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Spatial Distribution, Health Risk Assessment and Survey of Fluoride Pollution Source with GIS in Drinking Water: A Case Study, in Abarkouh, Iran

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ABSTRACT

Introduction: Exposure to high concentrations of fluoride in drinking water can negatively affect lung, liver and kidney tissues, and cause skeleton pain; however, lack of fluoride can cause tooth decay and bone problems.

Materials and Methods: In this study, the concentration of fluoride was investigated and its spatial distribution was carried out with Arc GIS software in underground water of Abarkouh aquifer. The health risk assessment, type of pollution distribution and its source was investigated using Moran's index.

Results: The average concentration of fluoride in 21 wells was 0.623 ± 0.296 mg/L which in 47.61% were less than the minimum concentration standard range set by the WHO guidelines. The Moran's index for fluoride concentration in the study area was 0.653 and given the z-score of 4.117. There is less than 1% likelihood that this clustered pattern could be the result of a random chance .

Conclusion: According to the results, Non-carcinogenic risk indicates a high risk for children (HQ = 1.03E0). The source of pollution is close to well No. 15. Investigating the study area and eliminating the pollution source is effective in decreasing the fluoride concentration of water and can reduce the health risk for children.

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Introduction

Fluoride is a vital element in the human body and most of which is supplied through water. At low concentrations, it is essential and is harmful at high concentrations [1]. The lack of fluoride can cause tooth decay and bone problems. Tooth decay has been significantly increased in societies with a fluoride content in water less than 0.5 mg/L [2]. Long-term consumption of its anion can have adverse effects, including bone and dental fluorosis, infertility, neurological problems, Alzheimer and thyroid problems [3-5]. Factors affecting the formation of fluoride contamination in water include weathering

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and leaching of rocks and fluoride-containing minerals, long reaction times of water and stone, the existence of active ions of sodium and bicarbonate, and pH [6, 7]. The pH is proportional to the calcium and magnesium deficiency and the fluoride concentration, so that alkaline water provides suitable conditions for the dissolution of the fluoride [3, 8]. So far, little research has been done on the contamination of fluoride in groundwater in Iran. In the study of the cause of the increase of fluoride in the water of Maku region of Iran in western Azerbaijan province [9], the results indicate high concentration of fluoride in samples taken from basaltic areas. The accumulation of fluoride in groundwater is related to the presence of Na^+ and HCO_3^- ions, so that these ions help to increase the solubility of fluoride-rich minerals. In the study of fluoride-rich waters in Mysonami area of Japan [10] it was concluded that the process of dissolving fluoride-containing minerals liberated fluoride. Investigating the reasons for the high fluoride in Pakistan waters [11] showed that the most important geochemical characteristics that cause high fluoride levels, are including TDS, alkaline pH, high Na^+ concentration and high sodium absorption rate. Investigation of the chemical processes controlling the fluoride accumulation in the underground water of Taiwan basin showed that high fluoride waters are seen in depth of less than 4 meters. This increase in fluoride in this water is due to diet; furthermore, the chemical composition of water affects the amount of solvent. The water having bicarbonate ions and sodium ions with alkaline pH increase the solubility of fluoride-rich minerals. A study in the water containing fluoride in Malawi [12] showed that the fluoride source is weathered biotite, hornblende and fluorite. Many of these waters have a superficial origin that penetrates into the weathering rock and dissolves fluoride. High levels of fluoride can also have volcanic origin. Surface and underground water studies using multiple analysis method in western of Niger Delta [13] revealed that fluoride pollution occurs in shallow water and is the main cause for the presence of fluoride-containing minerals, namely, hydroapatite, fluorapatite, cryolite and fluorespar. Furthermore, the water is rich in sodium and rich in magnesium and calcium ions. High levels of fluoride have been reported in some parts of the country, including the plains of Poldasht and Bazargan in Western Azarbaijan province [9].

Geographic information system (GIS) is a geostatistical technique that uses the ArcGIS software as a suitable tool to represent spatial distributions of various parameters in different environments like groundwater [14]. The GIS is a suitable tool to determine the quality of contaminants in groundwater between distant points [15- 18].

This study aimed to evaluate the concentration of fluoride in groundwater of Abarkouh, the spatial distributions and investigation of the source of contamination with the GIS software. Ultimately the health risk assessment of contact with fluoride in the studied population was evaluated.

Materials and Methods

Studied area

For this study, 21 drinking water supply wells in Abarkouh were sampled in 4 periods in 2016 (one sample a season). Fluoride concentration data were obtained from the health center laboratory of Abarkouh. The samples were collected from all wells that used as supply of drinking water in study area. For water sampling, used of a 1 L polyethylene. Then samples were labeled and transferred to the lab in 4 °C. Samples were analyzed using a flame atomic absorption spectrometer (FAAS, Spectra model AA-20, Varian, Australia). The demographic and geographic data of the studied area are presented in Table 1. The location of the wells in the county was shown in Figure 1.

