Bulletin of Environment, Pharmacology and Life Sciences
Bull. Env. Pharmacol. Life Sci., Vol 3 (Spl issue II) 2014: 263-271

Online ISSN 2277-1808
Journal's URL:http://www.bepls.com
CODEN: BEPLAD
Global Impact Factor 0.533
Universal Impact Factor 0.9804

Pb contamination and analysis of Aquifer in Karaj Plain, Alborz Province, Iran using GIS-based DRASTIC Model

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ABSTRACT

The state of groundwater pollution is a critical issue with increasing population and agricultural development in Iran. For this reason, vulnerability assessment is an important factor in any policy making decision in any part of country. Focusing on this issue, the article attempts to presents groundwater vulnerability for Pb concentration for the Karaj plain. The study area, Karaj plain is situated in northwest of Tehran, Iran, lies between latitudes 34°50′ to 35°30′ N and longitudes 47°12′, to 48°10′ E. Seven major hydro-geological factors;depth to water table, net Recharge, Aquifer media, Soil media, Topography, Impact of vadose zone and hydraulic Conductivity were incorporated into DRASTIC model and using GIS (soft ware) a groundwater vulnerabilitymap has created by overlaying. The output map shows that the west and southwest and southeast of the area aquifer ishighly vulnerable while areas in northern and central part of the area have less vulnerable. For testing of the vulnerability assessment, used Pbconcentrations measured for water samples of the study area and DRASTIC model. After combining these two, created map modified of groundwater .this map show that the southwest and south parts of aquifer have a critical Pbvulnerability limitation zones.
Keywords:*Aquifer vulnerability ·DRASTIC model, Pb contaminations. Karaj Plain*

INTRODUCTION

Ground water contamination vulnerability mapping is based on the idea that some part of land is more vulnerable to groundwater contamination than others (Piscopo, 2001). The concept of groundwater vulnerability was first introduced in France by the end of the 1960s to create awareness of groundwater contamination (Vrba and Zaporozec, 1994). Groundwater contamination vulnerability mapping is defined as the possibility of percolation and diffusion of Contaminants from the ground surface into the groundwater system. Groundwater vulnerability deals only with the hydrogeological setting and does not include pollutant attenuation. Groundwater vulnerability to contamination also was defined by the National Research Council(1993) as the tendency or likelihood for contaminants to reach a specified position in the groundwater system after introduction at some location above the uppermost aquifer. Many Approaches such as process-based methods, statistical methods, and overlay and index methods have been developed to evaluate aquifer vulnerability (Tesoriero et al, 1998). The process-based methods use simulation models to estimate the contaminant migration but they are constrained by data shortage and computational difficulties (Barbash&Resek, 1996). Statistical methods use statistics to determine associations between spatial variables and actual occurrence of pollutants in the groundwater. Their limitations include insufficient water quality observations, data accuracy, and careful selection of spatial variables (Babiker et al, 2004). Overlay and index methods join factors controlling the movement of pollutants from the ground surface into the saturated zone resulting in vulnerability indices at different locations. Their main advantage is that some of the factors such as rainfall and depth to groundwater can be available over large areas, which makes them suitable for regional scale assessments (Thapinta&Hudak, 2003). However, their major disadvantage is the subjectivity in assigning numerical values to the descriptive entities and relative weights for the different attributes. DRASTIC is an index model designed to produce vulnerability scores for different locations by combining several thematic layers. It is a well-established method that is often applied in the United States (Rupert, 2001; Merchant, 1994; Loague&Corwin, 1998; Wade et al, 1998; Stark et al, 1999; Fritch et al, 2000), Canada (Murat et al, 2004), Europe (Stigter et al, 2006; Vias et al,2005), South America (Tovar &Rodriguez, 2004; Herlinger&Viero,2006), Australia (Piscopo, 2001), New Zealand(McLay et al, 2001), Asia (Al-Adamat et al, 2003; El-Naqa, 2004; Thirumalaivasan et al, 2003; Rahman, 2007; Kim&Hamm,1999), and Africa (Lynch et al, 1997; Ibe et al, 2001). DRASTIC originally developed for manual overlay of semi quantitative data layers. However, the simple definition of its vulnerability index as a linear combination of factors shows the feasibility of the computation using GIS (Fabbri&Napolitano, 1995). RS (remote sensing) and GIS (geographic information system) are of great significancein DRASTIC model contamination Vulnerabilitymapping. These techniques have fundamentally changed our thoughts and ways to manage natural resources in general and water resources in particular(Madan et al, 2006). GIS is designed toanalyzeddiverse spatial data to represent spatially variable phenomena by applying a series of overlay analysis of data layers that are in spatial register (Bonham-Carter, 1996). Vulnerability assessment is a basis for initiating protective measures for important groundwater resources and will normally be the first step in groundwater pollution assessment (Foster et al, 2002). For the present study, DRASTIC model has used for Pb contamination vulnerability in Karaj plain.

