

Research Paper

Assessment of water quality suitability for agriculture in a potentially leachate-contaminated region

Aida H Baghanam¹, Vahid Nourani¹, Zohre Khodaverdi^{1*}, Amirreza T Vakili¹

¹ Department of water resources engineering, Faculty of civil engineering, University of Tabriz, Iran.

Abstract: Dump sites pose a significant threat to groundwater resources due to the possibility of leachate leakage into the aquifer. This study investigated the impact of leachate on groundwater quality in the south-west region of Zanjan City, Iran, where groundwater is utilized for drinking, agricultural, and industrial purposes. We analyzed 18 parameters of dump site leachate, including physicochemical, heavy metals, and bacterial properties, alongside 13 groundwater samples. Sampling was conducted twice, in November 2020 and June 2021, within a five-kilometer radius of the Zanjan dump site. We utilized the Leachate Pollution Index (LPI) to evaluate potential groundwater contamination by leachate leakage from nearby dumpsite. Additionally, due to the predominant agricultural activities in the study area, various indices were employed to assess groundwater quality for agricultural purposes, such as Sodium Adsorption Ratio (SAR), Soluble Sodium Index (SSI), Kelly Ratio (KR), and Permeability Index (PI). Our analysis revealed no observed contamination related to leachate in the study area according to the LPI results. However, with the persistent pollution threat, implementing sanitary measures at the dump site is crucial to prevent potential impacts on groundwater quality. Moreover, the assessment of groundwater quality adequacy for irrigation yielded satisfactory results for SAR, KR, and PI indices. However, during both the dry (November 2020) and wet seasons (June 2021), the SSP index indicated that 80% of the samples were not classified as excellent, suggesting groundwater may not be suitable for agriculture. Overall, our qualitative study highlights the significant impact of the dry season on groundwater quality in the study area, attributed to elevated concentration levels of the investigated parameters within groundwater sources during the dry season.

Keywords: Leachate pollution index (LPI); Sodium adsorption ratio (SAR); Soluble sodium index (SSI); Water quality in agriculture

Received: 26 Jun 2023/ Accepted: 29 Mar 2024/ Published: 10 Aug 2024

Introduction

Groundwater stands as a vital freshwater resources essential for various purposes including drinking, irrigation, and industrial activities. Its quality can vary based on factors such as location, geology, and the type and quantity of soluble ions present in

the water. Although groundwater is generally less susceptible to pollution due to the absence of suspended particles or organic matter, contamination poses a significant challenge as its quality is not easily restorable (Soujanya Kamble and Saxena, 2017). Freshwater scarcity, particularly prevalent in arid and semi-arid regions, underscores the critical need to safeguard both the quality and quantity of these resources (Baghanam et al. 2020).

The technical literature review highlights the potential deterioration of groundwater quality due to leachate leakage from landfills (Stefania et al. 2019). This study aimed to assess groundwater pollution related to leachate from the Zanjan dump site. Despite efforts to mitigate waste production

*Corresponding author: Zohre Khodaverdi, E-mail address: zohre.khodaverdi@gmail.com

DOI: 10.26599/JGSE.2024.9280021

Baghanam AH, Nourani V, Khodaverdi Z, et al. 2024. Assessment of water quality suitability for agriculture in a potentially leachate-contaminated region. *Journal of Groundwater Science and Engineering*, 12(3): 281-292.

2305-7068/© 2024 Journal of Groundwater Science and Engineering Editorial Office. This is an open access article under the CC BY-NC-ND license (<http://creativecommons.org/licenses/by-nc-nd/4.0>)

through strategies like composting, incineration, and recycling, burying waste remains the primary method of waste management in developing countries, including Iran (Baghapour et al. 2020), which intensifies the possibility of groundwater contamination from leachate. Municipal waste, predominantly organic materials in arid and semi-arid regions of Iran, coupled with low rainfall and high evaporation, leads to leachate production with a higher pollution load compared to wetter regions (Yousefi Kebria et al. 2014).

Leachate leakage from unsanitary landfills poses a serious threat to both human well-being and the environment. The extent of this threat is influenced by factors such as the quality and quantity of leachate, operational phase age of the landfill, technical capabilities of the facility, soil and climatic conditions, aquifer type, and proximity to water sources. Effective management and monitoring of landfills are critical to mitigate the risks associated with leachate leakage, even after landfill closure (Talalaj and Biedka, 2016). Inadequate landfill management in Iran results in the disposal of not only Municipal Solid Waste (MSW) but also hazardous waste, including hospital and industrial waste, exacerbating leachate pollution with pathogens, soluble organic matter, suspended solids, inorganic compounds, heavy metals, and toxic compounds (Talalaj and Biedka, 2016). To minimize the environmental impact and potential risks to water resources, proper landfill leachate management is imperative.

Groundwater plays a crucial role in the study area, serving as a primary resource for drinking, agriculture, and industry. However, assessing all water quality parameters can be time and cost-intensive. To address this, various water quality indices, including the Leachate Pollution Index (LPI), have been developed to evaluate the water quality considering land use and contamination type. LPI has been employed in several studies to evaluate water quality. Kumar and Alappat have conducted studies on leachate and the LPI index since 2005, identifying the parameters that influence leachate pollution load. Other research has also been conducted to investigate the degree of leachate pollution in both active and closed landfills (Alao et al. 2023; Kumar and Alappat, 2005a, 2005b; H. Mishra et al. 2018; Umar et al. 2010).

Moreover, several water quality indices relevant to groundwater suitability for irrigation have been applied in previous studies (Aher and Gaikwad, 2017; Mahammad et al. 2023; Patel et al. 2020; Soujanya Kamble and Saxena, 2017). This study collected and analyzed leachate samples from fresh

and aged waste at the Zanjan dump site, along with groundwater samples from both dry and wet seasons to investigate the impact of leachate on groundwater resources. Various water quality indices, such as Sodium Adsorption Ratio (SAR), Soluble Sodium Index (SSI), Kelly's Ratio (KR), and Permeability Index (PI) were employed to investigate groundwater suitability for irrigation, given agriculture's prominence in the study area. These analyses are crucial for assessing the potential impact of leachate on groundwater resources and determining groundwater suitability for agricultural use.

