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Evaluation of the Groundwater Quality Affected by Solid Waste Leachate Around Al-Diwaniyah Dumpsite Based on WQI

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Abstract

Open and unsanitary landfills have served for many years in developing countries such as Iraq as a standard and economically inexpensive method of solid waste disposal. Leachate generated from these dumps' bases seriously affects the surrounding environment, especially groundwater sources. There have been reports of potential environmental hazards associated with leachate in the Al-Diwaniyah open landfill in Iraq. Therefore, in this investigation the quality of groundwater and characteristics of observation wells around the dumpsite was studied. Groundwater samples collected from four hand-excavated wells at a dumpsite were analyzed periodically using standard methods in dry and wet seasons through the period (September 2023–March 2024) in order to evaluate leachate pollutants and their impact on groundwater quality. The main analyzed parameters in leachate and groundwater included pH, Electrical Conductivity, Turbidity, Total Suspended Solid, Total Dissolved Solid, BOD5, COD, Chloride, Sulphate, Nitrate, in addition to heavy metals including Iron, Zinc, Copper, Chromium, Lead, and Cadmium. To illustrate the spatial distribution of pollutants during the dry and rainy seasons, indicators were used to assess groundwater quality. The results of the groundwater quality index (Canadian model) reported poor groundwater and unsuitable for drinking and agriculture in (GW1, GW2) neighboring the dumpsite in the range of (100-500) m from the dumpsite. In contrast, GW3 water quality is often threatened, except for GW4, which was unsuitable for drinking but can be used for agriculture. Extending this research to other regions would enhance the environmental monitoring of groundwater and assess possible threats to human health in the study area. Constructing an engineered landfill that complies with authorized environmental standards would also be beneficial.

Keywords: *Al-Diwaniyah Dumpsite, Solid Waste, Leachate, Groundwater, Water Quality Index.*

1. Introduction

Municipal solid waste (MSW) management presents a substantial challenge, particularly in developing countries, due to limitations in technological advancement, infrastructure, and financial resources (Essien et al., 2022). The generation of municipal solid waste (MSW) has risen to 1.3 billion tons annually. Despite the reduction in municipal solid waste (MSW) production in Organization for Economic Co-operation and Development (OECD) member nations, it is anticipated that by 2025, the garbage produced will rise to 2.2 billion tons. Prevalent methods for the disposal and treatment of municipal solid waste (MSW) include direct methods such as Sanitary landfilling, open dumping, and indirect methods like composting and thermal treatment (incineration, anaerobic, pyrolysis, gasification). Developed and developing countries typically employ open dumping and landfills as the predominant and economical methods for MSW disposal; however, the environmental consequences have received considerable attention in recent decades (Mishra et al., 2019). The huge amounts of waste dumped daily require adequate landfill areas, management, and appropriate design. In developing nations like Iraq, problems related to the engineering designs of solid waste landfill sites can be constantly observed. In which the use of non-engineering landfills is widespread. At present, more than seven dumpsites and landfills can be found in Al-Qadisiyah Governorate, Iraq. Four of these dumps are located in the city of Diwaniyah. Unfortunately, most of these “wild” landfills consist only consisting of dumping grounds without any environmental protection, as it not preceded by an environmental and social impact assessment, consequently, they present potential risks to the ecosystem surrounding the dumpsites (particularly soil, and groundwater sources) and populations via the biogas release and particularly the production of leachates. Leachate is generated basically due to the biochemical disintegration of organic waste, surface runoff, infiltration of rainfall, and groundwater percolation. The formation of leachate differs according to several aspects, such as the method of burial, type of waste, climatic conditions, nature of the landfill, Operational landfill age, and the characteristics of the site (Jhamnani and Singh, 2009; Aziz and Entessar, 2023). Leachate generally contains trace metals, dissolved materials from organic and inorganic compounds, and xenobiotic organic materials (phenols, phthalates, benzene) (Arukwe et al., 2012; Talalaj, 2014). Leachate can be additionally categorized into three classes: mature, intermediate, and young. Due to anaerobic decomposition occurring at the dumpsite. The biodegradable fraction of organic contaminants in leachate diminishes markedly with the advancement of landfill age. Mature leachate contains much higher levels of refractory organic compounds than juvenile leachate (Zainol et al., 2012). Research indicates that open dumps remain the primary source of water and environmental pollution (Divya et al., 2020; Laskar et al., 2022) owing to leachate infiltration from landfills. This greatly impacted the physical and chemical properties of heavy metals (HMs) in groundwater (Udofia & Udiba, 2016). Unjust exposure to water with elevated levels of physicochemical substances and heavy metals risks human health (Jafarzadeh et al., 2022). The World Health Organization states that around 80% of all human illnesses are water-related. Consequently, it is imperative to identify, quantify, and assess the environmental toxicological profiles in groundwater contaminated by leachate from landfills, along with the health risks associated with municipal waste disposal, as once groundwater is polluted, its quality cannot be restored by merely halting the source of pollution (Ramakrishnaiah et al., 2009). Continuous monitoring of water quality is essential. Various methodologies exist for evaluating water contamination levels, either by experimentally identifying pollutants or estimating them using mathematical equations (Moo-Young et al., 2004; Aziz and Hussain, 2023). Some methods have been developed to evaluate the pollution level depending on available laboratory data, such as water quality and heavy metal pollution indices (Agarwal et.al, 2011). The current study problem is the contamination that may occur in groundwater by the Al-Diwaniyah open dumpsite, the final disposal site for the Al-Diwaniyah district. The current site lacks a leachate collection system, which allows it to penetrate the groundwater. In addition, the random communities surrounding the landfill are increasing, and they are using polluted groundwater in large quantities in their daily activities for domestic purposes and irrigation of agricultural lands. Therefore, it was necessary to analyze the changes in groundwater properties under the influence of leachate percolation in the Diwaniyah dumpsite. The present study aimed to assess the significant impact of municipal solid waste (MSW) leachate percolation on groundwater quality near an open dumpsite in Al-Diwaniyah District, Al-Qadisiyah, Iraq. The assessment was carried out by estimating the Water Quality Index (WQI) and evaluating the investigated groundwater's suitability for drinking and irrigation purposes. The results were then compared with the approved standard specifications by calculating the corresponding quality index.

