

The channel and characteristics of the stope supplied by atmospheric precipitation in the karst landform mining area

Xianzhi Shi (✉ zslsxz@aliyun.com)

Xingyi Normal University for Nationalities <https://orcid.org/0000-0002-9559-2066>

Weiqliang Zhang

China University of Mining and Technology - Xuzhou Campus: China University of Mining and Technology

Yongjin Tang

Guizhou Yuneng Mining Group

Ting Jiang

Guizhou Yuneng Mining Group

Shaojie Zhang

Guizhou Yuneng Mining Group

Chao Chen

Shuicheng Mining Group

Research Article

Keywords: atmospheric precipitation, mine water, recharge channel, characteristics, karst

DOI: <https://doi.org/10.21203/rs.3.rs-326474/v1>

License: © ⓘ This work is licensed under a Creative Commons Attribution 4.0 International License.

[Read Full License](#)

Abstract

Atmospheric precipitation causes some mining faces, mining areas or mines to be flooded every year. In order to explore the relationship between atmospheric precipitation and mine water inflow under Karst geomorphic conditions in Guizhou Province, some typical mine related data were collected systematically. It was found that atmospheric precipitation can supply mine goaf through weathered zone cracks, mining fissures, water conducting faults, water flowing subsided columns and karst channels. These channels are in the form of surface infiltration, pipeline flow and layered recharge Replenish the goaf. The results show that the mine water inflow is significantly affected by rainfall under all kinds of recharge modes, the correlation between them is significant under layered recharge mode—the correlation coefficient R reaches 0.88. The recharge channel is filled by loess and other materials on the surface, and has the self-healing characteristics of gradual plugging; the recharge amount is affected by the burial depth of coal seam and the rock combination characteristics of the upper roof. The deeper the coal seam is, the worse the recharge effect is to the mine. The results show that the atmospheric precipitation is the main water filling source of coal mine stope water inflow in the study area, and its recharge has seasonal characteristics. The mine water inflow in rainy season is 1.2-12 times of that in dry season, with an average of 1.9 times; the recharge of mine water by atmospheric precipitation has hysteresis, the lag time of surface infiltration recharge mine is generally 1-4 days, and the lag time of pipeline flow replenishing mine is generally 24 hours In general, the time lag of laminar flow recharge to mine is more than 2 days.

Introduction

The main coal producing areas in Guizhou are all located in the karst landform development area, and the underground water inflow of coal mines in this area is affected by the atmospheric precipitation to varying degrees^[1-6]. Atmospheric precipitation causes some mining faces, mining areas or mines to be flooded every year^[1], which has an impact on the safety production of coal mines. Through the prediction of mine water inflow, some researchers found that the mine water inflow is significantly affected by the atmospheric precipitation^[2-3]. On the basis of statistics of mine water inflow and atmospheric precipitation data, through the comparison of mine water inflow and relevant factor curves, Jiang Kaisheng and LV Bo studied the law of mine water inflow in Zhongling coal mine of Nayong County^[4], and believed that mine water inflow is closely related to atmospheric precipitation, mine water inflow in rainy season is significantly higher than that in dry season, and the trend lag of mine water inflow increase is related to the start time of atmospheric precipitation Department. The above research results^[2-4] have a time span of up to 10 years, mainly focusing on the impact of atmospheric precipitation on mine water inflow. Zhang Dehui thinks that the atmospheric precipitation can supply the mine through the karst channel by studying the hole inspection data. Shi Xianzhi and others found that the lower limit of karst development can reach 412.82m when they studied the occurrence characteristics of the karst groundwater in the coal measure strata roof, and the limestone layer in the Coal Measure Strata Roof can become the supply channel of the atmospheric precipitation. Both of them and other

scholars think that the fault can become a large one Channel of gas and water supply mine^[1,5-6]. In this paper, through the study of the different coal mine atmospheric precipitation supply channels in the main coal mining area of Guizhou Province, the various channels of the atmospheric precipitation supply to the mine water are demonstrated, and the characteristics of the water channel are studied, at the same time, the characteristics of the atmospheric precipitation supply are analyzed.

