

## Research Article

# Spatial and Temporal Distribution of Groundwater in Open-Pit Coal Mining: A Case Study from Baorixile Coal Mine, Hailaer Basin, China

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Groundwater distribution influenced by mining activities is hard to be tracked due to the lack of accurate and real-time monitoring data. To address the groundwater dynamic change data under the mining conditions of open-pit coal mines, a three-dimensional automatic observation network of groundwater was constructed, and this observation network takes open-pit as the center, showing a radioactive distribution, based on hydrogeological conditions, and observes different aquifers. The data was analyzed by integrating hydrology, mining activity, and meteorological data. Analytic hierarchy process was adopted to reveal the underground disturbance influencing factors, and suggestions for groundwater protection were given. The results show that the dynamic variations of the groundwater with time can be divided into 3 types (precipitation affected, unaffected type, and mining affected types). The drainage operation during the open-pit mining triggered the drop of groundwater level, resulting in a cone of depression. The maximum drawdown of the central groundwater level was 60 m. And the disturbance mainly occurred in the mining area where the maximum groundwater disturbance radius was 8 km. Artificial drainage was the main disturbance factor of groundwater, and the range of groundwater level drop within the disturbance radius was closely related to the distance from the open-pit coal mine and the drainage volume. The closer the distance to the mines and the higher the drainage volume led to the deeper the groundwater level drop. This study shows the importance of the three-dimensional observation network of groundwater and provides a good reference for groundwater resources protection and ecological restoration in open-pit coal mines.

## 1. Introduction

China is highly rely on the coal, and the proportion of coal in the energy structure will be continuously high [1]. For effective coal production, open-pit coal mining is adopted for their high recovery rate and high safety coefficient [2]. Open-pit coal mining can bring great economic benefits to the mining area; however, it may also induce ecological environment issues, especially in arid and semiarid mining areas

[3–9]. Hailaer Basin is an arid and semiarid area, which contains rich coal resources. It is an important base for the integrated development of coal and electricity in China [10]. The carrying capacity of groundwater resources is extremely limited, and the contradiction between groundwater protection and coal development is particularly prominent, especially in opencast coal mines located in grassland areas. Therefore, it is of great significance to study the impact of mining activities on groundwater in arid and semiarid regions.

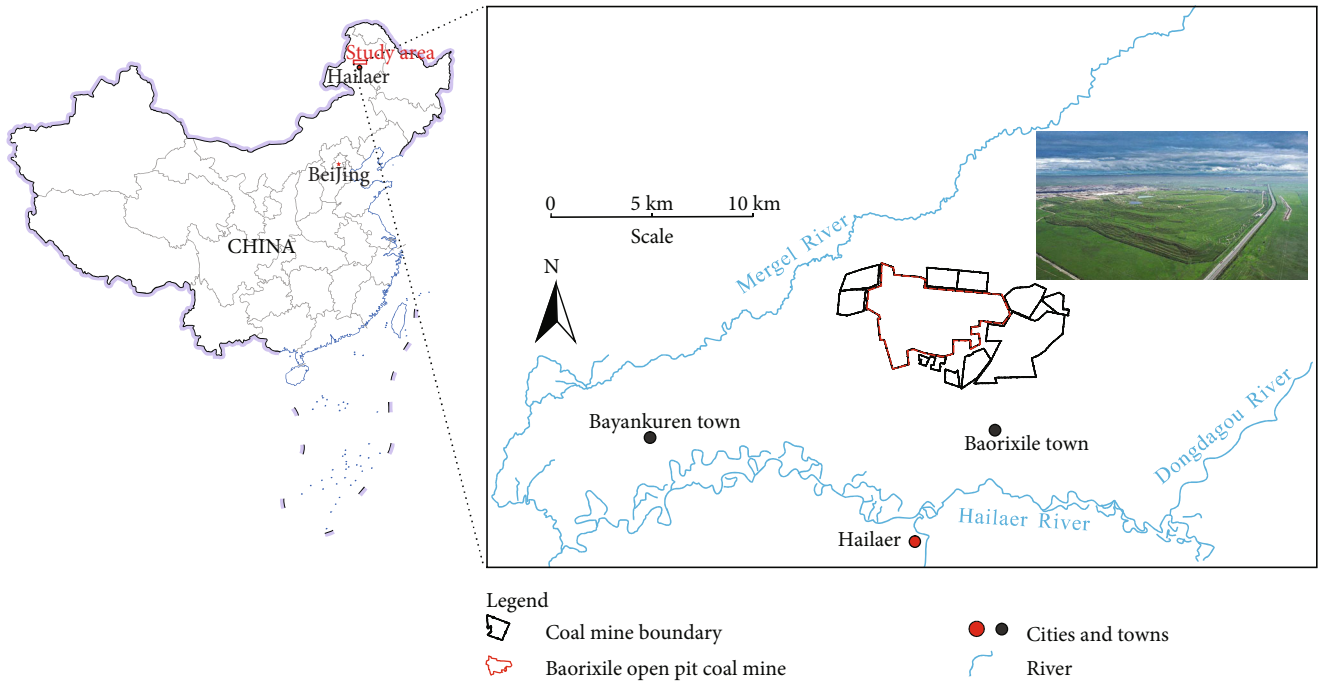


FIGURE 1: Location of the study area.

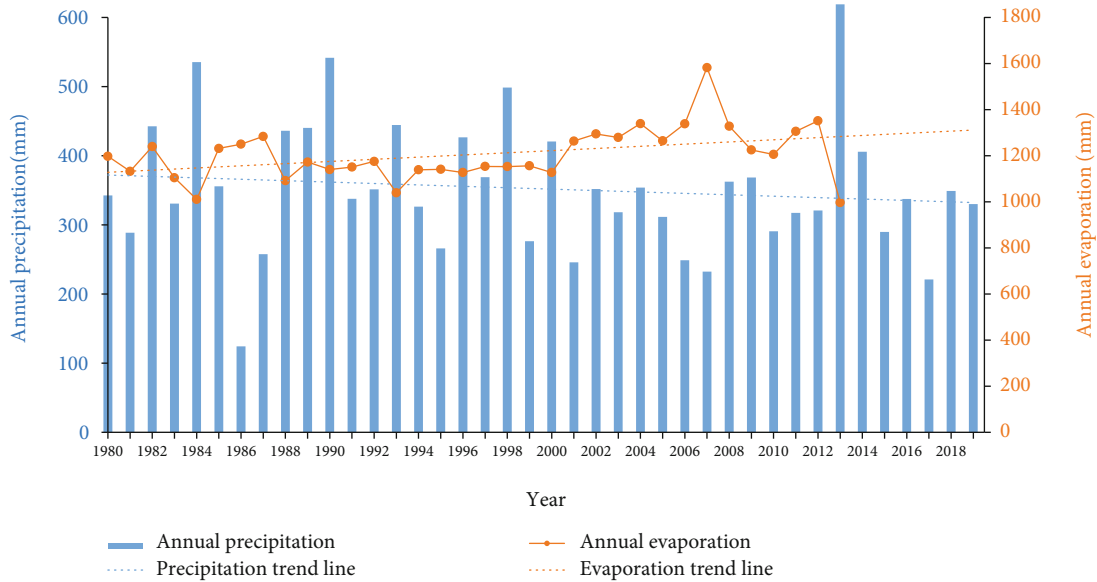


FIGURE 2: Variation curves of precipitation and evaporation in the study area.

