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Spatial distribution variation and probabilistic risk assessment of exposure to chromium in ground water supplies; a case study in the east of Iran

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ABSTRACT

A high concentration of chromium (VI) in groundwater can threaten the health of consumers. In this study, the concentration of chromium (VI) in 18 drinking water wells in Birjand, Iran, s was investigated over a period of two yearsNon-carcinogenic risk assessment, sensitivity, and uncertainty analysis as well as the most important variables in determining the non-carcinogenic risk for three age groups including children, teens, and adults, were performed using the Monte Carlo simulations technique. The northern and southern regions of the study area had the highest and lowest chromium concentrations, respectively. The chromium concentrations in 16.66% of the samples in an area of 604.79 km2 were more than World Health Organization (WHO) guideline (0.05 mg/L). The Moran's index analysis showed that the distribution of contamination is a cluster. The Hazard Index (HI) values for the children and teens groups were 1.02 and 2.02, respectively, which was more than 1. A sensitivity analysis indicated that the most important factor in calculating the HQ was the concentration of chromium in the consumed water. HQ values higher than 1 represent a high risk for the children group, which should be controlled by removing the chromium concentration of the drinking water.

1. Introduction

Due to the improper disposal of waste and poor maintenance during industrial activities, soil and groundwater contamination with the metal is widely observed in many sites around the world (Ellis et al., 2002; Testa et al., 2004; Fallahzadeh et al., 2018; Khamirchi et al., 2018). In most countries, the groundwater is one of the most important resources for agricultural activities and drinking purposes (Rahmani et al., 2010; Niu et al., 2014; Miri et al., 2016a). In recent years, the long-term use of groundwater resources and the discharge of industrial wastewater into the environment has led to an increase of groundwater contamination (Hadley and Newell, 2012). Chromium is one of the most important heavy metals used in various industrial processes that can be leaked into water bodies without considering efficient treatment methods (Fazlzadeh et al., 2017a). In the environment, chromium is present mainly in the oxidation states, in the trivalent [Cr(III)] and hexavalent [Cr(VI)] forms (Ghosh et al., 2003; Guertin et al., 2016). Cr (III) is essential for humans (multicellular organisms) for insulin metabolism, as well as for plants and animals in trace concentrations (Venitt and Levy, 1974; Witt et al., 2013; Alahabadi et al., 2017b). Acute exposure to hexavalent chromium causes diarrhea, dermatitis, nausea, liver and kidney damage, internal hemorrhaging, and respiratory problems. Skin contact may cause acute damages such as allergy, dermatitis, and skin necrosis. Also, inhalation may lead to irritation and respiratory sensitization (asthma) and additionally, increases cancer risk (Khosravi et al., 2014; Miri et al., 2017). Chromium has a bio-accumulate property inside the body. When the level of Cr(VI) in the body reaches to 0.1 mg/g of the body weight, it can ultimately lead to death (Fazlzadeh et al., 2017b). The permitted concentration of Cr (VI) in drinking water is equal to 0.05 mg/l based on the WHO guideline (Dubey and Gopal, 2007). The Monte Carlo simulation is used to analyze the risk for various chemicals with the risk assessment

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approaches. The Monte Carlo simulation has been used in various studies to calculate the hazard potential and evaluate the risk of pollutants in various environments (Wang et al., 2007; Kavcar et al., 2009; Miri et al., 2016b; Alahabadi et al., 2017a; Fallahzadeh et al., 2017). The GIS software has so far been used in extensive studies to model and evaluate various pollutants (Merchant, 1994; Cattle et al., 2002; Yan et al., 2015).

The present study aimed to investigate the chromium Cr(VI) concentration through sampling from 18 wells supplying drinking water during 2015 and 2016 in Birjand, Iran. The probabilistic risk assessment, sensitivity analysis, and uncertainty due to exposure to chromium were also evaluated. Finally, the spatial and temporal distribution of chromium concentration in the study areas was performed using the Kriging method and Moran's index in the ArcGIS software.

2. Material and methods

2.1. Study area and sampling protocol

The study area in this research is the city of Birjand with the geographical location of 59.2262° E 32.8649° N. The total population of the region is 261,324 people. The studied population is 235,590 people divided into three categories: 3–10 years (38,188 persons), 11–20 years (41,995 persons), and 21–72 years (155,407 people). Fig. 1 shows the geographic location of the studied areas (Sayadi et al., 2015).

For this study, sampling was done from 18 drinking water supplying wells in Birjand, Iran at four times (two years, one sample every six months; in total 72 samples were taken) from January 2015 to June 2016. In our study, to measure the Cr(VI) concentration, DR6000 Hach was used with three replications in measurement.