Table 1: The demographic and geographic data of the studied area

City	Population	City location	Study area (wells) location	Number of wells	Average flow (lit/sec)
Abarkouh	51552	31° 7'N-53°17'E	30˚52'N-31˚12'N 52˚50'E-53˚10'E	21	22.22 ± 2.63

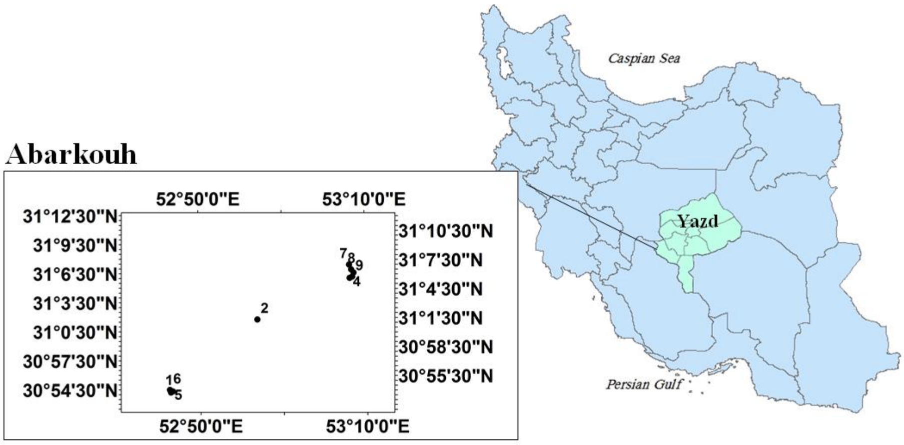

Figure 1: Geographic location of the studied area

Spatial distributions

In this study ArcGIS 10.4.1 (Esri, Berkeley, CA, USA) was used for spatial and fluoride distribution in the studied areas. The inverse distance weighting (IDW) method was used to prepare a fluoride zonation map. The IDW is an algorithm that uses data interpolation in a spatial form to predict the variable value by using the average weight of each variable and the distance between points [15]. The Moran's Index function in GIS software was used to study the source of contamination in this study.

Health risk assessment

In this study, three age groups of people were determined as 3 to 10 years, 11 to 20 years old and 21 to 72 years old to assess the health risk of Abarkouh population and evaluate their health potential [2, 6, 19]. Moreover, the amount of daily exposure to fluoride by drinking water was measured using the formula 1, which was introduced by the USEPA (1989) [20].

Formula 1: $\mathrm{EDI_{ing}} = \frac{\mathrm{C_W \times IR_W \times EF \times ED}}{\mathrm{BW \times AT}}$

EDI formula estimates the amount of daily received fluoride by drinking water based on mg/kg/day. In this formula, *Cw* is the fluoride concentration in drinking water based on mg/L, *IRw* is daily drinking water consumption based on person/day, *EF* is exposure frequency based on day/year, *ED* is exposure duration in terms of years, *BW* is Body weight in terms of Kg and AT is the average time in terms of day.

The Hazard quotient (HQ), the non-contact risk estimation for fluoride by drinking water, was calculated using Formula 2.

Formula 2: $\mathrm{HQ} = \frac{\mathrm{EDI}}{\mathrm{RfD}}$

RfD, expressing the reference fluoride dose via a special contact point in mg/kg/day, equals to 0.6 mg/kg/day [21].

Results

Fluoride concentrations were different in the studied area, from 0.14 mg/L to 1.17 mg/L with an average of 0.662 ± 0.33 mg/L, which was lower than the maximum standard value determined by the WHO (1.5 mg/L). However, it was less than the minimum standard in 47.61% of the cases. The histogram of fluoride concentration in drinking water in the Abarkouh area is shown in Figure 2. Overall, 52.38% of the samples were in the WHO standard range (0.5-1.5 mg/L), compared with WHO, EU [22] and Canada [23] guidelines. Moreover, 47.61% of cases were less than 0.5 mg/L.

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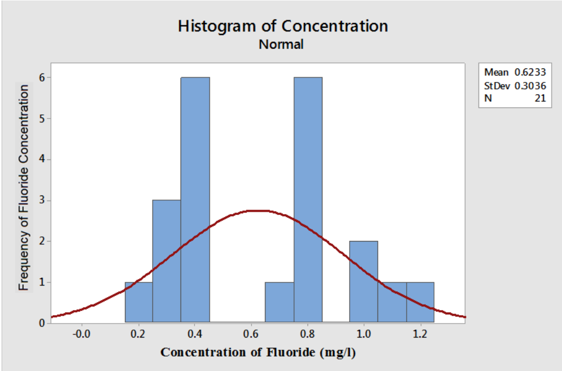

Figure 2: Histogram of the fluoride concentration in the studied area and the number of repetitions

Discussion

Spatial Distributions

The spatial distribution of fluoride by the IDW method with RMSE 0.091 in Abarkouh groundwater is shown in Figure 3. Drinking water well No. 15 has the highest concentration of fluoride in terms of spatial range. Groundwater in the eastern part of the catchment area has a fluoride concentration of less than 0.5 mg/L, less than the WHO guidelines [24]. According to studies, decreasing the amount of fluoride from 0.5 mg/L leads to increased dental caries [25- 27].