Open-pit coal mining groundwater drainage can cause groundwater disturbance [9, 11–14], and the existing articles on groundwater in open-pit mines mainly focus on the prediction of groundwater inflow [2, 14–17], groundwater as a disaster-causing factor for the safety evaluation of open-pit mine slopes [18–22], groundwater chemistry [5, 6, 23], and ecological evaluation [3, 4, 23, 24]. There are many articles on the change and prediction of groundwater inflow caused by open-pit mining from the perspective of numerical simulation, such as Soni and Manwatkar [16] used the modflow model to simulate and predict the groundwater inflow and

groundwater flow field changes in an open-pit coal mine in India under different mining conditions. Xue et al. [17] used a mining geological model to calculate the groundwater impact under different precipitation levels in the Zhuanlongwan mining area, Inner Mongolia. Zhao et al. [2] used the surfact model to assess the groundwater impact of an opencast coal mine in New South Wales and predicted the inflow of groundwater into the mining area during the entire project mining cycle. Rózkowski et al. [14] used numerical calculation and simulation of groundwater inflow in open-pit mines to formulate a reasonable drainage scheme. Haque et al. [9]

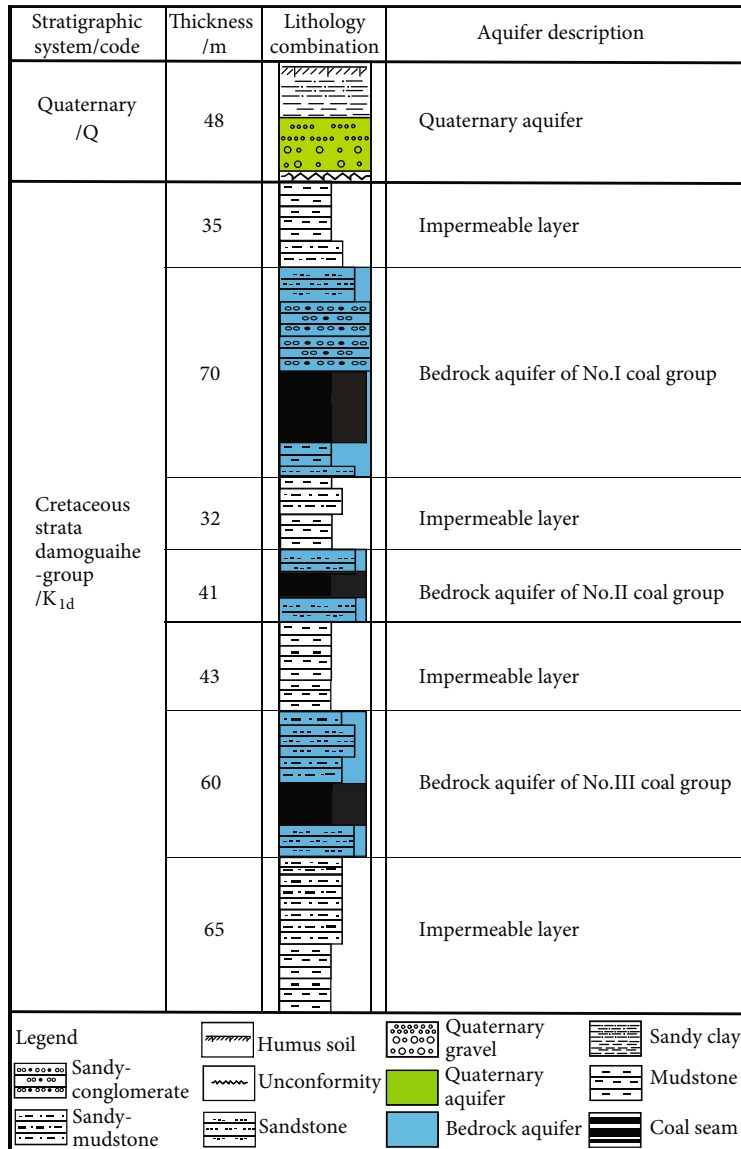


FIGURE 3: The schematic diagram of stratum and aquifer profile in the study area.

assess the vulnerability of groundwater due to open-pit coal mining using a drastic model. In terms of slope safety, Islam et al. [22] used the fem model to study the stress redistribution caused by mining and the impact of groundwater influx on slope safety. In the chemical change of groundwater in open-pit coal mines, Dong et al. [23] through the groundwater system evolutions in mining area before and after the mining actions of Yimin open-pit coal mine, the interactions between groundwater chemical and its environment was investigated. In the field of groundwater monitoring in open-pit coal mining areas, through long-term monitoring and analysis of the mining area in Riyadh, Saudi Arabia, Yihdego and Drury [15] found that open-pit mining activities in arid areas resulted in a significant drop in groundwater level. Existing articles on groundwater dynamic observation and data analysis mainly focus on urban groundwater source areas [11, 12, 25–28] and underground coal mining area [29–36], there are few articles about the spatial and temporal distribution charac-

teristics of groundwater, disturbance range, and factors under the condition of high-intensity mining in open-pit coal mines, and the distribution of the diving ecological groundwater level needs to be further studied.

Long-term drainage of groundwater in open-pit coal mining will lead to changes in groundwater flow near the stope [18, 23] and formed groundwater drawdown funnels in the mining pits [13, 15, 29, 37]. Through long-term observation of groundwater, the influence of open-pit coal mining on groundwater can be studied [11], which is helpful for groundwater management and protection [11, 12, 38–45]. Long-term observation of open-pit groundwater in arid areas generally shows a downward trend in groundwater level [15, 46]. At present, the observation of groundwater in an open-pit coal mine is mainly based on manual observation, which is time-consuming, labor-consuming, and error-prone [47]. In the cold and arid area, it is difficult to monitor groundwater due to low temperature in the autumn

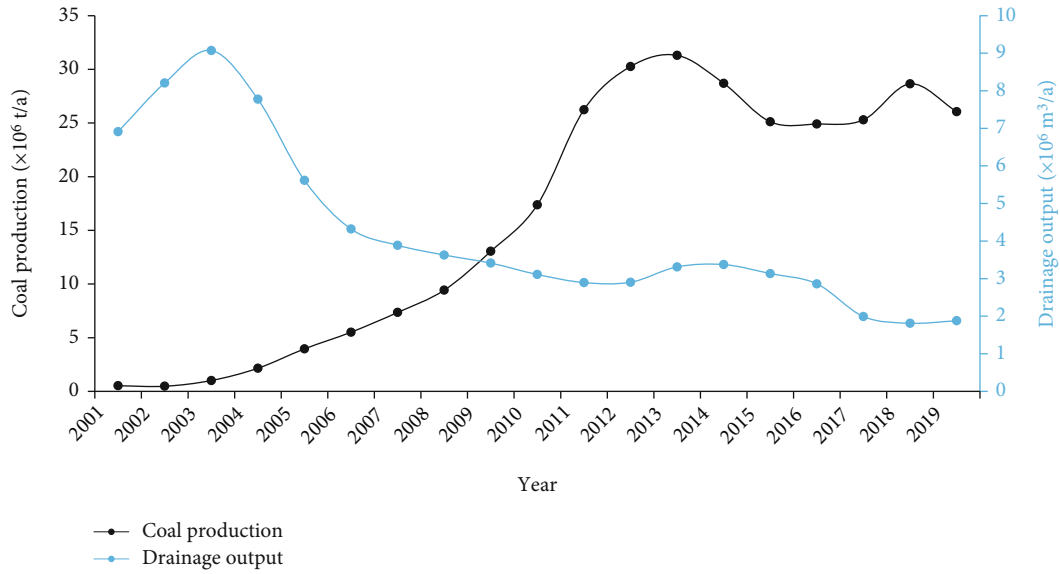


FIGURE 4: The variation of coal production and drainage output.

