ISSN: 0067-2904

Leachate Characterization and Evaluation of Ground Water Quality Around Landfill Area Using the Canadian Council Ministers of the Environment Water Quality Index

Sayran Yousif Jalal *, Dalshad Aziz Darwesh
Environmental Sciences and Health Department, College of Science, Salahaddin University - Erbil, Iraq

Received: 9/10/2022 Accepted: 25/1/2023 Published: 30/12/2023

Abstract

Municipal solid waste generation, management, and dumping are economic and ecological concerns that metropolitan areas, particularly those in developing nations, must address. This study intended to ascertain the impacts of solid waste on the quality of groundwater around trash dumps located inside and surrounding landfill sites in the city of Erbil. Samples of groundwater, as well as two samples of leachate, were collected from eight wells situated near landfills during the dry and rainy seasons of August 2021 and February 2022. Several physico-chemical parameters, including pH, EC, NO_2, NO_3, alkalinity, HCO_3, Na, Ca, Mg, Cl, SAR, total hardness, and heavy metals, were evaluated in the samples. During fieldwork, water quality index (z) measurements for summer and winter were combined with longitude (x) and latitude (y) information gathered by GPS. Using the inverse distance weighting approach, integrated xyz data was interpolated in ArcMap GIS software to measure the groundwater quality of the research region. According the CCME Water Quality Index, wells 4 and 8 had WQIs ranging from fair to marginal in both the winter and summer seasons (WQI). According to the data, cadmium contents in summertime were much greater (0.430–2.066 mg. l^{-}) than the WHO standard (0.003 mg. l^{-1}), deeming them unfit for human use. And that the high lead level in the summer (0.843-2.600 mg. l^{-1}) is caused by too many Pb batteries being thrown away.

Keywords: MSW, WQI, IDW, Leachate, Landfill.

توصيف الراشح وتقييم جودة المياه الجوفية حول منطقة المكب باستخدام مؤشر جودة المياه الصادر عن مجلس وزراء البيئة الكندي CCME WQI

سيران يوسف جلال *، دلشاد عزيز درويش
قسم علوم البيئة والصحة، كلية العلوم، جامعة صلاح الدين ، أربيل، العراق

الخلاصة

إن توليد النفايات البلدية الصلبة وإدارتها وطمرها هي اهتمامات اقتصادية وبيئية يجب أن تعالجها المناطق الحضرية، لا سيما تلك الموجودة في الدول النامية. هدفت هذه الدراسة إلى التحقق من آثار النفايات الصلبة على نوعية المياه الجوفية المحيطة بمواقع طمرالقمامة في مدينة أربيل والمناطق المحيطة بها. جمعت عينات المياه الجوفية من 8 ابار تقع بالقرب من أماكن طمر النفايات خلال موسمي الجفاف والمطر اب 2021 وشباط 2022 إضافة الى عينتين من المادة المترشحة. تم تقييم العديد من المؤشرات الفيزيائية الكيميائية، بما في ذلك

*Email: sayran.jalal@su.edu.krd

الأس الهيدروجيني، EC، NO_2، NO_3، القاعدية، HCO_3، Na، Ca، Mg، Cl، SAR، العسرة والمعادن الثقيلة. خلال العمل الميداني، تم دمج قياسات مؤشرجودة المياه (z) WQI للصيف والشتاء مع المعلومات المتعلقة بخطوط الطول (x) وخط العرض (y) بواسطة النظام العالمي لتحديد المواقع. تم إدخال بيانات xyz متكاملة في برامجيات نظام المعلومات الجغرافية ArcMap لقياس نوعية المياه الجوفية في منطقة البحث باستخدام منهج ترجيح المسافة العكسية IDW . ووفقاً لمؤشر نوعية المياه الصادر عن CCME ، تتراوح مؤشرات نوعية المياه في الآبارالمرقمة من 4 الى8، 4 و 8 بين مقبول و هاشمي في فصلي الشتاء والصيف. وفقاً لهذه البيانات، فإن محتويات الكادميوم في فصل الصيف أكبر بكثير (0.430−2.066 ملغم.لتر$^{-1}$) من معايير منظمة الصحة العالمية (0.003 ملغم.لتر$^{-1}$)، مما يجعلها غير صالحة للاستخدام البشري. ويرجع ارتفاع مستوى الرصاص في فصل الصيف (0.843−2.600 ملغم.لتر$^{-1}$) إلى التخلص من العديد من بطاريات الرصاص.

1. Introduction

Irregular MSWM activities may devastate our living environments, ultimately endangering public health. Unplanned trash disposal also harms the soil, surface and ground waterways. In order to meet human beings, need for water, groundwater is crucial. Because of the increased industrialization and urbanization, the groundwater has become more susceptible to contamination. Ground water, which was formerly thought to be quite clean, is currently deteriorating due to growing human activity [1] [2].

Despite being recognized as a significant source of pollution and a threat to groundwater quality, landfills remain the most popular method of trash disposal [1] [3] [4]. Mor *et al.* described the transfer of waste from a disposal area to a groundwater discharge and rainfall-induced penetration. A potent contaminated leachate is produced by the interaction of chemical, physical and microbiological methods in the disposal of contaminants in the debris into the flowing water [5] [6].

A waste disposal site's leachate contains a huge number of compounds, some of which are potentially toxic to the surrounding environment, especially groundwater [7] [8] [9]. Therefore, since landfills pose a significant hazard to regional consumers and the surrounding environment, detecting the quality of well water around landfills must be an important component of waste treatment. In recent years, a lot of studies have been done on how landfill leachate affects both surface and ground water and the issue has taken on a great deal of significance owing to the dramatic growth in the population [10] [11] [12].

The chemical quality of leachate changes is based on a variety of variables, such as the initial composition of the dumping waste products and the numerous chemical and biological processes that can take place as a result of the decaying garbage. The spatial variations in leachate composition are mostly attributable to variances in waste type and water penetration through the landfill cap [13] [14].

Numerous researchers in many domains employ geo statistics and GIS methods for multi-component data of spatial distribution [15]. Due to the time and resources required to gather data, it is not always feasible to assess the amount of contamination in each groundwater sample. Uncertainties in data are estimated at any point in space using a geostatistical interpolation method which follows a predetermined probability distribution [16] [17].
Several branches of environmental science have made use of interpolation methods, including IDW and Kriging. Panhalkar *et al.* said that the IDW's neighborhood method and radial basis function make it better and more accurate than Kriging. WQI and its incorporation into the

ArcMap 10.8 GIS program for spatial estimation using the IDW method, which is the combination of physico-chemical data, GPS data and field data. In this investigation, the influence of leachate percolation on groundwater quality was investigated in an unplanned landfill location. To investigate the probable relation of groundwater pollution, many physicochemical characteristics as well as heavy metals were assessed in leachate and groundwater samples. Also addressed were the effects of landfill depth and distance from sources of groundwater, as well as remedial techniques to prevent additional pollution of groundwater [18].

The assessment focused on the water's physical and chemical state criteria to see whether they complied with WHO drinking water quality guidelines. The project further analyzed the potential heavy metals presence in water sources. For the goal of determining the extent and, therefore getting information about the quality of the various water sources, indices of water quality and pollution evaluation were used.

The research also used statistical approaches to prepare the numerous potential variables that influence the quality of water, in addition to the impact of landfill distance on water quality. This investigation intended to evaluate the ground water quality by measuring some water quality indicators, such as pH, total dissolved solids, magnesium, total hardness, electrical conductivity, alkalinity, and sodium, and compared the findings to the Canadian Council of Ministers of the Environment (CCME) guidelines [19].
The purpose of this article was to conduct a qualitative examination of the leachate and groundwater around a landfill. Therefore, the goal of the research was to measure the influence of the Erbil waste landfill on the quality of drinking water in adjacent villages. Water quality index, and its spatial interpolation inside a geographical information system framework was a novel method used for exact monitoring and evaluation of groundwater quality in the research region.

2. Materials and Methods

2.1 Landfill Site

Erbil dump’s lies on the Erbil-Mosul highway's left side (near Kani-Qrzhala Subdistrict), roughly 15 kilometers from the center of Erbil City, Iraq. The longitude and latitude are 36°10′23″N and 43°35′32″E. The landfill began operating in 2001, covering an area of 37 acres. The vast bulk of the landfill area had already been occupied. The location gets almost 2000 tons of municipal solid waste every day (based on data collected from ELS administrative staff).

Mixed municipal solid waste is discarded without proper separation of components. There has been little research on the characteristics of municipal solid waste in Erbil. Scavengers on-site separate a tiny part of recyclable items, such as metals, glass, and plastic. The landfill leachate is released immediately into the surroundings and produces methane that is released into the atmosphere due to the lack of gas engineering and landfill design collection systems. Groundwater sources are affected by produced leachate (Figure 1).