1 Study area

Considering the significance of groundwater resources in the region, investigating pollution caused by dump site leachate is of utmost importance. The study area is bordered by the Zanjan River in the north, an industrial town to the east, and the municipal dump site to the southeast. Although the majority of the land is used for agricultural and horticultural purposes, the main industrial towns of Zanjan are located within and adjacent to this area. The unsanitary dump site of Zanjan, operational since 1995, presents a significant threat to groundwater due to the absence of a barrier layer and leachate collection systems essential for preventing leachate infiltration into the environment. Spanning an area of 50 hectares, this dump site is projected to continue operations for the next two decades. Furthermore, it receives approximately 340 tons of municipal waste daily from Zanjan city and neighboring areas.

According to the study by Gharejelou et al. (2017), the weight percentage of various compounds in one kilogram of municipal waste from five analyzed samples were as follows: 56.96% organic material, 10.39% plastic, 3.03% metals, 3.18% glass, 1.69% wood, 16.11% cardboard and paper, 3.77% textiles, 0.34% rubber, 3.59% garbage, and 0.57% bread. As illustrated in Fig. 1, organic material constitutes more than half of the waste weight, making it the primary source of leachate production.

The direction of groundwater flow in the study area was determined using the Inverse Distance Weighting (IDW) interpolation method based on piezometric data from the Water and Sewerage Organization of Zanjan Province in 2018. As depicted in Fig. 2, groundwater flow direction in the region is southeast to northwest.

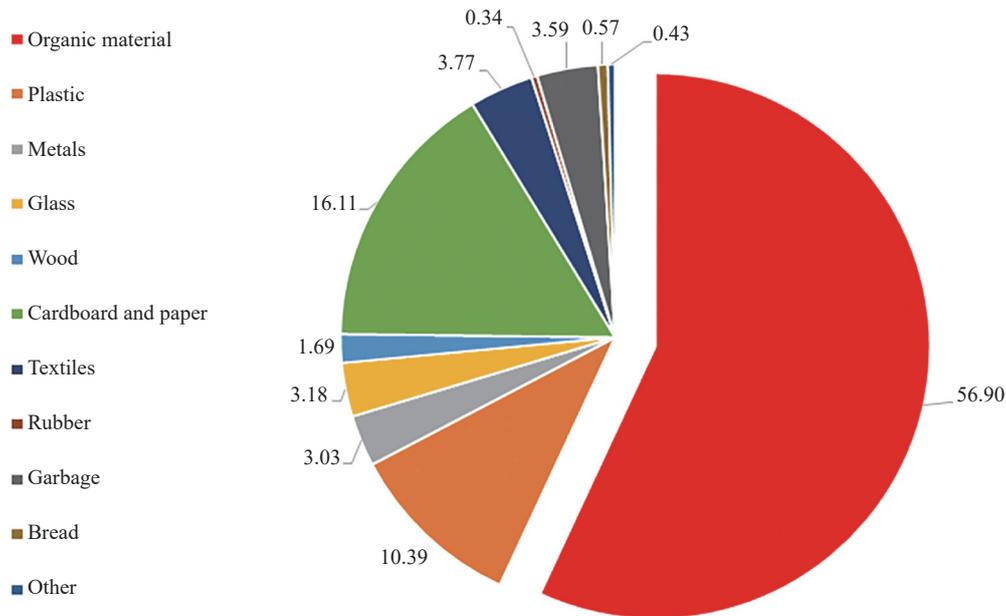


Fig. 1 Weight percentage of materials in Zanzan landfill

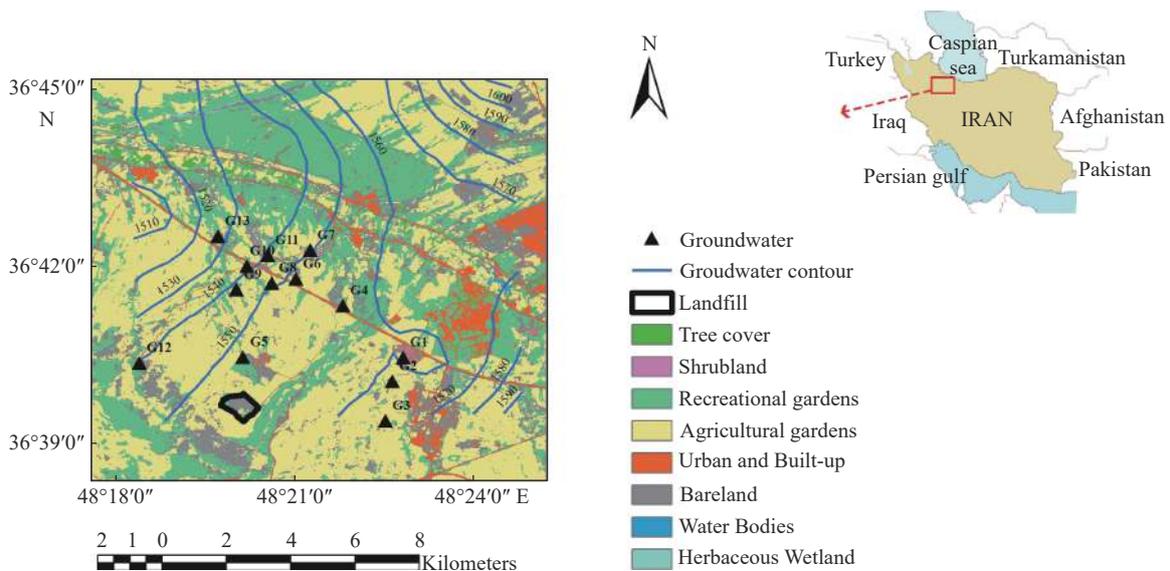


Fig. 2 The site of study area

2 Sample collection and methodology

2.1 Sample collection

Leachate: To evaluate the quality of leachate generated at the municipal dump site, four samples were meticulously collected and analyzed. Two samples were obtained from both fresh and mature leachate during both dry and wet seasons. The mature leachate was collected from old waste buried in the northwestern part of the dump site. Due to the absence of an effective leachate collection system, mature leachate samples were taken

from a pond in section A, taking into account the ground slope, as illustrated in Fig. 3. In addition, fresh leachate samples were collected from one-month-old waste at points B and C, as depicted in Fig. 3, during the designated sampling periods. These four samples are considered representative of the actual leachate quality in the dump site.

