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Environmental Impact of Landfill on Groundwater, South East of Riyadh, Saudi Arabia

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Abstract

The main objective of this work had been given to the environmental impact of landfill on groundwater. The groundwater in the study area had problems caused by the landfill and the high volumes of sewage water percolating into the groundwater. The existing soil stratigraphy at the landfill consisting of sandy sheet and fractured limestone lead to increasing leachate percolation into the groundwater. The groundwater resources are used mainly for crop irrigation in an agriculture dominated area. The chemical analysis of groundwater indicates that nitrate pollution can be a serious problem affecting groundwater due to the infiltration of leachate in landfill downward to groundwater and the use of nitrogen (N) fertilizers in agriculture. The high concentrations of NO3- and Zn especially in landfill site in groundwater, likely indicate that groundwater is being significantly affected by leachate percolation. The nitrate and Zinc concentrations in groundwater samples in landfill site reach 191 ppm and 1473 μ g/L respectively. The groundwater in the study area is exploited from fractured limestone aquifer belonging to several limestone formations and groundwater of the concerned aquifer exists under unconfined conditions. The groundwater flow direction is from the northwest to the southeast direction. The leachate produced by waste disposal sites contains large amounts of substances which are likely to contaminate groundwater. Chemical analyses were carried out on groundwater samples collected from the neighborhood of landfill yard and spread to southeast direction. The effects of dumping activity on groundwater appeared most clearly as high concentrations of total dissolved solids (TDS), electrical conductivity (EC), total hardness (TH), chloride, nitrates and sulphates. Groundwater samples from the wells situated close to the landfill were found to be more contaminated than that of the wells situated farther away.

Keywords: Environmental Impact, Landfill, Groundwater, Saudi Arabia

1. Introduction

Landfill has been identified as one of the major threats to groundwater resources. Leachate is composed of organic and inorganic compounds formed from decomposition of wastes. This leachate accumulates at the bottom of the landfill and percolates through the soil then to groundwater. Areas near landfills have a greater possibility of groundwater contamination because of the potential pollution source of leachate originating from the nearby site. Landfill is located at southeast of Riyadh city. Population increase, economic progress, expansion in urban areas, rapid development, and rising standards of living have all contributed to a sharp rise in solid waste generation in the Riyadh city. It is estimated that municipal waste generation rates in Riyadh city have increased from 4.47 million tons in 2000 to 7.3 million tons in 2009 and are rapidly growing in Riyadh City by a very high rate and exceeding nowadays 5 millions (Fig. 1). Accordingly, the different wastes increase by high rate in Riyadh City where the landfill is located in southeast of Riyadh City.

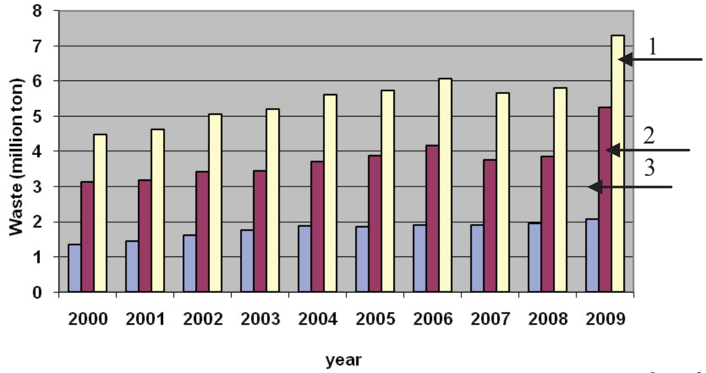


Fig. 1 Annual amounts of municipal solid waste (2000-2009), Riyadh city. 1, 2 and 3 represent commercial waste, other waste and household waste respectively.

The impact of landfill on the surface and groundwater has been investigated in a number of studies in recent years (Hussein et al., 2008).

