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SIMILARITIES IN THE FINGERPRINTS OF COAL MINING ACTIVITIES, HIGH GROUND WATER FLUORIDE, AND DENTAL FLUOROSIS IN ZARAND DISTRICT, KERMAN PROVINCE, IRAN

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ABSTRACT: In the present study, in Zarand district, Kerman province, Iran, we used a Geological Information System (GIS) to explore the relationship between the situation of coal mines, the drainage patterns, the topographic state of the district, the presence increased fluoride levels in ground water, and the prevalence of dental fluorosis. We found a strong relationship to be present between coal mining activities, high groundwater fluoride, and dental fluorosis with similarities in the spatial distributions, or fingerprints, of these parameters.

Key words: Fluoride; Fluorosis; Geology; Iran; Kerman province; Zarand district.

INTRODUCTION

In both animals and human beings, a variety of diseases and disorders have been associated with an excessive intake of fluoride, such as dental and skeletal fluorosis, infertility, brain damage, thyroid disorders, a decreased number of red blood cells, oxidative stress-related damage, intelligence deficits in children, osteoporosis, nervous system impairment, hypertension, and decreased fertility.[1-6] A number of developed and developing countries have a severe problem with the fluoride concentration in groundwater[7,8] and several studies have been carried out to remove fluoride from aqueous solutions.[9] Iran is among the countries exhibiting health problems due to the fluoride contamination of groundwater. While several studies have reported on the effect of fluoride of drinking water on human health, only a few geological studies exploring the origin of this problem have been carried out.

Sixty-seven percent of the population, aged 7–40 years, of the Zarand district of Kerman province in Iran, an area with a high concentration of fluoride in the drinking water, suffer from dental fluorosis.[1,3,10] After decades of study and research, this type of dental disorder is considered to be frequently related to a high fluoride content in the drinking water. It is generally accepted that geological formations may play an important role in increasing the fluoride level in the groundwater resources.

Most of the fluoride contaminated zones in the world are the result of high fluoride levels in subsurface aquifers where the fluoride originates from the chemical weathering of parent rocks such as sedimentary formations, mineralized veins, acidic igneous rocks,[11] some minerals such as apatite, fluorite, cryolite, topaz, micas, amphiboles and sellaite,[12-15] and some anthropogenic sources such as mining and industrial activities, the usage of pesticides, and brick kilns,[16,17] especially in arid and semi-arid environments.[7,11,18,19] The weathering and leaching of rocks releases fluoride into rock pore-waters. In addition, the discharge of industrial wastewaters brings about another source of fluoride in the subsurface.[16] The type of lithology that

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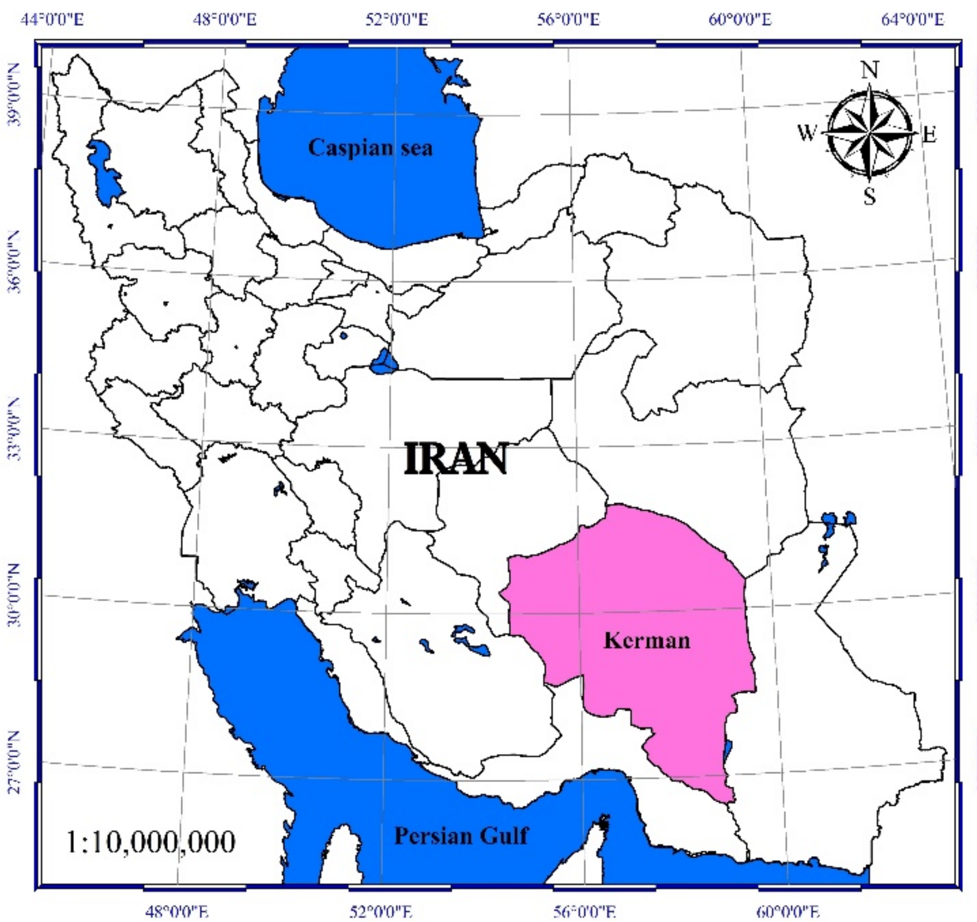
is eroded by flowing rainfall can be the controlling factor for the level of contamination of groundwater by fluoride.