Groundwater: Given that groundwater is predominantly used for agricultural purposes in the study area. To assess the suitability of groundwater for irrigation purposes and to examine the potential impact of dump site leachate on water quality, 13 well water samples were collected during both the dry and wet seasons within a maxi-

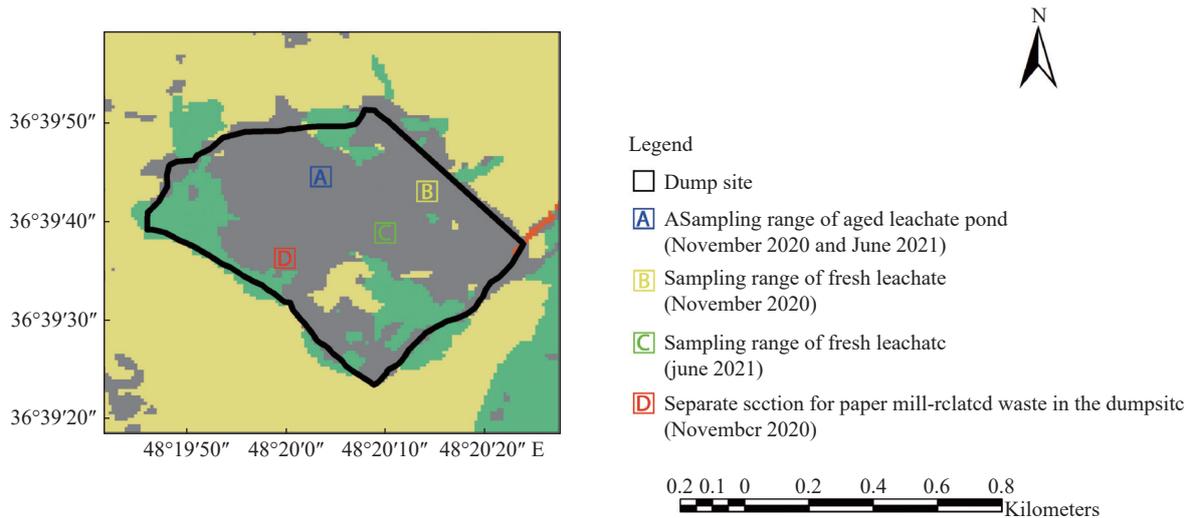


Fig. 3 Dump site leachate sampling points

radius of five kilometers from the dump site.

In this study, groundwater samples were collected from 13 wells located within five kilometers of the dump site. Sampling was conducted using one-liter Pyrex containers, which were initially rinsed with nitric acid and pumped for at least ten minutes before collection. The samples were then transported to the laboratory under controlled temperature below four degrees Celsius. Fig. 1 displays sampling points marked with G, comprising five wells designated for agricultural use, five for livestock and poultry, two for industrial purposes, and one for drinking water. Furthermore, Table 1 provides details on the location, distance, and depth of the wells relative to the dump site.

Both dump site leachate and groundwater

samples were analyzed for physicochemical, bacterial, and heavy metal parameters in accordance with APHA standards (Rice et al. 2017). Each test was performed three times to ensure accuracy. The results of the analyses conducted on the collected samples are presented and discussed in subsequent sections.

A detailed analysis of physicochemical parameters was conducted to identify the source of each contaminant in the leachate. The LPI was then calculated for both leachate and groundwater samples to evaluate the potential groundwater contamination by leachate. Subsequently, the suitability of groundwater resources for agricultural use was assessed using several indices, including the Sodium Adsorption Ratio (SAR), Sodium Saturation Percentage (SSP), Kelly's Ratio (KR), and

Table 1 Location of sampling in the vicinity of Zanjan dump site

Site	Depth /m	Distance from dump site /Km	Groundwater direction	Land use
1	130	3.4	Upstream	Agriculture
2	110	3.8	Upstream	Livestock
3	120	3.6	Upstream	Aviculture
4	80	3.5	Upstream	Aviculture
5	135	1.5	Downstream	Agriculture
6	8	2.9	Downstream	Residential
7	120	3.7	Downstream	Industrial
8	157	4.15	Downstream	Agriculture
9	140	4.3	Downstream	Agriculture
10	120	4.5	Downstream	Livestock
11	145	4.8	Downstream	Agriculture
12	85	5.2	Downstream	Aviculture
13	89	5.4	Downstream	Industrial

Permeability Index (PI). Brief descriptions of the applied indices are described as follows.

2.2 Methodology

2.2.1 LPI index

The LPI index is a commonly used method for assessing the potential contamination of leachate (Kumar and Alappat, 2005b). Formulated based on the Delphi method, this index assigns a weight to each pollutant to summarize complex leachate pollution data, as expressed in Equation 1 (Kumar and Alappat, 2005a).

$$LPI = \sum_{i=1}^n (W_i P_i) \tag{1}$$

Where: LPI is the indicator of leachate pollution; n indicates the number of sampling parameters, W_i represents the indicates weight (impact) of the i th pollutant (P_i).

When not all 18 parameters specified in the LPI method are available, the LPI can be calculated using Formula 2 (Kumar and Alappat, 2005a).

$$LPI = \frac{\sum_{i=1}^m (W_i P_i)}{\sum_{i=1}^m W_i} \tag{2}$$

The weight and sub-index of each pollutant are determined based on the importance and significance level of that pollutant in leachate pollution potential, according to expert opinions (Kumar and Alappat, 2005a).

2.2.2 Indicators for assessing water quality for agricultural use

In the context of water quality for irrigation, various initial parameters of drinking water, namely Ca, Na, Mg, K, and HCO_3 are used to evaluate water suitability for agricultural use (Aher and Gaikwad, 2017). Furthermore, SAR, SSP, PI, and

KR are key indicators used to assess water quality in agriculture.

