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Assessment and uncertainty analysis of groundwater risk

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ABSTRACT

Groundwater with relatively stable quantity and quality is commonly used by human being. However, as the over-mining of groundwater, problems such as groundwater funnel, land subsidence and salt water intrusion have emerged. In order to avoid further deterioration of hydrogeological problems in over-mining regions, it is necessary to conduct the assessment of groundwater risk. In this paper, risks of shallow and deep groundwater in the water intake area of the South-to-North Water Transfer Project in Tianjin, China, were evaluated. Firstly, two sets of four-level evaluation index system were constructed based on the different characteristics of shallow and deep groundwater. Secondly, based on the normalized factor values and the synthetic weights, the risk values of shallow and deep groundwater were calculated. Lastly, the uncertainty of groundwater risk assessment was analyzed by indicator kriging method. The results meet the decision maker's demand for risk information, and overcome previous risk assessment results expressed in the form of deterministic point estimations, which ignore the uncertainty of risk assessment.

1. Introduction

Groundwater, as a part of water resources, plays a major role in ensuring domestic water supply for residents and promoting the development of society and economy. While groundwater resources are used extensively by human being, the adverse impact on groundwater is also increasing. For areas with over-exploitation of groundwater, problems such as groundwater funnel, land subsidence and saline intrusion have emerged; for areas without qualified sewage treatment, groundwater contamination has directly led to the deterioration of groundwater quality. Therefore, correctly identifying the risk factors of the regional groundwater system and establishing a reasonable risk analysis model are crucial to control and improve the present situation of groundwater resources.

Groundwater risk assessment originated from groundwater vulnerability assessment, and has gradually developed to groundwater pollution risk assessment (Gurdak and Qi, 2012; Neshat and Pradhan, 2015; Zeng et al., 2016), health risk assessment of groundwater pollution (Twarakavi and Kaluarachchi, 2006; Su et al., 2013; Surdu et al., 2015) and risk assessment of groundwater development and utilization (Dong et al., 2013; F. Li et al., 2015). At present, *DRASTIC*, *GOD*, *EPIK* and other models has been widely used as standardized risk evaluation methods (Wang et al., 2012; Barroso et al., 2014; Kazakis and Voudouris, 2015). However, on account of the differences in natural conditions, economic development and groundwater exploitation among various regions, it is difficult to adopt only one set of index system to evaluate groundwater in all areas. Therefore, some researchers carried out the risk assessment of groundwater based on the actual conditions of study areas. For example, Dong et al. (2013) divided groundwater in Tianjin into seven functional areas, built the comprehensive risk evaluation model of groundwater exploitation and utilization to forecast the utilization risk of the third aquifer in years 2015, 2020, and 2030. X. Li et al. (2015) presented a relative risk model (RRM) for assessing the risk assessment of groundwater in the lower Liaohe River Plain, northeastern China, which was coupled with a series of indices. F. Li et al. (2015) divided the groundwater in Tianjin into different functional zones and established corresponding risk assessment index systems, respectively. The above articles evaluated groundwater risk according to the characteristics of study area. Therefore, improving standardized assessment model or re-establishing a new evaluation index system for a specific area is a much better choice.

Rational determination of index weight is also a key factor in influencing the results of risk assessment. Methods of determining index

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weight through analysis of its index impact on the evaluated object depend mainly on the experience of decision makers with a certain amount of arbitrariness, including Analytic Hierarchy Process (Dong et al., 2013) and the Delphi method (Zou et al., 2012). There is another class of methods based on sample information with strong mathematical foundation, including information entropy method (Zhu and Wang, 2010), maximal deviation method (Wu and Chen, 2007), etc. However, indexes in a groundwater risk evaluation system are difficult to meet the mutual independence, and using methods above might have information duplication (Pacheco and Fernandes, 2013). Therefore, in order to obtain reasonable index weights, it is crucial to use proper methods to reduce redundant of indexes.

The groundwater risk evaluation needs plenty of data, but it is impossible for each assessment index to have adequate measurement data under limited time and budget. So, data interpolation is inevitable, which directly leads to the uncertainty of groundwater risk assessment. The uncertainty of groundwater risk evaluation has been studied since 1990s (Daniels et al., 2000; X. Li et al., 2015; Neshat et al., 2015), in which Geostatistics is one of the effective methods. Indicator kriging, as a geostatistical approach, has been widely applied in calculating the probability of pollutants beyond a reasonable threshold to get the risk map of groundwater (Goovaerts et al., 2005; Jang et al., 2007, 2012; Kuisi et al., 2009; Chen et al., 2013; Jang, 2013; Narany et al., 2013; Chica-Olmo et al., 2014). However, researches based on indicator kriging mainly focused on one or several contaminations, rarely concentrated on the uncertainty of synthetic risk assessment results.

