Risk analysis and control of farmland irrigation with coal mine water

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Abstract. Mine water is a valuable unconventional water resource. According to the discharge of mine water and the factors of geographical location, climate, geological structure, mining depth and mining method, this paper analyzes the spatial distribution and treatment process of clean, containing suspended solids, high salinity, acid and special pollution mine water in China. Based on the instability of mine water inflow, the complexity of water quality in different mining areas and the difference of treatment process, the risk factors of water quantity, water quality and economy (treatment cost and irrigation benefit) of mine water farmland irrigation were analyzed. The risk prevention and control strategy of mine water farmland irrigation is put forward, which is of great significance to ensure food security.

1. Introduction
My country’s coal is mainly mined underground. In order to ensure the safe production of coal mines, a large amount of mine water must be discharged. Direct discharge not only wastes water resources, but may also pollute the environment. More than 75% of mine water in the country comes from large coal bases in water-deficient areas and severely water-deficient areas. The conflict between supply and demand of regional water resources is very acute. The treated mine water is the potential water resource for farmland irrigation, which can solve the problem of regional agricultural water conflicts (E. B. Gorigoryuk, 2005; National Development and Reform Commission, 2013; National Development and Reform Commission, 2019) to the instability of mine water inflow, the difference in water quality and treatment technology in different mining areas, there are risks in mine water utilization. Moreover, there is no uniform technical standard for mine water and farmland irrigation, and there are problems such as irregular mine water utilization and management. This paper analyzes the water quality characteristics and spatial layout of coal mine water in my country, analyzes the risks of mine water irrigation, and proposes prevention and control strategies for mine water irrigation risks, which are of great significance to ensure food security.

According to the frontier of mine water treatment technology, the use function and object orientation of the treated water, the mine water can be used in industry, life, agriculture and ecological environment. (Nariyan E, et al, 2017; Ma Lixin et al, 2017; GUO Juan, 2013; Wu Qiang, et al, 2010; WU Yao-guo, et al, 2004) In 2019, my country's coal mine water resources amounted to 57×108m³, and the utilization rate reached 80%. In the utilization of mine water in 2019, industrial water accounted for
60%; ecological environment water accounted for 30%; agricultural and domestic water consumption was the least. Mine water is used for agriculture, including farmland irrigation, reservoir water replenishment, aquaculture, and animal drinking. The treated mine water is added with a certain amount of soil conditioner, and the trace elements contained in the mine water can be used to increase food production [ZHOU Jianli, et al, 2011; Zhai jianping et al, 2014; Wang jian, 2015]. Through manual extraction and reinjection, the treated mine water area will be stored (SUN Wenjie, et al, 2019; Zhang Xiping, 2018). The goaf space left after coal mining will form a certain amount of water storage space. These goafs for storing water are connected through artificial passages to form a group of underground reservoirs [CHEN Yongchun, 2016], which can be used as agricultural irrigation water sources for regulating storage Mine water, increase the guarantee rate of agricultural irrigation water, and alleviate the shortage of water resources in the arid and semi-arid regions of western and northern my country (XU Zhimin, et al, 2017). For example, the water inflow of Shendong Daliuta Mine is about 8400m³/d, and the recovery rate is 95%. It can not only meet the requirements of underground fire sprinkler, power plant, coal washing supplement water, but also be used for farmland irrigation.

2. Spatial distribution and treatment process of coal mine water

2.1. Spatial distribution of coal mine water

The discharge of coal mine water is related to factors such as the location of the mine, climate, geological structure, mining depth and mining method. As far as regions are concerned, the general rule is that the water inflows in the eastern and southern regions are large, and the inflows in the west and northern regions are small. In terms of geological formations, coal seams are located in Ordovician limestone and Quaternary aquifer mine water. The quality of mine water varies greatly depending on the variety, type, method of mining, and the area and geological structure of the mine.

