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An Analysis of Environmental Effects of Kirkuk Landfill's Leachate on Groundwater Pollution

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ABSTRACT

The study examined how sanitary landfill waste and its leachate affected groundwater quality in the Kirkuk Governorate, Iraq. Seven sites were selected to monitor groundwater contamination from the landfill cell to the nearest residential area to calculate their samples' leachate pollution and water quality indices. Physical, chemical, and biological parameters were measured for such environmental indicators. Groundwater maps have been predicted using GIS techniques. The nine-month test period ran from February to November 2024. The results demonstrated that leachate concentrations affect groundwater properties. The amounts of Chemical Oxygen Demand (COD), Biochemical oxygen demand (BOD), SO_4^{-2}, PO_4^{-3}, NH_3^{+}, and phenol) were greater than permitted by WHO recommendations. Only the vicinity of the landfill cell showed the effects of heavy metals like Cr and Ni, while the residential areas remained unaffected. The LPI results for leachate samples ranged from 25.43 to 40.52. Also, the WQI of the test sites (GW1, GW2, GW3, and GW4) revealed that they were unsuitable for human use without treatment, whereas the groundwater at the other sites (GW5, GW6, and GW7) was adequate for limited irrigation. The findings of the correlation study indicated that the majority of the parameters had a substantial association with one another. The strong negative correlation between distance and parameters indicates that pollutant concentrations decrease when the distance from the landfill increases. The research recommends adopting scientific and technological means to mitigate pollution by using special pipe networks to prevent leachate leakage from the landfill cells and using modern techniques to treat leachate before it reaches the groundwater.

1. INTRODUCTION

In dry and semi-arid regions with limited surface water, groundwater is essential for meeting the water needs of several developing nations' residential, industrial, and agricultural purposes. This priceless resource is increasingly threatened due to anthropogenic activities above ground, such as uncontrolled development, continuing waste dumping, and inadequate land use management. Moreover, the chemical composition of groundwater dictates its use for people; therefore, evaluating it is essential for the social and economic development of both developed and emerging nations [1-3].

Urban trash collection and disposal is a critical challenge in municipal waste integrated management because of the rise in rubbish production per capita brought on by population growth and industrialization [4]. The predominant and most credible approach to managing municipal solid waste dumpsites (MSW) is burial in engineered landfills [5]. Landfills provide a short-term fix, but because they discharge pollutants, leachate, and landfill gas that damage the ecosystem, climate, water supplies, land, and human health, they seriously threaten the economy, society, and environment. Many contaminants in the environment are caused by MSW [6, 7].

Poorly collected, handled, and disposed of landfill leachate may seep into the soil and contaminate water aquifers, which in turn can pollute surface and groundwater sources [8, 9]. Leachate is a contaminated liquid that rises from solid waste landfills' ground level and contains suspended particles, organic and inorganic compounds, and other materials [9] and [10]. According to Rajoo et al. [11], the Leachate pollution index (LPI) standard value is 7.378, and its harmful environmental impact is highlighted when it is above that. During the wet season, leachate discharge may rise; during the dry/summer season, it can decrease [12]. Groundwater isn't the only thing landfills harm; they also harm the air and the soil [13]. Leachate seeps through soil particles and eventually reaches groundwater, contaminating it [3].

Hepatitis and dysentery are among the illnesses that can result from pollutants contaminating groundwater sources [14, 15]. Using a Groundwater Modelling System (GMS), the researcher [16] demonstrated that the concentrations of contaminants in the groundwater of the Karbala governorate rose over time and did not move in all directions at the same pace. According to the study [17], groundwater samples have

BOD, COD, SO_4^{-2}, PO_4^{-3}, and NO_3^- values that are higher than WHO specifications. The other study [18] indicated that the groundwater next to the landfill site had higher than allowed levels of physiochemical characteristics. One could suggest that groundwater pollution is virtually nonexistent due to the restricted percolation of leachate via soil throughout the summer [19].

The study aimed to test the leachate samples from the landfill site and groundwater samples extending between the landfill cell and the nearest residential area regarding physical, chemical, and biological properties and heavy metal content. Additionally, it seeks to ascertain the Water Quality Index (WQI) for groundwater samples and the LPI for leachate samples to examine leachate leakage's effect on the quality of groundwater and appropriateness for human use. Kirkuk sanitary landfill, which is newly constructed (started operation in 2008), was selected for this study. It accommodates more than 1000 tons of waste per day and extends over an area estimated at 192,915 square meters.

