Journal of Environmental Health and Sustainable Development

Spatial Analysis and Probabilistic Risk Assessment of Exposure to Nitrate in Drinking Water of Abarkouh, Iran

Reza Ali Fallahzadeh [1], Seyed Ali Almodaresi [2], Davoud Ghadirian [1], Ahmad Fattahi [3], Nasrin Homayoni bezi [4*]

[1] Environmental Science and Technology Research Center, Department of Environmental Health Engineering, Shahid Sadoughi University of Medical Sciences, Yazd, Iran.
[2] Department of GIS & RS, Engineering College, Yazd Branch, Islamic Azad University, Yazd, Iran.
[3] Department of Occupational Health, Shahid Sadoughi University of Medical Sciences, Yazd, Iran.
[4] Department of Environmental Health Engineering, School of Public Health, Bushehr University of Medical Sciences, Bushehr, Iran.

ARTICLE INFO

ORIGINAL ARTICLE

Article History:
Received: 24 January 2019
Accepted: 20 April 2019

Corresponding Author:
Nasrin Homayoni bezi

Email:
n.homayoni73@gmail.com

Tel:
+98 916 252 3893

Keywords:
Nitrate,
Geographic Information Systems,
Risk Assessment,
Drinking Water,
Abarkouh City.

ABSTRACT

Introduction: Several diseases, especially in infants such as some cancer and blue baby are related to the presence of nitrate in drinking water. The Environmental Protection Agency (EPA) specified the maximum contaminant level (MCL) of nitrate as 50 mg L^{-1} for regulated public water systems. This study aimed to evaluate the concentration of nitrate and to assess its probabilistic risk exposure in drinking water wells of Abarkouh city, Iran.

Materials and Methods: The average annual nitrate level was studied from 18 wells around Abarkouh in 2017. The Hazard Quotient (HQ) was also investigated as health risk assessment and sensitivity analysis was carried out for effective variables.

Results: Average concentration of nitrate was 27.57 ± 6.80 mg L^{-1} and all measured concentrations were below the permitted maximum standard (50 mg L^{-1}) according to the National Standard of Iran. The HQ value for children and adults were more than 1 (1.81) and less than 1, respectively. In calculating HQ for children, the most important variable was the concentration of nitrate in drinking water.

Conclusion: According to the results, children health is highly at risk in these areas and exposure to nitrate should be reduced for at-risk populations.

Citation: Fallahzadeh RA, Almodaresi SA, Ghadirian D, et al. **Spatial Analysis and Probabilistic Risk Assessment of Exposure to Nitrate in Drinking Water of Abarkouh, Iran**. J Environ Health Sustain Dev. 2019; 4(2): 744-52.

Introduction

Nitrate and nitrite are among the stable forms of nitrogen in aerobic systems [1]. Nitrate is widely used as a mineral fertilizer in agriculture. Furthermore, it is used as a food preservative. Sodium nitrate is considered as a preservative, especially in meat conserves [2]. The concentration of nitrate in surface water is naturally low and in the range of 0-18 mg L^{-1}. The entry of surface runoffs, especially runoff from agricultural land, can increase the concentration of nitrate in surface and groundwater [3]. Nitrate concentrations in surface waters are usually variable with season changes. In many European countries, nitrate concentrations have risen in recent decades; in some cases nitrate concentrations doubled in the last 20 years. For example, in some rivers in England, nitrate concentration had an average annual increase of 0.7 mg L^{-1} [4].

Efforts to treat wastewater containing nitrate compounds were targeted at reducing its concentration in environment [5]. The concentration of nitrate is usually low in groundwater under aerobic conditions and depends on the type of soil and its geological characteristics. In the United States, nitrate concentration in groundwater typically does not exceed 4-9 mg L^{-1} for nitrate and 0.3 mg L^{-1} for nitrite [6]. However, with increasing uncontrolled agricultural activities, nitrate concentration can increase dramatically [7]. For example, a concentration of more than 1500 mg L^{-1} was observed for nitrate in groundwater areas of India that was good for agricultural activities [8].

