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Environmental Impact Assessment of Sulaymaniyah Solid Waste Dumpsite Using Leachate and Soil Pollution Indices

Sura Mahdi Muhammad[1], Yaseen Ahmad Hamaamin[2], Nihad Bahaaldeen Salih[1]

[1]Department of Water Resources Engineering, College of Engineering, University of Sulaimani, KRG, Iraq, [2]Department of Civil Engineering, College of Engineering, University of Sulaimani, KRG, Iraq

ABSTRACT

Global urban population is rising that resulting more waste production. Globally, municipal solid waste (MSW) generation considered as a serious threat on the global environment and human wellbeing. Leachate from solid waste dumps poses significant environmental and health risks, particularly due to contamination in soil and water caused by heavy metals. In this study, environmental impacts of MSW are assessed and estimated for Sulaymaniyah city, KRG, Iraq, which is located at 10 km south of the city in the Tanjaro dumpsite. Soil and leachate samples were collected and analyzed for various expected pollutant, to assess the environmental contamination through using pollution indices. For assessing the leachate pollution index (LPI), some parameters were determined, such as potential of hydrogen (pH), total dissolved solid, biochemical oxygen demand (BOD_5), and chemical oxygen demand (COD), and chloride (Cl). LPI value (20.1377) is much higher than the related standards. High concentrations of metals, such as cadmium (Cd), iron (Fe), manganese (Mn), copper (Cu), chromium (Cr), nickel (Ni), and zinc (Zn), found in the soil near the site, however, the contamination level is not serious based on the checked pollution indices, such as pollution index (PI) and nemerow PI ($PI_{nemerow}$). PI for Cd, Fe, Mn, Cu, Cr, Ni, and Zn were 0.158, 0.024, 0.088, 0.176, 0.613, 0.786, and 0.225, respectively, whereas, $PI_{nemerow}$ value was 0.606, which classified the soil as a non-contaminated soil. Results of this study reveals that the Tanjaro dumpsite needs an engineered landfill and decent leachate treatment right away; since present conditions far over safe limits and threaten soil and water quality.

Index Terms: Solid Waste, Leachate, Soil Pollution, Pollution Index, Sulaymaniyah City

1. INTRODUCTION

Population growth and socioeconomic development has elevated solid waste generation. The world urban population, from 1950 to 2014 has increased rapidly, going from 746 million in 1950 to 3.9 billion in 2014 [1]. The population estimated by 2025 expected to be 9.7 billion inhabitants, in Asia and Africa's urban area increase with approximately 90% [2]. Global municipal solid waste (MSW) generation was 1.3 billion tons/year in 2016 and estimated to rise to around 2.2 billion tons/year by 2025 [3]. MSW generation rates influence economic development, industrialization, local climate and public habits. Solid waste is more generated due to the high urbanization and economic development rate. When income level and urbanization growing the consumption of products elevated and then more wastes will be generated. The waste generated by city residents is double that generated in rural areas [4], [5]. Solid waste generation is rising with urbanization and richness. In high income countries, MSW is produced at 2.13 kg/capita/day whereas, it is produced

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Corresponding author's e-mail: Sura Mahdi Muhammad, Department of Water Resources Engineering, College of Engineering, University of Sulaimani, KRG, Iraq. E-mail: sura.muhammad@univsul.edu.iq

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at rates as low as 0.84 kg/capita/day in lower and lower middle income [1].

MSW (trash and garbage) is the everyday discarded items by public from households, businesses and other places within a municipality. The principal constituents of MSW includes food leftovers, paper, such as office paper or newspaper and packaging paper, glass, plastics, textile, metals, horticultural waste, as well as bulky refuse. There exists a direct relation between the socioeconomic status of an area and the amount of waste produced [5]–[7].

Leachate is developed rainfall infiltrating into a MSW dumpsite or landfills which allows the pollutant draining [8]. In addition, the leachate from landfill dissolution has a considerable number of compounds due to this complex composition of waste, some of them expect to be a danger to nature and health if released into ecology [9]. Leachate mainly consists of; dissolved organic matter, inorganic micro components (calcium (Ca), magnesium (Mg), potassium (K), Fe, etc.), heavy metals and xenobiotic organic constituents transferring from households or industrial chemicals (phenols, aromatic hydrocarbons, chlorinated aliphatic hydrocarbons, pesticides, etc.) [10], [11]. Leachate from the solid waste dump has a significant positive influence on the both geotechnical and chemical properties of soil which is going to be changed because of leachate effect [12]–[16].

Heavy metals can be considered as one of the hazardous contaminations in leachate, they are toxic, disrupt the natural biological balance, and prevent self-purification mechanisms [17]. Researchers conducted on the effects of MSW leachate on the land environment. Awokunmi *et al.* 2010 found the highest concentration of heavy metals was recorded within the center of each dumpsite and there was a significant decrease in concentration as the distance from dumpsite center increased but leaching did not reach 200 m and more [18]. In the study of Kanmani and Gandhimathi 2013, leachate analysis shows high value of chemical oxygen demand (COD) and a low biochemical oxygen demand (BOD_5)/COD ratio, indicating methanogenic condition, which is the fourth stage of landfill life cycle. Heavy metals, such lead Pb, Cu, Mn, and Cd, were found in the soil, signaling contamination from leachate migration [19]. Hredoy *et al.* 2022 evaluated the impact of the Amin Bazar landfill, Bangladish on surrounding environments, focusing on the contamination of leachate and its effects on surface water, groundwater, soil, and plants [20]. The study results of Mouhoun-Chouaki *et al.* 2019 showed that MSW significantly altered soil characteristics, increasing organic matter content (4.35%) and heavy metal concentrations (Cu, Zn, Cd, Pb, Ni, Cr), though they did not exceed pollution thresholds [21]. Gebre and Debelie 2015 found that soil in the area was polluted by heavy metals, with Cd being the most significant pollutant, followed by Cr, cobalt (Co), Pb, Mn, and Ni. This pollution was caused by improper open landfill practices and lack of pollution control [22]. For instance, a leachate pollution index (LPI) is defined and measured for various landfills by Kumar and Alappat 2003 [23], and the sub-leachate pollution indices are determined: LPI organic (LPI_{or}), LPI inorganic (LPI_{in}) and LPI heavy metals (LPI_{hm}).