2. Materials and Methods

2.1. Site discretion

The dumpsite region belongs to the jurisdiction of the Directorate of Al-Diwaniyah Municipality, situated in the Abu Trareed region, District 22, along the Al-Diwaniyah - Samawah road, southeast of the city, approximately 11 km from the center of Al-Diwaniyah, at the coordinates of latitude 31° north and longitude 45° east (Diwaniyah-Basra), specifically at (32°00'08.9"N 45°03'18.5" E), as illustrated in fig. 1 and fig.2. Established in 1995, the present site encompasses 13 hectares of the total land area of Al-Diwaniyah district. Despite the dumpsite having environmental permission as per document No. 1011 dated 3/17/2011, it is not constrained by ecological or engineering limits. The facility caters to the inhabitants of the Al-Diwaniyah area, which had a population of 473,316 in 2022. The daily waste influx to the site is 450 tons, enclosed by an earthen barrier of between 3 and 4 meters in height. This site lacks a leachate drainage channel, essential amenities such as water, power, a scale for weighing garbage, and a substantial accumulation of waste four meters above ground level. The number of workers working at the site is (4) workers. Also, about 30-40 individuals of both sexes and all ages work to collect plastic and metal materials and sell them in the markets to meet their daily needs. Their work is related to solid waste, called (scavengers), and the spread of animals (such as stray animals and birds) that subsist on what is thrown out of various wastes, especially organic ones.

