table 6. A wide variation indicated in the leachate composition from different sanitary landfills. These data show that age of landfill and stability degree of solid waste have a significant effect on leachate characteristics. In the both leachates of the current study (active and closed site), several parameters (e.g., EC, TDS, Cl^-, K^+, As, Cu, Hg, and Ni) exhibited concentrations above those that reported in the literature.

Table 7 shows the correlations matrix (CM) for the two leachates sites and the shallow groundwater of the area. A strong correlation between two variables is indicated by correlation coefficients (r) greater than 0.7, while $0.5 < r < 0.7$ indicates moderate correlation, and $r < 0.5$ show weak correlation between two variables (Kumar et al. 2006). The result shows 57% of correlation coefficients are strong correlation, 32% are moderate correlation, and 11% are weak correlation. The high correlation coefficients show that they originate from anthropogenic influences (Kumari et al. 2013).

Groundwater contamination

The results of physical, chemical, and heavy metals analyses of groundwater samples collected from the landfill are given in Tables 8 and 9. In the present study, pH at all groundwater samples (except in BW2 and BW7) was about the normal rate (7.19–7.78). Samadder et al. (2017) reported that pH value from groundwater samples which were under a landfill effects (in India) varied from 6.14 to 8.1. Abd El-Salam and Abu-Zuid (2015) also showed that pH rate of water table samples from the sanitary landfill of Alexandria (Egypt) varied

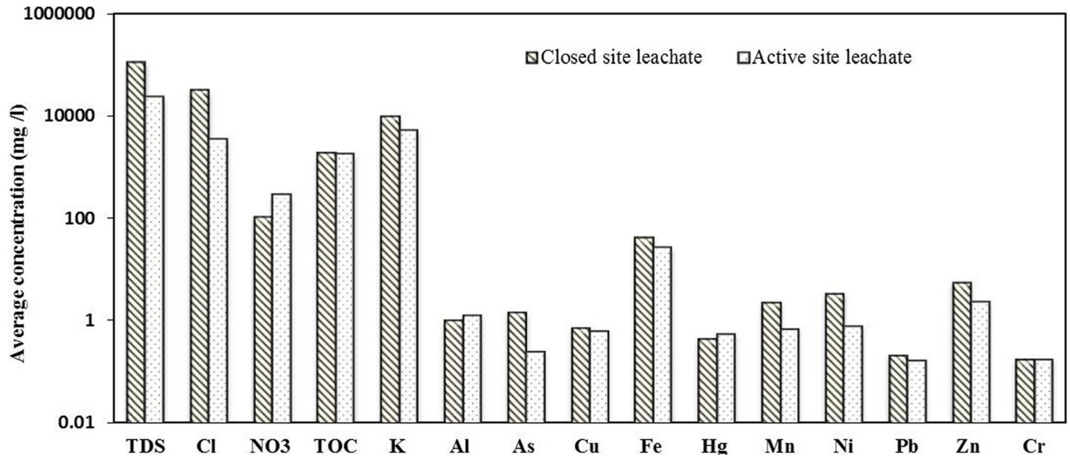

Fig. 2 Comparison between active and closed sites leachates

between 7.4 and 8.8. In Italy, Rapti-Caputo and Vaccaro (2006) reported the chemical characteristics of an unconfined groundwater influenced by a landfill leachate. The pH values of the groundwater samples were 7.16–7.9.

The EC data of the shallow groundwater ranged from 1080.18 to 10,875.43 μS/cm. The result showed groundwater salinity of the landfill site. EC of water at BW4, BW5, BW2, S1, and S2 were recorded as the high rates. The lower values were also recorded in the border of the landfill, which is an important indicator of the landfill effect on the groundwater quality. EC of two monitored wells near sanitary landfill in Alexandria, Egypt investigated by Abd El-Salam and Abu-Zuid (2015). They reported high EC values with means of 10,354 and 12,745 μS/cm.

TDS that indicates the general nature of water quality was ranged between 705.45 and 7504 mg/l. Its concentration was found to be remarkably high at BW4, BW5, BW2, S1, and S2. Based on TDS classification

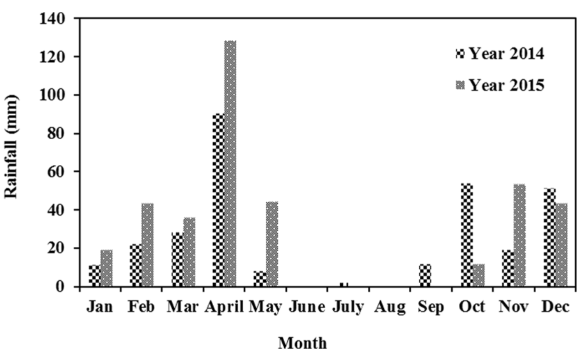

Fig. 3 Monthly rainfall distribution in the study area

(Rabinove et al. 1958), BW4 and BW5 were considered as the moderately saline sites and S1, S2, BW2, BW3, BW6, and BW8 were slightly saline sites. This high value may be due to the percolating leachate into the shallow water table of the area.

