ISSN: 2277-9655
Scientific Journal Impact Factor: 3.449
(ISRA), Impact Factor: 2.114

IJESRT

INTERNATIONAL JOURNAL OF ENGINEERING SCIENCES & RESEARCH TECHNOLOGY

EFFECT OF MUNICIPAL LANDFILL SITE ON QUALITY VARIATIONS OF GROUND WATER: CASE STUDY OF BOJNOURD AQUIFER, IRAN

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ABSTRACT

Ground waters are one of the important water supply resources that are constantly subjected to contamination. One of the factors contaminating ground water is leachate of municipal landfill sites. In order to investigate the effect of leachate on ground water in an area, qualitative parameters including EC, TDS, Cl^-, etc. are usually used. City of Bojnourd as the capital city of North Khorasan Province produces 140 tons of solid waste every day. A major part of this solid waste is buried in Bojnourd's only landfill site located in the northeast area of the city. Ground water sampling from several wells in Bojnourd aquifer was made during 1997-2013 and then variations of the above-mentioned parameters were investigated on the zoned map, especially areas influenced by the landfill site. In all of these maps, effect of landfill site on the aquifer was determined by observing a high amount of TDS, EC, and chloride around the studied area. Also, observing the variation curve and increasing trend of these three parameters in well 3 near the landfill can be other reasons which suggest the negative effect of landfill site on the ground water quality, especially in downstream regions.

Keywords: Bojnourd aquifer, landfill, TDS, chloride, electrical conductivity.

INTRODUCTION

Ground waters are one of the most important water supply resources in all countries. Excessive use of these resources and high production of municipal solid waste in the modern society have threatened the quality of ground waters and contaminated them. Growing increase of population and urbanization has increased the production of solid waste and pollutants so that collection and burial of these materials have turned into an environmental concern [1].

Municipal solid waste buried in the ground contains high water content; if surface waters penetrate into them, pollutant leachate is finally produced as a result of chemical and biological reactions inside the landfill, which contains toxic elements. Nature and polluting power of solid waste leachate depend on waste compounds, contact time of solid waste and water, and the volume. Leachate penetration can be a serious threat for water and soil contamination in the regions around landfill sites [2].

Leachate is accumulated at the bottom surface of landfill site and a substantial amount of this dangerous liquid comes in contact with the landfill subsoil. The accumulated leachate starts to penetrate and flow through the subsoil layers under different mechanisms. Afterwards, it enters the bottom aquifer. Increased concentration of leachate in ground water may exceed the permitted standards and contaminate the ground water [3].

In order to study the effect of leachate on ground waters in a region, qualitative parameters of water including hardness, alkalinity, turbidity, pH, electrical conductivity (EC), total dissolved solid (TDS), chloride content (cl^-), etc. are used; the relation between these parameters is also important [4]. As a result, studies which analyze the effects of landfill leachate and sewage on the quality of ground waters in Jordan in 1999 reported that leachate entry into aqueous environments is a very serious threat [5]. Also, in the studies on ground water resources in the areas near the landfill site of several metropolitan cities in Spain, pH, electrical conductivity, and concentration of rare elements had a considerable increase [6]. Since landfill sites are non-standard in most cities in Iran, produced leachate contaminates soil and ground water. This study was aimed to evaluate chemical contamination of ground waters,

ISSN: 2277-9655
Scientific Journal Impact Factor: 3.449
(ISRA), Impact Factor: 2.114

especially in the downstream of landfill site in city of Bojnourd.

Introducing the studied region

City of Bojnourd with the population of more than 200,000 people is the capital city of North Khorasan Province in the northeast of Iran. Its area is 6157 km^2, which occupies about 22% of the area of the province. Citizens of this city produce more than 140 tons of solid waste every day, a major part of which is buried with soil cover using trench and raving method in the city's only landfill site located in the northeast of Rozaneh city. In the downstream of the landfill are farmlands which are mostly irrigated by well water. This region has the average annual precipitation of 260 mm [7].