Precipitation that infiltrates the solid wastes disposed on land mixes with the liquids already trapped in the crevices of the waste and leach compounds from solid waste. The leachate diffuses into the soil and changes the chemical characteristics of groundwater. The leachate migrates from an unsaturated zone (soil) to groundwater table and mixes with groundwater. It forms a plume that spreads in the direction of flowing groundwater and contaminates the groundwater.

The degree of contamination in the aquifers depends on the transport rate of contaminants and aquifer parameters (porosity and hydraulic conductivity).The presence of land filled of wastes manifest slow the decomposition, emanation of gases, and outflow of leachate. The salinity of this leachate attains about 43,000 ppm. Waste mass shows various chemical reactions and complex evolutions that occur under the influence of two factors, the rainfall and micro-organisms. The landfill is underlain by highly fractured limestone, where the leachate is infiltrated by large amounts to the groundwater. The present study aims to throw the light on the impact of landfill on the groundwater in southeast of Riyadh City. In an effort to study the extent of the groundwater contamination, 10-groundwater sampling sites were selected. Three groundwater samples were taken from the neighborhood of landfill and other samples from southeast of landfill site and field sampling was done in May, 2010.

2. Site specification

This landfill is located upstream of Wadi Hanifa. The study area lies in the southeast of Riyadh City and occupies an area of about 17 km2. It is located between longitudes 46° 50´ and 47° 15´E and latitudes 24° 20´ and 24° 36´ N (Fig. 2).

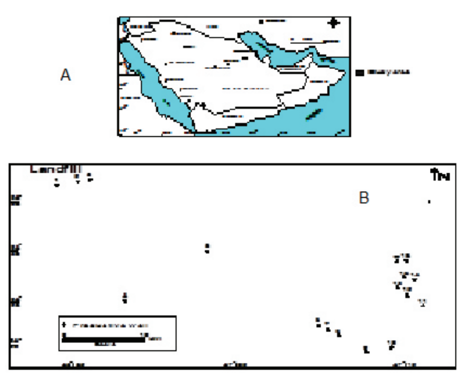


Fig. 2 a) Key map showing the location of the study area; b) Map showing the location of the productive wells in the study area.

The climatic regime of study area belongs to the arid type and characterized by extreme dry conditions associated with very hot summers and cold winters. The temperature ranges between 8o C and 43o The meteorological data from Riyadh station revealed that the average monthly rainfall for the period 1994-2003 varies from 2.9 mm in October to 33.1 mm in March. Since Riyadh city is located on the Najd plateau, away from any water body, the relative humidity is very low. The average relative humidity reached 10 % in summer and it attained 50 % in winter. The evaporation rates are very high in Riyadh throughout the year. The monthly maximum evaporation is 497 mm in summer and its minimum is 67 mm in winter. The earliest landfill was established in Riyadh in 1984 and closed in 2006. A new landfill was established over an area of about 1.5X106 m2.

Geology of Study Area

The geology of the studied area was investigated by several authors (Powers et al, 1966, Vaslet et al 1991 and Alwelaie, 1996). The study area is underlain by Phenerozoic sedimentary rocks forming a gentle homocline with an average dip of about one degree to northeast. These rocks are covered to a large extent by Quaternary deposits and these rocks ranging in age from Late Jurassic to Quaternary (Fig. 3). These rocks are mainly composed of fractured limestone, dolomitic limestone and chalky limestone with shale interbeds. They are built up of the following five formations, from base to top; Arab, Sulaiy, Yamama, Dughum and Wasia. These formations belong to Late Jurassic to Late Cretaceous ages in the study area. The landfill is underlain by fractured limestone belonging to limestone Jubaila Formation (Alwelaie, 1996).