The Study Area

The study area, Karaj plain is situated in northwest of Tehran, Iran, lies between latitudes 34°50′ to 35°30′ N and longitudes 47°12′, to 48°10′ E covering an area of 400sq km. The average height of the region is 1500 m above MSL.

There are more than 3000 large and small scale chemical, automotive and food industries in the region. (**Fig.1**)

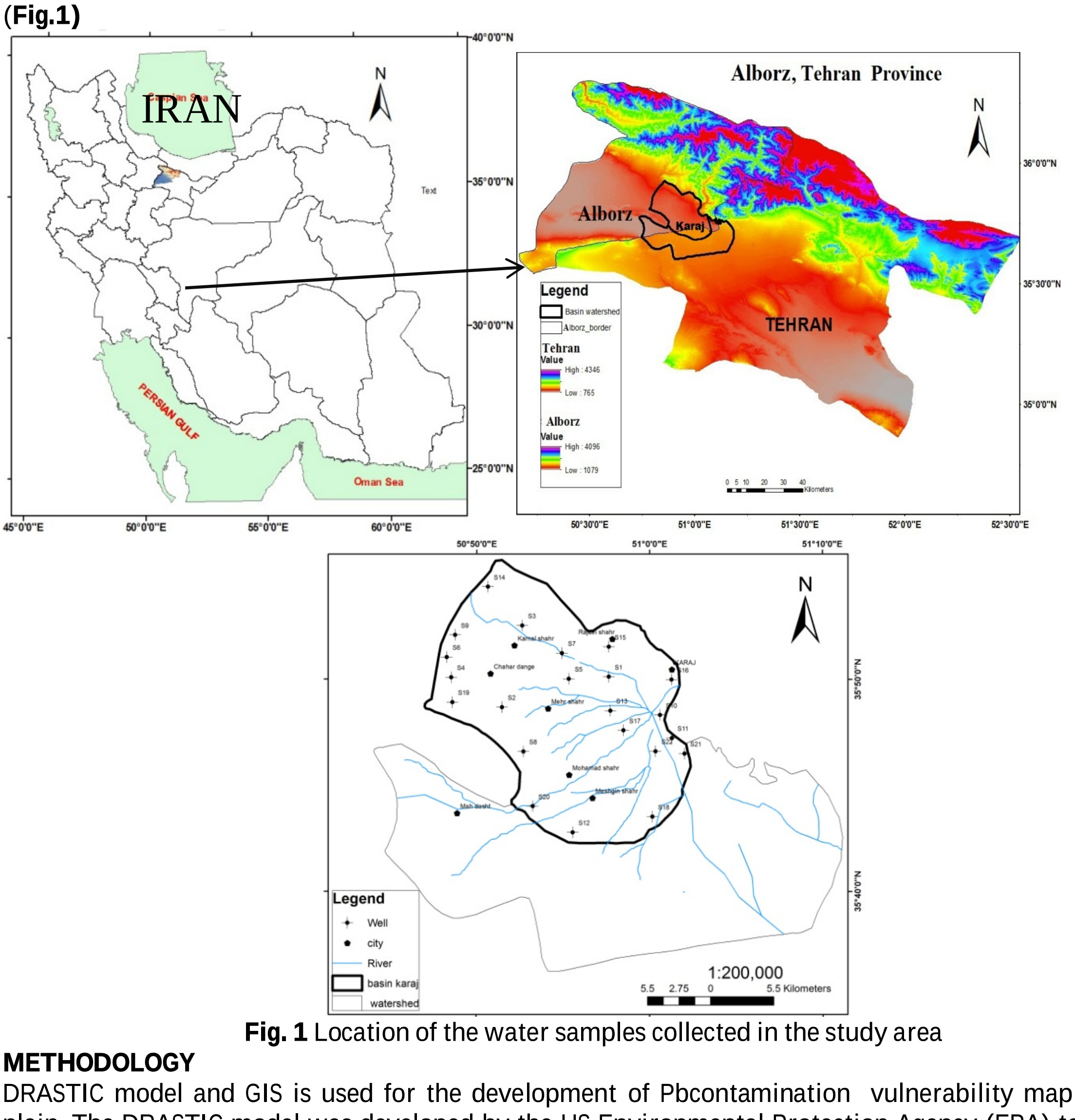

Fig. 1 Location of the water samples collected in the study area

METHODOLOGY

DRASTIC model and GIS is used for the development of Pbcontamination vulnerability map of Karaj plain. The DRASTIC model was developed by the US Environmental Protection Agency (EPA) to evaluate groundwater pollution potential for the entire United States (Aller et al, 1987). It was based on the concept, the heights of the hydro-geological setting that is defined as a composite description of all the major geologic and hydrologic factors that affect and control the groundwater movement into, through and out of an area (Aller et al, 1987). The acronym DRASTIC stands for the seven parameters used in the model which are: depth to water, net recharge, aquifer media, soil media, topography, impact of vadose zone and hydraulic conductivity (Table 1). DRASTIC uses a relatively large number of parameters (seven parameters) to compute the vulnerability index, which ensures the best representation of the hydrogeological setting. The numerical ratings and weights, which are established using the Delphi technique (Aller et al, 1987), are well defined and used worldwide. This makes the model suitable for producing comparable vulnerability maps on a regional scale. The necessary information needed to build up the several model parameters was available in the study area or could easily be inferred. Data analyses and model implementation were performed using the GIS software.

The model yields a numerical index that is derived from ratings and weights assigned to the seven model parameters. The DRASTIC Index is then computed applying a linear combination of all factors according to the following equation:

DRASTIC Index=DrDw+RrRw+ArAw+SrSw+TrTw+IrIw+Cr Cw (1)