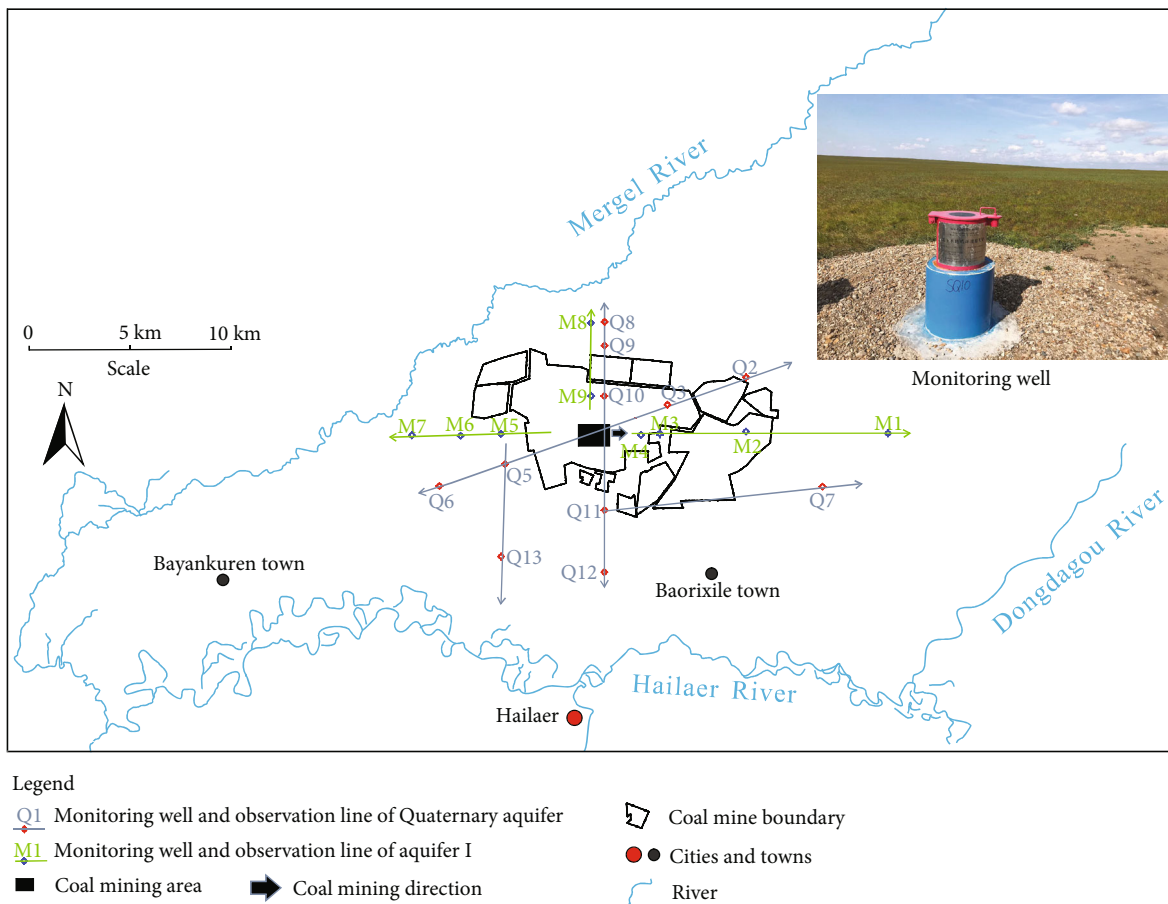


FIGURE 5: Drilling distribution map of the three-dimensional automatic observation network of groundwater.

and winter. The research on the spatial and temporal distribution characteristics of groundwater under high-intensity mining conditions in cold areas has not been systematically studied. In this paper, through the establishment of a remote

three-dimensional observation network of groundwater, the automatic monitoring of groundwater level and temperature and the spatial and temporal distribution of groundwater under high-intensity mining are revealed in Inner Mongolia.

TABLE 1: Layout parameters of groundwater automatic observation network.

Aquifer	Well	Equipment depth (m)	Distance from open-pit mine (m)	
Quaternary groundwater aquifer	Q2	38.67	11000	
	Q3	32.28	7000	
	Q5	48.39	4000	
	Q6	30.42	9000	
	Q7	22.43	13000	
	Q8	32.28	8000	
	Q9	29.62	6000	
	Q10	46.94	4000	
	Q11	59.96	4000	
	Q12	48.49	7000	
	Q13	35.51	8000	
	Coal groundwater aquifer	M1	30.47	14000
		M2	50.80	10000
M3		120.00	4000	
M4		140.00	3000	
M5		60.02	5000	
M6		59.68	8000	
	M7	30.23	11000	
	M8	28.74	8000	
	M9	108.00	3000	

The groundwater disturbance factors are discussed, and the targeted groundwater protection measures are proposed. The result can be of significance for groundwater resources protection and ecological restoration of open-pit coal mines in cold regions.

## 2. Geological Setting and Coal Mining Activities

The Baorixile open-pit mine (annual output of 35 million tons raw coal) is located in Baorixile town (Figure 1) where it is cold in winter, with the lowest temperature at  $-47^{\circ}\text{C}$  and the annual average temperature at  $-1.9^{\circ}\text{C}$ . The mining area contains 30 km longitudinally and 10 km latitudinally with a 300 km<sup>2</sup> mining area. The hydrogeological unit thereby covers about 80 km long from east to west, about 25 km wide from north to south, with an area of about 2000 km<sup>2</sup>.

The topography of the study area is high in the east and low in the west, with an altitude ranging between 600 and 750 m. The Hailar River in the south is the main river in this area, and the Dongdagou River in the east flows into the Hailar River from north to south. The Mergel River runs from north to west and flows into the Hailar River in the west.

The mining area belongs to an arid and semiarid climate with less precipitation and large evaporation. The annual precipitation from 1980 to 2018 is 124.5–619.1 mm (Figure 2), and the average precipitation is 352.3 mm. The precipitation mainly occur in July and August. With global warming and gradual drought, the precipitation in the area is decreasing year by year. From 1980 to 2018, the evapora-

tion range was 996.9–1582.7 mm, and the average evaporation was 1205.9 mm, showing an increasing trend year by year. Evaporation is greater than precipitation, which will reduce surface water to some extent.

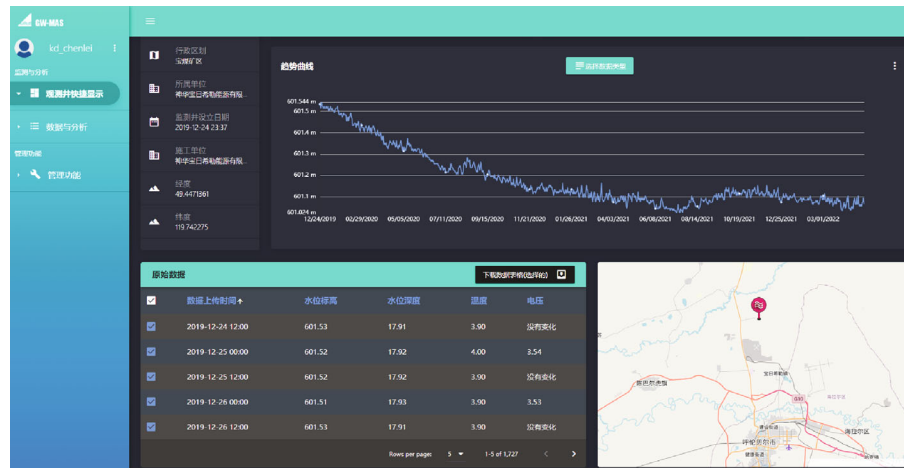
The main strata of the mining area are Cretaceous (K) and Quaternary (Q), and the coal-bearing strata are the Cretaceous Damoguaihe formation (K<sub>1d</sub>). There are three main mineable coal layers, which are named no. I, no. II, and no. III coal seams from top to bottom. At present, the main coal seam of the Baorixile open-pit coal mine is no. I. The aquifers are mainly Quaternary phreatic aquifer and Cretaceous coal bearing rock confined aquifer (Figure 3). The lithology of the Quaternary phreatic aquifer is mainly gravels, and the lithology of the Cretaceous confined aquifer is mainly composed of coal seam with developed fractures, roof, and floor conglomerate and sandstone, which are named coal-bearing aquifer no. I, coal-bearing aquifer no. II, and coal-bearing aquifer no. III from top to bottom. The lithology of the impermeable layer is mainly mudstone and siltstone.

Since the commissioning of the Baorixile mining area in 2001, at first, due to the high groundwater abundance of coal bearing formation, the initial value of artificial drainage of groundwater is relatively large, and the coal production is low. With the continuous groundwater drainage operation, the drainage amount increases first and then decreases. After the completion of the drainage of the static groundwater reserves, the drainage is mainly dynamic reserves, and the drainage amount reaches relatively stable. The coal production gradually increases and then tends to be relatively stable. Raw coal production was inversely proportional to drainage volume (Figure 4).