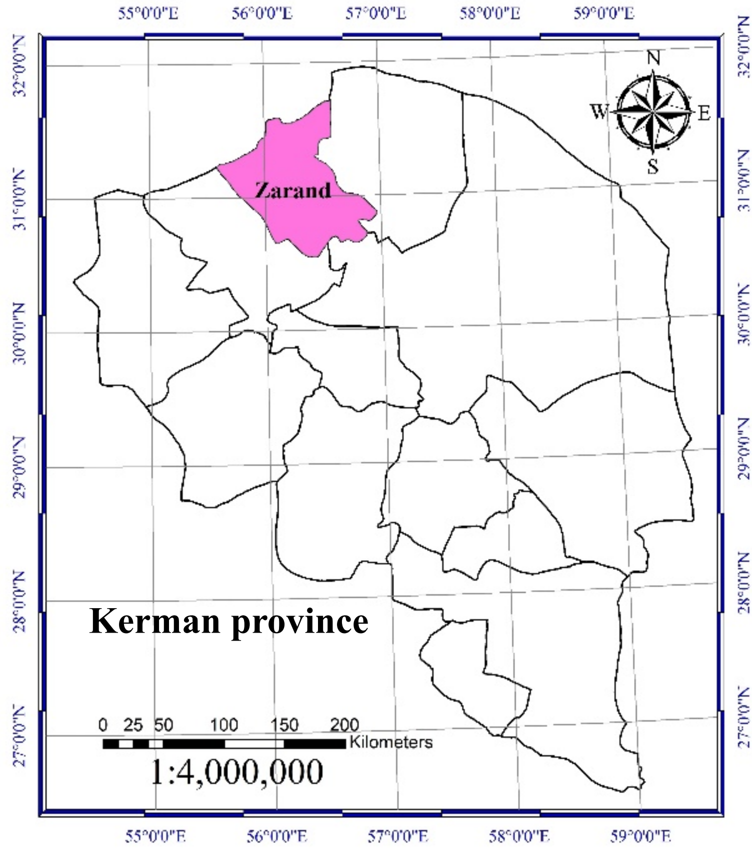
Coal mining activities can be a cause of fluoride contamination of groundwater. Although fluoride may be present abundantly in coal, only a few studies have examined the relationship between fluorosis and coal mining.[20-22] In the Zarand region in Kerman province of Iran there is a vast area of coal bearing strata and this is utilized in widely distributed coal mining activities and related coal and coke industries (Figures 1A and 1B).



1A

Figure 1A. Kerman province is the largest province in Iran, located in the south-east of Iran.

The aim of the present research aims was to explore the spatial association of groundwater fluoride and dental fluorosis with geological formations in the Zarand district of Kerman province, Iran, an area with a 67% prevalence of dental fluorosis.[10]



1B

Figure 1B. Zarand district is located in the northwest of Kerman province.

