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Evaluation of hierarchically weighted principal component analysis for water quality management at Jiaozuo mine

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ABSTRACT

This study presents an application of principle component analysis method to evaluate water quality data of both surface water and groundwater obtained at Jiaozuo mine area. The fifteen groups of data including physico-chemical and microbiological parameters were from 9 monitoring sites for a period of four years. The total dissolved solids; total hardness, chloride, fluoride, and nitrate (N) were identified as the most significant variables affecting water classification and quality. The water quality of two thirds of the monitoring sites was considered relatively good, indicating that the most of the shallow aquifer water in Jiaozuo mining area was generally good, and can be used as drinking water or industrial water after slight treatment. The shallow aquifer water in the areas of Macun, Wangfeng, and Hanwang must be intensively treated before utilization due to contamination. Macun and Hanwang, located in central Jiaozuo mining area, must be treatment with advanced green technology before any domestic use. This method provides an effective means to classify multi-zone water quality of a large mining operation area. It can regulate decision-making in time.

1. Introduction

Water shortage and pollution are serious environmental issues in developing countries (UN EP, 2007; Allsopp et al., 1989). Water quality evaluation methods have been developed to assess the current specific condition, including the artificial neural networks and canonical correlation analysis of water quality characteristics (Khalil et al., 2011), immobilized microorganisms for bioremediation of acidic mine wastewater (Macaskie et al., 1996). Along with the increasing demands of evaluation method for drinking water safety, assessment of water quality of polluted areas using multivariate statistical technique (Kazi et al., 2009), artificial neural network modeling (Singh et al., 2009), the water quality assessment, and analysis of the status of groundwater quality, is essential to the development of water environmental management planning, and effectively protect water resources.

A good water quality assessment method should not only quickly provide the water quality ranking, but also accurately reflect the spatial and temporal variations of water quality condition. Surface water quality assessment using multivariate statistical methods and soil pollution (Vieira et al., 2012), and immobilized microorganisms for bioremediation of acid mine wastewater (Macaskie et al., 1996). The accuracy of water quality assessment method is significant, and both widely and easily used in the environmental management or calculation. The common way of groundwater quality evaluation can be divided into: the water quality index method, the fuzzy comprehensive evaluation method, the multivariate statistical methods, the artificial neural network, the principal component analysis, or biotic indices (such as acidophilic microbial, sulphate-reducing bacteria). Different methods have been reported and some of them involves multivariate statistical technique (Kazi et al., 2009; Koklu et al., 2010), artificial neural network modeling (Singh et al., 2009), and artificial neural networks and canonical correlation analysis (Khalil et al., 2011), multivariate statistical technique (Kazi et al., 2009), chemical immobilization of heavy metals (Tichy et al., 1996).

In the process of groundwater quality evaluation of different needs, different methods usually obtain variable results with the characteristics of groundwater quality and regional differences. The main problem is that the complexity of the methods and the results are not unified, resulting in poor repeatability at the same time. China established the “Quality standard for ground water” (GB/T14848-93) in 1993, which is a generalized reference standard for classification. Applications of CCME Water Quality Index to monitor water quality (Lumb et al., 2006) are widely studied for bioremediation of metal contamination (Jackson et al., 2009), use of sulphate reducing bacteria

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Table 1
Pore water pollution state in Jiaozuo coal mine (mg/L).

Index	Situs								
	Wangfeng	Jiulishan	Macun	Fengying	Hanwang	Lifeng	Yanma	Zhucun	Fangzhuang
Turbidity	1.6	1.0	27	0.5	0.7	1.8	0.8	0.4	0.5
pH	7.0	6.5	7.0	7.0	7.0	6.9	7.0	7.0	7.0
Total hardness ($CaCO_3$)	367	300	346	295	224	227	256	298	248
Fe	0.037	0.135	0.112	0.153	0.039	0.184	0.129	0.041	0.029
Mn	0.004	0.047	0.013	0.007	0.047	0	0	0.009	0.002
Zn	0.016	0.113	0.013	0.439	0.007	0.544	0.005	0	0.128
Anionic synthetic detergent	0	0	0.16	0	0.17	0.06	0	0	0.08
Sulphate	45	54	35	58	31	26	24	29	70
Chloride	113	87	110	145	57	96	61	21	20
Total dissoluble solids	708	567	760	516	547	498	495	530	465
fluoride	0.64	0.61	0.71	0.30	0.64	0.76	0.76	0.78	0.82
Cr^{6+}	0	0	0.005	0	0.005	0	0.009	0.007	0
Pb	0.002	0.004	0	0.007	0.002	0.026	0.008	0	0
Nitrate(N)	12.99	12.80	11.83	16.67	10.24	3.87	4.89	6.60	5.51
Total bacterial count	242	107	321	218	425	206	131	68	82

for removal of heavy metals from acid mine drainage (Adam and Edyvean, 1996; Zhang et al., 2016), microbiology of acidic mine pollution and its bioremediation (Johnson, 1995, 1996; Martins et al., 2011a,b), sulphate-reducing bacteria to assist the removal of heavy metals from acidic mine drainage (Adam and Edyvean, 1996), effect of chelators on bioaccumulation of Cd (II), Cu (II), Cr (VI), Pb (II) and Zn (II) (Damodaran et al., 2013; Han et al., 2016), modernization of water quality programs in developing countries (Ongley, 1998).