## 3. Methodology

*3.1. Groundwater Data Acquisition Method.* Groundwater data collection is divided into automatic acquisition and manual acquisition. The groundwater level acquisition method in the study area has been used for irregular artificial observation of groundwater before the construction of an automatic observation network. The error is large, and the observation well is few. The cold weather in winter brings difficulties to the artificial long-term observation of groundwater. In order to realize the automatic collection of groundwater data, the three-dimensional automatic observation network of groundwater is designed firstly. This observation network takes the open-pit stope as the center, showing a radioactive distribution, based on hydrogeological conditions, and observes different aquifers. The confined groundwater in the Quaternary phreatic layer and the aquifer layer of coal no. I is observed hierarchically, and the long-term monitoring of groundwater in different directions and aquifers is realized.

Groundwater observation network in the Baorixile open-pit mine is shown in Figure 5. The observation network is centered on an open-pit mine, and 20 hydrological boreholes are arranged on the plane (Table 1), including 11 Quaternary aquifer observation wells and 9 coal no. I bearing aquifer observation wells. After the completion of each hydrological observation hole, the construction of a



(e)

FIGURE 6: Groundwater automatic observation network construction process pictures. (a) Workers are observing the groundwater level of herdsmen's wells. (b) Workers are drilling hydrogeological boreholes. (c) Workers are installing automatic groundwater level observation equipment. (d) Workers are calibrating parameters of automatic groundwater level observation equipment. (e) This is the client interface of the automatic groundwater observation system.

groundwater automatic monitoring well is carried out. The automatic monitoring equipment for groundwater cold resistance (Figure 6) is installed in each observation well. The acquisition and transmission time of groundwater parameters (groundwater level and groundwater temperature double parameters) is set. The groundwater data is col-

lected every 12 hours and transmitted to the Aliyun server through the internet of things wireless network. The groundwater level data is viewed and downloaded online through the remote monitoring system. This project has been completed in November 2019. The automatic acquisition, wireless transmission, and online remote monitoring of

TABLE 2: Judgement matrix scale and its meaning.

Scale	Implication
1	Comparing the two factors, they have the same importance.
3	Comparing two factors, the former is slightly more important than the latter.
5	Comparing the two factors, the former is more important than the latter.
7	Comparing two factors, the former is more important than the latter.
9	Comparing two factors, the former is more important than the latter.
2, 4, 6, 8	Represents the intermediate value of the above judgment
Reciprocal	The scale of factor $i$ versus $j$ is the reciprocal of the scale of factor $j$ versus $i$

TABLE 3: Random indicators RI.

$n$	1	2	3	4	5	6	7	8
RI	0	0	0.58	0.90	1.12	1.24	1.32	1.41

groundwater data (groundwater level and groundwater temperature) under high-intensity mining conditions of open-pit coal mines in cold regions are accomplished.

**3.2. Weight Analysis Method of Groundwater Disturbance Factors.** Determining the weight of groundwater disturbance factors can help to develop targeted groundwater protection measures [48], this paper uses the analytic hierarchy process (AHP) [49, 50] qualitatively and quantitatively evaluated the index weight [51]. The target was divided into several levels, the factors in each level were compared in pairs to obtain the relative comparison value of any two factors, and then the judgment matrix at each level was constructed. The maximum eigenvalues and corresponding eigenvectors of the judgment matrix at each level are calculated, and the rationality of the element value of the judgment matrix is verified by the consistency test results of the judgment matrix. Finally, the weight value of each factor in the judgment matrix relative to all factors in the corresponding level is obtained after normalization.

**3.2.1. Construction of Judgment Matrix.** When using AHP analysis, it is necessary to establish a judgment matrix for the same level of indicators by pairwise comparison. The level  $W$  contains events  $W_1, W_2, \dots, W_n$ . The expression of judgment matrix is

$$W = [W_1, W_2, \dots, W_n], \quad (1)$$

$$W_i = [W_{i1}, W_{i2}, \dots, W_{ij}, \dots, W_{in}]. \quad (2)$$

Among them,  $W_{ij}$  is the relative importance of  $W_i$  to  $W_j$ , which is usually expressed by the natural number 1–9 and its reciprocal. The larger the value, the higher the importance of  $W_i$  to  $W_j$ . The scale and meaning of the judgment matrix are shown in Table 2.

**3.2.2. Calculate the Sum of Feature Vectors and the Corresponding Feature Roots.** According to the constructed judgment matrix, the feature vector and feature root are

obtained, and the judgment matrix is normalized:

$$\overline{W}_{ij} = \frac{W_{ij}}{\sum_{k=1}^m W_{ik}} \quad (i, j = 1, 2, 3, \dots, m). \quad (3)$$

The normalized judgment matrix is added by rows to obtain  $\overline{U}_{ij}$ :

$$\overline{U}_{ij} = \sum_{j=1}^m \overline{W}_{ij} \quad (i, j = 1, 2, 3, \dots, m). \quad (4)$$

Calculating the maximum eigenvalue of judgment matrix  $\lambda_{\max}$ :

$$\lambda_{\max} = \frac{1}{m} \sum_{j=1}^m \frac{\sum_{i=1}^m \overline{W}_{ij} U_j}{U_j}. \quad (5)$$

**3.2.3. Consistency Testing.** Consistency test for constructed judgment matrix. Consistency indicators:

$$CI = \frac{\lambda - n}{n - 1}. \quad (6)$$

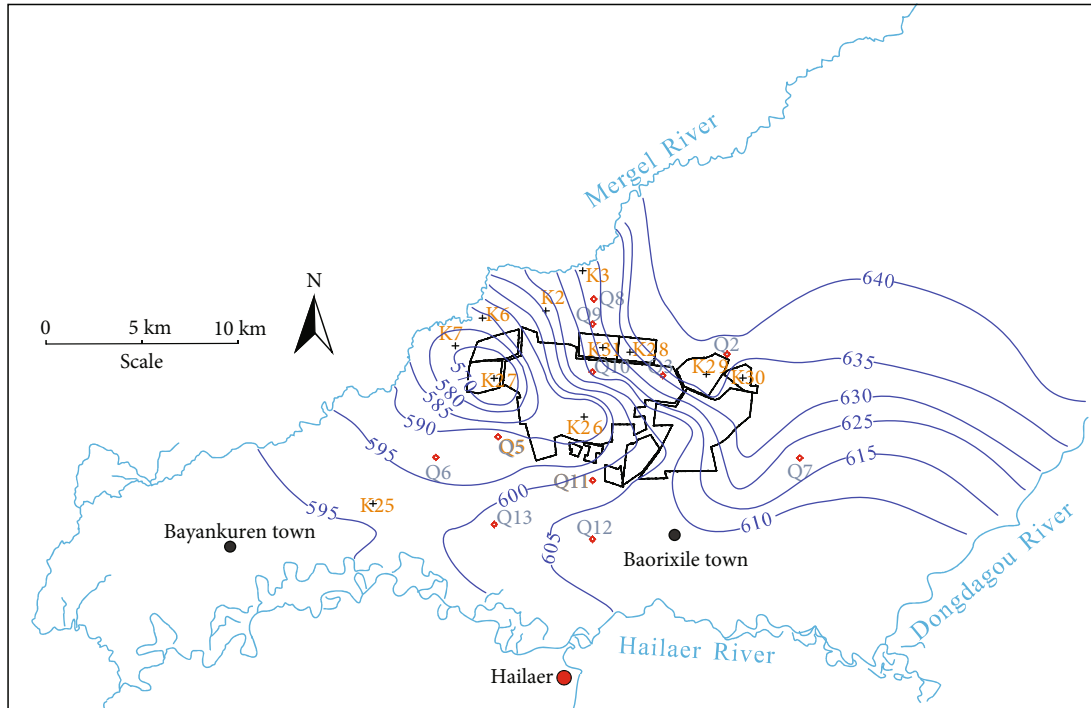
The random indicators RI are shown in Table 3. Define consistency ratios:

$$CR = \frac{CI}{RI}. \quad (7)$$

Usually,  $CR < 0.1$  passes the consistency test.

