Environmental Pollution 237 (2018) 356–365

Contents lists available at ScienceDirect

Environmental Pollution

journal homepage: www.elsevier.com/locate/envpol

Destruction processes of mining on water environment in the mining area combining isotopic and hydrochemical tracer

Yonggang Yang [a, **], Tingting Guo [b], Wentao Jiao [c, *]

[a] Institute of Loess Plateau, Shanxi University, Taiyuan, Shanxi, 030006, China
[b] College of Environmental and Resource Sciences, Shanxi University, Taiyuan, Shanxi, 030006, China
[c] Research Center for Eco-environment Sciences, Chinese Academy of Sciences, Beijing, 100085, China

ARTICLE INFO

Article history:
Received 10 December 2017
Received in revised form
26 January 2018
Accepted 2 February 2018

Keywords:
Mining
Isotope
Destruction processes
Water quantity
Water quality

ABSTRACT

There is less research on the hydrological system and its destruction processes mechanism in the mining areas, especially combined application of isotope technology and chemical signals, which is a key scientific problem that need to be solved. This study takes Jinci spring area in Shanxi as a case study. It is based on the data of hydrology and mining condition from 1954 to 2015, combining monitoring experiments, O^{18}, D, S^{34} and N^{15} tracing, chemical and model simulation. This study investigates the hydrological regularity and impacts of mining activities on water quantity and quality, and reveals the destruction process of hydrological system. The results show that: (1) Water chemical type shows an evolutionary trend of HCO_3^--Ca^{2+}-$Mg^{2+} \rightarrow SO_4^{2-}$-$HCO_3^-$-$Ca^{2+}$-$Mg^{2+} \rightarrow SO_4^{2-}$-$Ca^{2+}$-$Mg^{2+}$, due to the influence of exploitation and fault zones. Isotope tracer shows that mine pit water is formed by a mixture of pore water, karst water and surface water. (2) Although precipitation and seepage have a certain impact on the reducing of groundwater quantity, over-exploitation of water resource is still the main reason for reducing of groundwater quantity. Under the conditions of keeping the exploitation intensity at the current level or reducing it by 10%, groundwater level shows a declining trend. Under the condition of reducing it by 30%, groundwater level starts to rise up. When reducing by 50%, groundwater level reaches its highest point. Coalmining changes the runoff, recharge and discharge paths. (3) From 1985 to 2015, Water quality in the mining area is worsening. Ca^{2+} increases by 35.30%, SO_4^{2-} increases by 52.80%, and TDS (Total Dissolved Solid) increases by 67.50%. Nitrates come from the industrial and domestic wastewater, which is generated by mining. The percentage of groundwater coming from gypsum dissolusion is 67.51%, and the percentage from coal measure strata water is 34.49%. The water qualities of river branches are generally deteriorated.

1. Introduction

As a province with rich coal mining resources, Shanxi Province has been in trouble due to the lack of water resource in a long time. How to deal with water resource shortage is one of the problems that need to be addressed in Shanxi. Because the hydrological system of mining area has been long affected by mining activities, water quantity is shrinking dramatically and groundwater level lowered continuously. The natural environment of groundwater storage is severely damaged, and the recharge-discharge rule is changed. These situations cause growing eco-environmental problems, such as water pollution and ground subsidence (Hao et al., 2010). The mechanism of hydrological process in mining area remains a key scientific problem to be solved. 41% of Shanxi's total area is coal bearing. Among the 119 county-level cities, 94 of them have coal mines (Fan, 2005). Coal, aquifers, and cesspits coexist in a single geological body in Shanxi Province, making it a unique “water-coal system”. The widespread mining of coal resources lead to the destruction of underlying surface, and it particularly had an irreversible impact on hydro-environment.

At present, water resources studies in the mining area mainly focus on the evaluation of the quality and environmental characteristics of groundwater, the analysis of water inflow, as well as the migration and conversion of metallic elements. These study methods mainly are mathematical statistics, field surveys, and

---

[*] Corresponding author. No. 18, Shuangqing Road, Beijing 100085, China. Tel.: +86-010- 62843981; fax: +86-010- 62923549.
[**] Corresponding author.
E-mail address: wtjiao@rcees.ac.cn (W. Jiao).

https://doi.org/10.1016/j.envpol.2018.02.002
0269-7491/© 2018 Elsevier Ltd. All rights reserved.

water quality testing. The research on the mining activities' influence to local eco-system, and the change in water quality and quantity had done (Yang and Fu, 2017; Chaulya, 2003). The chemical composition of mine waters from metal and coal deposits is played by the oxidation of pyrite and other sulfides, resulting in the release of hydrogen ions, lowering pH level and increase the concentrations of sulfates, metals, metalloids and other elements in the mine waters (Howladar, 2013; Mackenzie and Pulford, 2002; Lottermoser, 2010). Acid mine drainage often contributes to an elevated concentrations of metals, excessing of maximum allowable concentrations in surface water, groundwater, and river (Shamsudduha et al., 2011; Jennings et al., 2008; Edraki et al., 2005). Mining has a large impact on the quality and quantity of water resources in the mine area are well reported (Li et al., 2012; Schellenbach and Krekeler, 2012; Alam et al., 2011; Norton, 1996). The United States holds a leading position in the research and application of mine water. In term of resource utilization, the U.S. uses not only traditional methods, but also the constructed wetland treatment technology. Japan is also a leading country in term of mine water resource utilization. In the U.K., 42% of its total mine water resource is utilized. Although nowadays, different countries have different technology and resource utilization percentage regarding mine water, they are all making important progress (Equeenuddin et al., 2010; Naicker et al., 2003).