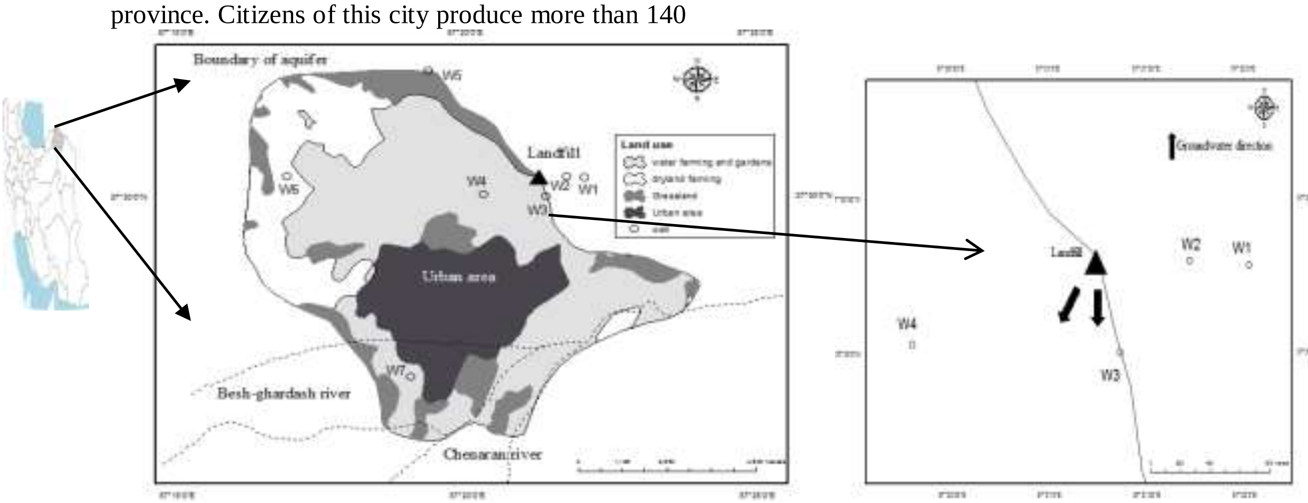

Figure 1- Location of Bojnourd aquifer and land use of different parts of the plain and selected studied wells

Surface and ground waters

Bojnourd aquifer, with the area of about 90 km^2, is a free, single-layer, and alluvial aquifer which is surrounded by the heights around the plain margins. Also, geometry of its reservoir is a small syncline. Surface stone of this plain is composed of clay marl sediments. Two permanent rivers flow through Bojnourd plain, which enter it from south, join each other, feed the aquifer, and exit the plain from the southeast. Main inlet and outlet boundaries of the ground waters of Bojnourd aquifer correspond to the river's inlet and outlet [8].

A major part of the Bojnourd studied heights is composed of limestone formations with appropriate water potential. Suitable water supply of the aquifer (especially from southern heights) and low water discharge capability and thickness of alluvium have increased ground water level of this plain in recent years. Flow direction of ground water is generally toward the east and northeast with an increasing east-ward hydraulic slope (direction of ground water is an influential factor for contamination diffusion in ground water [9]). In general terms, ground water depth in Bojnourd plain is low and a large part of this plain (including city of Bojnourd) has the depth of less than 15 m. Due to the high expansion of limestone formations in this area, a large volume of discharge of ground water resources is done by springs. In terms of consuming the water from springs in different parts, more than 97% of water withdrawal from springs is used for agriculture and less than 3% is used as potable water for the nearby inhabitants [8].

Bojnourd landfill site

Current landfill site of Bojnourd is located within the official perimeter of the city and 1 km away from the residential areas and main road. Bojnourd landfill site is located at the distance of more than 2 km from surface water resources and the surrounding rivers. Type of land formation in this area is mainly Tirgan formation (K_t) containing massive oolithilic and marl layers and alluvial sediments. Land slope is around 10 degrees.

Depth of ground water within Bojnourd landfill site was approximately 10 m; considering the flow direction of ground water in this region (which was toward south and southwest) and increased hydraulic slope to this site, the direct effects of landfill site on the quality of ground waters, especially in downstream regions, can be predicted [10].