Where D, R, A, S, T, I, C represent the seven hydrogeological factors, r is the notation value (1–10) and w is the weight value for a given parameter (1–5). The resulting DRASTIC index represents a relative measure of groundwater vulnerability for contamination. This model was selected based on the following considerations given in Table 1.

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Table 1 The DRASTIC model parameters (Aller et al, 1987)

Factor	Description	Relative weight
Depth to water	The depth from the ground surface to the water table, deeper water table levels imply lesser chance for contamination to occur.	5
Net recharge	The amount of water that penetrates the ground surface and reaches the water table.	4
Aquifer media	The saturated zone material properties, it controls the pollutant attenuation processes.	3
Soil media	The uppermost weathered portion of the unsaturated zone and controls the amount of recharge that can infiltrate downward.	2
Topography	The slope of the land surface, it dictates whether the runoff will remain on the surface to allow contaminant percolation to the saturated zone.	1
Impact of vadose zone	The unsaturated zone material, it controls the passage and attenuation of the contaminated material to the saturated zone.	5
Hydraulic conductivity	The ability of the aquifer to transmit water, hence determines the rate of flow of contaminant material within the groundwater system.	3

Development of the DRASTIC Vulnerability Index

To map the groundwater vulnerability of the study area, the DRASTIC indices calculated in the GIS environment and Eq. 1 used to produce the DRASTIC index. Several types of data are used to construct thematic layers of the seven model parameters:

Depth to Groundwater

Depth to water is important as it determines the depth of the material through which a contaminant travels before reaching the aquifer (Baalousha, 2006). Data recordedfrom piezometers in the study area were used to prepare the depth to water table layer. The depth to water layer was classified from one (least effect on vulnerability) to 10 (most effect on vulnerability) with regard to DRASTIC classification (Table 2). The resulting map is shown in **Fig. 2**.