Arab Formation: It is exposed on the surface in west of the study area and it is composed of limestone. Its thickness reaches 124 m at its type locality. It is belongs to Late Jurassic age. It is overlying Jubaila Formation and underlying Sulaiy Formation (Fig. 4). It is detected as water bearing formation. Sulaiy Formation: In the study area, the Sulaiy Formation occupies the majority of the surface. This formation overlies Arab Formation and underlies Yamama Formation. It belongs to Early Cretaceous age and reaches a thickness of 170 m at its type locality. It is composed of fractured limestone. Yamama Formation: this Formation is exposed on the surface in northeast of the study area. It is belongs to Lower Cretaceous. The thickness of this formation attains 46 m. It is mainly composed of argillaceous limestone. It overlies Sulaiy Formation and underlies Dughum Formation. This formation represents the water bearing formation, but it has a low groundwater potentiality. Dughum Formation: it is exposed on the surface in northeast of the study area and it belongs to the Lower Cretaceous. This formation is composed of sandstone. Wasia Formation: It is exposed on the surface in northeast of the study area. It is belongs to Late Cretaceous. Its thickness reaches 47 m, and increases towards the north direction. It is composed of sandstone with claystone intercalations. The thickness of this formation attains 600 m under Ruba Alkhali sand dunes. Wasia Formation represents the water bearing formation and it has a very high groundwater potentiality.

The Quaternary deposits cover the majority of south of study area (Fig. 3). These deposits are composed of sand, clay and basalt and their thicknesses are variable (Powers, et al., 1966). Structurally, the study area is characterized by predominance of monocline (Fig. 3), this monocline dips gradually towards the east and northeast directions (Powers, et al., 1966).

Hydrogeology

The soil stratigraphy of landfill consists of sandy sheet and gravel and is underlain by the fractured limestone belonging to the Jubaila Formation. This lithology allows leachate contamination to be infiltrated into the underlying unconfined aquifer. Extensive jointing of limestone allows leachate to infiltrate and move through them. The limestone aquifers are highly permeable due to fractures. The study area has four aquifers and is mentioned from top to base; Jubaila limestone, Hanifa limestone and Dhruma limestone (Fig. 4). These aquifers are hydraulically connected with each other due to the fractured system of the pervious aquifers. The groundwater aquifer exists under unconfined conditions and depths of the drilled wells range from 120 to 500 m (Table 1).

