PROSPECTIVE ON LANDFILLS IMPACT ON SOIL CHARACTERISTIC AND GROUNDWATER QUALITY – CASE STUDY, RABIGH CITY IN WESTERN REGION OF SAUDI ARABIA

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Abstract. Landfills are used in Saudi Arabia to dispose industrial and domestic wastes. The absence of effective management leads to pollution of the groundwater sources. This research focuses on the impact of landfills on soil and groundwater pollutions in Rabigh city in Saudi Arabia. The analysis involved 14 groundwater and 17 soil samples. The permissible limits were based on Saudi General Authority for Meteorology and Environmental Protection (GAMEP) while the Canadian Council of Ministers of the Environment (CCME) standards for the soil. The cations exceeding the standard were Na+, Ca2+, and Mg2 + while the anions were SO42-, Cl-, HCO3-, and NO3- respectively. Total dissolve solids (TDS) distribution indicated high salinity near landfills. Two hydrogeochemical type facies were identified NaCl and CaCl2. The highest concentrations of heavy metals, As, Cu, Co, Cr, Mn, Al, and Fe, were estimated as 0.059, 0.261, 0.640, 2.96, 3.30, 4.75, and 1170 mg/l respectively. They were below the permissible limits. The pH of the soil ranged from 7 to 9.6 suggesting strongly alkaline soil, due to the occurrence of Sodium Carbonate or Sodium Bicarbonate. The distribution of soil pH indicates the highest value is far upstream landfills. The Chromium and Nickel in the soil exceeds the permitted limit.
Keywords: *environmental hazards, geo-statistical analysis, heavy metals, leachates, sources pollutions, landfill sites*

Introduction

Solid and liquid municipal, agricultural and industrial wastes are known to be disposed of in landfills in remote areas, nearby areas where it is generated or in marine environment. Management of landfills required the implementation of certain design criteria in order to control soil and water pollution, especially with toxic elements that may pose risk to human health and increased environmental degradation (Idris et al., 2004; Sepúlveda et al., 2010). Landfill selection and design is influenced by the volume and characteristic of waste, land availability, cost and environmental risks. The arid environment with its harsh climate also calls for additional requirements to monitor the decomposition of waste and leakage of toxic residues to the surrounding soil and groundwater sources. Regardless of the waste treatment method applied, there are always residuals needed to be disposed. Disposing of waste in open dumps without proper design criteria has high environmental rehabilitation costs in urban areas (Elhag and Bahrawi, 2016). The leakage of leachate from open pit landfills can contaminate the surrounding soil and any shallow groundwater source especially if water is used for drinking purposes (Borggaard and Gimsing, 2008; Sharma et al., 2019). Contaminated groundwater with the surface water interaction bodies, like rivers and lakes, may make sources unfit for use irrigation, fishing, wildlife and recreational (Bakyayita et al., 2019; Mor et al., 2006). Environmental risks may be experienced from a variety of landfills configuration and types and require the implementation of certain site selection and design criteria and continuous monitoring measures during the operational life of the landfill (Allen, 2001; Laner et al., 2012; Madon et al., 2019).

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Investing in a thorough landfill location analysis is reducing the further costs of providing artificial and expensive ground protection measures. Furthermore, providing a suitable location with good natural ground protection reduces the environmental risks in case of accidents or failures (Elhag and Bahrawi, 2017).

Accelerated global economic development has contributed to the generation of large volumes of waste as well as improved design and monitoring criteria to reduce pollution from landfills. especially in developing countries as they strive towards greater and faster economic development with less priority given to waste management in their development agenda (Al-Amri et al., 2022; Rabeea et al., 2022).

Increased soil and water pollution level in a different part of the world from landfill with concern for human health impact gave emphases on the need for improved site selection criteria, improved design configuration, the use of effective lining material, and continuous monitoring however there still a large number of exiting or planned one that lack proper pollution protection measures (Elhag, 2016; Mor et al., 2006). Waste quantities generated in Europe and around the globe have a continuous upward trend usually proportional to living standards. The main reason is usually the high cost of establishing a waste management system. Another way of thinking is that production, waste generation, and waste management are one whole. The production does not result in welfare if the inevitably produced waste is dumped near the production resources, settlements and poses an everyday risk (Allam et al., 2020; Elhag and Takavakoglou, 2011).

The impacts of landfills on the groundwater and soil quality have been previously assessed and concluded that the landfill’s leachate was the main source of the contamination (Brand et al., 2018; Ikem et al., 2002; Patrick et al., 2017). The area contains many landfills specialized in treating industrial and hazardous wastes, and disposing of carbon ashes, in addition to disposing of municipal waste (Akinbile, 2012; Han et al., 2016; Milosevic et al., 2012; Negi et al., 2020; Regadío et al., 2012; Smahi et al., 2013; Talalaj, 2014).

Saudi Arabia landfills construction practices to store municipal waste and certain industrial wastes has been with mix successful to control their environmental pollution. During the early 1970 economic development activities and practices have focused on the disposal of wastes including medical and industrial near major urban centers by any means without giving due consideration to the implementation of management practices to eliminate or reduce the impact of their pollution on soil, water and human health risks (Elhag and Bahrawi, 2017; Farran et al., 2021).

