Irrigation Suitability Assessment of Groundwater in an Open Mining Area in Grassland Area

Shan CHONG\textsuperscript{1,2,*}, Wen-feng DU\textsuperscript{1}, Yun-lan HE\textsuperscript{1}, Zhen-guo XING\textsuperscript{2} and Lei CHEN\textsuperscript{1}

\textsuperscript{1}State Key Laboratory of Coal Resources and Safe Mining, China University of Mining and Technology (Beijing), Beijing 100083, China
\textsuperscript{2}State Key Laboratory of Water Resource Protection and Utilization in Coal Mining, State Energy Investment Group Co. LTD, Beijing 100011, China

*Corresponding author

Keywords: Groundwater, Hydrochemical, Irrigation suitability.

Abstract. In this paper, the investigation of groundwater in open-pit coal mine in grassland was carried out. The hydrochemical parameters of groundwater were detected. The chemical types of the groundwater were analyzed. The temporal variation characteristics of groundwater parameters were studied, and the suitability of the irrigation water quality was analyzed. The results showed that the main hydrochemical types of groundwater were SO$_4^{2-}$•Cl$^-$•Na$^+$•Mg$^{2+}$ and SO$_4^{2-}$•Cl$^-$•Na$^+$•Mg$^{2+}$(Ca$^{2+}$). USSL analysis showed that most of the groundwater samples in the study area belonged to the type of high salinization and low alkali damage. Wilcox diagram analysis showed that most of the groundwater was in good and usable water quality area, and no groundwater sample was in unusable area. The results of single factor index SAR, %Na, RSC and PI analysis showed that most of groundwater was suitable for irrigation. Therefore, the groundwater in the study area was generally suitable for irrigation in pastoral areas. This study is of great significance to the rational development and utilization of groundwater resources.

Introduction

Groundwater is very important to human life and ecological environment. However, the groundwater may be disturbed by the human activities\cite{1}, such as coal mining, especially in the arid and semi-arid grassland area. The groundwater level and quality may change dynamically with time of human activities. More and more research are focused on the groundwater dynamic change in the world\cite{2}. The temporal and spatial distribution characteristics of groundwater level and hydrochemistry were found to be caused by natural and human factors\cite{3-5}.

The research of groundwater quality has an important significance, since it can be to identify the groundwater pollution source and degree\cite{6-8}. There are many studies on the groundwater quality in the intense human activity area, such as water quality evaluation in coal mining\cite{9} and the migration of groundwater parameters along the pollution source\cite{10}. Although the analysis of groundwater quality is an important content in groundwater research\cite{11-13}, there are few related studies carrying out in domestic open-pit coal mine areas. Moreover, the main way of pasture irrigation is to extract groundwater in the arid and semi-arid grassland area, so it is very important to evaluate the suitability of groundwater irrigation in this area.

In this paper, we take the open-pit coal mine in grassland area as the research area and the temporal variation characteristics of groundwater quality during the development of open-pit coal mine were studied. The irrigation suitability of groundwater irrigation by using USSL and Wilcox and single factor evaluation method in this area was evaluated. This study is of great significance to the rational development and utilization of groundwater resources in grassland area.
Study Area

The open pit mine is part of the hydrogeological unit of Xilinhot basin. The supply of phreatic water in opencast mining area consists of atmospheric precipitation, lateral supply of river, melting water of ice and snow, atmospheric condensation water and groundwater runoff, of which atmospheric precipitation is the main one. The supply of fracture and pore confined water bearing rock group in conglomerate section and fracture confined water bearing rock group in coal seam is mainly supplied by atmospheric precipitation infiltration through concealed outcrop of aquifer and overflow infiltration in local weak section of aquifer.

There are faults F1 and F25 in the early mining area of the mine[14], all of which are normal faults with strike NE and dip angle greater than 50°. The fault zone is mainly composed of mudstone and plastic rock cemented by mudstone, with few fissures and undeveloped fracture zone, which can be regarded as water blocking fault. The open-pit mine is located in the hanging wall of the fault. The fault forms the water separation boundary, and the east, north and west are the supply boundary.