Excessive amounts of water-soluble ions in irrigation water can adversely affect plants and soils, leading to physical and chemical effects (Tahmasebi et al. 2018). High concentrations of sodium in irrigation water, for instance, can decrease soil permeability, thereby limiting air and water circulation (Patel et al. 2020). Thus, the SAR index, calculated based on the concentration of sodium relative to the amounts of calcium and magnesium, is a critical parameter in the assessment of agricultural water quality. The SAR index can be calculated using Equation 3, and its classification range is presented in Table 2.

$$SAR = \frac{Na^+}{\sqrt{(Ca^{2+} + Mg^{2+})/2}} \tag{3}$$

Another relevant index is the SSP, which evaluates water's tendency to undergo cation exchange reactions. The presence of sodium in water can reduce soil permeability, impeding nutrient delivery to plants and hindering overall plant growth (Patel et al. 2020). The SSP index can be calculated using Formula 4, and its qualitative classification range is also presented in Table 2.

$$SSP = \frac{(Na^+ + K^+) \times 100}{(Na^+ + K^+ + Ca^{2+} + Mg^{2+})} \tag{4}$$

The Kelly index (KR) represents the ratio of measured sodium to total calcium and magnesium. Higher sodium content in soil correlates with lower soil permeability, with higher KR values indicating an increased risk of reduced permeability (Kelley, 1941). A KR value less than one indicates suitable water for agriculture, whereas a value greater than one suggests unsuitability. The KR value can be calculated using Equation 5.

$$KR = \frac{Na^+}{(Ca^{2+} + Mg^{2+})} \tag{5}$$

Table 2 Limits set for agricultural indicators

Category/Index	SAR	SSP	KR	PI
Great	<10	<20	–	>75
Good	18–10	20–40	–	25–75
Medium	18–26	40–60	–	–
Suspect	–	60–80	–	–
Inappropriate	>26	>80	–	<25
Usable	–	–	<1	–
Unusable	–	–	>1	–

Note: In all the proposed indicators, values are entered in milliequivalents per liter

Lastly, the PI index is used to assess soil permeability, with higher PI values indicating a greater ion content. Prolonged use of mineral-rich water can decrease soil permeability, indirectly affecting agricultural productivity (Khanoranga and Khalid, 2019; Patel et al. 2020). Soil permeability depends on the concentrations of calcium, magnesium, bicarbonate, and sodium ions, and the PI index can be calculated using Equation 6. The classification limits for PI are also presented in Table 2, based on the study by Doneen (1962).

$$PI = \frac{(Na^+ + \sqrt{HCO_3^-}) \times 100}{(Na^+ + Ca^{2+} + Mg^{2+})} \quad (6)$$

Notably, the LPI index was calculated using various parameters such as pH, TDS, Cl, COD, NH₃, Cr, Zn, Cu, Pb, Fe, Ni, Hg, and coliform. In addition, agricultural indicators were calculated using the Na, Ca, Mg, K, and HCO₃ parameters. The results of the analysis of these parameters in groundwater and dump site leachate samples during both dry and wet seasons are presented in Table 3, indicating the observed range of changes.

3 Results and discussion

3.1 Leachate quality assessment

Table 3 illustrates that leachate samples collec-

ted during the dry season exhibit higher contamination levels compared to those obtained during the wet season. This disparity can be attributed to evaporation, which intensifies during elevated temperatures, leading to the concentration of various pollutants in groundwater.

Leachate pH, typically ranging from 4.5 to 9 in landfills, serves as indicator of landfill age, as reported by Tchobanoglous (1993). A mature leachate exhibiting a pH of 8.2 and 7.9 indicates the conversion of acidic compounds into methane and carbon dioxide during the dry and wet seasons, respectively. Conversely, fresh waste leachate was acidic, with pH values of 5.7 and 5.1 for the dry and wet seasons, respectively, resulting from the formation of carboxylic acid, which is characteristic of young or fresh leachate (Talalaj and Biedka, 2016). Based on Tchobanoglous (1993), the aged section of the Zanjan dump site has undergone four stages of development, reading relative stability, while the fresh waste area on the other side of the dump site remains in its early phases.

During the dry season, leachate exhibited significantly higher electrical conductivity (34,100 μs to 34,900 μs) compared to the wet season (26,000 μs to 26,700 μs), indicating elevated mineral levels including chloride, nitrate, and phosphate as anions and sodium, magnesium, calcium, and iron as cations. Total Dissolved Solids (TDS) parameter in fresh leachate during the wet and dry seasons was

Table 3 Summary of physicochemical parameters

Parameter	Groundwater						Parameter	Leachate			
	Dry seasons			Wet seasons				Dry seasons		Wet seasons	
	Average	Max	Min	Average	Max	Min		Fresh waste	Old waste	Fresh waste	Old waste
pH	6.5	7.2	6.1	6.5	6.8	5.9	PH	5.7	8.2	5.1	7.9
TDS (ppm)	755.6	2150	376.0	615.6	1210	350	EC (μs)	34,900	34,100	26,700	26,000
Cl (mg/L)	142.2	396.9	39.1	123.7	326.6	63.9	TDS (ppm)	17,400	17,100	13,400	13,100
COD (mg/L)	55.2	155.5	3.6	32.0	86.3	4.4	NO ₃ (mg/L)	200	50	160	40
NH ₃ (mg/L)	0.11	0.31	0.04	0.08	0.11	0.05	Cl (mg/L)	200	150	6,248	200
HCO ₃ (mg/L)	175.9	237.0	128.8	200.8	233.9	123.9	COD (mg/L)	55,750	9,079	42,522	5,500
Ca (mg/L)	229.5	410.0	128	103.7	234	40.6	PO ₄ (mg/L)	234	61	240	78
Mg (mg/L)	36.1	49.7	24.1	23.8	33.5	15.7	SO ₄ (mg/L)	1,800	200	1100	500
Na (mg/L)	142.3	621.0	36.4	67.8	178.5	22.9	NH ₃ (mg/L)	640	790	680	820
K (mg/L)	3.6	7.3	1.1	2.1	3.8	0.6	Hg (μg/L)	0.02	0.01	0.02	0.01
Hg (μg/L)	-	-	-	-	-	-	Cr (μg/L)	0.3	1.4	0.1	1.1
Cr (μg/L)	10.1	11.1	9.9	13.5	13.7	13.3	Cu (ppm)	0.2	0.17	0.04	0.03
Cu (μg/L)	4.1	4.2	4	4.4	4.8	4.1	Fe (ppm)	16	5.1	9.5	3
Fe (mg/L)	-	-	-	-	-	-	Ni (ppm)	0.6	1.4	0.5	1.1
Ni (μg/L)	1.5	2	1.2	1.1	1.1	1	Pb (ppm)	0.01	0.06	0.02	0.07
Pb (μg/L)	-	-	-	-	-	-	Zn (ppm)	3	0.42	0.25	0.03
Zn (μg/L)	-	-	-	-	-	-	Mn (ppm)	24	0.3	9.3	0.1
Coliforms	-	-	-	-	-	-	Coliforms	460	1100	460	1100

13,400 ppm and 17,400 ppm, respectively. Similarly in mature leachate, the TDS parameter was 13,100 ppm and 17,100 ppm during the wet and dry seasons, respectively. These values were consistent with the high electrical conductivity values.