Considering nitrates exposure, carcinogenesis was not reported in laboratory animals, but increased tumor growth was reported in animals exposed to high levels of nitrite [9]. Nitrate toxicity in humans depends on the reduction of nitrate to nitrite. The most important biological effect of nitrite in humans is conversion of hemoglobin to methemoglobin, which cannot carry oxygen to body tissues. Common clinical signs appear when more than 10 percent of hemoglobin is converted to methemoglobin, which is called methemoglobin anemia. High concentrations of methemoglobin may result in choking and death.

Typically, methemoglobin concentration in body is less than 2 percent, but it is less than 3 percent among children of younger than three months old [2]. Many reasons, such as the entrance of agricultural water and sewage industries can increase the concentration of nitrate in groundwater [5, 10]. In some previous studies over nitrate concentration in ground water in Iran, the nitrate concentration was higher than the standard level in some areas. For example, in the study conducted by Mousavifazl and Fathi Hafshejani, the nitrate concentration was investigated in ground water in Mashhad and Shahrekord, respectively. The results showed that nitrate concentration was higher than the standard level (50 mg L^{-1}) in some areas [11, 12].

Today, electronic systems and software are used to monitor groundwater and assess the risks of existing pollutants [13]. One of the best ways to prevent groundwater contamination is to investigate the spatial distribution of groundwater quality and use its results in managing water resources and land use [14]. Geographic Information System (GIS) is a new technology used to analyze and interpret the distribution of pollutants in environmental studies [15, 16]. Inverse distance weight (IDW) is one of ArcGIS's application techniques for spatial and pollutants' distribution, which simulates pollutant concentrations in other parts of the study area based on the distance between points and concentration of pollutants at each point [17]. So far, various GIS software has been used to analyze, interpolate, and zone various pollutants [18-22]. Health risk assessment is a method that measures risk assessment based on the input data such as concentration of chemical and other parameters. This method can examine the real risk in areas where low risk is considered. Most recently, health risk assessment was used as a reasonable method to calculate risk potential of chemical pollutants [23, 24]. The aim of this study was to investigate the concentration of nitrate in drinking waters wells of Abarkouh. In this study, the health risk was studied for different groups.

Materials and Methods

Study area, sampling and analysis

In this study, the drinking water of Abarkouh city located in Yazd province in center of Iran was investigated. This city is located in the GPS coordinates of 31.1304 N, 53.2504 E has a population of 51552. In this area, drinking water is provided by underground water. Nitrate concentration data were obtained from water lab of Yazd health office. This data were seasonally (Four seasons) sampled during 2017 and assessment was based on the average concentration of nitrate in the studied area in 2017. The concentration of nitrate was determined by spectrophotometer method with DR-5000.

The demographic and geographic data of the studied area are presented in Table 1 and Figure 1 shows the location of wells in the city.

Table 1: Demographic and geographical information of the studied area

City	Population	City location	Study area (wells) location	Number of wells	Average flow (lit sec^{-1})
Abarkouh	51552	31° 7'N - 53°17'E	30˚52'N - 31˚12'N 52˚50'E - 53˚10'E	18	22.22 ± 2.63

Figure 1: Geographic location of the studied area

Spatial distributions

In order to zone the nitrate concentration in drinking water, ESRI's ArcGIS 10.1 software was used. The IDW interpolation technique was used for zoning and providing an independent raster layer related to the concentration of contaminants in different points of the study area [25]. In many studies, IDW techniques were applied to zone pollutants, such as investigation of the heavy metals' presence in West Bokaro groundwater and its spatial variation [26] as well as the survey of Eğirdir Lake Basin groundwater quality assessment and risk assessment used by GIS [27]. As mentioned, IDW is a non-statistical method using spatial prediction techniques for environmental studies to predict the concentration of pollutants at geographical points with unspecified concentrations [28, 29].

In the IDW hypothesis, the predictive values have a linear relation with the available data. The IDW model is calculated by the following equation [30, 31].

Equation (1): $Wi = \frac{Di-\propto}{\sum_{i=1}^{n} Di-\propto}$,

Where, W is the station weight i, Di is the distance between point i and place of unspecified values, α is the weight of power, and n is the total number of points used in zoning.