1 Karst Landform And Characteristics Of Coal Seam Occurrence Area

Karst landform is formed by the dissolution of water, which accounts for 10% of the earth's surface. It is a very common landform. Karst landform is widely distributed in China, mainly in the carbonate exposed areas in the west of China; the national karst landform area is $0.91 \times 10^6 \sim 1.30 \times 10^6 \text{km}^2$ (including Guizhou $0.1091 \times 10^6 \text{km}^2$)^[7], among which Guangxi, Guizhou and the east of Yunnan account for the largest area. Yunnan Guizhou Plateau in Southwest China is the most typical distribution area of karst landform. There are a lot of coal resources at the junction of Yunnan, Guizhou and Guangxi in Yunnan Guizhou Plateau, which is one of China's hundred million ton coal production bases. The main coal producing areas in Guizhou are distributed in Zunyi City, Bijie City, Liupanshui City, Qianxinan Prefecture and Guiyang City^[11], mainly mining the coal seams of the Permian Longtan Formation between the Triassic Yelang formation (Feixianguan Formation) (T_1) and the Permian Maokou Formation, and each well field is located in the karst landform development area.

There are a large number of karst landforms in different development periods in Guizhou coal occurrence areas^[7-8]. The limestone strata exposed in the main coal producing areas range from the Triassic Yelang formation (Feixianguan Formation) (T_1) to the Permian Maokou Formation (P_{2m}). In karst landforms of different periods, weathering and karst crevices can cause deep burial of developed karst fissures and fissures, providing a good channel for the storage and infiltration of atmospheric precipitation^[5]. The main coal producing areas in Guizhou are distributed in Zunyi City, Bijie City, Liupanshui City, Southwest Guizhou and Guiyang City^[11] (see Figure 1). The coal seams of the Permian Longtan Formation between the Triassic Yelang formation (Feixianguan Formation) (T_1) and the Permian Maokou Formation are mainly mined. Each well field is located in the karst landform development area.

2 Channel Type Of Mine Water Supplied By Atmospheric Precipitation

2.1 Fissure passage

2.1.1 Weathering fissure

Before mining activities in coal mines, due to weathering, the buried depth of weathering zone of surface exposed rock is generally $10 \sim 30 \text{m}$ ^[12-14], and the development depth of local weathering fissures in some mining areas such as Datian coal mine in Panzhou is 65m. The weathering fissures contain water or phreatic water in the vadose zone, and even confined water in the low-lying areas of the mountains. Spring water will be exposed with seasonal changes. After the mining activity, the atmospheric

precipitation can supply the mine water through the weathering fracture. For example, the water inflow of the auxiliary shaft adit of Wufeng coal mine in Bijie area of Guizhou Province can reach 13m³/h in rainy season and only 3m³/h in dry season. Once the weathering zone directly or indirectly communicates with the water conducting fracture zone, the atmospheric precipitation can supply to the mine.

2.1.2 Mining fissures

According to the intensity of mining activities and the thickness of coal seam, the height of water conducting fracture zone after coal mining is also different^[15]. When the development height of the guiding zone reaches the surface, the weathered fracture zone or the aquifer connected with the surface, the atmospheric precipitation may supply the mine through the mining fracture. Coal mining will damage the surface and produce a large number of surface fractures (see Figure 2), which is conducive to the collection and infiltration of atmospheric precipitation. Due to the large number of coal seam outcrops in Guizhou, most of the coal mines adopt inclined shaft development. The first mining area is mostly near the shallow outcrop. In the early stage of mining, the water diversion fracture zone is affected by the atmospheric precipitation supply. For example, the nearest distance between the 10501 working face of Jiaxing coal mine in Nayong County and the surface is 95m, the maximum water inflow during the rainy season after mining reaches 51m³/h, and the water inflow during the dry season drops to 3m³/h, and then The period was stable at 2m³/h. No.6 Coal Seam of Shengan coal mine in Jinsha County is 162m away from the nearest surface. The maximum water inflow is 69m³/h in rainy season and 5m³/h in dry season.