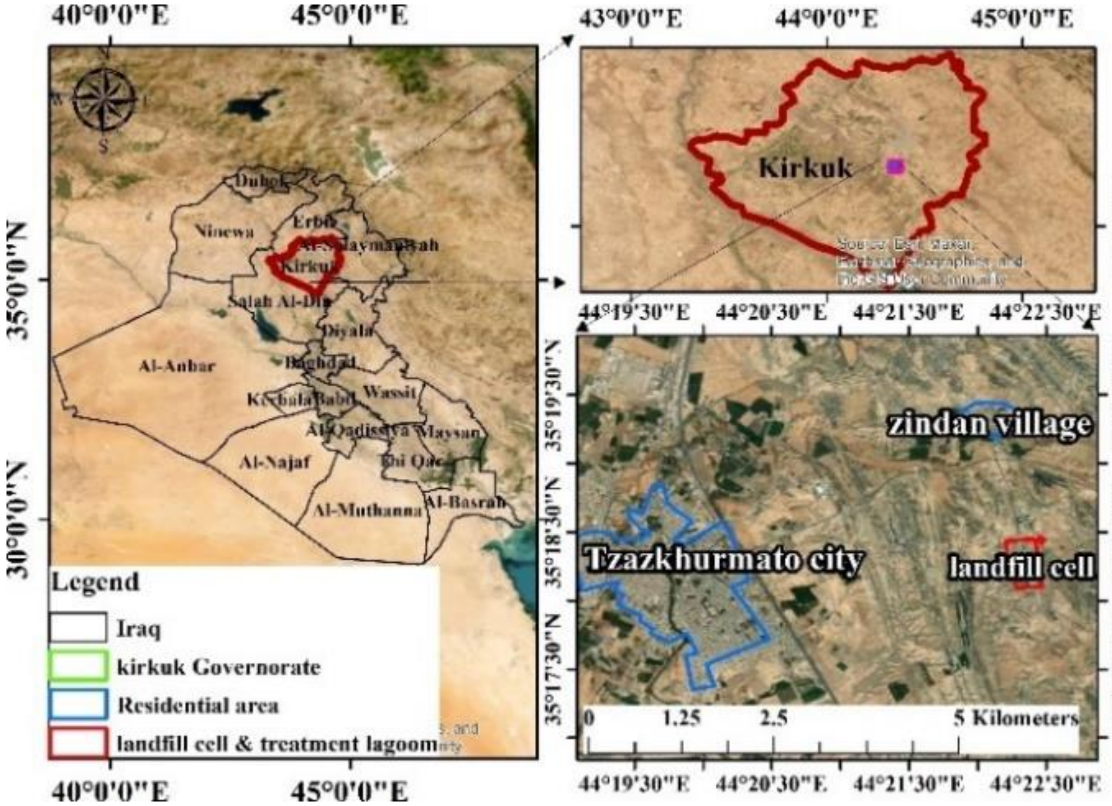

Figure 1. Locations of Kirkuk governorate and the study area

2. STUDY AREA

The Kirkuk Governorate is 90 km southeast of Erbil and 240 km north of Baghdad in northeastern Iraq. The Iraqi Planning Ministry estimates a population of around 1,726,409 and a total area of 9,679 square km as of 2021. Figure 1 illustrates the geographical position of the Kirkuk Governorate in Iraq. The region has a semi-arid climate characterized by scorching summers and moderate, humid winters, with an average annual precipitation of 250-320 mm. The sanitary landfill has a single cell of 300 by 600 m² with an average depth of 4 m, a main treatment basin for leachate, and a capacity to manage around 1000 tons of garbage daily. It is roughly 18 km south of Kirkuk City's southern and 3 km east of Tazakhurmato City. The site's operating design stipulates a ten-year lifespan for the landfill. Since its inception in 2008, the landfill is now using resources beyond the specified capacity. The site was selected to demonstrate its impact on water quality within the landfill and surrounding areas after it had exceeded its operational age. Therefore. The Universal Transverse Mercator (UTM) coordinate system provides the following coordinates for the landfill site: longitude (44°22'20.4"E) and latitude (35°18'16.9"N) 38 S.