Samadder et al. (2017) revealed that TDS concentration of groundwater near the studied landfill varied from 2400 to 7000 mg/l, which are significantly high concentrations. The higher values of TDS (2855 to 16,276 mg/l) than of our study's result were reported by Abd El-Salam and Abu-Zuid (2015). Improperly lined landfill may lead to increased TDS in groundwater.

COD as an important water quality (of organic pollution) index shows oxygen requirement to oxidize particulate organic matter in water. In this study, COD rate in the groundwater samples varied from 30.25 to 64.71 mg/l. According to the Abd El-Salam and Abu-Zuid (2015) results, the mean BOD_5 and COD concentrations from monitoring wells of the area were about 45–60 and 68–80 mg/l, respectively. They concluded that the groundwater samples of the landfill site contained little organic matter. Hassan and Ramadan (2005) also reported similar results, although conversely, Samadder et al. (2017) observed very high concentration values of BOD_5 (600–5400 mg/l) and COD (3640–6520 mg/l). In comparison with measured COD rates, the low BOD_5 value confirms that the landfill groundwater samples contained relatively a large amount of non-biodegradable organic matter.

Because of the existence of the cellulosic materials (paper) and vegetables in municipal solid waste, there is a high source of K^+ concentration in the leachate. Hence, it can be used as an indicator of groundwater

Table 5 Seasonal variation of the samples (average values) collected from the leachate ponds of the sites

Parameter (mg/l)[a]		pH	EC	TDS	BOD_5	COD	Cl^-	NO_3^-	TOC	K^+	
Dry season (June–October 2014)	P1	7.60	35,173	23,756	7111	9520	2920	252.2	1825	3500	
	P2	7.88	131,230	90,720	7210	9560	28,500	94.4	1900	4500	
Rainy season (January–May 2015)	P1	7.75	38,036	24,833	8903	11,413	3813	315	2058	5164	
	P2	8.06	194,025	137,850	10,556	13,493	33,066	118.8	2273	14,682	
Parameter (mg/l)[a]		Al	As	Cu	Fe	Hg	Mn	Ni	Pb	Zn	Cr
Dry season (June–October 2014)	P1	0.94	0.07	0.04	13.8	0.52	0.44	0.7	0.05	0.1	0.13
	P2	0.98	0.55	0.01	39.9	0.29	2.21	2.9	0.17	4.24	0.16
Rainy season (January–May 2015)	P1	1.32	0.34	0.17	24.7	0.65	0.51	0.73	0.12	0.49	0.248
	P2	1.05	2.86	1.78	44.5	0.55	2.29	4.3	0.27	7.63	0.264

[a] Except for EC (μS/cm) and pH, P1: active site leachate, P2: closed site leachate

pollution caused by leachate (Ellis 1980). Based on our results, the K^+ concentration in the groundwater samples varied from 2 to 233.3 mg/l. The high value recorded at BW4.

Cl^- is a mobile element of landfill leachate which affects groundwater quality. Each increase in its concentration rate generally consider as groundwater contamination. Therefore, Cl^- concentration used as an important tracer to verify groundwater pollution by the researchers (Loizidou and Kapetanios 1993). It ranged between 56.2 and 2730.2 mg/l in the groundwater samples. At BW4, BW5, BW2, and S1, its concentration was observed to be higher than the acceptable upper limits for potable water as proposed by WHO (250 mg/l for chloride).

The concentration of NO_3^- in the groundwater samples varied from 28.89 to 66.25 mg/l. At BW2, BW3, S1, S2, and BW4, it exceeds the permissible limit of human health that shows a moderately high concentration. In Malaysia, Bahaa-Eldin et al. (2010) studied the effect of a MSW landfill leachate on groundwater quality. Their results showed that the concentration of chloride (355.48 mg/l) and nitrate (10.40 mg/l) indicate that the groundwater quality was extremely affected by the migrated leachate from the landfill site.