Table 1. Spatial distribution of coal mine water

| Water quality type | Distribution area | Water quality characteristics |
|--------------------|------------------|------------------------------|
| Clean mine water   | Mainly distributed in my country’s Northeast, North China and other places | The water quality is good, the pH value is neutral, low salinity, basically does not contain SS, various water quality indicators meet the "Drinking Water Hygiene Standards" (GB 5749-85), only need a little treatment and disinfection to drink |
| Mine water with suspended solids | A type of mine water that is common in the process of mine mining, which accounts for a relatively large proportion of mine water discharge in my country, especially in the northern mining areas of my country. | Except for suspended solids, bacteria, sensory indicators exceeding the standard, other physical and chemical indicators meet the "Sanitary Standards for Drinking Water" (GB 5749-85) |
| High salinity mine water | It is mainly distributed in most of the mining areas in my country's Gansu, Ningxia, western Inner Mongolia, Xinjiang, as well as some mining areas in the Huanghuaihai Plain, Northeast China, North China, and East China. These mining areas are also areas where water resources are scarce in China. | Refers to mine water with total dissolved solids higher than 1000mg/L, which often contains high suspended solids, bacteria, etc. |
| Acid mine water | It is mainly distributed in the southern mining areas of my country, Sichuan, Guizhou, Guangdong, Hunan, Hubei, Guangxi, Zhejiang and Fujian, etc. The PH value is between 2 and 4. There are few water shortage mining areas in the north, but some coal mines (such as those in Wuda, Tongchuan, Zaozhuang, Zibo, Yima, etc.) also have acid mine water | Refers to mine water with a pH value of less than 5.5. In addition to the acidic water quality, it also contains high iron, suspended solids, bacteria, etc. |
| Special pollution type mine water | High-iron-manganese mine water is mainly concentrated in the eastern Meng and Yunnan-Guizhou regions, and the areas with high fluoride content in mine water are mainly concentrated in the Lianghuai region, Shanxi Jincheng region and parts of Inner Mongolia. | Mainly refers to mine water containing traces of toxic and harmful elements, mine water containing radioactive elements, or mine water containing oil. Among them, mine water containing iron and manganese is the most common. |
According to water quality, mine water can be divided into five main categories: clean mine water, mine water containing suspended solids, mine water with high salinity, acid mine water and special polluted mine water. See Table 1 for the spatial distribution of coal mine water.

2.2. Coal mine water treatment process
Clean mine water refers to mine water that has not been polluted. This kind of mine water has good quality, neutral pH, low turbidity, low salinity, low toxic and harmful elements, and basically meets the standards for irrigation water for farmland. For suspended solids, iron and manganese, high salinity, and acid mine water, there are engineering processes that use coagulation sedimentation + disinfection, contact oxidation + disinfection, and membrane technology for treatment and reuse.

2.2.1. Mine water treatment process with suspended solids. The general process of mine water containing suspended solids for treatment and reuse of irrigation water includes raw water quality detection-adjustment (pre-sedimentation)-clarification or coagulation sedimentation-filtration-disinfection-reuse for irrigation.

2.2.2. High salinity mine water treatment process flow. The general process of high salinity mine water treatment and reuse for irrigation water includes raw water quality detection-adjustment (pre-sedimentation)-clarification or coagulation sedimentation-filtration-activated carbon adsorption or ultrafiltration-reverse osmosis desalination-disinfection-reuse for irrigation.

2.2.3. Acid mine water treatment process. The general process of acid mine water treatment and reuse for irrigation water includes raw water quality inspection-adjustment (pre-sedimentation)-neutralization-filtration-disinfection-reuse for irrigation.

2.2.4. Iron and manganese mine water treatment process. The general process of iron and manganese mine water treatment and reuse for irrigation water includes raw water quality inspection-adjustment (pre-sedimentation)-oxidation-coagulation sedimentation-iron removal filter, manganese removal filter or simultaneous iron and manganese removal filter- Disinfection-reuse for irrigation.

3. Risk analysis of coal mine water irrigation
The risks of coal mine water and farmland irrigation are not only reflected in the instability of coal mine water influx, but also the quality of raw water is more complicated, and its treatment technology, process and cost are also different. Mine water is used as a resource for farmland irrigation and must meet the water quality standards for farmland irrigation; water supply prices must be considered inevitably. Therefore, mine water utilization risks mainly include: water volume, water quality, economic (treatment cost, irrigation benefit) and other factors.

