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Hydro-geochemical paths of multi-layer groundwater system in coal mining regions — Using multivariate statistics and geochemical modeling approaches

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HIGHLIGHTS

- Hierarchical cluster analysis, principal component analysis and inverse geochemical modeling are successfully applied.
- 4 major hydrogeochemical paths highlight groundwater and surface water chemical evolutions influenced by mining.
- The complex hydrogeochemical processes found in this research are compatible to the whole North China coal mining regions.

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ABSTRACT

Groundwater is an important drinking water resource that requires protection in North China. Coal mining industry in the area may influence the water quality evolution. To provide primary characterization of the hydrogeochemical processes and paths that control the water quality evolution, a complex multi-layer groundwater system in a coal mining area is investigated. Multivariate statistical methods involving hierarchical cluster analysis (HCA) and principal component analysis (PCA) are applied, 6 zones and 3 new principal components are classified as major reaction zones and reaction factors. By integrating HCA and PCA with hydrogeochemical correlations analysis, potential phases, reactions and connections between various zones are presented. Carbonates minerals, gypsum, clay minerals as well as atmosphere gases - CO_2, H_2O and NH_3 are recognized as major reactants. Mixtures, evaporation, dissolution/precipitation of minerals and cation exchange are potential reactions. Inverse modeling is finally used, and it verifies the detailed processes and diverse paths. Consequently, 4 major paths are found controlling the variations of groundwater chemical properties. Shallow and deep groundwater is connected primarily by the flow of deep groundwater up through fractures and faults into the shallow aquifers. Mining does not impact the underlying aquifers that represent the most critical groundwater resource. But controls should be taken to block the mixing processes from highly polluted mine water. The paper highlights the complex hydrogeochemical evolution of a multi-layer groundwater system under mining impact, which could be applied to further groundwater quality management in the study area, as well as most of the other coalfields in North China.

1. Introduction

Despite the rapid development of new energy, coal remains the dominant energy resource consumed in China. Most coalmines in North China are underground operations, and abundant groundwater bearing layers severely threaten mining safety (Wu and Wang, 2006). Groundwater is also the major drinking water resource in North China (Ma et al., 2011). There are about 61% of cities in China use groundwater as drinking water (Ministry of Water Resources of China, MWR, 2010a, 2010b). The official withdraw of fresh water supply in North China in 2015 is about 95.41 billion m^3 (Ministry of Water Resources of China, MWR, 2015). However, approximately 40% (2.7 G m^3) is affected by underground mining (Liu et al., 2010). Mining may influence the groundwater quality in various ways, depending on the hydrogeology, the geochemistry of the coal seam, and the geochemistry of adjacent aquifers. It is therefore, essential to understand how the water evolves and

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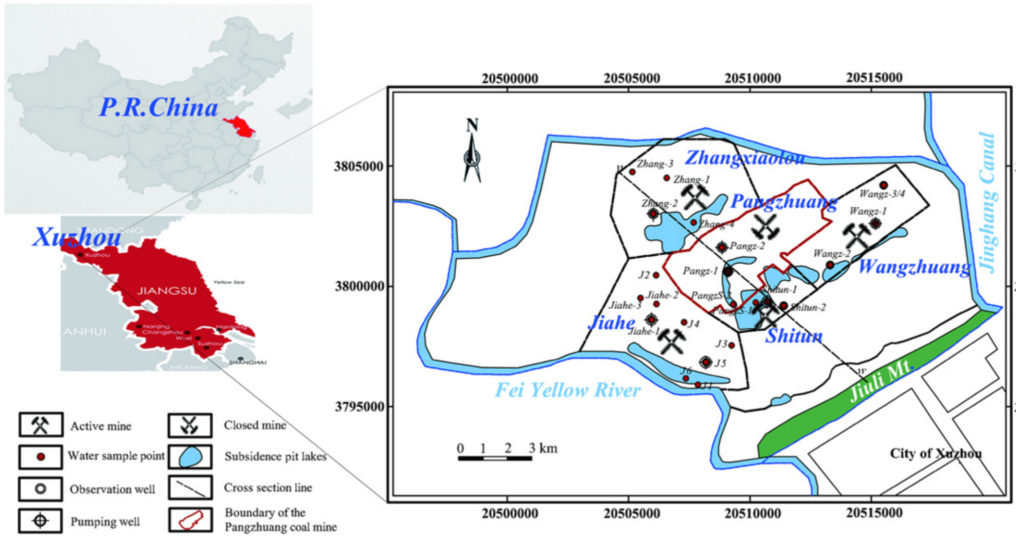

Fig. 1. General map of the studied area and water samples position (Xuzhou Coal Mining Group. Co. Ltd., 2005).

changes as well as its origins before environmental protection measures can be taken.