TOC is also used as a pollution indicator of groundwater under leachate effect in the saturated or unsaturated porous media (Jones-Lee and Lee 1993). Its origin is decomposed materials that include the following: i) natural organic matter such as humic and fulvic acids, amines, and urea, ii) synthetic materials such as detergents, pesticides, fertilizers, and herbicides (Hendricks 2007). In this study, the TOC concentration ranges from 0.2 to 26.9 mg/l. In BW4 and BW5, its concentration was recorded as the highest values, respectively. In BW2 and S1 which are under the active site leachate effect, TOC concentration in groundwater ranked as the lower rates. In the downstream area, TOC was decreased significantly. Due to this result, sampling location not only is an important factor, but the landfill age also plays a considerable role on the TOC rate.

In the present study, all heavy metals concentrations of the groundwater samples showed low values as shown in Table 9 and were below the allowable limits for drinking described by WHO (2011) except for Mn in BW4 and BW2 and Fe (0.331–1.041 mg/l) which exceeded the limits (0.1 for Mn and 0.3 mg/l for Fe). Abd El-Salam and Abu-Zuid (2015) obtained similar results. The physicochemical composition of the groundwater collected during the dry and wet seasons are shown in Table 10. These data are compared with drinking water quality standard (WHO 2011).

WQI results

The WQI value and water type of the individual samples are presented in Table 11. The WQI ranges from 53.8 to 597.8 and 64.2 to 720.3 for dry and rainy seasons, respectively. The dissolved ions in groundwater affected WQI values, particularly K^+, Cl^-, NO_3^-, Zn, Fe, Ni, and Mn. High iron and chloride concentrations in the groundwater caused a high WQI value, especially during the rainy seasons. The rainy season samples reveal a higher contaminate rates (more poor quality), compared with the dry season (Table 10). This may explained by a higher contaminate concentrations such as iron, chloride, nitrate, and TDS in the rainy season samples compared with the dry season samples. The WQI values

Table 6 Characteristics of the current study leachates compared with the literature

Landfill site	pH	EC	TDS	BOD_5	COD	Cl^-	NO_3^-	TOC	K^+	References
Aradkooh, Iran	4.12	–	–	–	59,400	9238	141	22,124	–	Safari and Bidhendi 2007
Shiraz, Iran	6.31	–	–	49,400	55,351	–	1460	–	–	Kheradmand et al. 2010
Saravan, Iran	8.2	–	–	–	4000–10,000	–	900–1200	–	–	Rasool et al. 2016
Sanandaj, Iran	–	3170	4438	–	112	481	0.115	–	–	Bagheri et al. 2017
Tabriz, Iran	6.7	–	32,000	21,000	35,600	–	–	–	–	Hajipour et al. 2011
Kermanshah, Iran	6.5	21,730	10,865	6245	11,170	1549	3000	–	–	Pirsaheb et al. 2015
Zahedan, Iran	–	–	9960	1960	4083	–	107	–	–	Amirian et al. 2017
UK	5.95–7.45	–	–	260–11,900	1160–23,800	233–2080	< 0.5–3.0	465–8000	117–780	Robinson and Maris 1985
Kuwait (active landfill)	6.9–8.2	1200–16,900	600–8430	30–600	157.9–9440	–	–	–	–	Al-Yaqout and Hamoda 2003
Kuwait (closed landfill)	7.2–8.06	6210–21,900	–	210–345	6400–8800	–	–	–	–	Al-Yaqout and Hamoda 2003
India	7.4–7.6	3870–4120	2027–2267	1500–3000	10,400–12,000	660–780	22.3–35	–	1632–1701	Naveen et al. 2016
France (new cell)	6.6–9	852–15,410	–	3–2300	87–12,787	5–1200	0.2–1957	4–1013	43–1150	Grisey and Aleya 2016
France (old landfill)	6.6–8.2	1520–6800	–	2–145	98–1581	58–590	< 0.3–660	34–222	75–483	Grisey and Aleya 2016
Portugal	7.6	20,700	–	300	4505	3823	85.9	1158	2.8	Vilar et al. 2011
China	2–10	–	–	40–73,000	100–90,000	5–6420	0.2–124	–	–	Weng et al. 2010
Current study (active site)	7.3–7.89	26,520–42,400	17,500–28,100	4742–12,110	6240–17,940	1640–4200	59.2–525	1300–2100	4500–6000	–
Current study (closed site)	7.59–8.19	58,100–245,550	38,900–176,800	5550–14,200	7600–18,080	14,200–59,000	82.61–129	1450–2300	4500–15,000	–