3. MATERIAL AND METHODS

Seven locations were selected to monitor groundwater pollutant concentrations in the landfill and its surroundings. The locations distribution was based on the distance between the landfill site and the residential area, as well as the locations of the wells in the area, as indicated in Figure 2. The locations of the leachate samples were distributed as follow: four samples from the edges of the cell and two samples from the center. The purpose was to adequately express the characteristics of the leachate in situ. Groundwater and Leachate Samples were collected in a 2.0L pre-cleaned polyethylene container, maintained at 4°C in the incubator, and analyzed according to American Public Health Association (APHA) Standard Methods (23rd Edition). Various analytical techniques were used for the examination of physicochemical, microbiological, and heavy metal parameters. Parameters such as electrical conductivity (EC), pH, and total dissolved solids (TDS) content were measured during the sample using the HI1285-51 electrode. The Chemical Oxygen Demand (COD) was measured using the HI839150 COD Reactor and the HI83399-01 Water and wastewater Multiparameter Photometer. Biochemical oxygen demand (BOD) was carried out using the VELP BOD EVO Sensor. Calcium (Ca^{2+}), potassium (K^{+}), phosphate (PO_4^{-3}), sulfate (SO_4^{-2}), and ammonia nitrogen (NH_3^{+}-N) were quantified using a UV–visible spectrophotometer (Shimadzu 1800) technique. The microbiological parameter was assessed using the most probable number (MPN) approach facilitated by laminar flow (Microfilt). Heavy metals such as lead (Pb), chromium (Cr), copper (Cu), nickel (Ni), and iron (Fe) were quantified using an atomic absorption spectrophotometer (novAA 800 atomic absorption spectrometer). Garmin GPS 72TM is used to determine the coordinates of sampling sites. The solid waste Leachate pollution index (LPI) was determined at the sanitary landfill site using standard formulas and figures mentioned in previous studies [20, 21].