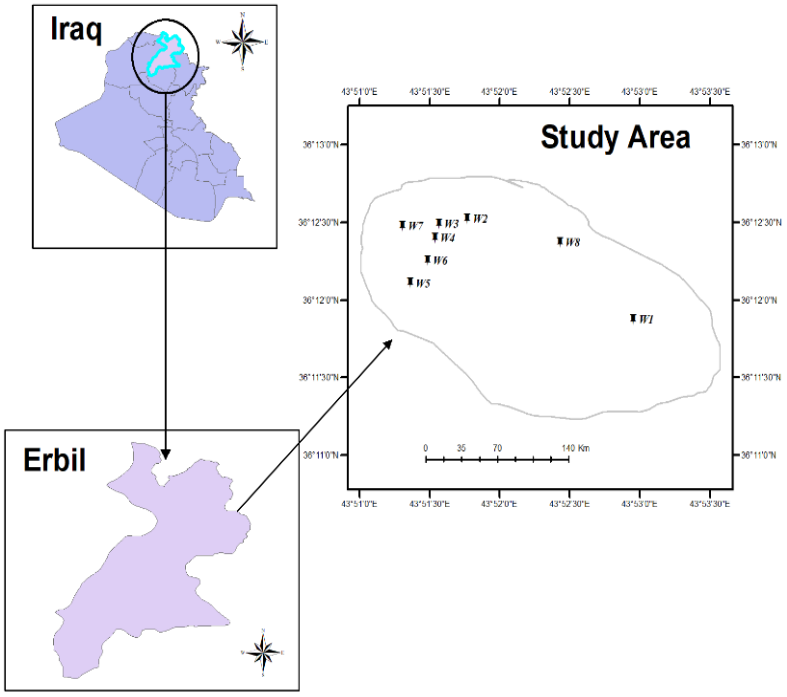

Figure 1: Map of Erbil city and location of groundwater near Erbil landfill site.

2.2 Leachate and Groundwater Sampling

The collecting of leachate samples was done from a natural pond that was situated close to a landfill and contained leachate that had just recently been dumped there. In order to decrease biological and chemical processes, the collected samples were taken straight to the lab and refrigerated at 4°C until they were used in an experiment [20]. Additionally, samples of untreated groundwater were obtained to measure the extent of pollution. Eight distinct groundwater samples near ELS were taken as fresh samples (Figure 1). Groundwater samples were gathered using the same methodology as leachate. Samples of groundwater and fresh landfill leachate were taken throughout both the dry and the wet seasons, in August 2021 and February 2022.

3. Methodology

Water's usefulness is restricted by its quality which may render it inappropriate for certain purposes. Hence, water quality evaluation is a crucial part of water evaluation and people's way of life. According to standard methods, leachate and groundwater samples generated by the Erbil landfill site were collected and tested for different physico-chemical properties including, pH, EC, nitrates, nitrites, TDS, alkalinity, bicarbonate, total hardness, calcium hardness, sodium, magnesium, SAR (Sodium adsorption ratio), as well as chlorides and heavy metals [20].

3.1 CCME Water Quality Index

The CCME WQI is a commonly applied process and an internationally recognized approach for evaluating water quality [21]. According to the equation created by the British Columbia Ministry of Environment, Lands and Parks [22], the index is widely utilized in water quality research based on its adaptability to the kind and number of parameters chosen for assessing water quality, water body type, and application timeframe. In addition, the benefit of this approach is that it allows researchers to employ regional water quality criteria [23].

Three components of the CCME WQI concept are:

1. **Scope**: Shows the number of parameters whose objectives are not met**.**
2. **Frequency:** This indicates the frequency with which certain goals are not fulfilled.
3. **Amplitude:** Reflects the amount by which the goals are not achieved.

Three elements make up the CCME WQI model (from 0 to 100) and indicate the overall water quality of the body of water, where 0 shows the "worst" and 100 represents the "best" value [19] [23]. The formulation of the WQI as described in the Canadian Water Quality Index, is represented in the following formulas [24]: The estimation for scope is F_1. This reflects the number of variables whose values did not meet the study's goals throughout the course of time.

$$F_1= \left(\frac{number\ of\ failed\ variables}{total\ number\ of\ variables}\right) * 100 \quad (3.1)$$

The estimate for frequency is F_2. This is the number of failed tests, or the total of individual tests that do not satisfy goals.

$$F_2= \left(\frac{number\ of\ failed\ tests}{total\ number\ of\ tests}\right)* 100 \quad (3.2)$$

Determining amplitude is F_3. This is the number of test values that failed because they did not achieve their goals. This stage has many steps. When excursion was first calculated, the number of times the test value was higher than the goal and has since then been called the excursion. The following equation can be used to figure out the excursion:

$$excursion= \left(\frac{failed\ test\ value}{guideline\ value}\right)*100 \quad (3.3)$$

In circumstances when the test result is smaller than the objective value, formula (3.4) is used

$$excursion= \left(\frac{guideline\ value}{failed\ test\ value}\right) - 1 \quad (3.4)$$

The normalized sum of excursions (nse) can be calculated by equation (3.5)

$$nse= \frac{\Sigma\ excursion}{number\ of\ tests} \quad (3.5)$$

Eventually, the amplitude (F_3) may be obtained from the equation (3.6)

$$F_3= \frac{nse}{0.01nse+0.01} \quad (3.6)$$

The CCME WQI is then computed using the formula indicated below:

$$WQI= 100- \frac{\sqrt{F_1^2+F_2^2+F_3^2}}{1.732}$$

The quality of water may then be graded according to one of the five categories listed in Table 1.

Table 1: CCME WQI categorization scheme [19] [23].

Category	WQI	Status
1	95-100	Excellent
2	80-94	Good
3	65-79	Fair
4	45-64	Marginal
5	0-44	Poor

3.2 Integration of WQI with GIS

During groundwater sampling, the computed WQI (z) for the dry and wet seasons was merged with GPS-collected data on geographical latitude (y) and longitude (x). In order to determine the groundwater quality, integrated xyz data was examined using the IDW approach in ArcMap 10.8 GIS software.

4. Results and Discussion

4.1 Groundwater

The examined area's ground water is utilized for home and other uses. The pH ranges of the water body are one of the most significant symbols of water quality and pollution levels [25]. The pH values for the examined summer and winter seasons varied from 7.89 to 8.26 and 8.296 to 8.630, respectively, indicating the water is somewhat alkaline in nature; all well water fell in the WHO's permitted range. EC is a useful to evaluate of the quantity of dissolved material in water. The electrical conductivity in the examined region extended from 925 to 1152.33 µS/cm and from 923 to 1158.7 µS/cm and was found to be elevated, particularly at well 1 (Table 2 and 3).

