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Health risk assessment of phreatic water based on triangular fuzzy theory in Yinchuan plain

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ABSTRACT

Groundwater quality relating closely to human health has become a great concern to the whole society, especially in heavily polluted areas. Yinchuan Plain, located in the arid and semi-arid region of Northwestern China, where people rely heavily on groundwater resource. However, due to the improper groundwater exploitation and negative effect of human activities in recent years, groundwater quality in Yinchuan plain become deteriorated. For the sustainable utilization and protection of groundwater resources, health risk assessment (HRA) of phreatic water is conducted in this paper. On the basis of model recommended by EPA, triangular fuzzy number is applied to establish risk assessment model for health risk assessment of adults and children in wet and dry seasons, respectively. Results of HRA indicate that carcinogenic risk of arsenic is highest among the risk from components in phreatic water, and the highest risk from arsenic to adults and children in wet and dry season are $6.48 \times 10^{-6}a^{-1}$ and $9.56 \times 10^{-6}a^{-1}$, $1.08 \times 10^{-5}a^{-1}$ and $1.59 \times 10^{-5}a^{-1}$, respectively. This study also states that in Yinchuan Plain carcinogenic risk from drinking groundwater can be 3–4 times magnitude higher than the noncarcinogenic risk. Also it is found that the health risk to children is as 1.5–2 times as to adults, while the uncertainties of adults' health risk are higher than that of children.

1. Introduction

In the past few decades there has been a growing awareness of the health hazards of chemicals present in the environment (Davis et al., 2001). Groundwater usually serves as the most important water resources utilized for domestic drinking, agricultural irrigation, and industrial activities in arid and semi-arid regions. The groundwater quality is of great importance to human health, the quantity and quality of groundwater because it affects soils, crops, and the surrounding environment (Kazi et al., 2009; Gu et al., 2013; Zhai et al., 2015, 2017; Emenikea et al., 2018). With the rapid development of agriculture, the acceleration of industrialization and the urbanization, and the increasing social demand for water resources during the past several decades, groundwater pollution has become an important public-health concern and a major national environmental issue in China. Groundwater quality relating closely to human health has become as important as its quantity due to the demand for safe water. Groundwater health risk assessment proves to be an effective method that relates groundwater pollution level with human health and describes quantitatively the harm risk of groundwater pollution to human health. Since the United States Environmental Protection Agency (USEPA) promulgated the Interim Procedures and Guidelines for Health Risk and Economic Impact Assessments of Suspected Carcinogens (Train, 1976), strict health and economic impact risk assessments have been an important part of the regulatory process. Subsequently, the EPA generated water quality standards for 64 contaminants (USEPA, 1980), as well as its first quantitative description of risk assessment (Su, 2015).

Various studies related to HRA has been conducted using the method recommended by the USEPA around the world, and many health risk assessment systems have been established for other countries (Tornqvist, 2011; Yu et al., 2017). By evaluating the level of harm to human health from groundwater pollution and acceptable risk level of human body, health risk assessment (HRA) can used as a guidance by administrative sector in groundwater environment protection, pollution remediation and water environment risk management (Khadam and Kaluarachchi, 2003; Kavcar et al., 2009; Shah et al., 2012; Muhammad

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and Khan, 2010; Zhang, 2013).

It is well-known that One Belt One Road (B&R) was initiated by Present of P. R. China, Xi Jinping in 2013. Ningxia Hui Autonomous Region is selected as the inland open economic pilot site, and serves as the strategic channel and support of B&R. The study area, located at the middle part of Ningxia Hui Autonomous Region, is on the both sides of Yellow River. Yellow River is utilized potentially as the irrigation water due to the increasing demand of agribusiness; thereby a great number of irrigation water was return to the phreatic aquifer. But, to the best of our knowledge, there are no literatures about the health risk assessment of groundwater to human health in the studied region. Therefore, in order to discover the current status of groundwater quality and identify the potential risk to human health, this study focuses attention on the quantitative assessment of human health risk of groundwater chemicals (Fe^{3+}, Mn, F^-, NO_3^- and As) with HRA model. With the aims of stablishing a more realistic base, the two common pathways (dermal and ingestion) and different receptors (adult and children) are considered, respectively. Generally 'four steps' (hazard identification, dose-response assessment, exposure assessment and hazard characterization) method is used in the traditional risk assessment of groundwater pollution to human health, which inherently contains some uncertainties. In the present study, fuzzy triangular number is applied to determine the risk fluctuation range in different confidence levels. The results obtained in study are expected to provide some clues to protect the groundwater environment and human health nationwide.