Landfill site	Al	As	Cu	Fe	Hg	Mn	Ni	Pb	Zn	Cr	References
Aradkooh, Iran	–	–	–	–	–	6.72	–	–	4.28	–	Safari and Bidhendi 2007
Shiraz, Iran	–	–	–	386.395	–	14.37	1.061	–	1.2015	0.0515	Kheradmand et al. 2010
Kuwait (active landfill)	0.2–4.5	–	0	0.3–54.1	–	–	0	0–0.2	0.0–4.8	0–0.2	Al-Yaqout and Hamoda 2003
Kuwait (closed landfill)	1.2–12.4	–	0–0.2	1.4–54.6	–	–	0.4–0.6	–	0.2–4.8	–	Al-Yaqout and Hamoda 2003
India	–	–	0.002–0.151	11.16–12.04	–	–	0.683–1.339	0.22–0.3	2.4–3	0.011–0.024	Naveen et al. 2016
France (new cell)	0.03–3.5	< 0.005–0.07	0.004–0.08	0.06–12	< 0.0005–0.003	< 0.1–1.9	0.01–0.2	0.00007–0.1	0.01–0.5	0.02–0.9	Grisey and Aleya 2016
France (old landfill)	< 0.01–6.7	< 0.005–0.08	0.005–0.95	0.01–21	< 0.0005–0.006	0.2–3.1	0.01–0.45	< 0.00005–0.45	0.02–2.4	< 0.005–0.3	Grisey and Aleya 2016
Portugal	–	95.6	0.1	8.5	–	0.9	0.8	36.4	1.2	2.2	Vilar et al. 2011

Table 6 (continued)

China	–	–	–	0.05–2820	–	0.07–125	–	0.002–2	0.2–370	0.01–8.7	Weng et al. 2010
China	–	–	–	–	–	–	0.08–0.42	0.06–0.6	–	0.12–4.14	Xiaoli et al. 2007
Czech Republic	–	0.0045–0.035	–	–	0–0.00064	–	0.034–0.155	0.003–0.015	0–0.0526	0.059–0.442	Zloch et al. 2018
Morocco	–	–	1.101	6.229	0.011	–	0.223	0.049	0.384	0.338	Tahiri et al. 2017
Denmark	–	0.0005–0.13	0.0005–0.67	0.08–180	0.00005–0.019	0.01–20	0.001–3.2	0.0005–1.5	0.00005–7.2	0.0005–1.3	Baun and Christensen 2004
UK	–	–	0.03–0.12	22.5–540	–	2.15–26.5	0.09–0.57	0.11–0.40	0.37–21.5	0.04–0.56	Robinson and Maris 1985
Current study (active site)	0.35–3.04	0.025–0.926	0.01–4.58	9.204–59.4	0.004–3.286	0.32–1.29	0.608–1.08	0.001–0.42	0.092–8.25	0.13–0.248	–
Current study (closed site)	0.37–1.55	0.038–5.7	0.01–3.56	13.09–88.34	0.008–1.58	0.66–5.25	1.47–5.06	0.001–0.386	0.25–13.84	0.104–0.264	–

Concentrations in mg/l except for pH and EC (μS/cm)

show that the quality of groundwater at some locations (BW2, BW3, S1, and S2) deteriorated in the rainy season. According to the WQI values, groundwater at BW4 in the dry and rainy seasons was found unsuitable for drinking (WQI > 300).

Treatment of the leachates

The characteristics of landfill leachate play a major role to select appropriate methods to treat before discharging to the environment. As mentioned before, disposed waste composition and its age affect the leachate composition and the contaminants concentration. Treatment of the leachate should be initiated along with the landfill operation, because in the young landfills, the biological treatment has a high efficiency on removal of biodegradable organic matter. However, while getting older, it becomes harder to remove recalcitrant compounds and consequently, a higher treatment cost is necessary (Castilhos Junior et al. 2009; Kawahigashi et al. 2014). In the case of the leachates containing a high organic material (COD > 10,000 mg/l, $0.4 < BOD_5/COD < 0.8$) as well a low nitrogen ammonia concentrations, the most appropriate approach is biological treatment (anaerobic and aerobic processes). However, for leachates with a high concentration of ammoniacal nitrogen and a low biodegradability, the most suitable approach is a physical–chemical process, linked with biological treatment (Pasalari et al. 2018).

In Iran, four methods that commonly used for landfill leachate treatment are: i) physicochemical methods ii) combined physical, physicochemical, and biological methods, iii) biological method, and iv) physical methods. Because of the rigorous environmental limits and existence of bio-recalcitrant elements in old leachate, most treatment methods have concentrated on physicochemical process, having ability to degrade refractory materials, and biodegradability increasing. The treatment cost data is highly variable due to differences in pretreatment technics employed prior to discharge and relevant strategies.