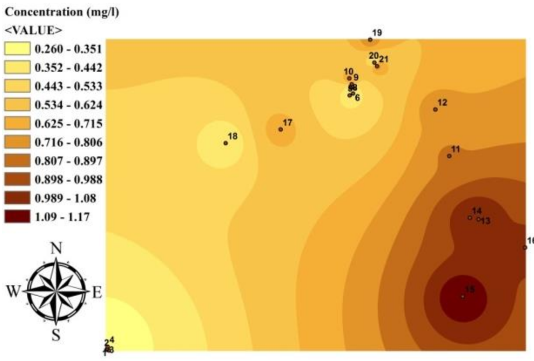

Figure 3: Zoning the fluoride concentration in the studied area

Health Risk Assessment

In this study in order to evaluate the health risk of fluoride in groundwater consumed for drinking, the non-carcinogenic risk (HQ) was used. The EDI is presented in Table 2 for populations in three age groups of young children, teenagers and adults exposed to fluoride by drinking water. For all the age groups except children, the average non-carcinogenic risk value was estimated less than 1 and negligible (Figures 4- 6). The reason for the high non-carcinogenic risk for young children was the low BW for this group compared to other age groups [28]. Initial signs of acute fluoride intoxication occur at a dose of 0.3 mg F kg-1 BW [29]. In this study, none of the age groups studied received this dose. For all the studied areas, the non-carcinogenicity of fluoride was classified as Adults > Teenagers > Children for three groups of exposed population. According to the results of health risk assessment, which is consistent with the study by Zhang et al. [30] and Guissouma et al. [31], the age group of young children is at potential risk.

Table 2: The amount of EDI and HQ calculated by the studied groups

Parameter	Adults		Teenagers		Children	
	Mean	95th percentile	Mean	95th percentile	Mean	95th percentile
EDI	2.22E-3	6.91E-2	9.41E-3	2.80E-2	1.89E-2	6.23E-2
HQ	3.78E-2	1.17E-1	1.54E-1	4.84E-1	3.06E-1	1.03E0