Materials and Methods

Through sorting out and analyzing various data of the open pit mine, 16 representative groundwater monitoring points were selected according to the hydrogeological conditions and characteristics of the mine area. The underground water sampling method was as follows: water was pumped to the surface by pumps in civil wells, and water was collected by samplers in hydrology wells at a depth of 1 m. The groundwater sampling device of hydrological well was used by a 1.5L sampler. When the sampler contacted the groundwater surface in the borehole, the rope was quickly released to the depth of 1 m below the water surface. After waiting for 3-5 min, the sampler was quickly pulled to the ground and water sample was quickly poured the into the PTFE storage bottle. Then the sample was put into the low-temperature storage box and sent to the laboratory for ion content detection. The indexes of pH, electrical conductivity, dissolved oxygen and turbidity were detected by HACH MS5 portable water quality detector on site. The ions were detected by ion chromatography (Dionex-500).

Results and Discussion

Basic Hydrochemical Characteristics of Groundwater

In this paper, groundwater was classified by Piper tri-line method. The Piper graph, proposed by Piper in 1944[15], consists of an equilateral parallelogram and two equilateral triangles. It can be seen from the piper diagram (Figure 1) that the anions were mainly SO_4^{2-} and Cl\textsuperscript{-}, and the cations were mainly Na\textsuperscript{+} and Mg\textsuperscript{2+}. The hydrochemical types of groundwater mainly included SO_4^{2-}\cdot Cl\textsuperscript{-}\cdot Na\textsuperscript{+}\cdot Mg\textsuperscript{2+} and SO_4^{2-}\cdot Cl\textsuperscript{-}\cdot Na\textsuperscript{+}\cdot Mg\textsuperscript{2+} (Ca\textsuperscript{2+}) in the mining area and surrounding pastures. The groundwater hydrochemical types in the hydrological wells in the mining area were mainly SO_4^{2-}\cdot Cl\textsuperscript{-}\cdot Na\textsuperscript{+}\cdot Mg\textsuperscript{2+}, while the groundwater hydrochemical types in the civil wells in the surrounding pastoral areas were mainly SO_4^{2-}\cdot Cl\textsuperscript{-}\cdot Na\textsuperscript{+}\cdot Mg\textsuperscript{2+} (Ca\textsuperscript{2+}) type.

![Figure 1. Hydrochemical types of groundwater.](image-url)
Temporal Variations of Groundwater Parameters

According to Figure 2 (a), it can be seen intuitively that the pH of most groundwater was between 7∼9, indicating that the groundwater in this area was neutral to slightly alkaline. The pH showed lower value in December 2017, comparing with August 2017 and August 2018. Three of all wells had a pH value higher than 9, which was reflected in the three sampling periods of August 2017, December 2017 and August 2018. According to Figure 2 (b), the electrical conductivity of most water samples was in the range of 1000∼2200 µS/cm. The average electrical conductivity of the groundwater samples first decreased and then increased during the three sampling periods of August 2017, December 2017 and August 2018. As can be seen from Figure 2 (c), most of the dissolved oxygen in water samples was within the range of 2∼9 mg/L. The dissolved oxygen value in winter 2017 was higher than that in summer 2017 and 2018, which was caused by the fact that the solubility of gas was related to the temperature of liquid, and the solubility of oxygen in water decreased with the increase of water temperature[16]. As can be seen from Figure 2 (d), the turbidity of most water samples was concentrated in the range of 0∼100 NTU. It can be intuitively seen that the groundwater gradually showed abnormally high turbidity during the three sampling periods of August 2017, December 2017 and August 2018. The reason may be that, before the rainy season sampling in August 2018, there was a continuous heavy rain in the local area for a month, and the exchange and mixing of atmospheric precipitation and groundwater were strong, resulting in the high turbidity of water samples taken from the hydrological well.

![Figure 2. Boxplot of groundwater parameters (a) pH (b) electrical conductivity (c) dissolved oxygen (d) turbidity.](image)

Wilcoxon Diagram and USSL Diagram Evaluation of Irrigation Water Quality

The open-pit mining area is located in Xilingol grassland area, which is surrounded by pastoral areas. In the dry season, groundwater is extracted for grassland irrigation. Therefore, it is worth discussing whether the groundwater is suitable for irrigation in pastoral areas. The US salinity laboratory classification diagram (USSL)[17] and Wilcoxon diagram[18] are often used to evaluate irrigation water quality.

In the USSL diagram, according to the degree of salinization, the irrigation water is divided into four categories: C1 (low salinization), C2 (moderate salinization), C3 (high salinization) and C4 (very...
high salinization). They are divided according to the electrical conductivity of water, and the range is respectively: <250 µS/cm, 250∼750 µS/cm, 750∼2250 µS/cm, >2250 µS/cm. Then, according to the different degree of sodium (alkali) harm and the sodium adsorption ratio, the water is divided into four categories: S1 (low degree of alkali damage), S2 (medium degree of alkali damage), S3 (high degree of alkali damage) and S4 (very high degree of alkali damage). Their range is respectively: <10, 10∼18, 18∼26, >26. All underground water sample points collected in the study area were drawn in the USSL diagram. As can be seen from Figure 3(a), most of the water sample points fell in the area of C3S1, indicating that most of the groundwater samples in the study area belong to the type of high salinization and low alkali damage.

