



ORIGINAL ARTICLE

Sobel sensitivity analysis for non-carcinogenic health risk assessment and water quality index for Kohgiluyeh and Boyer-Ahmad Province, Western Iran



Saeed Rajabi^{a,b}, Mohammad Reza Zarei^{a,b}, Ali Karamoozian^{c,d},
Amin Mohammadpour^{a,b}, Aboalfazl Azhdarpoor^{b,*}

^a Student Research Committee, Shiraz University of Medical Sciences, Shiraz, Iran

^b Department of Environmental Health Engineering, School of Health, Shiraz University of Medical Sciences, Shiraz, Iran

^c Modeling in Health Research Center, Institute for Future Studies in Health, Kerman University of Medical Sciences, Kerman, Iran

^d Department of Biostatistics and Epidemiology, Kerman University of Medical Sciences, Kerman, Iran

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Abstract Human activities and climate may have an impact on the water quality of reservoirs. Therefore, the present research aims to use the entropy water quality index assessment technique to analyze the water quality features of the main water supply reservoirs as well as to investigate the effect of water parameters on the water quality of the reservoirs. In this study, the total non-carcinogenic health risks from various exposure paths were estimated for adults and children. The water quality of the major water supply reservoirs in Kohgiluyeh and Boyer-Ahmad province was typically poor and unfit for human consumption. Besides, the non-carcinogenic risk was higher in males (0.958–1.497) and children (1.065–1.664) than in females (0.879–1.374) according to health risk assessments. Among the factors under study, magnesium and nitrate had the highest influence on the non-carcinogenic risk. Finally, the sensitivity of each of the parameters affecting the non-carcinogenic risk was assessed using *Sobel* sensitivity analysis. The results indicated that the nitrate concentration (C_w) and Ingestion Rate (IR) were the most sensitive in the oral state, while C_w and fraction of skin's surface area (F) were more sensitive in the dermal state.

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* Corresponding author.

E-mail address: azhdarpoor@sums.ac.ir (A. Azhdarpoor).

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1. Introduction

One of the most important requirements for health, growth, and development in today's societies is having high-quality drinking water, and every-one's attention is currently focused on the safety of water reservoirs. The conservation of water reservoirs is one of the initial and most fundamental steps in their management and exploitation (Yin et al., 2021, Ren et al., 2021, Bibi et al., 2021).

Scientific assessment of water resources is required to better understand their qualities and ensure the health and safety of the water consumed by humans. Health risk assessment associated with water resources can reveal a relationship between human health and water pollutants (Ji et al., 2020, Radfard et al., 2018). It is possible to make an essential and sensible decision about how to manage and safeguard water resources by assessing the health hazards posed by water resources. Under certain conditions, the physical and chemical qualities of water are altered as a result of its interaction with subsoil and rock, necessitating a change in the source of water supply. Different minerals can be present in water sources in the form of cations and anions, depending on the source of water supply (Deng et al., 2021, Jiries et al., 2022, Gugulothu et al., 2022).

Two of the most frequent substances that impact the quality of drinking water are nitrate (NO_3^-) and fluoride (F^-). Fluoride enters water primarily from geological and anthropogenic sources, with dissolved minerals containing fluoride serving as the primary source (Gao et al., 2020, Li et al., 2014). Excess fluoride in water causes high intake in people's bodies, particularly in youngsters, which has negative consequences such as caries and deformation of bones, whereas a lack of fluoride in water causes tooth decay (Li et al., 2014, Chandrajith et al., 2012). Nitrate pollution is a kind of manmade groundwater contamination that can come from both point (such as septic systems, dairy lagoons, wastewater effluent penetration, and livestock manure) and non-point origins (such as fertilizers, pesticides, manure application, atmospheric deposition, etc.). Increased NO_3^- pollution in drinking water causes health problems in children including methemoglobinemia, thyroid disorders, and high blood pressure (Radfarda et al., 2019, Azhdarpoor et al., 2019, Subba Rao, 2021). These NO_3^- and F^- produce a non-carcinogenic health risk, which is a critical factor for population health. Several studies have highlighted the negative health impacts of enhanced NO_3^- and F^- in groundwater (Ji et al., 2020).

Water quality can be assessed using a variety of methods including the water quality index (Şener et al., 2017), Entropy Water Quality Index (EWQI) (Wang et al., 2019), and fuzzy mathematical method (Dahiya et al., 2007). EWQI is the most extensively used approach for water quality assessment (Adimalla, 2021, Wang et al., 2019). The humans' ability to monitor and control water quality has improved as water science has progressed. The health risk assessment of water resources complements the quality evaluation of water resources and aids in evaluating the ions impacting water quality (Adimalla et al., 2018, Rao et al., 2021, Qasemi et al., 2023).

The risks of exposure to polluted water resources can be assessed and used to urge people to pollute water resources less by calculating health risks. There are a variety of assessment models in use around the world. One of the most prevalent models is the health risk assessment model proposed by the US Environmental Protection Agency (USEPA). To date, water quality and health risks have been assessed in several studies including those conducted by (Zheng et al., 2017) and (Chen et al., 2017) in northeast and northwest China.

In the present study, to assess the non-carcinogenic health risk factors related to F^- , NO_3^- , NO_2^- , Mg^{2+} , Mn^{2+} , and Fe^{2+} through ingestion and dermal paths, an effort has been made to 1. determine the distribution patterns of non-carcinogenic health risk assessment, 2. distinguish contaminant resources utilizing hydrochemistry markers, and 3. evaluate the non-carcinogenic health risk factors related to F^- , NO_3^- , NO_2^- , Mg^{2+} , Mn^{2+} , and Fe^{2+} through ingestion and dermal routes. The findings of this study can help interpret the complicated factors

affecting water quality, determine NO_3^- and F^- pollution sources, and assess the risk level as it is associated with population health for the long-term management of groundwater resources.

2. Materials and methods

2.1. Study area

Kohgiluyeh and Boyer-Ahmad is an Iranian province with Yasuj as its capital. This province that extends 16,249 km^2 and is bordered by Chaharmahal and Bakhtiari province in the north, by Khuzestan province in the west, by Bushehr province in the south, and by Fars and Isfahan provinces in the east is located along the Zagros Mountains, with the geographical coordinates of 29° 36' 00" and 31° 26' 00" North latitude and 49° 55' 00" and 51° 53' 00" East longitude. Rainfall in the province has decreased from the north-east to the south-west as a result of its geographic position, where around 80 % of it is surrounded by mountains. In addition, the area's average annual rainfall is approximately 863 mm, and the average temperature is 14°C (Fakhir Nasab et al., 2020). As indicated in Fig. 1, 130 wells were sampled from the 8 counties of Kohgiluyeh and Boyer-Ahmad.