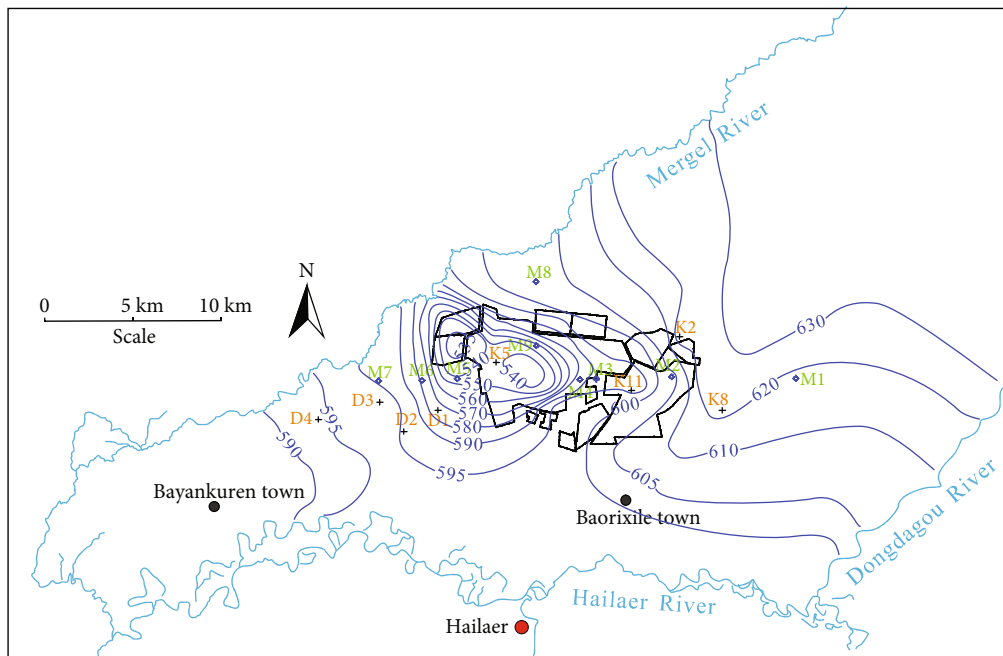
## 4. Results

**4.1. Distribution of Groundwater Flow Field under Mining Conditions.** In order to study the spatial distribution characteristics of groundwater, we draw the groundwater flow field diagram according to the monitoring data of groundwater level in 2020. It can be seen from the groundwater contour map (Figure 7) of the Quaternary phreatic aquifer that the flow direction of groundwater in the Quaternary aquifer is generally northeast to southwest. In the mining area, the contour density increases, the hydraulic gradient increases, and the groundwater level decreases significantly, forming a groundwater drawdown funnel, and the central groundwater level is 570 m. It can be seen from the groundwater



Legend  
 Q1 Automatic monitoring well of Quaternary aquifer  
 K1 Manual monitoring well  
 595 Groundwater level contour  
 Coal mine boundary  
 Cities and towns  
 River

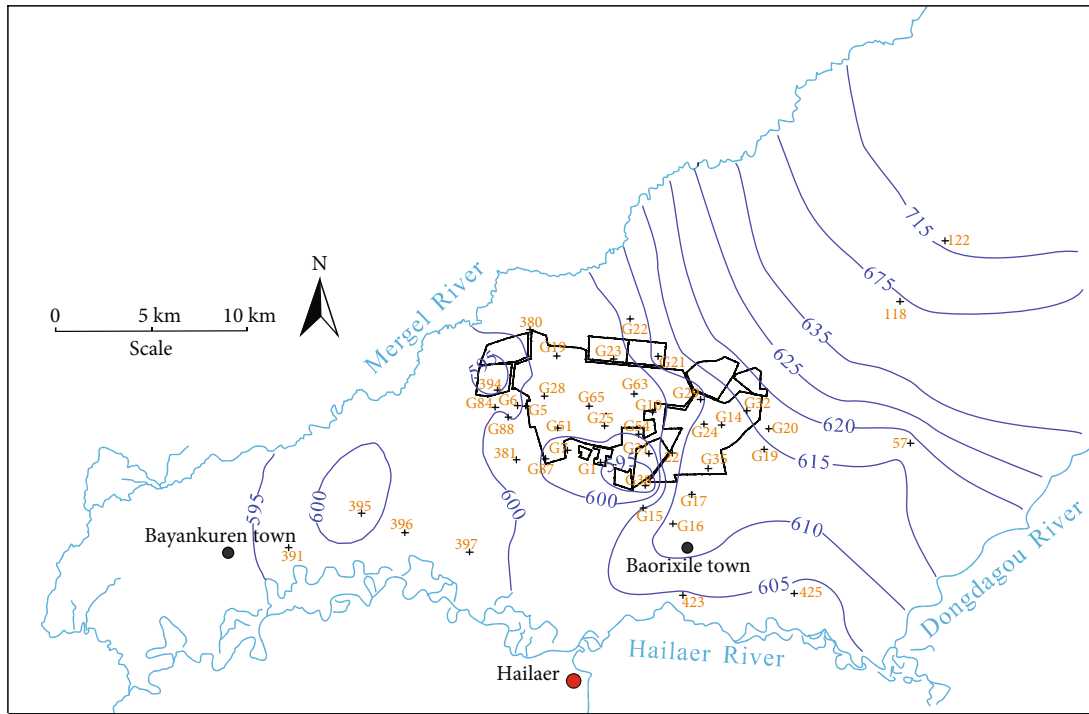
FIGURE 7: Groundwater contour map of Quaternary aquifer under open-pit coal mining conditions in 2020.



Legend  
 M1 Monitoring well and observation line of aquifer I  
 K8 Manual monitoring well  
 595 Groundwater level contour  
 Coal mine boundary  
 Cities and towns  
 River

FIGURE 8: Groundwater contour map of coal I aquifer after open pit mining in 2020.





Legend  
 G22 Manual monitoring well  
 595 Groundwater level contour  
 Coal mine boundary  
 ● Cities and towns  
 River

FIGURE 9: Contour map of groundwater in coal seam confined aquifer before open-pit mining in 1985.

contour map of aquifer I (Figure 8) that the flow direction of groundwater is generally similar to that of the Quaternary phreatic aquifer, and runoff flows from northeast to southwest. In the mining area, the closer to the pit, the greater the contour density, forming a groundwater drawdown funnel, the central groundwater level is 535 m.

4.2. *Variation of Groundwater Flow Field before and after Mining.* In order to study the characteristics of groundwater disturbance after coal mining, the groundwater level data of the coal-bearing seam before coal mining in 1985 were collected. At that time, the coal mine had not been developed, and the flow field was mainly controlled by topography. The groundwater level data can be used as the initial value of the groundwater level. From the contour map of the groundwater flow field before coal mining (Figure 9), the groundwater flow east to west as a whole, and the groundwater elevation in the mining area is 595–620 m.

After interpolation of groundwater level data in Figures 8 and 9, the contour map of drawdown (Figure 10) can be obtained. From the diagram, it can be seen that the maximum drawdown of groundwater level in the mining area is about 60 m. Through measurement, the influence radius and range of groundwater disturbance in open-pit coal mining can be obtained (Table 4). The maximum influence radius is about 8 km, and the maximum influence area is about 200 km<sup>2</sup>. The

mining affected type mainly occurs in the mining area, and the maximum influence area accounts for about 66.7% of the mining area and 10% of the research area.

4.3. *Temporal Variation of Groundwater Level.* According to the groundwater level data of groundwater automatic monitoring network in 2020, the variation curve is plotted. Combined with the fluctuation of the groundwater level curve and the variation of precipitation and drainage, the variation curve of the groundwater level can be divided into precipitation affected type, unaffected type, and mining affected type.

4.3.1. *Precipitation Affected Type.* This type is revealed by the observation wells of Q11, Q13, and M2. The fluctuation of the groundwater level curve of observation wells changes with the change of precipitation (Figure 11). The groundwater level increases after the increase of precipitation and decreases after the decrease of precipitation. The peak value of groundwater level lags slightly behind the peak value of precipitation and is less affected by drainage. It is mainly distributed in the area far from the open pit coal mining pit, deep aquifer burial, and good precipitation infiltration conditions.