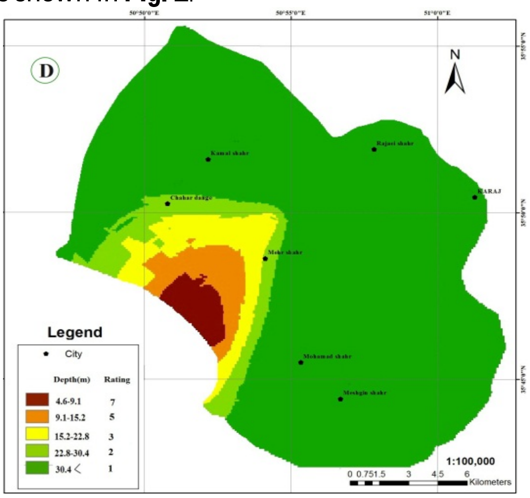


Fig. 2 Depth to Groundwater map according to DRASTIC Index

Net Recharge

Net recharge includes the average annual amount of infiltration and does not account for the distribution and intensity of recharge events. Recharge water is a significant medium for transporting contaminants from vadose zones to saturated zones. In the Ordos Plateau, there are nine groundwater systems (Yin et al, 2010). Two maps are required for the preparation of Recharge net. The first is a network of rainfall and second is the map of surface permeability of the study area and by multiplying these two maps; the recharge layer produced. Given that the average annual rainfall in this region is about 250 mm and the rate of permeability (Table 2). According to DRASTIC ranking model the net rechargeability of the area by and large is represented by one class.

Aquifer Media

Aquifer media describes consolidated and unconsolidated rock where water is contained. This also includes the pore spaces and fractures of the medium. The aquifer media therefore affect the flow within the aquifer. This flow path controls the rate of contaminant within the aquifer (Aller et al, 1987). Based on the 140 well logs available in the study area, the aquifer media layer was prepared. First, the aquifer media rating calculated for each well and by using these ratings and well locations, the aquifer media layer was prepared and finally converted to grid coverage. Aquifer media layer exhibits that most parts of the study area have the rating value equal two (Massive shale) and a small areas has two(Metamorphic/igneous) rating values (Fig. 3 and Table 2).

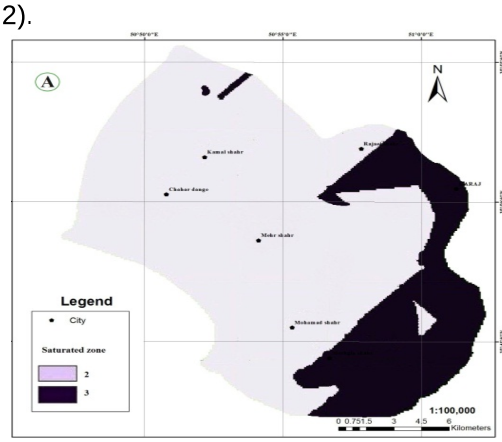


Fig. 3 Aquifer media map according to DRASTIC Index

Soil

DRASTIC soil map of the area was developed using a subsurface geology map, geological sections, and drilling profiles. The soil media layer reveals the recharge rate that could infiltrate into the pollution. The soil in the area consists of loam, sandy loam,clay loam.

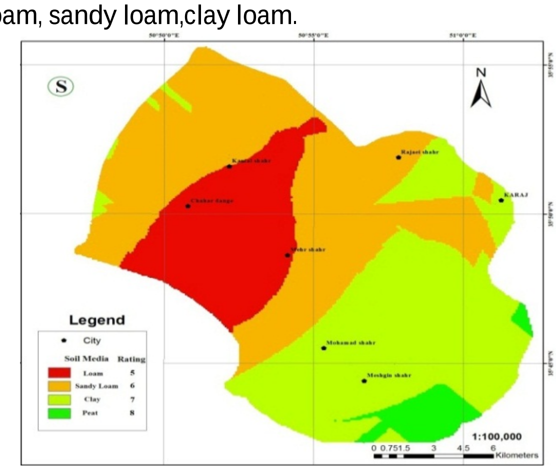


Fig. 4 Soil media map according to DRASTIC Index

Topography

Topography in the DRASTIC model displays the slope of the land surface(Aller et al, 1987). The topography was derived from the digital elevation model using a SOI map(1:100,000). The topography of the area was divided into five classes, which were mostly found in areas with slopes ranging from 0 to 6 %.