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Scientific Journal Impact Factor: 3.449
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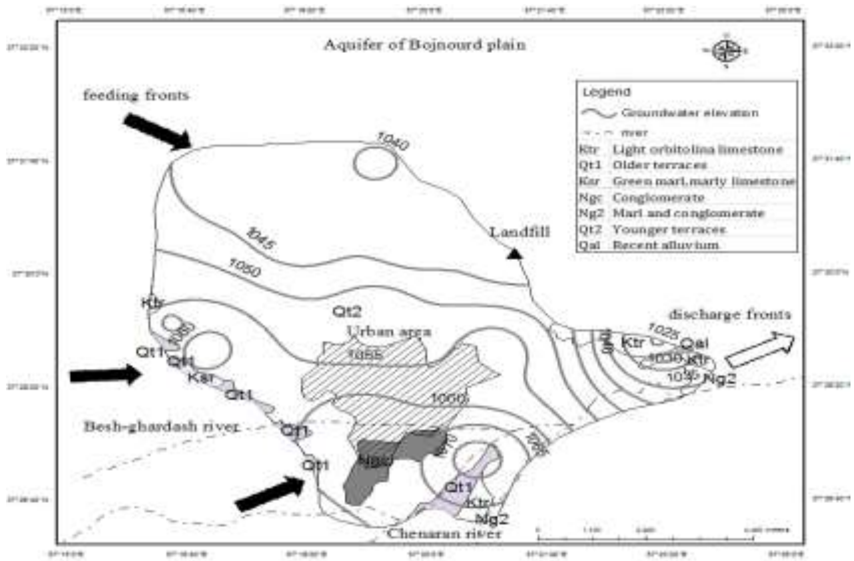

Figure 2- Bojnourd aquifer, discharge and supply fronts, and ground water level

Determining the constituents of municipal solid wastes is not an easy task because of non-homogeneity of solid waste; therefore, performing precise statistical methods entails some problems. The conventional method used for determining the solid waste composition is random sampling method. Results of previous studies for determining the physical composition percentage of Bojnourd landfill site are presented in Figure 3 [10].

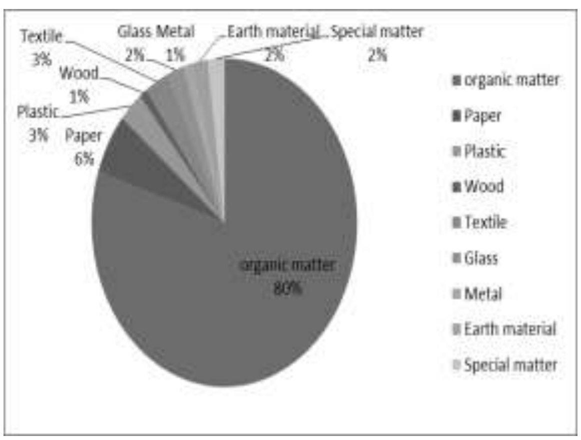

Figure 3- Mean weight percent of the physical constituents of Bojnourd's solid waste [10]

Estimating volume of produced leachate

Calculating and predicting the amount of leachate in a landfill site are very complex; in many cases, it is impossible to estimate the precise value. Also, estimating the produced leachate is performed by empirical relations. According to the available relations based on the daily produced solid wastes and precipitation rate, leachate volume of Bojnourd landfill site was estimated around 8,000 m3 per year [11].

MATERIALS AND METHODS

The points mentioned in previous sections, especially share of ground water resources for agricultural and drinking consumption, emphasize the necessity of conducting scientific studies on the quality of water from wells and springs and effect of leachate leakage from municipal landfill on them in Bojnourd landfill site. In this study, chemical contamination of ground waters, especially in the downstream of Bojnourd landfill site, was investigated.

In order to distribute the qualitative parameters of ground water, inverse distance weighting (IDW) interpolation method in the GIS system was applied. In this method, by specifying the variation trend of considered parameters (TDS, EC, and Cl^-), the aquifer environment is zoned into regions with similar hydrochemical properties [12]. Water samples from Bojnourd aquifer were collected from several wells throughout the entire aquifer during 1997-2013. Then, variations of the parameters mentioned in the zoning map, especially the landfill-affected regions, were investigated. Chemical samplings were performed in plastic containers. Chloride rate and TDS were determined using Mohr method (titration of silver nitrate) and dry residue measurement method, respectively. Electrical conductivity was measured by a conductometer device in the site.