Wilcox diagram (1955) simultaneously represented %Na and EC, which can be divided into five regions: excellent irrigation water quality area, good irrigation water quality area, usable irrigation water quality area, reserved irrigation water quality area and unusable irrigation water quality area[19]. If the water samples fall in the area with excellent water quality and the area with good water quality, the agricultural irrigation of such water will not bring salt or alkali damage. However, if the water samples fall in the usable area, the risk of alkali damage may be caused by irrigation, but the risk is relatively small, so appropriate measures can be taken to prevent the production of alkali damage. The water samples in the water quality reserve area will have the risk of salt damage and alkali damage if it is used for irrigation. The water in the area of unusable irrigation water quality area is not suitable for irrigation, which will cause serious salt and alkali damage. The water sample points were drawn in Wilcox diagram. As can be seen from Figure 3(b), %Na of shallow groundwater in the study area was concentrated in the range of 30%~80%. Most of the groundwater was in the good water quality zone and the usable water quality zone. One point was in the excellent water quality area, three points were in the water quality reserve area, and no groundwater sample was in the unusable area. Therefore, the groundwater in the study area was generally suitable for irrigation.

![Figure 3. Evaluation of irrigation groundwater quality (a)USSL diagram (b) Wilcox diagram.](image)

**Evaluation of Irrigation Water Quality by Single Index**

In addition to the classification and evaluation of USSL and Wilcox maps, the indicators commonly used for agricultural irrigation water quality evaluation include sodium absorption ratio (SAR), sodium percentage (%Na), residual sodium carbonate (RSC), permeability index (PI), etc. Many studies used these indicators to evaluate whether groundwater was suitable for irrigation. Aye et al. used these indicators to evaluate the irrigation water quality index of shallow groundwater in Maritime Djefara[20]. Ramesh et al. used these indexes to analyze the irrigation suitability of groundwater quality in Tondiar river basin of India, and found that only 36% of water samples were suitable for irrigation[21]. Jain et al. used the same method to evaluate the groundwater in Nalbari of India, and found that the groundwater in most places is suitable for irrigation[3].

SAR is an important parameter to indicate the content of sodium ion in irrigation water or soil solution, and it is also an important index to measure the degree of soil alkalinization caused by irrigation water. The higher the SAR value is, the stronger the ability of soil to absorb Na⁺, which will destroy the aggregate structure and permeability of soil and reduce the water conductivity. The water
quality is very suitable for irrigation when SAR is less than 10 (meq/L)1/2. The water quality is suitable when SAR is in the range of 10 and 18 (meq/L)1/2. The water quality is basically suitable when SAR is in the range of 18 and 26 (meq/L)1/2. The water quality is not suitable when SAR is more than 26 (meq/L)1/2.

%Na is used to represent the risk of alkali damage caused by irrigation water. The greater the %Na value is, the greater the risk of alkali damage is. If this kind of groundwater is used for irrigation, cation exchange may occur on the surface of the soil, where Na+ will be absorbed by the soil, releasing Ca2+ and Mg2+, reducing the permeability of the soil, thus causing the poor internal drainage of the soil. The groundwater quality is suitable for irrigation when %Na is less than 30%. The water quality is basically suitable for irrigation when %Na is in the range of 30% and 60%. The water quality is not suitable for irrigation when %Na is more than 60%.

RSC is used to characterize the alkali damage degree of groundwater. If RSC is negative, it indicates that the content of CO32- and HCO3- in water is smaller than that of Ca2+ and Mg2+, and there is no excess carbonate to react with Na+, so it will not increase alkali damage. Otherwise, if RSC is positive, it indicates that alkali damage is likely to be caused, and the greater the RSC value is, the greater the possibility of alkali damage is[22]. The water quality is very suitable for irrigation when RSC is less than 1.25. The water is basically suitable for irrigation when RSC is in the range of 1.25 and 2.5. The water is not suitable for irrigation when RSC is more than 2.5[23].