The landfill is complex in Al-Jahfa southeast of Rabigh (15 kilometers east of the Red Sea) that represents a source of danger, and the guarantor of the emission of toxic gases and unpleasant odors, in addition to the emission of dioxins, which may be transported by the northeast winds to the nearby areas, and the matter becomes more dangerous when the eastern winds blow, in addition to changing their directions during rainy seasons, to become southerly (Al Rashed, 2018; Hanjra et al., 2012). This accelerates the spread of pollutants, in addition to the pollution of the environmental media (water, air, soil), unless the waste is dealt with, treated, and disposed of properly, and conforming to environmental standards, and standard requirements (Patrick et al., 2017).

The influences of landfill leachates on groundwater quality water have drawn a lot of consideration since it is an overwhelming environmental consequence.

The recent establishment of major industrial zones or city in conjunction with new industrial policy to institutionalize strategic industries have stressed on the need to accommodate wastes in separate landfills.

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Rabigh City is characterized by intensive industrial activities and rapidly growing in terms of population and infrastructure. This rapid development results in a rising in waste generation. Due to the increased public concern on the impact of environmental pollution and future urban and industrial development, many studies were reported at Rabigh governorate (Bahrawi and Elhag, 2016).

Al-Hasawi and Hussein (2012) evaluated the physical, chemical, and bacterial contaminations of groundwater sources in a Rabigh region. Chloride element Cl was the most abundant anion followed by HCO_3^-, SO_4^{2-}, and NO_3^-, with their concentration exceeding the safe drinking limits according to Rout and Sharma (Rout and Sharma, 2011) standards. A recent study at Rabigh region indicated that groundwater is not suitable for use irrigation in indicated the water quality has been influenced by adjacent sanitary landfills and unlicensed dumpsites.

Given the importance of Rabigh as an emerging important industrial city with the potential to contribute toward enhancing economic development in line with Saudi Arabia 2030 strategy vision this study is hoped to shed light on the impact of an existing landfill pollution on the environment. The methodology involves laboratory physical and chemical analyses of 32 collected samples and the application of geostatistical techniques to explain their special distribution and variation on the soil and groundwater quality at a location southeast of Rabigh city.

Materials and methods

Study area description

Rabigh City is located on the Red Sea's coast at 22° 47′54″ N latitude and 39° 02′05″ E longitude in the Western region of Saudi Arabia. Rabigh region with its population of 104,621 covers an area of (Al Ahmadi et al., 2019) as shown in *Figure 1*. The climate at the region is characterized by a relative humidity ranging from 46.5% to 60% with an annual average of 52.3% and monthly average temperatures range from 22.9°C to 34.9°C. Monthly estimates of rainfall between 2013 and 2017 indicate that rainfall ranges from zero to 10.25 mm with a total annual rainfall of 26.4 mm (Al Ahmadi et al., 2019).

The region designated as an industrial zone contains many urban manufacturing activities (e.g., Aramco Company Refinery, Aramco Residential Area, Electric Power Plant, Water Supply Plant, and Arab Cement Factory) and agricultural activities. It became recently more important by contributing to the economic development of the King Abdullah Economic City located about 40 km from Rabigh city. Seven landfills are situated in Al-Juhfa in the south-eastern city of Rabigh about 16 km from Rabigh and 12 km from the Red Sea coast (*Fig. 1*). Existing landfills in Rabigh collect waste from households, fish and poultry farms, slaughterhouses, and small farms (Al Ahmadi et al., 2019).

Data collection

Groundwater samples were collected from the available sources by manual method from 14 well locations. The samples were collected with clean standard plastic and glass bottles to measure the physical and chemical water characteristics. The coordinates of the samples are presented in *Table 1* and the water samples are collected from an average depth of 7 m below the ground. The soil samples were collected by the Australian company working in Dammam region in Saudi Arabia.

