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Evaluation of Water-richness of Coal Seam Roof Based on Fractal Theory

Gelian Dai[1,2], Yazhou Wang[1], Chao Niu[1]

[1]School of Geology and Environment, Xi'an University of Science and Technology, Xi'an, shaanxi province, 710054, China

[2]Ministry of Land and Resources, Key Laboratory of Coal Resources Exploration and Comprehensive Utilization, Xi'an, shaanxi province, 710054, China

[*]Ya-zhou Wang: 1872688230@qq.com

Abstract. Before coal mining, the prediction and evaluation of eco-aquifer water-rich in advance is of great significance to prevent mine water damage in coal mines and protect ecological diving in mining areas. A large number of studies have shown that the surface water system is self-similar. On the basis of a brief review of the fractal theory, the fractal theory of water system is used to quantitatively evaluate the information of submarine aquifers in Xiaobaodang Mine, and a new research idea is put forward for the evaluation of aquifer-richness.

1. Introduction

At present, the main research and evaluation on water-richness aquifer in China and abroad mainly focus on three aspects: on-site pumping water test, qualitative research on geophysical exploration and multi-factor comprehensive analysis and prediction. Among them, the pumping water test has a large economic input, less drilling holes and low control precision, and the geophysical exploration methods controlled by topography, geological structure, lithology and other influencing factors. Although the multi-factor analysis method can fully tap the borehole data to make up for the mining area, the negative influence of subjective judgment can not be ignored in the selection of indexes, although various mathematical methods are used to calculate them[1-3].

The study shows that the surface water system is self-similar, the distribution of water system phase size, location and area are statistically consistent, therefore, the water-rich characteristics of the aquifer can be effectively reflected by the fractal dimension of the water system. The water level of the Salawusu Formation aquifer in Xiaobaodang mine field is shallow buried, generally about 1~10 m. The sedimentary thickness of the Salawusu Formation is restricted by the paleotopography, and there are relative watersheds between the grooves and all have independent hydrogeological units. The watershed is consistent with the current surface watershed. Under the constraints of topography and geomorphology, the flow field is mostly runoff from the top of the terrain like a valley, then flows to the valley, and the flow direction is basically consistent with that of the terrain. The aquifer is mainly discharged in the form of springs or seepage. For the study area, a large number of lakes are exposed and low-intensity construction (Xiaocaowan highway construction) is carried out in the area, which results in the phenomenon of diving in the Salawusu Formation (Figure 1), where the submersion is exposed, the aquifer is relatively more water-rich than undisclosed areas. Based on this phenomenon, the fractal dimension is used to evaluate the water enrichment of the groundwater aquifer in the study area.

Figure 1. Schematic diagram of Xiaocaowan diving in Xiaobaodang well field.

2. Fractal Theory

As a very popular and active new theory and subject, Fractal theory was first proposed by the American mathematician Benoit B. Mandelbrot[4-6]. The mathematical basis of fractal theory is fractal geometry, that is fractal geometry derived from fractal information, fractal design, fractal and other applications.

In the Earth system, the spatial distribution of many geological phenomena has a fractal structure. From microcosmic spherulites growth, quasi-crystal formation to macroscopic coastlines, contour contours, basin ups and downs, river networks, water vortices, cloud formations, seepage, diffusion, fault systems, mineral geometry such as tree stones, Spatial structures are all in the form of natural fractal dimension. In time, geomagnetic field, meteorology, earthquake, tectonic movement and the evolution of the entire earth have self-similar. In China, the application of fractal theory in the field of geology has become more and more active since the 90s of the 20th century, and its application has become more and more widespread. Especially in geological disasters, metallogenic prediction, tectonic geology and geochemistry, the fractal dimension can be quantitatively described. The complexity of geologic structure distribution can comprehensively reflect the quantity, scale, degree of development, influence range and combination mode of geological structure. Therefore, it is possible to predict the water inrush in coal mine roof and floor with good effect.