2.2. Sample collection and analysis

Local government authorities frequently evaluate the water quality of reservoirs. In Kohgiluyeh and Boyer-Ahmad province, there are eight reservoirs that were surveyed in the current research. The samples were taken from January to December 2021 and the water quality was evaluated weekly at each monitoring station. pH, Electroconductivity (EC), turbidity, Total Dissolved Solids (TDS), total alkalinity, total hardness, permanent hardness, temporary hardness, bicarbonate alkalinity, F^- , Cl^- , SO_4^{2-} , PO_4^{2-} , NO_2^- , NO_3^- , Ca^{2+} , Mg^{2+} , K^+ , Fe^{2+} , and Mn^{2+} were some of the monitored indicators. When the highest concentrations of water quality indicators were less than the detectable level, water quality was assessed using half of the detectable limit. Standard methodologies were used for the analysis. Before sampling, the samples were gathered in disposable polyethylene containers that had been rinsed three times. A portable pH meter was used to monitor the pH levels in place. Duplicates of every sample were also taken to guarantee the validity and accuracy of the data. In fact, the accuracy of the analyses were checked using verified reference materials under identical conditions and the dependability of the data was ensured (Zhang et al., 2018). Overall, 580 samples from the entire province were gathered over the course of a year and analyzed for various parameters in the dependable lab of the water and wastewater company using the techniques from the Standard Methods (Rice et al., 2012).

2.3. Entropy water quality index

EWQI is a comprehensive water quality evaluation method that has been widely used to determine the quality of water for drinking purposes (Su et al., 2018, Zhou et al., 2016). The steps for calculating the EWQI are as follows:

The first step in calculating the EWQI is to give each water quality measure the appropriate weight. The entropy e_j and

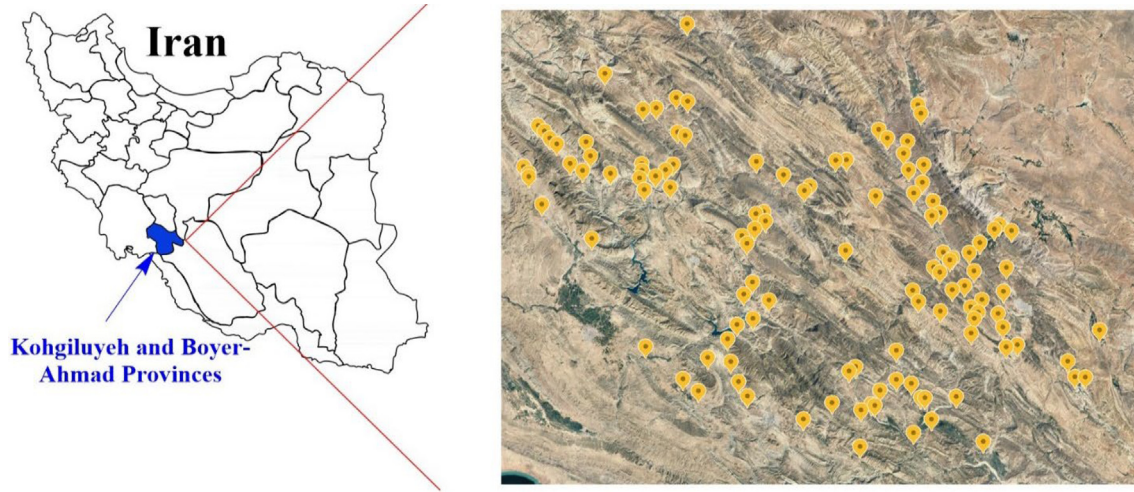


Fig. 1 Map of the study area and water sampling points.

entropy weight w_j can then be computed using Eq. (1) to Eq. (3).

$$e_j = -\frac{1}{\ln m} \sum_{i=1}^m p_{ij} \ln p_{ij} \quad (1)$$

$$p_{ij} = \frac{(1 + y_{ij})}{\sum_{i=1}^m (1 + y_{ij})} \quad (2)$$

$$w_j = \frac{(1 - e_j)}{\sum_{i=1}^m (1 - e_j)} \quad (3)$$

The second step in calculating the EWQI is to compute the quality rating scale (q_j), which can be done using Eq. (4).

$$q_j = \frac{C_j}{S_j} \times 100 \quad (4)$$

Where C_j is the concentration of the investigated water quality parameters and S_j is the water quality parameter recommendation value in the Iranian standard (ISIRI, 2010).

Finally, the EWQI can be determined using Eq. (5).

$$EWQI = \sum_{j=1}^m w_j q_j \quad (5)$$

According to the findings of the EWQI, water quality can be divided into five categories, namely excellent quality (less than 25), good quality (25 ~ 50), medium quality (50 ~ 100), poor quality (100 ~ 150), and extremely poor quality (greater than 150) (Adimalla, 2021, Su et al., 2018, Subba Rao et al., 2020).

2.4. Health risk assessment

Humans are exposed to toxic compounds in water through three major routes; i.e., ingestion through drinking water, intake through inhalation, and dermal exposure (Wang et al., 2021, Li et al., 2021, Ji et al., 2020). Since water is mostly utilized for drinking and bathing, the major exposure methods for the inhabitants in the study region were drinking water ingestion and dermal exposure. F^- , NO_3^- , NO_2^- , Mg^{2+} , Mn^{2+} , and Fe^{2+} were chosen to do the non-carcinogenic

health risk assessment according to the measurement data. In this research, age and sex were both regarded as the factors affecting the health risk, and three groups (children, adult females, and adult males) were deemed (Zhang et al., 2021).

Eq. (6) and Eq. (7) were used to assess the non-carcinogenic risk of drinking water consumption (He et al., 2021, He and Wu, 2019).

$$Intake_{Oral} = \frac{C \times IR \times EF \times ED}{BW \times AT} \quad (6)$$

$$HQ_{Oral} = \frac{Intake_{Oral}}{RfD_{Oral}} \quad (7)$$

Where IR was the ingestion rate of drinking water (L/day) and C was the contaminant concentration in the collected samples (mg/L). IR was divided into two components in this research. The first was direct water intake (IR_1), while the second was indirect water intake (IR_2) such as consuming food prepared with water. EF referred to the exposure frequency (day/year), and its value was 365 day/year. ED stood for the exposure duration (year), F (unit less) denoted the fraction of the skin's surface area in contact with water, BW referred to bodyweight (kg), AT was the average time of non-carcinogenic effects (day) (Karunanidhi et al., 2021), and RfD was the reference dosage (mg/(kg.day)). Based on the Integrated Risk Information System (IRIS) database of the USEPA, the RfD_{oral} levels for F^- , NO_3^- , NO_2^- , Mg^{2+} , and Mn^{2+} were 0.06, 1.6, 0.1, 11.0, and 0.14 mg/(kg.day), respectively (USEPA, 1996, Council and Committee, 1977). Additionally, the provisional-RfD for Fe^{2+} was 0.7 mg/(kg. day) (Agency, 2006). The particular values for each of these have been listed in Table 1 (Yin et al., 2021).

Eq. (8) to Eq. (11) were used to estimate the non-carcinogenic risk of dermal exposure (Li et al., 2017).

$$Intake_{Dermal} = \frac{DA \times EV \times SA \times EF \times ED}{BW \times AT} \quad (8)$$

$$DA = K \times C \times t \times CF \quad (9)$$

$$HQ_{Dermal} = \frac{Intake_{Dermal}}{RfD_{Dermal}} \quad (10)$$

Table 1 Parameter values for non-carcinogenic health risk assessment models.

