The Formation Mechanism of High Salinity Groundwater in Arid Area and Its Influence on Coalmines—A Case Study of a Coalmine in Xinjiang, China

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Abstract

The Turpan-Hami basin in western China's Xinjiang Province is a typical arid region, where there is no surface water and almost no meteoric precipitation. However, in this basin, abundant groundwater exists in Dananhu mining area, and the maximum mine water inflow is over 3000 m^3/h. It has a great influence on the safety production of the coalmine, and has also produced a large amount of the drainage costs. In order to find out why there is so much water in such arid areas, based on field investigation and monitoring, this paper studies the recharge source, the geological environment and the cyclic condition of the groundwater, as well as its influence on coal mining in this extremely arid area. The research finds that, firstly, the groundwater in this study area is macroscopically recharged by the Tianshan Mountains' snowmelt water through piedmont alluvial-pluvial fan in the way of underground runoff. Secondly, present in the high potassium, sodium contained and high porosity Jurassic aquifer, the groundwater characterizes is very high salinity and the Total Dissolved Solids (TDS) is up to 17 g/L under the strong evaporation and concentration effects. In addition, along the groundwater pathway from Tianshan Mountains' recharge source to the Dananhu mining area (about 150 km), the TDS increases from 0 g/L to 40 g/L gradually. This indicates that the groundwater cycle condition becomes worse constantly, and this can also be influenced by the local hydrogeological boundary and tectonic conditions. To conclude, the results of the paper highlight that, on the one hand, the abundant groundwater, recharged from the faraway Tianshan Mountains' snowmelt, significantly influences the mining safety of the coalmines; on the other hand, high salinity groundwater reflects that, the groundwater circulation is turning worse because of the boundary condition in the mining area, and these provide cogent basis for the program development of the mine drainage strategies.

Keywords: snowmelt, underground runoff, mine water inflow, mine drainage

Introduction

Western China has abundant coal reserves and a fragile ecological environment. It is a typical arid area. (Zhang et al. 2015) There is no surface water, and almost no atmospheric precipitation. In recent years, with the shift in the center of coal mining in China and the increasing intensity and scale of coal mining in the west, specific hydrogeological problems, such as highly saline groundwater, the closed mining conditions, and the large amount of mine water inflow, are constantly emerging. For example, the mine water inflow in the Ehuobulake Coalmine reaches more than 1,850 m^3/h (Zheng et al. 2013), which seriously threatens the coalmine safety.

In view of these problems, Chinese scholars (Li et al. 2013; Li et al. 2016a,b; Xu et al. 2018) have mostly studied the formation and evolution of high salinity groundwater in the arid areas by means of field investigations, hydrochemical data analysis, and isotopic tracing. For example, Li and Hao (1999) studied the pattern of groundwater formation and evolution in the inland basin of Northwest China by analyzing the sampled water chem-

istry data and systematically expounded the formation and evolution law of the underground salt water. Lei et al. (2016) studied the obvious stratification in the chemical characteristics of the underground water in the Ningxia area of China. Water infiltration and evaporation have an obvious influence on the water quality of the regional groundwater;. Ren and Yan (1999) analyzed the chemical characteristics and formation mechanisms of groundwater in the plain area of the Dalate Banner, Inner Mongolia, China. The authors focused on the spatial distribution characteristics and formation mechanisms of the chemical components of the phreatic and confined water. The results showed that the quality of the phreatic water was influenced by concentration and filtration mechanisms. In general, due to the climatic drought in western China, groundwater is subject to evaporation during runoff, and the groundwater chemistry gradually changes along the percolation path. In the discharge area, leaching, concentration, decarbonation, and desulphidation may occur along the seepage path. The water chemistry is generally a reflection of the higher salinity of sodium sulfate, sodium chloride, and sodium chloride of the water.

This paper takes the Dananhu mining area, which is located in the Turpan-Hami basin in the eastern Xinjiang Province, as an example, to study the source, environment, and cycling conditions of groundwater and the impact on the regional coalmines under extreme drought conditions.

Hydrogeological Setting of the Study Area

The Dananhu mining area is located in the Dananhu Township, Hami City, Xinjiang, China (Figure 1), and is part of the Dananhu Depression of the Turpan-Hami basin. The basin and the surrounding mountainous system have different hydrogeological systems (Tan, 2002). From a macroscopic point of view, the climate in the study area is extremely dry and reflects the overall characteristics of the Gobi Desert. There is no surface water and the average annual rainfall is less than 50 mm, but the evaporation exceeds 3,000 mm. The large amount of snowmelt water, stemming from the eastern Tianshan Mountains in the northern part of the study area, is the only source of recharge water in the region.