Landfills typically function as anaerobic systems, however, freshly buried waste often contains high oxygen levels due to mixing and insufficient compaction. Consequently, in fresh leachate, the nitrogen undergoes conversion from ammonia to nitrate through the nitrification process. This leads to higher nitrate levels in fresh leachate compared to mature dump site leachate, while mature leachate typically contains higher levels of ammonia than fresh leachate (Stefania et al. 2019; Vaverková, 2019). Ammonia concentrations in fresh leachates were recorded at 680 and 640 mg/L for the wet and dry seasons, respectively, whereas in mature leachates, these concentrations were higher at 820 mg/L and 790 mg/L. Ammonia is considered a persistent contaminant due to its stability under anaerobic conditions, resulting from the decomposition of the nitrogenous portion of biodegradable wastes (Kulikowska and Klimiuk, 2008). Over time, landfill conditions tend to transition towards anaerobic conditions. The nitrate levels in fresh leachate decreased from 200 mg/L to 160 mg/L, and in mature leachate, from 50 mg/L to 40 mg/L during the dry and wet seasons, respectively. It should be noted that leachate sampling points were located at different sites and during two distinct periods.

Phosphorus in leachate is primarily in the form of orthophosphate, which is relatively immobile in both waste and soil. It is mainly derived from the degradation of organic matter containing phospholipids and phosphoproteins (Kapelewska et al. 2019). In fresh leachate, the average concentration of phosphorus is 237 mg/L, while in mature leachate, it is 70 mg/L.

The sulfate concentration in leachate is primarily associated with the breakdown of proteins, household, and industrial waste commonly found in municipal waste. The concentration of this parameter tends to be higher in fresh leachate compared to mature leachate, attributed to the aerobic conditions present in fresh leachate (Abd El-Salam and Abu-Zuid, 2015). Specifically, sulfate concentrations in fresh leachate were 1,100 mg/L during the wet season and 1,800 mg/L during the dry season. In contrast, in mature leachate, these concentrations were lower at 500 mg/L and 200 mg/L during the wet and dry seasons, respectively.

Chlorine in leachate is considered stable as it does not get absorbed by the soil or participate in biochemical reactions, making it a suitable indicator of leachate in groundwater resources (Kumar and Alappat, 2005b; Ling and Zhang, 2017). Plastic and paper materials in waste are the primary sources of chlorine leachate. It was found that chlorine concentrations in fresh and mature leachate during the wet season were 200 and 150 mg/L, respectively, which fall within the range observed in other studied landfills (Abd El-Salam and Abu-Zuid, 2015; Baghapour et al. 2020; Mishra et al. 2018; Stefania et al. 2019).

Additional field investigations indicated that the increase in chlorine levels during the wet season could be linked to the disposal of paper mill waste, an industrial waste containing chlorinated compounds such as chlorine, chlorine dioxide, and chlorinated organic compounds, in the same section of the dump site as the municipal waste. Conversely, during the dry season, these types of waste were disposed of separately (Fig. 3), leading to lower chlorine levels compared to the wet season as outlined in Table 3.

The presence of heavy metals is ubiquitous in consumer and industrial products, such as batteries and electronic panels (Aucott, 2006). Heavy metals found in dump site leachate can be influenced by various factors including pH conditions. The high alkalinity and organic matter in leachate limit the solubility of heavy metals, causing them to be absorbed and deposited in the soil (Mishra et al. 2018; Talalaj, 2014). As a result, most heavy metal concentrations in leachate decrease over time, except for lead, which has a significant adsorption capacity for organic material (Kumar and Alappat, 2005a). In this study, the lead concentration in fresh leachate was 0.01 ppm and 0.02 ppm during the wet and dry seasons, respectively. However, the lead concentration in mature leachate was higher, at 0.06 ppm and 0.07 ppm, during the dry and wet seasons, respectively. These findings support the conclusion drawn by Kumar and Alappat (2005a).

Iron had the highest concentration among all the metal parameters, primarily due to the disposal of iron and steel waste, such as cans and car wreckage, without proper segregation at the dump site. This observation is supported by the findings of Mor et al. (2006) and Rana et al. (2018). The dark brown color of the leachate is mainly attributed to the oxidation of the iron to iron (III) and the formation of ferric hydroxide colloids (Mor et al. 2006). Over time, anaerobic conditions can accelerate iron corrosion (Sizirici and Tansel, 2010). In

this study, the maximum concentrations of iron and manganese in fresh leachate were 16 ppm and 24 ppm, respectively. Sizirici and Tansel (2010) reported that iron concentration tends to increase over the operational period under anaerobic conditions. However, in this study, complete anaerobic conditions were not achieved at our sampling location as access to the old dump site section was not granted, and leachate from the 3-4 years old ponds was sampled. Consequently, the iron concentration decreased, with the maximum concentration in the pond during both seasons being 5.1 ppm and 0.3 ppm, respectively. The high concentration of manganese in the leachate is due to its use in the production of iron and steel alloys and as an oxidant for cleaning, bleaching, and disinfection, such as in the form of potassium permanganate (Cotruvo, 2017). Since there is no proper recycling process for incoming waste to landfills in Iran, higher manganese concentration in the leachate resulted.

The Chemical Oxygen Demand (COD) decreases drastically over time as leachate undergoes stabilization. In stabilized leachates, COD typically falls within the range of 5,000 mg/L and 20,000 mg/L. Conversely, fresh leachate often exhibits higher COD values, ranging from 30,000 to 60,000 (Umar et al. 2010; Vaverková, 2019). However, in the current study, COD values in fresh leachate were notably elevated, with reported values of 55,750 mg/L and 42,522 mg/L during the dry and wet seasons, respectively. In contrast, the COD content in mature leachate from the sampling pond during the same periods was substantially lower, at 9,079 mg/L and 5,500 mg/L. This disparity can be attributed to the biodegradation of organic matter in the leachate over time (Umar et al. 2010).

The concentration of bacterial coliforms in both fresh and mature leachate was observed to be 460 mg/L and 1,100 mg/L, respectively, during both sampling periods. The data on coliform bacteria in the leachate revealed that the waste regime remained stable during the two sampling periods. Moreover, the increase in the value of this parameter was predictable due to the growth and multiplication of bacteria.