The main objective of the present study is to evaluate the public health and environmental impacts related with the MSW dumpsite located in the Tanjaro district of Sulaymaniyah city, KRG, Iraq. In addition, the study is aiming to provide critical insights to aid decision-makers and urban planners in identifying suitable areas for waste disposal and developing more effective waste management strategies.

2. MATERIALS AND METHODS

Soil and leachate samples from the dumpsite were also systematically collected for analysis to fulfil the aim of the study. The samples were then analyzed through a series of chemical and physical tests to find out the extent of pollution. Pollution index (PI) calculated by measuring the concentration of the heavy metals in leachate and soil. This index is an important indicator of environmental pollution caused by the improper disposal of solid waste and provides a measurable index of the degree of pollution at the site.

2.1. Study Area

Tanjaro dumpsite which is existing 10 km south of the Sulaymaniyah city, KRG, Iraq and is established in 1998 [24] is shown in Fig. 1. The population of city in 2024 is 782,500 inhabitants (Sulaymaniyah statistics directorate, 2025) and the population of Sulaymaniyah was 679563 inhabitants in 2008, it's increased by 15%. The estimated solid waste generation for the city of Sulaymaniyah was approximately 1000 tons/day in 2008 [24], and according to the Presidency of Sulaymaniyah Municipality around 1000–1100 tons/day of solid waste generated by 2024, currently about half the city solid waste treated properly according to specification in (Asia Al-Taqa Al-Mutajadida) solid waste treatment plant, and the remained transfer to the Tanjaro dumpsite without treatment. MSW in this site mainly domestic waste consisting of kitchen waste, paper, glass, plastic, metal, cardboard, and fabrics. Solid waste also includes waste from the city fish market,

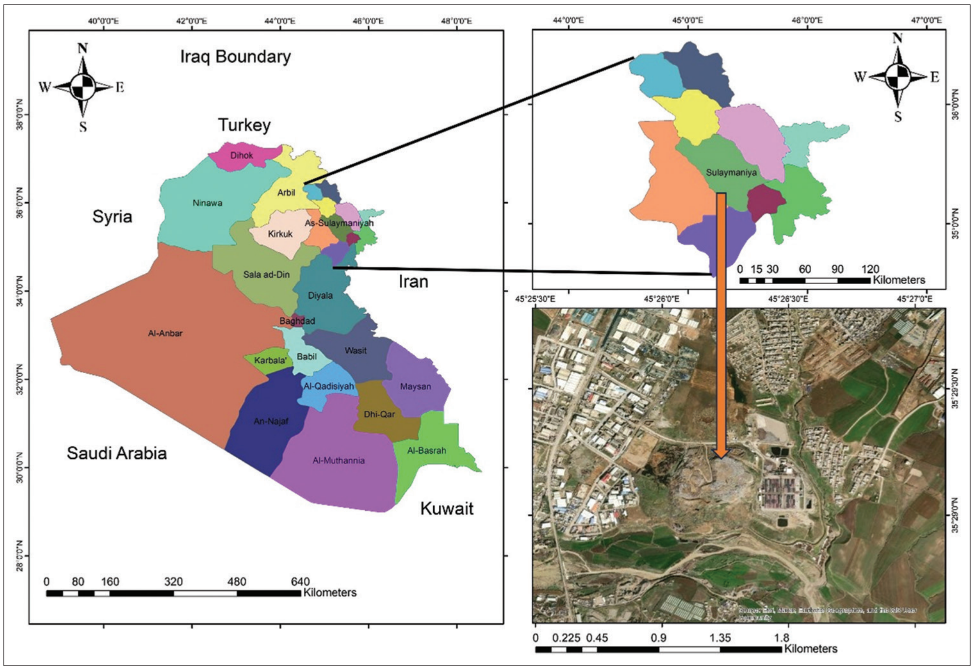


Fig. 1. Sulaymaniyah city dumpsite (Tanjaro district).

slaughterhouse, poultry market, dairy farm, non-infectious hospital waste, and car tires. The site is an unlicensed low-lying open dump where large mound of more than 12–20 m high waste existing.

2.2. Sampling and Testing of Leachate

The leachate samples of the Tanjaro dumpsite were collected in winter season when the leachate was stands as a pond in several locations from the dumpsite. The leachate samples were collected at the dumpsite randomly from two different locations, first sample was collected in December 2024 and second sample was collected in January 2025, the leachate samples locations are represented in Fig. 2. The samples were directly transferred through a polytetrafluoroethylene container to the laboratory for various physicochemical analyses. The leachate samples were analyzed for potential of hydrogen (pH), electrical conductivity (EC), total dissolved solid (TDS), COD, BOD_5, chloride (Cl), K, sodium (Na), nitrate (NO_3), phosphate (PO_4), and heavy metals (Ni, Cr, Cd, Cu, Pb, Fe, Zn).