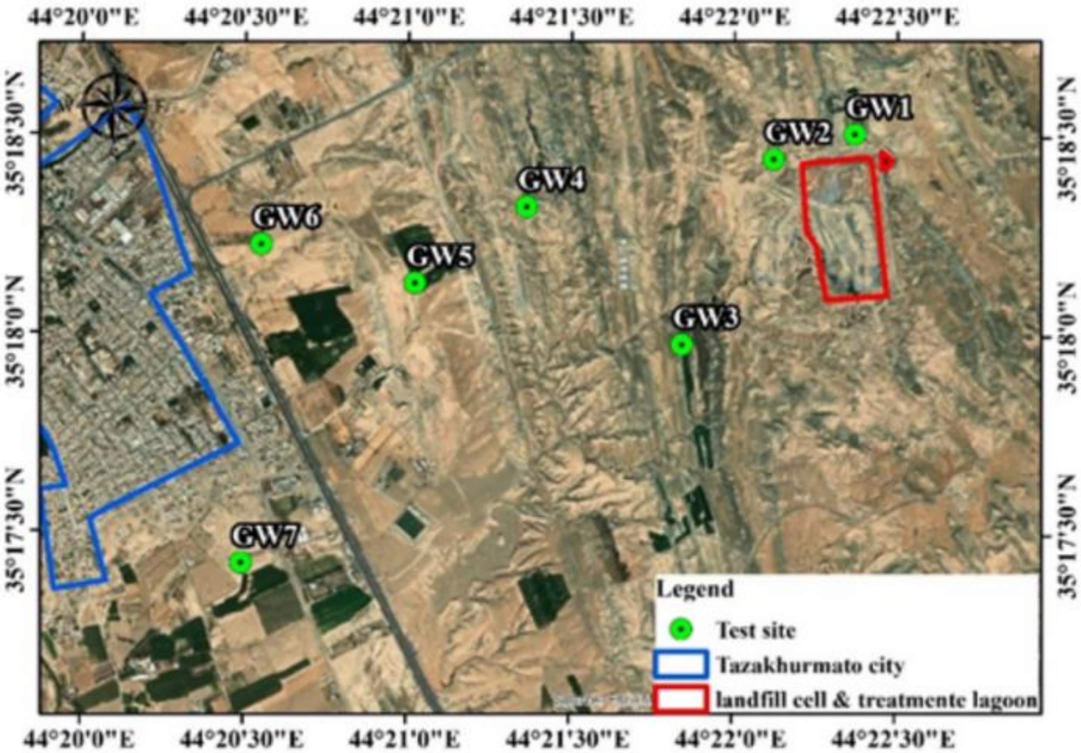

Figure 2. Locations of landfill and testing sites

The WQI was calculated by using (Weighted Arithmetic Water Quality Index Method), by using the Eq. (1) [22-24]:

$$WQI = \frac{\sum WnQn}{\sum Wn} \quad (1)$$

where, Qn = quality rating of the nth water quality parameter, Wn = unit weight of the nth water quality parameter. Qn determined by Eq. (2):

$$Qn = [(Vn - Vid)/(Sn - Vid)]*100 \quad (2)$$

where, Vn = estimated value of the nth water quality parameter's value at a certain sample location, Vid = the ideal value for the nth parameter in pure water (Vid for pH is 7 and 0 for all other parameters), Sn = Standard allowable value of the nth water quality parameter. The unit weight (Wn) is determined using Eq. (3):

$$Wn = K / Sn \quad (3)$$

$$K = [1/\Sigma(1/Sn = 1,2,3\ldots..n)] \quad (4)$$

Eq. (4) determines (K), the constant of proportionality. Table 1 shows the classification of groundwater according to the possible usages by calculating the WQI values.

Additionally, Geographic Information System (GIS) ArcMap, 10.8.2, was used to predict groundwater quality maps, and the results were analyzed with a special analysis tool called Inverse Distance Weighting Interpolation (IDW). To examine the complex interrelationships among many physicochemical factors, factor analysis of trace metals and Pearson's correlation were conducted using Microsoft Excel. Correlation analysis is an initial descriptive technique for assessing the extent of correlation between the variables concerned. The purpose of correlation analysis is to quantify the strength of the relationship between two variables.

Table 1. WQI classification values

WQI Value	Status	Possible Usages
0-25	Excellent	For drinking, irrigation, and industrial uses
26-50	Good	For drinking, irrigation, and industrial uses
51-75	Fair	For irrigation and industrial uses
76-100	Poor	For irrigation uses
101-150	Very Poor	For restricted uses of irrigation
Above 150	Unfit for Drinking	Treatment required before any uses

4. RESULTS AND DISCUSSION

In this study, two leachate samples were tested from the center of the sanitary landfill cell; their overall average was calculated and represented by sample 1, and four leachate samples at the sides of the cell were tested; their overall average was also calculated and represented by the sample 2. Table 2 presents the concentrations of the main pollutants in the untreated landfill leachate. Heavy metal analyses indicate the presence of Cu, Cr, Ni, and Pb in the leachate samples. The concentration of heavy metals was ranked as follows: Cu > Ni > Pb > Cr, from highest to lowest concentration. The detection of these metals signifies the dumping of various waste materials at the site, including steel scrap, lead batteries, lead-based paints, plastics, and pipes. LPI values exceeded the permissible limit (7.378) due to high concentrations of COD, BOD, phenol, ammonia, and heavy metals. The results of the laboratory analysis of the groundwater at the test sites represent the average numerical value of five readings for any testing location during the examination period (GW1, GW2, GW3, GW4, GW5, GW6, and GW7), which are shown in Table 3.

4.1 Evaluation of the leachate contaminants in groundwater

The groundwater at the testing locations (GW1, GW2, and GW3) beside the landfill showed significant concentrations of leachate contaminants, including COD, BOD, SO_4^{-2}, PO_4^{-3}, NH_3^{+}, and phenol. These concentrations start to vanish upon arriving at the residential area Figures 3 and 5-7.

