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# Spatial Distribution and Health Risk Assessment of Nitrate in Drinking Water: A Case Study in the Central Plateau of Iran

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***ABSTRACT***

***Introduction:*** This study aimed to determine nitrate levels in water wells supplying drinking water in Taft city, Iran, and assess the associated health risks using the method proposed by the US Environmental Protection Agency.

***Materials and methods:*** In 2021, the average annual nitrate levels were determined in 48 drinking water wells which were located in Zone 39 (Taft city). Health risk assessment and sensitivity analysis were conducted to identify the most influential variables.

***Results:*** The mean nitrate content in the water wells under study was 32.88 ± 18 mg/L. Out of the 48 examined water wells, 10 had nitrate levels higher than the standard value (50 mg/L) established by the Iranian Institute of Standardization (Standard No. 1053) and WHO. The calculated Hazard Quotient (HQ) for children and adolescents was greater than 1, while it was less than 1 for adults. Nitrate concentration in drinking water was found to be the most important influencing variable in the calculated HQ for children and adolescents.

***Conclusion:*** The results indicated that children and adolescents' health in the studied area is at risk, and appropriate measures must be implemented to avoid and control the exposure of these vulnerable groups; they can be continuous monitoring of nitrate levels using on-site treatment methods where nitrate concentrations exceed the standard level, and decommissioning wells with high nitrate levels.

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## Introduction

Nitrate is extensively applied in agriculture as a mineral fertilizer and also as a preservative agent in food products [1, 2]. Surface waters usually contain low concentrations of nitrate (0-18 mg/L); however, it varies with the change of seasons. From the available evidence, it is believed that nitrate concentration in surface and groundwater inceases as a result of surface runoff, especially runoff from farmlands. In aerobic conditions, the concentration of nitrate in groundwater is affected by soil properties.



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In many European countries, nitrate levels in water resources have increased over the past few decades and have doubled in some cases in the last 20 years. For example, some rivers in the UK have experienced an average annual increase of 0.7 mg/L of nitrates[3]. In the United States, the levels of nitrate and nitrite in groundwater typically remain below 4-9 mg/L and 0.3 mg/L, respectively [4]. Increased uncontrolled agricultural activities can easily increase nitrate concentrations [5]. For example, a concentration greater than 1500 mg/L of nitrate has been observed in groundwater around farmlands in some areas of India [6].

Although nitrate carcinogenicity has not been reported in laboratory animals, it has been reported that exposure to high concentrations of nitrite can increase cancerous tumors in animals[7]. The reduction of nitrate to nitrite is the main route of toxicity in humans, followed by the conversion of hemoglobin to methemoglobin which disrupts oxygen transfer, leading to methemoglobinemia after more than 10 percent of the hemoglobin is converted to methemoglobin[8, 9].

As methemoglobinemia progresses, suffocation, and finally, death occur. Normally, the concentration of methemoglobin in the body is less than 2%, and in the children under 3 months old, this concentration is less than 3% [2]. In many situations, such as the influx of agricultural runoff and industrial wastewater, there is a chance of increasing levels of nitrate in groundwater [10, 11].

Using electronic systems and computer software helps to better control water resources and also estimate the health risks of pollutants [12-14]. Moreover, estimating the spatial distribution of groundwater quality makes it possible to manage water resources and prevent groundwater pollution [15]. Geographic Information System (GIS), as a new technology[16], can be applied to analyze and interpret the pollutant’s distribution in water resources [17].

In order to assess the spatial distribution of pollutants, a useful and practical technique of ArcGIS software is inverse distance weighting (IDW) which simulates the concentration of pollutants in other parts of the investigated area with the given information about the distance between the points and the concentration of the pollutants everywhere [18]. Various studies have utilized GIS software to analyze and determine the types of pollutants present in different zones [19, 20].

The first purpose of the present work is to investigate nitrate concentration in groundwater in Taft city located in Yazd province, Iran. Second, the zoning of 48 wells supplying drinking water was done by determining the concentration of nitrate in them, and finally, the non-carcinogenic risks of nitrate exposure were estimated in three population groups such as children, adolescents, and adults.