Based on the results of the leachate tests, it appears that landfill age and operational stage affect leachate composition, thereby affecting the LPI index. The LPI index values in fresh leachate ranged between 24.54 and 27.93 during the two sampling periods in November and June (6 months). In contrast, the LPI from the pond was lower, with recorded values of 24.51 and 26.79. These findings are consistent with those of other studies, such as Kumar and Alappat (2005a) with an LPI of 19.66 with an LPI range of 5.43 to 20.76 for four active and closed landfills, and S. Mishra et al. (2018) with an LPI range of 23.8 to 30.

3.2 Groundwater quality assessment

Instead of describing each pollutant individually, LPI was employed as a representation of the overall impact of the leachate on groundwater quality. However, considering the primary usage of groundwater in the study area is for irrigation, Table 4 illustrates the quality of groundwater in terms of several indices, including SAR, SSP, KR, and PI.

Based on the results presented in Table 4, it can be observed that the average LPI value for the groundwater samples was 5.33, indicating that the leachate from the dump site has not contaminated

Table 4 Results of the evaluated indexes through sampling points (dry and wet seasons)

parameters		Average	Max	Min	Standard deviation	Coefficient of changes
Leachate LPI	Dry season	24.52	24.54	24.51	0.02	0
Groundwater LPI		5.32	5.5	5.15	0.11	0.02
SAR		2.15	7.73	0.66	1.81	0.84
SSP		26	52.69	12.53	10.99	0.42
KR		0.38	1.11	0.14	0.26	0.67
PI		35.23	55.56	25.58	8.32	0.24
Leachate LPI	Wet season	27.36	27.93	26.79	0.81	0.03
Groundwater LPI		5.34	5.40	5.08	0.55	0.10
SAR		1.5	2.9	0.62	0.71	0.47
SSP		28.37	43.4	16.93	7.54	0.27
KR		0.4	0.86	0.14	0.16	0.39
PI		49.84	64.93	35.59	9.27	0.19

the groundwater. There is a notable discrepancy between the LPI values obtained from the groundwater and the dump site, suggesting no leakage of leachate into the groundwater.

Table 4 also indicates that the SAR index values of groundwater in both sampling periods were within permissible limits, suggesting that sodium in the water does not pose a risk to agriculture in the region. Additionally, there was a downward trend in SAR index values in most wells during the transition from the dry to wet seasons.

Results from the SSP index suggest that groundwater salinity was more affected during the dry season (November 2020). Only 31% of wells (4 wells) were categorized as excellent, while 62% of wells (8 wells) fell within the good range, and 8% of wells (1 well) were classified as poor. However, during the wet season, the situation improved significantly, with only 8% of wells (1 well) rated as excellent for agricultural use, and the majority of wells were in the good range (between the dotted lines and the three lines in Fig. 4 that are painted), primarily due to the potassium parameter in this index.

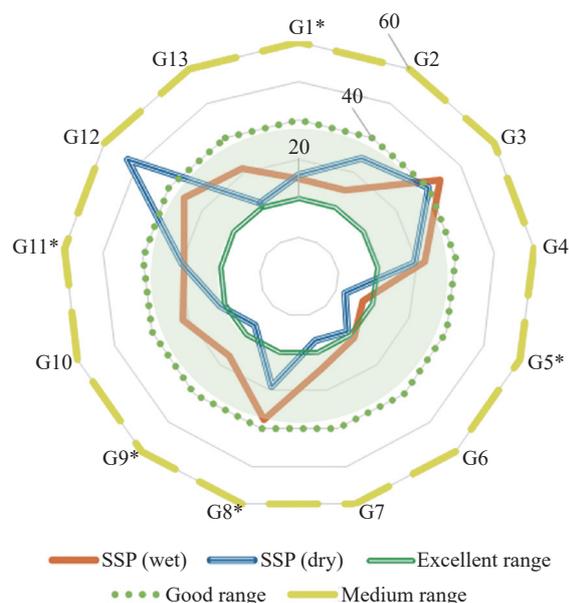


Fig. 4 Summary chart of SSP index (dry and wet seasons)

It is noteworthy that among the wells designated for agricultural use (Fig. 1), only well No. 5, which is the closest to the dump site, consistently showed favorable agricultural results in both sampling periods based on the SSP index. This observation suggests the potential absence of leachate leakage in groundwater sources near this well. Overall, the SSP index results suggest that the groundwater resources in the region are

currently suitable for agricultural use. However, continued monitoring and management are essential to ensure their long-term sustainability.

The KR index results (Table 4), indicate satisfactory groundwater quality in the study area. Only one well fell outside the acceptable range during the dry season, and this well had limited agricultural use.

As illustrated in Fig. 5, the PI index values in both sampling periods fall within the acceptable range delineated by the two dashed lines. The average value of this index during the two seasons was 42, indicating a relatively high level of parameters influencing soil permeability. It is crucial to note that prolonged use of mineral-rich irrigation water can diminish soil permeability, leading to difficulties in plowing and delay in young plants' growth (Khanoranga and Khalid, 2019). Since these parameters are largely anthropogenic, continued practices of this nature could elevate the PI index level, negatively impacting the agriculture in the region. During the wet season, the maximum PI index was observed in well No.11 with a value of 64.93, while the minimum was recorded in well No.5 during the dry season, which is used for agriculture. Table 4 summarizes the PI index values for all wells.

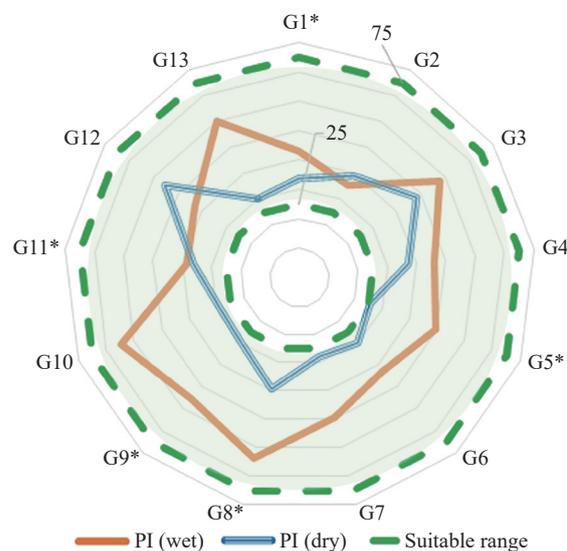


Fig. 5 Graph of PI index status in two sampling periods

This study's findings indicated that groundwater parameters' concentrations were higher during the dry season compared to the wet season, which can be attributed to seasonal changes. The geological formations in the study area, originating from volcanic activity, are known for their high concentrations of ions such as sodium and calcium (Hem, 1959). Specifically, the calcium ion concentration