Table 2. Values of LPI analysis

Parameter	Sample 1	Sample 2	Pi 1*	Pi 2*	Wi**	Pi*Wi1	Pi*Wi2
PH	7.6	8.3	5	5	0.055	0.275	0.275
Cr, (mg/l)	0.433	0.618	4	5	0.064	0.256	0.32
Fe, (mg/l)	7.713	3.685	5	5	0.045	0.225	0.225
Cu, (mg/l)	10	5.4	100	50	0.05	5	2.5
Pb, (mg/l)	0.436	0.2583	5	4	0.064	0.32	0.256
Ni, (mg/l)	1.376	1.209	8	8	0.052	0.416	0.416
NH_3^+-N, (mg/l)	1116	0.93	100	5	0.051	5.1	0.255
BOD, (mg/l)	13020	7920	70	60	0.061	4.27	3.66
COD, (mg/l)	31000	22010	85	80	0.062	5.27	4.96
Phenol, (mg/l)	28.9	17.4	35	25	0.057	1.995	1.425
Coliform, (cfu/ml)	19.3	14.5	33	25	0.052	1.716	1.3
Total					0.613	24.843	15.592
LPI 1	40.52692						
LPI 2	25.43556						

* Pi: (represent the subindex score) from LPI curves & **Wi: (represent the weight for the ith of pollutants variable) from LPI weight tables according to the [20, 21].

$$LPI = \sum_{i=1}^{m} WiPi / \sum_{i=1}^{m} Wi \quad (5)$$

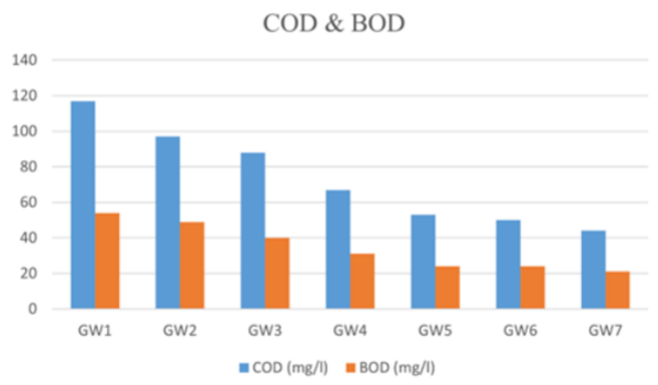

Figure 3. BOD and COD values at the test locations

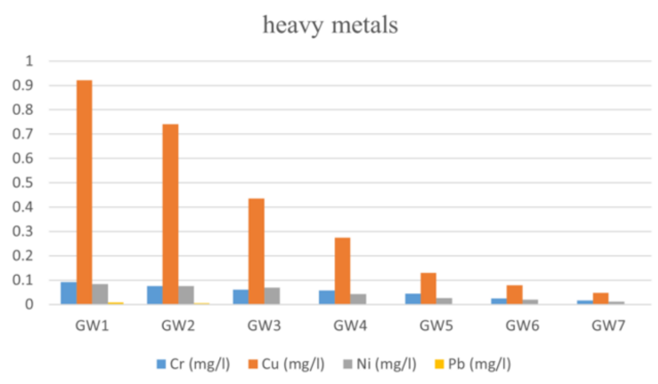

Figure 4. Heavy metal values at the test locations

The examination of the heavy elements identified the presence of Ni, Pb, Cr, and Cu. The concentration of heavy metals was ordered as follows: Cu > Cr > Ni > Pb, from greatest to lowest concentration. The concentration of Cu was within allowed levels at all test sites, whereas the concentration of Pb at GW1, GW2, and GW3 was also within legal limits and was not detected at the other locations. Ni and Cr concentrations above legal limits in GW1, GW2, and GW3, thereafter decreasing with distance from the landfill site, indicating that the presence of heavy metals in the regional groundwater is mostly attributable to leachate. The standard deviation (S.D.) results showed little deviation for heavy metals, while it was greater for COD, BOD, CL^- and SO_4^{-2}. The data comparison in Table 3 and Figure 4 supports the above statement by showing the leachate contaminants in groundwater. Table 3 shows the amounts of inorganic elements (TDS, Cl-, Ca^{+2}, K^+, Fe) and the electrical conductivity (EC) measurements. Testing locations within and adjacent to the landfill cell showed a rise in concentrations, while sites far from the cell showed a decrease. Table 4 and Figures 8 and 9 provide analytical findings that estimate the (WQI) and its appropriateness for diverse applications. The locations (GW1, GW2, GW3) deem this water unsuitable for human consumption unless it undergoes treatment. The results from (GW4) suggest that the groundwater can be exclusively used for restricted irrigation, while (GW5) also suggests irrigation use without restriction. However, the results of the analysis for the two sites (GW6 and GW7) indicate that the water is appropriate for agriculture and industrial uses.