2.2 Water conducting fault

In Guizhou karst area, the fault structure is developed, and the exposed surface faults account for a large proportion of the exploration exposed faults^[12]. According to the exploration data of the main coal producing areas such as Zunyi City, Bijie City, Liupanshui City, Qianxinan Prefecture and Guiyang City, the proportion of the large-scale faults exposed by the exploration of the coal producing areas is 84.5%, and the proportion of various faults exposed is 69.7%. Due to the later weathering and the filling of Quaternary soil, most faults do not have the function of water conduction without the influence of mining damage. Part of the faults are activated due to the later mining activities, forming a water diversion channel, so that the atmospheric precipitation can be filled into the working face or roadway through the karst aquifer, the water diversion fracture zone in the working face, the surrounding rock fracture and so on^[1]. Some faults close to the surface can directly supply the atmospheric precipitation to the working face after the roadway is exposed or the working face is mined. For example, during the rainy season, the 10403 comprehensive mining face of Shiqiao coal mine in Qianxi county is located at the footwall of a reverse fault with a drop of more than 30 m. after the working face is pushed forward 23 m, the maximum water output of the working face is 522 m³/h; the water source is the atmospheric precipitation collected in a low-lying place 2km away from the working face. The atmospheric precipitation takes the reverse fault as the channel and collapses into the working face, resulting in the occurrence of flooding

accidents. After the rainy season, the water inflow of the working face rapidly drops below $15\text{m}^3/\text{h}$, and the water inflow of the goaf after the end of mining is $3\text{m}^3/\text{h}$.

2.3 Water guide collapse column

In Guizhou area, the karst landform is the main one, most of the well fields in the area are exposed in a large area, with peak cluster depression landform developed, and internal valleys, depressions, sinkholes and funnels developed. For example, Longhua coal mine in Qianxi County and Linhua coal mine in Jinsha County have developed many karst landforms such as collapse pits. Falling water tunnel and underground karst pipeline are well developed in depression, which are good supply channels for atmospheric precipitation. Longtan Formation, the main coal bearing formation in Guizhou Province, does not have the conditions for the development of large-scale karst caves, collapse columns, collapse pits and other extremely thick limestone. The main coal bearing strata are developed with thick limestone strata, but the karst development is limited to the top of Longtan Formation. Therefore, once the coal seam water diversion fracture zone is connected with the overlying karst water diversion channel, the atmospheric precipitation can supply the mine. In the east of Bijie and Anshun, because of the limestone development of Maokou Formation at the bottom of the main coal bearing strata, when the collapse column developed in Maokou Formation is connected with the karst channel above the coal measure strata, after the mining of the working face, the gangue in the collapse column will fall behind, and the collapse column will form a good water conducting channel, and the atmospheric precipitation can be supplied to the mine through the collapse column. For example, the 11603 working face of Longhua coal mine in Qianxi County reveals that the two collapse columns are developed to the strata above the coal measure strata, and the roof collapse columns of the working face are dripping during the mining period. Another example is the 1908 working face of Qianjin coal mine in Qianxi County. During the rainy season, a subsided column (the long axis of the subsided column is 22.4m long, and the short axis is 15.5m long) is exposed. It causes the atmospheric precipitation to infiltrate the underground through the channel, causing water inrush at the working face, and the maximum water volume reaches $247\text{m}^3/\text{h}$. After the ground treatment, the water inrush of the working face decreases gradually after the working face passes through the collapse column, and then the water inrush of the goaf is maintained at about $4\text{m}^3/\text{h}$.

