Study on fractal dimension of spatial distribution patterns for hidden danger points of geological hazards: taking Huoxi Coalfield of China as an example

Qiaomei Su
Department of Surveying and Mapping,
College of Mining Engineering
Taiyuan University of Technology
Taiyuan, China
suqiaomei@tyut.edu.cn

Chenyu Wang
Department of International Education
Canvard College
Beijing Technology and Business University
Beijing, China
wangchenyuty@126.com

Shangmin Zhao
Department of Surveying and Mapping,
College of Mining Engineering
Taiyuan University of Technology
Taiyuan, China
zhaoshangmin@tyut.edu.cn

Jianmin Wang
Department of Surveying and Mapping,
College of Mining Engineering
Taiyuan University of Technology
Taiyuan, China
wangjianmin@tyut.edu.cn

Abstract—The purpose of the study is to propose the fractal features of the spatial distribution patterns of the hidden danger points of geological hazards in Huoxi Coalfield by using the box counting dimension and the information dimension. The results show that the spatial distribution patterns of hidden danger points of geological hazards in Huoxi Coalfield have obvious fractal characteristics and the two kinds fractal dimension value of debris flow were 0.5128 and 0.6538, 0.6744 and 0.7023 for the collapse, 0.8805 and 0.9149 for the landslide, 1.1129 and 1.1976 for the unstable slope, 1.2854 and 1.3986 for ground collapse, respectively. The fractal dimension values of all the correlation coefficient R^2 were greater than 0.9, it means that they have strong fractal dimension and have significant self-similarity. The results also shows that the fractal dimension value of ground collapse and unstable slope points are greater than the landslide, collapse and debris flow points, so the spatial distribution patterns of ground collapse and unstable slope points are more developed, numerous and aggregated than the others. Finally, using fractal theory to study the distribution characteristics of hidden danger points of geological hazards in Huoxi Coalfield, we can understand the distribution characteristics of geological hazards wholly and given the prevention and treatment recommendations.

Keywords: Geological hazard; hidden danger points; fractal; fractal dimension; Huoxi Coalfield

I. INTRODUCTION

Geological hazard is a destructive geological event, which poses a serious threat to the life and property of human beings, and restricts the sustainable development of human beings. Mine geological hazard is a branch of geological hazards, which is caused by the geological action and the destruction of human mining activities. Shanxi is a main coal producing area in China and over exploitation has aggravated the deterioration of geological environment, causing a series of hidden danger points of geological hazards, which include unstable slopes, potential landslides, potential collapses, potential debris flows and potential ground collapses that may jeopardize the safety of people's life and property, as well as landslides, collapses, debris flows, ground collapses, and so on, that have occurred but are still unstable.

The fractal theory which was founded by American French mathematician Mandelbrot in the middle of 1970s, has deeply made people to understand the nature law of irregular geometry, and find the fine structure hidden in the confusion things through the self-similarity within things, and provides new ideas and tools for people to know the whole from the parts and limited cognition limitless. The fractal theory has been widely used in many disciplines. Jiang et al. [1-3] have found that there are much fractal phenomena in various geological hazards. It not only deepens the traditional cognition of geological hazards, but also has great function for predicting.

For the geological hazards in coal mine areas, Xiao et al. [4, 5] have studied the characteristics, formation mechanism and countermeasures, however, there are few studies about the spatial pattern of geological hazards. This paper aims to study the distribution characteristics of hidden danger points of geological hazards using fractal theory, and quantitatively reveal the spatial distribution pattern features, the formation mechanism and distribution law of geological hazards in coal mining area, and scientifically provide some prevention and treatment recommendations.

II. STUDY AREA

The Huoxi Coalfield (35°40′28″–37°17′12″N, 111°5′43″–112°21′26″E), located at the center of Shanxi Province, China, is one of the six large Coalfields of Shanxi Province (Figure 1). It covers approximately 10,000 km^2. This area belongs to a temperate monsoon climate with the annual average temperature of 8.6 ℃. There are abundant coal resources in the study area, and due to excessive exploitation it is easy to cause surface damage and induce severe geological hazards.

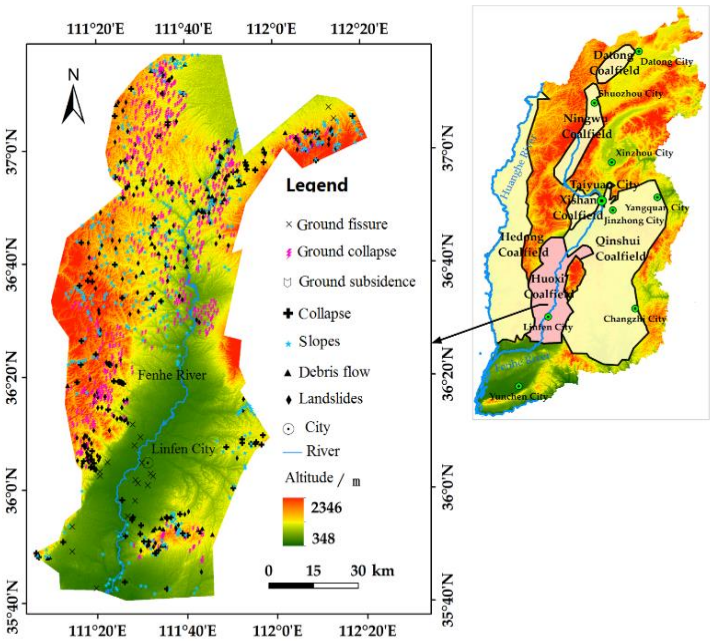


Figure 1. Location of the study area and distribution of geological hazards sites

