

# Investigation Method and Utilization Mode of Geothermal Resources in Abandoned Mines in Huainan and Huaibei

Liwen Zhang, Haifeng Lu\*

School of Earth and Environment, Anhui University of Science & Technology, Huainan, China  
Email: zlw061023@163.com, \*luhaifeng7571@126.com

**How to cite this paper:** Zhang, L.W. and Lu, H.F. (2022) Investigation Method and Utilization Mode of Geothermal Resources in Abandoned Mines in Huainan and Huaibei. *International Journal of Geosciences*, 13, 415-425.  
<https://doi.org/10.4236/ijg.2022.136022>

**Received:** May 18, 2022

**Accepted:** June 17, 2022

**Published:** June 20, 2022

Copyright © 2022 by author(s) and Scientific Research Publishing Inc.  
This work is licensed under the Creative Commons Attribution International License (CC BY 4.0).  
<http://creativecommons.org/licenses/by/4.0/>



Open Access

## Abstract

With the depletion of coal resources due to excessive exploitation and the increasing adjustment of the national energy structure, in response to the call of national policy, some mines are forced to close, and the reuse of abandoned mine resources plays an important role in the sustainable development of mining industry. This paper analyzes the general situation of abandoned mines in Huainan and Huaibei, elaborates the research methods of geothermal temperature and calculation methods of geothermal reserves in abandoned mines, analyzes and studies the utilization prospect of geothermal resources in abandoned mines in Huainan and Huaibei, and draws the following conclusions: the temperature of geothermal resources in abandoned mines in Huainan and Huaibei is 25°C - 60°C, which belongs to the moderate-hot water and warm water resources in low-temperature geothermal resources, and can be used for geothermal heating, industrial geothermal and entertainment industries. Based on the previous experience in geothermal resource utilization mode, this paper provides theoretical and technical support for the demonstration project of resource utilization and development of abandoned mines in the Huainan and Huaibei mining areas.

## Keywords

Abandoned Mines, Geothermal Resources, Geothermal Gradient

## 1. Introduction

Coal resource is indispensable primary energy in China and plays an important role. With the development and utilization of coal, there are more and more greenhouse gas emissions and various environmental problems. China's government has taken the method of coal production capacity to eliminate a num-

ber of low-capacity and resource-exhausted mines, but for these abandoned mines, there is still a variety of rich potential energy. Among them, geothermal resources can be better utilized than other residual gas or space resources. It belongs to renewable clean energy, and the utilization cost is also low, which meets the requirements of sustainable development advocated by China [1] [2] [3] [4]. Domestic and foreign scholars have carried out many studies on the utilization of geothermal resources in abandoned mines [5] [6]. For example, Zhang Yuan and other scholars take Qishan Mine as the research object, and put forward the comprehensive utilization mode of flood storage energy storage and heat extraction in abandoned mines, the water diversion, water storage, water extraction and heat extraction of abandoned mines are studied, and then the potential of flood storage energy storage is analyzed to promote the utilization of underground space in abandoned mines [7]. Guo Pingye and other scholars take Wangping village mine in western Beijing as the research object, analyze and discuss the energy storage utilization of underground space in abandoned mines, and put forward the reverse seasonal cycle energy storage process system of abandoned mines, so as to realize the effect of reverse seasonal cycle energy storage and improve the utilization efficiency of renewable energy [8].

There are few studies on the utilization of abandoned mines in the Huainan and Huaibei areas. Therefore, this paper analyzes the present situation of the development and utilization of geothermal resources in abandoned mines in Huainan and Huaibei, makes a comprehensive survey of geothermal resources in abandoned mines in Huainan and Huaibei, and puts forward some suggestions on the development and utilization of geothermal resources by remote sensing technology and the development and utilization mode of geothermal resources in abandoned mines, which is of great significance to promote the development of renewable energy in China. The purpose of this study is to strengthen the research on the development and utilization of abandoned mine resources, realize the national “dual carbon” goal, and provide theoretical and technical support for the reuse of abandoned mines in Huainan and Huaibei [9].