Factors that affect these costs include transport distance, treatment plant capacity, contaminant concentrations, pH and leachate quality characteristics, and environmental standards. Leachate treatment

Table 7 Correlations matrix for groundwater and leachate samples

	pH	EC	TDS	BOD_5	COD	Cl^-	NO_3^-	TOC	Cu	Fe	Mn	Ni	K^+	Cr
pH	1													
EC	0.258	1												
TDS	0.256	0.997	1											
BOD_5	0.297	0.683	0.673	1										
COD	0.292	0.668	0.657	0.998	1									
Cl^-	0.224	0.920	0.912	0.745	0.744	1								
NO_3^-	0.124	0.240	0.233	0.703	0.708	0.191	1							
TOC	0.240	0.778	0.779	0.994	0.994	0.710	0.721	1						
Cu	0.216	0.427	0.435	0.248	0.244	0.156	-0.013	0.274	1					
Fe	0.286	0.844	0.839	0.790	0.767	0.762	0.595	0.882	0.402	1				
Mn	0.169	0.407	0.400	0.689	0.683	0.796	0.314	0.639	0.138	0.487	1			
Ni	0.227	0.610	0.606	0.672	0.649	0.578	0.742	0.902	0.132	0.774	0.207	1		
K^+	0.263	0.946	0.947	0.941	0.940	0.915	0.449	0.915	0.166	0.865	0.764	0.751	1	
Cr	0.216	0.806	0.806	0.987	0.987	0.735	0.752	0.979	0.170	0.940	0.747	0.906	0.907	1

Strong correlation; Moderate correlation; weak correlation

costs (capital and operational) may constitute between 5 and 15% of the total landfilling costs before its end of operation (closure). Aftercare period of landfill, the leachate treatment costs (capital and operational) can constitute over 50% of the total landfilling costs (Johannessen 1999).

Table 8 Analysis of groundwater samples collected from the borewells and the spring S1 and S2

Borewell	Water analysis parameter									
	pH	EC (µS/cm)	TDS (mg/l)	DO (mg/l)	BOD_5 (mg/l)	COD (mg/l)	Cl^- (mg/l)	NO_3^- (mg/l)	TOC (mg/l)	K^+ (mg/l)
BW1 (as control)	7.74	600	398	2.5	4.7	18	45	11.8	0.45	2
BW2	6.96	3270	2220	2.25	9.51	31.5	466.7	66.25	1.5	7.66
BW3	7.42	2899	1576	3.27	14.08	35.09	125.6	62.06	0.2	3
BW4	7.19	10,875.43	7504	1.57	21.74	64.71	2730.2	63.92	26.9	233.3
BW5	7.08	4436.87	3131	2.12	9.6	30.25	1109	28.89	14.93	8
BW6	7.53	1495.54	1027.18	3.5	14.62	36.75	73.8	43.11	0.5	3
BW7	6.95	1375	933.27	3.75	12	33.5	56.2	30.06	0.23	4
BW8	7.61	1612.27	1094.45	3.66	13.81	32.91	110.6	43.81	0.2	3
BW9	7.78	1080.18	705.45	2.72	15.28	38.81	59.4	31.41	0.2	2
S1	7.41	3704.66	2547.44	3.3	18.25	48.8	267	65.93	1.26	3.33
S2	7.27	3424	2272	3.8	15.27	40	130.4	60.39	0.2	3

Table 9 Chemical analysis of groundwater samples collected from the borewells and the spring S1 and S2

Borewell	Water analysis parameter									
	Al (mg/l)	As (mg/l)	Cu (mg/l)	Fe (mg/l)	Hg (mg/l)	Mn (mg/l)	Ni (mg/l)	Pb (mg/l)	Zn (mg/l)	Cr (mg/l)
BW1 (as control)	0.009	0.01	0.01	0.41	0.002	0.07	0.035	0.001	0.01	0.003
BW2	0.012	0.005	0.011	*1.041*	0.003	*0.221*	0.072	0.004	0.015	0.003
BW3	0.012	0.005	0.011	*0.957*	0.002	0.039	0.034	0.004	0.023	0.005
BW4	0.008	0.022	0.01	*0.819*	0.003	*0.563*	*0.133*	0.002	0.026	0.004
BW5	0.011	0.004	0.011	*0.621*	0.005	0.07	0.075	0.004	0.02	0.009
BW6	0.01	0.008	0.011	*0.507*	0.003	0.022	0.034	0.003	0.031	0.005
BW7	0.009	0.007	0.013	0.331	0.003	0.017	0.031	0.004	0.06	0.004
BW8	0.01	0.008	0.012	*0.469*	0.003	0.021	0.034	0.004	0.032	0.005
BW9	0.009	0.004	0.013	*0.477*	0.003	0.023	0.037	0.004	0.010	0.004
S1	0.012	0.014	0.01	*0.77*	0.003	0.047	0.05	0.003	0.019	0.005
S2	0.008	0.005	0.009	*0.64*	0.002	0.03	0.033	0.002	0.019	0.005