In term of the reason of water resources damage (Shao, 2001), toke the coal mines as example, evaluated the mining activitie-s'impacts on groundwater, and also categorized the impacts to different degrees analyzed the coalmine drainage's impacts on water resources in Daliuta Coal Mine. Duan and Duan (2007) used the Huachang Coal Mine as case study, evaluating the effect of coal mining on groundwater environment. Fan et al. (2009) used the Yushenfu Mine in Northern Shaanxi as a case study, analyzing the groundwater flow field variation in shallowly buried coal seam mining activities. In terms of mining activities' impacts on mining area water resources, current studies focus on areas such as groundwater environmental characteristics, evaluation on water resources, analysis of water inflow, pollution of surface water, as well as the negative effects of coal mine wastewater and toxic substances. The research methods include water quality bioassays, field surveys, and statistics. Although there are scholars who use numerical simulation to carry out simulated evaluation of water resource in mining area, there are still limitation factors such as it cannot truly reflect the relationship between mining and water resource (Schellenbach and Krekeler, 2012; Longinelli et al., 2008; Panda et al., 2007).

The application of isotopes in the study on watershed hydrological process can effectively avoid the distortion problem in the simulation of natural conditions, and can show the real laws in hydrological process. Based on mass balance and stable isotope concentration balance, researchers use isotope to carry out qualitative and quantitative research on all aspects of the water recycling process, having been achieved significantly in the fields such as the determination of watershed system boundary, the separation of water flow hydrograph, the identification of water runoff path and water vapor source, the origins of groundwater, and also the hydraulic connections and transformations among different water bodies (Ohlanders et al., 2013; Longinelli et al., 2008). The isotope can provide direct information for the research on groundwater formation, stream path, age, recharge elevation, source, and composition ratio. It can be applied to the study on paleoclimate, dam foundation seepage, plant water use efficiency and spatio-temporal change, as well as the effects of rainfall, snow, ice melting, evaporation, drought, elevation and terrain on the hydrological process (Yang et al., 2011, 2012). Stable isotope technology plays a special role in solving these problems. These studies strengthened the combination of isotopic methods with traditional hydrological methods, and laid a certain foundation for the isotope tracer in hydrological process.

At present, the research mainly focus on plains, basins, deserts, and karst areas. The research on the ecological fragile area like coalmines is relatively weak. These studies mainly focus on areas like the precipitation isotope distribution characteristic, the evaporation induced isotopic fractionation, the rainfall-runoff relationship, and the interchange between groundwater and surface water. Study on the hydrological processes of different hydrological response units is relatively rare. In particular, there is a lack of study on the mining areas' hydrological system and its destruction processes mechanism, especially combined application of isotope technology and chemical signals.

This study takes Jinci spring area in Shanxi as a case study. Based on the collection and organization of historical data (from 1954 to 2015) on meteorology, hydrology, and mining status, this study combine the methods such as field monitoring experiments, O^{18}, D, S^{34} and N^{15} isotope tracing, water chemical signals, and model simulation. This study analyzes the transformations among water bodies, including groundwater, surface water, rainfall and mine pit water in this mining area; investigates the hydrological laws of mining area water recharge, runoff, and drainage; clarifies the destructing impacts of mining activities on watershed water quantity and water quality; and also reveals the destruction processes mechanism of hydrological system in this mining area. This study aims to provide scientific evidence and reference for an effective prevention of water environmental destruction, and the safeguarding of water ecology in mining area.

2. Area description

Jinci spring area is located in the upstream watershed of Fen River (111°56′–112°30′E, 37°34′–38°20′N), with an out elevation of 802.59–805.00 m. The area's eastern boundary is Fen River, with Fenhe Reservoir to the west, Guojialiang Village to the south. The northern area starts with Fenhe No. 2 Reservoir, with the administrative boundary between Gujiao and Jingle Counties. The southern area starts with Fenhe No. 2 Dam, with the administrative boundary between Gujiao and Jiaocheng Counties. The total area is 2049.60 km^2. The elevation is 800–2202 m. The Jinci spring area has a relatively significant overall terrain drop. The mountain area makes direct contact with the basin by significant terrain drop, forming the basic landscape pattern. The area's annual average temperature is 9 °C, and the annual change rate is high. The annual mean hour of sunshine is 2450 h. The annual mean evaporation is 2031.30 mm. The annual mean precipitation is 507 mm, basically concentrating in summer and fall. Stormy rainfalls are common, with less rainfall during winter and spring (Hao et al., 2010; Fan, 2005).

The largest river within Jinci spring area is Fen River. Its branches include Tianchi River, Shizi River, Tunlan River, Yuanping River, Dachuan River, Liulin River, Shanjiuyuan River, Huyu River, Yumen River, Fengyu Ravine, Yeyu Revine, Liuzi Revine, and Baishi Ravine. These are all seasonal rivers. There are all kinds of groundwater development within Jinci spring area: Bedrock fissure water in the West and North; carbonate karst crevice water and clastic rock fissure water largely concentrated in the Middle Western mountains, and loose rock pore water widely distributed in Taiyuan rift-subsidence basin area.

69% of the total area in Jinci spring area is coal bearing. The total area of coal field is 660 km^2. It is one of the six major coal fields in Shanxi Province, and is an important coking coal base in China. Coal mines are located in middle part of Shanxi anticline, with Taihang Mountain fault-uplift to the East, and Lüliang Mountain fault-uplift