MATERIALS AND METHODS

To find the relationship between the ground water fluoride level, the prevalence of dental fluorosis, and coal mining activities, we mapped, using a Geological Information System (GIS), the amount of fluoride in the groundwater of the region, the prevalence of dental fluorosis, and the presence of coal mining and related industrial activities. This method gives a better visualization and interpretation of the ground water fluoride levels, the distribution of dental fluorosis, and the presence of coal mining activities by combining them by overlaying. The method can illustrate the effect of the alteration of different variables on a specific multilayer map and enable an easier understanding of the relationships by giving a more attractive and precise view of the problem. This could help motivate the policy makers to present a solution for the problem. This could be followed by monitoring changes in the groundwater fluoride levels over the years and comparing these with changes in mining and industrial activities using the advantages of a GIS.[23]

The data on the prevalence of dental fluorosis and the fluoride levels in the drinking water were obtained from previous studies in the Zarand district, Kerman province of Iran. The dental fluorosis data was collected by a trained dentist who carried out all

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dental examinations using special dental instruments. Five hundred and fifty people, who were residents in the region for the first six years of their life (the time in which dental fluorosis may affect the permanent teeth), participated in this fluorosis survey in a multi-stage random sampling method (city district/village, street, family, and person). The participants' fluorosis status was recorded as well as their demographic data and their past and present drinking water sources.[3,10]

The level of fluoride contamination of the drinking water of the study area was analyzed by the ion chromatography method at 35 locations. For this purpose, after washing the sampling containers by acid, each of them was flushed with the sample water three times and then filled and sent to the lab to determine the fluoride content.[3,10]

RESULTS

The topography and drainage pattern of the region are shown in Figure 2.

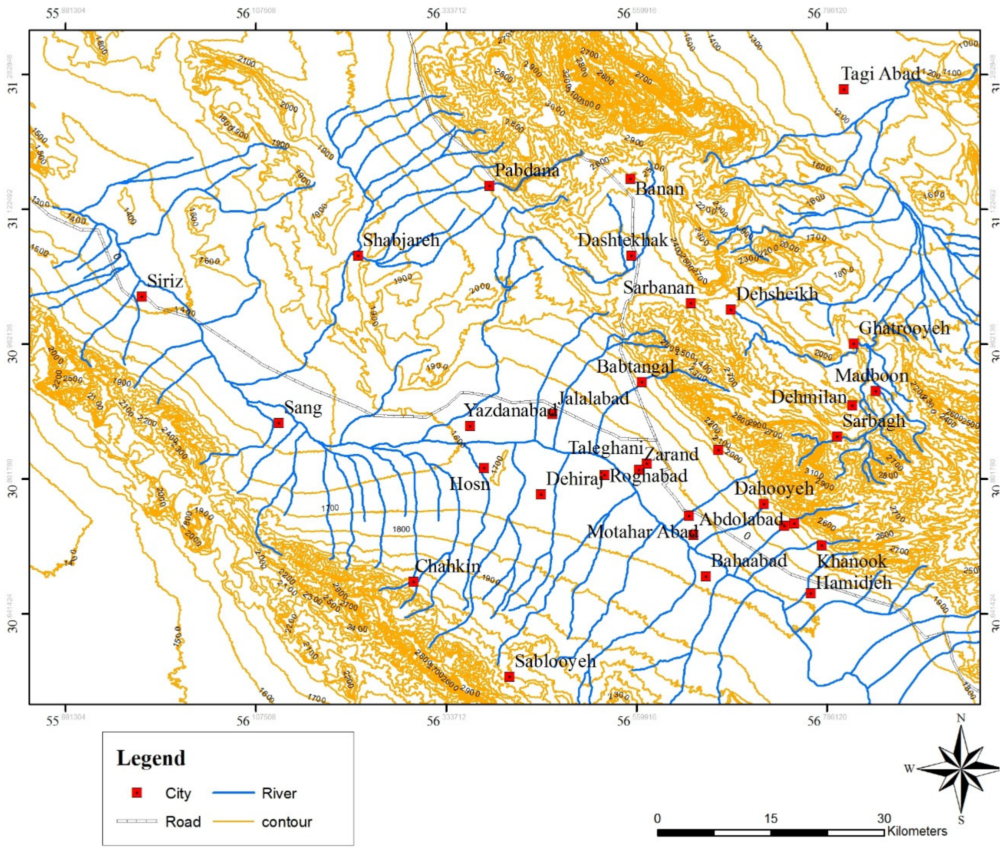

Figure 2. Topographic map of the studied region (brown lines) and the pathways of the drainage pattern (blue lines) that originate from the elevations.

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The location of coal mines and the coal-related factories in the area are shown in Figure 3.