2.4 Karst channel

In Bijie City, Zunyi City, Guiyang city and the eastern part of Qianxinan Prefecture, Guizhou Province, a stable limestone of Changxing formation is developed above the Longtan Formation of the main coal mining strata in the karst area. The thickness of the limestone is 32.5-48.6m, the average thickness is 39.5m, and the average distance to the nearest mining area is 27.4m. The aquifer is one of the main direct or indirect supply aquifers of the mine. In some mines, the limestone karst fissures of Changxing formation are developed, and the atmospheric precipitation can be transported to the mining face through the karst development area of the limestone outcrop wind oxidation zone of Changxing Formation, forming a karst supply channel^[5,16]. The No.5 coal seam mined by Jiuyuan coal mine in Jinsha County is 106-251m away from the surface and 37.4m away from the limestone of Changxing

formation. The limestone outcrop of Changxing formation is supplied by atmospheric precipitation. The maximum water inflow in the goaf is $85\text{m}^3/\text{h}$ in rainy season and $7\text{m}^3/\text{h}$ in dry season.

3 Characteristics Of Supply Channels Of Atmospheric Precipitation

3.1 Surface infiltration

After the completion of coal mining in the mine, a large area of surface subsidence results in the development of ground fracture zones, with fracture width ranging from 0 to 3m (see Figure 1), and depth ranging from tens of meters to tens of meters, forming a good atmospheric precipitation infiltration channel. A large area of surface fracture development forms a good condition for the atmospheric water surface infiltration underground. Through the atmospheric precipitation after large-scale infiltration, it gradually collects and seeps into the working face, and flows into the mine in the working face or goaf (as shown in Figure 3), resulting in water dripping from the roof of the working face, water sprinkling, water inrush from the goaf, and the increase of water inrush from the mine. Under the condition of surface infiltration, because the surface soil layer and aquifer need a certain period of water saturation, the underground water inflow will increase obviously after several days of continuous precipitation. In karst mountain areas of Guizhou Province, there is a phenomenon that the surface infiltration of atmospheric precipitation causes the increase of mine water inflow, and even causes water damage accidents in flooded working face and flooded mining area^[1]. For example, the distance between 2608 working face and the ground is less than 100m in Dafang County Wufeng coal mine, and the ground in gob area of working face is rapidly supplied by surface atmospheric precipitation after mining (see Figure 4), resulting in The working face and its lower horizontal mining area are flooded,.

In Guizhou area, the supply mode of atmospheric precipitation to coal mines is mainly surface infiltration. Because of the large infiltration area of atmospheric precipitation and the large number of small fissures on the surface, it is difficult to control the water diversion channel on the surface. Generally, the measures of increasing drainage capacity to forcibly discharge the mine water and filling the fissures on the surface are adopted to prevent and control the supply of atmospheric precipitation to the underground.

3.2 Pipeline flow characteristics

The supply channel of atmospheric precipitation with the characteristics of pipeline flow channel has the characteristics of relatively short underground time, concentrated water inflow and large water inflow. This kind of supply channel is composed of collapse column, karst channel and fault fracture zone^[1,5,16]. After the collapse column is exposed in the 1908 working face of Qianjin coal mine in Qianxi County, the atmospheric precipitation can flow into the underground within 24 hours. With the increase and decrease of rainfall, the underground water inflow changes significantly, as shown in Figure 5. The water from the 10403 working face of Shiqiao coal mine can reach the underground working face 2 hours after the ground rainfall.

The supply channel of atmospheric precipitation with the characteristics of pipeline flow generally has a centralized precipitation collection area on the ground. According to the change characteristics of the water inflow in the collection area, the mine can find the location of atmospheric precipitation supply and manage the collection location. Generally, the treatment effect is good.