Parameters	Units	Children	Adult males	Adult females
IR ₁	L/day	0.52	1.73	1.22
IR ₂	L/day	0.21	0.57	0.47
ED	Year	12	30	30
BW	Kg	20	70	56
AT	Day	4380	10,950	10,950
t	h/day	0.4	0.4	0.4
EF	Day/year	365	365	365
F	Unit less	0.65	0.65	0.65
SA	cm ²	7557	17,000	15,000

$$RfD_{Dermal} = RfD_{Oral} \times ABS_{gi} \quad (11)$$

Where EV stood for daily dermal contact exposure frequency that was 1 in this study, SA was the surface area of the skin (cm²), and K was the permeability of the skin that was considered 0.001 cm/h. The contact time (h/day) or exposure time (ET) was set at 0.4 h/day for both adults and children (Li et al., 2016). ABS_{gi} was a gastrointestinal absorption factor with a value of 1 for all the ions and CF was a conversion factor with a value of 0.001. Eq. (12) and Eq. (13) were used to calculate the total non-carcinogenic risks.

$$HI_i = HQ_{Oral} + HQ_{Dermal} \quad (12)$$

$$HI_{total} = \sum_{i=1}^n HI_i \quad (13)$$

Where HI referred to the non-carcinogenic risk index. HI less than 1 denoted a tolerable risk, whereas HI ≥ 1 indicated a higher-than-tolerable non-carcinogenic risk (Zhou et al., 2021).

2.5. Sobol sensitivity analysis

To find the relevant input parameters and evaluate their impacts on the variance of the exposure outcomes, use was made of Sobol sensitivity analysis combined with the Monte Carlo approach (Sobol, 2001). The Sobol Sensitivity Indices (SIs) refer to the ratio of the partial variable to the overall variable. The first term of SI is named First Order Sensitivity Index (FOSI), which explains the impact of a single variable on the variance in model results. The second term is named Second-Order Sensitivity Index (SOSI) that explains the impact of the interaction between variables. Finally, the Overall Order Sensitivity Index (TOSI) is used to compute the overall influence of the variable on the final variance. Sensitivity indices greater than 0.1 (highly sensitive), 0.01–0.1 (sensitive), and less than 0.01 (insensitive) represent significantly relevant, prominent, and unresponsive input variables, respectively (Mukherjee and Singh, 2022, Mukherjee and Singh, 2021). In the current research, Sobol sensitivity analysis was carried out utilizing the R-platform ('EnvStats', 'sensobol', 'Enviro-PRA' packages), version 4.1.2.

2.6. Spatial distribution

This investigation revealed the spatial distribution of the health risk assessment. The Arc-GIS program (10.8.1 version)

was utilized to analyze the spatiotemporal variations in the concentrations of contaminants in groundwater in this area to detect high contamination locations by Inverse Distance Weighted (IDW) analysis (RadFard et al., 2019).

3. Results and discussion

3.1. General hydrochemistry

Based on the findings of laboratory and field experiments, the chemical features of groundwater were detailed. The statistical information on the appropriateness of groundwater for drinking based on Iranian Standard (ISIRI, 2010) and World Health Organization's (WHO) guidelines (Organization, 2017) has been presented in Table 2. Based on the results, the mean temperature of groundwater over a year was 19.44 °C, which contributed to regulating the responses in the groundwater and aquifers media. In addition, the groundwater in the region was considerably mineralized. The average EC and TDS were 567.4 μmhos/cm and 319.1 mg/L, respectively, indicating that the liquid phase of water had a considerable contact with both gaseous and solid media. None of the samples exceed the Iranian Standard and WHO-recommended limits for EC and TDS (Organization, 2017, ISIRI, 2010). Moreover, the mean pH of the groundwater was 7.64, which indicated that it was moderately alkaline. As seen by the mean concentration of 195.2 mg/L in groundwater, the total alkalinity of groundwater was mostly attributable to soluble carbon dioxide molecules in water. Furthermore, the average hardness of the groundwater in the area was 239.3 mg/L as CaCO₃, indicating that the groundwater in the region was extremely hard. Water with a hardness of more than 200 mg/L in 58.1 % of the samples was unfit for human consumption (Organization, 2017).

The mean Ca²⁺ and Mg²⁺ levels in groundwater were 58.65 mg/L and 20.01 mg/L, respectively. Sandstone, limestone, basalts, and dolomites found in the region might considerably contribute to Ca²⁺ and Mg²⁺ levels in groundwater. In all WHO-mandated samples, the quantity of Ca²⁺ ions were within the allowed level, but the level of Mg²⁺ ions surpassed the allowed limit in 3 % of the samples. Additionally, the mean K⁺ content was 2.42 mg/L, which might be due to the potential for K⁺ to be absorbed back through groundwater movement. K⁺ is produced by the ion exchange process and can come from both geological and human origins in groundwater. If potassium compounds are widely utilized, farming can add K⁺ to groundwater. Moreover, the concentration of Mn²⁺ in groundwater was averagely 0.17 mg/L. According to the WHO guidelines, the allowable level of Mn²⁺ is 0.1 mg/L. The WHO's guideline was exceeded in almost 45 % of the samples. Finally, the Fe²⁺ concentration differed widely from well to well, with a mean of 0.18 mg/L. The WHO has established a maximum of 0.3 mg/L for Fe²⁺ in drinking water (Nawale et al., 2021).

In the research region, SO₄²⁻ levels in groundwater varied from 1 to 612 mg/L (mean: 55.48 mg/L). In 6 % of the samples, the level of SO₄²⁻ ions surpassed the allowed limit. Groundwater may contain SO₄²⁻ as a result of atmospheric deposition. It is impossible to rule out the potential of sulphur-bearing minerals like pyrite occurring in coal. Sulfate fertilizers can play a role, as well (Marghade et al., 2021,

Table 2 Statistical data on the acceptability of the study field's groundwater for drinking purposes according to WHO's guidelines.

Parameter	N = 580				Iranian standard	WHO	Percentage of the samples having higher values than	
	Min.	Max.	Mean	Std. Dev.			Iranian standard	WHO
Temperature (°C)	18	22	19.44	1.43	–	–	–	–
pH	7.02	7.89	7.64	0.291	6.5–8.5	6.5–8.5	0 %	0 %
EC (µmhos/cm)	210	1960	567.4	245.4	–	–	–	–
Turbidity (NTU)	0.04	4.9	0.73	0.67	5	5	0 %	0 %
TDS (mg/L)	32	771	319.1	136.8	1000	1000	0 %	0 %
Total alkalinity (Methyl orange)	85	400	195.2	66.7	–	–	–	–
Total hardness (mg/L)	50	908	239.3	122.2	200	200	58.1 %	58.1 %
Permanent hardness (mg/L)	35	652	144.4	82.8	–	–	–	–
Temporary hardness (mg/L)	10	284	89	46.2	–	–	–	–
Bicarbonate alkalinity (mg/L)	23	488	230.9	72.9	–	–	–	–
F ⁻ (mg/L)	0.0	1.3	0.45	0.22	1.5	1.5	0 %	0 %
Cl ⁻ (mg/L)	0.2	78	13.57	17.23	250–400	200–600	0 %	0 %
SO ₄ ²⁻ (mg/L)	1	612	55.48	89.2	250–400	400	6 %	6 %
PO ₄ ²⁻ (mg/L)	0.01	1.1	0.24	0.25	–	–	–	–
NO ₂ ⁻ (mg/L)	0	0.65	0.06	0.12	3	3	0 %	0 %
NO ₃ ⁻ (mg/L)	0.01	90.7	13.41	10.87	50	50	1 %	1 %
Ca ²⁺ (mg/L)	0.63	250	58.65	30.11	300	75–200	5 %	8 %
Mg ²⁺ (mg/L)	2.4	55.2	20.01	9.56	30	30	3 %	3 %
K ⁺ (mg/L)	0.02	20.3	2.42	4.02	–	10	–	5 %
Fe ²⁺ (mg/L)	0.0	1	0.18	0.2	0.3	0.3	9 %	9 %
Mn ²⁺ (mg/L)	0.0	2	0.17	0.34	0.1	0.1	45 %	45 %