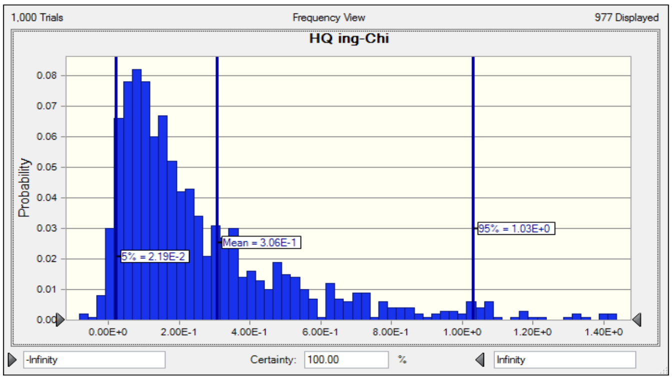

Figure 4: The range of the HQ for the young children population

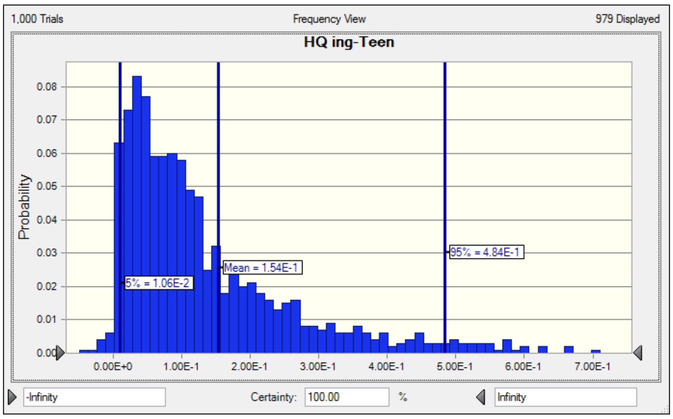

Figure 5: The range of the HQ for the Teens population

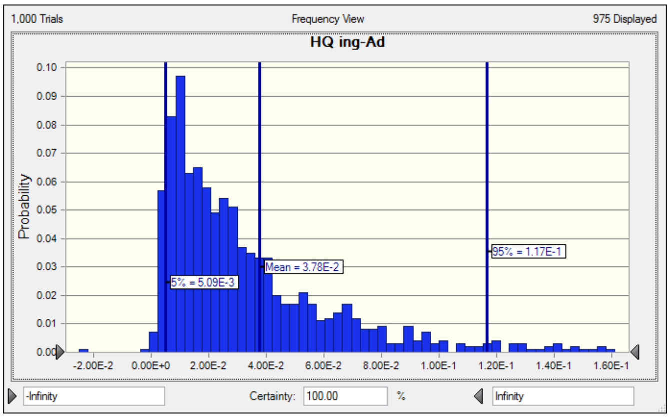

Figure 6: The HQ range for the Adults population

Sensitivity Analysis

Sensitivity analysis was performed to determine the most effective variable on the calculated health risk value. Figure 6 shows the results of the sensitivity analysis for the assessment of non-carcinogenic risk for the three age groups of young children, teenagers and adults exposed to fluoride.

In all the age groups, the concentration of fluoride (CW) in drinking water was the most important variable affecting the health risk values. The factors affecting the amount of drinking water consumed in a day are the weather conditions of the that area, so that, with increasing temperature, drinking water consumption (IRW) increases and the person is exposed to higher levels of fluoride [32, 33]. Fluoride can also enter the human body through other ways of contact, such as absorption through skin contact [21] and eating various foods [34].

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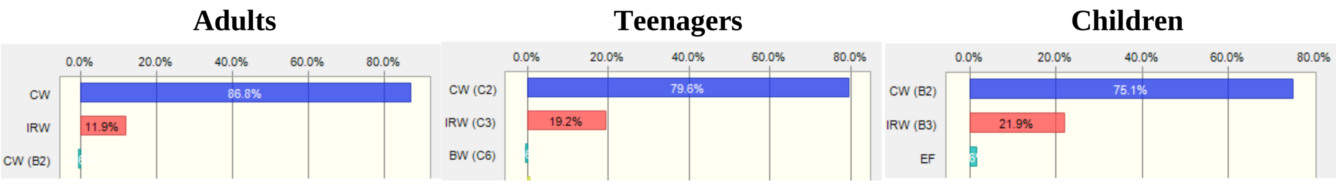

Figure 6: The results of the sensitivity analysis of the variables involved in calculating the HQ by the studied groups

Analysis of Moran's Index

The Moran's index for fluoride concentration in the studied area was 0.653 with a z-score of 4.117, representing the cluster pattern of the distribution of fluoride concentration. The cluster pattern indicates the point of contamination (Figure 7). According to the results of zoning, the source of contamination is near well No. 15.

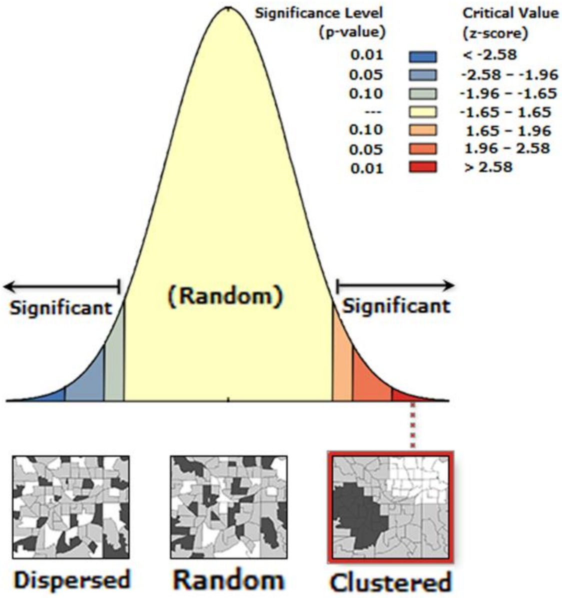

Figure 7: Moran's Index Analysis Results

Conclusion

In this study, the concentration of fluoride was evaluated in 21 drinking water supply wells in Abarkouh. The results showed that the concentration of fluoride in water in these wells is less than the maximum amount of guidelines set by the Iranian Standards Institute and, on the other hand, is lower than the minimum standard in 47% of the cases. Then the zoning of fluoride was done in the studied area. The results showed that the highest concentration of fluoride was in well No. 15. According to the Moran's index, the contamination spread pattern is cluster that indicates the point of contamination. The HQ non-carcinogenic risk assessment was performed for the three groups of age in the studied area and it was observed that the HQ values in the young children group were greater than 1 and therefore were at risk. The sensitivity analysis test showed that the most important factor in increasing the health risk is the fluoride concentration in drinking water; therefore, reducing the concentration of fluoride can reduce the risk.

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Conflict of interest

No conflict of interest has been stated by the authors.

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