Health Risk Assessment

In this section, the risk of non-carcinogenicity associated with nitrate was studied to evaluate its health effects. Hazard Quotient or Non-carcinogenic hazards related to the nitrate was calculated by the following equation.

Equation (2): $HQ = \frac{EDI}{RfD}$

Where, RfD is the reference dose for nitrate that has been received by a specific exposure pathway in mg $Kg^{-1}day^{-1}$ based on the USEPA's Integrated Risk Information System (IRIS) database.

The Estimated Daily Intake (EDI) shows the daily intake of nitrate consumed by drinking water and is estimated using Equation 3 introduced by USEPA (1989) [32].

Equation (3): $EDI = \frac{C_W \times IR_W \times EF \times ED}{BW \times AT}$

In this equation, Cw is the concentration of nitrate in drinking water in mg L^{-1}, IRw is the drinking water ingestion rate based on L day^{-1}, EF is the exposure frequency based on Day $year^{-1}$, ED is the exposure duration in terms of years, BW is the body weight in Kg, and AT is the averaging time in days.

In this study, the sensitivity analysis technique was used to determine how different values of input variables can effect risk assessment in the assumed conditions. In this study, risk assessment was conducted using the Monte Carlo Simulation technique which is provided by the Oracle Crystal Ball (ver 11.1.2.4) software [33-35].

Ethical issues

This study was conducted with the approval of Shahid Sadoughi University of Medical Sciences and Health Services, Medical Ethics Committee. Code: IR.SSU.SPH.REC.1397.104

Results

The results of nitrate concentration analysis within 18 wells of Abarkouh showed that nitrate concentration in the studied wells was less than the standard set by both the EPA guidelines and Industrial Research of Iran No. 1053, which is 50 mg L^{-1} [36].

Figure 2 shows the concentrations and repetitions of nitrate in the wells. Based on Figure 2, the maximum concentration was 40 mg L^{-1} and the most frequent concentration was 25 mg L^{-1}. Wells number 1 to 4 had the highest nitrate concentration. The RMSE was 0.09826 for zoning nitrate concentration. Based on the risk assessment results for children and adults, the children group had a HQ of higher than 1, which represents a high risk population. Sensitivity analysis showed that concentration of drinking water nitrate was the most important factor affecting health risk of both groups.