in water resources ranged from 128 mg/L to 410 mg/L and 40.6 mg/L to 234 mg/L during dry and wet seasons, respectively. Moreover, the maximum magnesium concentrations were 49.7 mg/L and 33.5 mg/L, during the dry and wet seasons, respectively. The average sodium concentrations were 142.3 mg/L and 67.8 mg/L during dry and wet seasons, respectively. Furthermore, the maximum concentrations of potassium ions were 7.3 mg/L and 3.8 mg/L during dry and wet seasons, respectively. The elevated concentrations of these ions can be attributed to the geological structure of the region. It's worth noting that these parameters were more pronounced in the northern section of the study area due to the concentration of recreational and agricultural gardens in this section (Fig. 2). Overall, this study offers valuable insights into the assessment of leachate pollution at the Zanjan dump site and groundwater quality for agricultural uses. For better comprehension, the results of groundwater analysis are summarized in Fig. 6.

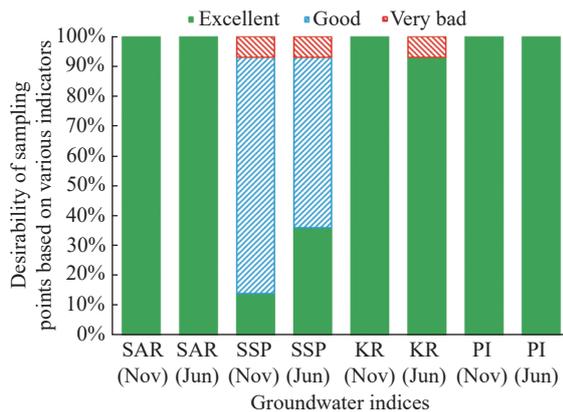


Fig. 6 Summary of groundwater analysis for agricultural use

4 Conclusion

In this study, we investigated the pollution potential of leachate produced from the unsanitary Zanjan municipal waste dump site using the LPI index. Our findings suggest that the parameters analyzed at this dump site align with those obtained in other studies, confirming that the produced leachate is highly polluting. However, the study also discovered that the leachate had not penetrated into the groundwater sources in the study area. To assess the suitability of groundwater for irrigation, SAR, SSP, KR, and PI indices were employed. The results indicated that the region's water resources were generally suitable for agricultural uses based on the SAR, KR, and PI

indices. However, according to the SSP index, only 20% of the wells were considered excellent for this purpose. Despite the absence of leachate contamination in well NO.5, which is the closest to the dump site, we recommend drilling monitoring wells at various depths and distances from the dump site to assess the potential impact of leachate. Continuous monitoring is advised to determine the least impact of leachate on groundwater. If the unsanitary burial operations persist, there could be a risk of leachate infiltration into groundwater sources in the future. Therefore, further studies are warranted, and the construction of sanitary dump sites and leachate control measures should be considered to mitigate the potential environmental hazards associated with the Zanjan municipal waste dump site.

References

- Abd El-Salam MM, I Abu-Zuid G. 2015. Impact of landfill leachate on the groundwater quality: A case study in Egypt. *Journal of Advanced Research*, 6(4): 579–586. DOI: [10.1016/j.jare.2014.02.003](https://doi.org/10.1016/j.jare.2014.02.003).
- Aher K, Gaikwad S. 2017. Irrigation groundwater quality based on hydrochemical analysis of Nandgaon Block, Nashik district in Maharashtra. *International Journal of Advanced Geosciences*, 5(1): 1–5. DOI: [10.14419/ijag.v5i1.7116](https://doi.org/10.14419/ijag.v5i1.7116).
- Alao JO, Abdo HG, Ayejoto DA, et al. 2023. Evaluation of groundwater contamination and the health risk due to landfills using integrated geophysical methods and Physiochemical water analysis. *Case Studies in Chemical and Environmental Engineering*, 8: 100523. DOI: [10.1016/j.cscee.2023.100523](https://doi.org/10.1016/j.cscee.2023.100523).
- Aucott M. 2006. The fate of heavy metals in landfills: A Review. New Jersey Department of Environmental Protection New Jersey.
- Baghanam AH, Nourani V, Aslani H, et al. 2020. Spatiotemporal variation of water pollution near landfill site: Application of clustering methods to assess the admissibility of LWPI. *Journal of Hydrology*, 591(prepublish): 125581.
- Baghapour MA, Shooshtarian MR, Zarghami M. 2020. Process mining approach of a new water quality index for long-term assessment under uncertainty using consensus-based

