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Risk assessment of groundwater with multi-source pollution by a long-term monitoring programme for a large mining area

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ABSTRACT

Environmental problems caused by mineral exploitation have increased significantly, a situation that has serious effects on the surrounding groundwater quality, especially with respect to the descent of the groundwater table caused by deep mining and multi-source pollution produced by auxiliary projects. Therefore, the study of groundwater risk assessment from multi-source pollution and the development of a long-term monitoring programme to manage such problems are essential. A copper-molybdenum opencast mine was the target of this study. Based on an analysis of the hydrogeological conditions of the mining area, aquifer parameters were obtained through field drilling and pumping tests. A finite element subsurface flow (FEFLOW) system was utilized to construct a numerical model that can analyse and predict the migration of multi-source pollutants during groundwater pumping and drainage in the mining area. The migration of pollutants is controlled not only by natural groundwater flow, but it is also strongly influenced by water drainage during deep mining, an activity that causes the multi-source pollutants to migrate to the mining centre. Therefore, both influencing factors should be considered when assessing the risk of groundwater pollution by multi-source pollutants. A reasonable groundwater monitoring programme that considers the migration direction and the distance of the pollutants from the groundwater movement in a non-natural flow field under the influence of a groundwater funnel during deep mining is also necessary.

1. Introduction

With the current economic development, the demand for mineral resources is increasing rapidly, an issue that is coupled with the number of mines. Thus, groundwater pollution becomes a serious problem. In opencast mining areas, deep mining and auxiliary projects usually cause groundwater funnelling and poor groundwater quality.

Numerical simulations are commonly used to address groundwater problems and provide a foundation for research on groundwater problems in mining areas. A two-dimensional simulation model named SPRING was introduced to study the subsidence of the land caused by groundwater extraction, and hence, an optimized, well-designed programme was developed (Peter et al., 2009). Zhou et al. (2009) investigated the process of drainage during mining using the Groundwater Modelling System (GMS) simulation software, and Guo et al. (2012) developed a groundwater flow model by using the finite element method under various mining conditions. Based on the FEFLOW software and the GIS technology, Guo et al. (2010) produced a groundwater flow model to predict regional groundwater dynamics during mining. However, to improve the protection of the quality of the mine groundwater, a reasonable and effective long-term monitoring mechanism is necessary to avoid the problem (Wang and Liang, 2006; Wu, 2003). If the groundwater pollution has already occurred in the mining area, in addition to the traditional physical treatment, water control method, water extraction and external treatment, bioremediation has also been found to be an effective option. There are currently three main lines of research involving microorganisms. First, biological precipitation by the microorganism can cause the soluble metal ions to separate from the water phase, thus removing them from the bulk solution (Johnson, 1994; 1995; 1996; Adam and Edyvean, 1996; Macaskie et al., 1996). Second, the biotransformation by microorganisms can reduce the toxicity of heavy metal ions in the soil or water and thus decrease the pollution of the groundwater (Cheung and Gu, 2007; Dong et al., 2013; Máthé et al.,

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2012; Islam and Sar, 2011; Nirola et al., 2016). Third, the biological adsorption by microorganisms can reduce the biologically active and available toxic metal ions, thereby reducing the metal ion concentration in the groundwater (Tsezos et al., 1996; Votruba et al., 1996; Cegarra et al., 1996; Colin et al., 2012; Li et al., 2013).

Although the contaminated groundwater can be addressed by physical treatment, extraction treatment or bioremediation, the groundwater environment has already been polluted, and its remediation costs time and money. Therefore, reasonable groundwater pollution monitoring is an effective method to avoid or minimise the risk of groundwater pollution. The present study mainly focuses on the groundwater problem caused by mining or by the monophyletic migration law of pollutants (Neves and Matias, 2008; Dhakate et al., 2008). However, as studies on the risk evaluation of large mining areas with multi-source pollution and long-term monitoring plans for quantity and quality problems of groundwater did not involve many resources, long-term monitoring programmes for large mining areas must be investigated.

Considering a large-scale copper-molybdenum opencast mine as an example, a conceptual model is established based on the investigation and analysis of the hydrogeological conditions in the mining area. The transport law of multi-source pollutants in the mining area with and without drainage is studied using the mathematical model and the solute transport model of the FEFLOW system. Subsequently, a reasonable and effective long-term groundwater monitoring system and management measures are identified and advanced for this mining area. Accordingly, the results and suggestions herein can serve as useful references for similar large-scale opencast mining areas.