Table 2: Ground water analysis at summer season of the year 2021

Wells	W1	W2	W3	W4	W5	W6	W7	W8
pH	8.26±0.113^{a}	8.23±0.113^{a}	8.20±0.113^{a}	7.96±0.113^{a}	7.92±0.113^{a}	7.97±0.113^{a}	7.89±0.113^{a}	7.90±0.113^{a}
EC (µS/cm)	1152.33±10.26^{a}	1051.33±10.26^{a}	1008.67±10.26^{a}	1032.00±10.26^{a}	925.00±10.26^{a}	975.67±10.26^{a}	930.67±10.26^{a}	1043.00±10.26^{a}
Cl (mg.l^{-1})	76.00±3.38^{a}	56.00±3.38^{bc}	69.33±3.38^{bc}	50.67±3.38^{ab}	34.00±3.38^{c}	32.67±3.38^{c}	31.33±3.38^{de}	49.33±3.38^{cd}
T.H (mg CaCO$_3$/l)	506.67±15.069^{a}	446.67±15.069^{bc}	426.67±15.069^{bc}	454.67±15.069^{bc}	420.00±15.069^{c}	461.33±15.069^{bc}	454.67±15.069^{ab}	218.67±15.069^{d}
Ca.H (mg CaCO$_3$/l)	99.73±10.59^{ab}	112.27±10.59^{a}	84.80±10.59^{a}	49.87±10.59^{ab}	59.73±10.59^{ab}	96.27±10.59^{ab}	107.73±10.59^{a}	72.00±10.59^{ab}
Alk. (mg.l^{-1})	60.33±15.815^{a}	59.67±15.815^{ab}	64.67±15.815^{abc}	74.33±15.815^{abc}	55.33±15.815^{bc}	110.33±15.815^{ab}	65.00±15.815^{abc}	54.67±15.815^{c}
HCO$_3$(mg CaCO$_3$/l)	73.61±19.295^{a}	72.79±19.295^{ab}	78.89±19.295^{abc}	90.69±19.295^{abc}	67.51±19.295^{bc}	134.61±19.295^{ab}	79.30±19.295^{abc}	66.69±19.295^{c}
NO2 (mg.l^{-1})	0.37±1.705^{a}	0.40±1.705^{a}	0.32±1.705^{a}	0.56±1.705^{a}	0.36±1.705^{a}	0.33±1.705^{a}	0.24±1.705^{a}	0.36±1.705^{a}
NO$_3$ (mg NO$_3$-N/l)	0.80±0.046^{e}	0.98±0.046^{de}	1.01±0.046^{cd}	1.10±0.046^{bc}	0.98±0.046^{cde}	1.52±0.046^{a}	1.24±0.046^{ab}	0.96±0.046^{de}
Na (mg.l^{-1})	71.32±8.805^{a}	78.84±8.805^{a}	21.53±8.805^{a}	77.90±8.805^{a}	88.24±8.805^{ab}	64.75±8.805^{ab}	75.09±8.805^{ab}	76.02±8.805^{a}
K (mg.l^{-1})	3.56±1.158^{a}	3.56±1.158^{a}	1.84±1.158^{a}	2.82±1.158^{a}	3.56±1.158^{a}	2.33±1.158^{a}	3.07±1.158^{a}	2.82±1.158^{a}
Mg (mg CaCO$_3$/l)	7.20±2.894^{ab}	7.20±2.894^{b}	4.80±2.894^{b}	25.44±2.894^{a}	14.40±2.894^{ab}	4.80±2.894^{a}	10.08±2.894^{ab}	16.64±2.894^{ab}
TDS (mg.l^{-1})	633.78±5.643^{a}	578.23±5.643^{b}	554.77±5.643^{b}	567.60±5.643^{b}	508.75±5.643^{e}	536.62±5.643^{d}	511.87±5.643^{e}	573.65±5.643^{c}
SAR (meq/l)	1.855±2.039^{ab}	1.944±2.039^{ab}	0.614±2.039^{b}	2.230±2.039^{a}	2.651±2.039^{a}	1.743±2.039^{ab}	1.850±2.039^{ab}	2.093±2.039^{ab}
Zn (mg.l^{-1})	0.220±0.058^{b}	0.220±0.058^{b}	0.396±0.058^{b}	0.226±0.058^{b}	0.136±0.058^{b}	0.156±0.058^{b}	0.230±0.058^{b}	0.433±0.058^{a}
Cd (mg.l^{-1})	0.763±0.292^{a}	1.763±0.292^{a}	0.430±0.292^{a}	2.066±0.292^{a}	1.600±0.292^{a}	0.583±0.292^{a}	0.743±0.292^{a}	0.540±0.292^{a}
Pb (mg.l^{-1})	2.010±0.459^{a}	2.333±0.459^{a}	0.823±0.459^{a}	2.086±0.459^{a}	2.090±0.459^{a}	0.843±0.459^{a}	2.600±0.459^{a}	1.933±0.459^{a}
Mn (mg.l^{-1})	0.103±0.013^{a}	0.090±0.013^{a}	0.066±0.013^{a}	0.053±0.013^{a}	0.066±0.013^{a}	0.056±0.013^{a}	0.060±0.013^{a}	0.046±0.013^{a}

Ni (mg.l^{-1})	4.933±0.399^{a}	0.480±0.399^{b}	0.066±0.399^{b}	0.046±0.399^{b}	0.050±0.399^{b}	0.266±0.399^{b}	0.383±0.399^{b}	0.326±0.399^{b}
Cu (mg.l^{-1})	0.966±0.12^{a}	0.500±0.12^{ab}	0.270±0.12^{ab}	0.043±0.12^{b}	0.026±0.12^{b}	0.040±0.12^{b}	0.063±0.12^{b}	0.050±0.12^{b}
Cr (mg.l^{-1})	2.766±0.371^{a}	3.500±0.371^{a}	0.186±0.371^{b}	0.190±0.371^{b}	0.186±0.371^{b}	0.210±0.371^{b}	0.400±0.371^{b}	0.180±0.371^{b}
Hg (mg.l^{-1})	0.008±0.001^{a}	0.005±0.001^{a}	0.005±0.001^{a}	0.006±0.001^{a}	0.005±0.001^{a}	0.005±0.001^{a}	0.005±0.001^{a}	0.004±0.001^{a}

Note: Values in each row with different letters are significantly different and values with same letters are not significantly different.

Table 3: Ground water analysis at Winter season of the year 2022.

Wells	W1	W2	W3	W4	W5	W6	W7	W8
pH	8.63±0.113^{a}	8.546±0.113^{a}	8.53±0.113^{a}	8.52±0.113^{a}	8.6±0.113^{a}	8.29±0.113^{a} 6	8.343±0.113^{a}	8.326±0.113^{a}
EC (µS/cm)	1158.7±10.26^{a}	1047.7±10.26^{a}	1054.3±10.26^{a}	1063±10.26^{a}	943±10.26^{a}	951.3±10.26^{a}	923±10.26^{a}	948±10.26^{a}
Cl (mg.l^{-1})	60±3.38^{a}	58±3.38^{bc}	59.333±3.38^{bc}	57.333±3.38^{ab}	43±3.38^{c}	40.67±3.38^{c}	54±3.38^{de}	45.33±3.38^{cd}
T.H (mg $CaCO_3$/l)	449.33±15.069^{a}	378.67±15.069^{bc}	380±15.069^{bc}	382.67±15.069^{bc}	380±15.069^{c}	400±15.069^{bc}	445.3±15.069^{ab}	300±15.069^{d}
Ca.H (mg $CaCO_3$/l)	44.266±10.59^{ab}	41.866±10.59^{a}	45.066±10.59^{a}	34.133±10.59^{ab}	43±10.59^{ab}	42.13±10.59^{ab}	49.87±10.59^{a}	33.87±10.59^{ab}
Alk. (mg.l^{-1})	200±15.815^{a}	175±15.815^{ab}	98.333±15.815^{abc}	125±15.815^{abc}	100±15.815^{bc}	114±15.815^{ab}	96±15.815^{abc}	67±15.815^{c}
HCO_3(mg $CaCO_3$/l)	244±19.295^{a}	213.5±19.295^{ab}	119.97±19.295^{abc}	152.5±19.295^{abc}	122±19.295^{bc}	139.1±19.295^{ab}	117.5±19.295^{abc}	81.74±19.295^{c}
NO_2 (mg.l^{-1})	6.2±1.705^{a}	5.246±1.705^{a}	8.293±1.705^{a}	8.206±1.705^{a}	8.24±1.705^{a}	8.28±1.705^{a}	8.3±1.705^{a}	10.11±1.705^{a}
NO_3 (mg NO_3-N/l)	1.03±0.046^{e}	1.05±0.046^{de}	1.246±0.046^{cd}	1.246±0.046^{bc}	1.12±0.046^{cde}	1.13±0.046^{a}	1.346±0.046^{ab}	1.06±0.046^{de}
Na (mg.l^{-1})	117.49±8.805^{a}	108.14±8.805^{a}	103.35±8.805^{a}	103.35±8.805^{a}	90.57±8.805^{ab}	95.22±8.805^{ab}	72.78±8.805^{ab}	109.1±8.805^{a}
K (mg.l^{-1})	8.333±1.158^{a}	8.26±1.158^{a}	8.05±1.158^{a}	8.036±1.158^{a}	8.1±1.158^{a}	8.096±1.158^{a}	7.78±1.158^{a}	8.053±1.158^{a}
Mg (mg $CaCO_3$/l)	27.36±2.894^{ab}	20.32±2.894^{b}	18.56±2.894^{b}	25.44±2.894^{a}	19.52±2.894^{ab}	22.72±2.894^{ab}	23.52±2.894^{a}	15.68±2.894^{ab}
TDS (mg.l^{-1})	637.27±5.643^{a}	576.22±5.643^{b}	576.88±5.643^{b}	584.65±5.643^{a}	518.833±5.643^{e}	523.2±5.643^{d}	507.7±5.643^{e}	521.4±5.643^{c}
SAR (meq/l)	3.408±2.039^{ab}	3.417±2.039^{ab}	3.260±2.039^{b}	3.249±2.039^{a}	2.857±2.039^{a}	2.927±2.039^{ab}	2.120±2.039^{ab}	3.874±2.039^{ab}
Zn (mg.l^{-1})	0.076±0.058^{b}	0.094±0.058^{b}	0.074±0.058^{b}	0.062±0.058^{b}	0.054±0.058^{b}	0.075±0.058^{b}	0.158±0.058^{b}	0.41±0.058^{a}
Cd (mg.l^{-1} l)	0.015±0.292^{a}	0.006±0.292^{a}	0.006±0.292^{a}	0.006±0.292^{a}	0.006±0.292^{a}	0.006±0.292^{a}	0.006±0.292^{a}	0.006±0.292^{a}
Pb (mg.l^{-1})	0.046±0.459^{a}	0.044±0.459^{a}	0.087±0.459^{a}	0.051±0.459^{a}	0.04±0.459^{a}	0.054±0.459^{a}	0.066±0.459^{a}	0.056±0.459^{a}
Mn (mg.l^{-1})	0.03±0.013^{a}	0.025±0.013^{a}	0.053±0.013^{a}	0.015±0.013^{a}	0.016±0.013^{a}	0.014±0.013^{a}	0.015±0.013^{a}	0.007±0.013^{a}
Ni (mg.l^{-1})	0.005±0.399^{a}	0.003±0.399^{a}	0.006±0.399^{a}	0.005±0.399^{a}	0.003±0.399^{a}	0.005±0.399^{a}	0.005±0.399^{a}	0.006±0.399^{a}
Cu (mg.l^{-1})	0.012±0.12^{a}	0.014±0.12^{a}	0.014±0.12^{a}	0.016±0.12^{a}	0.016±0.12^{a}	0.017±0.12^{a}	0.016±0.12^{a}	0.015±0.12^{a}
Cr (mg.l^{-1})	0.05±0.371^{a}	0.033±0.371^{b}	0.07±0.371^{b}	0.06±0.371^{b}	0.043±0.371^{b}	0.056±0.371^{b}	0.053±0.371^{b}	0.056±0.371^{b}
Hg (mg.l^{-1})	0.002±0.001^{a}	0.005±0.001^{a}	0.004±0.001^{a}	0.006±0.001^{a}	0.003±0.001^{a}	0.005±0.001^{a}	0.005±0.001^{a}	0.003±0.001^{a}