## **2. Overview of the Study Area**

### **2.1. Natural Geographical Conditions**

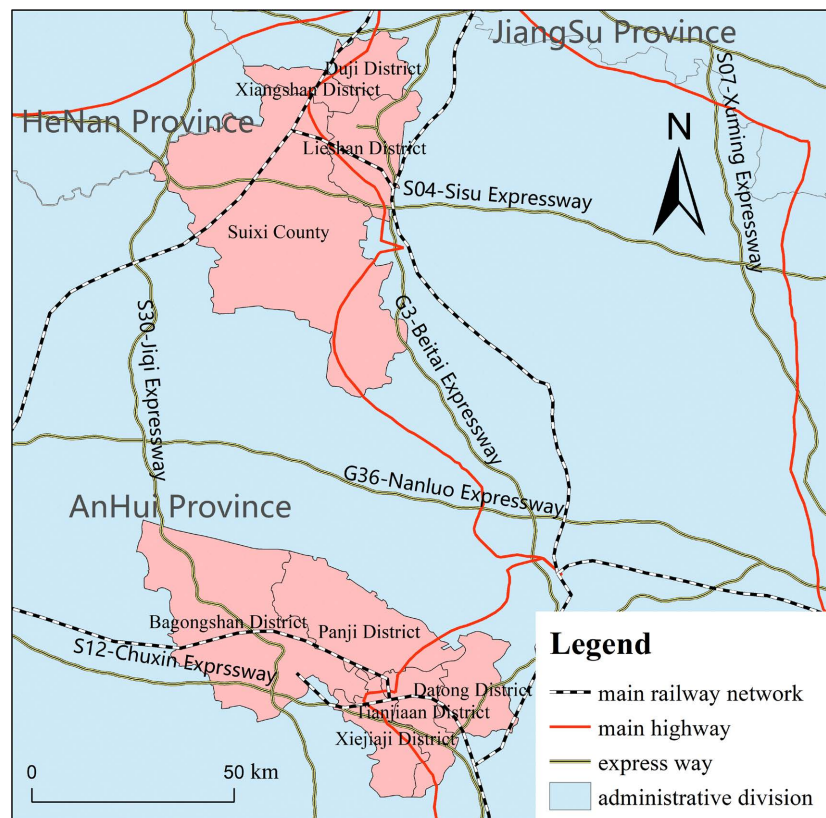
Lianghuai region is located in the most developed east China, with obvious geographical advantages and convenient transportation. In terms of road transportation, G35, G3, G36, G30 and S04 expressways and provincial roads run through the whole area. In terms of air traffic, it has Fuyang and Bengbu airports.

The area is located in the north of the Huaihe River, the south of the Yellow River flood, caused by the Yellow River flood and the Huaihe River alluvial, so the natural resources are quite rich. Water resources are mainly composed of natural rainwater, river transit water and groundwater. The Lianghuai regions are connected to the fan-shaped terrain of the Yellow River crevasse, and the

south is separated by the Huaihe River and the Jianghuai hilly area. The terrain in the region is gentle, most of which belong to the plain area, and only the limestone residual hills are scattered in the northeast. In terms of the terrain, northern Anhui is high in the northwest and low in the southeast, and there is a skew trend from northwest to southeast. Due to the influence of the winding cutting changes of Huaihe River and its tributaries and the successive southward flooding of the Yellow River in the modern times, the internal alluvial deposits continue to accumulate and form the interphase distribution of hills, slopes and depressions in the plain. The topography of the residential area is ups and downs, with the geomorphological characteristics of “large flat and small uneven”. An overview of the study area is shown in **Figure 1**.

## 2.2. Regional Strata

In terms of rock strata zoning, the Lianghuai region belongs to the Xuhuai strata structural zoning of the Jin-Ji-Lu-Yu stratigraphic area on the southeast edge of the North China stratigraphic region. It is bounded by the Tanlu fault zone and borders with the South China stratigraphic region in the east. The north and west are adjacent to Henan, Jiangsu and Shandong provinces, and the south is to the Yingshang-Dingyuan fault layer. The strata in each period in this area are relatively developed except the strata missing from late Middle Ordovician to early Carboniferous.