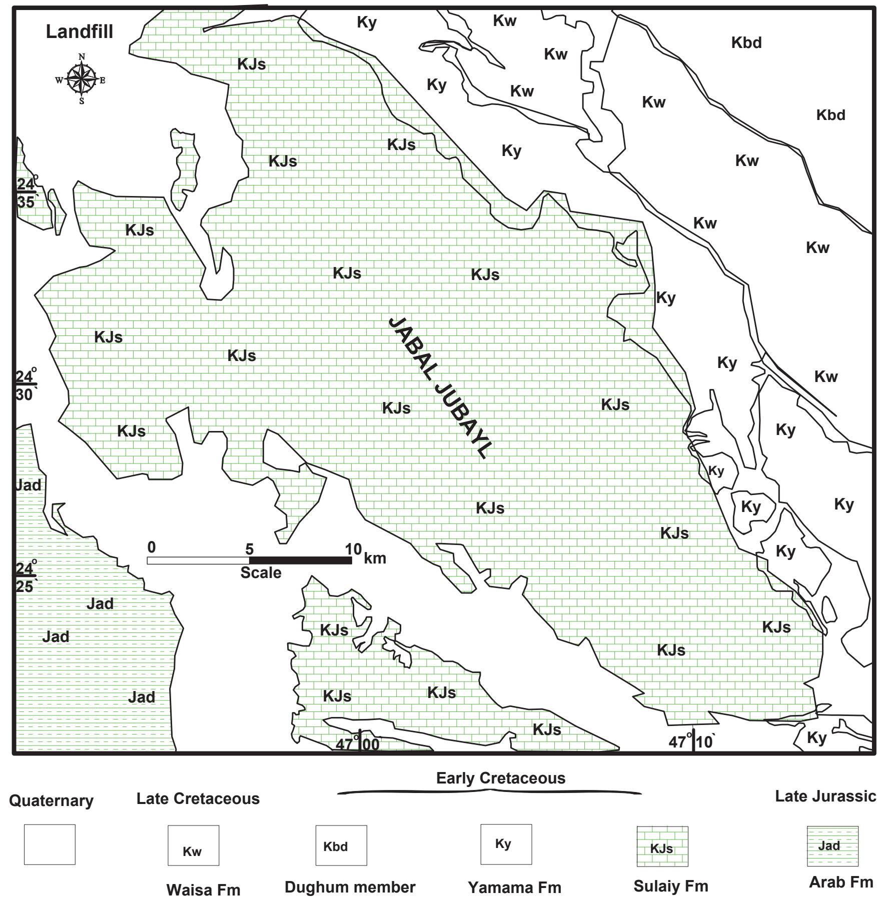


Fig. 3 Geological map of study area ((modified after Max Steineke, Harriss, Parsons and Berg, 1979).

Table (1): Hydrogeological data of study area. nd : not detected

Well No.	Elevation (msl)	Total depth (m)	Depth to the water (m)	Water level (msl)	Salinity (ppm)
1	607	400	7	600	2209
2	615	120	25	590	nd
3	595	400	nd	nd	2414
5	587	400	87	505	nd
6	662	400	237	425	2860
7	650	350	nd	nd	3073
8	645	500	nd	nd	3041
9	640	450	230	410	2912
11	500		nd	nd	3120
14	507	500	nd	nd	2571
15	506	83	nd	nd	288
16	514	500	nd	nd	2767