4.3.2. *Unaffected Type.* This type is revealed by the observation wells of Q2, Q8, Q9, Q12, and M7. The fluctuation of groundwater level curve of observation wells is gentle

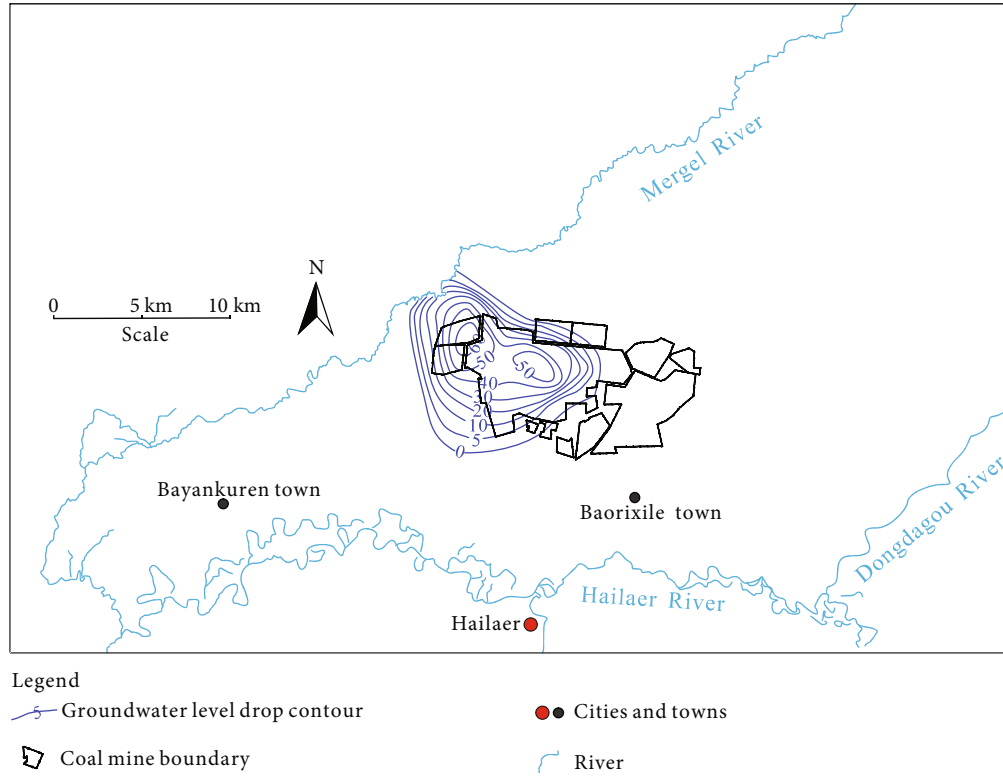


FIGURE 10: Contour map of groundwater in coal seam confined aquifer after open pit mining in 2020.

TABLE 4: Radius and range of groundwater disturbance after open pit mining.

Groundwater drawdown (m)	Influence radius (km)	Influence area (km <sup>2</sup> )
5	4.0-8.0	50-200
10	3.5-7.5	38-176
20	3.5-7.0	38-153
30	3.0-6.0	28-113
40	2.5-3.5	20-39
50	2.0-2.5	12-20
60	1.5-2.0	7-12

(Figure 12), which is basically not affected by drainage and precipitation changes. It is mainly distributed in areas far from open pit coal mining, good groundwater runoff conditions, and deep aquifer burial.

**4.3.3. Mining Affected Type.** This type is revealed by the observation wells of Q3, Q5, Q6, Q7, Q10, M1, M3, M4, M5, M6, M8, and M9. The fluctuation of groundwater level curve of observation wells is greatly affected by drainage (Figure 13). When the precipitation increases, the groundwater level does not increase but decreases. When the drainage amount is greater than the supply amount, the groundwater level shows a gradual downward trend, and the groundwater level dynamic shows a typical con-

sumption type, which is mainly distributed in the area near the open-pit coal mining area.

**4.4. Spatial Variation of Groundwater before and after Coal Mining.** Before open-pit coal mining, the groundwater flow field was mainly controlled by topography. The distribution of groundwater was basically consistent with the topography, and the groundwater flow field generally flowed from northeast to southwest.

After the open-pit coal mining, the overburden and rock layers on the coal seam were completely stripped, resulting in the destruction of the aquifer above the coal measure strata, which changed the running state of the groundwater. And under the action of gravity, the mining pits became the new groundwater catchment center, and the open-pit coal mine drainage became the main factor controlling the groundwater flow field. The drainage of open-pit coal mines is a dynamic and continuous process. With the continuous drainage of aquifers, the groundwater level continues to drop, forming a groundwater depression cone with the mining pit as the center. In the groundwater cone area, the flows of groundwater are changed from the horizontal direction to the vertical, increasing both the hydraulic gradient and the groundwater velocity. The groundwater disturbance factor is mainly the influence of artificial drainage, followed by precipitation evaporation. When the drainage groundwater and precipitation evaporation are consistent, the groundwater disturbance at different locations is also affected by the distance between observation wells and mining pits, recharge

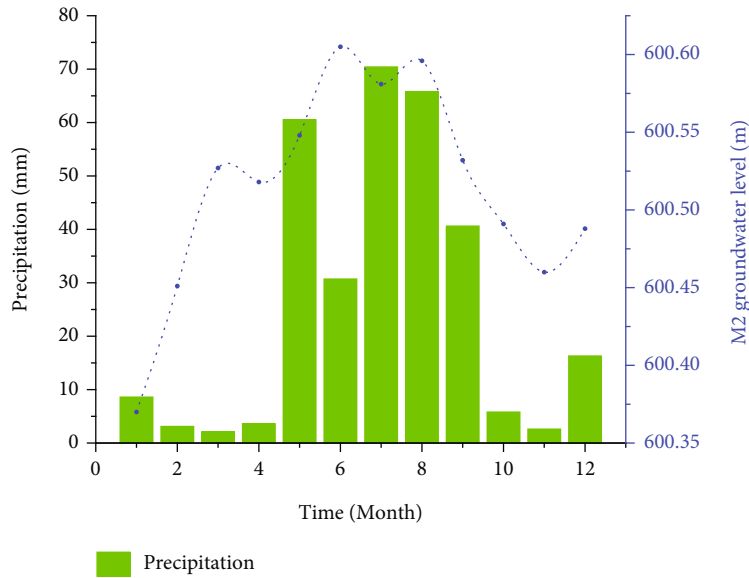


FIGURE 11: Characteristics of temporal dynamic change curve of precipitation-affected groundwater level (M2).

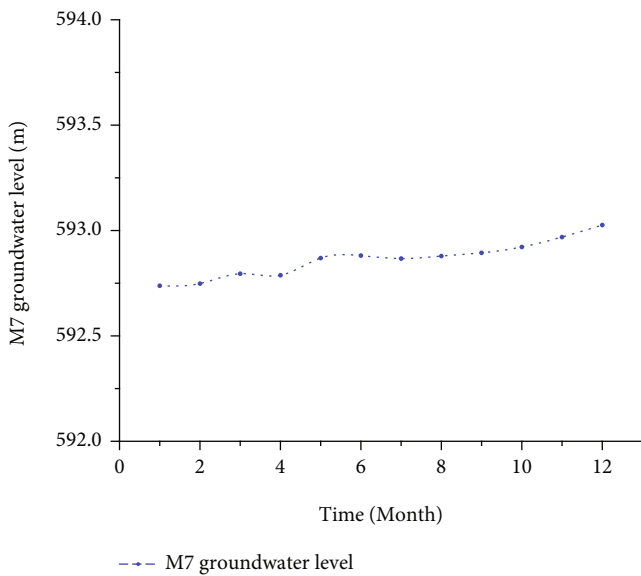


FIGURE 12: Characteristics of time series dynamic change curve of unaffected groundwater level (M7).

runoff conditions, aquifer buried depth, and landform factors. With the expansion in the scale of open-pit coal mining and the nonstop advancement of the stope, the outflow of groundwater increases continuously, the groundwater level drops, and the cone of depression becomes larger. When the static reserves of groundwater in the open-pit coal mining area are drained to reach the dynamic reserves, the groundwater depression cone also reaches a dynamic equilibrium, and the groundwater flow field is mainly determined by the topography and the open-pit coal mine drainage combined, instead of being determined solely by the topography.