## Materials and methods

### *The study area*

A part of groundwater in Taft city located in zone 39 was studied, with a population of about 47,267 people and 48 wells which had 22.22 ± 2.63 average flow; the wells were located at 31˚15'N - 31˚50'N and 53˚35'E - 54˚05'E. Figure 1 indicates the geographic location of water wells in the city.



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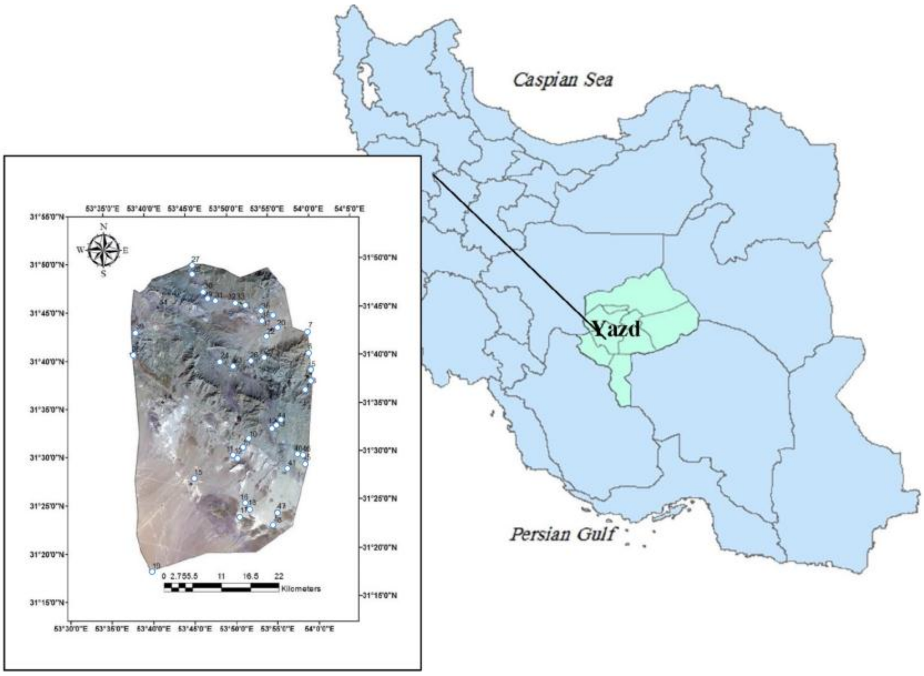


**Figure 1:** The geographical location of the study area

***Nitrate determination***

Nitrate concentration in drinking water was determined by the 4500 - $NO3^-$ method. The samples were collected in polyethylene bottles and stored unacidified for up to 48 h at the temperature below 6 °C without freezing. Analysis of the collected samples was carried out by the Ultraviolet Spectrophotometer technique at the wavelength of 220 nm.

***Spatial analysis and risk assessment***

ArcGIS 10.1 software developed by ESRI was used to map the drinking waters with heavy metals in a city [21, 22]. The interpolation technique or IDW was applied for zoning and preparation of an independent rostrum layer associated with the concentration of the pollutants in various points of the study area [21]. Furthermore, an estimation of the non-carcinogenic risks for nitrate was done using the following equation [23, 24]:

$$HQ = \frac{EDI}{RfD}$$

,where HQ is the hazard quotient, EDI defines estimated daily intake, and RfD is the oral reference dose. Moreover, the calculation of EDI was performed utilizing the subsequent equation [23]:

$$EDI = \frac{C \times CF \times IR \times ED \times EF}{BW \times AT}$$

,where C is the nitrate concentration, CF represents the conversion factor, IR is the drinking water ingestion rate, EF indicates exposure frequency, ED stands for exposure duration, BW represents body weight, and AT denotes the averaging time. Table 1 shows the necessary parameters for EDI calculation.