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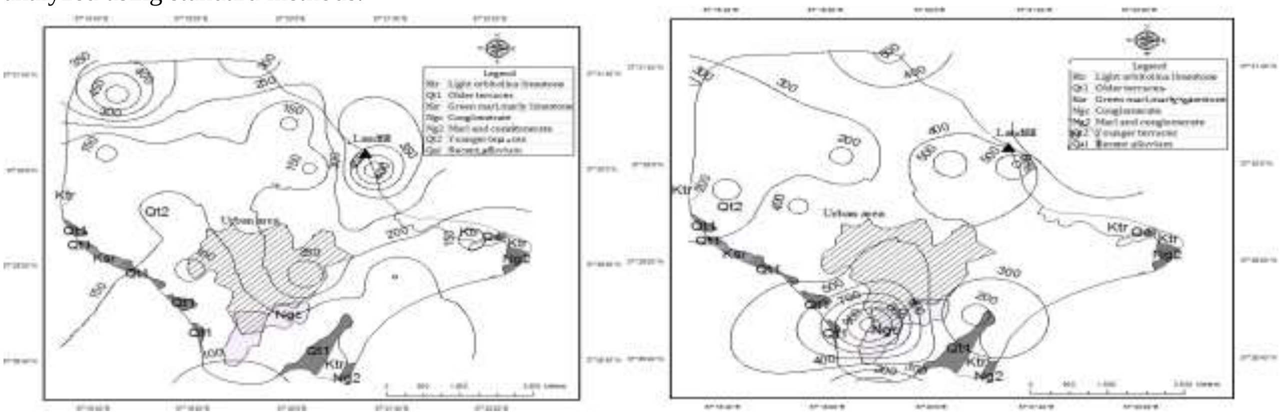
This study was a descriptive, case-control research, in which 4 wells (2 wells in the downstream of the landfill site within agricultural farms and 2 wells in the upstream of landfill site as control) were investigated. Selecting control wells was based on the flow direction of ground water in the studied area and landfill site. Two samplings were annually carried out: one in spring and one in autumn; then, the samples were transferred to the laboratory to be analyzed using standard methods.

RESULTS AND DISCUSSION

Results of water sampling from ground water in Bojnourd plain during 1997-2011 are presented as distribution maps of electrical conductivity, TDS, and chloride:

Map of chloride variations in ground water
Tables



(a) *(b)*

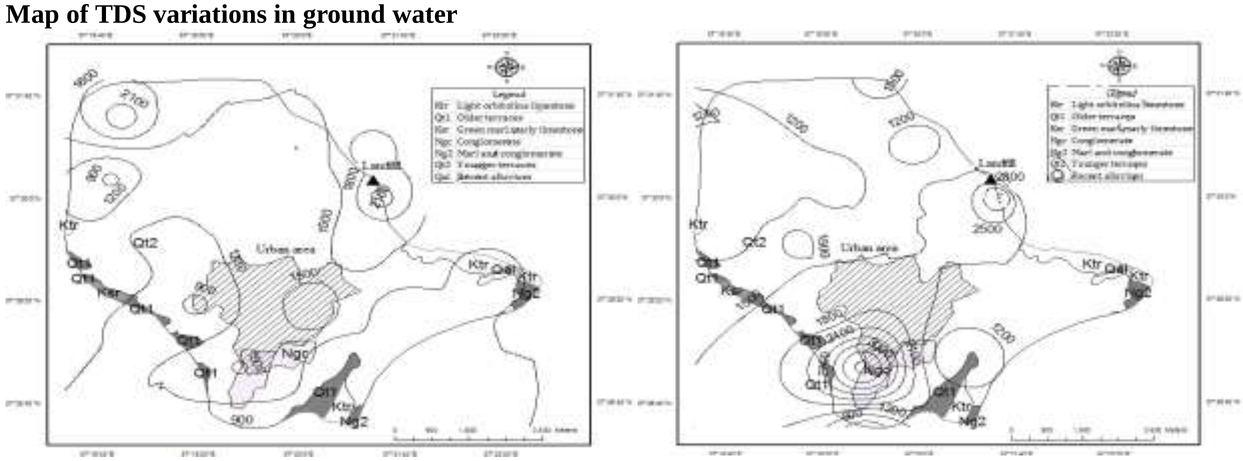
Figure 4- Map of chloride variations in Bojnourd aquifer in 1997 (a) and 2013 (b)

As shown in the chloride distribution map in 1997, it is evident that the amount of this ion in ground water varied between 100 and 400 mg/lit. Minimum chloride content was around 100 mg/lit in the central and southern parts of the plain, while its maximum value was around 400 to 450 mg/lit in the eastern part (around landfill site) and northwestern corner

According to the chloride distribution map of Bojnourd aquifer in 2013, it is evident that quality of ground water was generally reduced in terms of this ion and chloride contents were increased in most areas so that chloride ion content varied between 200 and 900 mg/lit. Minimum and maximum values of 200 and 900 mg/lit were observed in the central and western parts of the aquifer and the southern parts of the city, respectively. In the eastern part of the aquifer and close to the landfill site, chloride content was around 650 mg/lit, which showed an increase of about 250 mg/lit compared to the value obtained in 1997. This issue indicates the negative effect of landfill site on the quality of ground water in terms of increased chloride content. Extreme variations and increase in chloride content in the southern areas of the city might be the result of constructing wastewater treatment plant and discharge of its wastewater to this area.