**Figure 1.** Overview of Huainan and Huaibei.

## 2.3. Overview of Abandoned Mines

### 1) Abandoned mine in Huainan

There are 13 abandoned mines in Huainan, among which Panji No. 1 coal mine is a closed well without pit closure, Jiulonggang mine, Xiejiaji mine, Xinzhuangzi mine and Balitang mine field are closed mines.

### 2) Abandoned mine in Huaibei

There are 24 abandoned mines in Huaibei, among which Wolonghu coal mine is a closed well without pit closure, and other coal mines are closed mines.

## 3. Ground Temperature Investigation and Research

### 3.1. Geothermal Gradient

Geothermal gradient refers to the temperature increased by the ground temperature for every 100 m increase in depth, the unit is °C/hm, which is expressed in G. Generally close to the normal geothermal gradient of 1.6 - 3.0°C/hm [10].

1) *Geothermal gradient in the whole well section (i.e. from the constant temperature zone to the bottom of the hole):*

$$G_w = \frac{T - T_0}{H - H_0} \times 100 \quad (1)$$

$G_w$  is the average geothermal gradient of the whole drilling section, in unit of °C/hm;  $T$  is the measured temperature;  $T_0$  is the temperature of constant temperature zone;  $H$  is the depth of temperature measurement point;  $H_0$  is the depth of thermostatic zone.

2) *Geothermal gradient of bedrock surface:*

$$G_b = \frac{T - T_1}{H - H_0} \times 100 \quad (2)$$

$G_b$  is the average geothermal gradient below the bedrock surface, in unit of °C/hm;  $T$  is the measured temperature;  $T_1$  is bedrock surface temperature;  $H$  is the depth of temperature measurement point;  $H_0$  is the depth of thermostatic zone.

Geothermal gradient, as a scale to judge whether geothermal temperature is normal or not, is one of the important parameters to reflect geothermal status in a region, as shown in **Table 1**.

Based on the obtained geothermal gradient value and ground temperature, the horizontal distribution and vertical distribution of ground temperature are studied. The horizontal geothermal gradient distribution map and vertical geothermal temperature distribution map are made by using the Suffer software, so as to interpret the ground temperature distribution characteristics of abandoned mines in Lianghuai clearly and intuitively.

**Table 1.** Division of positive anomaly of mine ground temperature.

Geothermal gradient (°C/hm)	<1.6°C/hm	1.6 - 3.0°C/hm	>3.0°C/hm
State	negative anomaly	normal	positive anomaly

### 3.2. Rock Thermal Physical Parameters Test

The thermal physical parameters of rock are an important index to study the thermal state of the deep earth and the heat exchange between air and surrounding rock in various engineering rock masses. Therefore, it is necessary to test the thermal physical parameters of rock samples collected from abandoned mines in Lianghuai [11] [12] [13].

#### 1) Thermal conductivity

Thermal conductivity can reflect the heat conduction capacity of a substance. It refers to the ratio coefficient of heat and temperature gradient through a unit area in a unit time. Generally speaking, the thermal conductivity of different rocks varies little; on the contrary, it varies greatly among the same rocks. In terms of thermal conductivity, dry sand, dry clay and soil in the loose layer are the lowest.

$$K = \frac{QD}{F(T_2 - T_1)} \quad (3)$$

$Q$  is the heat;  $D$  is the thickness of the rock sample;  $T_2 - T_1$  is the temperature difference between the two walls of the rock sample;  $F$  is the cross-sectional area.

Calculation formula of average thermal conductivity:

$$\bar{K} = \frac{\sum_{i=1}^n K_i d_i}{D} \quad (4)$$

$d_i$  is the thickness of the corresponding rock layer;  $K_i$  is the thermal conductivity of the corresponding rock layer;  $D$  is the total thickness of the section rock layer.

#### 2) Specific heat capacity

The specific heat capacity of rock refers to the heat absorbed or released by rock per unit weight when the temperature rises or decreases by 1 K. The calculation formula is:

$$c = \frac{Q}{m\Delta T} \quad (5)$$

$c$  is the specific heat capacity of rock, in unit of J/g·°C;  $Q$  is the heat required to increase or decrease the temperature value  $\Delta T$  by heating or cooling the rock  $m$ , in unit of J;  $m$  is the weight of the rock, in unit of g;  $\Delta T$  is the temperature value increased or decreased, in unit of °C.