Note: Values in each row with different letters are significantly different and values with same letters are not significantly different.

The fact that the groundwater around the dump has higher conductivity levels shows how it has influenced the quality of the water. Typically, the maximum amount of Cl^- in water is regarded as an indicator of both a source of pollution and a marker for the contamination of groundwater [26]. The content of Cl- in the samples of groundwater varied from 31.33 $mg.l^{-1}$ to 76 $mg.l^{-1}$ and from 40.67 $mg.l^{-1}$ to 60 $mg.l^{-1}$. Winter and summer chloride concentrations were found to be quite high at well 1 (Tables 3 and 5). Groundwater with large amount of Cl^- is likely derived from polluting sources like domestic effluents, fertilizers, and septic tanks. However, the presence of such Cl^- amounts may due to natural sources such as precipitation and fluid inclusion dissolution. People with heart or renal illness are negatively affected by an increase in Cl^- levels [27]. Correlation matrix is illustrated in Table 4. The highest positive correlations were found between the electrical conductivity and chloride was 0.77.

Table 4: Correlation between physicochemical parameters of Ground waters

	pH	EC	Cl	T.H	Ca.H	Alk.	HCO_3	Na
pH	1							
EC	0.762152	1						
Cl	0.615817	0.7710403	1					
T.H	0.263629	0.3131971	0.381849	1				
Ca.H	0.088412	-0.0744107	0.18025	0.744043	1			
Alk.	0.65484	0.7951789	0.566151	0.547419	0.168164	1		
HCO_3	0.654182	0.7945267	0.566743	0.549051	0.169859	0.999997	1	
Na	0.479007	0.7468422	0.331351	-0.31055	-0.53508	0.509642	0.507839	1

Hardness in ground water is mostly caused as a result of the existence of magnesium, calcium, carbonates, bicarbonates, sulfates, and chlorides. If the water's hardness is lower than 50 $mg.l^{-1}$, it is soft. And if it is between 50 and 100 $mg.l^{-1}$, water will be somewhat considered soft. When the hardness values are between 101 and 200 $mg.l^{-1}$ and over 200 $mg.l^{-1}$, the water is considered mildly hard and very hard, respectively. Summer hardness levels varied from 218.67 to 506.67 $mg.l^{-1}$, whereas winter values ranged from 300 to 449.33 $mg.l^{-1}$. Again, the investigation revealed the presence of an excessive amount of hardness-causing cations and anions near the water samples. It was discovered that W1 had a higher overall hardness in the summer and winter. The high hardness concentration of the ground water imparts a saline flavor, rendering the water unsuitable for drinking, agriculture and other home uses. Additionally, hardness adds to the inefficient and expensive functioning of water-using equipment [28].

Except for wells 4, 5 and 8, high calcium concentration was detected in all wells throughout the summer months. The Ca content fluctuated between 49.87 and 112.27 $mg.l^{-1}$ throughout the summer and ranged between 33.87 and 49.8 $mg.l^{-1}$ throughout the winter. Third most prevalent element in the earth crust is calcium. Too many Ca ions cause kidney stones and irritation and pain in the urinary channels.

Alkalinity is determined by the mix of bicarbonate and carbonate present in the water samples. There was no carbonate content in the water samples. Therefore, the bicarbonate concentration was the only contributor to the overall alkalinity. The pH of samples containing just bicarbonate alkalinity was 8.3 or below. In this instance, bicarbonate alkalinity and total alkalinity were equal. Alkalinity observed to be greater than hardness may be attributed to the

existence of potassium and sodium salts, in addition to magnesium and calcium which are basic. All wells' alkalinity concentrations fell within the allowed range of 55.33 to 110.33 mg.l^{-1} in the summer and 67 to 200 mg.l^{-1} in the winter. Due to the presence of calcareous materials and the production of CO_2, there were more carbonate and bicarbonate in landfills.
During the winter season, the HCO_3 concentration in wells W1 and W2 occurred from 213.5 to 244 mg.l^{-1}. However, during the summer season all wells water concentrations were within the allowed range, and seasonal changes were also noted. This could be associated with the ionic soil composition, buffering capacity and precipitation [27].

The concentration of nitrate ranged from 0.80 to 1.52 mg.l^{-1} in the summer to 1.03 to 1.346 mg.l^{-1} in the winter in ground water samples. Although there were significant differences ($p \leq 0.05$) between wells among the ground water sites, the approved concentration limit for nitrate is 45 mg/l. The distribution of nitrate in the ground water in the research region showed that human excrement was a source of nitrate that enters the aquifers and likely the Erbil dump yard. Both liquid and solid wastes are responsible for the rise in nitrate concentration in the study area. Groundwater nitrate pollution might have been caused by pollutant discharges include sewage discharge, effluent from on-site cleaning, leachate from solid waste facilities, and the utilization of wastewater for irrigation [29]. Excess nitrate content in groundwater produces methemoglobinemia or blue baby syndrome sickness in babies, as well as diseases of the gastrointestinal tract, respiratory system and brain system [30].

In summer, the content of nitrite varied from 0.24 to 0.56 mg.l^{-1} which was within allowed limits. In winter, the nitrite varied from 5.24 to 10.11 mg.l^{-1}. According to statistics, the NO_2 levels fluctuate significantly ($p \leq 0.05$) from season to season (Table 5).

Table 5: LSD with Physical and chemical parameters of the samples collected according to seasons.

Parameters	S1	S2	LSD
pH	8.040	8.470	0.072
EC (µS/cm)	1014.833	1011.167	6.463
Cl (mg.l^{-1})	49.917	52.250	2.966
TH (mg $CaCO_3$/l)	423.667	389.500	10.036
CaH (mg $CaCO_3$/l)	85.300	41.833	0.986
Alkalinity (mg.l^{-1})	68.042	121.958	2.030
HCO_3 (mg $CaCO_3$/l)	83.011	148.789	2.476
NO_2 (mg.l^{-1})	0.367	7.860	0.022
NO_3 (mg NO_3-N/l)	1.075	1.154	0.015
Na (mg.l^{-1})	69.211	100.025	0.351
K (mg.l^{-1})	2.943	8.089	0.035
Mg (mg $CaCO_3$/l)	11.320	21.640	0.696
TDS (mg.l^{-1})	558.158	556.142	3.555
SAR (meq/l)	14.262	6.326	0.067
Zn (mg.l^{-1})	0.253	0.126	0.062
Cd (mg.l^{-1})	1.061	0.007	0.144
Pb (mg.l^{-1})	1.840	0.056	0.239
Mn (mg.l^{-1})	0.068	0.022	0.015
Ni (mg.l^{-1})	0.819	0.005	0.082
Cu (mg.l^{-1})	0.245	0.015	0.110

Cr ($mg.l^{-1}$)	0.953	0.053	0.163
Hg ($mg.l^{-1}$)	0.006	0.001	0.005

Note: S1= Summer season, S2= Winter season.