3.3 Layered Supply

The conditions for the supply of atmospheric precipitation to the mine through a specific aquifer are relatively strict. The aquifer should not only have a surface outcrop or close to the surface and be easy to accept the supply of atmospheric precipitation, but also have a water diversion channel. Moreover, the aquifer can directly or indirectly supply to the mine. A layer of limestone of Changxing formation with a thickness of 32.5–48.7m and an average of 39.5m is generally developed above the coal measure strata of Longtan Formation in Guizhou Province. The distance between the limestone and the top minable coal seam of Longtan Formation is 1–67.4m and an average of 27.5m, which is generally within the water conducting fracture zone of coal seam and is the indirect or direct water filling aquifer of coal mine^[5]. The aquifer in each mine field is mostly exposed in strips. The strata exposed by drilling are mostly developed with oblique fractures and vertical fractures. Most of the fracture surfaces are filled with vein calcite. The width of the fracture surface is different. Occasionally, corrosion cracks or solution holes are found. Water rust is more common in corrosion cracks. The dissolution holes are mostly filled with calcite crystals. The core of water leakage holes is relatively broken, which can be used as atmospheric precipitation supplement for mine mining. For example, Jiuyuan coal mine in Jinsha County (see Figure 6). Occasionally, there are dissolution fractures or dissolution holes, and most of the dissolution fractures are filled with water rust. Most of the dissolution holes are filled with calcite crystals, and the core of the leakage hole is relatively broken. According to the drilling water leakage of the aquifer revealed during the exploration of different well fields, the drilling water leakage rate is 13.3–69.4%, with an average of 29.0%. The thickness of No.4 coal seam in Xintian coal mine of Qianxi county is 2.8m, 27m away from the overlying Changxing Formation limestone. The limestone of Changxing formation is within the scope of water flowing fracture zone of No.4 coal seam, which is the indirect water filling aquifer of the mine. During the mining period of 1402 working face, the water gushing closely follows the working face and has obvious correlation with atmospheric precipitation (as shown in Fig. 7 and Fig. 8), the regression equation between them is,

$$y = -0.00003x^6 + 0.0038x^5 - 0.1578x^4 + 3.167x^3 - 30.889x^2 + 130.74x - 111.8 \quad [1]$$

The correlation coefficient R was 0.88. The water quality test data showed that the water quality type of the working face was HCO₃-Ca water, and the content was low, the water gushing from the working face was atmospheric precipitation. For the mine with layered infiltration conditions, the recharge area of atmospheric precipitation near the rock outcrop is large, so it is difficult to prevent and control the infiltration of atmospheric precipitation on the ground.

4 Characteristics Of Mine Water Supplied By Atmospheric Precipitation

4.1 Seasonality

The change of mine water inflow in Guizhou with seasons is obvious, as shown in Figure 9. The main coal producing areas in Guizhou are located in the karst development area, both in rainy season and dry season. During the rainy season, the atmospheric precipitation supply to the mine is obvious, and the mine water inflow is obviously increased; during the dry season, the atmospheric precipitation is relatively small, and the mine water inflow is obviously reduced. According to the statistical data of different mines, the water inflow in rainy season is generally 1.2-12 times of that in dry season, with an average of 1.9 times. This feature is obviously different from the North China type strata mining area with thick Quaternary unconsolidated sediments.

4.2 Hysteresis

The infiltration amount of atmospheric precipitation is affected by topography, overburden, thickness of overburden, rainfall continuity, rainfall, development degree of infiltration (flow) fissures, fissure water content and water content of aeration zone^[17-18]. Due to the large amount of evaporation in Guizhou, the water stored in the weathering fissures of the topsoil and shallow strata is easy to evaporate. After the continuous supply of atmospheric precipitation, the surface fissures can gradually infiltrate into the coal bearing strata and supplement the mine after being saturated. The infiltration of atmospheric precipitation is obviously affected by the terrain. In Guizhou, the terrain fluctuates greatly. If the duration of moderate to heavy rain is short, the surface runoff is rapid, The infiltration water quantity is less, generally has little influence on the underground water inflow; the continuous rainfall is the reuse factor that affects the change of the mine water inflow.