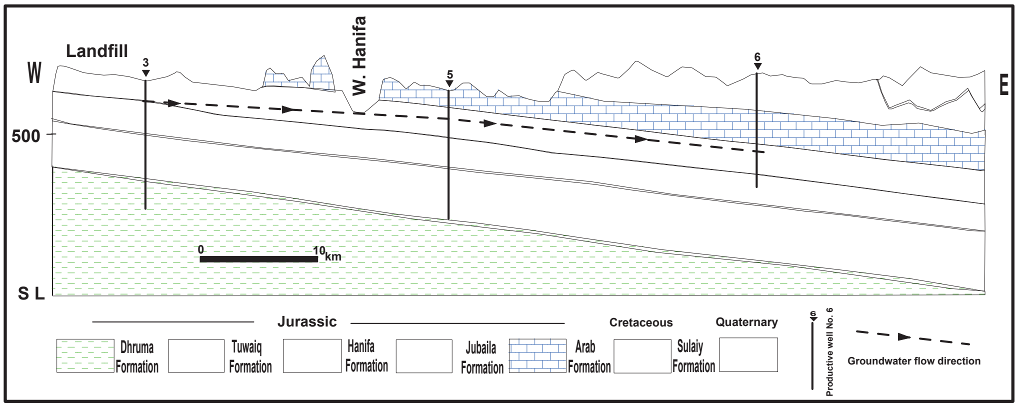


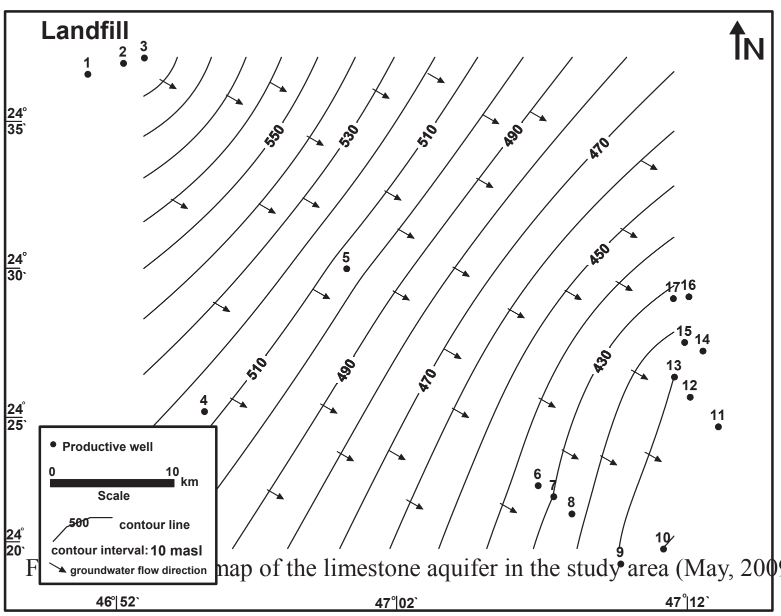
Fig. 4 Hydrogeological cross-section

Hydrogeological cross-section (Fig. 4) shows that the depth to the water table varies between 7 m in landfill site and 237 m below ground surface. It is noticed that the water table is near from ground surface in landfill area. This causes a degradation of the groundwater quality near the landfill area by the percolation of leachate.

Discussion

Depth to the water and flow direction

The depth to the water was measured in 2009 in the present work for 9 productive wells in the investigated area. It varies from 7 m below ground surface (well no. 1) at northwest of study area (landfill site) to 237 m (well no. 6) at east of study area (Table 1). In the landfill area, the depth to water is near from the ground surface and the leachate of landfill seepages downward to groundwater. The water level of groundwater in the study area varies from 410 msl (well no. 9) at southeast of the study area to 600 msl (well no. 1) at northwest of the study area. The groundwater contour map shows the groundwater flow from northwest to southeast directions (Fig. 5). The groundwater flow and the gradient of ground surface are in the same direction. This is caused the groundwater pollution to increase in the study area. The estimated hydraulic gradient of groundwater is 0.003 m/m on average.



F map of the limestone aquifer in the study area (May, 2009)

Hydrochemistry

Results of the analyzed parameters in groundwater samples are given in Table 2. These parameters depend on the analyses of 10 groundwater samples and one leachate. They will be described herein through the following:

Table (2): Chemical analyses of groundwater samples (December, 2006).

Well No.	EC	TDS ppm	TH (ppm)	Ions (ppm)						
				Ca^{++}	Mg^{++}	Na^{+}	K^{+}	HCO_3^{-}	SO_4^{--}	Cl^{-}
1	3500	2209	1301	419	62	196	16.2	248	1100	292
3	3830	2414	1307	376	109	238	18.7	204	1250	321
6	4470	2860	1573	419	128	280	21.6	200	1050	678
7	4800	3073	1651	468	124	347	23.9	244	1300	652
8	4750	3041	1743	517	110	320	8.5	216	1347	310
9	4550	2912	1693	523	94	293	10.5	212	1159	630
11	4875	3120	1620	451	120	398	10.6	283	1460	512
14	4017	2571	1618	490	96	178	19.8	216	1347	310
15	450	288	200	49	19	20	1.2	145	52	45
16	4360	2767	1683	506	102	227	18.4	229	1474	326
Leachate	70060	49700	nd	40	210	8100	13500	15250	3200	14100

nd: not detected

Groundwater salinity

In arid regions, evapotranspiration rates are much higher, recharge is less, flow paths are longer, and residence times are much greater and hence much higher levels of natural mineralization (Chilton and Seiler 2006). Total dissolved solids (TDS) comprise inorganic salts and any organic matter dissolved in water. Return flows from irrigated agriculture may increase the groundwater salinity. The salinity of groundwater is variably controlled by the host rock due to the constant rock_water interaction that takes place in any aquifer. The groundwater salinity of limestone aquifer belongs mainly to blackish water type (1000 -10000 ppm) according to (Tood, 1980) except groundwater sample no. 15 is fresh water type (<1000 ppm). The groundwater salinity ranges from water of 450 ppm (well no. 15) to 3120 ppm (well no. 11). The low groundwater salinity of sample no. 15 is probably attributed to the fact that this well tapping of shallow aquifer (80 m depth) is recharged directly from rainfall and seepage of surface water. In general, the groundwater salinity increases due east direction with groundwater flow (Fig. 6).