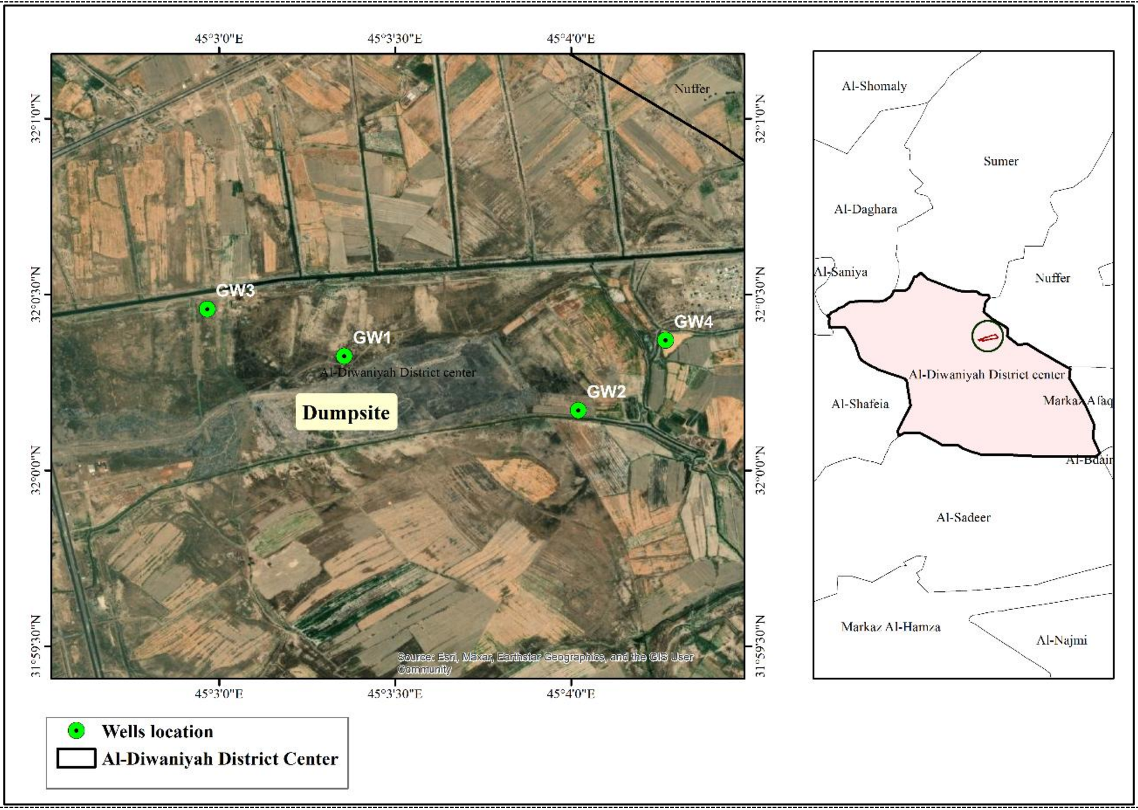

Fig. 1: The current Dump site in Al-Diwaniyah city.

Fig. 2: Al-Diwaniyah dumpsite in dry and wet seasons (Taken by author).

2.2 Features of the study area

The following presents some ecological, topographical, and meteorological features of the research region:

2.2.1 Groundwater level

The study area suffers from the rising groundwater level, as it was found from the field study that the groundwater depth in the observation wells surrounding the dumpsite did not exceed 4 m in winter and 4-5 m in summer with steady state flow from the north-west to south-east. The limitations of groundwater depth prescribed by Iraqi standards are not less than 10 m, and this poses a threat to groundwater and leads to its contamination through the leakage of leachate into the water-bearing layers, which is a danger to the population that uses these wells.

2.2.2 Topography and slope level

The surface of the study area represents a part of the Iraqi sedimentary plain, which is characterized by its flat surface and lack of general slope which appeared to decrease in the center of Diwaniyah district to about (10-15) meters and inclining from the northwest towards the south and southeast as shown in fig.3. Therefore, the slight slope in the study area is considered suitable for establishing a landfill site where the leachate and polluted water pass through, and it can be dealt with later.