Generally, the shallower the coal seam is from the surface, the more obvious the influence of the atmospheric precipitation is. The farther the coal seam is from the surface, the more obvious the lag is. In the mines obviously supplied by the atmospheric precipitation, the lag time of the surface infiltration supply mine is generally 1-4 days, such as Jiuyuan coal mine, Sheng'an coal mine in Jinsha County and Wufeng coal mine in Dafang County, etc.; the lag time of the atmospheric precipitation supply mine water is longer for some coal mines which are deeper from the surface, such as Nuodong coal mine in Qianxinan Prefecture, where the coal seams are nearly horizontally stored, with an average distance of 304m from the surface The mine water inflow began to increase (decrease) and lagged behind the rainy season (dry season) for 3-4 months. The lag time of pipeline supply is generally within 24 hours, such as Qianjin coal mine and Shiqiao coal mine in Qianxi County. The time to recharge the mine with stratified flow is generally 2 days later.

4.3 Self healing

In Guizhou Karst mining area, the surface is mostly covered by loess layers with different thickness of quaternary system. Due to the erosion of continuous rainfall and the disturbance of mining to the surface strata, a large number of rainwater carries loess particles into the rock fissures and flows into the mine stope, resulting in a lot of mine goafs and mine water inrush in the roadway showing an unearthed yellow color. During the rainy season, the Loess particles flowing into the pores of the rock stratum will gradually cause pore blockage and water inflow of the mine with the decrease of rainfall or precipitation in the pores of the rock stratum during the dry season, and even some goafs will not flow out after 3~5 years. In the first year after mining in the 1501 working face of Jiaxing coal mine in Nayong County, the water inflow of the working face in the rainy season reached 53m³/h. in the second year, the water inflow was significantly reduced to 10m³/h during the rainy season, and then it was stable at 2m³/h during the rainy season. In the 1614 working face of Wufeng coal mine in Dafang County, the water inflow of the goaf (145m³/h in the initial rainy season) and the final goaf decreased to less than 10m³ / h in the rainy season.

4.4 Buried depth characteristics

The coal seam burial depth and lithologic combination characteristics have obvious influence on the infiltration supply of atmospheric precipitation. The amount of water supplied by atmospheric precipitation is not the same in the mining face with the same depth. When some coal mines have limestone and other hard strata as the key layer in the coal seam roof, the combination characteristics of soft and hard rocks lead to the fact that the atmospheric precipitation has no influence on the water filling in the goaf of some coal mines when the mining distance is less than 150m from the surface. For example, the working face of No.15 coal seam in Xing'an Coal Mine, Jinsha County is about 100m away from the surface, and the upper stratum is composed of limestone, sandstone, sandy mudstone, mudstone and coal seam. The water inflow in the goaf of the working face is generally under 2m³/h, and the impact of atmospheric precipitation on the water inflow is not obvious. In Gaoshan coal mine and Jiaozishan coal mine of Anshun, the water inflow of the shallow working face is obviously affected by the atmospheric precipitation, and the deep influence is gradually reduced. The coal seam mined by Dahebian coal mine in Liupanshui is 314~677m away from the ground. In the shallow level, the mine water inflow in rainy season is 2.2 times of that in dry season, 1.3 times in deep level and 1.7 times of the mine statistical data over the years.

5 Conclusion

- (1) In the karst developed area of Guizhou, the atmospheric precipitation is the main supply source of mine water in the process of coal mining.
- (2) The main channels of precipitation supply mine are surface weathering fracture, mining fracture, fault, water diversion collapse column, limestone karst fracture, etc.

(3) The surface infiltration is mainly through mining fractures, and the infiltration range is large. With the characteristics of pipeline flow, the atmospheric precipitation supplies rapidly, and the mine water inflow increases and decreases obviously with the rainfall. There is an obvious correlation between bedded infiltration and rainfall, the correlation coefficient r is 0.88.

(4) The mine water supplied by atmospheric precipitation has seasonal characteristics. The mine water inflow in rainy season is 1.2–12 times of that in dry season, with an average of 1.9 times. The supply channel is gradually blocked by the filling of loess particles on the surface, which has the characteristics of self-healing. The mine water replenished by atmospheric precipitation is affected by the buried depth of mining coal seam and the lithology combination of the upper ground layer. The deeper the mining coal seam is buried, the smaller the impact of atmospheric precipitation on the mine water inflow, and the longer the lag time.