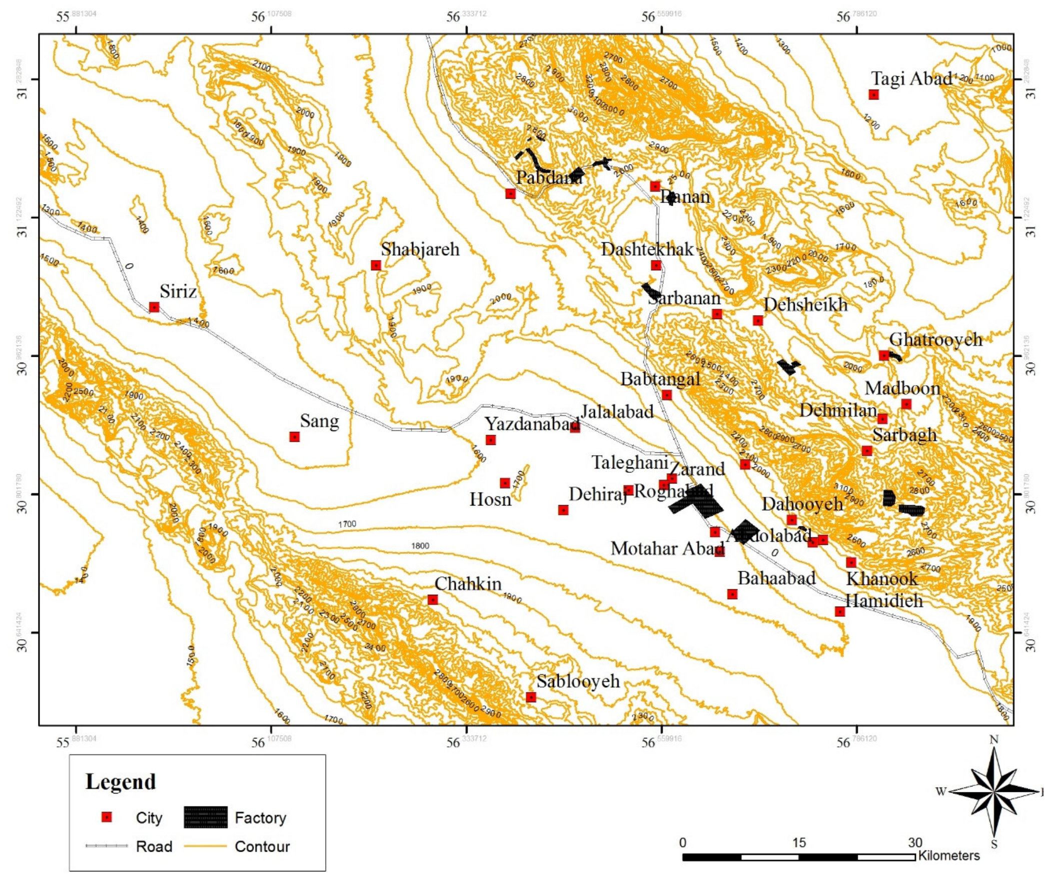

Figure 3. The location of coal mines and the coal-related factories in the area is shown by dark polygons.

The spatial variation in the level of groundwater fluoride in the study area is shown in Figure 4.[3,10] The fluoride content of the groundwater was higher in a band in the central areas with a northwest-southeast (NW-SE) alignment.