2. Geological conditions of Jiaozuo

Jiaozuo is a typical mining city for coal supply in China. After several decades of operation and development, the hydrological environment of the mining area is deteriorating. The groundwater monitoring data of a number of factors such as pH, total hardness, soluble solid etc. were recorded. Other factors such as *Escherichia coli* and bacteria index exceeded the standard seriously; ammonia nitrogen, nitrate nitrogen, chloride, fluoride, and volatiles exceeded the standard at different locations. With the hydrological environment deteriorating, water pollution is increasingly significant and has seriously restricted the sustainable development of social economics in Jiaozuo city.

The locations of each coal mine in Jiaozuo are shown in Fig. S1. Jiaozuo city is located in the transitional zone of the Taihang Mountains and the North Plain of Henan Province. It belongs to the warm temperate zone continental climate, where surface water system consists of many developed rivers, belonging to two major basins of the Yellow River and Haihe River. Throughout the region terrain, northwest of Jiaozuo is high while southeast is low with a fully developed landform type. The strata exposed in the region are mainly consisted of Archean metamorphic rocks, the Sinian quartz sandstone, Cambrian and Ordovician carbonate rocks, Carboniferous and Permian coal bearing strata, Triassic shale, Neogene mudstone, sandstone, quaternary loess.

Jiaozuo city located in the south of NeocathaysianTaihang Mountain uplift, and leading edge of reflex are of east wing of epsilon type structure in the southeast of Shanxi Province and North of East Qinling Mountains, where the latitudinal tectonic belt intersect with the arc zone. A variety of structural forms has been widely developed in the area of the Yanshan movement, high angle normal fault. According to the structural features and formation and spatial distribution, they can be divided into: EW tectonic system, epsilon type structural system, New Cathaysian tectonic system and NW trending tectonic system. The main faults through the mining area consists of the Pangu Temple fracture, the Phoenix Valley fault, Jiulishan mountain fault. Major water bearing rock formation in the mining area is carbonate karst fissure water, located in the Phoenix Valley fault and Jiaozuo mining area. Aquifer lithology is Ordovician. The lower limestone is tectonic fissures and karst development. The followed is clastic rock, carbonate rock and karst fissure water, mainly distributed in Jiaozuo mining area. The carboniferous sandstone and limestone interbedded. Limestone is consisted of nine layers; the second layer and the eighth layer of limestone are the main aquifers.

3. Water pollution source and classification

3.1. The pollution of coal gangue leaching water to water

Coal mine in Jiaozuo city has a long history of operation. The coal gangue of each mine increased yearly. The coal gangue has become one of the main problems of mine environmental geology. Coal gangue is composed of a mixture of inorganic matter and a small amount of organic matter, inorganic matter include minerals and water, minerals changes with the coal quantity of gangue, composition is very complex; the organic substances include benzo(a)pyrene, chloroform, carbon tetrachloride. Elements mainly include Si, Al, Fe, Ca, Mg, K, Na, S, Ti, P, and mostly in the form of aluminum silicate.

The chemical composition of coal gangue in Jiaozuo mining area is mainly composed of SiO_2 (50.09%–58.21%), Al_2O_3 (15.7%–28.11%) and Fe_2O_3 (4.61%–5.49%). Gangue piled in the oxidation environment is highly susceptible to oxidation. Under action of infiltration water rich in oxygen and carbon dioxide, it was leached into groundwater, the chemical oxidation and biological oxidation processes will continue to carry out, dividing into three stages:

$$Fe_2 + \frac{7}{2}O_2 + H_2\,O \rightarrow 2Fe^{2+} + 2SO_4^{2-} + 2H^+$$

$$2Fe^{2+} + \frac{1}{2}O_2 + 2H^+ \rightarrow 2Fe^{3+} + 2H_2O$$

$$FeS_2 + 14Fe^{3+} + 8H_2\,O \rightarrow 15Fe^{2+} + 2SO_4^{2-} + 16H^+$$

Under the influence of precipitation, the leaching water directly infiltrates into the ground, on the one hand, it will cause a certain amount of pollution penetrating into the surrounding soil. On the other hand, it may also have an effect on the groundwater quality. The analysis of coal gangue leaching water is described in Table 1. Both Hg and Cd were not detected in leaching water; the other 5 factors meet the requirements of the Class III of the irrigation water quality standards. Therefore, the pollution of a small amount coal gangue leaching water to surface water and groundwater may be ignored, however, the long-term effect of coal gangue leaching water on soil will enrich some elements in soil, after a long time, resulting in the pollution of soil and ground water.