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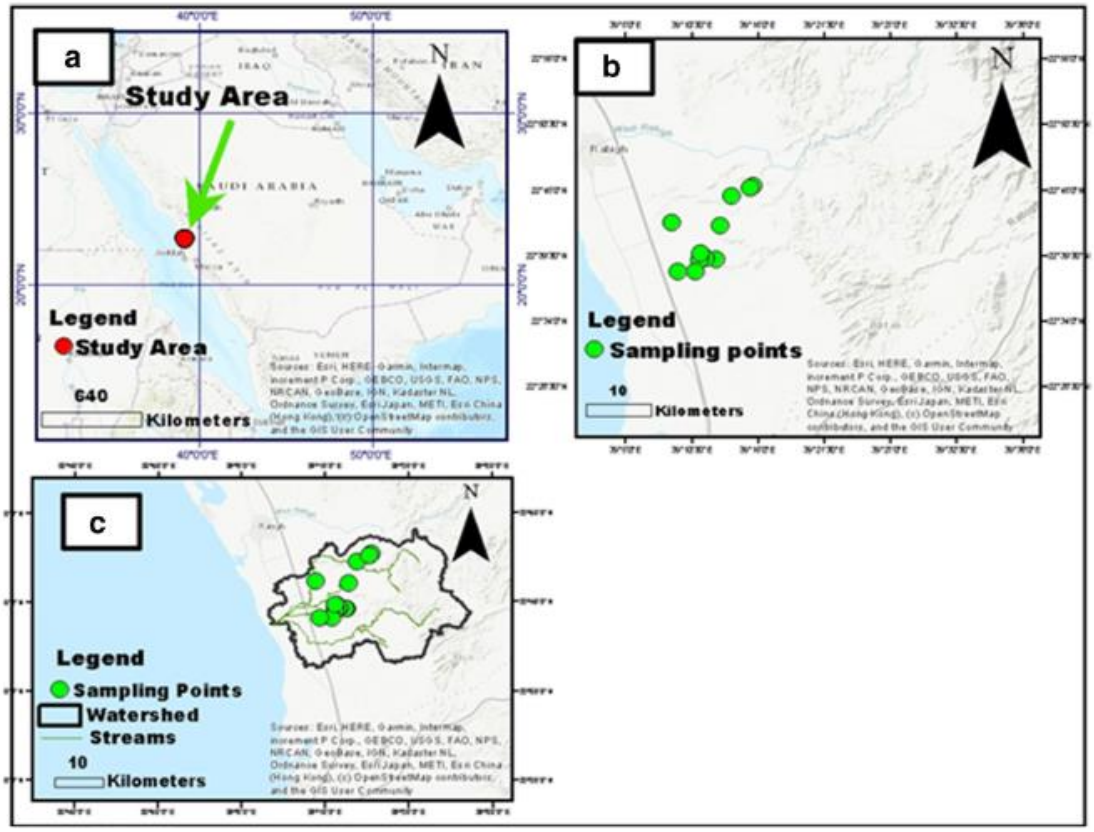

Figure 1. *Location map of the study area including the sampling sites*

The soil samples were collected from several places near the landfill, the wadi streams, in the sand dunes, sewage landfill, in the salty marches and coastal area. The locations of the samples are illustrated in *Tables 2* and 3. The samples were collected from the soil surface 15 cm under the surface soil. The weight of the samples were about 500 grams. 17 soil samples were collected. Some of them are near the water wells and some others are far from the water wells. The sample were collected by the same Australian company working in Dammam region in Saudi Arabia.

Most of the natural soil attributes vary in time and space, generating continuous surface properties different than their profile characteristics. The soil at the surface contains an infinite number of points that are difficult to evaluate by the typical sampling process as well as time-consuming and expensive. Usually to accumulate as much as possible soil information to rely on storing, manipulating, and visualizing processes. In this study seventeen soil samples were collected, to evaluate soil contamination while fourteen groundwater samples suitability for different uses. The location of the collected samples within the vicinity of the landfill is shown in *Figure 1*. The groundwater samples collected during the period of September and October 2018 and later evaluated were: Electrical conductivity (EC), Bicarbonate as $CaCO_3$, Total Dissolved Solids (TDS), Sodium (Na), Calcium (Ca), Magnesium (Mg), Potassium (K), Chloride (Cl) and Sulphate (SO_4) and Chemical Oxygen Demand (COD). The soil sampling heavy metal elements were: Arsenic (As), Aluminium (Al), Cadmium (Cd), Cobalt (Co), Chromium (Cr), Copper (Cu), Nickle (Ni), Selenium (Se), Vanadium (V), and Zinc (Zn).

Random stratified sampling was applied to reduce the impact of the sampling time. Accordingly, the sampling process was achieved by dividing the terrain into strata with random sampling according to Beretta (Beretta et al., 2014) by weighing 50 grams of soil nurtured for 8 h in sodium polyphosphate solution and submerge in a 1-L solution using the volumetric cylinder. The mixture was watered down to 1 litter with distilled water. The sample density was measured by a Bouyoucos densitometer after 2 h and 40 s from the last rattling.

Data analysis

The laboratory analyses involved the detection of heavy metals as they represent toxic elements that can impact human health and degrade the environment. The detection procedure was based on aspirated liquid sampling and mixed as an aerosol with acetylene and air (combustible gasses). The designated mixtures were stirred into burning flames of temperatures extending from 2100 to 2800°C. The heavy metals detection was achieved by applying methods of Lindsay and Norvell (Lindsay and Norvell, 1978) and the United States Environmental Protection Agency (EPA) improved by Rockwell et al. (2005) using an Atomic Absorption Spectrometer (Perkin Elmer, 2100).

Geo-statistical analysis

The data was analyzed by geostatistics technique, in ARCGIS software, in order to examine the physical main soil and water characterizes variation in space and time in conjunction with Geographical Information System (GIS) extrapolation space variation. The technique provides quantifiable explanations of the spatial disparity of soils and enhances estimation accuracies of the soil characterization for data interpolation according to the known spatial distribution equation (Weibel, 1996):

$$\gamma_{(k)} = \frac{1}{2\,n(k)} \sum_{i=1}^{n(k)} [Z(X_i) - Z(X_{i+k})]^2 \qquad \text{(Eq.1)}$$

where: $n(k)$ - number of pairs of observation; $Z(x_i)$ - soil property measured in point X_i, and in point X_{i+k}.