#### 3) Density

In the density test of rock, water purification weighing method can be used to test: specifically, based on Archimedes principle, with paraffin seal to weigh, the calculation formula is:

$$\rho_0 = \frac{m_0}{m_1 - m_2} \quad (6)$$

$\rho_0$  is the density of paraffin;  $m_0$  is the mass of paraffin in air, in unit of g;  $m_1$  and  $m_2$  are the mass of wax-impregnated rock sample and hanging wire in air

and water, in unit of g respectively.

$$\lambda = \left( \frac{1}{\rho_0} - 1 \right) \quad (7)$$

$\lambda = \left( \frac{1}{\rho_0} - 1 \right)$  is used as a constant in the following equation.

$$\rho = \frac{m}{(m - m_3) - \lambda(m_4 - m)} \quad (8)$$

$\rho$  is the density of rock, in unit of  $\text{g/cm}^3$ ;  $m$  is the weight of the rock in the air, in unit of g;  $m_3$  and  $m_4$  are the mass of rock wax in air and water respectively, in unit of g.

#### 4) Heat generation rate of rock

Rock heat generation rate is the heat generated by the decay of radioactive elements per unit volume of rock in unit time. The heat generation rate of rock plays an important role in controlling the distribution of geothermal field. The determination of heat generation rate parameters of rock can provide important data basis for the calculation of geothermal reserves in coalfield and mining area. The determination of rock heat generation rate is mainly determined by the radioactive factors uranium (U), thorium (Th) and potassium (K) in the rock. The calculation formula is:

$$Q_A = 0.315(0.73C_u + 0.2C_{Th} + 0.27C_k) \quad (9)$$

$Q_A$  is the heat generation rate, in unit of  $\mu\text{W/m}^3$ ;  $C_u$ ,  $C_{Th}$  and  $C_k$  are K and content in rock U and Th respectively, and the unit of U is  $10^{-6}$  g/g (ppm). The unit of Th is  $10^{-6}$  g/g (ppm); the unit of K is %.

### 3.3. Distribution of Terrestrial Heat Flow

The earth heat flow is the heat flow, which generally refers to the heat transmitted from the interior of the earth to the surface. It is a phenomenon of heat transfer from the interior of the earth to the surface. The earth heat flow is an extremely important parameter for the prediction of deep temperature, which provides an important basis for the formation mechanism and evolution of geological structures and the evaluation of coal resources in mines.

$$q = K \frac{dT}{dZ} \quad (10)$$

$q$  is the heat flow value, the unit is  $\text{mW/m}^2$ ,  $K$  is the thermal conductivity, the unit is  $\text{W/(m}\cdot\text{k)}$ ,  $\frac{dT}{dZ}$  is the geothermal gradient, and the unit is  $^{\circ}\text{C/m}$ . The early heat flow value is represented by  $\mu\text{cal}/(\text{cm}^2\cdot\text{s})$ , abbreviated as HFU (Heat flow unit), and the relationship between the two is  $1\text{HFU} = 1 \mu\text{cal}/(\text{cm}^2\cdot\text{s}) = 41.868 \text{mW/m}^2$ .

### 3.4. Surface Temperature Inversion

In the investigation of geothermal resources, using remote sensing technology to

determine the location of geothermal disasters is an extremely favorable method. Thermal infrared remote sensing technology is widely used in geological structure, geothermal anomaly detection and its manifestations due to its fast, efficient and wide monitoring range. According to the band characteristics of thermal infrared remote sensing data obtained by the sensor, the surface temperature inversion is carried out based on the corresponding algorithm, and the ground distribution image is analyzed by ArcGIS software to determine the geothermal anomaly area. Thermal infrared remote sensing technology can not only find geothermal marks, but also study thermal control structure information according to its distribution law, which plays an important role in geothermal disaster exploration [14].

## 4. Geothermal Reserves Survey and Geothermal Resources Development and Utilization Model Research

### 4.1. Calculation Model of Thermal Storage Method

Most geothermal energy reserves are calculated by thermal storage method. As for geothermal resources, thermal reservoirs are widely distributed in the Lianghuai area, which is a sedimentary basin type. The thermal storage method is mainly used to calculate the heat and geothermal water storage in the thermal reservoir, and the thermal energy calculation is mainly carried out from two aspects: total heat energy and recoverable heat energy [15].