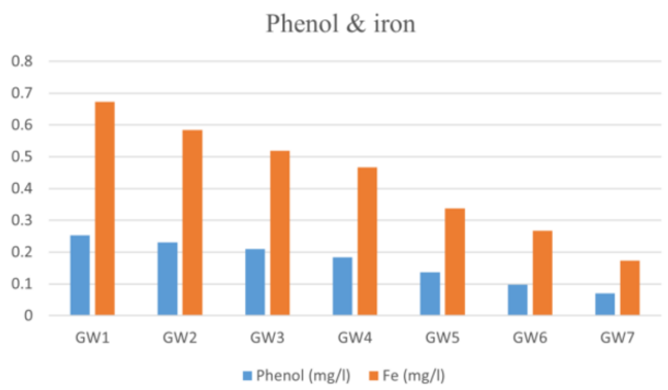

Figure 5. Phenol and iron values at the test locations

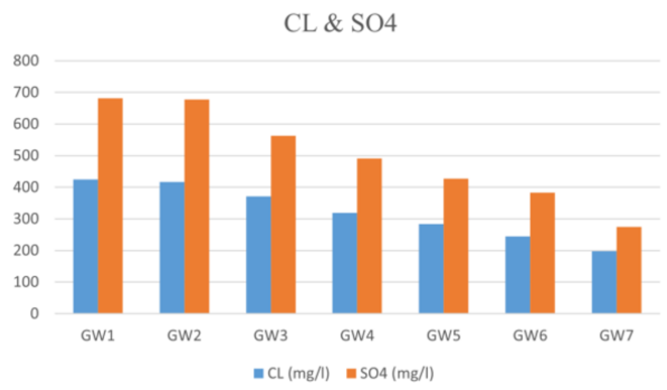

Figure 7. SO_4^{-2} and CL-values at the test locations

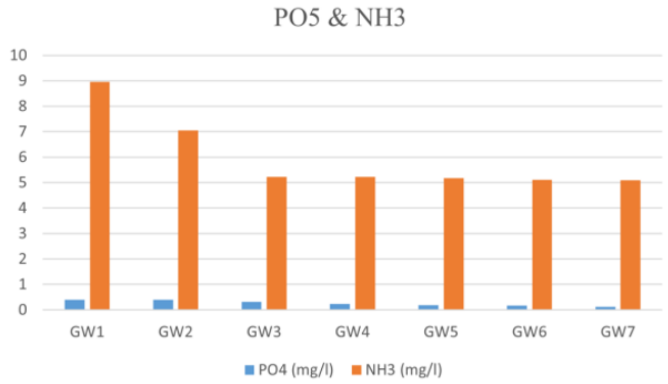

Figure 6. PO_4^{-3} and NH_3^{+} values at the test locations

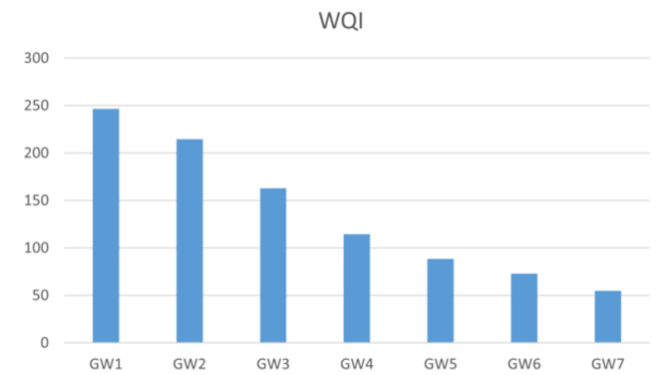

Figure 8. The water quality index of the groundwater in testing sites

Table 3. Values of the leachate contaminants in the groundwater of the testing sites