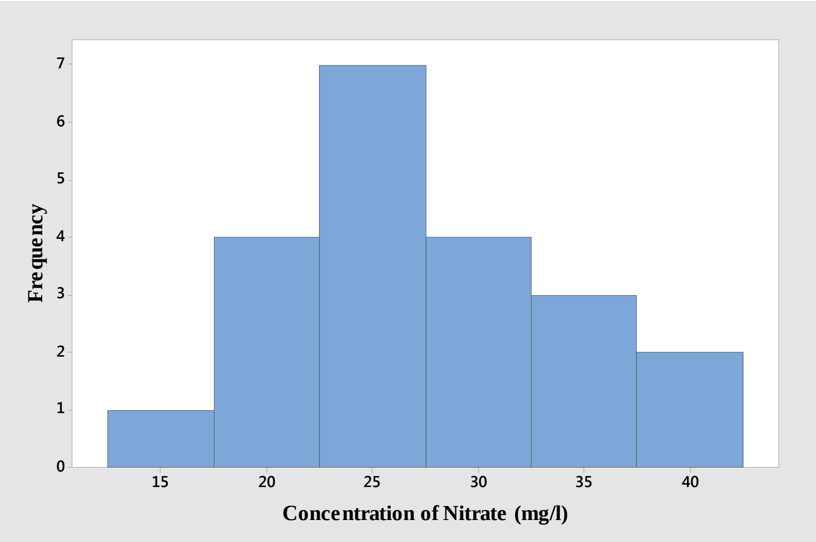

Figure 2: Histogram of nitrate concentration and frequency in the study area

Discussion

Spatial distributions

The spatial distribution of nitrate concentration was conducted by ArcGIS software using the IDW technique in the studied area. Based on the spatial variation, wells numbers of 1-4 had the highest concentrations of nitrate; whereas, wells numbers 13, 14, and 16 had the lowest nitrate concentrations. Figure 3 shows the map prepared based on the concentration of nitrate in the 18 studied wells. High concentrations of nitrate in these wells, which are near each other and in the same region, can indicate a source of regional pollution such as agriculture. Therefore, the area should be investigated in terms of the contamination source. The concentration of nitrate in groundwater under aerobic conditions is usually low and depends on the type of soil and its geological characteristics. In the United States, nitrate concentration in groundwater typically ranges from 4-9 mg L^{-1} for nitrate and 0.3 mg L^{-1} for nitrite [37]. However, with increasing uncontrolled agricultural activity, nitrate concentration can increase significantly [38]. For example, a concentration of more than 1500 mg L^{-1} was observed for nitrate in groundwater of India that was used for agriculture [8]. Mousavifazl et al. conducted a study to evaluate nitrate in 276 wells in Mashhad city, Iran. The nitrate plans showed that nitrate concentrations in a certain part of some areas are higher than the standard limit [39]. In another study Fathi Hafshejani et al. evaluated the spatial distributions of nitrate concentration in 100 groundwater wells of Shahrekord (Iran) from 2006 to 2011. The results showed that concentrations of nitrate were high in the south part of the studied area, which can be caused by the presence of municipality treatment plants and intensive cattle farming in this area [11].