The kriging method assumes spatial correlation which maintains that the distance and direction between sample points were the main factors dominating the projected values at unidentified points. Interpolation equation according to Stoer and Bulirsch (2013) can provide further detail on the sample characteristics:

$$Z\,(X_o) = \sum_{i=1}^{n} \lambda_i \, Z(x_i) \qquad \text{(Eq.2)}$$

where: $Z\ (x_o)$ - the interpolated value of variable Z at location X_o, $Z(x_i)$ - values calculated at location x_i, λ_i; - weighed coefficients determined based on the semi-variogram.

The Kriging reveals any kind of trend in relation to global or random short-range variation that the data might include. Trend Analysis Tool through GIS technique provides a three-dimensional perspective of the data variance. This was accomplished by predicting the sample locations on an x, and y planarly as the value of the element of each sample is given in the z dimension. Furthermore, the values of the elements are

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expected on the x, z, and y, z planes as scatter plots. A global trend occurs if a curve is a polynomial line that can fit across the data.

Since the weights were based on the distance and direction of the sampled data, the spatial arrangement must be in some way quantified. This quantification was done through the sample-fitted model (Stoer and Bulirsch, 2013). The trend and random error equation were conducted as follows:

$$Z(S) = \mu(S) + \varepsilon(S) \quad \text{(Eq.3)}$$

The symbol "S" represents the predicted location. *Z(S)* is the variable under forecasting. μ*(S)* is the deterministic trend. ε*(S)* is the spatially-autocorrelated random error.

Results and discussion

Groundwater analysis

The chemical features of the groundwater are shown in *Table 1*. The PH value ranged from 4.58 to 8.08 with a mean pH of 6.98 indicating a slight acidity. The TDS values indicated a wide range of high salinity from 1490 to 80300 mg/l with 64% of the values as saline waters (Bachu and Adams, 2003; Khuhawar et al., 2019). The spatial distributions of TDS show high concentrations in the central area close to locations of seven landfills in the area (*Fig. 2*), indicating leakage of leachate to improperly lined (Ebraheem et al., 1997; Vahabian et al., 2019).

Table 1. *Physio-chemical analysis of major elements of groundwater samples (mg/L) in the study area*

	LatN	LongE	EC	pH	TDS	COD	DO	Ca^{++}	Mg^{++}	Na^{++}	K^{++}	SO_4^{-2}	Cl^-	HCO_3	NO_3
1	22.63733	39.18053	**73100**	6.88	**48700**	80	8.6	3790	1710	11500	299	1940	26900	134	0.27
2	22.65339	39.20875	96500	6.95	67100	76	9	2890	964	17800	369	2770	37200	62	22.8
3	22.65333	39.20833	84200	7.02	47400	80	9.1	3650	1710	14200	214	2310	32100	71	14.9
4	22.66194	39.18667	99900	6.98	70500	84	9.2	5670	1870	16200	216	1760	38700	68	18.5
5	22.66214	39.18683	95500	7.13	67400	84	9.3	4820	1620	15800	178	2080	37000	48	7.16
6	22.65633	39.19239	116000	6.81	80300	76	8.8	6420	2170	19000	253	1940	44900	38	ND
7	22.66094	39.18908	92100	6.48	64100	81	6.6	4920	1680	14900	242	1620	35700	99	0.02
8	22.65558	39.19419	3330	7.97	2170	10	9.1	299	39	308	15	929	483	93	1.51
9	22.6525	39.18586	86500	4.58	60200	77	8.7	5380	1870	12400	192	1530	33800	0.8	ND
10	22.75678	39.26008	2310	7.58	1490	27	8.5	85	47	342	14	282	542	206	2.02
11	22.70158	39.21419	15200	7.12	9960	52	8.5	873	213	2000	15	320	3280	192	4.89
12	22.74261	39.23025	16300	7.03	10800	78	8.4	461	114	3090	75	886	5320	108	0.03
13	22.75311	39.25511	9910	7.15	6560	58	9.1	653	138	1360	42	258	3820	62	0.34
14	22.63644	39.15511	2650	8.08	1740	46	9.2	126	116	255	12	329	663	148	11.7

Boldface means above the limit

The high salinity concertation may be attributed to the characteristics of arid regions with high evaporation rates, low recharge rat, long travel paths, high residence periods, and high natural mineralization of soil and groundwater sources (Gao et al., 2014; Xia et al., 2016).

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The cationic concentration of Ca_2^+, Mg_2^+, Na^+, and K^+ elements ranged from 85 to 6420, 39 to 2170, 255 to 19000, and 12 to 369 mg/l, with a mean of 2859.8, 1018.6, 9225.4, and 152.6 mg/l, respectively. The foremost ionic chemical observations revealed that Na and Ca_2^+ were the most predominant cationic elements followed by Mg_2^+.