2.3. LPI

2.3.1. LPI and sub-indices

The LPI is a method created when a group of 80 experts, who are experienced environmental engineers and had worked in the area of waste management and were distributed around the globe was selected to conduct the present survey. Based on two individual surveys, 18 leachate pollution parameters were included in the LPI. Table 1 list of 18 leachate pollutants and significance levels.

The LPI can be calculated by using (1) [25].

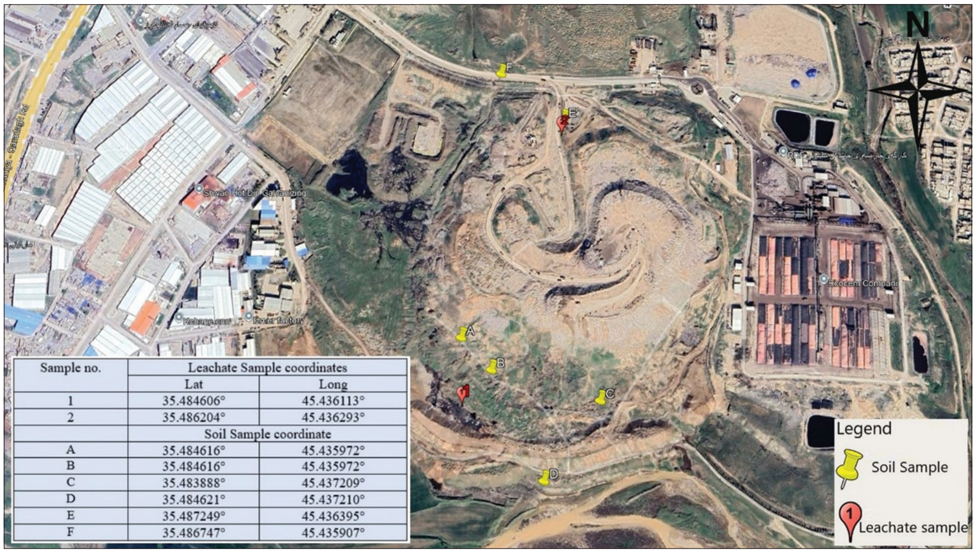
$$LPI = \sum_{i=1}^{n} w_i p_i \tag{1}$$

Where LPI= weighted additive LPI, wi= weight for the ith pollutant variable which is represented in Table 1; pi= sub-index score of the ith leachate pollutant variable and determined from the sub-index rating curves along with 90% confidence limits (represented as *x*-error bars) for the pollutants included in this subgroup [25]; n is the number of leachate pollutant variables applied in finding LPI; and $\sum_{i=1}^{n} w_i = 1$.

In cases of a lack of data for all leachate pollutant variables in LPI, the LPI can be determined using the available leachate pollutants concentration. If so, the LPI can be obtained by using (2).

$$LPI = \frac{\sum_{i=1}^{m} w_i p_i}{\sum_{i=1}^{m} w_i} \tag{2}$$

Where m is the quantity of leachate pollutant parameters present for the sample but in this case m <18 and $\sum_{i=1}^{m} w_i < 1$. Hence, not all the 18 leachate pollutant parameters are present



Sample no.	Leachate Sample coordinates	
	Lat	Long
1	35.484606°	45.436113°
2	35.486204°	45.436293°
	Soil Sample coordinate	
A	35.484616°	45.435972°
B	35.484616°	45.435972°
C	35.483888°	45.437209°
D	35.484621°	45.437210°
E	35.487249°	45.436395°
F	35.486747°	45.435907°

Fig. 2. Leachate and soil samples locations at Tanjaro dumpsite.

TABLE 1: The significance and weights of the 18 pollutants [25]

No.	Pollutant	Significance	Pollutant weight
1	COD	3.963	0.062
2	BOD_5	3.902	0.061
3	Total coliform bacteria	3.289	0.052
4	Phenolic compounds	3.627	0.057
5	pH	3.509	0.055
6	Chloride	3.078	0.048
7	TKN	3.367	0.053
8	Ammonia nitrogen	3.250	0.051
9	Total dissolved solid	3.196	0.050
10	Lead	4.019	0.063
11	Mercury	3.923	0.062
12	Zinc	3.585	0.056
13	Arsenic	3.885	0.061
14	Total chromium	4.057	0.064
15	Iron	2.830	0.045
16	Copper	3.170	0.050
17	Nickel	3.321	0.052
18	Cyanide	3.694	0.058
	Total	63.165	1.000

in the Tanjaro leachate samples, so the LPI will be calculated by using (2).

2.3.2. Sub-indices of LPI

To make the LPI a more informative and applicable index for the scientific community and practitioners, the LPI is broken down into three sub-indices. These three component sub-indices are derived from the leachate quality and they represent the high frequency pollutants in the landfill leachate. Leachate can be described as having physical, chemical, and bio compositions. The physical characteristics of leachate are color, odor, solids, temperature, etc., while the chemical components can be classified into organic and inorganic matter. The organisms involved are some of numerous viruses and pathogens which have been found in leachate. Other contaminants of concern include biodegradable organics, heavy metals and other dissolved inorganics.