Overall, the hydrological and geological conditions of the study area are characteristi-

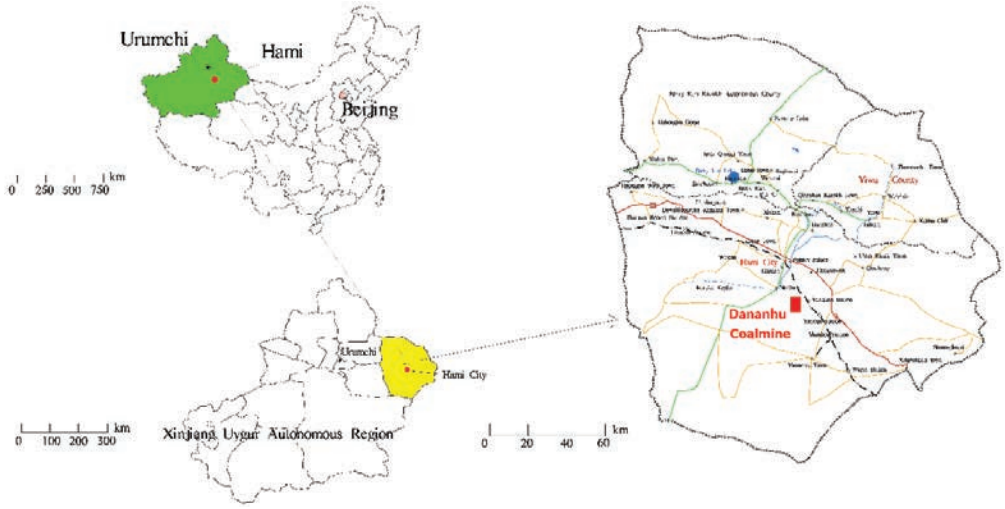

Figure 1 *Location of the Dananhu NO. 5 Coalmine.*

cally thought of as closed: the southern and western parts of the study area are bound by the Jueluotage Uplift, characterized by a large area of igneous dew that has a good water insulation ability; the north boundary is the Sha'er Lake Uplift, which is also composed of igneous rocks. A supply gap exists in the middle, but the groundwater level in the northern area of the Sha'er Lake Uplift decreased, and, as such, recharge of the region is not currently possible. It has been determined that the Sha'er Lake Uplift is an impervious boundary; there is no natural impervious boundary in the east. Therefore, there is potential for groundwater recharge. It is assumed that the snowmelt from the Tianshan Mountains reaches the edge of the Dananhu Depression in a north to south direction and then enters the depression from east to west along the gap, recharging the groundwater in the mining area (Figure 2).

Research Methods

A survey route was planned and executed according to the hydrogeological structure characteristics and macro-recharge conditions of the flood plain in front of the Tianshan Mountains (as shown in Figure 3). During the field survey and investigation, several surface and phreatic water samples are collected on the way from the Tianshan Mountains to the eastern edge of the Dananhu Depression. When entering the Dananhu Depression, samples could only be collected from the confined water in the coalmines. Three mine water samples were collected from the confined water and four samples from phreatic and surface water.

Results and Discussion

High salinity mine water formation

Groundwater salinity characteristics

On the basis of the analysis of regional macro-recharge water sources and hydrogeological boundary conditions in the study area, groundwater recharge routes in the mining area were identified on the basis of changes in salinity of the collected water samples along the survey route.

Table 1 outlines the variation in salinity between the water samples. The results indicate that the salinity of the snowmelt from the Tianshan Mountains was 287 mg/L, representing the regional supply source. With increasing distance along the groundwater runoff path from the mountains, the phreatic groundwater was recharged by snowmelt water, and the salinity of the groundwater increased to 660 mg/L. This occurs when the snowmelt water flows along the Tianshan Mountains to the east edge of the Dananhu Depression. When the water reached the