Hydrogeochemical evolution of groundwater system have been extensively explored recently, and air-rock-water interactions are the key mechanisms in most cases. Various methods, including simple scatter plots, multivariate statistical analysis, isotopes, laboratory column simulation, geochemical modeling, GIS, etc., have been applied to investigate the variety of complicated processes occurring in regional and local groundwater systems (Hem, 1985; Plummer et al., 1990, 2002; Busby et al., 1991; Langmuir, 1997; Güler et al., 2002; Appelo and Postma, 2005; André et al., 2005; Sharif et al., 2008; Cloutier et al., 2008; Nordstrom, 2011; Carucci et al., 2012; Asta et al., 2015; Voutsis et al., 2015; Cortes et al., 2016; Sako et al., 2016).

Because of negative impacts on the groundwater environment, acid mine drainage (AMD) and coal mine drainage (CMD), in active or abandoned mines, have received extensive attention using chemical analyses and modeling throughout the world (Wolkersdorfer, 2006). Studies illustrating the sophisticated interactions and hydrogeochemistry characterizing groundwater evolutions under mining operations have also been emphasized (Collon et al., 2006; Cravotta, 2008a, 2008b; Elliot and Younger, 2007; Gammons et al., 2013; Grande et al., 2013; Sako et al., 2016).

In the specific area of interest in North China, researchers have addressed comparable issues in coal mining regions. Traditional and innovative approaches including isotopes, tracer tests, and geochemical modeling have been employed to find the origins and flow properties of shallow and deep groundwater in North China coalfields (Guo and Yanxin, 2003; Gui, 2007; Ma et al., 2011; Huang and Chen, 2012; Chen et al., 2013; Han et al., 2013; Huang et al., 2016).

In this research, the multivariate statistical approaches of hierarchical cluster analysis (HCA) and principle component analysis (PCA) are performed to summarize the large dimensions of the datasets. Hierarchical cluster analysis (HCA) is a very useful method, as it could easily classify and simplify the complicated multi-variate observation datasets in hydrochemical studies. (Güler et al., 2002, 2012; Voutsis et al., 2015; Blake et al., 2015; Sako et al., 2016; Cortes et al., 2016; Carucci et al., 2012; Cloutier et al., 2008; Morán-Ramírez et al., 2016; Chihi et al., 2015). Principal component analysis (PCA) reduces the dimensionality of complex and numerous chemical datasets by creates new uncorrelated components from the original variates (Güler et al., 2002, 2012; Voutsis et al., 2015; Blake et al., 2015; Sako et al., 2016; Cortes et al., 2016; Carucci et al., 2012; Cloutier et al., 2008; Morán-Ramírez et al., 2016). The subsequent hydrogeochemical paths and connections analysis and modeling are based on HCA and PCA. Many researchers have

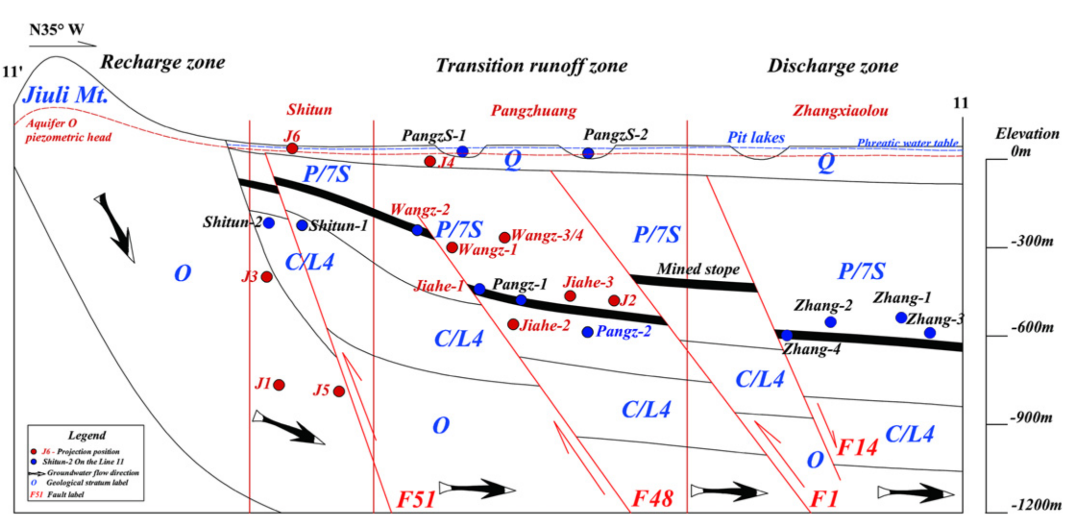

Fig. 2. Cross section and hydrogeological map of the mining area -Line 11 (Note: Sampling points in red are projected positions for easier understanding as they are not on the line 11, see Fig. 1). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)