## 5. Discussion

**5.1. Groundwater Disturbance Influencing Factors after Coal Mining.** In the process of open-pit mining, the load above the coal seam in the mining area will be completely stripped, the aquifer above the coal series will be drained, and an open funnel area will be formed. The groundwater discharge of the aquifer in the mining area changes from the original natural runoff discharge along the dip direction of the strata to the drainage mode dominated by drainage and artificial discharge. Due to the destruction of the natural recharge, runoff, and discharge conditions of the groundwater in the region, the groundwater recharge in the downstream area is reduced, and the groundwater resources are reduced. The destruction of groundwater resources during open-pit mining is mainly caused by the drainage of groundwater caused by coal mining, which leads to the loss of regional groundwater resources. Drainage volume and precipitation are the direct factors that cause groundwater level fluctuation.

**5.1.1. Drainage Volume.** In order to study the relationship between drainage volume and groundwater level, taking M5 observation station as an example, the plot of average groundwater level from January to December 2020 and the corresponding monthly drainage volume are drawn. The correlation diagram between the two was established (Figure 14). It can be seen from the diagram that with the increase of drainage, the groundwater level decreases, the decline is large, and the trend is obvious. There is a negative correlation between the two, and  $R^2$  value is 0.9316. It indicates that a large amount of groundwater drainage is an important reason for groundwater level decline.

**5.1.2. Precipitation.** Precipitation is an important source of groundwater recharge, and its seasonal and interannual variations have important driving significance for the dynamic

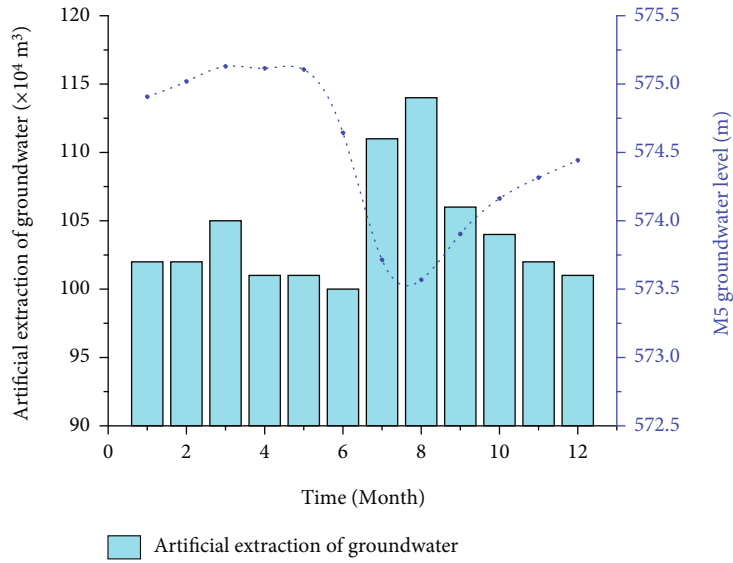


FIGURE 13: Time series dynamic curve characteristics of mining-affected groundwater level (M5).

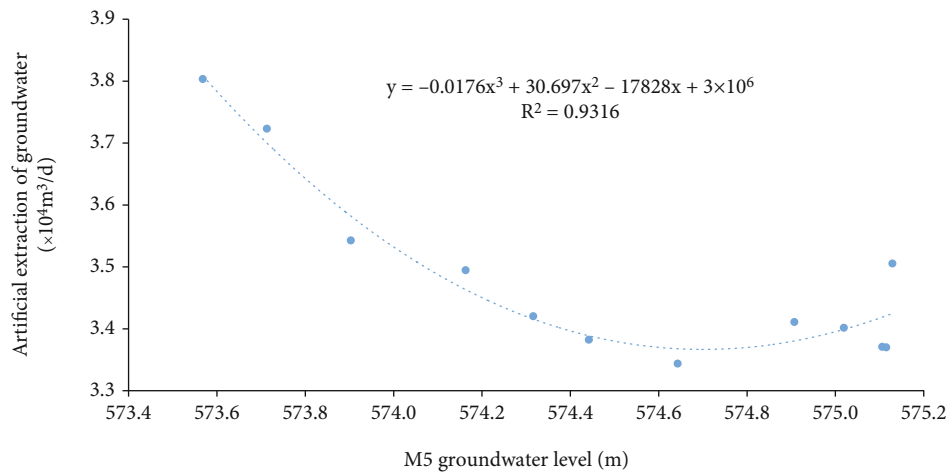


FIGURE 14: Correlation curve between groundwater level of M5 observation well and drainage volume of coal mine (January–December 2020).

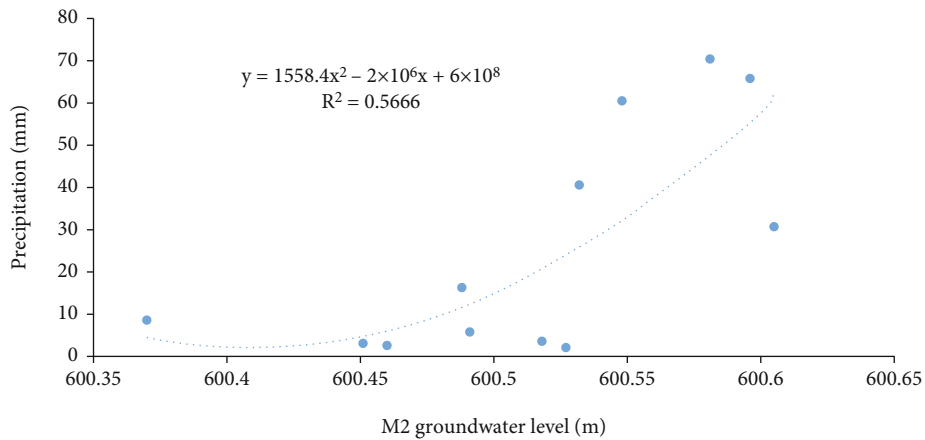


FIGURE 15: Correlation curve between groundwater level and precipitation in M2 observation well (January–December 2020).

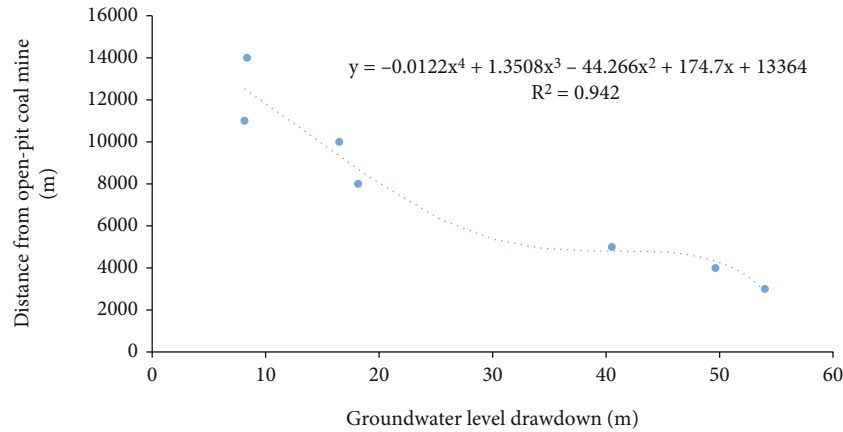


FIGURE 16: Correlation curve between groundwater level drop of observation well and open-pit mine distance.