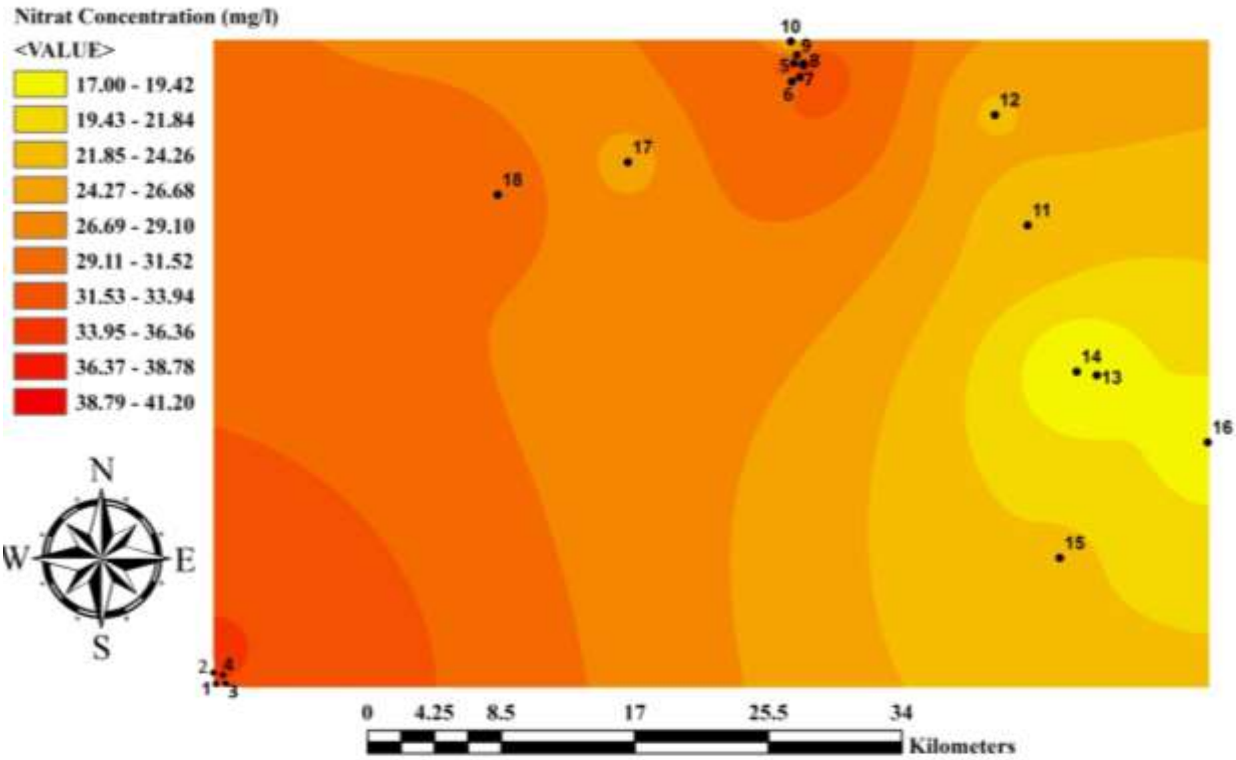

Figure 3: Zoning the concentration of nitrate in the studied area

Health Risk Assessment

An HQ non-carcinogenic risk assessment was conducted to assess health risk. According to this assessment, in the case that HQ is higher than 1, the target population is considered to be at high health risk and water consumption can cause illness. The population studied in this research was divided into two groups of children (0 to 7 years old) as well as teens and adults (over 7 years old). Figure 4 shows the calculated HQ for children and Figure 5 shows the HQ for teens and adults.

The average non-carcinogenic risk for the adult group in the study area was estimated to be less than 1 and therefore, it is negligible. The HQ values for the 95th percentile in the adult age group was less than 1 and for children group was higher than 1, which indicates a high non-carcinogenic risk for the children age group. The

reason of high risk for children is their low body weight [40]. The highest 95th percentile of the calculated HQ in the study areas was 1.81 for children, which shows a higher non-carcinogenic risk. For all studied regions, the non-carcinogenic risk of nitrate for the two exposed groups was Adults<Children. According to the results of health risk assessment, children are the population at risk, which is similar to the results reported by Zhang et al. [41] and Guissouma et al. [42]

Sensitivity analysis

Sensitivity analysis was conducted to determine the most effective variable in increasing the health risk. Figures 6 and 7 show the sensitivity analysis of variables in calculating HQ for children and adults, respectively. Based on the results, the amount of nitrate concentration in drinking water had the greatest impact on increasing non-carcinogenic risk for the two groups; so, decrease of nitrate concentration in water can reduce the risk of health. It should be noted that due to the high non-carcinogenic risk for children group, reducing the concentration of nitrate would have the most effect in reducing the health risk. In addition to drinking water, nitrate can also enter the body through other forms of contact, such as skin absorption [23] and the consumption of various foods [36]. In this regard, the best way to reduce pollutant concentrations in this area is to investigate the whole region and eliminate the sources of contamination [43]. As a result, reduction of nitrate concentration would reduce the health risks in children group [24].