Organization, 2017). On the other hand, phosphate concentrations were low (0.24 mg/L). The highest phosphate level was 1.1 mg/L, while the lowest value was 0.01 mg/L. The mean NO₂⁻ and NO₃⁻ concentrations in groundwater were 0.06 and 13.41 mg/L, respectively. Inappropriate disposal, sewage, and farming in the region were the substantial contributors to NO₃⁻ in groundwater. The NO₃⁻ exceeded the Iranian standard and WHO's limit of 50 mg/L in 1 % of the samples. Finally, the level of F⁻ varied from 0 to 1.3 mg/L (mean: 0.45 mg/L). Aqueous media with F⁻ carrying minerals caused F⁻ to enter the groundwater in the studied region (Sankhla and Kumar, 2018, Organization, 2017, ISIRI, 2010).

3.2. Water quality assessment

F⁻, NO₃⁻, NO₂⁻, Ca²⁺, Mg²⁺, Mn²⁺, and Fe²⁺ were chosen as water quality parameters in this research to accomplish an all-water quality evaluation utilizing the EWQI. The EWQI calculations for the groundwater samples have been provided in Table 3. Accordingly, EWQI was 80 to 516 for the measured variables in a year. One reservoir had medium-quality water (rank 3), while the other had severely poor-quality water (rank 5) that could be utilized for drinking after considerable treatment. Overall, the findings demonstrated that the quality of groundwater was typically unfit for drinking throughout the year. The evaporating and concentrating impacts of the groundwater might be attributed to high temperatures and high evaporation rates throughout the year. Furthermore, the increase in surface water and groundwater levels over a year made it simpler for surface water, which could be contaminated by animal feces, human excrement, and other sources, to permeate into groundwater.

Drinking water is transmitted by pipelines and increased temperature will alter the development of microorganisms in pipelines, resulting in a rise in bacteria, microorganisms, and byproducts and lowering the overall quality of water. Mg²⁺ and NO₃⁻ are two important ions for determining water quality. Agricultural activities are linked to NO₃⁻ concentrations in various seasons. The water quality of the groundwater is often inadequate for house use. The water quality of Gachsaran was better than that of other reservoirs, which suggested that climate change could have a big influence on the groundwater quality (Ji et al., 2020).

3.3. Health risk assessment

Since groundwater is the primary supply of drinking water, the health risks associated with ingesting polluted water gets to be a major concern (Adimalla, 2021). The Hazard Quotient

Table 3 Water quality assessment results using the entropy-based matter element extension analysis.

Counties	EWQI	Water Quality
Basht	194	Extremely poor quality
Boyer-Ahmad	175	Extremely poor quality
Bahmai	299	Extremely poor quality
Choram	233	Extremely poor quality
Dana	380	Extremely poor quality
Gachsaran	80	Medium quality
Lendeh	426	Extremely poor quality
Kohgiluyeh	516	Extremely poor quality

(HQ_{oral}) for the consumption of drinking water in adult males ranged from 0.955 to 1.492, with an average of 1.179. This measure ranged from 0.877 to 1.371 in adult females, with an average of 1.083. For children, the HQ_{oral} through the consumption of drinking water varied from 1.061 to 1.658, with an average of 1.310. Based on the results, 75 % of the samples for adult males, 50 % for adult females, and 100 % for children had an HQ_{oral} surpassing 1, indicating that almost all the samples might cause non-carcinogenic risks. Dermal exposure had a lower hazard quotient (HQ_{dermal}) compared to oral exposure, ranging from 0.003 to 0.004, 0.002 to 0.004, and 0.004 to 0.007 for adult males, adult females, and children, respectively. This showed that the non-carcinogenic risk was primarily transmitted through the oral ingestion of polluted water. The overall non-carcinogenic health risks (HI_{total}) for children, adult females, and adult males have been presented in Table 4. Accordingly, adult males had a non-carcinogenic risk of 0.958 to 1.374 (mean: 1.086), adult females had a non-carcinogenic risk of 0.879 to 1.374 (mean: 1.086), and children had a non-carcinogenic risk of 1.065 to 1.664 (mean: 1.315). These findings suggested that adults and children in the study region encountered a significant non-carcinogenic health risk. On the other hand, children in the research region faced higher non-carcinogenic health risks in comparison with adults. However, no significant difference was observed between the adult males and females in terms of health risks. Similar studies have also revealed a greater health risk for children compared to adults, implying that children were more sensitive to pollutants compared with adults (Li et al., 2021, Wang et al., 2021). The non-carcinogenic health risks associated with the Bahmai reservoir were greater than those associated with other reservoirs.

Pollutants lead to health concerns in diverse ways. As indicated in Fig. 2, Mg^{2+} (57.93 %) followed by NO_3^- (39.80 %) were the most important factors in non-carcinogenic risks. Other pollutants contributed by less than 5 % to non-carcinogenic risks, implying that Mg^{2+} and NO_3^- might be the causes of negative human health impacts. The sequence, in which the contaminants contributed to non-carcinogenic risks was as follows: $Mg^{2+} > NO_3^- > F^- > Mn^{2+} > Fe^{2+} > NO_2^-$.

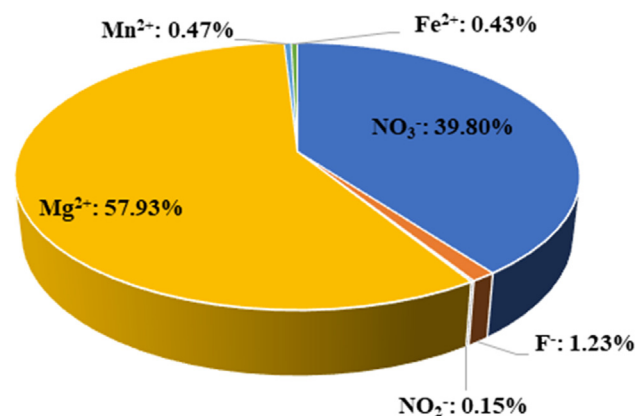


Fig. 2 Contributive ratios of non-carcinogenic risk pollutants to health risks.

Generally, there are three uncertainties in every health risk assessment: model uncertainty, parameter uncertainty, and input data uncertainty. In the present study, there were some uncertainties in the model itself. For instance, SA and DA were computed using experimental models and, consequently, the SA and DA values varied depending on the used experimental models. In addition, assessment models contained a large number of factors, each of which was correlated to a level of uncertainty. For adults and children, the water consumption rate was considered 0.52 to 1.73 L/d in a direct way and 0.21 to 0.57 L/d in an indirect way in this research. These estimates were based on statistical data, but they varied from person to person. Various rates of consumption result in different dangers. Likewise, BW, AT, and EV quantities are all derived from statistical data, and various people may have various parameter quantities. Furthermore, the input data had an element of uncertainty. Even though all the water samples were evaluated in a qualified laboratory using conventional processes and techniques, both analytical and systematic errors were unavoidable and added to the level of uncertainty. Despite these concerns, the study findings were credible and useful. The findings indicated the mean risk levels, with

Table 4 Non-carcinogenic health risks for children, adult males, and adult females.