In this study, the water intake area of the South-to-North Water Transfer Project in Tianjin, China, was chosen as a study region. The water intake area refers to the beneficial regions, where water is transferred from the donor basin to the recipient basin. The study region is the most flourishing economic areas in Tianjin, also groundwater over-exploitation areas. After the South-to-North Water Transfer Project is carried out, water resource structure will be adjusted gradually by replacing over-exploitation of groundwater with water diversion. So, it is necessary to analyze the current situation of groundwater risk before the groundwater is adjusted.

The aim of this study was to evaluate the risk of groundwater in the water intake area. Based on the different characteristics of shallow and deep groundwater, four-level evaluation index systems were constructed, respectively, and the final risk maps were achieved by the product of normalized index values and synthetic weights. On the basis, the uncertainty of groundwater risk was analyzed by indicator kriging. The results are of great significance for risk control and groundwater management in Tianjin.

2. Study region

Water intake area of the South-to-North Water Transfer Project in Tianjin, hereinafter referred to as the water intake area, is located in the south of Tianjin, including Tianjin City, Beichen District, Xiqing District, Dongli District, Jinnan District, Dagang District, Tanggu District, Hangu District and Jinghai County (Fig. 1).

The water intake area belongs to the temperate semi-humid continental monsoon climate with four distinct seasons. The average annual precipitation is approximately 600 mm. The average annual temperature is about 12 °C, gradually reducing from south to north. Major geomorphology is alluvial and coastal plain formed by the modern transgressive layers and river deposits. The northwest region is alluvial plain which varies in elevation from 10 m to 2.5 m. The southeast region is coastal plain which varies in elevation between 1 and 2 m with saltern areas. The ground water system in Tianjin has three main aquifers, the Quaternary, Tertiary and Lower Paleozoic-Sinian aquifers.

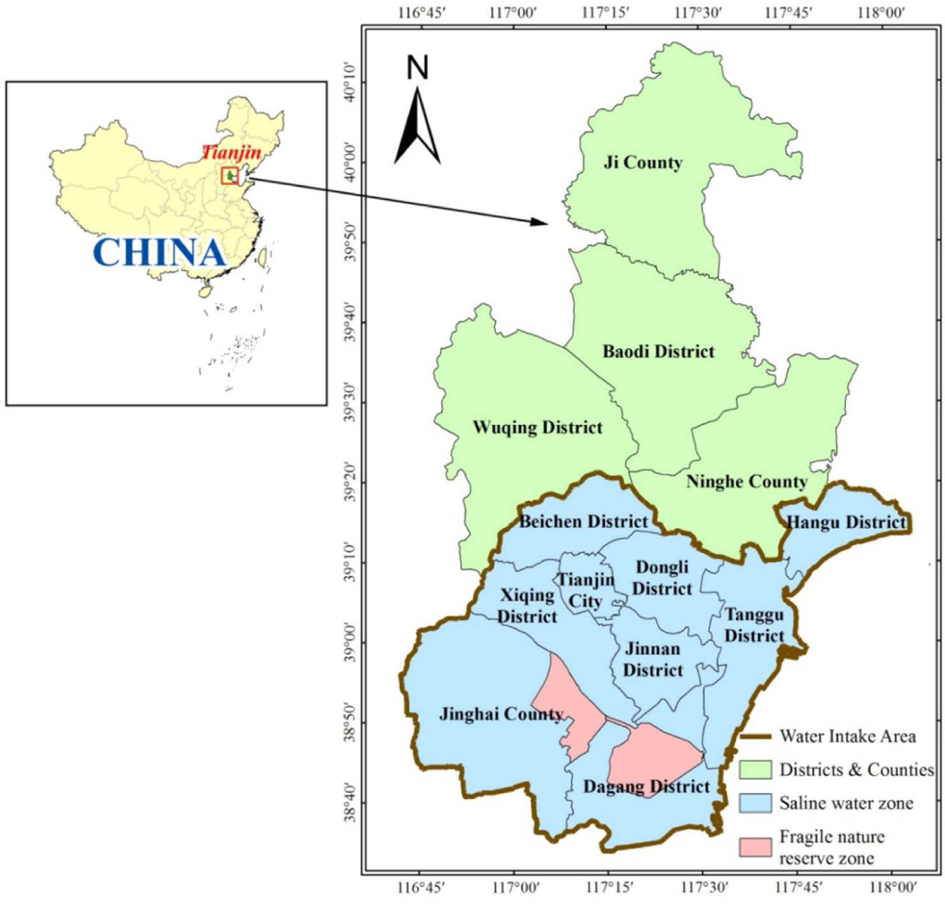

Fig. 1. Tianjin and the water intake area.