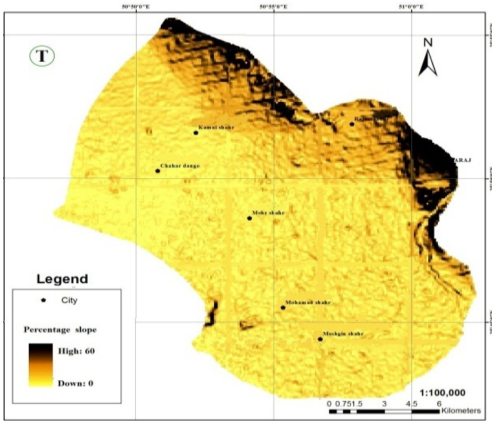


Fig. 5 Topographic map according to DRASTIC Index

Impact of Vadose Zone

The impact of the vadose zone was classified based on the drilling logs for each well. The impact of the vadose zone consists of Sand, gravel, Sandstone, Bedded limestone and silt. The weights and ratings for the vadose zone are shown in Table 3. Vadose zones have been mapped as shown in **Fig.6.**

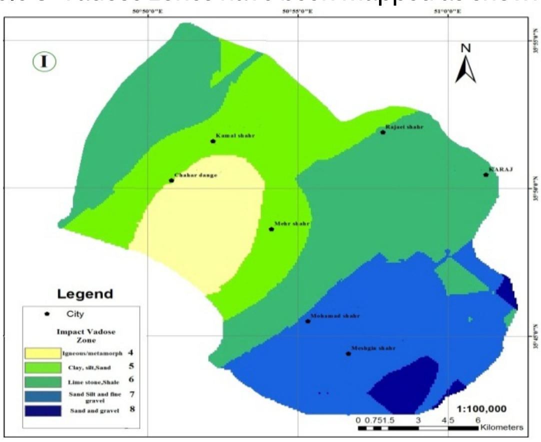


Fig.6 Map of Impact of vadose zone according to DRASTIC Index

Hydraulic Conductivity

The hydraulic conductivity of the aquifer was computed according to the following equation: $k = T/b$, where k is the hydraulic conductivity of the aquifer (m/s), T is the transmissivity(m^2/s), and b is the thickness of the aquifer (m). The hydraulic conductivity distribution map was generated using pumping test results of the area. Regions with maximum hydraulic conductivity exhibited higher chances of distribution contamination. Hydraulic conductivity was derived by measurement, and the GIS-ArcView was applied to interpolate the hydraulic conductivity and create the raster layer. Hydraulic conductivity could be divided into three classes. (Fig7 and Table 2).

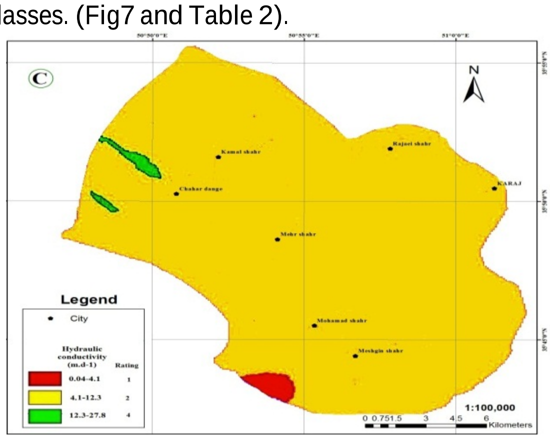


Fig.7 Hydraulic conductivity map according to DRASTIC Index

Table 2. Classification and rating of parameters of DRASTIC model in the Karaj plain

Rating	*Parameter*	*Rating*	*Parameter*	*Rating*	*Parameter*
	Depth to water(m)		**Aquifer media**		**Soil Media**
7 5 3 2 1	4.6-9.1 9.1-15.2 15.2-22.8 22.8-30.4 30.4 <	2 3	Massive Shale Igneous / metamorphic	5 6 7 8	Loam Sandy Loam Clay Peat
	Topography(%)		**Impact of Vadose zone**		**Hydraulic Conductivity(m/d)**
1 3 5 9 10	≥18 12-17.9 6-11.9 2-2.5 0-1.9	4 5 6 7 8	Igneous / metamorphic Clay, Silt, Sand Lime stone, Shale Sand, Silt and Gravel fine Sand, Gravel	1 2 4	0.04 - 4.1 4.1 – 12.3 12.3 – 27.8

The DRASTIC Vulnerability Index

The final raster for the overall Vulnerability Index was created using the raster calculator in Spatial Analyst tools by combining the seven hydro-geological data layers as illustrated in table 1. By following the method and theoretical model proposed (Alleret al, 1987), the final vulnerability maps of both qualitative and quantitative were developed (fig8a and b).