The eighteen leachate pollutant variables used in the LPI are divided by the following three components groups to generate three sub-LPIs, as indicated in Table 2 [25].

However, because only 11 of those variables are available in the Tanjaro leachate samples, the sub-LPIs are divided as follow; LPI_{or} is consists of COD and BOD_5; LPI_{in} is consists of pH, TDS, and Cl; LPI_{hm} is consists of Cr, Pb, Zn, Ni, Cu, and Fe. The wi used in calculating the sub-indices is represented in Table 3 [25].

2.4. Sampling and Testing of Soil

The dumpsite is illegal and not according to specification. Solid waste dumped without proper engineered landfill. Soil samples collected after removal of the dumped solid waste. We dug down about 60 cm with a hand auger to gather the samples. From six different spots within the dump, we collected around 300–500 g of soil each and placed them in clean containers. The soil samples loactions are represented in Fig. 2. We then sent the soil samples to a lab to test for different chemical elements. We specifically looked for heavy metals, such as Fe, Mn, Zn, Ni, Pb, Cr, Cu, and Cd to see how polluted the soil samples were.

2.5. Soil PI

2.5.1. Single PI

PI exhibits the contamination degree of each heavy metal, which is calculated by using (3).

$$PI = \frac{C_i}{S_i} \quad (3)$$

Ci and Si refer to the heavy metal concentration in a soil sample and its allowable limit, respectively [26]. Based on this, we can divide the soil into five categories based on pollution levels. If the PI is <1, the soil is considered clean. On the other hand, if the PI is >5, the soil is highly polluted. PI classification is shown in Table 4 [27].

TABLE 2: Sub-LPIs of leachate pollutant variables

Index	Variables
LPI_{or}	COD
	BOD_5
	Phenolic compounds
	TCB
LPI_{in}	pH
	TKN
	Ammonia nitrogen
	TDS
	Cl
LPI_{hm}	Chromium
	Lead
	Mercury
	Arsenic
	Cyanide
	Zinc
	Nickel
	Copper
	Iron

COD: Chemical oxygen demand, BOD_5: Biochemical oxygen demand, TDS: Total dissolved solid, LPI: Leachate pollution index

TABLE 3: The sub-index weight factors of the LPI parameters

Index	Parameters	Weight factor
LPI_{or}	BOD_5	0.263
	COD	0.267
	Phenolic compounds	0.246
	TCB	0.224
LPI_{in}	pH	0.214
	TKN	0.206
	Ammonia nitrogen	0.198
	TDS	0.195
	Cl	0.187
LPI_{hm}	Chromium	0.125
	Lead	0.123
	Mercury	0.121
	Arsenic	0.119
	Cyanide	0.114
	Zinc	0.110
	Nickel	0.102
	Copper	0.098
	Iron	0.088

COD: Chemical oxygen demand, BOD_5: Biochemical oxygen demand, TDS: Total dissolved solid, LPI: Leachate pollution index

2.5.2. $PI_{nemerow}$

$PI_{nemerow}$ is used for evaluating the overall soil contamination level that contains all the heavy metals that have been analyzed, the $PI_{nemerow}$ must be found by using (4) [28]:

$$PI_{nemerow} = \sqrt{\frac{\left(\frac{1}{n}\sum_{i=1}^{n} PI\right)^2 + (PI_{max})^2}{2}} \quad (4)$$

Where PI has been defined in the previous section, PI_{max} refers to the upper limit of all intensive pollution indicators, whereas, n indicates the quantity of heavy metals. Based on $PI_{nemerow}$ factor, five groups of soil contamination are given in the Table 5.

3. RESULTS AND DISCUSSION

3.1. Tanjaro Dumpsite Solid Waste Composition

The MSW of Sulaymaniyah city is sorted in all zones separately before being transported to the Tanjaro dumpsite, this MSW is separated according to the four seasons as shown in the Table 6. Fig. 3. Shows the waste components for the year 2024.

3.2. Leachate Sample Characteristics

Characteristics of leachate that collected from the Tanjaro dumpsite in Sulaymaniyah city are presented in Table 7, chemical, physical, and biological characteristics.

pH of the Tanjaro dumpsite leachate was 7.83, as a mean value of the two samples. pH value of landfill leachate of this study exceeds the recommended standard values according to Lee and Jones-Lee 1993 [29], the typical concentration values of (pH) ranged (5–7.5) for municipal landfill leachate. The leachate samples were determined to be alkaline. The EC was measured at a mean value of 40120.0 µS/cm. Major ions,

TABLE 4: Based on PI soil pollution index classification [27]

PI value	Soil pollution
PI < 1	-
1 < PI < 2	Low
2 < PI < 3	Medium
3 < PI < 5	Strong
PI > 5	Very strong

TABLE 5: Classification of soil contamination according to $PI_{nemerow}$ [27]

Class	A	B	C	D	E
$PI_{nemerow}$	≤0.7	0.7–1	1–2	2–3	≥3
Soil quality	No contamination	Very low contamination	Low contamination	Medium contamination	Extreme contamination

TABLE 6: Municipal solid waste composition based on the four seasons of 2024 year