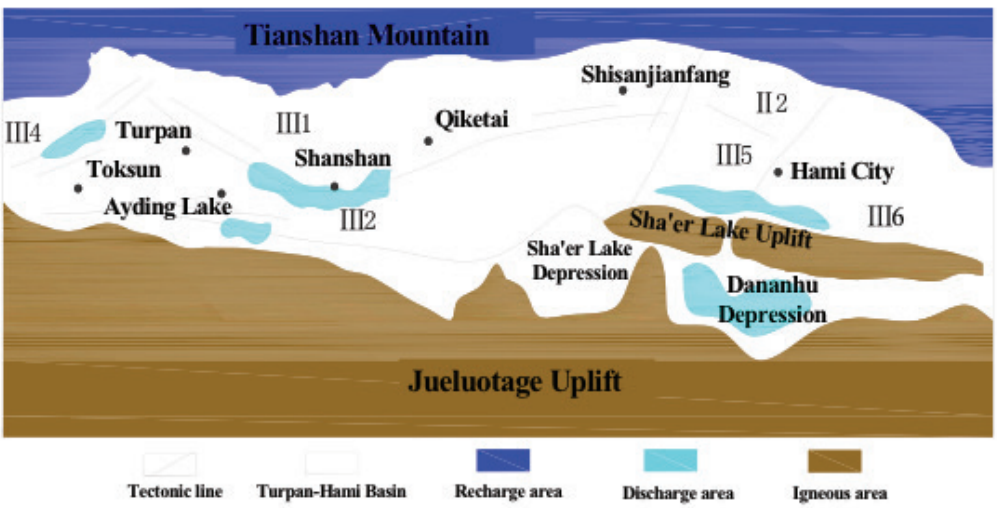

Figure 2 *Hydrogeological of the study area.*

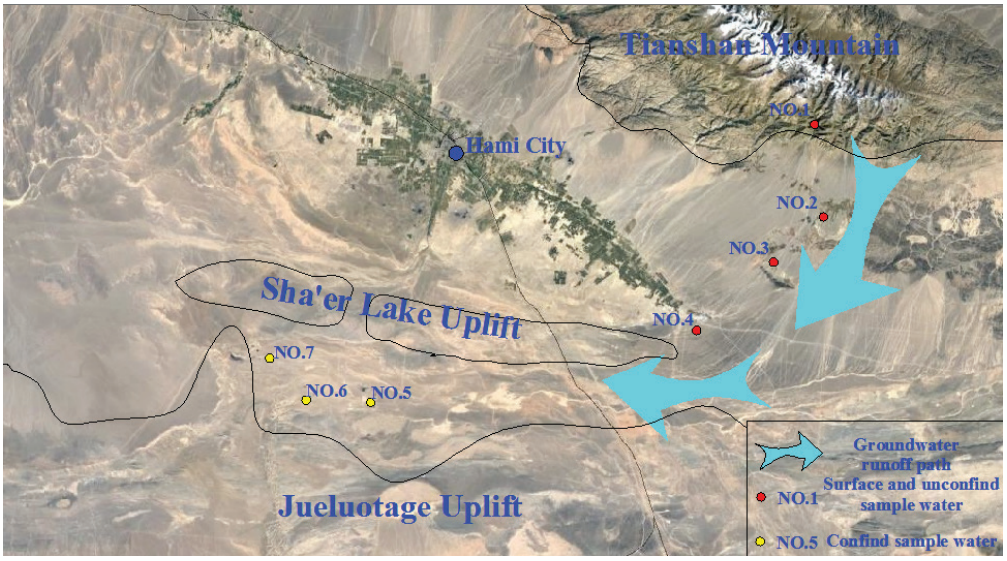

Figure 3 *Map of the survey road.*

depression, the salinity of the groundwater increased sharply from the east to the west because of concentration due to the intense evaporation. At depth in the Dananhu Depression, the salinity in the Dananhu No. 5 Coalmine was 17,670 mg/L and up to 40,000 mg/L at the most western end of the depression in the Goushen NO. 1 Coalmine. When combining the observations of the western, northern, and southern hydrogeological boundaries, it was concluded that the snowmelt from the Tianshan Mountains supplies groundwater to the study area through long-distance subsurface runoff. However, because of the changing regional hydrogeological conditions and poor recharge conditions, mainly caused by evaporation losses typical of recharge steaming style, the groundwater along the path is characterized by a gradual increase in the salinity from east to west and the formation of highly saline conditions in the mining area.

Groundwater chemical ion characteristics

Because of the gradual deterioration in the circulation conditions during the recharge of mine water from the snowmelt, combined with the closed boundary conditions of the Dananhu Depression, some water samples were collected along the route to determine the mine water environment (Table 2).