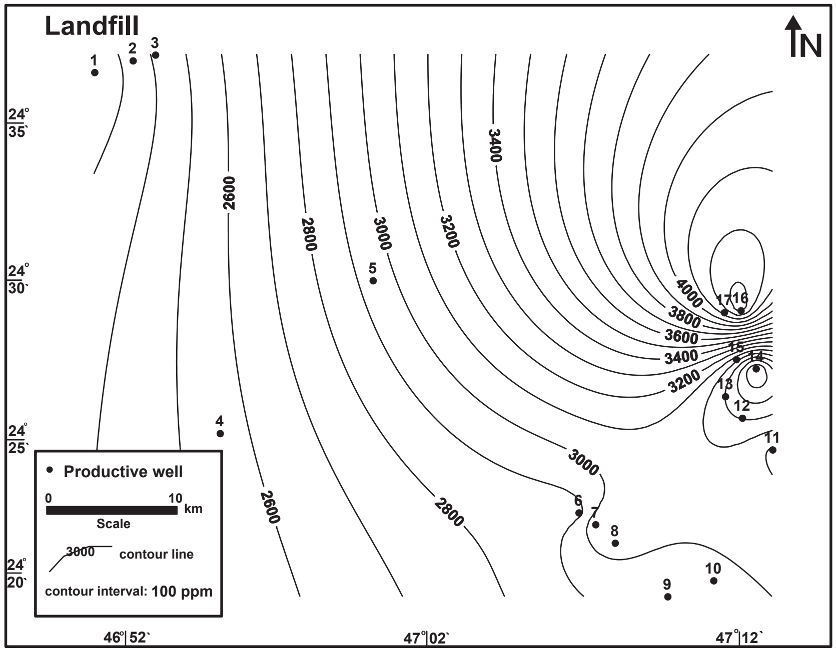


Fig. 6 Distribution map of groundwater salinity in the study area

Ion Dominance

The sequences of the ions represent the variation in chemical composition of groundwater, which is mainly controlled by the lithology of water bearing rocks. The ion dominance of the groundwater in study area is represented by two orders:

1- Ca2+>Na+>Mg2+ / SO42->Cl->HCO3-. Such ion dominance has been encountered in most of the groundwater samples.

2- Ca2+>Mg2+>Na+ / HCO3-> SO42- >Cl- (samples 7 and 15).

Ca2+ and Mg2+

According to the ion concentrations, the calcium is dominant among the cations (49 ppm to 523 ppm) and sulfate is dominant among the anions (52 ppm to 1474 ppm) in the majority of the groundwater samples. So, the water chemical type is calcium sulfate, except samples 7 and 15 having calcium bicarbonate. The high concentration of Ca2+ and Mg2+ in the groundwater is mainly attributed to the fact that the aquifer is composed mainly of limestone and dolomite rocks rich in calcium and magnesium. The presence of carbonate rocks such as calcite and dolomite in the sediments determines the high HCO3- concentrations throughout the aquifer, which range between 145 and 283 ppm.