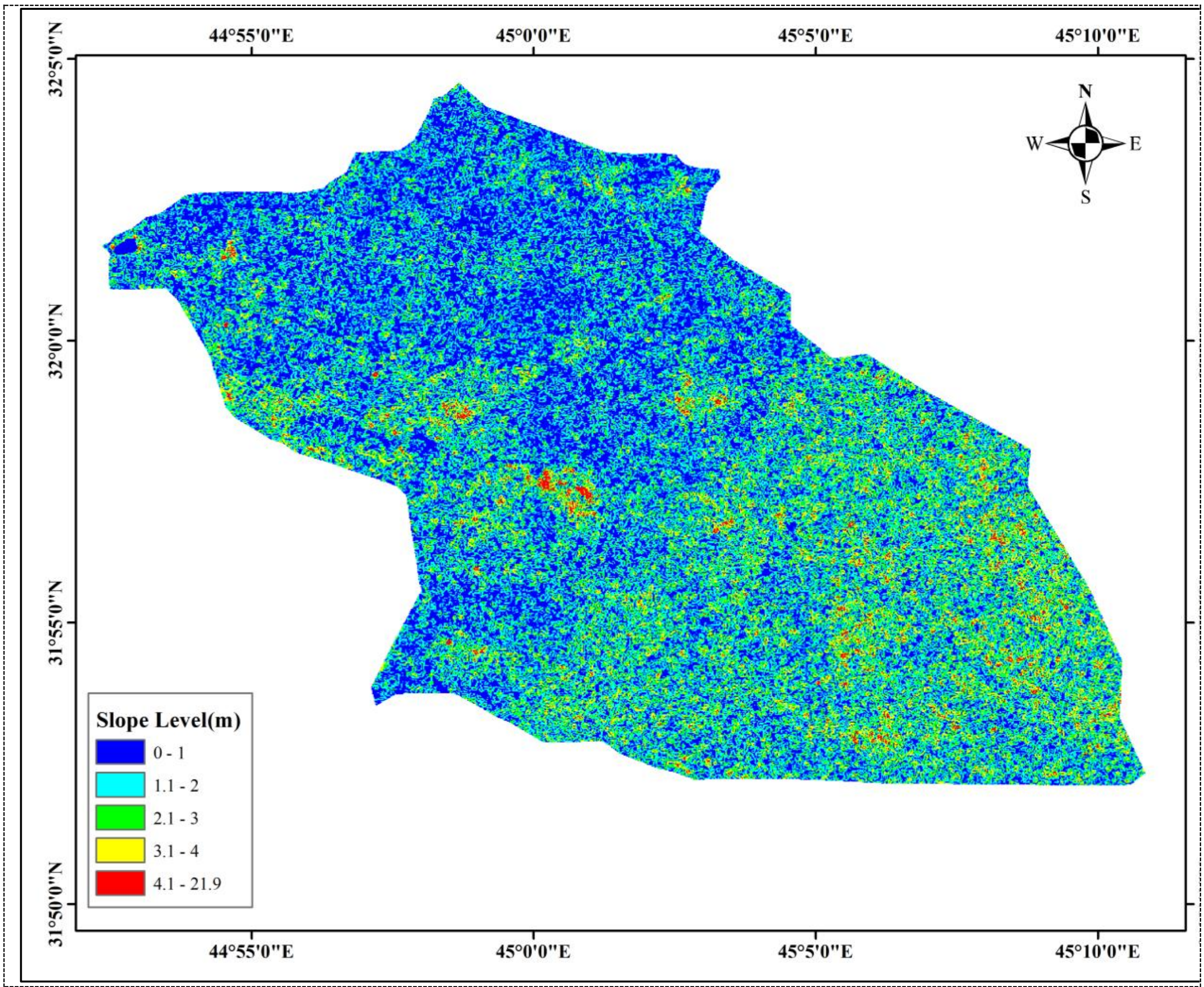

Fig. 3: Regression levels for Diwaniyah district center based on USGS data.

2.2.3 Soil quality in the study area

Most of the research area is covered by sedimentary plain soil, making it suitable for building solid waste landfills. The loam soil in the study area is characterized by its poor porosity and low permeability, which reduces leachate leakage from the dumpsite into the groundwater.

2.3. Groundwater Sampling

The sampling program of any chemical analysis primarily affects the accuracy and quality of the analysis. Therefore, much emphasis has been placed on sampling locations' identification and selection processes in the present investigation. Different water sources near the chosen dumpsite were surveyed in the field survey. Since there are no wells for sampling groundwater, and the dump is located in a remote area, it isn't easy to reach by the (dredger) excavator mechanism. The researcher had to rent a hand auger to dig wells at specific distances from the dumpsite and take samples. A total of four shallow- wells with 4" and 6" diameters were dug and marked for groundwater sampling as per the sloping of the study area to a depth ranging from (5-13) m below the ground level within the distance of 100 m,250m,500 m, and 750 m, respectively, around the dump see fig. 4. The Global Positioning System (GPS) was used to geo-reference each sample location, and the maps and geolocations of the monitoring wells points were plotted after the reconnaissance tours using Google Earth and ArcGIS 10.8

software to offer clear photos of the research area. Table 1 illustrates the details of the groundwater sampling points. The groundwater samples were collected and preserved in plastic containers that were sterilized and dried, then sent to the lab, where they were kept in a refrigerator at 4°C and samples were examined within 6 hours after being promptly placed in ice boxes at temperatures lower than 5°C.

Fig. 4: Groundwater observation wells in the study area (Taken by author).

Table 1: Groundwater monitoring wells details.

Groundwater Sample	The distance from the dumpsite	Coordinate	
		Latitude(N)	Longitude(E)
GW1	100	32°00'19.5"	45°03'21.3"
GW2	250	31°59'59.8"	45°03'40.7"
GW3	500	32°00'27.5"	45°02'58.0"
GW4	750	32°00'22.2"	45°04'16.1"

3. Methodology

Laboratory studies were conducted to ascertain the properties of the gathered groundwater samples. The analyses included physicochemical parameters and heavy metals using the protocols specified in the Standard Methods for Examination of Water and Wastewater (APHA, 2017), which included: (pH, electrical conductivity(EC), total suspended solids(TSS), Turbidity, Turbidity, total dissolved solids(TDS), Biochemical oxygen demand (BOD), Chemical oxygen demand (COD), Chloride ion (Cl^-), Nitrate ion(NO_3^-), Sulphate ion(SO_4^{-2})) and heavy metals (cadmium, nickel, chromium, lead, copper, iron, and zinc). Multiple experimental techniques and instruments have been used to analyze different physicochemical components. Summaries of these methods are provided in the following sections, while a full explanation can be found in the 23rd edition (APHA, 2017).

3.1. Calculation of Water Quality Index

One popular and internationally recognized technique for evaluating water quality is the CCME WQI (Khan et al., 2005). The formula created by the Ministry of Environment, Lands, and Parks in British Columbia (CCME, 2012) indicates that the index is extensively employed in water quality research due to its flexibility regarding the type and quantity of parameters selected for evaluating water quality, the kind of water body, and the duration of application. This technique enables researchers to use regional water quality parameters (Khan et al., 2005).
The CCME WQI idea has three components:

1. **Scope:** refers to the ratio of parameters whose values deviate from the established norms for the model (noncompliant variables).
2. **Frequency:** This denotes the rate at which specific objectives remain unachieved (the count of unsuccessful tests or the aggregate of individual assessments that fail to meet objectives).

3. **Amplitude:** Indicates the extent to which the objectives are unmet (the quantity of test results that failed to meet their targets).