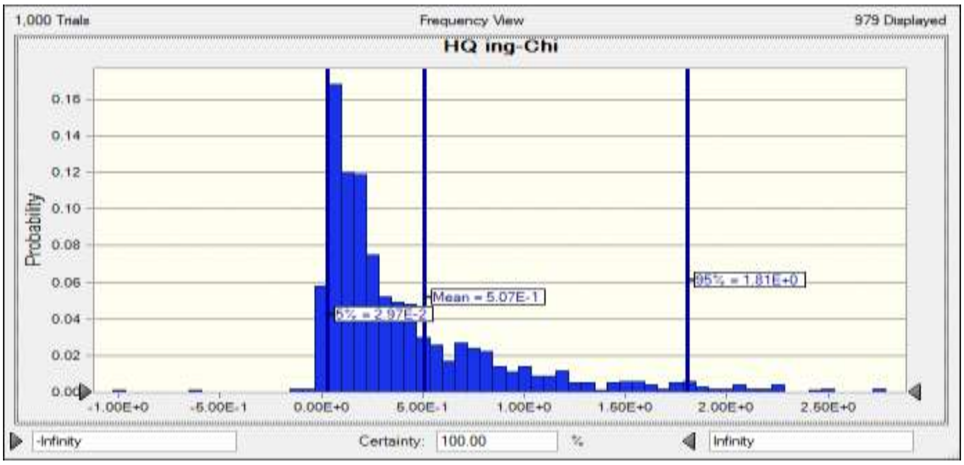

Figure 4: The range of HQ for the children population

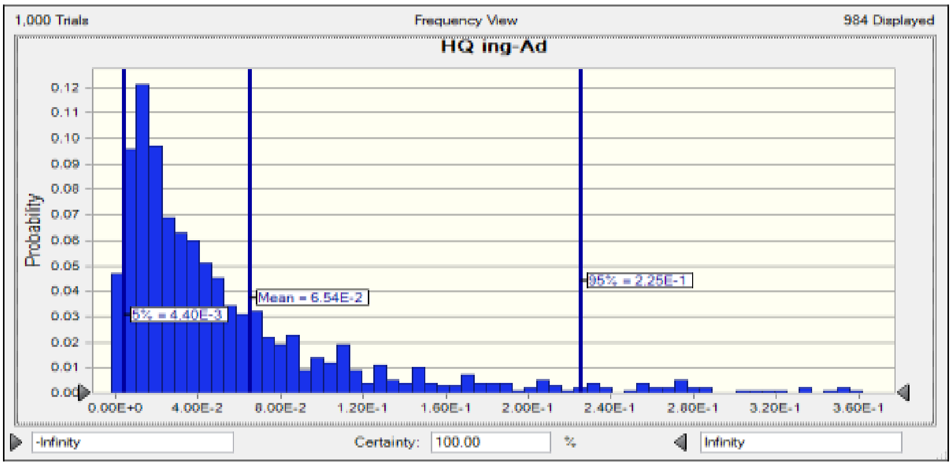

Figure 5: The range of HQ for the teens and adults population

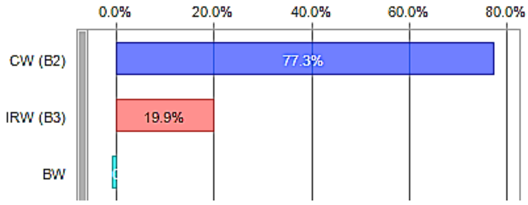

Figure 6: The results of sensitivity analysis of the variables involved in calculating HQ for the children population

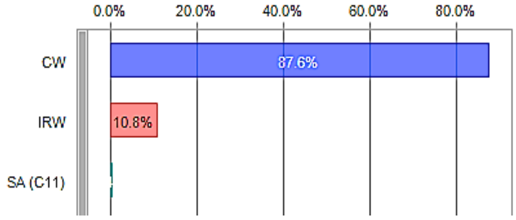

Figure 7: The results of sensitivity analysis of the variables involved in calculating HQ for teens and adults population

Conclusion

In this study, nitrate concentrations were investigated in 18 drinking water supply wells in Abarkouh city of Yazd. The results showed that nitrate concentration in these wells was less than the guidelines set by the Institute of Standards and Industrial Research of Iran. Subsequently, nitrate concentration was measured in the study area. According to the findings, the highest concentrations of nitrate were in wells 1 - 4. Moreover, HQ or non-carcinogenic risk assessment was performed for the two populations in the study area. The results indicated that the HQ values were more than 1 in the children group; therefore, they are at high risk. Sensitivity analysis test showed that the main variable involved in increasing the health risk was concentration of nitrate in drinking water; so, reducing the concentration of nitrate can reduce the risk level in the population at risk.

Acknowledgements

The authors would like to thank the Environmental Science and Technology Research Center of Shahid Sadoughi University of Medical Sciences for technical support.

Funding

This study was funded by the Environmental Science and Technology Research Center, Shahid Sadoughi University of Medical Sciences, Yazd.

Conflict of interest

No conflict of interest was stated by the authors.

References

1. Fan AM, Steinberg VE. Health implications of nitrate and nitrite in drinking water: an update on methemoglobinemia occurrence and reproductive and developmental toxicity. Regul Toxicol Pharmacol. 1996; 23(1): 35-43.
2. WHO. Guidelines for drinking-water quality. World Health Organization; 2004.
3. Rezaei M, Karimi F, Parviz M, et al. An empirical study on aflatoxin occurrence in nuts consumed in Tehran, Iran 2013. Health. 2014; 6(08): 649.
4. Young C, Morgan-Jones M. A hydrogeochemical survey of the chalk groundwater of the banstead area, survey, with particular reference to nitrate. Journal of the Institution of Water Engineers and Scientists. 1980; 34(3): 75-83.
5. Azadi NA, Fallahzadeh RA, Sadeghi S. Dairy wastewater treatment plant in removal of organic pollution: a case study in Sanandaj, Iran. J Adv Environ Health Res. 2015; 2(2): 73-7.