2. Study area

2.1. Location

Yinchuan Plain is located in the north of Ningxia autonomous region within longitude 105°45′-106°56′E and latitude 37°46′-39°23′W, and covering 7690 km^2 (Fig. 1). It's located in the upper-middle reaches of the Yellow River, and the south to the Qingtongxia, the north reaches the Shizuishan mountain, and the west by the Helan mountain and the west to edge of the Ordos Plain. At an altitude of 1100–1200 m, Yinchuan Plain is the lowest areas in Ningxia. The study area can be divided administratively into over 10 counties (cities) including Yinchuan, Qingtongxia and Wuzhong city. Traffic is well developed in the Yinchuan Plain. 109 national highway and Baolan railway throughout the study area, and airline has been opened to many major cities including Beijing, Shanghai, Guangdong. Roads, railways, aviation constitute a three-dimensional transportation network to all over the country.

The study area lies in Yellow River Basin. As the main river in this area, the Yellow River and its tributaries run through Yinchuan Plain from southwest to northeast, with the length of 191 km. The Yellow River flows out in Shizui mountain, and has apparent impact on the development of topography and groundwater system. Benefiting from the Yellow River, agriculture in Yinchuan Plain flourished for thousands of years with enough irrigation.

2.2. Hydrogeology

The thickness of Cenozoic reaches to 7000 m, Quatenary thickness is 2000 m, and Paleogene is over 1700 m in study area. The huge pore space of the loose deposits becomes the place for groundwater movement and storage, which constitutes the large-scale "underground reservoir". However, detailed reconnaissance of the loose deposits is available merely within the depth of 250 m. According to storage conditions, groundwater in study area can be divided into four types: porous water in loose deposits, clastic fissure water, carbonate fissure water, and bedrock fissure water. The later three are sporadic distribution in Yinchuan Plain, and emphasized aquifer in this study is porous water in loose deposits (Qian et al., 2012; Yang et al., 2018).

Phreatic water in study area can be recharged by leakage and irrigation infiltration from the Yellow River, precipitation, lateral runoff. Leakage and irrigation infiltration from the Yellow River is the major recharge source which accounts for more than 82% of total groundwater recharge.

Phreatic runoff is influenced by natural and artificial factors such as topography, lithology, drainage, and ditches. Phreatic water flows from southwest to northeast in study area, but there are some differences in runoff direction and conditions in different regions. In the surrounding area of the Yinchuan Plain, groundwater flows from the sides to the middle of the area with large hydraulic gradient. In the southern area, phreatic water flows to the Yellow River.

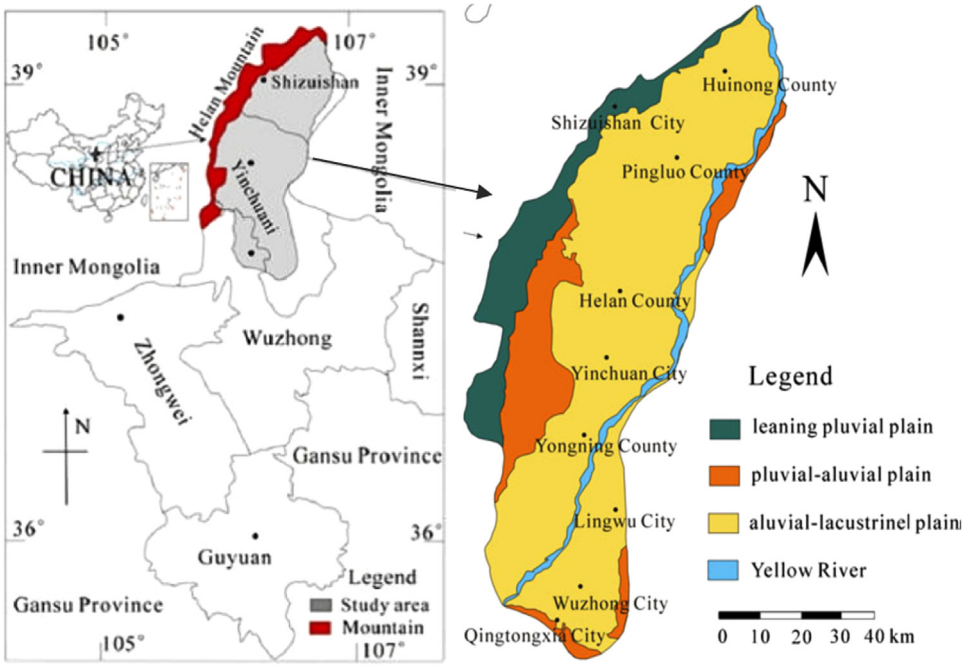

Fig. 1. Outlined location of study area (according to Qian et al., 2014).