The total heat energy calculation formula is:

$$Q_R = c \cdot A \cdot h \cdot \Delta T \quad (11)$$

$Q_R$  is the total heat energy buried in the underground thermal reservoir, in unit of kcal.  $c$  is the average specific heat capacity of water and rock, in unit of kcal/m<sup>3</sup>·°C;  $A$  is the area of the study area, and the unit is m<sup>2</sup>;  $h$  is the thickness of the thermal reservoir, in unit of m;  $\Delta T$  is the difference between the temperature of the thermal reservoir and the temperature of the thermostatic zone, in unit of °C.

$$c = \rho_w \cdot c_w \cdot \varphi + \rho_r \cdot c_r \cdot (1 - \varphi) \quad (12)$$

$c$  is the average specific heat capacity of water and rock, in unit of kcal/m<sup>3</sup>·°C;  $c_w$  and  $c_r$  are the specific heat capacities of water and rock, respectively, in unit of J/kg·°C;  $\rho_w$  and  $\rho_r$  are the densities of water and rock, respectively, in unit of kg/m<sup>3</sup>;  $\varphi$  is the porosity of thermal reservoir rock.

Recoverable heat energy reserves are calculated using recovery factor method. Recoverable thermal energy means that only part of the total thermal energy of thermal reservoir can be exploited as utilization. The ratio of mining heat energy to total heat energy is called recovery rate, and the calculation formula is:

$$Q_{wh} = Q_R \times r \quad (13)$$

$Q_{wh}$  is recoverable energy reserves, in unit of J;  $Q_R$  is the total thermal energy reserves of thermal reservoir, in unit of J;  $r$  is the recovery rate.

## 4.2. Geothermal Development and Utilization of Abandoned Mines in Lianghuai Area

In the code for *Geological exploration of geothermal resources*, the temperature of geothermal resources is classified, and the use of temperature is proposed. According to previous studies, it is concluded that the temperature of geothermal resources in lianghuai coal field is basically 25°C - 60°C, which belongs to moderate-hot water and warm water resources in low temperature geothermal resources. According to the corresponding table, warm water can be used for breeding, soil heating greenhouse, crop irrigation and so on, while moderate-hot water can be used for medical physiotherapy, bathing, greenhouse agriculture, agricultural irrigation and so on (**Table 2**).

### 1) *Geothermal heating*

Geothermal heating mainly has two aspects: geothermal heating and domestic water, at present, geothermal heating projects as the main purpose. Lianghuai coalfield can combine low temperature geothermal resources with high technology to realize geothermal heating and solve the energy waste and environmental pollution caused by coal burning. When the temperature cannot meet the requirements of direct heating, the heat pump technology and other secondary heating can be used to save coal resources and achieve the purpose of energy conservation and emission reduction.

### 2) *Industrial geothermal*

Geothermal energy has many uses in industry. It can be used for all forms of drying and distillation processes, for simple heating or cooling in processes, or for heating in various mining and material processing. The pH value of geothermal water in Lianghuai coal mine is generally higher than 8, belonging to weak neutral alkaline water, which is not eroded by acid and whose hardness is often more than 200 mg/l. Geothermal water in Lianghuai coal mine can be used as industrial boiler water after certain treatment.

### 3) *Entertainment industry*

Using medium temperature hot water for geothermal fish farming, hot spring

**Table 2.** Classification of geothermal resources temperature.

Temperature classification	Temperature/°C	Usage	
High temperature geothermal resources	≥150	power generation, drying, heating	
Medium temperature geothermal resources	90 - 150	power generation, drying, heating	
hot water	60 - 90	heating, physical therapy, bath, greenhouse	
Low temperature geothermal resource	moderate-hot water	40 - 60	physiotherapy, bath, heating, greenhouse, breeding
	warm water	25 - 40	bathing, greenhouse, breeding, agricultural irrigation



development, tourism vacation development and construction. Taking hot spring as an example, hot water can be used by 5 - 10 people per cubic meter, and its profit can reach 30 - 50 Yuan. In general, the utilization of geothermal resources can bring several times or even dozens of times of added value. On the one hand, the geothermal resources of abandoned mines are utilized, on the other hand, it also promotes the development of local civil economy, which not only solves the problem of resource waste, but also brings people new entertainment opportunities and tourism experience.