The overall quality of water bodies is based on the resulting value, which should range from 0 to 100; 0 shows the "worst category" and 100 represents the "best category" (CCME, 2017; Khan et al., 2005). The formulation of CCME WQI is described in the following equations (Mahagamage and Manage, 2014):

Scope (F_1) is calculated from the following equation:

$$F_1 = \frac{Number\ of\ faild\ variables}{\text{Total number of variables}} \times 100 \qquad (1)$$

Frequency (F2) is calculated from the following equation:

$$F_2 = \frac{Number\ of\ faild\ test}{\text{Total number of test}} \times 100 \qquad (2)$$

Amplitude(F3): This stage contains several steps:

1. Excursion: This represents the number of times the test value is higher than the value of the set standard. It is calculated from the following equation:
   a. $$excursion = \frac{faild\ test\ value}{\text{Objective}} \qquad (3)$$
2. In circumstances when the test result is smaller than the objective value, formula (4) is used.
$$excursion = \frac{\text{Objective}}{faild\ test\ valuee} \qquad (4)$$
3. The normalized sum of excursions (nse) may be computed using the following equation:
$$nse = \frac{\sum_{i=1}^{n} excursion}{\text{number of test}} \qquad (5)$$
4. Eventually, the amplitude (F3) may be obtained using the following equation:
$$F_3 = \frac{\text{nse}}{\text{0.01 nse +0.01}} \qquad (6)$$
5. The CCME WQI for each sample is then computed using the formula indicated below by using the results of the parameters in Table 3:

$$WQI\ (for\ each\ G.W\ sample) = 100\ - \frac{\sqrt{F^2{}_1 + F^2{}_2 + F^2{}_3}}{1.732} \qquad (7)$$

Water quality may then be graded according to one of the five categories listed in Table 2.

Table 2: Classification and description of the water quality according to the Canadian Water Quality Index(CCME, 2017).

WQI	Status	Category
(95-100)	Excellent	Protected water quality means assuming that no sources threaten or pollute the water and that the water is very close to natural or pure levels.
(80-94)	Good	Water quality is safeguarded; yet, it is vulnerable or deficient in a straightforward manner, and the water condition seldom strays from the requisite or preferred standard.
(65-79)	Fair	Water quality is often safeguarded; nonetheless, it is sometimes compromised, and its state may differ from the necessary or optimal standards.
(45-64)	Marginal	Water quality is often threatened or weak, and its condition deviates from the required or desirable level.

(0-44)	Poor	The water quality is always threatened or weak, and the water condition constantly deviates from the required or desirable level.

4. Result and Discussion

4.1 Physicochemical properties of groundwater

The analytical results of several physical and chemical parameters derived from groundwater samples taken at manually dug observation wells close to the MSW dumpsite are shown in Table 3. Fig. 5 shows the equipment used to analyze the samples.. Table 4 summarizes the allowable limits of related parameters set by the World Health Organization (WHO, 2022) and the Iraqi Standard (IQS, 2009) that are used to compare with the results as in table 4. The purpose of the comparison is to assess the degree of groundwater contamination brought on by leachate percolation during the September 2023–March 2024 study period.

Fig. 5: Laboratory equipment used in physical and chemical analysis of G.W samples.

Table 3 : Average values of physicochemical parameters of groundwater in dry and wet seasons

Season / Parameter	GW1		GW2		GW3		GW4	
	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet
pH	7.74	7.55	7.49	7.644	7.570	7.29	7.470	7.38
EC	14.035	11.928	13.3	12.4146	23.745	20.22	3.863	2.586
TDS	10827	9331.8	10120.5	10204.4	17414.5	14546.6	2168.5	1432
TSS	396	607.4	468.5	541	205.5	371.8	30.5	52.8
Turbidity	15	44.28	13.33	44.4	5.8	20.414	1.3	2.586

BOD	13	47	11.85	39.2	7.5	20.9	2.25	13.42
COD	94	136.6	107.50	143	17.0	42.3	6.50	17.6
Cl	7439	5090.48	6296.50	4682.6	6833.5	5032.48	827.8	645.82
So4	4675.58	4068.73	4399.17	3377.2	3522.2	3815.89	764.070	394.25
No3	8.220	6.1238	11.63	8.398	8.324	7.63	11.755	8.49
Cadmium	0.051	0.0237	0.04	0.0072	0.016	0.0032	0.002	0.001
Chromium	0.084	0.1908	0.10	0.304	0.007	0.028	0.000	0
Copper	0.509	0.101	0.43	0.172	0.097	0.063	0.019	0.039
Iron	0.407	0.772	0.46	0.823	0.140	0.258	0.049	0.096
Nickel	0.165	0.099	0.09	0.047	0.109	0.039	0.043	0.027
Lead	0.092	0.306	0.04	0.069	0.011	0.044	0.000	0
Zinc	0.901	0.413	0.85	0.4	0.673	0.363	0.35	0.14

∗ All values in (mg/L), excluding EC in (mS/cm), pH, and ratio of (BOD^5/COD) without unit.