The sodium content varied from 21.53 to 88.24 $mg.l^{-1}$ during the summer and from 72.78 to 117.49 $mg.l^{-1}$ in the winter. Every sample obtained was within the permitted value specified by IS standards.

Summer and winter potassium concentrations ranged from 1.840 to 3.550 $mg.l^{-1}$ and 7.780 to 8.333 $mg.l^{-1}$ respectively. The lowest potassium content was found in the ground water. Rainfall, potash fertilization and the weathering of potassium silicate minerals were the primary potassium sources for groundwater [31].

The magnesium content ranged from 4.800 to 25.440 $mg.l^{-1}$ in the summer and from 15.680 to 27.360 $mg.l^{-1}$ in the winter. The high magnesium content could be the result of leachate percolating into the ground water. A high quantity of magnesium has a laxative effect on humans.

According to BIS (Bureau of Indian Standards) and WHO standards, the TDS in ground water must not exceed 500 mg/l. But regrettably all of the stations' values throughout the summer and winter seasons, beside a few, were high. The TDS varied from 508,7 to 633,78 $mg.l^{-1}$ during the summer and from 507,7 to 637,27 $mg.l^{-1}$ during the winter respectively. The connection between the EC and TDS levels was linear. Among all the samples, sample W1 had the highest TDS.

In addition, according to the Sodium Adsorption Ratio (SAR), the examined ground waters were categorized as good for irrigation purposes based on a prior technique [32]. In the summer, the maximum value was determined to be 2.230 meq/l at well 4, while the minimum number was determined to be 0.614 meq/l at well 3. Winter SAR concentrations ranged from 2.120 meq/l to 3.874 meq/l. There were substantial changes in SAR values across wells during different seasons.

Due to their toxicity and accumulative nature, poisoning of groundwater by heavy metals has garnered considerable attention. Through the weathering of rock minerals and human activity, these metals are introduced into the environment. Tables 2 and 3 describe the metal ion concentrations in groundwater samples obtained throughout the summer and winter seasons. The amounts of Zn, Mn, and Hg in ground water collected near the landfill were well below the allowable limit. Except for Cd, Ni, Pb, Cr, and Cu, the concentration in the summer indicated a modest rise beyond the permitted limit. However, in the winter season, the concentrations of Zn, Cd, Mn, Ni, Cu, and Hg were below acceptable levels, although the concentrations of Pb and Cr raised. The amount of Mn ranged from 0.027 to 0.067 $mg.l^{-1}$. Statistically there were significantly differences ($p \leq 0.05$) among all wells (Table 5). And mercury contents in all wells and seasons were significantly different ($p \leq 0.05$) (Figure 3, Table 6 & 7). This conclusion predicted that the heavy metal content will be greater in the summer than in the winter due to the increased activity of chemical reactions throughout the summer.

Table 6: Mean ± SE for parameters measured at studied ground water samples.

Parameters	W1	W2	W3	W4
pH	8.445±0.113^{a}	8.388±0.113^{a}	8.365±0.113^{a}	8.238±0.113^{a}
EC (µS/cm)	1155.5±10.26^{a}	1049.5±10.26^{b}	1031.5±10.26^{b}	1047.5±10.26^{b}
Cl ($mg.l^{-1}$)	68±3.38^{a}	57±3.38^{bc}	64.333±3.38^{ab}	54±3.38^{c}
TH (mg $CaCO_3$/l)	478±15.069^{a}	412.667±15.069^{bc}	403.333±15.069^{bc}	418.667±15.069^{bc}
Ca.H (mg $CaCO_3$/l)	72±10.59^{ab}	77.067±10.59^{a}	64.933±10.59^{ab}	42±10.59^{b}
Alk. ($mg.l^{-1}$)	130.167±15.815^{a}	117.333±15.815^{ab}	81.5±15.815^{abc}	99.667±15.815^{abc}
HCO_3(mg $CaCO_3$/l)	158.803±19.295^{a}	143.147±19.295^{ab}	99.43±19.295^{abc}	121.953±19.295^{abc}
NO_2 ($mg.l^{-1}$)	3.283±1.705^{a}	2.823±1.705^{a}	4.307±1.705^{a}	4.383±1.705^{a}
NO_3 (mg NO_3-N/l)	0.917±0.046^{e}	1.015±0.046^{de}	1.127±0.046^{cd}	1.174±0.046^{bc}
Na ($mg.l^{-1}$)	94.409±8.805^{a}	93.493±8.805^{a}	62.511±8.805^{b}	90.627±8.805^{a}
K ($mg.l^{-1}$)	5.946±1.158^{a}	5.909±1.158^{a}	4.943±1.158^{a}	5.428±1.158^{a}
Mg (mg $CaCO_3$/l)	17.28±2.894^{ab}	13.56±2.894^{b}	11.68±2.894^{b}	25.44±2.894^{a}
TDS ($mg.l^{-1}$)	635.525±5.643^{a}	577.225±5.643^{b}	567.325±5.643^{b}	576.125±5.643^{b}
SAR (meq/l)	10.368±2.039^{ab}	10.643±2.039^{ab}	5.519±2.039^{b}	12.329±2.039^{a}
Zn ($mg.l^{-1}$)	0.148±0.058^{b}	0.157±0.058^{b}	0.236±0.058^{b}	0.144±0.058^{b}
Cd ($mg.l^{-1}$)	0.389±0.292^{a}	0.885±0.292^{a}	0.218±0.292^{a}	1.036±0.292^{a}
Pb ($mg.l^{-1}$)	1.028±0.459^{a}	1.189±0.459^{a}	0.456±0.459^{a}	1.069±0.459^{a}
Mn ($mg.l^{-1}$)	0.067±0.013^{a}	0.058±0.013^{a}	0.06±0.013^{a}	0.034±0.013^{a}
Ni ($mg.l^{-1}$)	2.469±0.399^{a}	0.242±0.399^{b}	0.036±0.399^{b}	0.026±0.399^{b}
Cu ($mg.l^{-1}$)	0.49±0.12^{a}	0.257±0.12^{ab}	0.142±0.12^{ab}	0.03±0.12^{b}
Cr ($mg.l^{-1}$)	1.408±0.371^{a}	1.767±0.371^{a}	0.128±0.371^{b}	0.125±0.371^{b}
Hg ($mg.l^{-1}$)	0.004±0.001^{a}	0.003±0.001^{a}	0.003±0.001^{a}	0.003±0.001^{a}

Note: Values in each row with different letters are significantly different and values with same letters are not significantly different.

Table 7: Mean ± SE for parameters measured at studied ground water samples.

Parameters	W5	W6	W7	W8
pH	8.242±0.113^{a}	8.133±0.113^{a}	8.115±0.113^{a}	8.112±0.113^{a}
EC (µS/cm)	934.167±10.26^{c}	963.5±10.26^{d}	926.833±10.26^{c}	995.5±10.26^{c}
Cl (mg.l^{-1})	38.667±3.38^{de}	36.667±3.38^{e}	42.667±3.38^{de}	47.333±3.38^{cd}
T.H (mg $CaCO_3$/l)	400±15.069^{c}	430.667±15.069^{bc}	450±15.069^{ab}	259.33±15.069^{d}
Ca.H (mg $CaCO_3$/l)	51.6±10.59^{ab}	69.2±10.59^{ab}	78.8±10.59^{a}	52.933±10.59^{ab}
Alk. (mg $CaCO_3$/l)	77.667±15.815^{bc}	112.167±15.815^{ab}	80.667±15.815^{abc}	60.833±15.815^{c}
HCO_3 (mg $CaCO_3$/l)	94.753±19.295^{bc}	136.843±19.295^{ab}	98.413±19.295^{abc}	74.217±19.295^{c}
NO_2 (mg.l^{-1})	4.3±1.705^{a}	4.303±1.705^{a}	4.27±1.705^{a}	5.237±1.705^{a}
NO_3(mg NO_3-N/l)	1.051±0.046^{cde}	1.324±0.046^{a}	1.295±0.046^{ab}	1.011±0.046^{de}
Na (mg.l^{-1})	89.404±8.805^{ab}	79.982±8.805^{ab}	73.934±8.805^{ab}	92.585±8.805^{a}
K (mg.l^{-1})	5.829±1.158^{a}	5.211±1.158^{a}	5.423±1.158^{a}	5.437±1.158^{a}
Mg (mg $CaCO_3$/l)	16.96±2.894^{ab}	13.76±2.894^{b}	16.8±2.894^{ab}	16.16±2.894^{b}
TDS (mg.l^{-1})	513.792±5.643^{e}	529.925±5.643^{d}	509.758±5.643^{e}	547.525±5.643^{c}
SAR (meq/l)	13.102±2.039^{a}	9.398±2.039^{ab}	9.043±2.039^{ab}	11.953±2.039^{ab}
Zn (mg.l^{-1})	0.095±0.058^{b}	0.116±0.058^{b}	0.194±0.058^{b}	0.422±0.058^{a}
Cd (mg.l^{-1})	0.803±0.292^{a}	0.295±0.292^{a}	0.375±0.292^{a}	0.273±0.292^{a}
Pb (mg.l^{-1})	1.065±0.459^{a}	0.449±0.459^{a}	1.333±0.459^{a}	0.995±0.459^{a}
Mn (mg.l^{-1})	0.042±0.013^{a}	0.036±0.013^{a}	0.038±0.013^{a}	0.027±0.013^{a}
Ni (mg.l^{-1})	0.027±0.399^{b}	0.136±0.399^{b}	0.195±0.399^{b}	0.167±0.399^{b}
Cu (mg.l^{-1})	0.022±0.12^{b}	0.029±0.12^{b}	0.04±0.12^{b}	0.033±0.12^{b}
Cr (mg.l^{-1})	0.115±0.371^{b}	0.133±0.371^{b}	0.227±0.371^{b}	0.118±0.371^{b}
Hg (mg.l^{-1})	0.003±0.001^{a}	0.003±0.001^{a}	0.003±0.001^{a}	0.003±0.001^{a}