6.Manassaram DM, Backer LC, Moll DM. A review of nitrates in drinking water: maternal exposure and adverse reproductive and developmental outcomes. Cien Saude Colet. 2007; 12(1): 153-63.

7.Ward MH. Workgroup report: Drinking-water nitrate and health-recent findings and research needs. Environ Health Perspect. 2005; 113(11): 1607.

8.Jacks G, Sharma V. Nitrogen circulation and nitrate in groundwater in an agricultural catchment in southern India. Environmental geology. 1983; 5(2): 61-4.

9.Speijers G, Van Went G, Van Apeldoorn M, et al. Integrated criteria document Nitrate effects. appendix to RIVM report No: 1987 (758473007).

10. Kheradpisheh Z, Almodaresi SA, Khaksar Y, et al. Zoning of groundwater contaminated by Nitrate using geostatistics method (case study: Bahabad plain, Yazd, Iran). Desert. 2014; 19(1): 83-90.

11. Fathi Hafshejani E, Beigi Harchegani H. Spatial variability and mapping of nitrate and phosphate in Shahrekord groundwater over a period of five years. Journal of Water and Soil Science. 2013; 17(65): 63-75.

12. Mousavi S, Balali-Mood M, Riahi-Zanjani B, et al. Concentrations of mercury, lead, chromium, cadmium, arsenic and aluminum in irrigation water wells and wastewaters used for agriculture in Mashhad, northeastern Iran. Int J Occup Environ Med. 2013; 4(2): 200-80.

13. Fallahzadeh RA, Gholami M, Madreseh E, et al. Comparison of using an electronic system and conventional monitoring method for monitoring the quality of drinking water and defects discovery in rural area water distribution network of Abarkouh, Iran. Health. 2015; 7(01): 35.

14. Ehsani H, Javid A, Hasani A, et al. Evaluation of nitrate variation and total dissolved solids trend in drinking water using GIS Hamedan plain ground. 10th national Conference on Environmental Health; 2007.

15. Merchant JW. GIS-based groundwater pollution hazard assessment: A critical review of the DRASTIC model. Photogramm Eng Remote Sensing. 1994; 60: 1117.

16. Khosravi R, Eslami H, Almodaresi SA, et al. Use of geographic information system and water quality index to assess groundwater quality for drinking purpose in Birjand City, Iran. Desalination Water Treat. 2017; 67(1): 74-83.

17. Cressie N. Statistics for spatial data.John Wiley & Sons; 2015.

18. Gaus I, Kinniburgh D, Talbot J, et al. Geostatistical analysis of arsenic concentration in groundwater in Bangladesh using disjunctive kriging. Environ Geol. 2003; 44(8): 939-48.

19. Barca E, Passarella G. Spatial evaluation of the risk of groundwater quality degradation. A comparison between disjunctive kriging and geostatistical simulation. Environ Monit Assess. 2008; 137(1): 261-73.

20. Dayani M, Mohammadi J, Naderi Khorasgani M. Geostatistical assessment of Pb and the related soil physical and chemical properties in near-surface soil around Sepahanshahr, Isfahan. Desert. 2010; 15(2): 139-49.

21. Motaghian H, Mohammadi J. Statistical and geostatistical appraisal of spatial variability of aggregate stability and aggregate-associated organic carbon content on a catchment scale in a semi-arid region, central Iran. Desert. 2012; 17(1): 27-39.

22. Jafari M, Tahmoures M, Mohammad Asgari H, et al. Assessment of soil property spatial variation based on the geostatistical simulation. Desert. 2012; 16(2): 87-100.

23. Fallahzadeh R, Ghaneian M, Miri M, et al. Spatial analysis and health risk assessment of heavy metals concentration in drinking water resources. Environ Sci Pollut Res Int. 2017; 24(32): 24790-802.

24. Fallahzadeh RA, Ghadirian D. Spatial distribution, health risk assessment and survey of fluoride pollution source with GIS in drinking water: A case study, Abarkouh, Iran. Journal of Environmental Health and Sustainable Development. 2018; 3(2): 496-503.