Table 4: Standard specification of water quality criteria for drinking and irrigation purposes used in the Water Quality Index

Parameter	World Health Organization WHO(2022)	Iraqi Standard (IQS, 2009)
pH	6.5–8.5	5–9
EC	1.2	2.0
TDS	500	-
TSS	200	45
Turbidity	5 NTU	-
Cl	250	250
So4	250	500
No3	50	15
BOD	2.5	30
COD	2.5	90
Cadmium	0.003	0.01
Copper	2	0.2
Chromium	0.05	0.1
Nickel	0.07	0.2
Lead	0.01	2
Zinc	3	2
Iron	0.3	5

4.2 Application of Geographic Information System (ArcGIS)

Geographic information system (ArcGIS) software was employed as an aid tool to define the direction of groundwater flow and the migration direction of leachate beneath the surrounding area.

Specifying the groundwater's flowing direction enables the interpretation of the geochemical characteristics of leachate as it migrates downgradient from the landfill. The flow direction in the study area is mostly from west to east and southeast. Fig. 4 and fig. 5 show the topographic contours and groundwater flow direction based on data from previous studies(Al-Qura Ghuli, 2014).

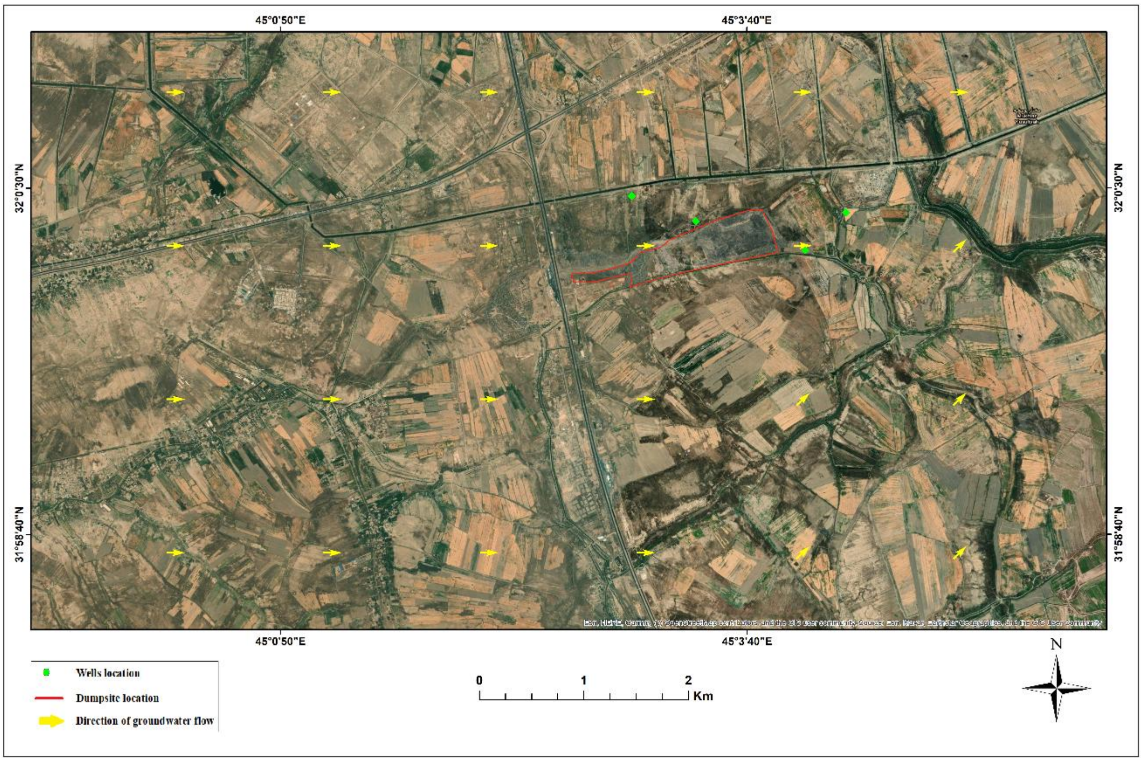

Fig. 6: Direction of groundwater flow in the study area.