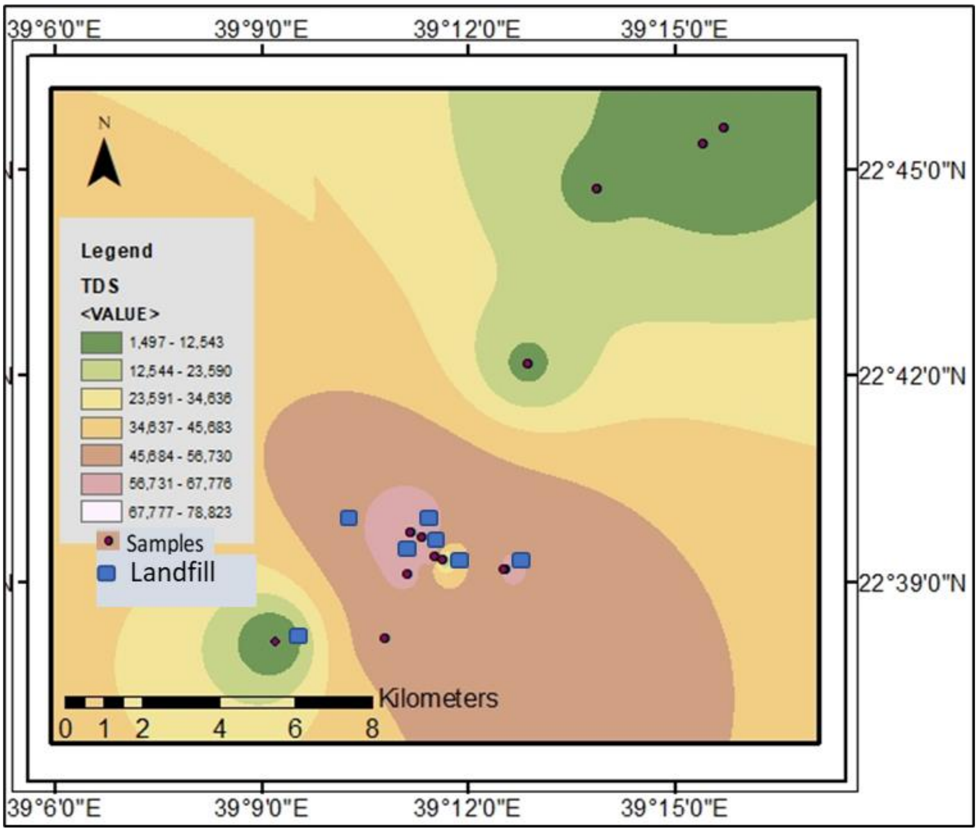

Figure 2. *The spatial distribution of the groundwater salinity*

The dissolved anions of $SO_4{}^{2-}$ Cl^-, HCO_3^- and NO_3^- ions ranged from 258 to 2770, 483 to 44900, 0.8 to 206, and 0.02 to 22.8 mg/l with a mean of 1353.9, 21457.7, 95, and 7 mg/l respectively. The most important anionic elements were the $SO_4{}^{2-}$ Cl^-, $HCO_3^{-,}$ and NO_3^-, with the sulphate and chloride being the most principal anions followed by the bicarbonate and the nitrate compounds, respectively.

Chemical Oxygen Demand (COD) is a tool to measure oxygen corresponding to the organic matter content of the water prone to oxidation throughout robust chemical oxidation processes and hence is an index to represent organic pollution (Chaplin, 2014; Yang et al., 2019). The COD in groundwater varied from 10 to 84 mg/L, which reflects the occurrence of organic water pollutants shown in *Table 1* indicating groundwater contamination**.**

Further analyses of the cations and anions were made applying the piper's Trilinear diagram (*Fig. 3*), using the AquaChem software indicating that most of the cations were sodium and calcium bases, while the anions were mainly chloride and sulphate association (Hu and Boyer, 2018; Wilkes, 2002) Moreover, two hydrogeochemical feces were identified as, NaCl and CaCl types.

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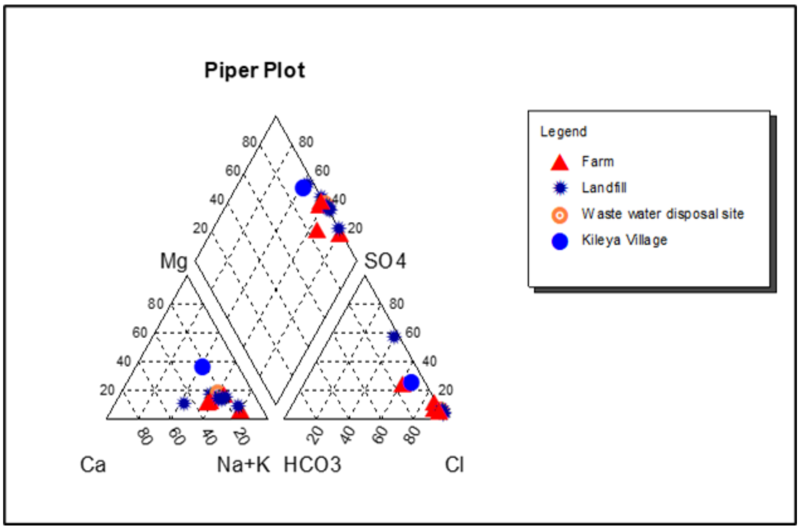

Figure 3. *The Piper's trilinear diagram*

The Gibbs diagram (Gibbs and Patten, 1970), was applied to evaluate the chemistry of water source in the study area in relation to their origin from rain and rock association ruck types as shown in *Figure 4*. The Gibbs diagram configuration indicates the groundwater chemical characteristics were influenced by the evaporation process. This could be explained due to the chemical weathering of the rocks that leads to higher salinity caused by higher rates of evaporation (Gaillardet et al., 1999; Jia et al., 2017).