**Table 1:** Necessary parameters for EDI calculation

| Parameters | Unit | Description | Values | | | Ref |
|---|---|---|---|---|---|---|
| | | | Children | Teens | Adults | |
| EDI | Mg/kg/day | Estimated daily intake through ingestion | Will be evaluated | Will be evaluated | Will be evaluated | - |
| Cw | Mg/L | Concentration of nitrate in water | Measured | Measured | Measured | - |
| IRw | l/day | Ingestion rate of drinking water | 1.25 ± 0.57 | 1.58 ± 0.69 | 1.95 ± 0.64 | (23) |
| EF | Day/year | Exposure frequency | Min:180 Mode:345 Max: 365 | Min:180 Mode:345 Max: 365 | Min:180 Mode:345 Max: 365 | (24) |
| ED | Year | Exposure duration | 6 | 15 | 50 | (23) |
| BW | Kg | Body weight | 16.68 ± 1.48 | 46.25 ± 1.18 | 57.03 ± 1.10 | (25) |
| AT | Days | Average time | 2190 | 5475 | 18250 | (23) |

## Results

### *Nitrate concentration*

Based on the results, the average nitrate concentration in the investigated water wells was 32.88 ± 18 mg/L. Out of the 48 wells examined, 10 wells had a nitrate concentration higher than the standard value (50 mg/L) determined by the Iranian Institute of Standardization (standard 1053).

Figure 2 shows the nitrate concentration in the studied wells and the number of replicates for each concentration. According to the data in Figure 2, the maximum concentration was 100 mg/L, and the most frequent concentration was 30 mg/L.

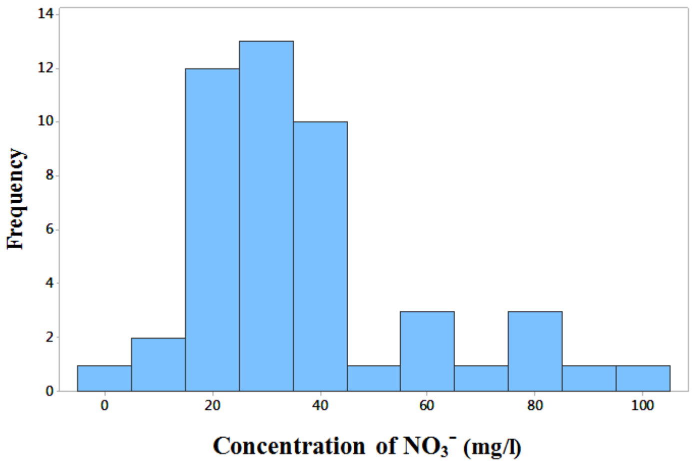


**Figure 2:** Histogram plot of the concentration of nitrate in the study area and the number of repetitions

### *Spatial distribution analysis*

The IDW technique of ArcGIS software was used to map nitrate concentration in the study area. According to the zoning, wells 20, 9, 33, 37, 39, 38, 48, 36, 30, and 21 had the highest concentration of nitrate (above 50 mg/L), respectively, while well 14 had the least nitrate concentration at 4 mg/L. Figure 3 shows the mapping of the nitrate concentration in the 48 studied wells.



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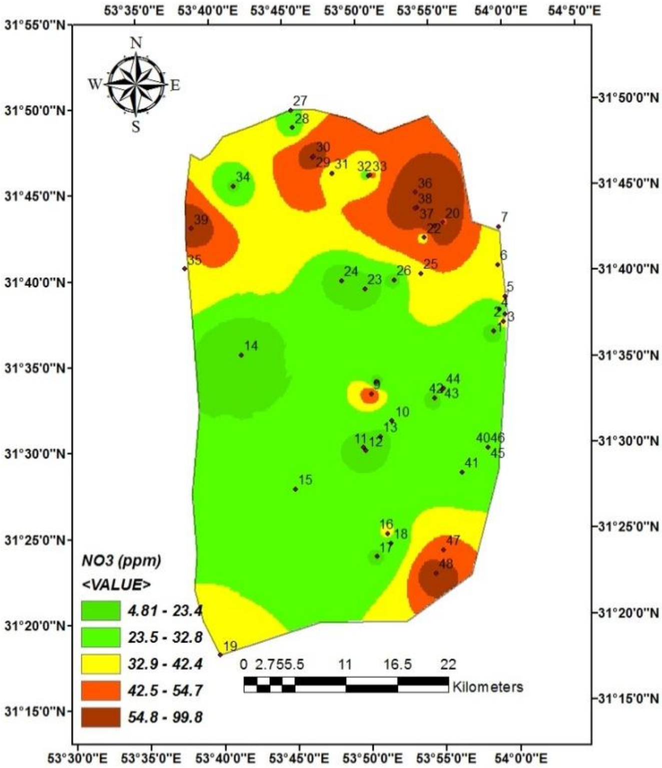