Counties	HQ_{oral}			HQ_{dermal}			HI_{total}		
	Children	Adult males	Adult females	Children	Adult males	Adult females	Children	Adult males	Adult females
Basht	1.209	1.088	0.999	0.005	0.003	0.003	1.214	1.092	1.003
Boyer-Ahmad	1.061	0.955	0.877	0.004	0.003	0.002	1.065	0.958	0.879
Bahmai	1.658	1.492	1.371	0.007	0.004	0.004	1.664	1.497	1.374
Choram	1.519	1.368	1.256	0.006	0.004	0.003	1.526	1.372	1.259
Dana	1.274	1.147	1.053	0.005	0.003	0.003	1.279	1.150	1.056
Gachsaran	1.356	1.221	1.121	0.006	0.004	0.003	1.362	1.225	1.125
Lendeh	1.215	1.094	1.005	0.005	0.003	0.003	1.220	1.097	1.008
Kohgiluyeh	1.184	1.066	0.979	0.005	0.003	0.003	1.189	1.069	0.981
Min	1.061	0.955	0.877	0.004	0.003	0.002	1.065	0.958	0.879
Mean	1.310	1.179	1.083	0.005	0.003	0.003	1.315	1.182	1.086
Max	1.658	1.492	1.371	0.007	0.004	0.004	1.664	1.497	1.374

individual risks varying within a reasonable range around the average. These results are particularly important for decision-makers, since they provide them with broad risk information that leads to making informed decisions based on the majority of people. When comprehensive information is supplied, it is often difficult to make sound decisions. Decision-makers, for instance, find it hard to make judgments if they take into account each individual's real-life circumstances (Li et al., 2016, Qasemi et al., 2019, Nabizadehb et al., 2019).

The drinking water supplies of several towns, including Tehran, Mashhad (Khorasan Razavi), Ardabil, Ahwaz (Khuzestan), and Qom, have greater nitrate concentrations than the level advised by the Institute of Standards and Industrial Research of Iran (ISIRI) and WHO. This is according to a study by Darvishmotevalli et al. in Iran, which evaluated the carcinogenic hazards associated with nitrate exposure in drinking water. As a result, the cancer risk associated with nitrosamine, which is created when nitrate is taken through drinking water, is higher in these cities. According to this study, there is a significant link between nitrate exposure and the occurrence of cancer in the vast majority of Iranian districts whose drinking water sources have been restricted (Darvishmotevalli et al., 2019). The level of nitrate in drinking water was identified by Fallahzadeh et al. as the most crucial factor. The average nitrate concentration was 27.57 to 6.80 mg/L, and all observed amounts were below the allowed maximum threshold. Children in this group were at a high risk since their HQ values were more than 1. The author came to the conclusion that lowering the concentration of nitrate might lower population risk (Fallahzadeh et al., 2019).

3.4. Sobol sensitive analysis

The Sobol sensitivity analysis was performed to analyze the most relevant input factors related to the non-carcinogenic health hazards related to nitrate contamination in drinking water in the population of the region. The factors for this model have been listed in Table 1. As the table depicts, the oral model had four input factors, namely nitrate concentration in groundwater (C_w), Body Weight (BW), Exposure Frequency (EF), and Intake Rate (IR_1 and IR_2), while the dermal model had six input factors as follows: contaminant concentration (C_w), the fraction of skin contact (F), exposure during shower time (ET), BW, skin surface area (SA), and EF.

According to the results of Sobol sensitivity analysis (Fig. 3), the C_w parameter was the most effective parameter in oral HQ among the children (0.793), males (0.386), and females (0.466). Following C_w , the parameters were ranked as IR (0.093) > EF (0.024) > BW (0.007) in the children and as IR (0.321, 0.274) > BW (0.022, 0.022) > EF (0.011, 0.014) in male and female adults. The BW value was less than 0.01 among the children, indicating its insensitivity in terms of relevance. Besides, the EF value was the less sensitive parameter in adult males and females. However, since the C_w value was more sensitive in females than in males, it could be concluded that this parameter was more important in females, while IR was more important in males. Since the total sensitivity was higher than the first-order sensitivity, these parameters had interactions. The values of the effective parameters in total Sobol sensitivity in oral HQ were as follows: $C_w = 0.874$, $IR_1 = 0.156$, $EF = 0.042$, and $BW = 0.013$ for children, $C_w = 0.627$,

$IR_1 = 0.559$, $BW = 0.055$, and $EF = 0.029$ for males, and $C_w = 0.675$, $IR_1 = 0.474$, $BW = 0.051$, and $EF = 0.032$ for females. The interaction diagram (Fig. 3) for the children showed that C_w had interaction effects with three factors, with the effect being significantly stronger for C_w - IR_1 compared to C_w -EF and C_w -BW, which varied for different IR_1 values. There were also interactions between C_w -BW, C_w - IR_1 , BW- IR_1 , C_w -EF, and IR_1 -EF in both males and females. However, the severity of this interaction was much greater between IR_1 and C_w , and all the other parameters, except for EF-BW, had very little interactions. Furthermore, the children were more exposed to non-carcinogenic risks from water contaminants in comparison with adults, and C_w was among the most effective parameters in the oral HQ of this group. The sensitivity study findings for IR_2 were comparable to the sensitivity analysis results for IR_1 , which was due to the same parameters and the same way of exposure to nitrate in water (Fig. 4). The effective parameters in oral HQ in total Sobol sensitivity were $C_w = 0.793$, $IR_2 = 0.093$, $EF = 0.024$, and $BW = 0.007$ for children, $C_w = 0.386$, $IR_2 = 0.321$, $BW = 0.022$, and $EF = 0.011$ for males, and $C_w = 0.466$, $IR_2 = 0.274$, $BW = 0.022$, and $EF = 0.014$ for females.

C_w was the most important and effective parameter in dermal HQ amongst children (0.837), males (0.783), and females (0.792). The parameters were ranked as F (0.064) > EF (0.025) > BW (0.008) in the children and as F (0.060, 0.060) > BW (0.044, 0.038) > EF (0.024, 0.024) in male and female adults. All the ET and SA values were less than 0.01, showing their insensitivity to the dermal HQ. Furthermore, because the C_w value was larger in females than in males, this parameter was more essential in females. However, BW was more important in males. Moreover, because the total sensitivity was greater than the first-order sensitivity, it might be inferred that these factors interacted with each other. Considering the total Sobol sensitivity in dermal HQ, the effective parameters were $C_w = 0.901$, $F = 0.108$, $EF = 0.044$, and $BW = 0.013$ for children, $C_w = 0.868$, $F = 0.104$, $BW = 0.077$, and $EF = 0.042$ for males, and $C_w = 0.874$, $F = 0.105$, $BW = 0.067$, and $EF = 0.043$ for females. In the children, the interaction diagram (Fig. 5) revealed that C_w interacted with three parameters, with the influence of C_w -F being much greater than C_w -EF and C_w -BW, which changed for various F values. In both males and females, there were interactions between C_w -F, C_w -BW, and C_w -EF, with the intensity of the interaction between F and C_w being significantly stronger compared to the other parameters. All the other parameters had moderate interactions. Similar results were also obtained in another study conducted by Karunanidhi et al. on nitrate concentrations amongst children, males, and females. The results also indicated that children were more sensitive to changes in the parameters affecting health risk compared to males and females (Karunanidhi et al., 2021).