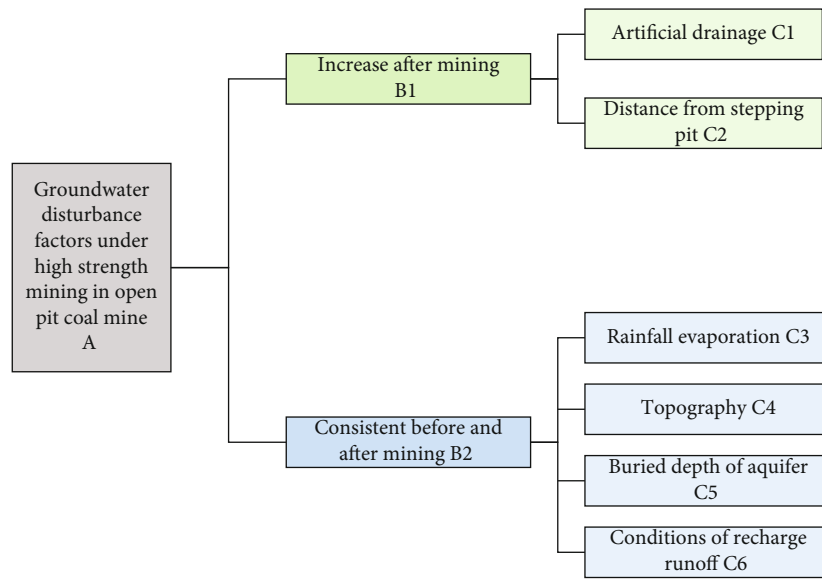


FIGURE 17: Structural model of groundwater disturbance factors.

change of groundwater in the region. Groundwater recharge is directly related to the amount of local precipitation. Precipitation in open-pit mining area is directly converted into water accumulation in mining area. In order to further analyze the variation of groundwater level with precipitation, the groundwater level from January to December in 2020 was used as the abscissa, and the corresponding monthly precipitation was used as the ordinate. The correlation diagram between the two was established (Figure 15), from the diagram, it can be seen that with the increase of precipitation, the groundwater level increased, and the groundwater level decreased after the decrease of precipitation, they were shown to be positively correlated, and the  $R^2$  value reached 0.5666.

5.1.3. *Other Influencing Factors.* In a certain period of drainage and precipitation, the groundwater level at different

locations is disturbed differently. In order to study the relationship between groundwater drawdown and pit distance, the groundwater level drawdown of M1, M2, M3, M4, M5, M6, and M7 observation wells is used as the abscissa, and the distance from the pit is used as the ordinate. The correlation diagram between the two is established (Figure 16). It can be seen from the figure that the closer to the open-pit coal mine, the greater the decline of groundwater level in the observation well. The decline of groundwater level is negatively correlated with the distance to the open-pit mine, and the  $R^2$  value reaches 0.942. It indicates that drainage is an important factor affecting groundwater resources. The closer to the mining pit, the greater the amount of artificial drainage is, and the greater the disturbance is. The drainage effect of mining pit has different degrees of influence on groundwater resources in different distribution areas, and the magnitude of this influence is inversely proportional to

TABLE 5: Pair-wise comparison judgment matrix A-B<sub>1-2</sub>.

A	B1	B2	Weight
B1	1	3	0.75
B2	1/3	1	0.25

TABLE 6: Pair-wise comparison judgment matrix B<sub>1</sub>-C<sub>1-2</sub>.

B1	C1	C2	Weight
C1	1	3	0.75
C2	1/3	1	0.25

TABLE 7: Pair-wise comparison judgment matrix B<sub>2</sub>-C<sub>3-6</sub>.

B2	C3	C4	C5	C6	Weight
C3	1	5	5	5/3	0.5
C4	1/5	1	1	1/3	0.1
C5	1/5	1	1	1/3	0.1
C6	3/5	3	3	1	0.3

TABLE 8: Standard weight of all factors.

Goal A	Weight B	Weight C	Weight
A	B1	C1	0.5625
		C2	0.1875
		C3	0.1250
	B2	C4	0.0250
		C5	0.0250
		C6	0.0750

the distance from the coal mining area, that is, the closer to the open-pit coal mine, the greater the influence of coal mining on groundwater resources.

In addition to drainage volume, precipitation, and observation well location, groundwater disturbance is also affected by other secondary factors such as topography, aquifer depth, and recharge runoff conditions: The lower the terrain is, the more groundwater will be collected, and the more groundwater will be lost after dredging. The shallower the aquifer is, the more easily it will be disturbed. The location with more groundwater recharge and less discharge will be more likely to be disturbed after dredging and drainage. The discharge volume increases, and the groundwater disturbance degree increases.

## 5.2. Quantitative Analysis of Groundwater Disturbance Factors

**5.2.1. Different Influencing Factors Classification.** Combined with mining conditions, six factors, namely, artificial drainage (A), precipitation (B), landform (C), distance from mining pit (D), aquifer burial depth (E), and recharge-runoff condition (F), were determined to classify the target layer hierarchically (Figure 17).

**5.2.2. Different Influencing Factors Weight.** Random consistency ratio  $CR = 0 < 0.1$  (Tables 5, 6, and 7). It shows that the judgment matrix is consistent and does not need to adjust the element value of the judgment matrix.

The analytic hierarchy process (AHP) was used to analyze the influencing factors of each disturbance, and the weight value of each influencing factor in different mining periods (Table 8) was determined. The calculation results show that the artificial drainage weight is 0.5625, which is the main factor, followed by the distance from the mining pit, the weight is 0.1875, the influence weight of precipitation, recharge runoff conditions, aquifer depth, and topography are 0.125, 0.075, 0.025, and 0.025.

**5.3. Suggestions on Groundwater Protection in High-Strength Mining Area.** According to the characteristics of groundwater disturbance factors and the results of influence weight analysis, artificial drainage is the main factor. Precipitation-evaporation, topography, distance from mining pit, and recharge runoff conditions are secondary factors and objective natural factors. With the climate drought, the decrease of precipitation, and the increase of evaporation, the groundwater level decreased to some extent. By reducing the drainage capacity of groundwater and improving the utilization rate of drainage are the main measure to reduce the disturbance of groundwater in mining area. The excessive drainage of groundwater in mining area can be reduced by stopping drainage vertical wells. After the groundwater gushing from the mining pit is treated as the production and living water for recycling, the abundant water is stored in the underground reservoir constructed under the dump and the ground reservoir after the ecological restoration of the waste land on the dump for standby. These water saving measures have important practical significance for the protection of groundwater in the high-intensity mining of open-pit coal mines and are beneficial to the coordinated development of green mining of open-pit coal mines and the sustainable utilization of groundwater.

## 6. Conclusions

To address the groundwater dynamic change data under the mining conditions of open-pit coal mines, a three-dimensional automatic observation network of groundwater was constructed to obtain long-term dynamics, with the variation of groundwater flow field under the mining conditions can be compared and analysed, the conclusions obtained are as follows:

- (1) The maximum drawdown in the study area was about 60 m and the maximum influence radius of about 8 km. The maximum influence range accounted for about 66.7% of the mining area and about 10% of the hydrological unit area
- (2) Apart from mining influenced groundwater variation curves, the precipitation influenced and unaffected groundwater were also recognized. Both of which are distributed in the mining area and beyond, accounting for 33.3% of the mining area. The

precipitation affected type was mainly distributed upstream of the mining area, and the precipitation infiltration conditions were good. The unaffected type was mainly distributed in the north and south of the mining area, far from the mining pit, and the aquifer is deeply buried

- (3) The groundwater was influenced by topography and precipitation before coal mining, of which topography was the most important. After mining, artificial drainage and precipitation were the key factors. Thus, groundwater recycling and protection should be conducted during mining activities

## Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

## Disclosure

Part of the manuscript has been published in the preprint, the link to the preprint is doi:10.20944/preprints202202.0016.v1, although the preprint has been successfully withdrawn.

## Conflicts of Interest

The authors declare that they have no conflicts of interest.

## Authors' Contributions

Funding acquisition and methodology were done by Wenfeng Du; conceptualization, data curation, and writing—original draft were done by Lei Chen; investigation was done by Yunlan He; investigation and methodology were done by Qiangmin Wang; investigation was done by Peiqiang Gao; project administration was done by Quansheng Li.

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