**Figure 3:** Spatial distribution analysis in the studied area

Moran index for nitrate concentration in the area under study was equal to 0.158, and the Z-Score was 2.45 (Figure 4), which represented a clustered pattern of distribution of nitrate concentration. The cluster model displays the point of pollution.

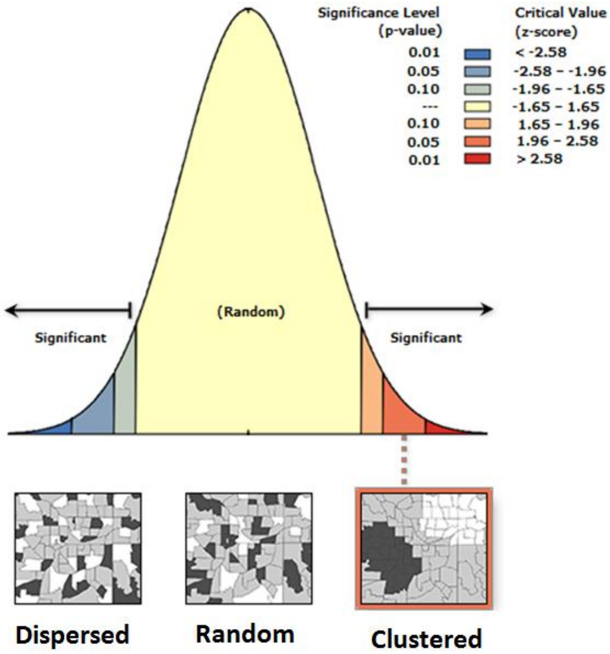


**Figure 4:** Results of Moran index



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***Non-cancer risk assessment***

To conduct risk assessment, the studied population was classified into three age categories: children (0 to 7 ), adolescents (7 to 19), and adults (19 and above). The results from the HQ calculation for each group are shown in Figures 5.