Table 2 shows the heavy metal concentrations of groundwater samples (mg/L) in the study area. Most of the heavy metals are found in Samples 1 and 7, however, most samples do not detect heavy metals. Al appeared in 8 out of 13 samples and Zinc appeared in 11 out of 14 samples. Other elements appeared in some samples and do not appear in other samples. Sample 9 shows only Al. Sample 13 shows only Cu. Al and Zn appeared in most of the samples (1, 2, 3, 4, 6, 7, 8, 10, 12, and 14).

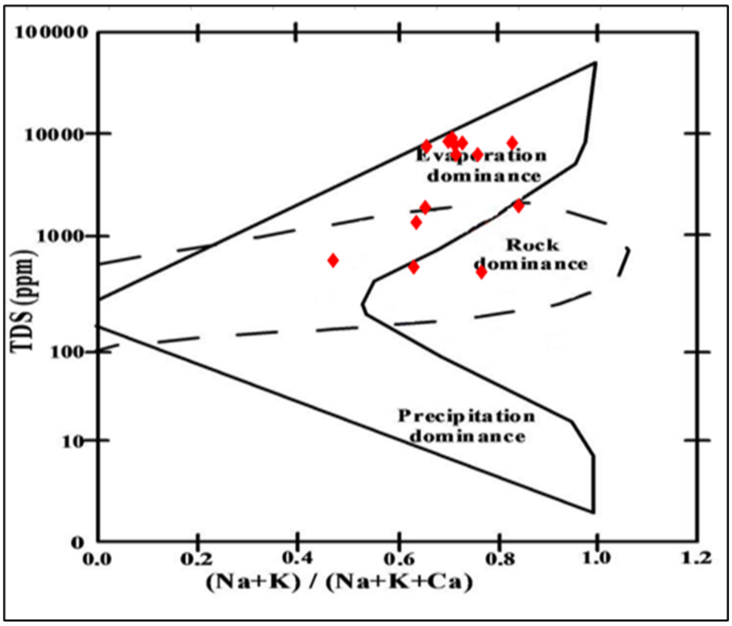

Figure 4. *Gibbs diagram of groundwater samples in the study area*

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Table 2. *Heavy metal concentrations of groundwater samples (mg/L) in the study area*

Sample No.	LatN	LongE	Al	As	Cd	Co	Cu	Cr	Ni	Se	V	Zn
1	22.63733	39.18053	681	0.**059**	0.0014	**0.64**	**1.16**	**2.96**	**3.73**	ND	3	3.17
2	22.65339	39.20875	1.06	ND	ND	ND	ND	ND	ND	ND	ND	0.171
3	22.65333	39.20833	1.74	ND	ND	ND	ND	ND	ND	ND	ND	0.1
4	22.66194	39.18667	0.55	ND	ND	ND	ND	ND	ND	ND	ND	8.62
5	22.66214	39.18683	ND	ND	ND	ND	0.002	ND	ND	ND	ND	3.44
6	22.65633	39.19239	4.75	ND	ND	ND	0.021	0.026	ND	ND	ND	3.44
7	22.66094	39.18908	235	0.032	ND	0.16	0.261	0.792	0.734	ND	0.65	0.555
8	22.65558	39.19419	0.45	ND	ND	ND	ND	ND	0.002	ND	0.01	0.052
9	22.6525	39.18586	0.45	ND	ND	ND	ND	ND	ND	ND	ND	ND
10	22.75678	39.26008	ND	ND	ND	ND	ND	ND	ND	ND	0.01	0.008
11	22.70158	39.21419	ND	ND	ND	ND	ND	ND	ND	0.03	0.02	ND
12	22.74261	39.23025	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.044
13	22.75311	39.25511	ND	ND	ND	ND	0.003	ND	ND	ND	ND	ND
14	22.63644	39.15511	ND	ND	ND	ND	ND	0.003	0.002	ND	0.01	0.047

ND: not detectable, boldface means above the limit

Soil analysis

The chemical characteristics of 17 soil samples is shown in *Table 3*. The quality of soil attribute configuration depends on sampling density. A short sampling spacing may result in the detailed information for the study area, according to the objectives of the study. The focus of the analyses was to evaluate the samples soil contents that may exceed the maximum allowable limits of heavy metal toxicity of the standards Canadian Environmental Protection Act (CEPA) (2007).