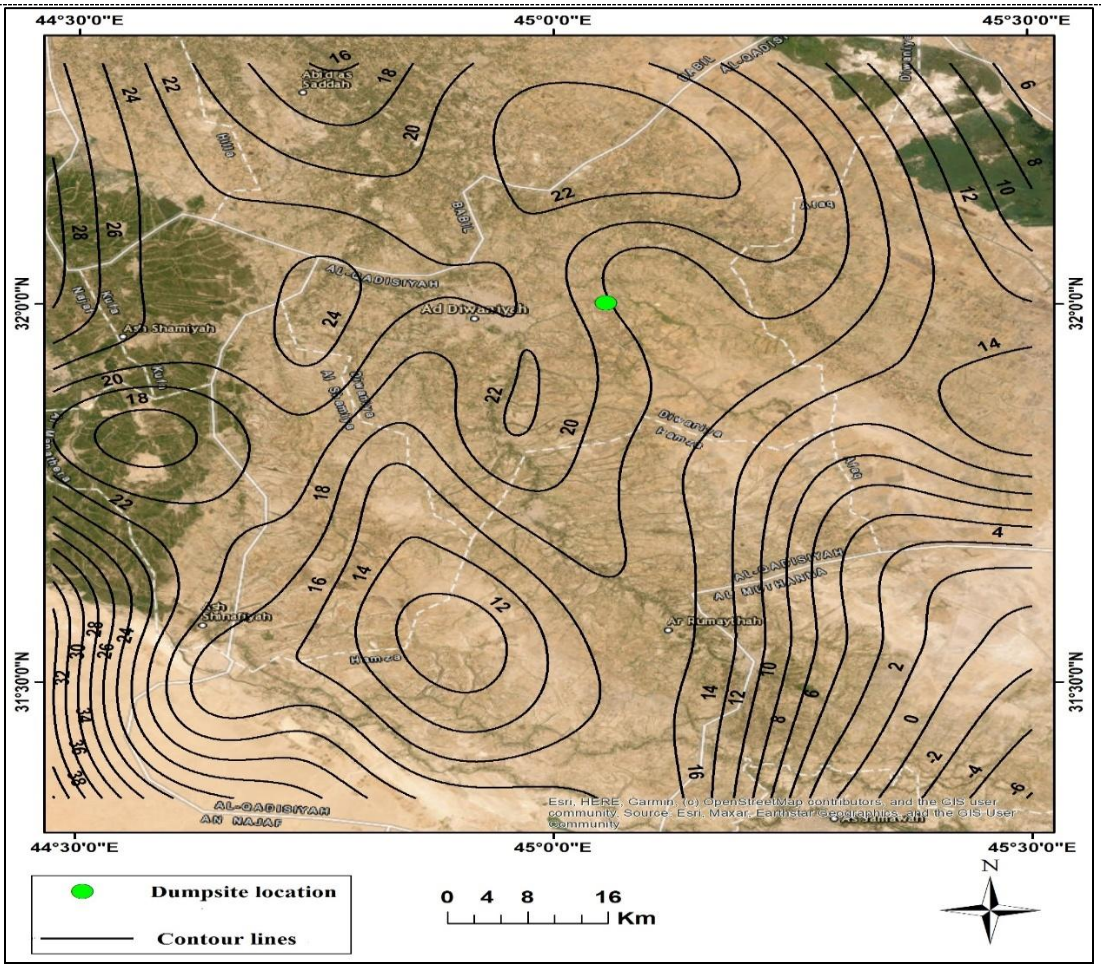

Fig. 7: Contour lines of groundwater in study area.

4.3 CCWQI for groundwater

In the present study, the CCME WQI approach was applied using the procedure illustrated in the previous section by equations (1–7). The tested parameters were selected based on the materials dumped in the area, the extent of quality and purity we need for the purposes used, and lastly, for understanding their deviation from the accepted limits. The CCMEWQI application calculations regarding heavy metals and physicochemical properties of groundwater were based on data in Tables 2, 3, and 4.

Considering the CCMEWQI calculated results based on **(WHO)** standards for drinking purposes for groundwater sampling sites, three sampling points were categorized as poor, and one sampling point as marginal. Fig. 8 reveals that, considering all samples, GW1, GW2, and GW3 have displayed the poorest quality in the context of (CCME WQI).

Table 5: Variation of WQI at each site and standard categories of CCMEWQI based on tables 2, 3, and 4.

Overall	GW1		GW2		GW3		GW4	
	DWQI	**IWQI**	**DWQI**	**IWQI**	**DWQI**	**IWQI**	**DWQI**	**IWQI**
F1	76.47	53.33	76.47	60	70.59	33.33	35.29	26.67
F2	70.59	46.67	73.53	50	55.88	30	32.35	20
F3	90.64	77.46	89.49	75.83	86.24	74.91	44.36	16.25
WQI Score	20.32	39.39	19.87	37.15	28.02	49.59	62.31	78.59
Category	**Poor**	**Poor**	**Poor**	**Poor**	**Poor**	**Marginal**	**Marginal**	**Fair**