3.5. Spatial distribution

F^- , NO_3^- , NO_2^- , Ca^{2+} , Mg^{2+} , Mn^{2+} , and Fe^{2+} all showed a wide range of contamination from mild to severe. Nonetheless, the HI of the three groups (children, males, and females) revealed the comparable geographical distribution patterns of the environmental risk (Fig. 6a, b, and c). The hazard in this area was substantially higher compared to other places. Addi-

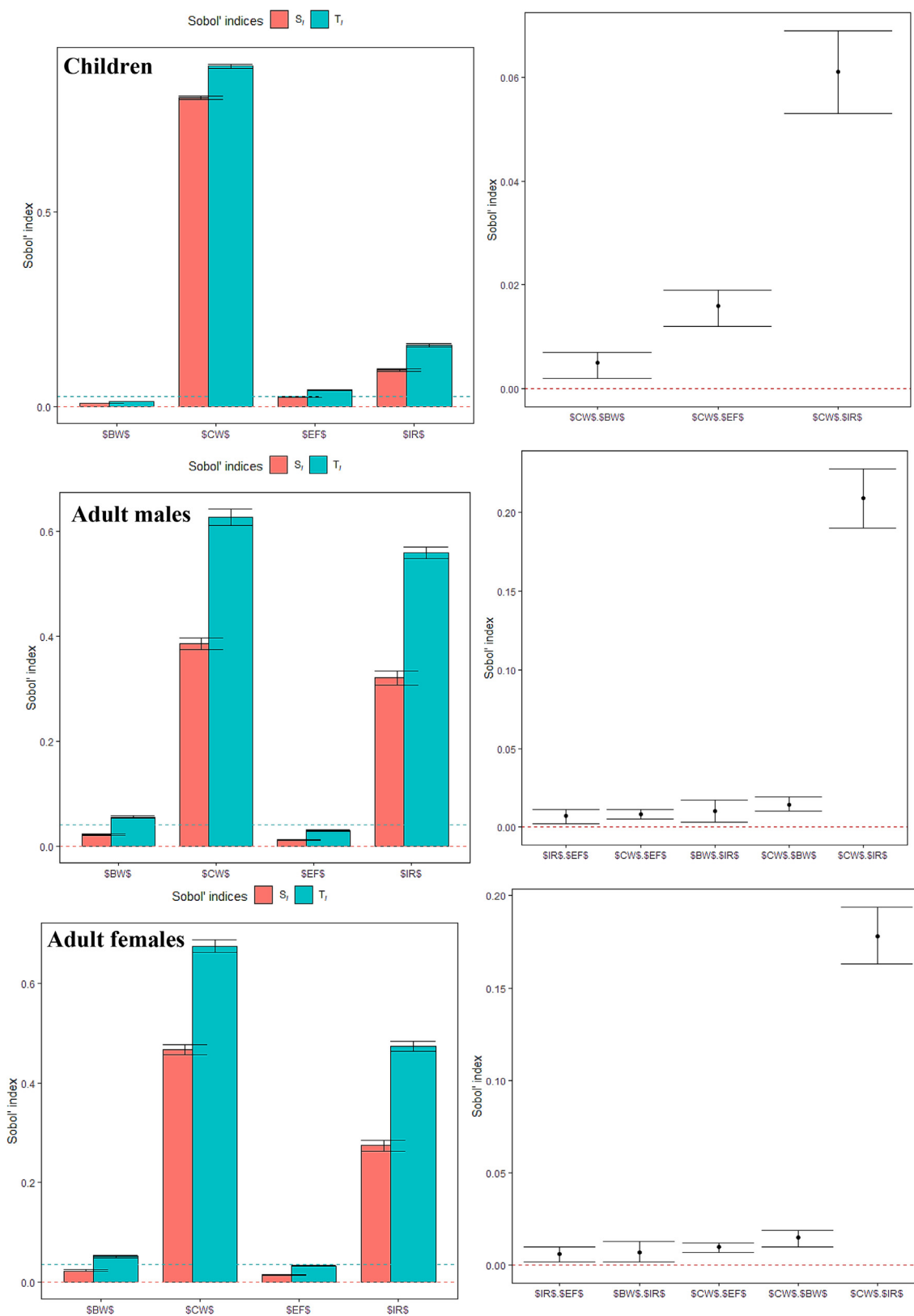


Fig. 3 Sensitivity analysis based on the oral HQ ingestion model (C_w , BW, IR_1 , EF) for the three age groups considering the first-order effect (S_i), total effect (T_i), and pair-wise interactions.