### 4.3. Application of Remote Sensing Technology in Geothermal Development

The remote sensing data and geological data are processed, and the investigation of geothermal resources is superimposed with traffic factors, development conditions, market economy and geological ecological environment carrying capacity by ArcGIS software using analytic hierarchy process, expert weight method and other evaluation methods. Finally, the suitable area for the development of geothermal resources in abandoned mines in Huainan and Huaibei areas is obtained. The prospect prediction of geothermal resources development planning is put forward, which provides scientific basis for the development and utilization of geothermal resources in Huainan and Huaibei areas, and delineates a more suitable geothermal development zone. The utilization rate of geothermal resources is maximized [16].

### 4.4. Examples of Geothermal Development and Utilization in Abandoned Mines

Due to resource and technical limitations, specific geothermal development and utilization modes of abandoned mines in Lianghuai are yet to be explored. Therefore, relevant researches are carried out by referring to the experiences of geothermal resource utilization modes proposed by other domestic scholars.

#### 1) *Low temperature heat energy utilization system*

Refer to the comprehensive utilization technology of low temperature heat energy in the coal mine of Wutongzhuang in Hebei, the effect is remarkable. The system can comprehensively recover low temperature heat energy such as mine drainage and coal mine return air. The comprehensive utilization system of low temperature heat source in coal mine realizes the step utilization of heat source and can replace the traditional boiler in winter and air conditioning in summer. This system not only reduces the energy consumption, but also realizes the value of multi-use in the actual situation, and solves the problems of daily life such as heating in winter, bathing hot water and cooling in summer [17] [18].

#### 2) *Open and closed loop hybrid geothermal utilization system*

The Asturias mine in Spain, which closed in 2018, used this open-closed-loop hybrid geothermal system to address environmental pollution and resource waste caused by mine closure. The main components of open and closed loop hybrid geothermal utilization system include tubular heat exchanger, heat pump,

mine and clean water loop. The advantage of this system lies in that the open-closed-loop hybrid system combines the uses of the open-loop and closed-loop systems. The open-loop system is used for the main network, and the closed-loop system is used for the supply of the measurement local pipe network, so as to realize artificial intelligence management at both ends of supply and demand and make energy exchange and storage more convenient [19].

## 5. Conclusions

It is of great significance to carry out the comprehensive investigation and utilization model of geothermal resources in abandoned mines in the Huainan and Huaibei areas for improving the safety level of coal mines in China, ensuring national energy security, sustainable and healthy economic development, reducing resource waste and improving the utilization efficiency of abandoned mine resources. The development and utilization of abandoned mine resources in China are difficult, and it has its own characteristics in various aspects such as technical level and industrial policy. Therefore, in the development and utilization of abandoned mine geothermal resources, it is necessary to establish its own development and utilization model based on its own reality and other successful practice results. Based on the long-term sustainable development strategy, it is necessary to combine typical demonstration with steady progress, and implement the principle of safety first and cost-benefit unification.

Future research on geothermal resources of abandoned mines should focus on the development of geothermal resources of abandoned mines in many aspects, promote the work on geothermal resources of abandoned mines, and strive to open up a new frontier for the research and application of geothermal utilization technology, so as to develop more convenient and efficient systems for the recovery and utilization of geothermal resources of abandoned mines. At the same time, it is necessary to improve the management agencies of relevant government departments, develop relevant laws and policies, realize the reuse of abandoned mines, promote the sustainable development of mines and economic recovery, and make contributions to the development of energy conservation and emission reduction.

## Acknowledgements

This study was supported by the second batch of new projects of public geological work in Anhui Province in 2021. The data used in this article can be obtained directly from the communication author.

## Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

## References

- [1] Huo, R., Xu, X.Y. and Jiang, Y.D. (2019) Present Situation and Prospect of Renewa-

- ble Energy Development and Utilization in Abandoned Mines Abroad. *Coal Science and Technology*, **47**, 267-273.
- [2] Xie, Y.Q., Gao, H., Su, Z.G., Li, C., Dong, L.J. and Zhu, J.L. (2020) Development and Utilization of Waste Mine Geothermal Resources. *Solar Energy*, **10**, 13-18.
- [3] Li, Q.S., Li, R.F., Zhang, G.J., Zhang, K. and Yang, Y.M. (2019) Development and Utilization Strategy of Renewable Energy in Abandoned Mines in China. *Coal Economy Research*, **39**, 9-14.
- [4] Pu, H., Xu J.C., Bian, Z.F. and Schuttrumpf, H. (2022) Close/Abandoned Mine Geothermal Energy Exploitation and Utilization of the Research Status and Progress. *Journal of Coal*, 1-26.
- [5] Xu, G.L., Yuan, J.R., Tu, Z.X., Zeng, G.P. and Yu, J.W. (2012) Comprehensive Utilization of Abandoned Mines. *China Population, Resources and Environment*, **22**, 360-362.
- [6] Zhou, Y.M. (2020) Research on Evaluation of Development and Utilization of Underground Space of Abandoned Coal Mine. Chongqing University, Chongqing.
- [7] Zhang, Y., He, X.P., Shi, P. and Zhang, H.W. (2022) Study on Comprehensive Utilization Mode of Flood Storage, Energy Storage and Heat Recovery in Abandoned Mine. *Coal Science and Technology*, 1-8.
- [8] Guo, P.Y., Wang, M., Sun, X.M. and He, M.C. (2022) Research on Anti-Seasonal Cyclic Energy Storage in Underground Space of Abandoned Mine. *Journal of China Coal Society*, 1-14.
- [9] Ren, H., Wu, G.Q., Ning, S.Z., Zhu, S.F., He, X.L., Liang, Y.P., Wang, X.J, Li, H.L., Geng, J.J. and Qiao, J.W. (2018) Resource Development and Utilization and Geological Guarantee of Closed Coal Mine. *China Coal Geology*, **30**, 1-9.
- [10] Peng, T., Ren, Z.Q. and Zhang, H.C. (2016) Heat Generation Rate Characteristics of Coal Measures Rocks in Huainan and Huaibei Coalfields. *Shanxi Coal*, **36**, 4-7.
- [11] Shao, Y.H. (2015) Study on the Influence of Thermal Effect of Magmatic Intrusion on Mine Geothermal Field. Anhui University of Technology, Ma'anshan.
- [12] Zhang, Q. (2015) Investigation of Thermal Damage and Prediction of Wind Temperature in Pansan Mine. Anhui University of Technology, Ma'anshan.
- [13] Xu, S.P. (2014) Study on the Distribution Law and Control Mode of Geothermal Field in Lianghuai Coalfield. Anhui University of Technology, Ma'anshan.
- [14] Yang, J.Y., Wen, X.W. and Tan, H.B. (2021) Geothermal Inversion and Geothermal Anomaly Prediction of Remote Sensing Data in Nimu Area, Tibet. *Geological Review*, **67**, 1770-1779.
- [15] Ren, Z.Q. (2016) Geological Characteristics of Deep Geothermal and Evaluation of Geothermal Resources in Panji Mining Area. Anhui University of Technology, Ma'anshan.
- [16] Zhai, X.D., Xing, L.X., Yuan, N.N., Wang, X.D., Gao, Z.Y. and Chen, X. (2015) Application of Thermal Infrared Remote Sensing in Geothermal Anomaly Extraction. *Anhui Agricultural Science*, **43**, 358-360.
- [17] Jia, Z.Q., Jiang, J.H., Liu, Z. and Feng, C.Y. (2018) Prospect Analysis of Geothermal Utilization in Modern Agricultural Construction in Shijiazhuang. *Agriculture and Technology*, **38**, 176-177, 182.
- [18] Liu, J.G. (2013) Research and Application of Coal Mine Low Temperature Heat Source Utilization Technology. *Coal Science and Technology*, **41**, 124-128.
- [19] Pu, H., Bian, Z.F., Zhang, J.X. and Xu, J.C. (2021) A Waste Mine Geothermal Resources Reuse System Research. *Coal Journal*, **46**, 677-687.