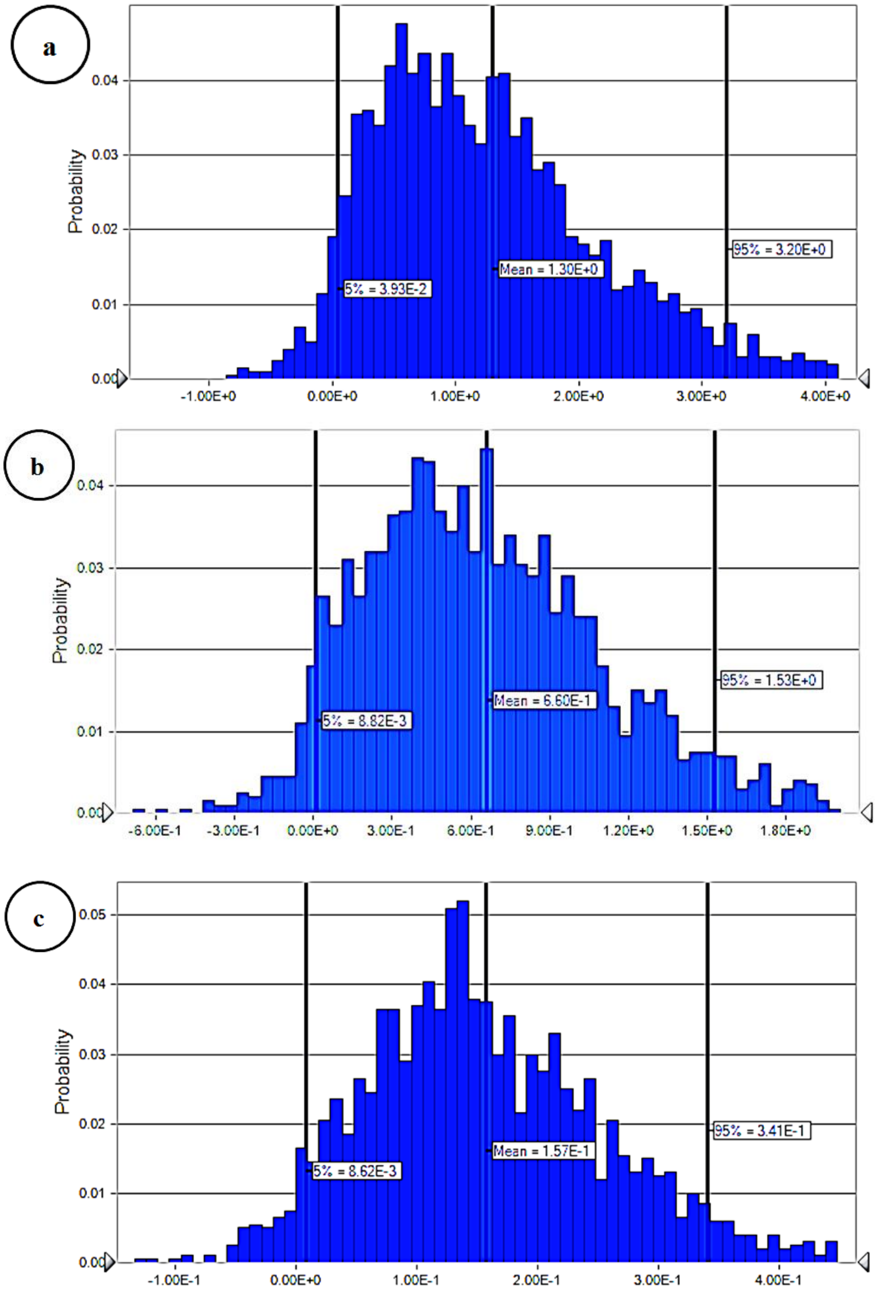


**Figure 5:** Calculated HQ for children,adolescents, andadults

***Sensitivity analysis***

Figures 6 presents the results ofsensitivity analysis regarding the variables involved in calculating HQ for children, adolescents, and adults. According to the findings, nitrate levels in drinking water for all the three age groups could increased the risk of non-carcinogenic effects. Therefore, diminishing the level of nitrate in well water can significantly reduce the health impacts of pollution.


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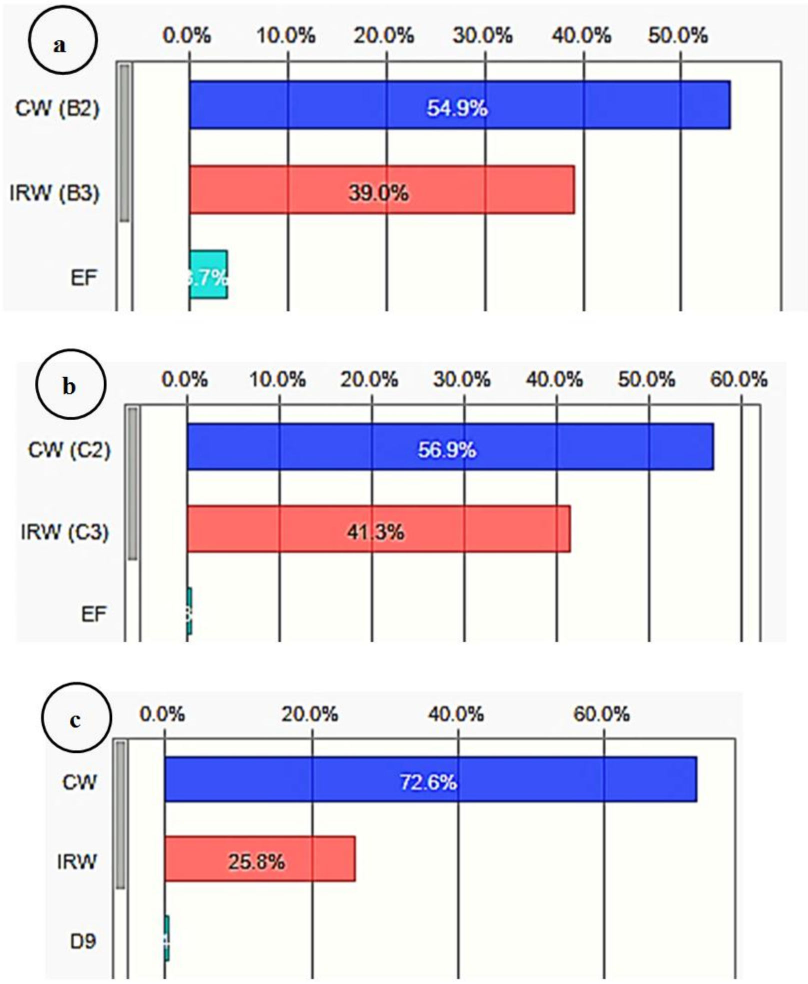