Parameters	Allowable Limits	GW1	GW2	GW3	GW4	GW5	GW6	GW7	Mean	S.D
pH	6.5-8.5	8.06	8.17	7.96	7.65	7.72	7.72	7.76	7.863	0.200
TDS, (mg/l)	1000	1745	1833	1628	1633	1621	1517	1512	1641.2	115.7
EC, (µS/cm)	400	2816	2789	2543	2487	2483	2368	2361	2549.5	184.9
COD, (mg/l)	10	117	97	88	67	53	50	44	73.714	27.50
BOD, (mg/l)	5	54	49	40	31	24	24	21	34.714	13.13
Cr, (mg/l)	0.05	0.092	0.076	0.061	0.058	0.044	0.025	0.016	0.053	0.027
Cu, (mg/l)	2	0.921	0.740	0.436	0.275	0.129	0.079	0.047	0.375	0.342
Ni, (mg/l)	0.07	0.083	0.075	0.069	0.042	0.027	0.019	0.011	0.047	0.029
Pb, (mg/l)	0.01	0.009	0.005	0.002	0	0	0	0	0.002	0.003
Fe, (mg/l)	0.3	0.673	0.584	0.519	0.466	0.338	0.267	0.173	0.431	0.179
CL^{-}, (mg/l)	250	424	417	371	319	283	244	197	322.14	86.66
SO_4^{-2}, (mg/l)	250	681	677	563	491	427	383	275	499.57	151.5
PO_4^{-3}, (mg/l)	0.04	0.397	0.392	0.319	0.237	0.186	0.161	0.124	0.259	0.111
Ca^{+2}, (mg/l)	75	1004	931	902	730	487	340	314	672.57	290.45
K^{+}, (mg/l)	0.5	5.709	5.315	3.453	3.378	3.174	2.674	2.611	3.759	1.245
NH_3^{+}, (mg/l)	0.1	8.952	7.042	5.226	5.215	5.167	5.109	5.088	5.971	1.490
Phenol, (mg/l)	0.001	0.253	0.231	0.209	0.184	0.136	0.097	0.070	0.169	0.069
Total no. of Bactria/ml	500	$11*10^4$	$11*10^4$	109800	109400	109000	108000	108200	109200	832.666

Consequently, we can infer that the influence of untreated leachate on the surrounding region can significantly extend up to 1.3 kilometers; however, its effect diminishes towards the closest residential area, about 3 km.

All of the parameters that have been studied have had their correlations, which show the statistical relationship between them, calculated and given in matrix form. Based on these correlation values, a correlation has been constructed for the selected criteria to be examined. Strong associations between two variables are indicated by a high correlation coefficient (near 1 or -1), whereas no link is indicated by a value near zero [25].

According to Justus Reymond et al. [26], values over 0.6 identify the factors with strong correlations. Table 5 and Figure 10 show a strong positive correlation between tested parameters; this demonstrates that the groundwater contamination originates from the same leachate as the solid waste landfill.

Figure 9. Contour line's water quality index of the groundwater

The strong negative correlation between distance and parameters indicates that pollutant concentrations were likely to diminish as distance increases from the landfill site. The water quality index value also diminishes with expanding distance from the landfill location, indicating an improvement in water quality towards the nearest residential area.

Table 4. WQI values for groundwater quality at the testing sites

Testing site	Distance	WQI Value	Status	Possible Usage
GW1	150-meter north landfill	246.57	Unsuitable for Drinking	Treatment is required before use
GW2	150-meter east landfill toward the city	214.43	Unsuitable for Drinking	Treatment is required before use
GW3	650-meter east landfill toward the city	162.94	Unsuitable for Drinking	Treatment is required before use
GW4	1300-meter east landfill toward the city	114.53	Very Poor	Restricted use for Irrigation
GW5	1800-meter east landfill toward the city	88.61	Poor	Irrigation
GW6	2500-meter east landfill toward the city	72.89	Fair	Irrigation and Industrial
GW7	3000-meter east landfill toward the city	54.80	Fair	Irrigation and Industrial