PI value is affected by long-term irrigation and the content of Na+, Ca2+, Mg2+ and HCO3- in soil[20]. The water is suitable for irrigation when PI is more than 75%. The water is basically suitable for irrigation when PI is in the range of 25% and 75%. The water is not suitable for irrigation when PI is less than 25%.

The calculation formulas of SAR, %Na, RSC and PI are shown in formula (1) - (4) [24, 25]:

\[
SAR = \frac{Na^+}{\sqrt{(Ca^{2+} + Mg^{2+})/2}} \tag{1}
\]

\[
%Na^+ = \frac{K^+ + Na^+}{K^+ + Na^+ + Ca^{2+} + Mg^{2+}} \times 100\% \tag{2}
\]

\[
RSC = (CO_3^{2-} + HCO_3^-) - (Mg^{2+} + Ca^{2+}) \tag{3}
\]

\[
PI = \frac{Na^+ + \sqrt{HCO_3^-}}{Ca^{2+} + Mg^{2+} + Na^+} \tag{4}
\]

According to Figure 4, the SAR value of groundwater in the study area ranged from 1.1~8.2 (meq/L)1/2, all of which were within 10 (meq/L)1/2, which were very suitable for irrigation. The range of %Na value was 36.5~79.7%, and the range of %Na value of groundwater in most sampling points was 0~60%, which was suitable for irrigation. Some points were more than 60%, which was not suitable for irrigation. The SAR values ranged from -18.1 to -2.8, all of which were negative, indicating that the groundwater in all sampling points was suitable for irrigation. PI value ranged from 39.6% to 71.1%, indicating that groundwater was basically suitable for irrigation in the study area.

**Conclusions**

The main conclusions of this paper are as follows:

1. The groundwater in the study area was alkaline and brackish water. The groundwater hydrochemical type in the mining area was mainly SO42-•Cl•Na+•Mg2+, while the groundwater hydrochemical type in the surrounding pastoral area was mainly SO42-•Cl•Na+•Mg2+ (Ca2+) type.
(2) Compared with summer, the pH and electrical conductivity of groundwater samples were relatively low in winter, while the dissolved oxygen was relatively high, indicating that climate factors might have a certain impact on the pH, electrical conductivity and dissolved oxygen of groundwater.

(3) SAR, %Na, RSC and PI were analyzed by using the single factor index evaluation method for water quality evaluation of agricultural irrigation water. It was found that most of the groundwater was suitable for irrigation, while only four wells had %Na value over 60%, which was not suitable for irrigation.

Figure 4. Irrigation suitability analysis (a) SAR (b) Na% (c) RSC (d) PI.

(4) USSL analysis showed that most of the groundwater samples in the study area belong to the type of high salinization and low alkali damage. Wilcox diagram analysis showed that most of the groundwater was in good water quality area and usable area, and no groundwater sample was in unusable area. Therefore, the groundwater in the study area was generally suitable for irrigation.

Acknowledgement
The authors thank the support of National Key Research and Development Program (2016YFC0501102), State Key Laboratory of Water Resource Protection and Utilization in Coal Mining Open Fund (GJNY 18-73.20) and China Postdoctoral Science Fund (00-240017).

References
[1] P. Liu, N. Hoth, C. Drebenstedt, Y. Sun, Z. Xu, Hydro-geochemical paths of multi-layer groundwater system in coal mining regions-Using multivariate statistics and geochemical modeling approaches, Sci. Total Environ. 601 (2017) 1-14.
[2] Y. Jia, B. Xi, Y. Jiang, H. Guo, Y. Yang, X. Lian, S. Han, Distribution, formation and human-induced evolution of geogenic contaminated groundwater in China: A review, Sci. Total Environ. 643 (2018) 967-993.
[3] C.K. Jain, U. Vaid, Assessment of groundwater quality for drinking and irrigation purposes using hydrochemical studies in Nalbari district of Assam, India, Environ. Earth Sci. 77 (2018)1-14.
[4] R. Barzegar, A.A. Moghaddam, A.H. Nazemi, J. Adamowski, Evidence for the occurrence of hydrogeochemical processes in the groundwater of Khoy plain, northwestern Iran, using ionic ratios and geochemical modeling, Environ. Earth Sci. 77 (2018)1-17.

[5] D. Thakur, S.K. Bartarya, H.C. Nainwal, Tracing ionic sources and geochemical evolution of groundwater in the Intermountain Una basin in outer NW Himalaya, Himachal Pradesh, India, Environ. Earth Sci. 77 (2018)1-23.