**Figure 6:** Sensitivity analysis of the estimated HQ for children, adolescents, and adults

## Discussion

The present study investigated nitrate levels in 48 regional water supply wells which provide water for a population of 47,260. The results indicated that the concentration of nitrate in 10 of the wells under study was exceeded the standard level (50 mg/L). According to the nitrate concentration zoning, 8 out of of 48 of the studied wells (16.66% of the total investigated wells) in the northern part of the study area contained nitrate levels that exceeded the standard level. Moreover, The clustered pattern of nitrate distribution in the examined area was revealed by Moran's index, showing the point distribution of the contamination source.

An examination of the area, where the wells with high concentrations of nitrate were located, showed that most of the activities in that area was limited to agricultural activities. In the mentioned area, irrigation was based on an ancient method called flood irrigation which produced large volumes of runoff, mainly contaminated with nitrogen fertilizers. The use of nitrogen fertilizers and the infiltration of runoff into groundwater led to contamination of groundwater with nitrate [25, 26]. Fallahzadeh et al. reported that using nitrogen fertilizers in agriculture was the main reason for groundwater contamination with nitrate in areas with agricultural activity [26]. Livestock activities were another cause of groundwater pollution with nitrate [27, 28]. Releasing and penetrating domestic and human wastewater was also another source of groundwater pollution with nitrate [29, 30].

Non-cancer risk assessment among the studied groups indicated that the calculated HQ for children and adolescents was above 1, which



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suggested a high risk for developing the disease through drinking water. The calculated risk for child population was three times higher than the ones calculated for the adolescent population. Various studies have shown that the risk of developing the disease in children is higher than other age groups during exposure to high concentrations of pollutants [23, 31]. Factors such as high surface area to volume ratio increase the calculated risk for children [23]. High nitrate concentrations have caused an HQ of above 1 regarding adolescents.

The sensitivity analysis results indicated that nitrate concentration was the most influential variable increasing non-cancer risks, with rates of 54.9% and 56.9% in children and adolescents, respectively. Previous studies also highlighted the high impact of the pollutant concentration variable on increasing health risk when the pollutant concentration is higher than standard [32, 33]. Reducing pollutant concentrations could reduce non-carcinogenic risk. Therefore, drainage and prevention of surface water infiltration into groundwater in areas where agricultural activities were the main activity of the region that could significantly reduce the concentration of pollution entering groundwater [34].

### *Limitation*

The main limitations of this study was lack of nitrite measurement. Moreover, it is recommended to measure other pollutants such as heavy metals in future studies.

## Conclusion

The obtained results revealed that 10 water wells had higher nitrate concentrations than the standard limit provided by the Iranian Institute of Standards. Moreover, the obtained HQ in the children and adolescent population was higher than 1.0. The sensitivity analysis also indicated that high concentrations of nitrate in drinking water increase health risks. In conclusion, minimizing pollutant concentrations can remarkably decrease the calculated non-cancer risk. Therefore, drainage and prevention of surface water infiltration into groundwater in areas with high agricultural activities are suitable ways to reduce nitrate concentration in groundwater.