The italicized values present concentration of the parameter above the standard rates, according to WHO

Table 10 Seasonal variation of the groundwater samples

Dry season (June–October 2014)					Rainy season (January–May 2015)				
Sample (mg/l)[a]	BW2	BW3	BW4	BW5	BW2	BW3	BW4	BW5	WHO limit
pH	6.89	7.11	7.09	6.89	7.07	7.6	7.54	7.42	6.5–8.5
EC	*2368*	*2143*	*11,052*	*4320*	*4773*	*3754*	*13,104*	*4507*	1500
TDS	*1699*	*1083*	*7681*	*2958*	*3088*	*2627*	*9002*	*3235*	500
BOD_5	*8.5*	*10.6*	*18.05*	*9.04*	*11.2*	*23.35*	*21.52*	*10.53*	5
COD	*27.2*	*32.5*	*63*	*28.4*	*38.67*	*59.67*	*63.75*	*33.33*	10
Cl^-	140.67	123	*2591*	*1100*	*562.5*	130	*2938*	*1115*	250
NO_3^-	*50.32*	*50.75*	*54.96*	27.1	*75.15*	*88.7*	*77.35*	30.087	45
TOC	0.3	0.1	*15*	*14.5*	2.1	0.3	*32*	*15.15*	2
K^+	7	2	*200*	7	8	4	*250*	8.5	12
Al	0.014	0.019	0.007	0. 01	0.008	0.008	0.01	0.012	0.2
As	0.005	0.025	*0.036*	0.005	0.005	0.006	0.004	0.003	0.01
Cu	0.01	0.01	0.01	0.012	0.01	0.01	0.01	0.01	2
Fe	*0.728*	*0.402*	0.32	0.318	*2.1*	*1.23*	*1.65*	*1.37*	0.3
Hg	0.004	0.002	0.004	0.006	0.003	0.003	0.004	0.002	0.006
Mn	0.058	0.055	*0.862*	*0.05*	*0.49*	0.042	*0.23*	0.103	0.1
Ni	0.044	0.043	*0.122*	0.056	*0.118*	0.055	*0.19*	*0.107*	0.07
Pb	0.006	0.005	0.002	0.006	0.001	0.001	0.001	0.001	0.01
Zn	0.014	0.02	0.035	0.025	0.017	0.018	0.015	0.012	3
Cr	0.006	0.01	0.007	0.01	0.002	0.002	0.002	0.009	0.05

[a] Except for EC (μS/cm) and pH

The italicized values present concentration of the parameter above the recommended rates, according to WHO

Table 11 Computation of water quality index (WQI) for individual groundwater samples

Sample	WQI (dry season)	Water type	WQI (rainy season)	Water type
BW1	53.8	Good water	64.2	Good water
BW2	101	Poor water	258.8	Very poor water
BW3	152.9	Poor water	210	Very poor water
BW4	597.8	Unsuitable for drinking	720.3	Unsuitable for drinking
BW5	210.9	Very poor water	273.1	Very poor water
BW6	62.7	Good water	72.6	Good water
BW7	68	Good water	88.8	Good water
BW8	68.6	Good water	90.6	Good water
BW9	55.7	Good water	76.4	Good water
S1	100.7	Poor water	289.1	Very poor water
S2	95.3	Good water	263.9	Very poor water

Table 12 leachate treatment costs compared with total investment and operation costs (US$/Tonne)

Site	Annual leachate generation	Treatment costs (investments and operational costs)	Liner/leachate collection	All other landfill investments	Operation and maintenance (except leachate treatment)	Total landfill costs
Active	50 m^3/day	1.6	3	2.5	3.6	10.7
Closed	30 m^3/day	5.2	0.95	1.8	1	8.95

In this research, the leachate treatment costs were compared with total investment and operation costs for the active and the closed sites leachates. It assumes that the landfill has a natural clay lining and the aerobic biological process with ammonia stripping is the relevant treatment method. Leachate treatment costs for the landfill are shown in Table 12 and Fig. 4. as shown, the leachate treatment costs in the active and closed sites constitute 15 and 58% of total landfilling costs, respectively.