3. Fractal dimension calculation process

Fractal dimension as an important parameter to describe fractal, its common similarity dimension, Hausdorff dimension, capacity dimension, box dimension and so on. There are many methods for fractal dimension calculation, in which the box-counting method is a simple and objective fractal dimension method. This method uses box-counting method as follows:

(1) All lakes in the study area were first transferred to clear paper at the same scale (1: 10000). According to the latitude and longitude grid, the mining area is divided into blocks of 2000×2000m. Within each block, statistics are made on all lakes in the study area. The blocks traced by the initial grid are numbered and recorded in the center of each grid. The study area is divided into 72 blocks, and the fractal dimensions are respectively calculated.

(2) On the basis of the initial grid, the grids N (r) containing lakes trace under each scale are respectively obtained by taking 1/2, 1/4, 1/8 and 1/16 grids respectively.

(3) Acquisition of water system information dimension

The Hungarian scientist Renyi established the method of computing the dimensionality of information by using information entropy from the perspective of probability theory: the more ordered a system, the lower the information entropy. Using the distribution probability of water area in the study area as the information entropy, the water-richness degree of submerged aquifers can be well reflected.

First define the information equation:

$$I = -\sum_{i=1}^{N(l)} P_i(l) \ln P_i(l)$$

Where l is the side length of the grid used in the fractal dimension measurement, $P_i(l)$ is the probability of the water system in the fractal object falling into a grid, N is the number of all the grids.

If the probability of falling into each grid are the same, then

$$\sum_{i=1}^{N(l)} P_i(l) = N(l) * P_i(l) = 1$$

then $P_i(l) = 1/N(l)$, At this point, each of the following sums is independent of the number.

$$D_I = -\lim_{l \to 0} I / \ln l = \lim_{l \to 0} \sum_{i=1}^{N(l)} [1/N(l)] \ln[1/N(l)] / \ln l = \lim_{l \to 0} \ln[1/N(l)] / \ln l = -\lim_{l \to 0} \ln N(l) / \ln l$$

Then the opposite of the slope is the information dimension.

Taking one of the grids as an example $l_0 = 2000$, the similar ratio as $l_1 = l_0/2$, $l_2 = l_1/2$, $l_3 = l_2/2$, $l_4 = l_3/2$ (Figure 2), measured with a different side length l_i of the measurement box corresponding to $N(l_i)$, respectively, l_i can be 1000, 500, 250, 125. In the coordinate system of $\ln N(l_i) - \ln l_i$, the above points are fitted by the least squares method to obtain a straight line L (Figure 3), R^2 = 0.9981≥0.98, and the fitting result is good, then the inverse of the fitted straight line L is the information dimension of the square grid unit. Similarly, calculate the fractal dimension of each block in the study area

The fractal dimension of the block is assigned to the center of the block, and then the contour of the fractal dimension is interpolated by Kriging method (Figure 4).

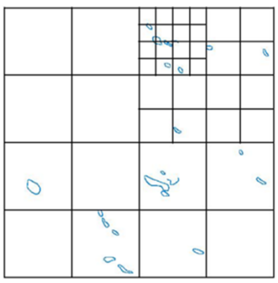

Figure 2. A block of fractal dimension value method of seeking a schematic diagram