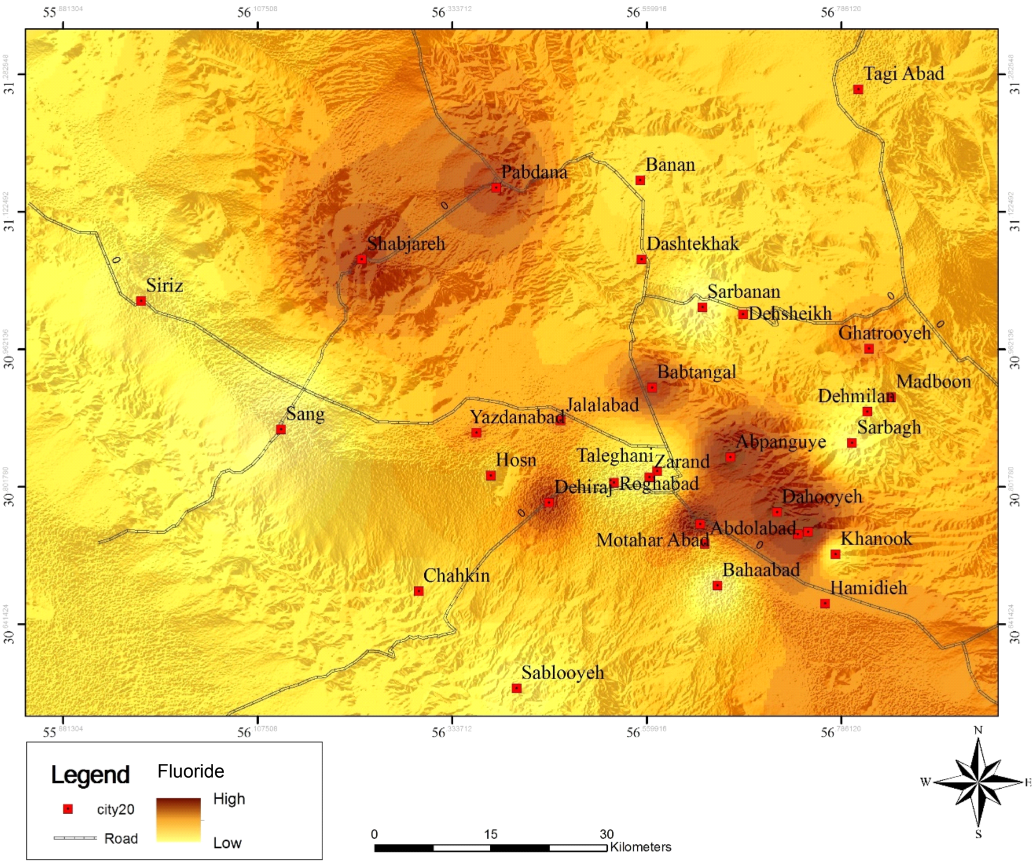

Figure 4. Spatial variation of the groundwater fluoride in the study area.[3,10]

The distribution of dental fluorosis is shown in Figure 5.[3,10]

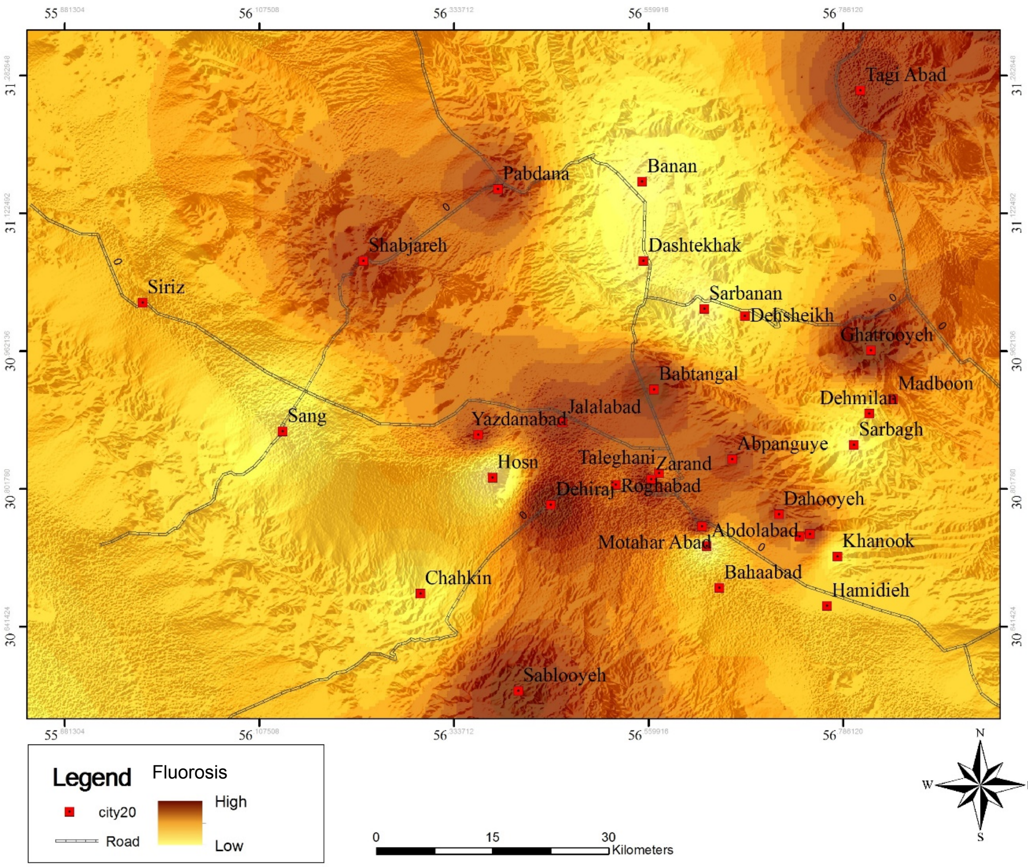

Figure 5. Dental fluorosis distribution in the study area.[3,10]

DISCUSSION

Fluorine, the lightest and most electronegative element in the halogen group, is abundant in the earth's crust and occurs in water as the negatively charged fluoride ion, F^-. The widespread occurrence of geogenic fluoride in groundwater is a major public health concern worldwide. Coal may contain 295 ppm of fluorine[16] and coal-based power stations can release fluoride into the environment.[13] Coal mining is one of the core industries that contribute to the economic development of the Zirand district. Coal excavating, with both opencast and underground mining methods, affects the environment, especially water resources, by discharging large amounts of mine water and leaching toxic compounds which have passed through the coal bearing geological formations. Penetration of these waters into deep aquifer reservoirs results in health problems.