Components	January, February, March	April, May, June	July, August, September	October, November, December	Total
Food	67.11	64.75	64.62	56.32	63.2
Paper	3.16	3.47	3.07	3.98	3.42
Plastic	7.21	7.27	9.37	9.36	8.30
Metal	3.62	4.14	3.55	5.46	4.20
Glass	2.90	2.10	2.35	2.02	2.30
Fabrics	2.88	2.93	2.93	3.33	3.0
Garden waste	1.91	1.93	2.98	4.22	2.8
Miscellaneous	11.21	13.41	11.13	15.30	12.8

All values are in tons

TABLE 7: Leachate characteristics of the Tanjaro dumpsite

Parameters	First location	Second location	Mean value
pH	8.13	7.54	7.83
EC	34000.0	46240.0	40120.0
TDS	20740.0	23800.0	22270.0
Cl	4670.0	4400.0	4535.0
Na	1560.0	1200.0	1380.0
K	4000.0	4101.0	4050.5
PO_4	92.0	62.4	77.2
COD	1200.0	2420.0	1810.0
BOD_5	910.1	1510.1	1210.1
NO_3	728.0	720.0	724.0
Ni	1.229	3.066	2.1475
Fe	10.12	39.26	24.69
Pb	0.9955	1.334	1.16475
Cu	0.158	0.226	0.192
Cd	0.046	0.014	0.03
Zn	0.431	1.87	1.1505
Cr	0.885	1.142	1.0135

Except pH and EC, all parameters are in mg/L. TDS: Total dissolved solid

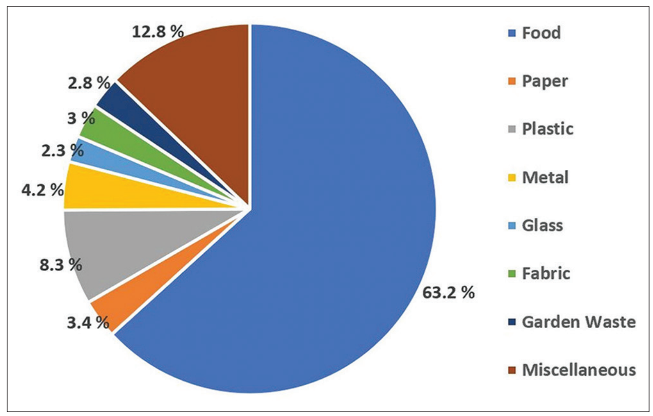


Fig. 3. Composition of MSW of Sulaymaniyah city in the year 2024.

such as Ca, Mg, Na, and K are the reasons for the presence of EC in leachate samples [30]. TDS of the Tanjaro leachate is 22270.0 mg/L, respectively, this result is approximately similar to that result of Trichy dumpsite in India [19]. The reason responsible for the high values of TDS is leaching of ions.

Cl concentration was 4535.0 mg/L, which was higher than the value as observed by De *et al.* 2016 [31]. The complexation, sorption and precipitation reactions are negligible in Cl because it is one of the inorganic macro components. Therefore, it can react as a reasonable contaminant [11]. Na can be a common contaminant since it doesn't easily form precipitates or complexes [32]. Similarly, K can also act as a contaminant and show how much the leachate is diluted [33]. This is why we found high levels of Na and K at the dumpsite, measuring 1380.0 mg/L and 4050.5 mg/L, respectively.

PO_4- P is mainly released into the leachate by the biological degradation of the organic matter containing phospholipids and phosphoproteins [34]. The concentration values of phosphate (PO_4) in the Tanjaro dumpsite first and second leachate sample were 62.4 mg/L and 92.0 mg/L, respectively, and the average mean value of 77.2 mg/L. The results showed that these concentrations are greater than the permissible limits which were recommended by Lee and Jones-Lee 1993 [29]. The mean value for concentration of COD is 1810.0 mg/L, and the concentration of BOD_5 was 1210.1 mg/L. The concentration of BOD_5 and COD was low and it showed that it was in its young stage as the ratio of BOD_5/COD was between 0.5 and 1.0 [35]. High concentration of NO_3

was observed in the Tanjaro dumpsite at a mean value of 724 mg/L. The reason that was in charge of for the reveal of NO_3 from the MSW is the proteins decomposition. The significant outcomes of nitrogen (N) pollution by ammoniacal nitrogen are the eutrophication of the aquatic resources and the increasing in oxygen demand [36].

A slightly alkaline pH, a low biodegradability ratio and a high NO_3 level appear. The Tanjaro dumpsite leachate now produces methane. Chemical reactions with sulfides, carbonates, hydroxides limited heavy metal amounts [37], this fact explains the methane production stage [11].

Thus, high concentration of Pb was found in the Tanjaro dumpsite leachate with the mean value of 1.16475 mg/L. The high Pb concentration in the Tanjaro dumpsite leachate is associated with human activities, such as the use of Pb batteries, the use of Pb in paints and pipes [38]. Leachate samples showed values of Zn (1.1505 mg/L) and Cr (1.0135 mg/L). The major sources of Zn are pesticides and fertilizers as an agro-chemicals [39]. As for Cr, it is mostly from Pb-Cr batteries, colored plastic bags, empty paint cans, and other discarded plastic stuff lying around at the dumpsite [39]. Electroplating waste and leather tanning also represent a significant chromium origin [40]. The dark blackish-brown color of the Tanjaro dumpsite leachate samples resulted from a shift in the oxidation state. Ferrous ions (Fe^{+2}) changed to ferric ions (Fe^{+3}), which caused this color change. This blackish brown color of leachates is because of the forming of ferric hydroxide colloids and fulvic complexes by Fe^{+3} [41]. Mean value of Fe was 24.69 mg/L in the dumpsite, which probably the steel-based scraps are the cause [38]. Cu concentration of the Tanjaro leachate samples was 0.192 mg/L which is within the permissible limits of recommended by [29] for components of municipal landfill leachate "typical" concentration range (0.02–1 mg/L), but Ni is not in the range whereas, it's value was 2.147 mg/L. Heavy metals in leachate might come from mixing different types of waste together at the dump [31].