3.1. Water volume risk factors
Water volume risk refers to the problem of insufficient water volume and water surplus during the utilization of mine water, which does not match the irrigation demand time. When an accident occurs in a mining enterprise that cannot guarantee the extraction of sufficient water, or when a water treatment equipment has an emergency, it will not be able to supply water in full, and irrigation demand will not be guaranteed. Due to the precipitation replenishment, which reduces the demand for irrigation water, the conventional mine water supply will be surplus. When there is not enough storage space, this part of the water will be abandoned, which is a waste of resources and will affect economic benefits. Therefore, the water volume risk is mainly reflected in the instability of mine water inrush and the adaptability of irrigation water demand. It can be characterized by three indicators: the rate of change of mine water inrush, the proportion of mine water potential, and the rate of water supply guarantee.
3.1.1. Change rate of mine water inflow. Mine water inflow includes normal water inflow and maximum water inflow. Normal water inflow refers to the amount of water that flows into the pit or mine relatively steadily from the mining system during the mining process of the mine (this article mainly refers to coal mines); the maximum water inflow refers to the maximum amount of water that flows into the mining system per unit time. The change in mine water inflow refers to the difference between the maximum water inflow and the normal water inflow. The change in mine water inflow rate is the ratio of the change in mine water inflow to the normal water inflow. The greater the rate of change of mine water inflow, the more unstable the mine water inflow and the greater the risk of mine water utilization, and vice versa.

3.1.2. Water supply guarantee rate. On the time scale, due to the continuity of coal mining, water gushes in the mine all year round; while the growth of crops is seasonal, wheat and corn are mainly irrigated from April to October, and the water gushing in the mine is not fully compatible with the irrigation water demand. The difference in time requires the construction of water storage projects or underground reservoirs to adjust the mine water inflow during the irrigation period of the storage fee and increase the water supply guarantee rate. The higher the water supply guarantee rate, the lower the risk, and vice versa.

3.1.3. Proportion of mine water potential. The potential amount of mine water utilization refers to the amount of water after deducting the used amount from the planned annual available amount. The proportion of mine water potential is defined as the ratio of the planned annual mine water potential to the mine water inflow. Its size directly affects the supply and demand balance of mine water utilization, and is an important parameter in the process of mine water utilization. The greater the proportion, the greater the potential of mine water utilization, and the lower the risk; otherwise, the greater.

3.2. Water quality risk

Water quality risk refers to whether the water quality of mine water can meet the requirements of irrigation. The water quality risk discussed in this article only refers to the water quality that does not meet the irrigation requirements caused by sudden mining accidents, water treatment equipment accidents, sudden pollution of storage space, and damage to transportation pipelines. The influence of water quality factors on mine water utilization risk can be characterized by the following indicators: suspended solids content, soluble solids content, toxic substances (fluoride, arsenic, sulfide) content, total iron (manganese) content, etc.

3.2.1. Suspended matter content. Suspended matter content refers to the concentration of water-insoluble solid substances suspended in water. The greater the content of suspended matter, the more serious the pollution, and the greater the risk of mine water utilization; otherwise, the smaller.

3.2.2. Soluble solid content. The soluble solid content refers to the total amount of various ions, molecules, and compounds that can be dissolved in water. The larger the soluble solids content in the water, the harder the water quality, the worse the water quality, and the greater the risk of mine water utilization; otherwise, the smaller.

3.2.3. Toxic content. Highly toxic substances in mine water generally include fluoride, sulfide, arsenic and their inorganic compounds as a class of carcinogens, and are listed as toxic and harmful water pollutants (the first batch). The level of toxic content directly affects the quality and availability of water. The higher the content, the worse the water quality, and the higher the risk of utilization; otherwise, the lower. Since the types and contents of toxic substances in mine water are different, the pollutant with the strongest pollution is selected according to the "Classification Standard for Coal Mine Water" (GB/T19223-2015) for classification.
3.2.4. **Total iron (manganese) content.** Iron, manganese, and their compounds are also important water quality pollutants, and their content directly affects the color, turbidity and overall quality of water. The greater the total iron and manganese content, the worse the water quality, the higher the processing difficulty and cost, and the greater the risk of mine water utilization; otherwise, the smaller.

3.3. **Economic risk factors**

There are many types of coal mine water and its nature is complex. There are even many mine water containing iron, manganese, arsenic, sulfide and other toxic and harmful elements. At present, the types of coal mine water that can be used as irrigation water have not been defined, and the treatment process and process parameters have not been demonstrated. It is difficult to ensure that the effluent after treatment can stably meet the "Farmland Irrigation Water Quality Standard" (GB 5084-2005) and "Coal Mine The requirements of Technical Guidelines for Water Utilization (GB-T 31392-2015) and the Quality of Irrigation Water for Farmland Irrigation in Urban Sewage Recycling (GB 20922-2007) bring great food security risks to the subsequent use of farmland irrigation. The process of collecting, processing, and transporting mine water requires investment in corresponding equipment costs, drug treatment costs, pipeline costs, and water resource taxes. These will increase the cost of mine water utilization. The higher the cost, the higher the risk. Economic risk factors can be characterized by the following indicators: treatment costs, irrigation benefits.