The Zarand coal mines are situated in the southeast of Iran which belongs geologically to the Central Iran Zone. This region is mountainous with elevations of up to 3300 m above sea level (Figure 2) and is affected by the tectonic activity of the Kouhbanan fault.[24] The elevated mountains in this region are mainly composed of Paleozoic to Cenozoic aged dolomite, limestone, sandstone, shale, and coal.

The Kouhbanan mountain belt, the largest geomorphic element in the north of Zarand, trending NW-SE, was itself geologically affected as a result of the tectonic situation and collision of Iranian and Arabian continental plates and situation of the Lut block.[25-28] The interaction between two forcing factors, namely tectonics and lithology, has been proposed to be responsible for the evolution of the valleys and alluvial fan architecture in different parts of the study area that are very suitable for the extraction of groundwater by wells and qanats.[29,30]

The climate of the region is arid and continental, with severe winters and hot summers.[23] The temperature ranges from +45ºC (June–July) to –5ºC (January–December). The maximum precipitation occurs during February–April and the average precipitation is 165 mm/year. The rock types of Zarand coal mine region are summarized in the Table. The lithology is mainly sedimentary, and coal-bearing strata are divided to five zones, namely, A, B, C, D, and E, with D containing the highest coal reserves in the region. The coal zones A and B belong to the Upper Triassic, C belongs to the Lower Jurassic, and D and E are the youngest coal zones belonging to the Middle Jurassic.

Table. Rock types of the Zarand coal mine region[31] (Ss: sandstone, Sltst: siltstone, Arg: argillite, Carb: carbonaceous)

Lithology	Thickness (m)	Coal zones	Coal mines
Ss, Sltst, Arg, Carb arg, coal seams	135–1,350	E	Pabdana, Hamkar
Ss, Sltst, coal seams	20–190	D	Pabdana, Hojedk, Hamkar, Hashuni
Ss, Arg, Sltst, coal seams	36–770	C	Babnizu, Eshkeli, Pabdana
Ss-Sltst, arg, coal seams	140–610	B	Babnizu, Eshkeli, Hojedk
Sltst, Ss	100–640	A	Dahrud, Neyzar, Hojedk

In the process of mining, by both underground coal mining and the opencast method, huge amounts of water are discharged on to the surface to facilitate the mining operation. The discharged water often contains high values of Total Suspended Solids (TSS), Total Dissolved Solids (TDS), hardness, and heavy metals, which indicate the potential for contamination of the surface water and the groundwaters.[32]

Mine excavation often has a water influx, either due to rainfall or to the interception of ground water flows.[33,34] These waters are utilized for processing and dust suppression and some of them may be pumped out of the mine. In some of the coal mines of the study area, such as the Pabdana coal mine, the coal contains pyrite which makes the mine water acidic and causes pollution of the surrounding streams.

The runoffs generated after rain can give rise to serious pollution problems. The overburden dumps near the coal mines, the coal washing plant, and the coking plant in the Zarand district are usually very susceptible to erosion. Some overburden coal dumps may be piled up at the bank of the seasonal rivers, such as with the Pabdana coal mine, and they may ultimately find their way to the groundwater.

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The topography and drainage pattern can affect fluoride leaching from the high altitudes in the Zarand district and the subsequent accumulation of fluoride in the aquifers leading to an increase in the prevalence of dental fluorosis in the area.

The impact of coal mining and the related industrial activities on the fluoride content of the groundwater of their catchment area can be detected from the spatial analysis of water samples in the Zarand coal mine field. Comparing the previous data[3,10] and the position of the mining and industrial zones shows a strong correlation between the level of fluoride in the groundwater and presence of coal mines, dump sites, and related industries in the water catchment area (Figures 2 and 4).