3.3. Leachate Pollution Indices

For calculating LPI for the first and second location of the dumpsite, the concentrations of 18 leachate characteristics are summarized in 3rd and 6th columns, respectively, in the Table 8. The sub-index curves mentioned by [42] help us figure out the pollution ratings for different leachate pollutants. For example, the value for NO_3 was 60, which show they have the highest pollution potential at the Tanjaro dumpsite locations. Cl, BOD_5 and COD, had the medium value for pi; 57, 27 and 42 for first location; 53, 32.5 and 37 for the second location, respectively. pi for TDS was 55.5 and for total Cr was 6 for the Tanjaro dumpsite leachate.

The calculated mean LPI value for the Tanjaro leachates is 20.13, and the LPI standard value for disposal limit of treated leachate for inland surface water was 7.378 [43], that is mean

TABLE 8: LPI for the first and second leachate samples and their mean value for the Tanjaro dumpsite, Sulaymaniyah city

Parameters (1)	Weights, *wi* (2)	First location	*pi* (4)	*wipi* (5)	Second location	*pi* (7)	*wipi* (8)	Mean value
		Concentration values, mg/L (3)			Concentration values, mg/L (6)			LPI (9)
pH	0.055	8.13	2.5	0.1375	7.54	5	0.275	
TDS	0.050	20740.0	63	3.15	23800.0	55.5	2.775	
BOD_5	0.061	910.1	27	1.647	1510.0	32.5	1.9825	
COD	0.062	1200.0	57	3.534	2420.0	53	3.286	
Fe	0.045	10.12	5	0.225	39.26	5	0.225	
Cu	0.050	0.158	5.5	0.275	0.226	5.5	0.275	
Ni	0.052	1.229	5.5	0.286	3.066	7	0.364	
Zn	0.056	0.431	5	0.28	1.87	5	0.28	
Pb	0.063	0.9955	7	0.441	1.334	7	0.441	
Cr	0.064	0.885	5.5	0.352	1.142	6	0.384	
Cl	0.048	4670	42	2.016	4400.0	37	1.776	
Sum	$\sum w_i$=0.606			$\sum w_i p_i$=12.343			$\sum w_i p_i$=12.07	
LPI				LPI1= $\frac{\sum w_i p_i}{\sum w_i}$ 20.36			LPI2= $\frac{\sum w_i p_i}{\sum w_i}$ 19.91	LPI=20.13

Except pH, all parameters are in mg/L

the LPI of this study is much greater than the standard LPI. The highly contaminated dumping ground is responsible for the high value of LPI, so the leachate before being discharged into the inland surface water also the soil around the site, it must be adequately treated.

Table 9 shows the sub-LPI scores for the first and second location of the dumping site, along with the limits for treated leachate disposal in inland waters. The average values of LPI_{or}, LPI_{in}, and LPI_{hm} in the leachate samples were 42.46, 33.12, and 5.79, respectively. These values for the Tanjaro dumpsite were significantly higher than the standards for treated leachate sub-indices (LPI_{or}, 7.03; LPI_{in}, 6.57, and LPI_{hm}, 7.89) [31]. The main value of COD in LPI_{or} participating 65.24% in the ground of the Tanjaro (according to $w_i p_i$), the major pollutant for the LPI_{in} was TDS, which contributed about 58.51% in the dumpsite ground, in LPI_{hm} all heavy metals were approximately have the same percentage, but Pb was the greatest which contributed about 22.99%, Fig. 4.

3.4. Soil Pollution Indices

Many studies have been conducted on soil contamination issues that polluted with heavy metals, and the findings of most of those studies are that soils near industrial areas and landfill sites are polluted [44], [45]. Leachate toxicity affects human cells; therefore, this study highlights the significance of MSW, which releases contaminants into the water sources and soil [46]. Dumpsite leachate can lead to heavy metal contamination in water and soil [19]. Table 10 represents the result values of the heavy metals found in the soil samples.

In the six locations studied, compared to other heavy metals, Fe had the highest levels, whereas, Cd had the lowest level.

TABLE 9: Sub-LPI for the first and second locations and mean value in the Tanjaro dumpsite, Sulaymaniyah city