According to World Health Organization's (WHO) standard, maximum permitted amount of chloride in potable water is 250 mg/lit; considering the chloride distribution map in ground water, it is evident that ground water of the majority of areas in Bojnourd aquifer had less quality than the standard, which showed that the quality of ground water was in a worrisome condition.

Map of TDS variations in ground water



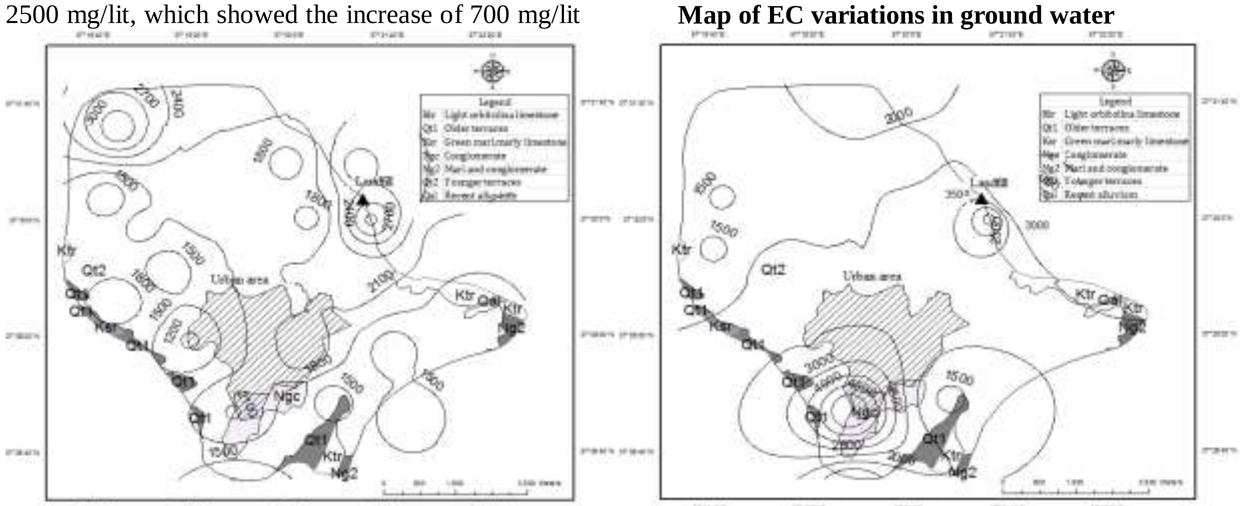
(a) *(b)*

Figure 5- Map of TDS variations in Bojnourd aquifer in 1997 (a) and 2013 (b)

Total dissolved solids (TDS) include sum of solid materials which are water-soluble; but, they do not contain suspended sediments, colloids, and soluble gases. The more the concentration of water-soluble salts, the higher the electrical conductivity and water hardness would be [13]. According to TDS distribution map in 1997, it is observed that, in the areas near the landfill site, TDS content was almost 1800 mg/lit. Negative effects of landfill site in the region along with the low depth of ground water (10 m) which facilitates leachate penetration into the soil and aquifer caused the TDS content to increase and quality of ground water to decrease. Minimum TDS values of Bojnourd aquifer in 1997 were around 900 mg/lit and in the western and southern areas of the aquifer. Also, maximum values of TDS in the eastern (near the landfill site) and northwestern areas of the aquifer were 1800-2100 mg/lit.

In 2013, TDS value near the landfill site reached 2500 mg/lit, which showed the increase of 700 mg/lit compared to the data in 1997 (35% increase). Reduced quality of ground water and increased TDS in this region might be related to the solid waste landfill, increased accumulation of solid waste, and consequently increased production and penetration of leachate volume into the ground water. TDS values of the ground water in Bojnourd in 2013 varied between minimum of 1200 mg/lit (central and western areas of the aquifer) and 3000 mg/lit (southern areas of the city). It must be noted that depth of the ground water in the western and northwest areas of the aquifer was among the most important factors for the desirable quality of ground water compared to other areas. According to World Health Organization (WHO), standard TDS value for potable water is at most 1000 mg/lit; thus, quality of ground water, in terms of TDS value, was not satisfactory as potable water in any areas of the aquifer.