The locations in the northwestern and southeastern parts of the study area display higher fluoride concentrations as well as a higher occurrence of dental fluorosis (Figures 4 and 5). The NW to SE spatial pattern of groundwater fluoride distribution in the study area is evident in the fluoride concentration map (Figure 4). The distribution of the coal mines and their related industries show that the groundwater fluoride distribution is controlled primarily by the geological formations, with the highest drinking water fluoride levels and a higher prevalence of dental fluorosis occurring in the areas with coal bearing formations.

CONCLUSIONS

High fluoride concentrations in groundwater, up to 3.45 mg/L, occur in the Zarand area where one of the most important coal fields of Iran is located. The spatial pattern of the groundwater fluoride distribution and the prevalence of dental fluorosis resembles the coal mine and coal related factories fingerprint. The high fluoride groundwater zones are located mainly in the discharge areas. Regional investigation indicates that geological processes could be responsible for the increase in fluoride contamination of groundwater from the recharge areas to the discharge areas. Geographic Information System analysis provides a basis to further investigate the regions where drinking water is drawn from aquifers of coal bearing formation under similar tectonic settings. The geological study reveals that fluoride distribution in this area is geologically controlled and, in the recharge, and flow-through area, interactions between groundwater and coal mining industries could be the major factors for the increase of the groundwater fluoride concentration.

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CONFLICTS OF INTEREST

The authors declare no conflict of interest.

REFERENCES

1 Aghaei M, Derakhshani R, Raoof M, Dehghani M, Mahvi AH. Effect of fluoride in drinking water on birth height and weight: An ecological study in Kerman province, Zarand county, Iran. Fluoride 2015;48(2):160-8.

2 Balarak D, Mahdavi Y, Bazrafshan E, Mahvi AH, Esfandyari Y. Adsorption of fluoride from aqueous solutions by carbon nanotubes: determination of equilibrium, kinetic, and thermodynamic parameters. Fluoride 2016;49(1):71-83.

3 Derakhshani R, Tavallaie M, Raoof M, Mohammadi TM, Abbasnejad A, Haghdoostf AA. Occurrence of fluoride in groundwater of Zarand region, Kerman province, Iran. Fluoride 2014;47(2):133-8.

4 Mohammadi AA, Yousefi M, Yaseri M, Jalilzadeh M, Mahvi AH. Skeletal fluorosis in relation to drinking water in rural areas of West Azerbaijan, Iran. Scientific Reports 2017;7(1):17300.

5 Kheradpisheh Z, Mirzaei M, Mahvi AH, Mokhtari M, Azizi R, Fallahzadeh H, et al. Impact of drinking water fluoride on human thyroid hormones: A case-control study. Scientific Reports 2018;8(1):2674.

6 Rahmani A, Rahmani K, Dobaradaran S, Mahvi AH, Mohamadjani R, Rahmani H. Child dental caries in relation to fluoride and some inorganic constituents in drinking water in Arsanjan, Iran. Fluoride 2010;43(3):179-86.

7 Gupta S, Mondal D, Bardhan A. Geochemical provenance and spatial distribution of fluoride in Groundwater in parts of Raniganj coal field, West Bengal, India. Arch Appl Sci Res 2012;4(1):292-306.

8 Biglari H, Chavoshani A, Javan N, Hossein Mahvi A. Geochemical study of groundwater conditions with special emphasis on fluoride concentration, Iran. Desalination and Water Treatment 2016;57(47):22392-9.

9 Bazrafshan E, Ownagh KA, Mahvi AH. Application of electrocoagulation process using iron and aluminum electrodes for fluoride removal from aqueous environment. Journal of Chemistry 2012;9(4):2297-308.

10 Malek Mohammadi T, Derakhshani R, Tavallaie M, Raoof M, Hasheminejad N, Haghdoost AA. Analysis of ground water fluoride content and its association with prevalence of fluorosis in Zarand/Kerman: (Using GIS). Journal of Dental Biomaterials 2017;4(2):379-86.

11 Edmunds WM, Smedley PL. Fluoride in natural waters. In: Selinus O, editor; Alloway B, Centeno JA, Finkelman JA, Fuge R, Lindh U, Smedley P, associate editors. Essentials of medical geology. Revised ed. Dordrecht, The Netherlands: Springer; 2013. pp. 311-36.

12 Hem JD. Study and interpretation of the chemical characteristics of natural water. 3rd ed. Alexandria, VA, USA: Department of the Interior, US Geological Survey; 1985. Available from: https://pubs.usgs.gov/wsp/wsp2254/pdf/wsp2254a.pdf

13 Pickering W. The mobility of soluble fluoride in soils. Environmental Pollution Series B, Chemical and Physical 1985;9(4):281-308.