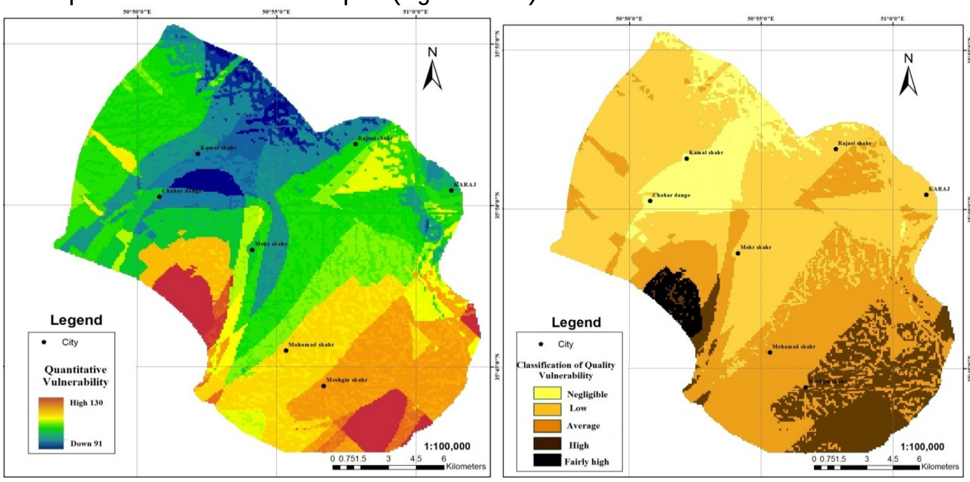


Fig. 8. The vulnerability DRASTIC map of Karaj Plain (**a**, Quantitative,**b**,Quality)

DRASTIC Model Testing

By assigning degree of vulnerability to each unit, Pb vulnerability map of aquifer of studyarea was developed. Since the ratio of the weight age considered for layers is different, it is necessary to have comparison and confirmation for the correct validation. The theoretical model proposed byAller and Bennett (Aller et al, 1987) is considered and by assigning degree of vulnerability to each unit

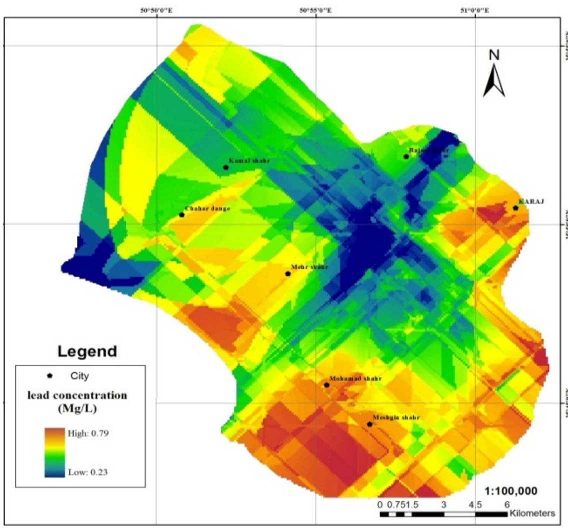
Water samples collected from agriculture wells were analyzed for Pb concentration in the laboratory, Ministry of Power, Iran (table 3and 4). The measured Pb concentration of the study area and the theoretical model proposed byAller and Bennett (Aller et al, 1987) are used forcomparison. Based on the results and analysis, Pb concentration vulnerability maps are constructed (Figure 9 a and b). By considering weigtage for all the parameters discussed above and drastic model and using multivariate statistical method (principal component analysis), the correlation coefficient between DRASTIC model parameters and lead layer was calculated by Arc GIS 10.1 software, Pb contamination limits map has developed (Figure 10). According to Fig. 10,Pb concentration vulnerability at the south and southwest and south eastern parts of study area is high and in the northern,and central parts is relatively low.