Map of EC variations in ground water



(a) *(b)*

Figure 6- Map of EC variations in Bojnourd aquifer in 1997 (a) and 2013 (b)

ISSN: 2277-9655
Scientific Journal Impact Factor: 3.449
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Close attention to EC variations in 1997 shows that these variations varied within 1500-3000 µS. Near the landfill site, this value was approximately 2700 µS. Over time, in 2013, EC value for ground water near the landfill site was increased to about 3500 µS (30% increase). In other parts of the aquifer, minimum (western areas) and maximum (southern areas of the city) EC values for ground water were 1500 and 4500 µS, respectively. As mentioned earlier, variation trends of EC and TDS were proportional to each other.

The important characteristic of ground water required for processing the qualitative data of aquifer is mean salinity of water. Chemograph (mean EC) of Bojnourd aquifer showed that EC value had an incremental trend during 2003-2013 and reached 2300 µS in 2013. By comparing this value and EC in the same year for the areas near the landfill site (which was around 3500 µS), an evident difference and thus negative effects of landfill site on quality of ground water can be understood [13].

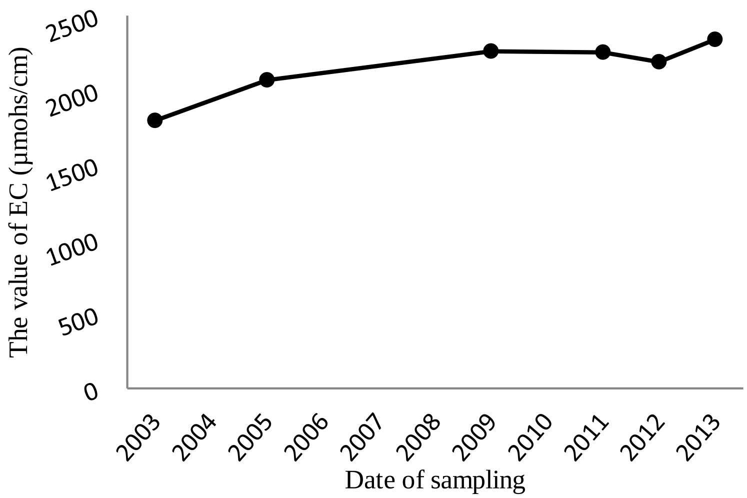

Figure 7- Chemograph of Bojnourd aquifer

In order to investigate and compare the quality variations of ground water in Bojnourd plain, diagrams of chloride, EC, and TDS variations for W3 (east of the aquifer and near the landfill site), W5 (north of the aquifer), W6 (west of the aquifer), and W7 (southern part of the city) wells during 1997 to 2013 are presented below:

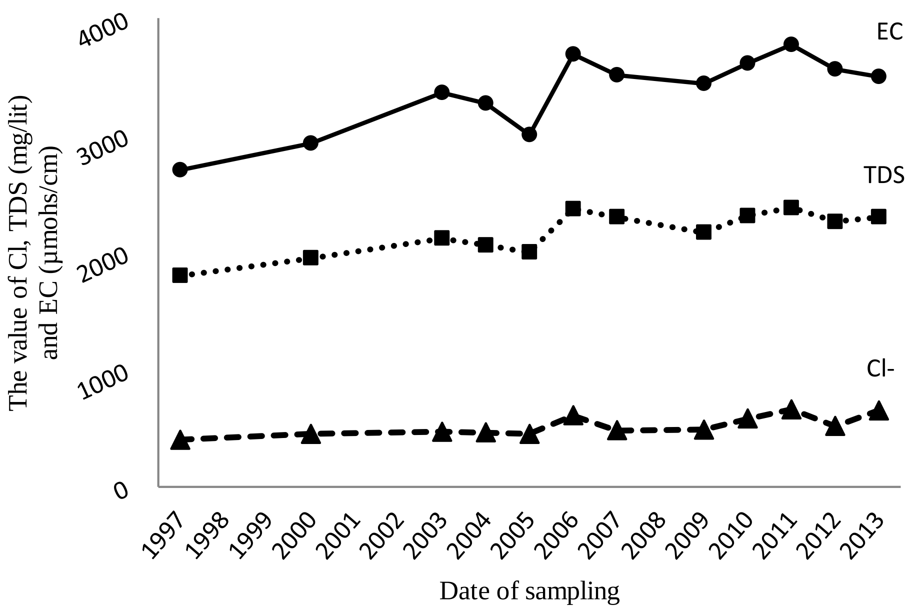

Figure 8- Variations of TDS, EC, and chloride in Bojnourd aquifer in W3 (near the landfill site)

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Well 3 was the closest well to the landfill site and the most evident effects of landfill site were observable in this well. As mentioned before and according to the above figure, negative effects of landfill site on the quality of ground water considerably increased chloride content, EC, and TDS in this well during the study. It can be claimed that average increase of TDS, chloride, and EC was around 30 mg/lit, 15 mg/lit, and 50 µS per year, respectively.