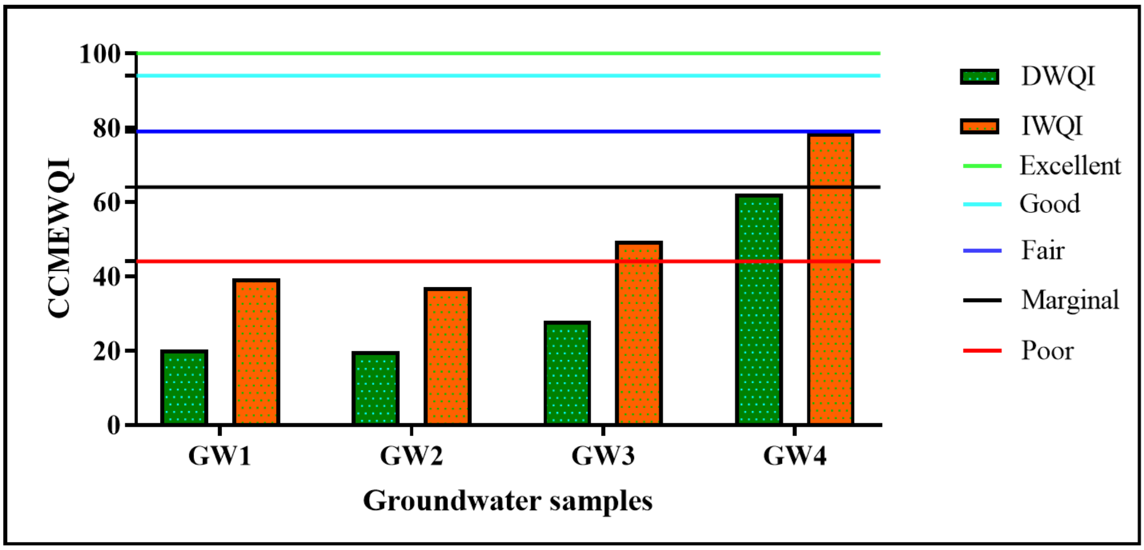

Fig. 8: Variations of DWQI and IWQI at the selected groundwater sample sites in the study area.

Near the dumpsite, within a range of 100 to 500 meters, are all the poor status sample spots. This suggests that the water quality at these locations is constantly deteriorated or damaged. The migration of leachate towards groundwater may be the cause of this. Downstream, 750 meters from the disposal site, was the last marginal status sample point. This shows that water quality is frequently endangered or deteriorated at the test site, which may be caused by agricultural fertilizers as well as decomposing plants and animals.

On the other hand, the water quality index (WQI) computed based on the FAO for agricultural purposes restrictions showed a gradation in its categories from fair to poor, as shown in Table 5.

Fig. 8 shows that GW1 and GW2 have the worst water quality in the CCMEWQI context. However, the other sampling points display better water quality and graduate from marginal to fair in GW3 and GW4, respectively.

In general, it is concluded from the above that water quality in study sites has varied depending on the earth's slope and distance from the dumpsite, as conditions usually deviate from natural levels. The WQI values obtained from the CCMEWQI calculation indicate groundwater is not recommended for various household activities. Whereas for irrigation purposes, it was evident that some of the stations had usable groundwater. Moreover, the findings of the CCMEWQI show that the water has to be treated to eliminate both chemical and physical contaminants because the open waste disposal site has a substantial influence and the water quality has drastically declined as a result of human activities such as waste dumping in a messy way (Lack of a sanitary and engineering method for landfilling waste).

5. Conclusion

There is a lack of information on the pollution status resulting from the unlawful open dumpsite in Al-Diwaniyah city and its impact on the surrounding ecosystem, particularly groundwater, Therefore, the major concerns in the current study were serious influence of leachate emerging from dumpsite on the quality of groundwater around Al-Diwaniyah dumpsite in addition to elucidating the degree of groundwater quality, and whether it is appropriate for human consumption and irrigation uses using many related indices.

Based on the CCME-WQI classification, drilled well water (GW1, GW2, and GW3) is not the best option to use for drinking purposes because most drilled wells are classified as producing water poor, but groundwater from wells that are more than 500 m away from the landfill (GW4) can be used for irrigation.

The aforementioned indicates that leachate migration from the dump's base significantly affects the regional groundwater. Even though remedial measures cannot be implemented immediately due to financial restrictions, proper preventative measures should be undertaken promptly to decrease the detrimental effects on groundwater. Some proposed preventive and mitigating measures are listed below:

1. Rehabilitation of existing unlined landfills and developing inexpensive on-site leachate treatment facilities.
2. The generated leachate must be collected by creating wells, which should be diverted into a basin (with a suitable lining system) for remediation.
3. Al-Diwaniyah Municipality Directorate must execute effective solid waste management for the dumpsite as a long-term strategy.
4. Continuously oversee and regulate the groundwater next to the landfill to prevent the migration of leachate that might contaminate the groundwater resources.

This study requires further investigation, such as drilling more wells around the dump and taking periodic samples from groundwater for a longer period.

Simulation software can be used to simulate and predict the extent of leachate migration in the coming years.

There is a need to study and assess other risks related to disposal sites, such as soil and air contamination, and potential health hazards emerging from direct exposure of nearby villagers.

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