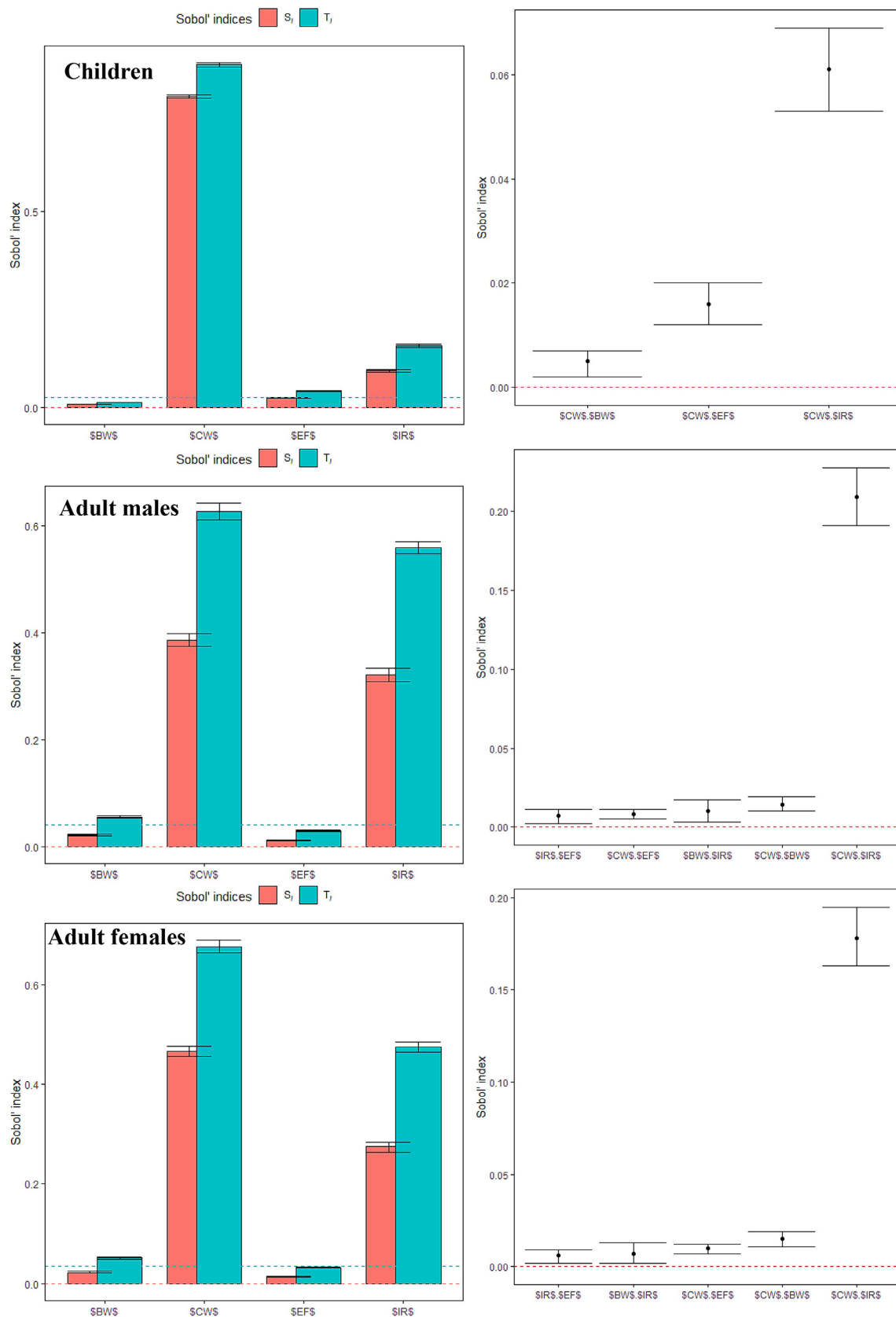


Fig. 4 Sensitivity analysis based on the oral HQ ingestion model (C_w , BW, IR_2 , EF) for the three age groups considering the first-order effect (S_i), total effect (T_i), and pair-wise interactions.

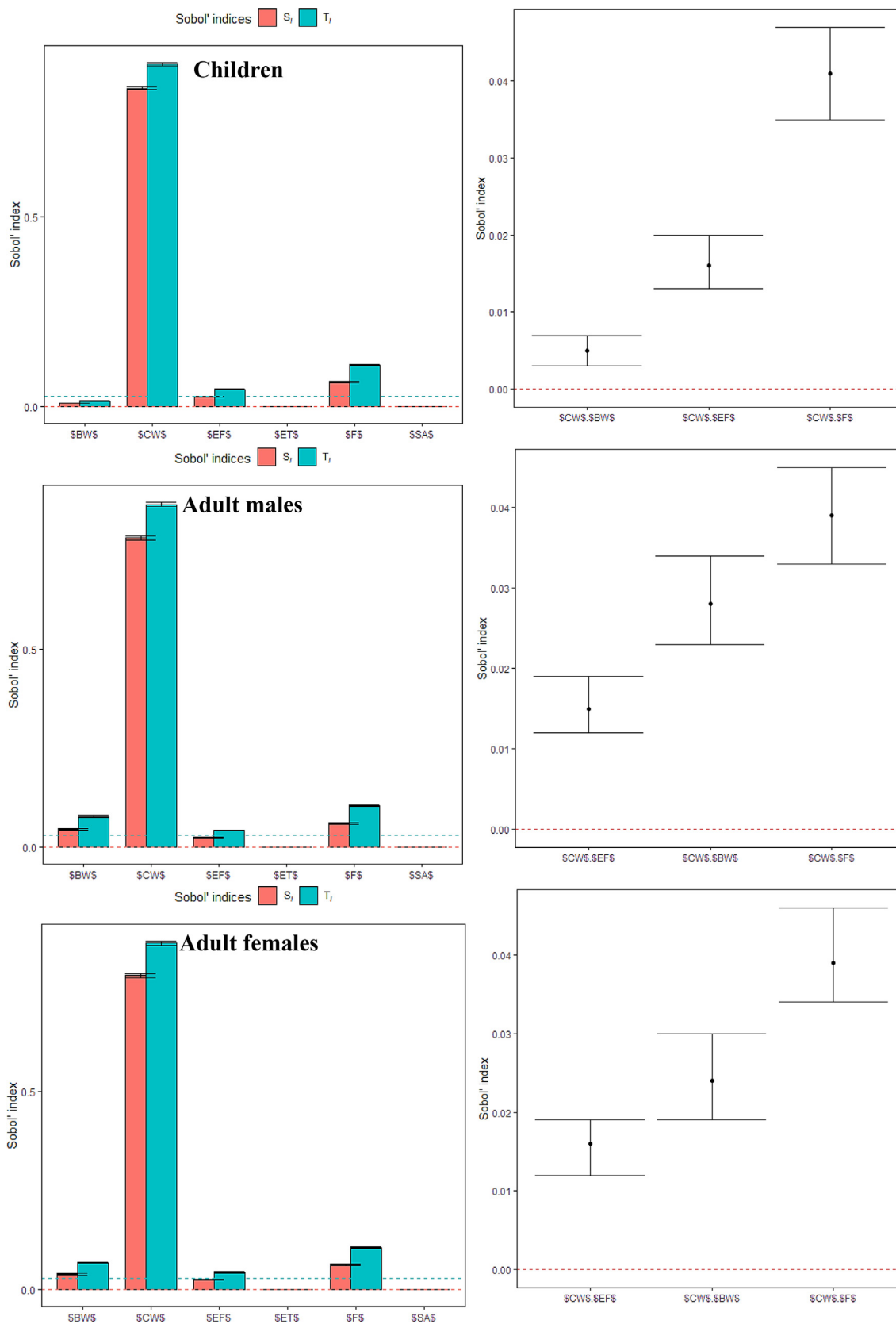


Fig. 5 Sensitivity analysis based on the dermal HQ model (C_w, BW, SA, F, ET, EF) for the three age groups considering the first-order effect (S_i), total effect (T_i), and pair-wise interactions.