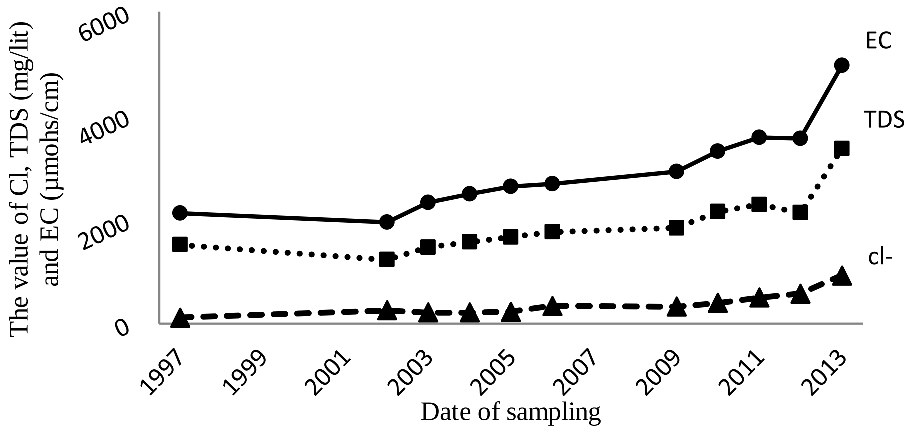

Figure 9- Variations of TDS, EC, and chloride in Bojnourd aquifer for well 7 (southern part of the city)

As observed in the figure, values of all the three parameters in this well were higher than those obtained for other parts of Bojnourd plain; they also had a considerable increase during this study, which can be attributed to the construction of wastewater treatment plant and the consequent discharge of wastewater to the plain. Increased amount of wastewater enter the treatment plant due to the increased population of the region and increased discharge of wastewater into the region causes a severe decrease in the quality of ground water.

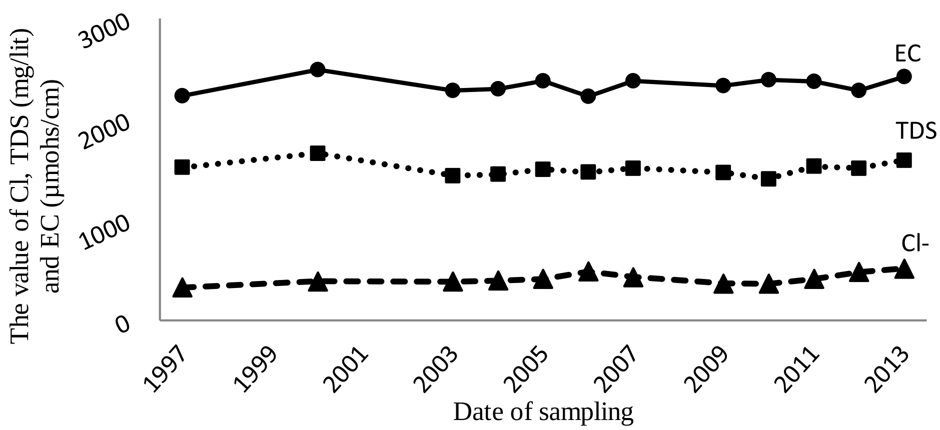

Figure 10- Variations of TDS, EC, and chloride in Bojnourd aquifer for well 5 (north of the aquifer)

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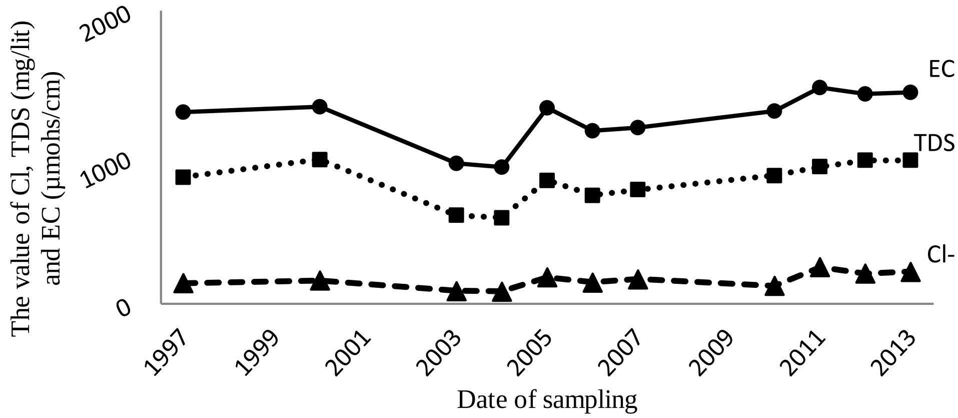