2.2. Health risk assessment

In this study, the Hazard quotient (HQ) is an estimate of non-carcinogenic risks; it was applied to assess the health risks associated with exposure to chromium through ingestion and dermal contact with groundwater in the study area. An HQ more than 1 represents a high potential for non-carcinogenic risk, and an HQ less than 1 indicates a safe level of pollutants.

In the present study, the health risk potential was calculated for three age groups of three to 10 years (children group), 11–20 years old (teens group), and 21–72 years old (adults group). For this purpose, the amount of daily exposure through ingestion and dermal contact with chromium in the groundwater was calculated by Equations (1) and (2), which are presented by USEPA (1989) (26).

$$EDI_{ing} = \frac{C_w \times IR_w \times EF \times ED}{BW \times AT} \tag{1}$$

$$EDI_{derm} = \frac{C_w \times SA \times K_p \times F \times ETs \times EF \times ED \times 10^{-3}}{BW \times AT} \tag{2}$$

Where EDI_{ing} and EDI_{derm} indicate the estimated daily intake through ingestion and dermal absorption, respectively. The explanation for each of the parameters of Equations (1) and (2), and their values based on previous studies is presented in Table 1.

The Hazard quotient (HQ) related to contact with chromium through drinking water is calculated by Equation (3).

$$HQ = \frac{EDI}{RfD} \tag{3}$$

Where RfD indicates the reference dose of chromium in a specific exposure pathway in mg/kg/day. Based on the USEPA Integrated Risk Information System (IRIS) database, related to USEPA, the RfD_{ing} value for chromium is equal to 3×10^{-3} mg/kg/day (Huang et al., 2017) through oral contact with drinking water. Also, the RfD_{derm} value for dermal exposure to this metal is 1.5×10^{-5} mg/kg/day (Smith, 1994).

Finally, the HI (Hazard Index) was calculated using Equation (4).

$$HI = HQderm + HQing \tag{4}$$

2.3. Monte Carlo simulation and sensitivity analysis

In the case when a single-point value is used for each variable in risk quantification, the probability of uncertainties increases in estimates. In order to reduce the probability of error, it is necessary to use a set of numbers in the domain of the variables involved in the calculation of risk, for which purpose the Monte Carlo simulation is used (Wu et al., 2011). The sensitivity analysis is another part of the Monte Carlo simulation, which allows the user to identify the variables that have the

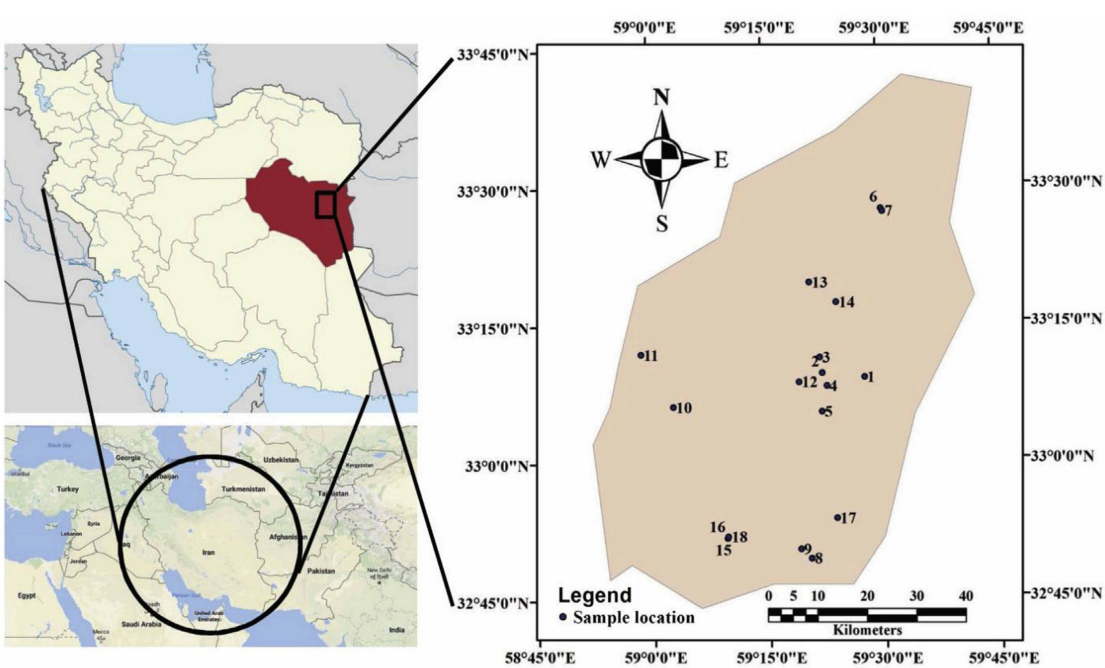

Fig. 1. Geographical location of study area.