3.3.1. **Processing cost.** Before the mine water reaches each user, it needs to be treated according to the different water quality requirements of each user. Therefore, when considering the utilization risk of mine water, it is inevitable to consider the treatment cost factor. Obviously, the higher the cost, the higher the risk, and vice versa.

3.3.2. **Irrigation benefits.** Mine water is processed for farmland irrigation, which produces irrigation benefits for farmers. Irrigation benefit is the increased output value of mine water irrigation. Obviously, the higher the increase in output value, the higher the advantage of irrigation benefit, the lower the risk of mine water utilization.

4. **Risk prevention and control of coal mine water irrigation**

4.1. **Formulated "Mine Water Utilization-Farmland Irrigation Standard"**

In view of the lack of a unified national or industry standard for mine water reuse, treatment technology selection, and water quality requirements for reused water, there is an urgent need to formulate "Mining Water Utilization-Farmland Irrigation Standards" to clearly define what can be used The types of coal mine water used for farmland irrigation: after clarification or coagulation sedimentation, filtration and disinfection treatment, the various water quality indicators can meet the requirements of the "standard" mine water containing suspended solids; after coagulation sedimentation, filtration, desalination and disinfection treatment Afterwards, the various water quality indicators can meet the high salinity mine water required by the "Standard"; after coagulation, neutralization, and filtration, the various water quality indicators can meet the acid mine water required by the "Standard", after oxidation and coagulation After precipitation, filtration and disinfection, the various water quality indicators can meet the iron-manganese-containing mine water required by the "Standard".

4.2. **Research and development of mine water treatment automation monitoring system**

In view of the low degree of automation of well water treatment technology and equipment, many links require manual operation, and there are greater management risks. The types and dosages of coagulants and coagulant aids need to be determined according to tests and similar projects There is an urgent need to develop an automated monitoring system for mine water purification treatment to realize functions such as automatic dosing, automatic sludge discharge, process monitoring and remote network monitoring. Coagulants and coagulants should be of the level of farmland irrigation water. Disinfectants
(oxidants) and disinfection equipment remain in the farmland irrigation water during the disinfection (oxidation) process. The content of impurities and the concentration of disinfection (oxidation) by-products should not exceed the threshold requirements of the "Standard". Combining the raw water quality components of different types of mine water, determine the appropriate treatment equipment. Reduce the cost of water treatment, improve management level and work efficiency.

4.3. Improve mine water treatment technology

In view of the risk of mine water quality, it is urgent to strictly control the technical parameters of each link of mine water treatment to meet the threshold requirements of the "Standard". When the suspended solids content in the mine water exceeds 300mg/L, a pre-sedimentation unit should be installed before the purification treatment. The pre-sedimentation unit can be built together with the adjustment tank; the average water temperature of the mine water entering the reverse osmosis system should be higher than 12℃, otherwise it should be set. The water heating system can raise the water temperature to between 18～25℃. The specific parameters are determined according to the selected membrane material and process requirements; the contact oxidation method for removing iron and manganese requires a pH value of at least 7.0, but not exceeding the "standard" threshold requirements.

5. Suggest

Establish and improve policies, regulations and measures for mine water and farmland irrigation. The state provides policy support to increase mine water and farmland irrigation supporting projects through tax incentives, financial subsidies, etc., to reduce the cost of mine water and farmland irrigation, and to promote the standard and orderly irrigation of mine water and farmland.

Improve scientific and technological safeguard measures for mine water utilization. Further research includes conventional treatment technologies such as coagulation, sedimentation and filtration, and advanced treatment technologies such as ultrafiltration and reverse osmosis. Study and establish the "Mining Water Utilization-Farmland Irrigation Standards", establish and improve the relevant standard system and supervision and management system for the utilization of mine water resources.

Establish economic guarantee measures for mine water and farmland irrigation. Broaden financing channels, increase capital investment, encourage all sectors of society to invest in mine water and farmland irrigation projects, and promote large-scale mine water and farmland irrigation.

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