Table 3. *Heavy metals concentrations of soil samples (mg/kg) of the study area boldface means above the limit)*

Sample No.	LatN	LongE	pH	As	Cr	Cu	Ni	Zn	Mn	Al	Fe
1	22.63086	39.11990	7	5.3	47.8	33.5	61.1	54.5	475	14700	28400
2	22.822491	38.98047	7.9	ND	38.5	28.5	39.9	45.6	421	11900	27000
3	22.81799	39.07756	9.6	5.8	41.3	34.1	49.2	56.5	504	13900	28800
4	22.75983	39.03213	7.9	5.1	33.8	20.8	31.8	34.8	462	11100	22100
5	22.74416	39.15110	8.8	ND	29.5	20.8	30.6	35.5	349	8780	22700
6	22.74324	39.24870	9.5	ND	38	28	49.9	39.9	559	10800	25700
7	23.04100	38.95334	9.5	ND	59.9	27.9	90.9	38.7	416	9950	25300
8	22.86828	39.21389	8.8	ND	27.6	23.6	28.9	48.8	570	11000	26800
9	22.67028	39.14052	8.6	5.3	37.2	24.8	46.2	40.8	340	10000	24800
10	22.51642	39.26913	9.6	ND	30.1	16.4	21.6	41.2	295	8710	23600
11	22.65339	39.20874	8.2	5.4	58.5	36	81.5	36.1	307	10600	19200
12	22.66214	39.18682	8.2	ND	43.4	22	57.4	79.4	289	10500	22400
13	22.65952	39.19016	8.5	ND	27.9	15.1	29.2	45.6	236	7280	17700
14	22.65675	39.19254	8.3	ND	29.5	18.5	32.8	34	333	8740	18900
15	22.65346	39.19043	8.3	6.8	54.1	24.8	53.9	38.8	504	14200	24200
16	22.63730	39.18047	9.2	7.4	45.6	32.5	50	50.8	499	12800	28400
17	22.53838	39.34574	9.2	ND	68.6	25.8	81.4	36	364	9400	23800
Threshold value*			6 to 8	12	64	63	50	200	-	-	-
Min			**7**	< 5	**27.6**	**15.1**	**21.6**	**34**	**236**	**7280**	**17700**
Max			**9.6**	**7.4**	**68.6**	**36**	**90.9**	**79.4**	**570**	**14700**	**28800**
Average			**8.7**	**5.4**	**41.8**	**25.5**	**49.2**	**44.5**	**407.2**	**10844.7**	**24105.9**

*Maximum permissible concentrations as defined by CCME 1999 - ND: not detectable

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The heavy metals concentrations ranges for Cr 27.6-to 68.6 mg/kg, Cu from 15.1 to 36 mg/kg, Ni from 21.6 to 90.9 mg/kg, Zn from 34 to 79.4 mg/kg and Mn from 236 to 70 mg/kg. The uppermost concentration of, Cu, Zn, and Mn is below the permitted threshold limit (*Table 3*) while the Chromium and Nickel elements exceed the permitted threshold limit.

Since Ni and Cr is being a very toxic elements with concentrations exceeding the upper limit further elaboration of their special distributions in *Figures 5* and *6*, respectively. These figures show higher Ni and Cr concentrations in the southeastern part of the study area with a lower concentration in the northeastern part. The high concentration of both Ni and Cr elements indicated high soil contamination in the proximity of the landfills.

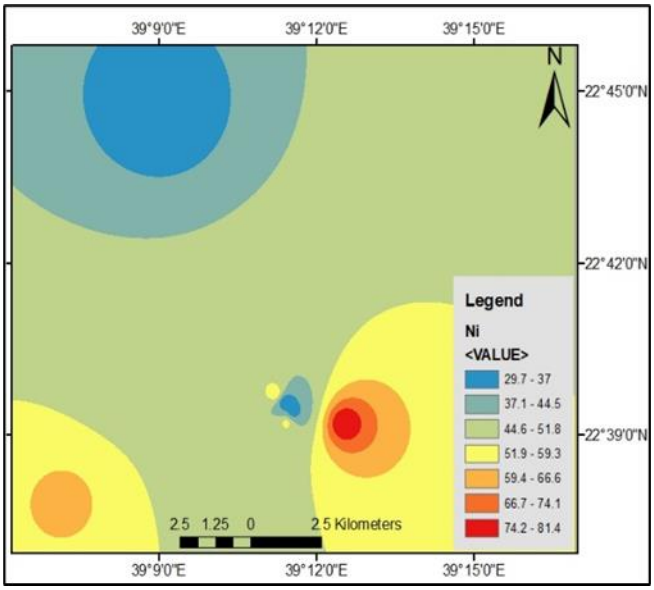

Figure 5. *The soil Ni (mg/kg) spatial distribution concentration in the study area*