25. Eslami H, Almodaresi S, Khosravi R, et al. Assessment of groundwater quality in Yazd-

Ardakan plain for agricultural purposes using geographic information system (GIS). Journal of Health. 2018; 8(5): 575-86.

26. Tiwari AK, Singh PK, Singh AK, et al. Estimation of heavy metal contamination in groundwater and development of a heavy metal pollution index by using GIS technique. Bull Environ Contam Toxicol. 2016; 96(4): 508-15.
27. Şener Ş, Şener E, Davraz A. Assessment of groundwater quality and health risk in drinking water basin using GIS. J Water Health. 2017; 15(1): 112-32.
28. Miri M, Shendi MRA, Ghaffari HR, et al. Investigation of outdoor BTEX: Concentration, variations, sources, spatial distribution, and risk assessment. Chemosphere. 2016; 163: 601-9.
29. Azimzadeh HR, Fallahzadeh RA, Ghaneian MT, et al. Investigation of chemical characteristics and spatiotemporal quantitative changes of dust fall using GIS and RS technologies; a case study, Yazd city, central plateau of Iran. Environmental Health Engineering and Management Journal. 2017; 4(1): 45-53.
30. Xie Y, Chen T-b, Lei M, et al. Spatial distribution of soil heavy metal pollution estimated by different interpolation methods: Accuracy and uncertainty analysis. Chemosphere. 2011; 82(3): 468-76.
31. Almodaresi SA, Jafari SJ, Hosseinzadeh E, et al. Investigation of fluoride concentration in rural drinking water resources of bardaskan county using geographic information system (GIS) in 2014. Journal of Torbat Heydariyeh University of Medical Sciences. 2016; 3(4): 32-41.
32. EPA A. Risk assessment guidance for superfund. Volume I: human health evaluation manual (Part A): EPA/540/1-89/0021989.
33. Dan JG, Guix A, Martí V, et al. Monte Carlo simulation as a tool to show the influence of the human factor into the quantitative risk assessment. Process Saf Environ Prot. 2016; (102): 441-9
34. Ren L, He L, Lu H, et al. Monte Carlo-based interval transformation analysis for multi-criteria decision analysis of groundwater management strategies under uncertain naphthalene concentrations and health risks. J Hydrol. 2016; 539: 468-77.
35. Greenland S. Sensitivity analysis, Monte Carlo risk analysis, and Bayesian uncertainty assessment. Risk Anal. 2001; 21(4): 579-84.
36. Fallahzadeh RA, Almodaresi SA, Dashti MM, et al. Zoning of nitrite and nitrate concentration in groundwater using Geografic Information system (GIS), case study: drinking water wells in Yazd City. Journal of Geoscience and Environment Protection. 2016; 4(03): 91.
37. EPA U. Estimated national occurrence and exposure to Nitrate/Nitrite in public drinking water supplies. US Environmental Protection Agency Washington DC; 1990.
38. WHO. Health hazards from nitrates in drinking-water: Report on a WHO meeting, copenhagen, 5-9 march 1984: world health organization, Regional Office for Europe; 1985.
39. Moosavi Fazl SH, Alizadeh A, Ghahraman B. Application of geostatistical methods for determining nitrate concentrations in groundwater (Case study of Mashhad plain, Iran). International Journal of Agriculture and Crop Sciences. 2013; 5(2): 32-41.
40. Fallahzadeh RA, Miri M, Taghavi M, et al. Spatial variation and probabilistic risk assessment of exposure to fluoride in drinking water. Food Chem Toxicol. 2018; 113: 314-21.
41. Huang D, Yang J, Wei X, et al. Probabilistic risk assessment of Chinese residents' exposure to fluoride in improved drinking water in endemic fluorosis areas. Environ Pollut. 2017; 222: 118-25.
42. Guissouma W, Hakami O, Al-Rajab AJ, et al. Risk assessment of fluoride exposure in drinking water of Tunisia. Chemosphere. 2017; 177: 102-8.
43. Fallahzadeh RA, Khosravi R, Dehdashti B, et al. Spatial distribution variation and probabilistic risk assessment of exposure to chromium in ground water supplies; a case study in the east of Iran. Food Chem Toxicol. 2018; 115: 260-6.