Note: Values in each row with different letters are significantly different and values with same letters are not significantly different.

4.2 Leachate

The physical and chemical features of leachate are mostly determined by the waste's composition and water concentration. The properties of the leachate samples obtained from the Erbil landfill site have been included in Table 8. The pH range of the leachate was determined to be 7.180 to 7.786. Comparatively large amount of electrical conductivity (3865.333 µS/cm) and total dissolved solids (2125.933 mg.l^{-1}) suggested inorganic substance existence in the leachate samples. The amount of zinc (7,030 mg/l) in the samples indicated that the landfill accepted batteries and fluorescent bulb trash. The concentration of Pb (13.703 mg.l^{-1}) in the summer leachate samples implied the disposal of Pb batteries, photo-processing chemicals, Pb-based paints, and Pb-containing pipelines in the study area [32] [33].

In addition, Cr (22,400 mg.l^{-1}), Cu (2,866 mg.l^{-1}) and Ni (25,633 mg.l^{-1}) were also found in the leachate samples during the summer. However, the quantity of these metals was much lower during the winter. On the other hand, the presence of exceptionally high nickel content might be ascribed to the dumping of industrial trash in the landfill region. A wide range of garbage was buried at the Erbil landfill site which was most probably the source of Zn, Pb, Cr, Cu, and

Ni in leachate [33] [34]. Christensen et. Al [35] also discovered these chemicals in leachate. Chromium and its derivatives have many industrial applications. They are widely used in leather polishing and treatment, the fabrication of refractory steel, electrolytic washing agents, catalytic production, etc. [36]. These human actions have resulted in extensive environmental pollution with Cr and the deposition of Cr-contaminated wastes. The findings of groundwater and leachate outcomes differed from [37] [38].

Table 8: Mean ± SE **for** physicochemical parameters of leachate.

Seasons	Summer		Winter	
Leachate	**L1**	**L2**	**L1**	**L2**
pH	7.290±0.002^{c}	7.180±0.002^{d}	7.786±0.002^{a}	7.616±0.002^{b}
EC (µS/cm)	2275.666±4256.333^{c}	1549.333±4256.333^{d}	3550.666±4256.333^{b}	3865.333±4256.333^{a}
Cl (mg.l^{-1})	60.000±34.583^{a}	70.000±34.583^{a}	31.666±34.583^{b}	27.000±34.583^{b}
T.H (mg $CaCO_3$/l)	4554.000±35.666^{b}	3432.000±35.666^{c}	4653.000±35.666^{b}	6600.000±35.666^{a}
Ca.H (mg $CaCO_3$/l)	514.800±25.343^{c}	594.000±25.343^{c}	1425.600±25.343^{b}	2455.200±25.343^{a}
Alk. (mg.l^{-1})	5247.000±10.122^{c}	6039.000±10.122^{b}	8085.000±10.122^{a}	6105.000±10.122^{b}
HCO_3 (mg $CaCO_3$/l)	6401.340±13.234^{c}	7367.580±13.234^{b}	9863.700±13.234^{a}	7448.100±13.234^{b}
NO_2 (mg.l^{-1})	34.933±2.012^{a}	35.506±2.012^{a}	31.473±2.012^{b}	27.486±2.012^{c}
NO_3 (mg NO_3-N/l)	1.120±0.005^{a}	0.505±0.005^{c}	0.942±0.005^{b}	0.927±0.005^{b}
Na (mg.l^{-1})	73.702±0.893^{a}	63.054±0.893^{b}	59.982±0.893^{c}	51.435±0.893^{d}
K (mg.l^{-1})	12.728±0.606^{c}	17.693±0.606^{a}	15.310±0.606^{b}	13.254±0.606^{c}
Mg(mg $CaCO_3$/l)	776.160±23.557^{a}	451.440±23.557^{b}	261.360±23.557^{c}	110.880±23.557^{d}
TDS (mg.l^{-1})	1251.616±65.777^{c}	852.133±56.777^{d}	1952.866±56.777^{b}	2125.933±56.777^{a}
SAR (meq/l)	4.105±0.012^{a}	3.905±0.012^{a}	2.922±0.012^{b}	2.030±0.012^{c}
Zn (mg.l^{-1})	7.030±0.201^{a}	6.966±0.201^{a}	0.343±0.201^{b}	0.413±0.201^{b}
Cd (mg.l^{-1})	5.000±0.405^{b}	6.963±0.405^{a}	0.036±0.405^{c}	0.034±0.405
Pb (mg.l^{-1})	12.416±0.671^{a}	13.703±0.671^{a}	0.169±0.671^{b}	0.217±0.671^{b}
Mn (mg.l^{-1})	5.516±0.424^{b}	8.613±0.424^{a}	0.169±0.424^{c}	0.217±0.424^{c}
Ni (mg.l^{-1})	22.333±0.272^{b}	25.633±0.272^{a}	0.038±0.272^{c}	0.066±0.272^{c}
Cu (mg.l^{-1})	2.800±0.008^{a}	2.866±0.008^{a}	0.089±0.008^{b}	0.108±0.008^{b}
Cr (mg.l^{-1})	19.700±0.520^{b}	22.400±0.520^{a}	0.508±0.520^{c}	0.592±0.520^{c}
Hg (mg.l^{-1})	0.017±0.0001^{a}	0.012±0.0001^{b}	0.002±0.0001^{c}	0.003±0.0001^{c}

Note: Values in each row with different letters are significantly different and values with same letters are not significantly different.

4.3 CCME Water Quality Index

Figures 3 and 4 depict the summer and winter WQI findings respectively. In this investigation, all wells water used for drinking purposes during the summer months had WQI values indicating poor quality. Most of the time, water quality was endangered or had worsened, and conditions were normally not at natural or ideal levels. According to drinking water

regulations, only wells 4 and 8 measured 53.545 and 65.081 which were deemed fair and marginal water respectively [39]. According to Table 1, the water quality in well 4 is fair, meaning that it is generally safe but occasionally threatened or degraded, whereas the water quality in well 8 is marginal, meaning that it is threatened or degraded; circumstances frequently relate to natural or acceptable levels.

During the winter, the WQI ratings of all wells were rated as poor because water quality was endangered or had worsened, and conditions were usually not at natural or ideal levels. But wells 2, 4, and 8 had respective readings of 50.23, 75.299, and 50.949. Wells 2 and 8 were classified as having marginal regularity; water quality was endangered or had degraded; circumstances frequently differed from natural or acceptable values. However, well 4 was ranked as fair quality as water quality was usually protected, but was sometimes threatened or damaged. Normally, the quality went beyond what is natural or ideal (Table 9).

By calculating the WQI, it was possible to discern between drinking-quality and drinking-unsuitable locations which could aid scientists, policymakers, and the general public in water resource management. In groundwater samples, geographical and temporal fluctuations in the parameters and WQI were identified (Figure 2). Contributing to these variations were (a) the huge impact of the MSW disposal area and associated concentrated agricultural operations in the research region, (b) the aquifer being refilled alongside leachate from the dumping yard area throughout the forced to retreat precipitation seasons in the work area, and (c) elevation of the existing region was from southeast to northwest [17]. Thus, the combined WQI maps indicated the same general pattern for the subsurface movement of groundwater contamination. On the basis of summer and winter WQI values, themed maps of groundwater quality were created for the current research region (Figures 3 & 4).