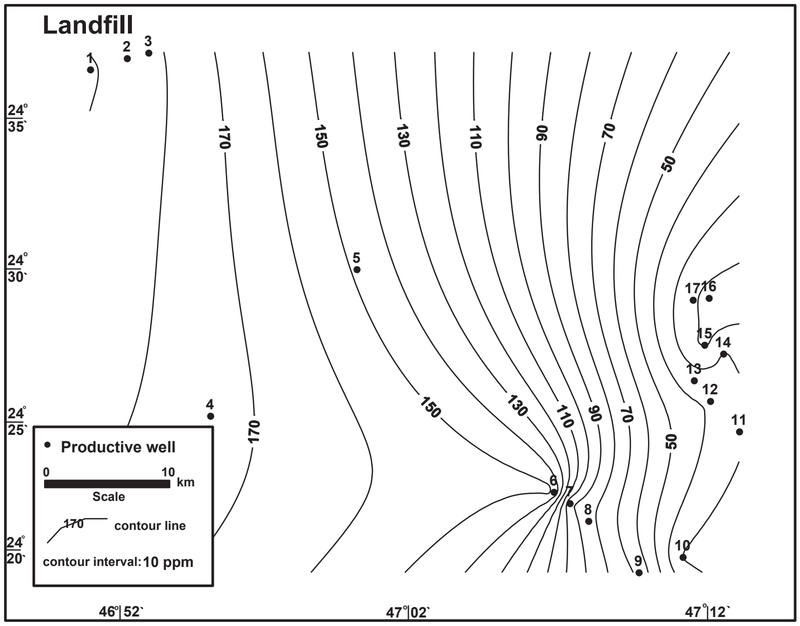


Fig. 7 Distribution of nitrate in groundwater. Data from May 2009

Cl-

An excess of Cl^- in groundwater is usually taken as an index of pollution and as tracer for groundwater contamination (Loizidou and Kapetanios, 1993).

Our results are also supported by the results of Ghrefat (2013) who found that natural waters are capable of dissolving more minerals under suitable physicochemical conditions.

The concentration of Cl^- in the groundwater samples ranged between 45 ppm to 678 ppm. High Cl^- content in groundwater is likely to originate from pollution sources such as domestic effluents, fertilizers, and septic tanks, and from natural sources such as rainfall. The high concentration of chloride in groundwater in the study area is attributed probably to the return flows from irrigated agriculture which may increase the chloride concentration. Increase in Cl^- level is detrimental to people suffering from diseases of heart or kidney (WHO 1997).

Nitrate concentration (NO_3^{2-})

Leachates from landfill and return flows from irrigated agriculture are the source of most of the NO3 in groundwater in the study area. Nitrate is the most ubiquitous chemical contaminant in world's aquifers and the levels of contamination are increasing. The highest value of NO3 occurs in groundwater in the landfill (northwest of the study area). The concentrations of NO3 in groundwater vary from 191 ppm in landfill area (northwest of the study area) to 20 ppm in east of the study area. Figure 7 shows the concentration of NO3 increasing towards the east direction far from landfill. Sixty percent of samples in the study area have nitrate concentrations that exceed the drinking water limit of 50 ppm (WHO 2006), with an average nitrate concentration in the groundwater of 88 ppm. As illustrated in Figure 7, anomalously high NO3 concentrations (191 and 183 ppm) are found in northwest area located around the landfill area. Nitrate concentration in groundwater depends on the hydrogeological conditions and site of landfill in study area. In the unconfined shallow aquifer (a few meters deep), where the depth to the water in landfill reached 7 m, the decrease in nitrate with depth can be due to the process of the reduction of nitrate by oxidation of organic matter within the sediments (Gillham and Cherry 1978). However, the high levels of nitrate concentration may be due to nitrification and denitrification process due to the presence of the leachates from landfill. This suggestion is also supported by the results of Ahmed et al. (2012) who concluded that nitrification efficiency was found to be above 91% at temperatures above 25 oC even at short hydraulic residence times in the waste water treatment plant which is similar to the condition of the landfill.

Zink Concentration (Zn2+)

Groundwater is polluted with zinc, due to the presence of large quantities of zinc in leachate, which is infiltrated downward the groundwater. Zinc is a trace element that is essential for human health. The concentration of Zinc in groundwater samples ranged from 20 to 1473 μ g/L and was significantly very high at sites 1 and 3 (landfill site), which further support that groundwater near landfill site is being significantly affected by leachate percolation. The constructed map of distribution of zinc in groundwater reveals a decrease of zinc from northwest (landfill area) to southeast direction (Fig. 8).