In order to clarify the relationship between the samples and whether there were defined groups among them, the chemical data including TDS, K^+, Cl^-, BOD_5, TOC, NO_3^-, Fe, Ni, Mn of the leachate, and groundwater samples were applied to PCA. As shown in Fig. 5, first two principal components could be explained 90% of the

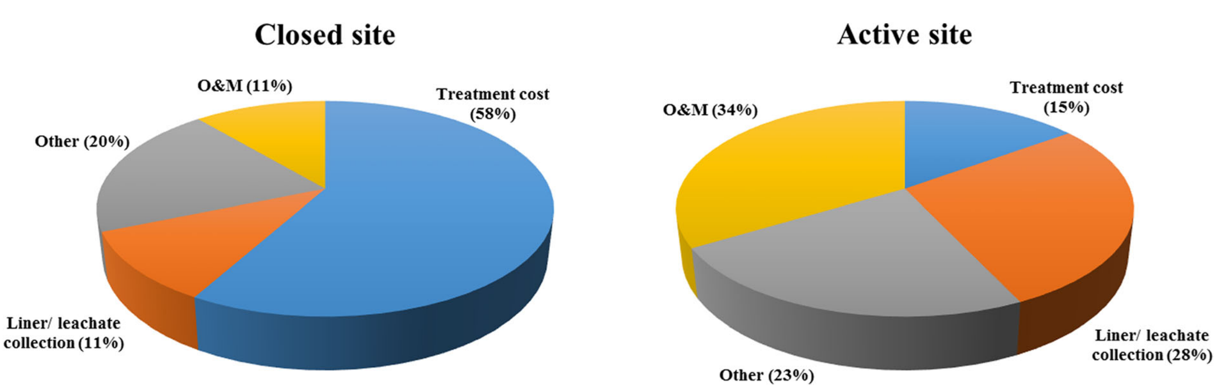

Fig. 4 leachate treatment costs compared with total landfilling costs

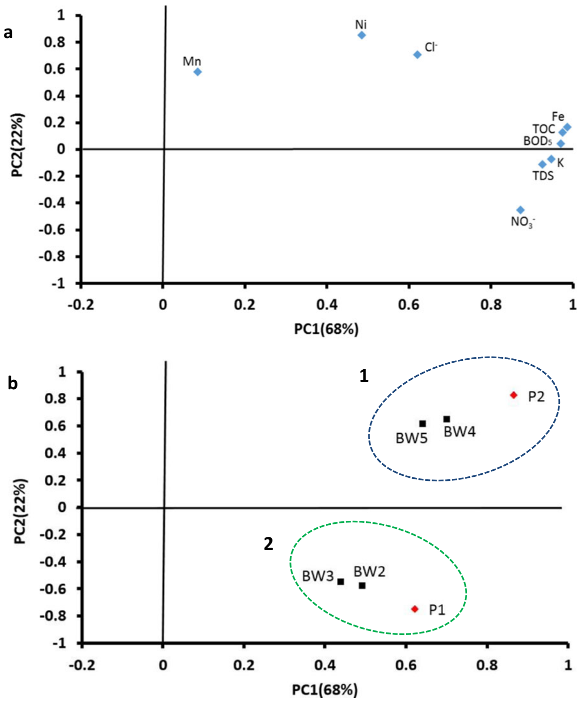

Fig. 5 Multivariate analysis graphs of the data (leachate ponds and groundwater) **a** PCA loading graph **b** PCA Scores graph

variation in the data set and are sufficient for interpretation of the landfill. The loading graph identifies which variables have the largest effect on the PCs. The score graph shows the data structure and detects clusters, outliers, and trends. In this study, all samples are placed in the positive value of the PC1. It is observed that samples that are placed in the positive values of the PC2 are influenced by concentrations of Cl^-, Ni, and Mn while samples with negative values on the PC2 are influenced by the concentration of NO_3^-, (Fig. 5 a, b).The results revealed the two groups are distinguished. The first group consists of closed site leachate (P2) and the borewells BW4 and BW5 and the second group composed of active site leachate (P1) and the borewells BW2 and BW3.

Effect of leachate age and sampling distance on the water quality parameters

Result of ANOVA test for the leachates of active and closed sites and the sampling distances (borewells) is presented in Table 13. The result shows that the groundwater quality parameters were influenced by the leachate ages and the interaction of leachate ages and the sampling distances ($p < 0.01$).

Comparison of the means water quality parameters related to the leachate ages

Comparison of the means groundwater quality parameters (observed in BW2, BW3 and BW4, BW5) related to the leachates ages is shown in Table 14. According to these results, the maximum value of Cl^-, Fe, TOC, COD, TDS, and EC was obtained in BW4 and BW5, where they were under the closed site leachate. The maximum NO_3^- was also obtained in BW2 and BW3, where they were under the active site leachate. However, the differences of all water quality parameters between BW2, BW3 and BW4, BW5 were not significant ($p < 0.05$).