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## Conflict of interest

The authors declared no conflict of interests.

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## Ethical considerations

The authors have fully addressed ethical issues including plagiarism, informed consent, misconduct, data fabrication, and/or falsification, double publishing and/or submission, redundancy, etc.

## Code of ethics

The present study has been approved by the Ethics Committee of Shahid Sadoughi University of Medical Sciences, Yazd (IR.SSU.SPH.REC.1400.037).

## Authors' contributions

All the authors contributed to the study's conception and design. Preparation of material, data collection, and analysis were performed by Reza Ali Fallahzadeh, Mahmoud Taghavi, Seyed Ali Al-Modaresi and Fariborz Omidi. The first draft of the manuscript was written by Reza Ali Fallahzadeh, Tannaz Nasiri, Fatemeh Dehghani, and Fariborz Omidi. All the authors commented on the previous versions of the manuscriptand read and approved the final manuscript.



## References

1.Fan AM, Steinberg VE. Health implications of nitrate and nitrite in drinking water: an update on methemoglobinemia occurrence and



[ DOI: 10.18502/jehsd.v9i2.15843 ]

reproductive and developmental toxicity. Regulatory Toxicology and Pharmacology. 1996; 23(1):35-43.
2. World Health Organization. Guidelines for drinking-water quality [Internet]. Geneva: World Health Organization; 2011. Available from: http://www.who.int/mediacentre. [cited Jul 25, 2011].
3. Skeffington R. European nitrogen policies, nitrate in rivers and the use of the INCA model. Hydrol Earth Syst Sci. 2002;6(3):315-24.
4. Manassaram DM, Backer LC, Moll DM. A review of nitrates in drinking water: maternal exposure and adverse reproductive and developmental outcomes. Environmental Health Perspectives. 2006;114(3):320-7.
5. Ward MH, DeKok TM, Levallois P, et al. Workgroup report: drinking-water nitrate and health—recent findings and research needs. Environmental Health Perspectives. 2005; 113(11):1607-14.
6. Jacks G, Sharma V. Nitrogen circulation and nitrate in groundwater in an agricultural catchment in southern India. Environmental geology. 1983;5(2):61-4.
7. Fallahzadeh RA, Almodaresi SA, Ghadirian D, et al. Spatial analysis and probabilistic risk assessment of exposure to nitrate in drinking water of Abarkouh, Iran. Journal of Environmental Health and Sustainable Development. 2019;4(2):744-52.
8. Saini A, Kanwar P, Garg J. Potential health risk assessment of nitrate in groundwater of Tonk district in Rajasthan, north western India. Int J Environ Anal Chem. 2024:1-14.
9. Huang S, Guo J, Xie Y, et al .Distribution, sources, and potential health risks of fluoride, total iodine, and nitrate in rural drinking water sources of North and East China. Science of the Total Environment. 2023;898:165561.
10. Azadi NA, Fallahzadeh RA, Sadeghi S. Dairy wastewater treatment plant in removal of organic pollution: a case study in Sanandaj, Iran. Environmental Health Engineering and Management Journal. 2015;2(2):73-7.
11. Kherad Pisheh Z, Almodaresi S.A, Khaksar Y, et al. Zoning of groundwater contaminated by nitrate using geostatistics methods (case study: Bahabad plain, Yazd, Iran). Desert (Biaban)[Internet]. 2014;19(1):83-90. Available from: https://sid.ir/paper/636961/en. [cited June 15, 2014].
12. 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):35-40.
13. Fallahzadeh RA, Mahvi AH, Meybodi MN, et al. Application of photo-electro oxidation process for amoxicillin removal from aqueous solution: modeling and toxicity evaluation. Korean J Chem Eng. 2019;36(5):713-21.
14. Dehghani F, Omidi F, Fallahzadeh RA, et al. Health risk assessment of occupational exposure to heavy metals in a steel casting unit of a steelmaking plant using Monte–Carlo simulation technique. Toxicology and industrial health. 2021;37(7):431-40.
15. Ehsani H, Javid A, Hasani A, et al., editors. Evaluation of nitrate variation and total dissolved solids trend in drinking water using GIS Hamedan plain ground. 10th National Conference on Environmental Health; 2007.
16. Alam A, Kumar A, Singh A. A GIS approach for groundwater quality evaluation with entropy method and fluoride exposure with health risk assessment. Environmental Geochemistry and Health. 2024;46(2):47.
17. Merchant JW. GIS-based groundwater pollution hazard assessment: a critical review of the DRASTIC model. Photogramm Eng Remote Sensing. 1994;60:1117.
18. Cressie N. Statistics for spatial data. John Wiley & Sons; 2015.
19. Gaus I, Kinniburgh D, Talbot J, et al. Geostatistical analysis of arsenic concentration in groundwater in Bangladesh using disjunctive kriging. Environmental geology. 2003;44(8): 939-48.
20. Jafari M, Mohammad AH, Tahmoures M, et al. Assessment of soil property spatial variation