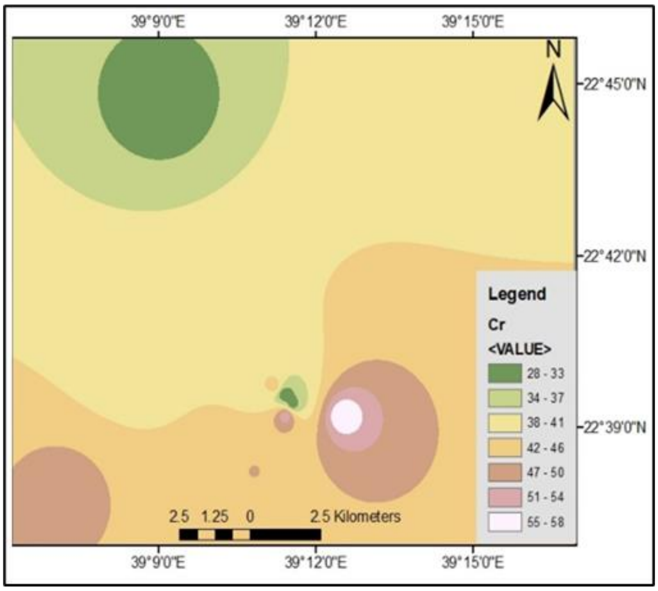

Figure 6. *The soil Cr concentration (mg/kg spatial distribution) in the study area*

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The analyses indicated the soil pH ranged from 7 to 9.6 with an average value of 8.7 indicating strong alkalinity. Such high alkalinity could be related to the occurrence of sodium carbonate (Na_2CO_3) or sodium bicarbonate ($NaHCO_3$) that be attributed to either natural weathering impact or water flow over the surface (Noulas et al., 2018; Razo et al., 2004). The spatial pH values distributions is shown in *Figure 7*, with their highest values observed in the North-East part of the study area located far away from the landfill sites. The landfill sites has not to be impacted on the soil pH.

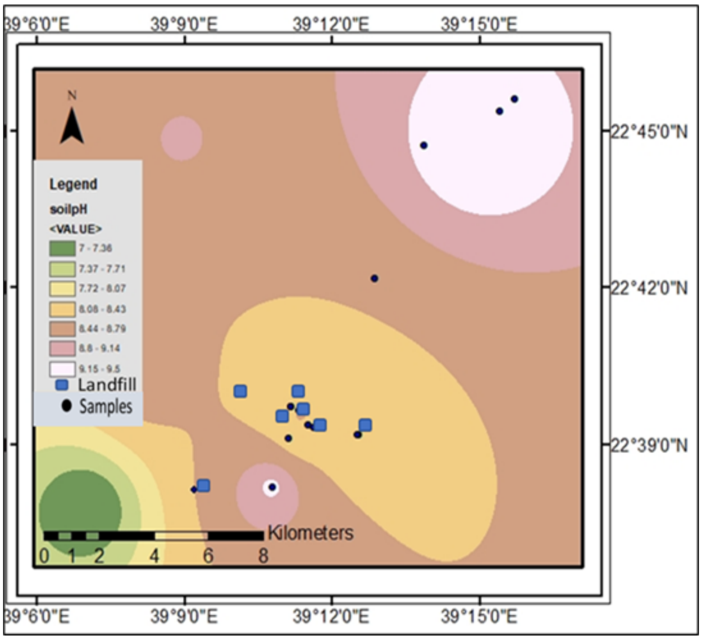

Figure 7. *The soil Ph spatial distribution in the study area*

Conclusions

The current study evaluated the impacts of landfill sites on the soil and the groundwater quality in the South-East of Rabigh city. The study focused on laboratory analyses of fourteen groundwater samples and seventeen soil samples with emphases on heavy metals given their toxicity impact on human being and the environment. Parameters values variation and distribution were explained through the application geostatic technician supported by GIS visualization parameters distributions. The groundwater heavy metals concentrations were assessed according to the General Meteorological and Environmental Protection Authority (GAMEP), standard allowable limits while for soil according to the Canadian Council of Ministers of the Environment (CCME) the standard permissible limits. The groundwater was contaminated with the most prevalent constituents high levels of TDS, Na^+, Ca^{2+}, Mg^{2+}, Cl^-, SO_4^{2-} with Na^+ and Ca^{2+} followed by Mg^{2+}. The TDS' spatial distribution shows that groundwater near the landfill is under a great impact on landfill sites. The foremost anions of SO_4^{2-}, Cl^-, HCO_3^-, and NO_3^- were found to be sulphate and chloride accompanied by bicarbonate and nitrate compounds. The Gibbs diagram indicates evaporation is the principal factor affecting groundwater chemistry. Hydrogeochemical type facies of NaCl and CaCl facies have been identified. The results showed that metals As, Cu, Zn, Zn, Mn, Al, and Fe are below the permitted limits. The soil pH ranged from 7 to 9.6 with an average value of 8.7 implying that the soils in nature were highly alkaline. The high soil

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alkalinity may be due to the occurrence of Sodium Carbonate (Na_2CO_3) or Sodium Bicarbonate ($NaHCO_3$) in the soil. The average concentration of chromium and Nickel elements in the soil exceeds the permissible threshold limit, while the maximum concentration of As, Cu, Zn, and Mn is below the permissible threshold. The concentration of all the parameters examined was higher in soil than in groundwater, which can be due to the high affinity between soil and element organic matter material. This contribution of this study lies in providing a practical technique through a laboratory chemical analysis of sample to be collected and the application of geostatistic techniques to evaluate pollution from existing landfills. The approach indicates that groundwater sources in neat landfills may poses high heavy metals contamination risk if water will be used for drinking and irrigation purposes. Landfills design must include an effective monitoring procedure. It is recommended to make a further analysis of the microbial water quality in the future.

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