Table 3 Ranges and ratings Pb concentrations (mg/l)

Rating	Pb concentration(mg/l)
Negligible	0.2 – 0.47
Low	0.47 – 0.53
Average	0.53 – 0.58
High	0.58 – 0.62
Very high	0.62 – 0.8

Table 4 Pb concentrations (mg/l) in Karaj Plain

samples	Pb(mg/l)
S1	0.2
S2	0.61
S3	0.49
S4	0.56
S5	0.45
S6	0.58
S7	0.3
S8	0.62
S9	0.54
S10	0.58
S11	0.6
S12	0.71
S13	0.2
S14	0.59
S15	0.26
S16	0.63
S17	0.47
S18	0.58
S19	0.2
S20	0.62
S21	0.59
S22	0.57



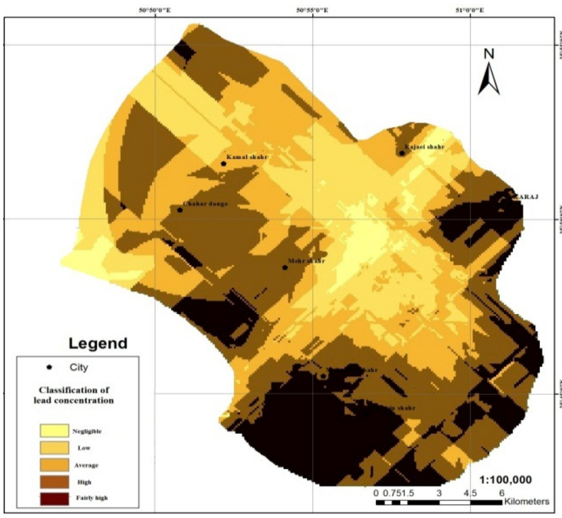


Fig 9.Pb concentrations vulnerability map of Karaj Plain (a, Quantitative, b, Quality)

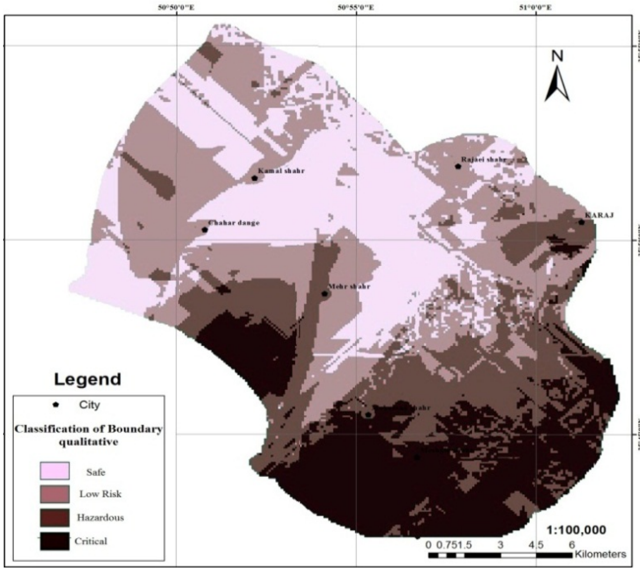


Fig10.Preparation of qualitative limits Karaj plain with DRASTIC model and Pb contaminations map

CONCLUSIONS

In this paper, the authors made an attempted to assess thePb concentration vulnerability of the aquifer of Karaj plain by employing the empirical index DRASTIC model. Seven geological/environmental parameters wereused to represent the natural hydrogeological setting of the Karaj aquifer. A map has been created using the DRASTIC model and a GIS to represent groundwatercontaminationvulnerability in Karaj plain and classified as low vulnerable area (north and northeast),low risk vulnerable area(central) and hazardous area (south and southwest area), critical area to pollution (south area).
Results of chemical analysis of water samples showed that Pb concentration in the groundwater at south and southwest parts of study area is more than in north and northeast parts. These results confirm the vulnerability assessment. Correlation analysis between DRASTIC parameters and Pb concentration layers showed that Pb concentration has the best correlation with impact of vadose zone parameter,followed by depth to water table parameter. The groundwater pollution vulnerability map of Karaj plain is ideal for use in future land-use planning studies, where potential contamination may occur.

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