[ DOI: 10.18502/jehsd.v9i2.15843 ]

[ DOI: 10.18502/jehsd.v9i2.15843 ]





based on the geostatistical simulation. 2012:87-101.

21. 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.
22. Eslami H, Esmaeili A, Razaeian M, et al. Potentially toxic metal concentration, spatial distribution, and health risk assessment in drinking groundwater resources of Southeast Iran. Geoscience Frontiers. 2022;13(1):101276.
23. Fallahzadeh RA, Ghaneian MT ,Miri M, et al. Spatial analysis and health risk assessment of heavy metals concentration in drinking water resources. Environmental Science and Pollution Research. 2017;24(32):24790-802.
24. Dehghani F, Kamalinia M, Omidi F, et al. Probabilistic health risk assessment of occupational exposure to isoflurane and sevoflurane in the operating room. Ecotoxicology and environmental safety. 2021; 207:111270.
25. 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(3):91-6.
26. Fallahzadeh RA, Azimzadeh HR, Khosravi R, et al. Using Geographic Information System (GIS) and Remote Sensing (RS) in zoning nitrate concentration in the groundwater of Birjand, Iran. Journal of Advances in Environmental Health Research. 2016;4(3):129-34.
27. Corniello A, Ducci D, Ruggieri G. Areal identification of groundwater nitrate contamination sources in periurban areas. J Soils Sediments. 2007;7(3):159-66.
28. Jalili M, Hosseini MS, Ehrampoush MH, et al. Use of water quality index and spatial analysis to assess groundwater quality for drinking purpose in Ardakan, Iran. Journal of Environmental Health and Sustainable Development. 2019;4(3):834-42.
29. Shepherd M. Factors affecting nitrate leaching from sewage sludges applied to a sandy soil in arable agriculture. Agriculture, Ecosystems & Environment. 1996;58(2-3):171-85.
30. Khorasani H, Kerachian R, Aghayi MM, et al., editors. Assessment of the impacts of sewerage network on groundwater quantity and nitrate contamination: case study of Tehran. In World Environmental and Water Resources Congress 2020. American Society of Civil Engineers;2020.53-66.
31. 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 and Chemical Toxicology. 2018;115:260-6.
32. Omidi F, Dehghani F, Fallahzadeh RA, et al . Probabilistic risk assessment of occupational exposure to volatile organic compounds in the rendering plant of a poultry slaughterhouse. Ecotoxicology and Environmental Safety. 2019;176:132-6.
33. Fallahzadeh RA, Miri M, Taghavi M, et al. Spatial variation and probabilistic risk assessment of exposure to fluoride in drinking water. Food and Chemical Toxicology. 2018;113:314-21.
34. Fallahzadeh RA, Almodaresi SA, Ghadirian D, et al. Spatial analysis and probabilistic risk assessment of exposure to nitrate in drinking water of Abarkouh, Iran. Journal of Environmental Health and Sustainable Development. 2019.

 