Groundwater quality parameters related to the sampling distance

According to Table 15, the maximum value of the all water quality parameters was obtained in a short distance. The differences on the water quality parameters rates (except to Fe and COD) between the short and long distances were not significant ($p < 0.05$). However, the differences of Fe and

Table 13 ANOVA result for the leachates ages effect and the sampling distance on the groundwater quality

Source	df	Mean square						
		Cl^-	Fe	NO_3^-	TOC	COD	TDS	EC
L.A. effect ♣	1	5271180**	0.04**	206**	492**	61**	25411717**	52108134**
L.A. effect × SD♣♣	2	1372319**	0.04**	210**	123**	688**	10823937**	23385535**

**significant at $p < 0.01$, ♣ leachate age (L.A.), ♣♣ sampling distance (SD)

Table 14 Comparison of the means water quality parameters related to the leachates ages

Borewells under leachate age effect	Cl^-	Fe	NO_3^-	TOC	COD	TDS	EC
BW2, BW3 (P1): active site L.	296.2[a]	0.7200[a]	64.00[a]	5.233[a]	41.95[a]	1753[a]	2552[a]
BW4, BW5 (P2): closed site L.	1919.6[a]	0.8649[a]	53.86[a]	20.917[a]	47.48[a]	5318[a]	7656[a]

In each column, means with the same letter/s are not significantly different ($p < 0.05$)

Table 15 Comparison of the means water quality parameters related to the sampling distance from the leachates

Sampling Distance	Cl^-	Fe	NO_3^-	TOC	COD	TDS	EC
≤ 300 m (L1)	1599[a]	0.89[a]	64.92[a]	18.58[a]	56.76[a]	5026[a]	7290[a]
≥ 1000 m (L2)	617[a]	0.70[b]	52.93[a]	7.57[a]	32.67[b]	2045[a]	2918[a]

In each column, means with the same letter/s are not significantly different ($p < 0.05$)

COD between the short and long distances were significant ($p < 0.05$).

Groundwater quality parameters related to interaction of the leachate age effects and the sampling distances

Comparison of the means water quality parameters related to the interaction of the leachates ages effect and the sampling distance is shown in Table 16. According to these results, maximum and minimum Cl^-, TOC, TDS, and EC were obtained in P2L1 and P1L2, respectively. The maximum (0.96) and minimum (0.62 mg/l) value of Fe was obtained in P2L1 and P1L2, respectively. Also, the maximum (65.93) and minimum (43.8 mg/l) value of NO_3^- was obtained in P1L1 and P2L2, respectively. The maximum (64.71) and minimum (30.25 mg/l) value of COD was obtained in P2L1 and P2L2, respectively. Differences of all the water quality parameters between all treatments were significant ($p < 0.05$).

Conclusions

This study focused on an uncontrolled landfill in a semi-arid climate of Iran. The landfill composed of a closed and active sites. The results indicated that the pollutants concentration in the leachate pond of the closed site (with older solid wastes) was more than one of the active site. This is probably due to climatic conditions (low annual precipitation and extreme dryness) of the study area that resulted in slow waste decomposition. Therefore, chemical characteristics of the leachates in semi-arid climatic region such as our study site differ significantly from those in wet climatic regions, as reported by researchers. Comparison of the average water quality parameters concentrations related to the age of waste

Table 16 Comparison of the means water quality parameters related to interaction of the leachates ages effect and the sampling distance

L.A. effect × SD	Cl^-	Fe	NO_3^-	TOC	COD	TDS	EC
P1L1	467[c]	0.8214[b]	65.93[a]	10.27[c]	48.8[b]	2547[c]	3705[c]
P1L2	126[d]	0.6186[d]	62.07[c]	0.2[d]	35.09[c]	959[d]	1399[d]
P2L1	2730[a]	0.9571[a]	63.92[b]	26.9[a]	64.71[a]	7504[a]	10875[a]
P2L2	1109[b]	0.7728[c]	43.8[d]	14.93[b]	30.25[d]	3131[b]	4437[b]

In each column, means with same letter/s are not significantly different ($p < 0.05$). PiLj: shows the interaction of the leachates ages effect and the sampling distance from the leachates, P1: active site leachate effect, P2: closed site leachate effect, L1: short distance sampling points (≤ 300 m), L2: long distance sampling points (≥ 1000 m) leachates and sampling distance (using ANOVA test) shows a direct relationship between physicochemical characteristics of groundwater and the leachate ponds. Therefore a statistical testing including a main factor (age of leachate) and a subfactor (distance from the source of pollutant) was proposed to illustrate the landfill role on the groundwater quality.

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