(5) During the rainy season in Guizhou Province, accidents occur in working face, mining area or mine every year. It is necessary to study the mechanism of atmospheric precipitation infiltration in mines threatened by atmospheric precipitation.

Declarations

Compliance with Ethical Standards

Conflict of interest

The authors declare that we have no conflict of interest.

Acknowledgments

This study is funded by “the National Natural Science Foundation of China (Grant No. 41807233)”, and the Priority Academic Program Development of Jiangsu Higher Education Institutions.

References

- [1] Zhang Dehui. 2011. Water control technology of inclined shaft grouting under complex geological conditions. *Zhongzhou Coal*, 2: 37-39.
- [2] Wang Haijun. 2019. Prediction of water inflow of Huoshaopu coal mine in Panxian basin, Guizhou [J]. *Coal Geology of China*, 7: 44-51.
- [3] Li Lan. 2015. Prediction of mine water inflow in Qinglong Coal Mine, Qianxi, Guizhou. *Coal Technology*, 9: 228-230.
- [4] Jiang Kaisheng, Lu Bo. 2009. Gushing Law of Mine Water and Prevention and Cure Measures of Mine Water. *Coal Technology*, 2: 86-88.

- [5] Shi Xianzhi, Qian Zibo, Li Tongwen, et al. 2017. Study on the occurrence characteristics of karst groundwater in coal measures Roof . Coal Engineering, 1: 63-66
- [6] Xu Jian. 2018. Hydrogeological characteristics of faults in Hongcai coal mine investigation area, Shuicheng County, Guizhou Province and its impact on mine water filling. Resource Information and Engineering, 5: 72-73
- [7] Deng Xiaohong, Bi Kun. 2001. Distribution area and characteristics of karst and non karst landforms in Guizhou. Journal of Guizhou Education College, 4: 43-46
- [8] Lin Junqing. 2004. Analysis on the distribution area and distribution characteristics of karst landform in Guizhou Province. Guizhou Geology, 3: 177191-193
- [9] Phillips J D. 2017. Landform transitions in a fluvio karst landscape. Zeitschrift Für Geomorphologie, 14:109-122
- [10] Shufen Huang, Anjun Lan, Jiaqiong Ma, et al. 2014. Information extraction of typical karst landform based on RS. Paper SPIE 9158, Published in SPIE Proceedings Vol. 9158, 14 May, 2014.
- [11] Tang Xiangui, Zhang Wei, Kong Weimin. 2013. Present situation and potential evaluation of coal resource in Guizhou Province. China Coal, 10: 27-30
- [12] Feng zewei, Zhou Zhufeng. 2017. Exploration of safe driving technology for shallow coal seam passing through deep weathered zone. Inner Mongolia Coal Economy, 19: 121-123
- [13] Guo Yonghai, Wang Hailong, Dong Jiannan, et al. 2012. Distribution and enrichment regularity of weathering fracture water in Beishan area. World nuclear Geosciences, 4: 222-226
- [14] Han Wei. 2017. Treatment measures for collapse in weathered zone of rock excavation by vertical shaft method. Water Conservancy and Hydropower Construction, 2: 26-29.
- [15] Guo Wenbing, Lou Gaozhong. 2019. Definition and distinguishing method of critical mining degree of overburden failure. Journal of China Coal Society, 3:755-766.
- [16] Han Baoping, Li Min, Gan Zhijie. 1996. Influence of karst pipeline flow on coal mining in Nantong Mining Area. Ground Water, 4:175-176
- [17] Yao Guanghua, Chen Zhenghua, Xiang Xiqiong. 2012. Study on the characteristics of aquifer damage and surface water infiltration under mining conditions in Karst Mountain Area. Hydrogeological Engineering Geology, 5: 16-20, 25
- [18] Wang Shufang. 2014. Research progress of precipitation infiltration supplement in karst aquifer system. Journal of China Hydrology, 6: 1-8