- fuzzy decision support system. *Water Resources Management*, 34(3): 1155–1172. DOI: [10.1007/s11269-020-02489-5](https://doi.org/10.1007/s11269-020-02489-5).
- Cotruvo JA. 2017. WHO guidelines for drinking water quality: First addendum to the fourth edition. *American Water Works Association Journal*, 109(7): 44–51. DOI: [10.5942/jawwa.2017.109.0087](https://doi.org/10.5942/jawwa.2017.109.0087).
- Doneen L. 1962. The influence of crop and soil on percolating water. Proc. 1961 Biennial conference on Groundwater recharge.
- Gharejelou F, Parizanagheh AA, Zamani AA. 2017. Qualitative/quantitative studies and physical/chemical analysis of municipal solid wastes in Zanjan City University of Zanjan.
- Hem JD. 1959. Study and interpretation of the chemical characteristics of natural water.
- Kapelewska J, Kotowska U, Karpińska J, et al. 2019. Water pollution indicators and chemometric expertise for the assessment of the impact of municipal solid waste landfills on groundwater located in their area. *Chemical Engineering Journal*, 359: 790–800. DOI: [10.1016/j.cej.2018.11.137](https://doi.org/10.1016/j.cej.2018.11.137).
- Kelley WP. 1941. Permissible composition and concentration of irrigation water. *Transactions of the American Society of Civil Engineers*, 106(1): 849–855. DOI: [10.1061/TACEAT.0005384](https://doi.org/10.1061/TACEAT.0005384).
- Khanoranga, Khalid S. 2019. An assessment of groundwater quality for irrigation and drinking purposes around brick kilns in three districts of Balochistan Province, Pakistan, through water quality index and multivariate statistical approaches. *Journal of Geochemical Exploration*, 197: 14–26. DOI: [10.1016/j.gexplo.2018.11.007](https://doi.org/10.1016/j.gexplo.2018.11.007).
- Kulikowska D, Klimiuk E. 2008. The effect of landfill age on municipal leachate composition. *Bioresource Technology*, 99(13): 5981–5985. DOI: [10.1016/j.biortech.2007.10.015](https://doi.org/10.1016/j.biortech.2007.10.015).
- Kumar D, Alappat BJ. 2005. Analysis of leachate pollution index and formulation of sub-leachate pollution indices. *Waste Management & Research*, 23(3): 230–239. DOI: [10.1177/0734242X05054875](https://doi.org/10.1177/0734242X05054875).
- Kumar D, Alappat BJ. 2005. Evaluating leachate contamination potential of landfill sites using leachate pollution index. *Clean Technologies and Environmental Policy*, 7(3): 190–197. DOI: [10.1007/s10098-004-0269-4](https://doi.org/10.1007/s10098-004-0269-4).
- Ling CP, Zhang Q. 2017. Evaluation of surface water and groundwater contamination in a MSW landfill area using hydrochemical analysis and electrical resistivity tomography: A case study in Sichuan Province, Southwest China. *Environmental Monitoring and Assessment*, 189(4): 140. DOI: [10.1007/s10661-017-5832-7](https://doi.org/10.1007/s10661-017-5832-7).
- Mahammad S, Islam A, Shit PK. 2023. Geospatial assessment of groundwater quality using entropy-based irrigation water quality index and heavy metal pollution indices. *Environmental Science and Pollution Research*, 30(55): 116498–116521. DOI: [10.1007/s11356-022-20665-5](https://doi.org/10.1007/s11356-022-20665-5).
- Mishra H, Karmakar S, Kumar R, et al. 2018. A long-term comparative assessment of human health risk to leachate-contaminated groundwater from heavy metal with different liner systems. *Environmental Science and Pollution Research*, 25(3): 2911–2923. DOI: [10.1007/s11356-017-0717-4](https://doi.org/10.1007/s11356-017-0717-4).
- Mishra S, Tiwary D, Ohri A. 2018. Leachate characterisation and evaluation of leachate pollution potential of urban municipal landfill sites. *International Journal of Environment and Waste Management*, 21(4): 217. DOI: [10.1504/ijewm.2018.093431](https://doi.org/10.1504/ijewm.2018.093431).
- Mor S, Ravindra K, Dahiya RP, et al. 2006. Leachate characterization and assessment of groundwater pollution near municipal solid waste landfill site. *Environmental Monitoring and Assessment*, 118(1): 435–456. DOI: [10.1007/s10661-006-1505-7](https://doi.org/10.1007/s10661-006-1505-7).
- Patel MP, Gami B, Patel A, et al. 2020. Climatic and anthropogenic impact on groundwater quality of agriculture dominated areas of southern and central Gujarat, India. *Groundwater for Sustainable Development*, 10: 100306. DOI: [10.1016/j.gsd.2019.100306](https://doi.org/10.1016/j.gsd.2019.100306).
- Rice EW, Bridgewater L, Association APH. 2017. Standard methods for the examination of water and wastewater (Vol. 23). American public health association Washington, DC.
- Sizirici B, Tansel B. 2010. Projection of landfill stabilization period by time series analysis of leachate quality and transformation trends of VOCs. *Waste Management*, 30(1): 82–91.

- DOI: [10.1016/j.wasman.2009.09.006](https://doi.org/10.1016/j.wasman.2009.09.006).
- Soujanya Kamble B, Saxena PR. 2017. Environmental impact of municipal dumpsite leachate on ground-water quality in Jawaharnagar, Rangareddy, Telangana, India. *Applied Water Science*, 7(6): 3333–3343. DOI: [10.1007/s13201-016-0480-6](https://doi.org/10.1007/s13201-016-0480-6).
- Stefania GA, Rotiroti M, Buerge IJ, et al. 2019. Identification of groundwater pollution sources in a landfill site using artificial sweeteners, multivariate analysis and transport modeling. *Waste Management*, 95: 116–128. DOI: [10.1016/j.wasman.2019.06.010](https://doi.org/10.1016/j.wasman.2019.06.010).
- Tahmasebi P, Mahmudy-Gharaie MH, Ghassemzadeh F, et al. 2018. Assessment of groundwater suitability for irrigation in a gold mine surrounding area, NE Iran. *Environmental Earth Sciences*, 77(22): 766. DOI: [10.1007/s12665-018-7941-1](https://doi.org/10.1007/s12665-018-7941-1).
- Talalaj IA. 2014. Assessment of groundwater quality near the landfill site using the modified water quality index. *Environmental Monitoring and Assessment*, 186(6): 3673–3683. DOI: [10.1007/s10661-014-3649-1](https://doi.org/10.1007/s10661-014-3649-1).
- Talalaj IA, Biedka P. 2016. Use of the landfill water pollution index (LWPI) for groundwater quality assessment near the landfill sites. *Environmental Science and Pollution Research*, 23(24): 24601–24613. DOI: [10.1007/s11356-016-7622-0](https://doi.org/10.1007/s11356-016-7622-0).
- Tchobanoglous G. 1993. Integrated solid waste management engineering principles and management issues. Water Science & Technology Library. DOI: [10.1016/0921-3449\(93\)90020-G](https://doi.org/10.1016/0921-3449(93)90020-G).
- Umar M, Aziz HA, Yusoff MS. 2010. Variability of parameters involved in leachate pollution index and determination of LPI from four landfills in Malaysia. *International Journal of Chemical Engineering*, 2: 49–54. DOI: [10.1155/2010/747953](https://doi.org/10.1155/2010/747953).
- Vaverková. 2019. Landfill impacts on the environment—Review. *Geosciences*, 9: 2–16. DOI: [10.3390/geosciences9100431](https://doi.org/10.3390/geosciences9100431).
- Yousefi Kebria D, Taghizadeh M, Darvish G. 2014. Effect of leachate penetration on the chemical and physical properties of MSW landfill soils (Case Study: Tonekabon Landfill). *Nashrieh Shimi va Mohandesi Shimi Iran*, 33(2): 63–69.