Index	Parameter	*wi*	Pollutant conc. (first location)	*pi*	*wipi* (first location)	Pollutant conc. (second location)	*pi*	*wipi* (second location)	*wipi* (mean value)	Disposal standards for leachate (inland surface water) [25] Sub-LPI
LPI_{or}	COD	0.267	1200.0	57	15.219	2420.0	53	14.151	14.685	
	BOD_5	0.263	910.1	27	7.101	1510.0	32.5	8.5475	7.824	
	Summation	$\sum w_i$=0.53			$\sum w_i p_i$=22.32			$\sum w_i p_i$=22.69	22.509	
	$LPI_{or} = \frac{\sum w_i p_i}{\sum w_i}$				42.11			42.81	42.46	7.03
LPI_{in}	pH	0.214	8.13	2.5	0.535	7.54	5	1.07	0.8025	
	TDS	0.195	20740.0	63	12.285	23800	55.5	10.8225	11.55	
	Cl	0.187	4670.0	42	7.854	4400	37	6.919	7.386	
	Summation	$\sum w_i$=0.596			$\sum w_i p_i$=20.67			$\sum w_i p_i$=18.81	19.738	
	$LPI_{in} = \frac{\sum w_i p_i}{\sum w_i}$				34.68			31.56	33.12	6.57
LPI_{hm}	Cr	0.125	0.885	5.5	0.6875	1.142	6	0.75	0.718	
	Pb	0.123	0.9955	7	0.861	1.334	7	0.861	0.861	
	Zn	0.110	0.431	5	0.55	1.87	5	0.55	0.55	
	Ni	0.102	1.229	5.5	0.561	3.066	7	0.714	0.637	
	Cu	0.098	0.158	5.5	0.539	0.226	5.5	0.539	0.539	
	Fe	0.088	10.12	5	0.44	39.26	5	0.44	0.44	
	Summation	$\sum w_i$=0.646			$\sum w_i p_i$=3.638			$\sum w_i p_i$=3.854	3.745	
	$LPI_{hm} = \frac{\sum w_i p_i}{\sum w_i}$				5.63			5.96	5.79	7.89

All parameters are in mg/L, except pH. COD: Chemical oxygen demand, BOD_5: Biochemical oxygen demand, TDS: Total dissolved solid, LPI: Leachate pollution index

As shown in Fig. 5, the metal amounts in the soil varied across different sites. The high levels of Fe, which range from 69.0% to 83.23%, are likely due to the dumping of tin-based waste and metal scraps. On the other hand, Cd levels are below 1 mg/kg because the soil is good at absorbing metals. Sources, such as used batteries, paint, pipes, and electrical waste contribute to Cu emissions [38], [47]. Factors that influence the heavy metal levels in the soil and nearby water around landfills include the shape of the land, the soil's ability to absorb metals, and the proximity of water sources to the landfill [48]. Moving various pollutants, especially heavy metals, from the landfill's liquid waste to water sources nearby is a big problem in managing this waste. Many developing countries have been studying this issue [49].

Generally, heavy metal concentrations in soil relies on how concentrated the metals are in the liquid that seeps through it [38], the soil particles absorption rate for metals [19],

TABLE 10: Tanjaro dumpsite heavy metals concentrations in the specific soil samples (mg/kg)

Locations	Ni	Fe	Pb	Cu	Cd	Zn	Cr	Mn	Total
A	56.125	783.61	ND	9.75	0.0447	21.76	84.375	72.85	1028.52
B	69.5	775.33	ND	18.59	0.149	35.55	127.5	169.65	1196.27
C	10.875	623.55	ND	2.99	0.149	9.66	19.9875	81.94	749.15
D	24.125	744.67	ND	9.89	0	28.30	45.875	172.18	1025.04
E	42.875	757.98	ND	4.89	0.0596	26.64	113.25	152.09	1097.78
F	36	761.70	ND	7.84	0.1192	20.40	77.875	153.13	1057.06

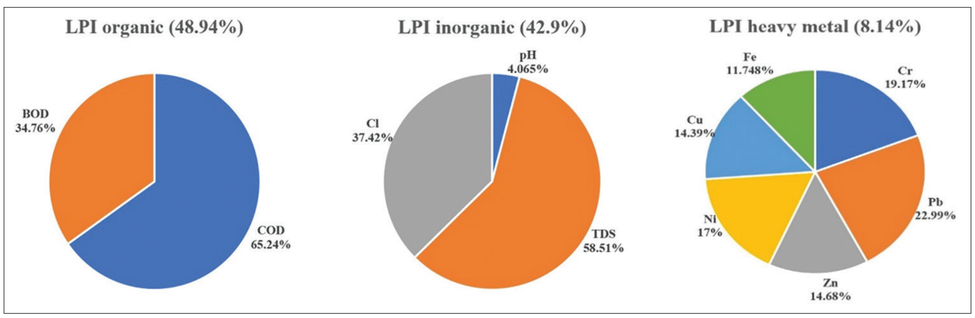


Fig. 4. Distribution of the mean value of the elements of: LPI_{or}, $LPI_{in,}$ and LPI_{hm} for the leachate of the Tanjaro dumpsite, Sulaymaniyah city.