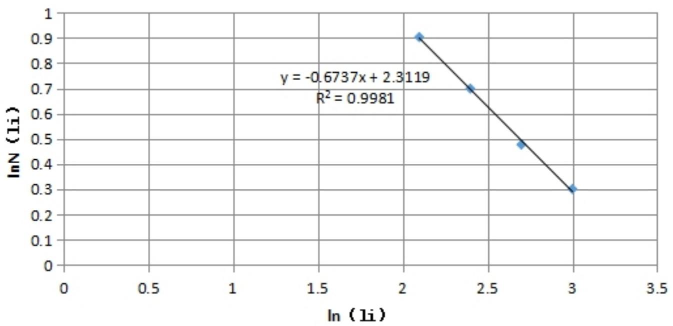

Figure 3. The calculation of water system fractal dimension

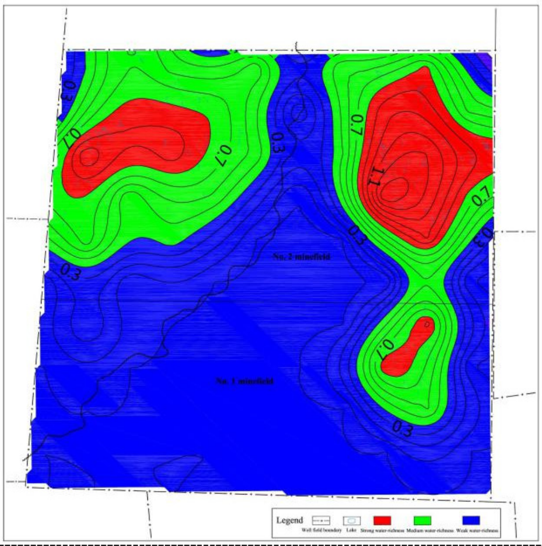

Figure 4. Fractal Contour map of XiaobaoDang mine water system

4. Result analysis

Fractal dimension value not only reflects the complexity of distribution of water system, but also can be used to characterize the water-richness of submerged aquifer. Where the lake is abundantly exposed, the fractal dimension of the information has a large fractal value, the maximum fractal dimension can reach 1.38. When the fractal dimension of water is less than 0.3, there is basically no diving.

Based on the above information, the water quality of submarine aquifers in the study area can be divided into three regions.

- Strong water-richness areas ($D_I > 0.7$): In this area, there are more submersion, mainly in the northern part of the study area, the middle of No.2 minefield and a small part of the eastern part of the study area.
- Medium water-richness areas ($0.3< D_I \leq 0.7$): This area is mainly located around the strong water-rich area, mainly in the north and southwest of No.2 minefield and also has a small part of northeast part of No. 1 minefield.
- Weak water-richness areas ($D_I \leq 0.3$): In the area, almost no diving outcrops were found, which mainly distributed along the watershed and accounted for most of the area.

5. Conclusion

Based on the analysis of geological and hydrogeological data in the study area, according to the self-similarity of surface water system, the fractal theory of water system is used to quantitatively evaluate the information fractal dimension of submersible aquifer affecting shallow coal seam mining in Xiaobodang mine field. The water-rich aquifer is partitioned, in which the area with strong water-rich is mainly located in the middlet of No. 2 mine field and a small part of the eastern part of the mine field, the middle water-rich area is mainly distributed in the north and southwest of No. 2 well field and the part in the northeast of No. 1 mine field, and the weak water-rich area mainly distributes along the watershed.

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References
[1] Dai GL. (2016) Mine water disaster prevention and control. Xuzhou: China University of Mining and Technology press.
[2] Jiang HM, Jiang HM, Li L, Rong XL, Wang MY, Xia YP, Zhang ZC. (2017) Model test to investigate waterproof-resistant slab minimum safety thickness for water inrush geohazards. Tunn Undergr Space Technol, 62:35–42.
[3] Ma D, Rezania M, Yu HS, Bai HB. (2017) Variations of hydraulic properties of granular sandstones during water inrush: effect of small particle migration. Eng Geol, 217:61–70.
[4] Shi LQ, Liu L, Zhou J, et al. (2014) Fault fractal information dimension and its application in floor water burst. Coal Mining Technology, 19(1): 12-16.
[5] Mandelbrot B B. (1977) Fractals: forms, chance and dimension. W. H. Freeman, San Francisco.
[6] Mandelbrot B B. (1982) The fractal geometry of nature. W. H. Freeman, San Francisco.