Table 5. Pollutant concentration correlation matrix in groundwater

	Distance	*pH*	*TDS*	*EC*	*COD*	*BOD*	*Cr*	*Cu*	*Ni*	*Pb*	*CL⁻*	SO_4^{-2}	PO_4^{-3}	*WQI*
Distance	1													
pH	-0.79	1												
TDS	-0.90	0.82	1											
EC	-0.92	0.87	0.95	1										
COD	-0.95	0.85	0.84	0.94	1									
BOD	-0.95	0.89	0.88	0.96	0.99	1								
Cr	-0.97	0.73	0.89	0.94	0.95	0.94	1							
Cu	-0.92	0.87	0.89	0.98	0.98	0.99	0.95	1						
Ni	-0.98	0.85	0.86	0.92	0.98	0.98	0.95	0.95	1					
Pb	-0.79	0.84	0.77	0.92	0.93	0.93	0.85	0.96	0.84	1				
CL⁻	-0.99	0.81	0.91	0.94	0.96	0.96	0.98	0.94	0.99	0.82	1			
SO_4^{-2}	-0.99	0.82	0.92	0.95	0.96	0.96	0.97	0.95	0.97	0.83	0.99	1		
PO_4^{-3}	-0.98	0.88	0.91	0.96	0.98	0.99	0.96	0.97	0.99	0.87	0.99	0.99	1	
WQI	-0.95	0.88	0.89	0.97	0.99	0.99	0.96	0.99	0.98	0.93	0.97	0.97	0.99	1

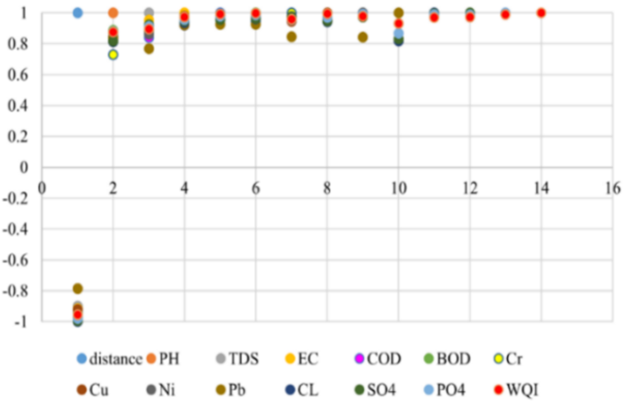

Figure 10. Pollutant concentration correlation analysis in groundwater

5. CONCLUSION

Kirkuk sanitary landfill was selected as the research site due to its importance to the environment, community, and surrounding residential areas. The study sought to clarify the significant effect of solid waste leaching on groundwater properties. The leachate from the Kirkuk landfill has extraordinarily high values for almost all physicochemical criteria. The LPI results referred to exceeded the permissible limit by nearly 450%. The impact of leachate percolation on the adjacent groundwater is apparent. The majority of the groundwater's physicochemical characteristics were found to exceed their respective acceptable limits. Heavy metals such as Pb and Cu were below the permissible limit, while Ni and Cr exceeded the allowable limit. According to WQI, Groundwater properties were significantly affected for 1.3 km away from the landfill's outside and were unfit for human consumption unless treated. Used for drinking purposes, it leads to many health issues for humans, animals, and plants. Meanwhile, groundwater for the remaining distance (1.7 km) from the nearest residential area was unfit for drinking and could be used for limited irrigation and industrial applications. As the distance from the landfill site grows, pollutant concentrations tend to decrease, according to the matrix for correlation analysis between parameters, which indicates a significant correlation.

The study recommends adopting scientific and technological means to mitigate the impact of sanitary landfill leachate. Special pipe networks should be used to drain the leachate leaking from the landfill cells to safe sites for collection and treatment using modern treatment techniques. Future studies should also investigate the health effects of environmental pollution in the area.

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NOMENCLATURE

pH	Degree of acidity or alkalinity of a tested sample
TDS	Total dissolved solids (mg/l)
EC	Electrical conductivity (μS/cm)
COD	Chemical oxygen demand (mg/l)
BOD	Biochemical oxygen demand
Qn	Quality rating of the nth water quality parameter
Wn	Unit weight of the nth water quality parameter
Vn	Estimated value of the nth water quality parameter's value at a certain sample location
Vid	The ideal value for the nth parameter in pure water
Sn	Standard allowable value of the nth water quality parameter
WQI	Water quality index
LPI	Leachate pollution index
GIS	Geographic information system
IDW	Inverse distance weighting interpolation