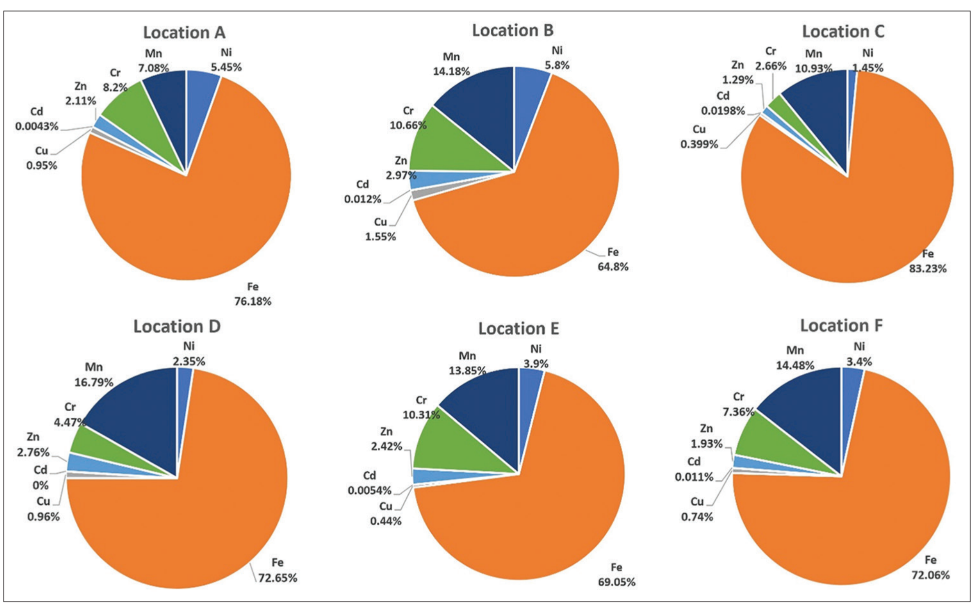


Fig. 5. Percentage of heavy metals in the soil of the six locations.

TABLE 11: The PI and $PI_{nemerow}$ calculated for the study area locations

Sample	$PI_{nemerow}$	PI						
		Cd	Fe	Mn	Cu	Cr	Ni	Zn
A	0.816	0.0812	0.0261	0.0482	0.1911	0.6617	1.1059	0.2072
B	1.032	0.2709	0.0258	0.1123	0.3645	1.0	1.3694	0.3380
C	0.2106	0.2709	0.0207	0.0542	0.0586	0.1567	0.2142	0.092
D	0.366	0	0.0248	0.1140	0.1939	0.3598	0.4753	0.2695
E	0.6702	0.1083	0.0252	0.1007	0.0958	0.8882	0.8448	0.2537
F	0.5411	0.2167	0.0253	0.1014	0.1537	0.6107	0.7093	0.1942
S_i (mg/kg) [52]		0.55	30000	1510	51	127.5	100.5	105

$PI = \frac{C_i}{S_i}$, C_i (from Table 10)

precipitation amount, and long-term accumulation of the metal in soil [50]. When there is more metal in the leachate, the levels of heavy metals in the soil arise, and the absorption ability of ions by the soil also increases. During the rainy season, the amount and concentration of heavy metals in the contaminated soil are lower [50].

The levels of metals in soil samples are as follows: Fe> Mn> Cr> Ni> Zn> Cu> Cd. PI and $PI_{nemerow}$ have been used to figure out the pollution levels at the Tanjaro dumpsite, which can be noted in Table 10. For most heavy metals in the soil samples, the PI showed they were considered non-contaminated, except for Ni in sample A, Cr and Ni in sample B, which fell into a low contamination category. As noted in Table 5, the $PI_{nemerow}$ for the soil at the Tanjaro dumpsite is also labeled as non-contaminated. In comparison, the PI and $PI_{nemerow}$ for soil samples from Tehran's landfill are also non-contaminated; this improvement is due to effective waste separation operations at the Aradkooh Complex, Iran [27]. The management of industrial and hazardous waste has stopped the inflow of domestic waste from the current waste type. That's why proper disposal of industrial waste is crucial for keeping the levels of heavy metals low. Another analysis suggested that the land around the dumpsite was polluted with heavy metallic elements, but the ground beneath the dumpsite was even more polluted [51]. The impact of leachate heavy metals on soil pollution can be identified by comparing their concentration with the allowable limits [27].

4. CONCLUSION

The following conclusions can be drawn from the conducted experimental work of this study:

- About half of the MSW from Sulaymaniyah city goes to the Tanjaro dumpsite, which has hazardous implications and degrading the environment. Results of leachate and soil samples from the dumpsite area showed diverse contaminations, which need urgent movement toward proper solid waste treatment.
- The penetration of available leachate in the Tanjaro dumpsite area yielded in diverse contamination levels. Urgent actions are proposed to be carried out toward proper solid waste treatment.
- The study outcomes yielded in an average heavy metal concentrations regarding the two studied locations in the Tanjaro dumpsite, which is 30.38 mg/L. Fe concentration has been found to as the greatest concentration, which comprised 78.33% of all metals, whereas, Cd got the lowest percentage and constituted 0.18% of the total heavy metals.
- The obtained LPI value shows that the area is very unbalanced and poses risks for leachate from the Tanjaro dumpsite. LPI value found to be 20.1377, meaning that the collected leachate from the Tanjaro exceeds the allowable limit (the highest acceptable LPI value for leachate in inland surface water is 7.378).Furthermore, the obtained sub-LPI values, LPI_{or}= 42.46; LPI_{in}= 33.12 and LPI_{hm}= 5.79 mean that these values are much higher than the leachate disposal standards of 7.03, 6.57 and 7.89 for LPI_{or}, $LPI_{in,}$ and LPI_{hm}, respectively, for inland surface water.
- The average value of total heavy metals in the checked soil samples is 1025.63 mg/kg. Mn and Fe found to be the greatest concentrations, 13.03% and 72.26%, respectively. Cu and Cd found to be the lowest concentrations, 0.87% and 0.0085%, respectively, among the metals accumulated in the soil samples. The average value of $PI_{nemerow}$ for checked soil samples found to be 0.606, which is classified within the non-contamination class.
- The uncontrolled changes that happen regularly in the dumpsite of the Tanjaro are increasing the risk level,

which requires a need to set up a proper landfill for the existing solid waste.

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