According to the analysis of water quality evolution, in the process of remotely replenishing mine water from the snowmelt from the Tianshan Mountains, the ion concentration increases as the recharge distance increases. The proportion of K^+, Na^+, and Cl^- with high solubility increased continuously along the flow path, whereas the proportion of weakly soluble Ca^{2+} and Mg^{2+} and acidic SO_4^{2-} and HCO^{3-} decreased. Finally, the main cations present in the Dananhu NO. 5 Coalmine are K^+ and Na^+, and the main anion is Cl^-, forming $Cl{\bullet}SO_4^-Na$ water. These results indicate that after the submergence of snowmelt water into the groundwater, evaporation due to the climatic drought is the main excretion method. Cations that have low solubility of salts in the water, such as Ca^{2+} and Mg^{2+}, precipitated first, followed by highly soluble K^+ and Na^+. At the same time, due to the closed circulation conditions of the recharge process, the groundwater flow is slow allowing for SO_4^{2-} and HCO_3^- in the groundwater to produce "desulfurization" and "decarburization" and the proportion of them slowly decrease. This indicates that the underground water system in the mining area exhibits evaporative excretion, closed conditions, and poor fluidity in the environment.

Table 1. Groundwater salinity test results in the study area.

NO.	Sampling point	Water types	Salinity (mg/L)
1	Uradai Reservoir	Snowmelt water	287
2	Santoul Village	Phreatic aquifer	298
3	Qincheng Reservoir	Surface water	293
4	Zhongmei NO. 10 Coalmine	Phreatic aquifer	660
5	Zhongdiantou Coalmine	Confined aquifer	14000
6	Dananhu No. 5 Coalmine	Confined aquifer	17670
7	Guoshen No. 1 Coalmine	Confined aquifer	40000

Table 2. Summary of groundwater quality.

NO.	Sample point	The main ion content (mg/L)					
		K^+Na^+	Ca^{2+}	Mg^{2+}	Cl^-	SO_4^{2-}	HCO_{3-}
1	Uradai Reservoir	27.32	48.68	12.83	10.21	110.31	127.04
2	Santoul Village	9.36	63.49	20.54	13.61	75.73	201.3
3	Qincheng Reservoir	18.81	52.91	19.25	23.79	83.14	161.28
4	Zhongmei NO. 10 Coalmine	206.24	11.84	1.80	129.23	256.84	0
6	Dananhu NO. 5 Coalmine	4203.25	859.78	322.74	6940.85	2604.60	134.06

Impact on the mine water inflow

During the mining process, the water inflow rate in the Dananhu NO. 5 Coalmine exceeds 3,000 m^3/h, which increases the threat of mine water hazards and has a great impact on coalmine safety, but the highly saline and the Cl•SO^{4-}Na type ions characteristics of the mine water indicate that the groundwater recharge is minimal, and evaporation is the main excretion method. So, it can thus be inferred that the abundant underground water in the coalmine is dominated by static reserves. Therefore, during the mining process, the water inflow from aquifers in the vicinity of the coal-bearing strata can be treated with hydrophobic pressure reduction or predrainage.

Conclusions

(1) The intensity and scope of coal mining in the western part of China are gradually increasing. New hydrogeological problems are constantly emerging. The formation of mine water in the region have been identified, and their environment is of great significance for safety of coalmine production. Therefore, an effective method is needed to solve this problem.

(2) In this study, water samples were collected during field surveys. Combined with regional macro-hydrogeological boundary conditions, the groundwater recharge route was determined starting from the snowmelt from the Tianshan Mountains that remotely recharges the mining area from north to south and then from east to west. Affected by evaporation and concentration along the way, the snowmelt from the Tianshan Mountains becomes highly saline under the closed environment of the groundwater system in the mining area, which is rich in potassium and sodium salts.

(3) The results of the study have identified the formation process of mine water,.,Therefore, it provides the basis for targeted mine safety and the prevention and control of mine water hazards. This also provides guidance and reference for mine water hazards with similar conditions.

Acknowledgements

This research was financially supported by The National Basic Research Program of

China (No.2013CB227901), the National Key Research and Development Program of China (No.2017YFC0804101) and the National Natural Science Foundation of China (No. 41502282). The authors thank the editors and reviewers for their constructive suggestions.

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