Table 9: Groundwater samples and their WQI

Wells	Longitude	Latitude	WQI (Summer)	WQI (Winter)
W1	42.1173922	36.19771	38.564	35.943
W2	42.1371778	36.2087	36.413	50.239
W3	42.14054722	36.20817	41.418	38.356
W4	42.14103333	36.20663	65.081	75.299
W5	42.14191667	36.20421	41.268	40.393
W6	42.14395	36.20179	41.517	40.386
W7	42.14487778	36.20793	39.141	40.377
W8	42.12613056	36.20617	53.545	50.949

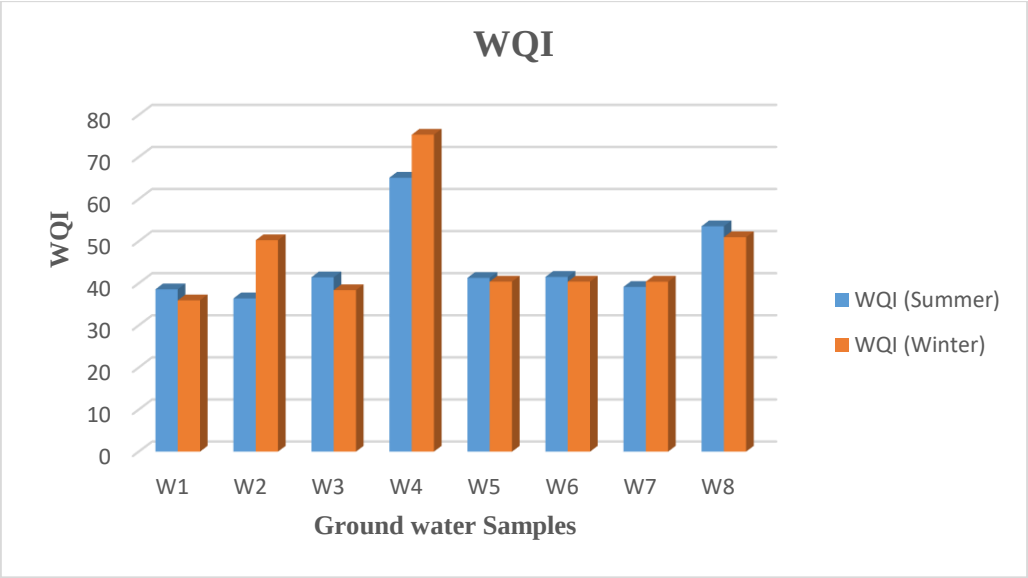

Figure 2: Variation in WQI in groundwater samples.

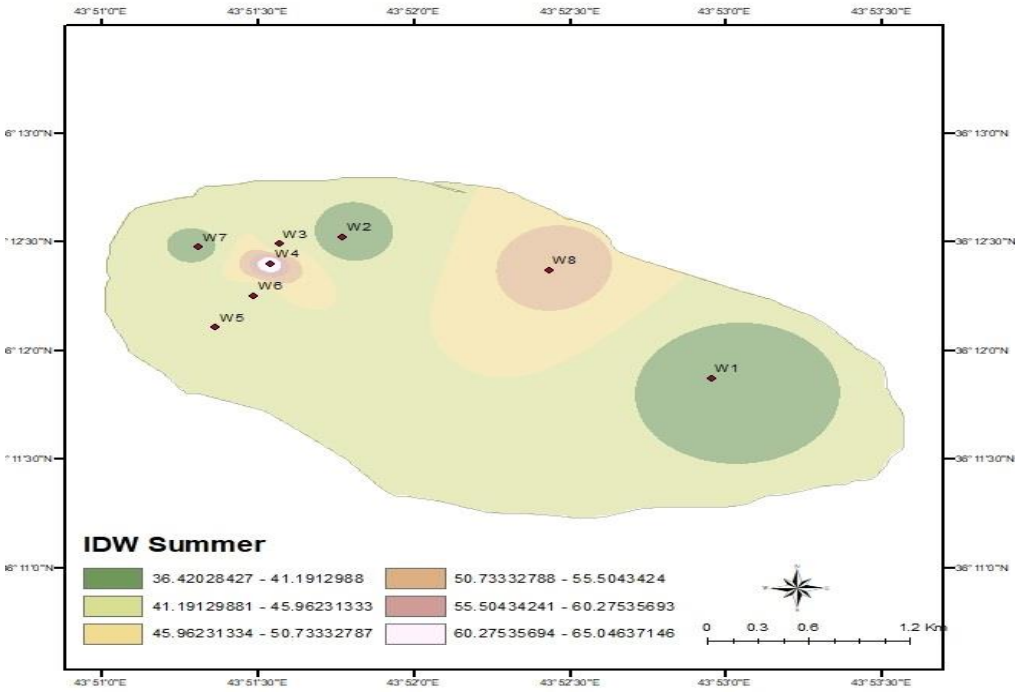

Figure 3: WQI to the study area (Summer)

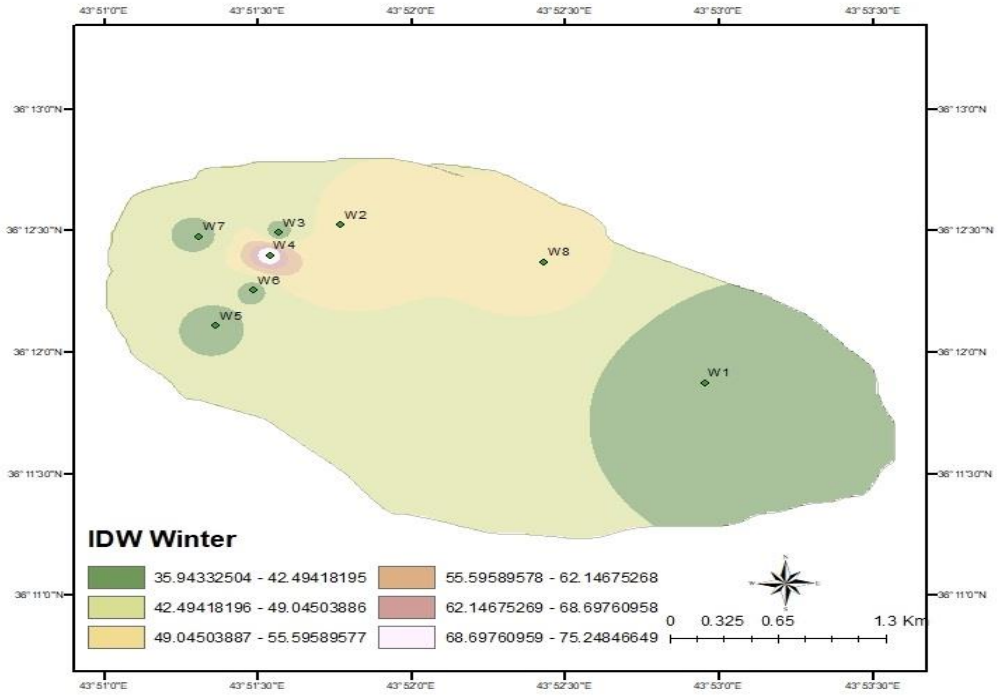

Figure 4: WQI to the study area (Winter).

References

[1] D. Fatta, A. Papadopoulos and M. Loizidiu, "A study on the Landfill Leachate and its Impacts on the Groundwater Quality of the Greater Area," *Environmental Geochemistry and Health*, vol. 21 no. 2, pp. 171–190, 2022.

[2] N. Vasavi and Naseem, "Impact of Solid Waste Disposal on Quality of Ground Water Around Different Landfill Sites of Nizamabad City," *Telangana State. International Journal of Engineering Research & Technology (IJERT),* vol. 9, no. 03, pp. 214-215, 2020.

[3] S. Mor, K. Ravindra, R. P. Dahiya and A. Chandra, "Leachate Characterization and Assessment of Groundwater Pollution Near Municipal Solid Waste Landfill Site," *Environmental Monitoring and Assessment,* vol. 118, no. 1-3, pp. 435–456, 2006.

[4] D. Abiriga, S. Vestgarden and H. Klempe, "Groundwater Contamination from A Municipal Landfill: Effect of age, Landfill Closure, and Season on Groundwater Chemistry," *Science of the Total Environment,* vol. 737, no. 7, pp. 214-221, 2020.

[5] J. B. Christensen, C. Jensen, Z. Gron, D. L. Filip and T. H. Christensen, "Characterization of the Dissolved Organic Carbon in Landfill Leachate-Polluted Groundwater," *Water Res,* vol. 32, no. 1, pp. 125-135, 1998.

[6] T. H. Christensen, P. Kjeldsen, H.J. Albrechtsen, G. Heron, P. H. Nielsen, P. L. Bjerg and P. E. Holm, "Attenuation of Landfill Leachate Pollutants in Aquifers," *Critical Reviews in Environmental Science and Technology,* vo. 24, no. 2, pp.119–202, 2020.