[6] A. Hao, Y. Zhang, E. Zhang, Z. Li, J. Yu, H. Wang, J. Yang, Y. Wang, Review: Groundwater resources and related environmental issues in China, Hydrogeol. J. 26 (2018) 1325-1337.

[7] A. Rasool, A. Farooqi, T. Xiao, W. Ali, S. Noor, O. Abiola, S. Ali, W. Nasim, A review of global outlook on fluoride contamination in groundwater with prominence on the Pakistan current situation, Environ. Geochem. Health 40 (2018) 1265-1281.

[8] L. Zhang, X. Qin, J. Tang, W. Liu, H. Yang, Review of arsenic geochemical characteristics and its significance on arsenic pollution studies in karst groundwater, Southwest China, Appl. Geochem. 77 (2017) 80-88.

[9] M.L. Lin, W.H. Peng, H.R. Gui, Hydrochemical characteristics and quality assessment of deep groundwater from the coal-bearing aquifer of the Linhuan coal-mining district, Northern Anhui Province, China, Environ. Monit. Assess. 188 (2016)1-13.

[10] X. Huang, H. Deng, C. Zheng, G. Cao, Hydrogeochemical signatures and evolution of groundwater impacted by the Bayan Obo tailing pond in northwest China, Sci. Total Environ. 543 (2016) 357-372.

[11] M. Kurdi, T. Eslamkish, Hydro-geochemical classification and spatial distribution of groundwater to examine the suitability for irrigation purposes (Golestan Province, north of Iran), Paddy Water Environ. 15 (2017) 731-744.

[12] S. Kumari, A.K. Singh, A.K. Verma, N.P.S. Yaduvanshi, Assessment and spatial distribution of groundwater quality in industrial areas of Ghaziabad, India, Environ. Monit. Assess. 186 (2014) 501-514.

[13] H. Arslan, N.A. Turan, Estimation of spatial distribution of heavy metals in groundwater using interpolation methods and multivariate statistical techniques; its suitability for drinking and irrigation purposes in the Middle Black Sea Region of Turkey, Environ. Monit. Assess. 187 (2015)1-13.

[14] S. Jiang, X. Kong, H. Ye, N. Zhou, Groundwater dewatering optimization in the Shengli no. 1 open-pit coalmine, Inner Mongolia, China, Environ. Earth Sci. 69 (2013) 187-196.

[15] A.M. Piper, A graphic procedure in the geochemical interpretation of water analyses, Trans Am Geophys Union, 25(1944):914-928.

[16] M.M.V.G. Silva, E.M.C. Gomes, M. Isaias, J.M.M. Azevedo, B. Zeferino, Spatial and seasonal variations of surface and groundwater quality in a fast-growing city: Lubango, Angola, Environ. Earth Sci. 76 (2017)1-17.

[17] US Salinity Laboratory Staff, Diagnosis and improvement of saline and alkali soils, US Department of Agricultural Hand Book 60, US Department of Agricultural soils, Washington, 1954.

[18] L.V. Wilcox, Classification and use of irrigation waters, vol 969. USDA Circular, Washington, DC, 1955.

[19] P. Li, H. Qian, J. Wu, Y. Zhang, H. Zhang, Major Ion Chemistry of Shallow Groundwater in the Dongsheng Coalfield, Ordos Basin, China, Mine Water Environ. 32 (2013) 195-206.
[20] B. Ayed, I. Jmal, S. Sahal, N. Mokadem, S. Saidi, E. Boughariou, S. Bouri, Hydrochemical characterization of groundwater using multivariate statistical analysis: the Maritime Djeffara shallow aquifer (Southeastern Tunisia), Environ. Earth Sci. 76 (2017)1-22.

[21] K. Ramesh, L. Elango, Groundwater quality and its suitability for domestic and agricultural use in Tondiar river basin, Tamil Nadu, India, Environ. Monit. Assess. 184 (2012) 3887-3899.

[22] C. Almeida, S. Quintar, P. Gonzalez, M. Mallea, Assessment of irrigation water quality. A proposal of a quality profile, Environ. Monit. Assess. 142 (2008) 149-152.

[23] S.M. Yidana, Groundwater classification using multivariate statistical methods: Southern Ghana, J. Afr. Earth Sci. 57 (2010) 455-469.

[24] L.A. Richards, Diagnosis and improvement of saline and alkaline soils, US Department of Agriculture hand book, US Salinity Laboratory, California, 1954.

[25] L.D. Doneen, Notes on Water Quality in Agriculture. Department of Water Science and Engineering, University of California, California, 1964.