Figure 11- Variations of TDS, EC, and chloride in Bojnourd aquifer for well 6 (west of the aquifer)

According to Figures 10 and 11, it is evident that the quality of ground water in the northern and western areas of the aquifer was much better than that in the eastern areas near the landfill site. Further, variation trends of TDS, EC, and chloride in this area which had no polluting source like landfill site or wastewater treatment plant were either almost constant or increased with a milder slope than W3 well.

Diffusion of leachate into the aquifer

Pollution is usually transmitted via convection, molecular diffusion, mechanical dispersion, and a combination of convection and molecular diffusion mechanisms. In the convection transfer method, water movement from a point with higher potential to another point with lower potential causes contamination diffusion. Therefore, the flow direction of ground water is effective for leachate diffusion rate [9]. In order to investigate the manner of this effect, variation rates of TDS, EC, and chloride in W1 to W4 wells were considered in 2013.

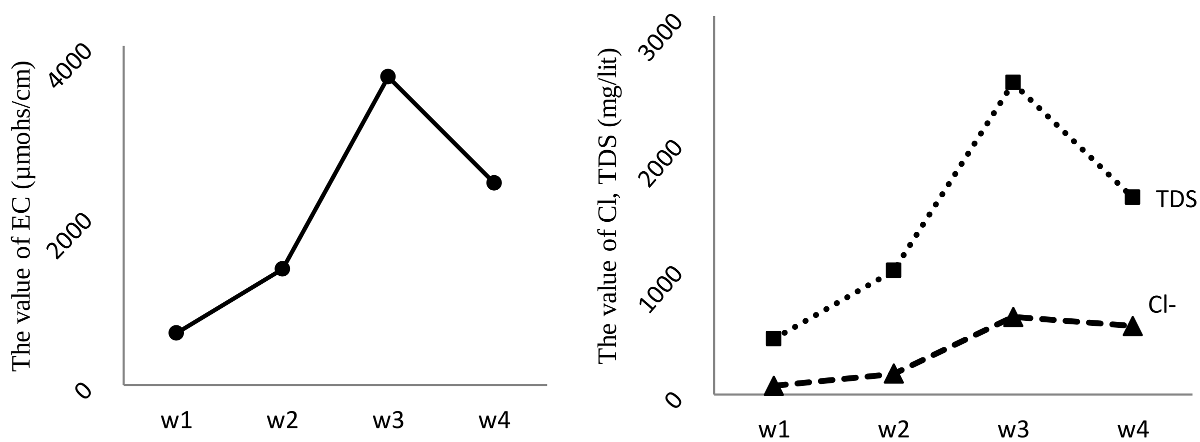

Figure 12- Variations of TDS, EC, and chloride in wells near the landfill site

According to the figure and as expected, values of TDS, chloride, and EC in well 3 were higher than other wells. Well 3 was located 1 km away from the landfill site and concurrent with the ground water flow; so, it is natural that effects of landfill site were more considerable in it. Well 4 had less contamination due to greater distance from the landfill site (around 2.5 km). Selecting wells 1 and 2 and very low values of these parameters in these wells clearly demonstrate the effects of ground water direction on the contamination diffusion caused by leachate diffusion in the aquifer.

CONCLUSION

Results of this study showed that the quality of ground water in Bojnourd aquifer was generally low and not within the recommended standard values for potable water. Also, research suggested that maximum contamination and quality reduction of ground water were related to the eastern part of the aquifer and southern part of the city. The wells around the landfill site were selected according to the direction of ground water which showed that maximum landfill effects were on well 3 that was located near the landfill site and had the same direction as the ground water. Although the role of landfill site in polluting the ground water in the eastern part of the aquifer and other wells in the region is undeniable, such contamination cannot be merely attributed to the landfill site; low depth of wells which increases the possibility of contamination with surface waters, discharge of agricultural wastewater, effects of formation, dissolution of sediments in ground water, etc. are other factors that might adversely affect the quality of ground water.

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