14 Datta P, Deb D, Tyagi S. Stable isotope (18O) investigations on the processes controlling fluoride contamination of groundwater. Journal of Contaminant Hydrology 1996;24(1):85-96.

15 Jadhav SV, Bringas E, Yadav GD, Rathod VK, Ortiz I, Marathe KV. Arsenic and fluoride contaminated groundwaters: a review of current technologies for contaminants removal. Journal of Environmental Management 2015;162:306-25.

16 Ali S, Thakur SK, Sarkar A, Shekhar S. Worldwide contamination of water by fluoride. Environmental Chemistry Letters 2016;14(3):291-315.

17 Dobaradaran S, Fazelinia F, Mahvi AH, Hosseini SS. Particulate airborne fluoride from an aluminium production plant in Arak, Iran. Fluoride 2009;42(3):228-32.

18 Chae G-T, Yun S-T, Kwon M-J, Kim Y-S, Mayer B. Batch dissolution of granite and biotite in water: implication for fluorine geochemistry in groundwater. Geochemical Journal 2006;40(1):95-102.

19 Edmunds W. Characterization of groundwaters in semi-arid and arid zones using minor elements. In: Nash H, McCall, editors. Groundwater quality. London and New York: Chapman and Hall; 1994. pp.19-30.

20 Watanabe T, Kondo T, Asanuma S, Ando M, Tamura K, Sakuragi S, et al. Skeletal fluorosis from indoor burning of coal in southwestern China. Fluoride 2000;33(3):135-9.

21 Wu D, Zheng B, Tang X, Li S, Wang B, Wang M. Fluorine in Chinese coals. Fluoride 2004;37:125-32.

22 Li Y, Wang W, Yang L, Li H. Environmental epidemic characteristics of coal-burning endemic fluorosis and the safety threshold of coal fluoride in China. Fluoride 2003;36:106-12.

23 Mehrabi A, Khabazi M, Almodaresi SA, Nohesara M, Derakhshani R. Land use changes monitoring over 30 years and prediction of future changes using multi-temporal Landsat imagery and the land change modeler tools in Rafsanjan city (Iran). Sustainable Development of Mountain Territories 2019;11(1):26-35.

24 Rahbar R, Shafiei Bafti S, Derakhshani R. Investigation of the tectonic activity of Bazargan Mountain in Iran. Sustainable Development of Mountain Territories 2017;9(4):380-6.

25 Abbasnejad A, Mirzaie A, Derakhshani R, Esmaeilzadeh E. Arsenic in groundwaters of the alluvial aquifer of Bardsir plain, SE Iran. Environmental Earth Sciences 2013;69(8):2549-57.

26 Derakhshani R, Farhoudi G. Existence of the Oman Line in the Empty Quarter of Saudi Arabia and its continuation in the Red Sea. Journal of Applied Sciences 2005;5:745-52.

27 Hashemi F, Derakhshani R, Bafti SS, Raoof A. Morphometric dataset of the alluvial fans at the southern part of Nayband fault, Iran. Data in Brief 2018;21:1756-63.

28 Rashidi A, Khatib MM, Nilfouroushan F, Derakhshani R, Mousavi SM, Kianimehr H, et al. Strain rate and stress fields in the West and South Lut block, Iran: Insights from the inversion of focal mechanism and geodetic data. Tectonophysics 2019;766:94-114.

29 Kermani AF, Derakhshani R, Bafti SS. Data on morphotectonic indices of Dashtekhak district, Iran. Data in Brief 2017;14:782-8.

30 Abbasnejad A, Abbasnejad B, Derakhshani R, Hemmati Sarapardeh A. Qanat hazard in Iranian urban areas: explanation and remedies. Environmental Earth Sciences 2016;75(19):1306.

31 Shahabpour J, Doorandish M, Abbasnejad A. Mine-drainage water from coal mines of Kerman region, Iran. Environmental Geology 2005;47(7):915-25.

32 Tiwary R. Environmental impact of coal mining on water regime and its management. Water, Air, and Soil Pollution 2001;132(1-2):185-99.

33 Alipour M, Derakhshani R. Water management and AMD minimizing in Sarcheshmeh mine, Iran. American-Eurasian Journal of Agricultural and Environmental Science 2010;7(2):188-94.

34 Derakhshani R, Alipour M. Remediation of acid mine drainage by using tailings decant water as a neutralization agent in Sarcheshmeh copper mine. Research Journal of Environmental Sciences 2010;4(3):250-60.