2. Materials and methods

2.1. General situation of the mining area

2.1.1. Mine condition

The copper-molybdenum deposit has a large resource reserve with a shallow bury that is suitable for large-scale opencast mining. The ore body is distributed primarily in the contact zone between the monzonitic granite porphyry and the surrounding sandstone. The copper-molybdenum ore consists of 46.39 million tons of industrial copper ore, 143.058 million tons of industrial molybdenum ore, 195.32 million tons of low-grade copper ore, and 186 million tons of low-grade molybdenum ore.

The project consists of open-pit mining areas, industrial sites, waste dumps, tailings, mining area roads and other components. As mining occurs in stages, the drainage programme for the mining area is divided into two periods, of which the first period is 12 years of unwatering to 35 m and the second period is 16 years of unwatering to −40 m. The entire open-pit mining operation spans 28 years. Per a feasibility study on mining design, primary groundwater pollution sources are found to include seepage water from spoil banks, tailings, turbidity reservoirs and environmental protection reservoirs. The distribution of these sources is presented in Fig. 1.

2.1.2. Natural and Geographical conditions

The mine site is located in a tectonic erosion medium mountain area with an elevation of 150–400 m. The highest point of the site, located at the top of the Yuanzhu hill, is 592.0 m, while the lowest point, at 93 m, is in the northeastern part of the construction zone along the Shachong River. The relative elevation is 200 m in this area, and the terrain in the north is higher than that in the south. A small basin is situated in the ore body distribution range.

The mining area is in a subtropical monsoon climate that is warm, humid and wet with an average annual rainfall of 1404.1 mm.

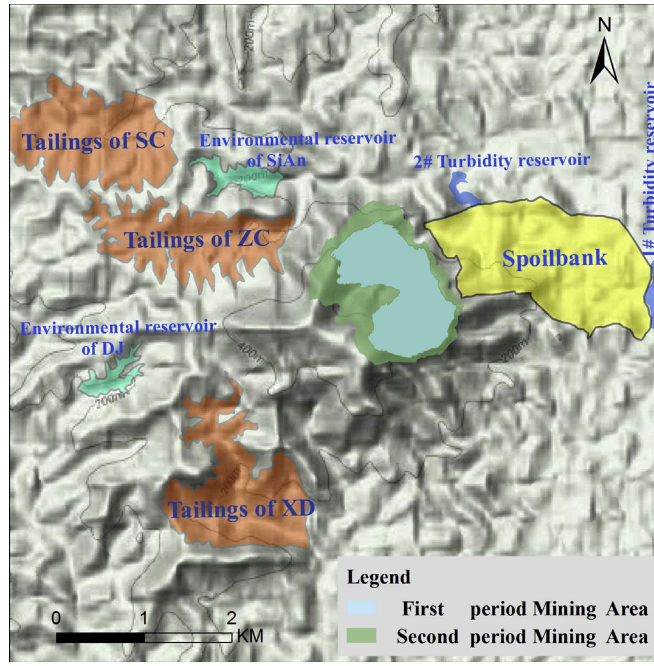

Fig. 1. Project distribution in the mining area.

2.1.3. Geological conditions

With the Shatou-Xiaying fault 20 km away from the mining area and the Jinzhuang-Douping fault 15 km away from the mining area, there is nearly no fault effect on the mining area.

The most widely distributed and exposed stratum in the mine area is the Cambrian Shuikou group with different generations of intrusive rocks at the edge. The Cambrian Shuikou group mainly consists of sandstone and shale, and Quaternary alluvial and eluvial formations are distributed along the river and valley. The bedding is well developed and is usually lamellar to thick-bedded with joints and cleavage. The underpart is composed of several layers of silicalite, the central layer is granule conglomerate, and the upside consists of numerous layers of grit or grit containing fine gravel, lenticular limestone, and dolomitic limestone. The Quaternary is primarily located in the northeast and southwest and consists of gravel, sand and clay.

2.2. Hydrogeology conditions and conceptual model of mining area

To conduct the mathematical and physical simulation, the hydrogeology conceptual model generalizes the actual border, internal structure, permeability, hydraulic characteristics and recharge-discharge conditions of the aquifer system. Establishing the hydrogeology conceptual model scientifically and accurately is the key factor of groundwater numerical simulation studies.

2.2.1. Simulation range

According to the hydrogeological conditions of the mining area as well as the regional environmental protection goals and distribution of sensitive areas, the simulation range was determined such that the northern boundary of the model was based on the watershed with a length of 35 km; the eastern boundary of the model was based on the Hejiang River with a length of 38 km; the southern boundary of the model was based on the Ditou-Dupingxu fault with a length of 14 km; and the western boundary of the