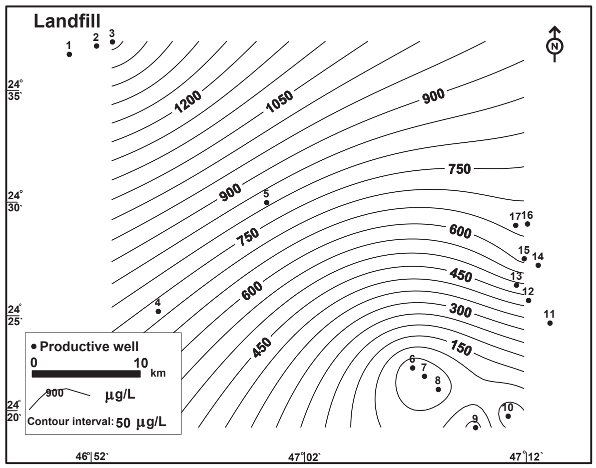


Fig. 8 Distribution of zinc in groundwater. Data from May 2009

Hypothetical salts

The combination between ions reveals the formation of different varieties from salt assemblages. The groundwater of the studied aquifers reveals the following two groups of hypothetical salts combinations (Table 3).

1- Group I: NaCl, MgSO4, CaSO4, Ca (HCO3)2 and MgCl2 (wells 6, 7, 8, 9, 14 and 15). This assemblage has been encountered in the majority of groundwater samples and comprise MgCl2 of marine origin reflecting leaching of marine sediments of limestone aquifer.

2- Group II: NaCl, MgSO4, CaSO4, Ca (HCO3)2 and Na2SO4 (wells 1, 3, 11 and 16). The groundwater samples of this group reveal different percentages of salt assemblages due to cation exchange as well as dissolution of marine sediments.

Table 3. Chemical analyses of the studied groundwater samples

Well No.	Hypothetical salts							
	Ca/Mg	SO_4/Cl	NaCl	$MgCl_2$	Na_2SO_4	$MgSO_4$	$CaSO_4$	$Ca(HCO_3)_2$
1	4.1	2.8	23.39	nd	2.17	14.6	48.3	11.54
3	2.1	2.9	23.57	nd	4.53	23.24	39.97	8.69
6	2	1.1	28.81	14.38	nd	9.46	39.94	7.41
7	2.2	1.5	32.62	4.59	nd	16.73	38.1	7.96
8	2.8	1.2	28.85	13.04	nd	5.44	44.58	8.09
9	3	2.3	27.78	11.39	nd	5.11	48.07	7.65
11	2.3	2.1	29.18	nd	6.01	19.76	35.67	9.38
14	3.1	3.2	20.32	1.36	nd	18.08	51.46	8.78
15	1.6	0.8	18.37	8.48	nd	22.83	nd	49.79
16	3	3.4	21.07	nd	2.44	19.08	48.82	8.59

nd= not detected

Ion ratios

1- Ca/Mg: is more than one, due to the fact that the groundwater aquifer is composed mainly of limestone.

2- SO_4/Cl: This ratio could be taken as a guide for detecting any excess of sulfate in groundwater associated with sulfate minerals dissolution or sewage contamination. This ratio is more than one in groundwater samples due to the expected infiltration of irrigation water (rich in sulfate) to the aquifer.

5. Conclusion

To summarize this study, the main findings are: 1- Sandy sheet and gravel soil underlain by fracture limestone aquifer in landfill site cause highly percolation of leachate downward to groundwater, 2- In the landfill area, the depth to watertable is low and the leachate of landfill seepages downward to groundwater, 3- The main source of nitrate contamination in groundwater is the infiltration of leachate in landfill site downward to groundwater and the use of nitrogen (N) fertilizers in agriculture, and 4-The concentration of zinc in groundwater around the landfill site support the conclusion that groundwater near landfill site is being significantly affected by leachate percolation.

The main recommendations of this study are: 1- Reducing the infiltration of the water through the landfill must be covered by impermeable clay layer. Due to this less water will enter and subsequently less leachate will be generated, thereby reducing the amount of leachate reaching the landfill base, and 2- Extraction and recycling of the leachate collected at the base cab, so that less amount will enter the aquifer lying below.

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