[7] T. H. Christensen, P. Kjeldsen, P. L. Bjerg, D. L. Jensen, B. J. Christensen, A. Baun, H. Albrechtsen and G. Heron, "Biogeochemistry of Landfill Leachate Plumes," *Applied Geochemistry*, vol. 16, no. 7-8, pp. 659–718, 2001.

[8] P. Kjeldsen, M. A. Barlaz, A. P. Rooker, A. Baun, A. Ledin and T. Christensen, "Present and Long-Term Composition of MSW Landfill Leachate: A review," *Critical Reviews in Environmental Science and Technology*, vol. 32, no. 4, pp. 297–336, 2002.

[9] E. Durmusoglu and C. Yilmaz, "Evaluation and Temporal Variation of Raw and Pre-treated Leachate Quality from an Active Solid Waste Landfill," *Water, Air, and Soil Pollution*, vol. 171, no. 1, pp. 359–382, 2006.

[10] C. B. Oman and C. Junestedt, "Chemical Characterization of Landfill Leachates—400 Parameters and Compounds," *Waste Management*, vol. 28, no. 10, pp. 1876–1891, 2008.

[11] J. Saarela, "Investigations of Surface Parts of Three Closed Landfills and Factors Affecting them," *Environ Monit Assess*, vol. 84, no. 1-2, pp. 183–192, 2003.

[12] K. Amano, E. Danso-Boateng, E. Adom, D. Nkansah, E. Amoamah and E. Appiah-Danquah, "Effect of Waste Landfill Site on Surface and Ground Water Drinking Quality," *Water and Environment Journal,* vol. 35, no. 2, pp. 715–729, 2021.

[13] P. Kjeldsen, P. Bjerg, K. Rugge, J. K. Pedersen, B. Skov, A. Foverskov, S. Wurtz and T. H. Christensen, "Assessing the Variability in Leachate Migration from an old Municipal Landfill, in: R. Cossu, H. T. Christensen and R. Stegmann (eds) Proceedings Sardinia 93," *Fourth International Landfill Symposium*. Sardinia, Italy, vol. 21, no.2 pp. 1519–1531, 2017.

[14] F. Parvin and M. Tareq, "Impact of Landfill Leachate Contamination on Surface and Groundwater of Bangladesh: A systematic Review and Possible Public Health Risks Assessment," *Applied Water Science*, vol. 11, no. 100, pp. 1-17, 2021.

[15] A. K. Gorai and S. Kumar, "Spatial Distribution Analysis of Groundwater Quality Index Using GIS: A Case Study of Ranchi Municipal Corporation Area," *Geoinformatics Geostatist*, vol. 1, no. 2, pp.1–11, 2013.

[16] M. H. Davijani, A. N. Anvar and M. E. Banihabib, "Locating Water Desalination Facilities for Municipal Drinking Water Based on Qualitative and Quantitative Characteristics of Groundwater in Iran's Desert Regions," *Water Resour Manag,* vol. 28, no. 10, pp. 3341–3353, 2014.

[17] S.S. Panhalkar and A.P. Jarag, "Assessment of Spatial Interpolation Techniques for River Bathymetry Generation of Panchganga River Basin Using Geoinformatic Techniques," *Asian J Geoinformatics*, vol. 15, no.3, pp. 9–15, 2016.

[18] D. Kulikowska, M. Zielińska and K. Konopka, "Treatment of Stabilized Landfill Leachate in an Integrated Adsorption– Fine-Ultrafiltration System," I*nternational Journal of Environmental Science and Technology,* vol. 16, no. 1, pp. 423–430, 2019.

[19] Canadian Council of Ministers of the Environment (CCME), "Canadian Water Quality Guidelines for the Protection of Aquatic Life," *CCME Water Quality Index 1.0. User's Manual. Winnipeg: CCME,* 2001.

[20] APHA, "Standard Methods for the Examination of Water and Wastewater (21st ed.,). Washington," DC: *American Public Health Association,* 2005.

[21] A.A. Khan, R. Paterson and H. Khan, "Modification and Application of the Canadian Council of Ministers of the Environment Water Quality Index (CCME WQI) for the Communication of Drinking Water Quality Data in Newfoundland and Labrador," *Water Quality Research Journal,* vol. 39, no. 3, pp. 285-293, 2004.

[22] Canadian Council of Ministries of the Environment (CCME), "Scientific Criteria Document for the Devel- opment of the Canadian Water Quality Guidelines for the Protection of Aquatic Life, "2012.

[23] A.A. Khan, A. Tobin, R. Paterson, H. Khan and R. Warren, "Application of CCME Procedures for Deriving Site-specific Water Quality Guidelines for the CCME Water Quality Index," *Water Quality Research Journal,* vol. 40, no. 4, pp. 448-456, 2005.

[24] M. G. Munna, M. Chowdhury, A.A. Ahmed, S. Chowdhury and M. M. Alom, "A Canadian Water Quality Guideline-Water Quality Index (CCME-WQI) Based Assessment Study of Water Quality in Surma river," *Journal of Civil Engineering and Construction Technology,* vol. 4, no. 3, 81-89, 2013.

[25] A. M. Rabee, B. M. Abdul-Kareem and A. S. Al-Dhamin, "Seasonal Variations of Some Ecological Parameters in Tigris River Water at Baghdad Region, Iraq," *Journal of Water Resource and Protection,* vol. 3, no. 4, pp. 262-267, 2011.

[26] M. Loizidou and E. Kapetanios, "Effect of Leachate from Landfills on Underground Water Quality," *Sci. Total Environ,* vol. 128, no. 1, pp. 69–81, 2021.

[27] World Health Organization (WHO), "Guidelines for drinking-water quality," *3 rd Ed*. vol.1. Geneva, 2004.

[28] S. S. Kuppusamy, P. Muthusamy, B. Murugesan and A. Murugesan, "Assessment of Ground Water Contamination in Soil Due to Leachate Migration from an Open Dumping Site of Dharapuram Municipality, Tamilnadu, India," *Advances in Applied Science Research,* vol. 6, no. 12, pp. 53-58, 2020.

[29] F.T. Wakida and D.N. Lerner, "Non-Agricultural Sources of Groundwater Nitrate: A Review and Case Study," *Water Research,* vol. 39, no. 1, pp. 3-16, 2005.

[30] D. Majumdar and N. Gupta, "Nitrate Pollution of Groundwater and Associated Human Health Disorders," *Indian Journal of Environmental Health,* vol. 42, no.1, pp. 28-39, 2000.

[31] C. K. Jain, A. Bandyopadhyay and A. Bhadra, "Assessment of Ground Water Quality for Drinking Purpose, District Nainital, Uttarakhand, India," *Environmental Monitoring and Assessment*, vol. 166, no. 1, pp. 663-676, 2010.

[32] C. Sadashivaiah, C. R. Ramakrishnaiah and G. Ranganna, "Hydrochemical Analysis and Evaluation of Groundwater Quality in Tumkur Taluk, Karnataka State, India," *International Journal of Environmental Research and Public Health*, vol. 5, no. 3, pp. 158-164, 2008.

[33] M. C. Z. Moturi, M. Rawat and V. Subramanian, "Distribution and Fractionation of Heavy Metals in Solid Waste from Selected Sites in the Industrial Belt of Delhi, India," Env*iron. Monit. Assess*, vol. 95, no. 1, pp. 183-199, 2021.

[34] S. Mor, K. Ravindra, A. R. Vischher, P. Dahiya and A. Chandra, "Municipal Solid Waste Characterization and Its Assessment for Potential Methane Generation at Gazipur Landfill Site, Delhi: A case study," *Bioresource Technology*, Communicated, 2005.

[35] T. H. Christensen and P. Kjeldsen, "Basic Biochemical Processes in Landfills. In T. H. Christensen, R. Cossu, & R. Stegmann (Eds.), Sanitary landfilling: Process," *Technology and Environmental Impact*, vol. 1, no. 1, pp. 29–49, 2019.

[36] A.K. Shanker, C. Cervantes, H. Loza-Tavera and S. Avudainayagamdet, "Chromium Toxicity in Plants," *Environment International*, vol. 31, no. 5, pp. 739–753, 2005.

[37] BSI. "Indian Standard for Drinking Water Specification," IS: 10500 1991 and Amendment, *Bureau of Indian Standards*, New Delhi, 2017.

[38] WHO. "International Drinking Water Supply and Sanitation Decade Review of National Baseline Data," *WHO Offset Publication*, no. 85, World Health Organization, Geneva, 1997.

[39] World Health Organization (WHO), "Guidelines for Drinking–Water Quality," 3rd Edition. Recommendations, Geneva Switzerland, pp. 515-517, 2018.