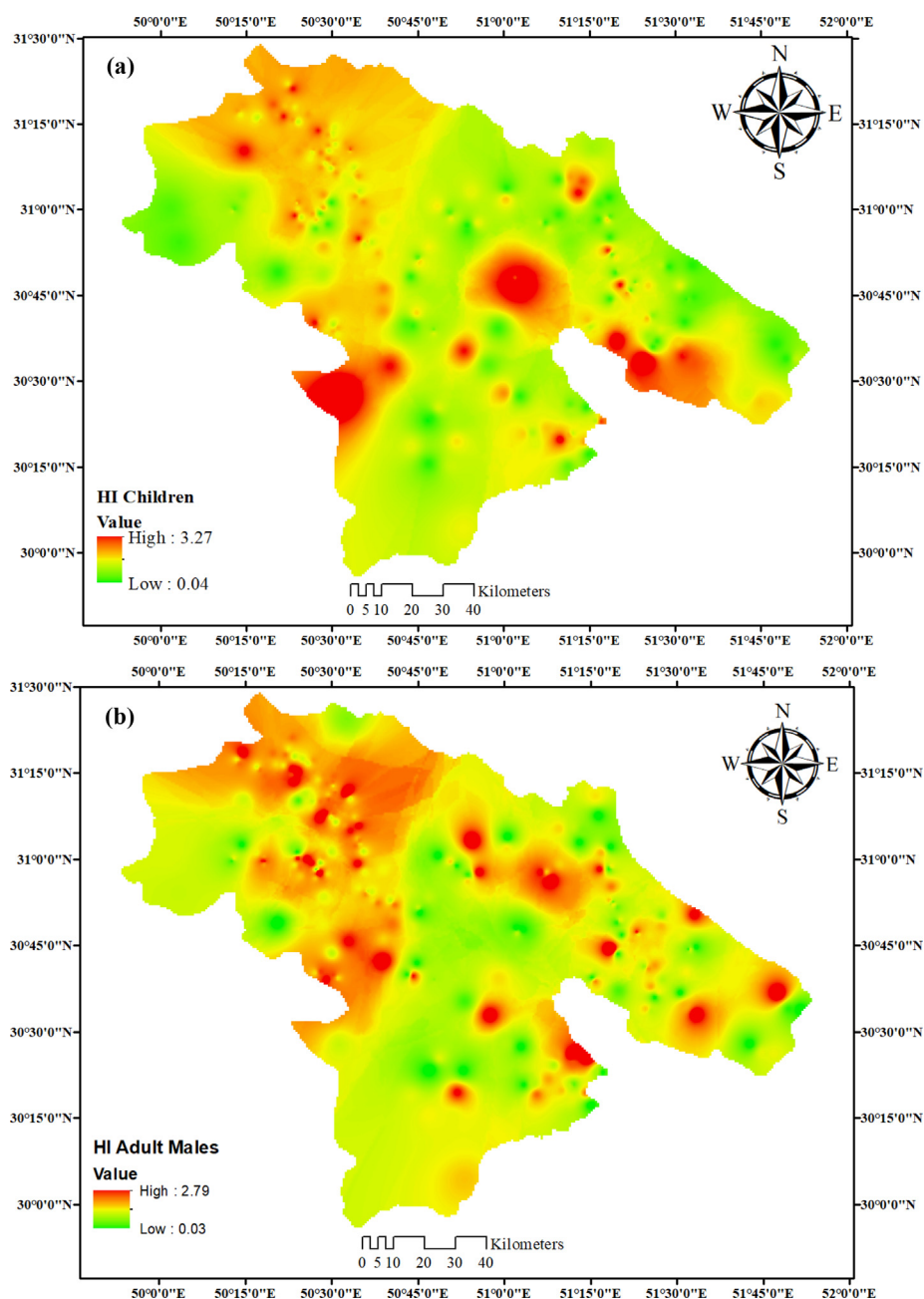


Fig. 6 Spatial distribution of HI in children (a), adult males (b), and adult females (c).

tionally, the concentrations of these ions were higher in the west, northwestern, and bordered areas with Fars province than in other regions. This provided obvious environmental consequences inside these zones, needing more monitoring. Given that groundwater is the principal supply of water in Kohgiluyeh and Boyer-Ahmad province, it is logical to assume that the ions concentrations are rather higher in these resources than in other regions (Davraz and Batur, 2021). Ion concentrations have risen as a result of geological composition, land use in the vicinity of groundwater sources, pollution leakage from diverse sources, and industrial effluent infiltration. Furthermore, ions concentrations alter with precipitation and annual rainfall, and groundwater levels shift from season to season. In places with high ion concentrations,

the watershed height and depth are usually low. Another consideration is the general east-to-northwest slope of Kohgiluyeh and Boyer-Ahmad plains. As a result, agricultural operations should be established carefully (Ehya and Mosleh, 2018). Groundwater overuse to suit municipal, industrial, and agricultural demands can change the properties and natural components of water. Development and upgrade of the wastewater collection system as well as the rate at which industrial effluent is generated are the other factors that influence the concentrations of water pollutants (e.g., nitrate and fluoride). Monitoring of wells, reservoirs, and nearby regions is crucial due to the natural and human factors that affect the concentrations of ions in groundwater (Adeli Moghadam et al., 2020, Das and Nag, 2022).

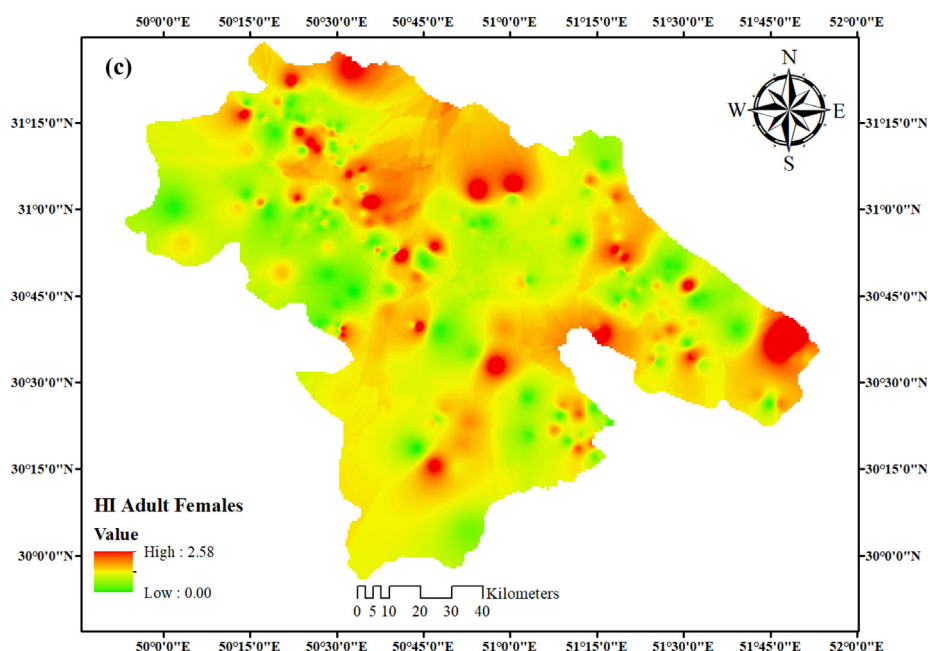


Fig. 6 (continued)

4. Conclusion

The present study investigated the water quality parameters of eight counties in Kohgiluyeh and Boyer-Ahmad province. The EWQI was used to assess the water quality of the counties. Health risk assessment was also conducted, taking into consideration the participants' gender and age. Based on the results, the reservoirs in the eight counties had a poor quality of water. Except for Gachsaran, the majority of the reservoirs had a severely poor water quality throughout the year. On the other hand, all the water quality indicators did not match the requirements for drinking, suggesting minor contamination in a nearby reservoir, except for Gachsaran. Consumption of polluted groundwater in the research region was attributed to human health concerns for people via a variety of routes including oral consumption and dermal exposure. For adult females, the overall non-carcinogenic risks ranged from 0.879 to 1.374. Adult males and children had considerably greater non-carcinogenic risks, ranging from 0.958 to 1.497 and 1.065 to 1.664, respectively. Mg^{2+} and NO_3^- were the primary pollutants that contributed to the total non-carcinogenic risk. The sequence, in which the contaminants contributed to non-carcinogenic risk was as follows: $Mg^{2+} > NO_3^- > F^- > Mn^{2+} > Fe^{2+} > NO_2^-$. The sensitivity of the factors affecting the non-carcinogenic risk was further explored using the *Sobel* sensitivity analysis. The results indicated that nitrate concentration (C_w) was most sensitive in both oral and dermal conditions, which was followed by IR for oral condition and fraction of skin's surface area (F) for dermal condition. Using the findings of this study, local decision-makers will be better informed, thereby providing a better management of groundwater resources in these areas.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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