III. METHODOLOGY AND RESULTS

A. Geological hazards inventory

Figure 1 shows the geological hazards inventory map in the study area. A total of 1420 geological hazards sites are mapped including collapse, ground fissure, ground subsidence, ground collapse, landslides, debris flows, and slopes, collected by the Bureau of Land and Resources in 2009, is represented by the X, Y coordinates of its central point. The distribution of geological hazards types in Huoxi Coalfield is shown in figure 2. Figure 2 shown that there are 20 the ground fissure points and 1 ground subsidence point in the study area, it is too few to be discussed, so only 5 types can be analyzed.

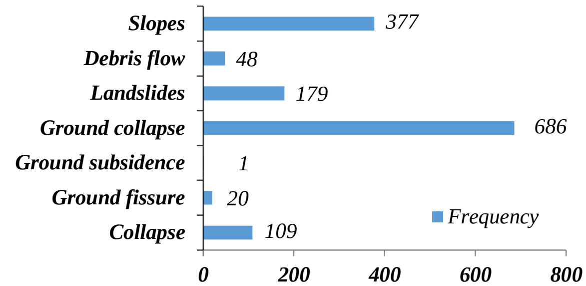


Figure 2. Distribution of geological hazards type in Huoxi Coalfield

B. The box counting dimension and the information dimension

The fractal dimension is used to characterize the complexity of the spatial distribution of geological hazard points in Huoxi Coalfield, the formulas are expressed as:

$$N = Cr^{-D} \quad (1)$$

In the formula, r is a feature scale, and N represents the number of objects with r, C is a proportional constant and D is a fractal dimension. There are many other fractal calculation methods in calculation formula of the fractal dimension, including box counting dimension and information dimension.

For the box counting method, the study will be divided into several side length of square lattice, and then determine the existence of geographical elements of the lattice (also called non empty lattice number) N(E), changing the length of the epsilon values, and generate the corresponding N(E), and the fractal dimension D_b is calculated as:

$$D_b = \lim_{\varepsilon \to 0} \frac{\log N_\varepsilon}{-\log \varepsilon} \quad (2)$$

For the information dimension method, the total area of geographical elements is assumed to be N, the number of individuals with nonempty lattice is Ni. The probability of individual distribution in each non empty lattice is $P_i=N_i/N$, and the amount of information is $I_i= -P_i \ln P_i$, then the total amount of information is expressed as:

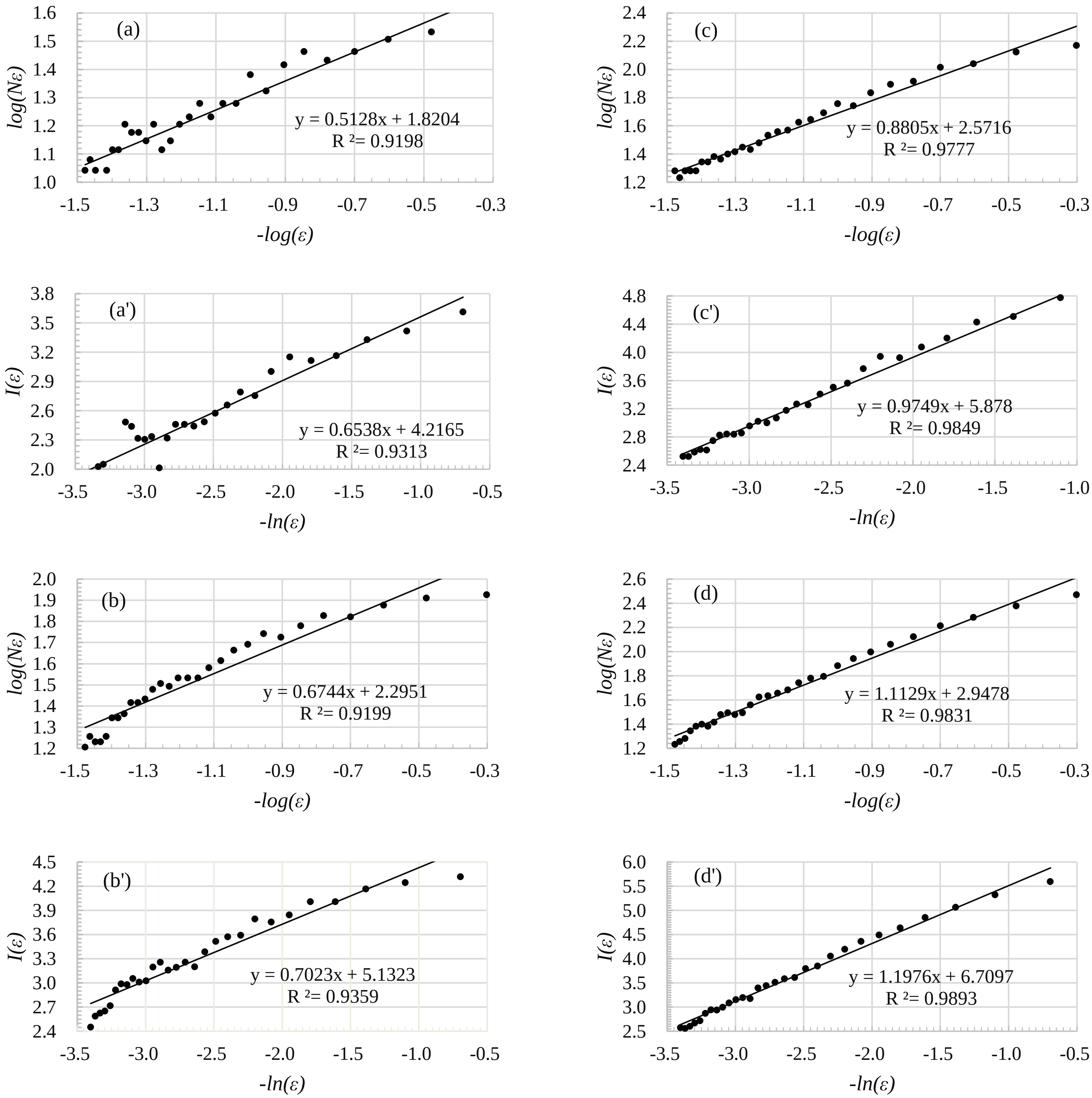
$$I(\varepsilon)=\sum I_i \quad (3)$$

Then the information dimension is expressed as:

$$D_i = -\lim_{\varepsilon \to 0} \frac{I(\varepsilon)}{-\ln \varepsilon} \quad (4)$$

C. The fractal features of the spatial distribution patterns

The fractal dimension calculation results of the geological hazards in Huoxi Coalfield are shown in Figure 3. Figure 3 shows that the R^2 of all geological hazard fractal dimension fitting curves is above 0.9, so the spatial distribution of geological hazards in Huoxi Coalfield has strong fractal characteristics.


(a)
y = 0.5128x + 1.8204
R ²= 0.9198
log(Nε)
-log(ε)
(c)
y = 0.8805x + 2.5716
R ²= 0.9777
log(Nε)
-log(ε)
(a')
y = 0.6538x + 4.2165
R ²= 0.9313
I(ε)
-ln(ε)
(c')
y = 0.9749x + 5.878
R ²= 0.9849
I(ε)
-ln(ε)
(b)
y = 0.6744x + 2.2951
R ²= 0.9199
log(Nε)
-log(ε)
(d)
y = 1.1129x + 2.9478
R ²= 0.9831
log(Nε)
-log(ε)
(b')
y = 0.7023x + 5.1323
R ²= 0.9359
I(ε)
-ln(ε)
(d')
y = 1.1976x + 6.7097
R ²= 0.9893
I(ε)
-ln(ε)

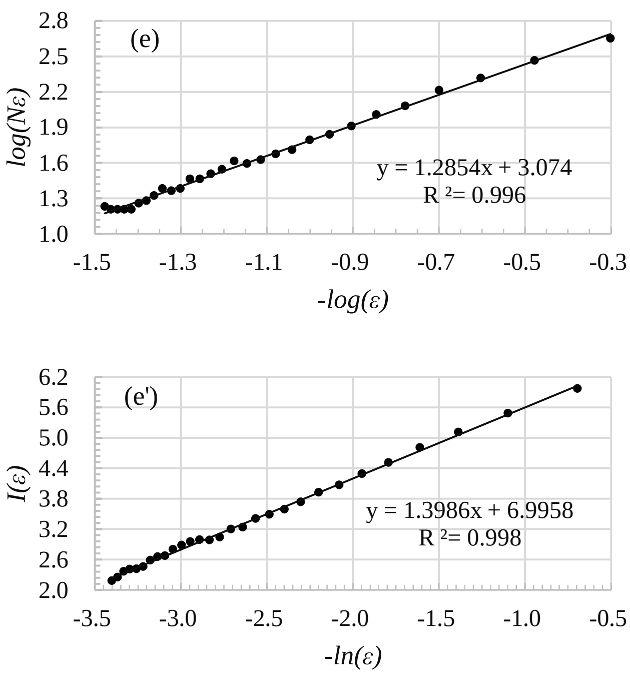


Figure 3. Fractal dimension of different geological hazards (a) (a′)debris flow; (b) (b′)collapse; (c) (c′) landslides; (d) (d′)slopes; (e) (e′) ground collapse

D. The Fractal Dimension Values

According to Figure 3, the fractal dimension (the box counting dimension and information dimension) values of different geological hazards are shown in Table 1.

TABLE I. FRACTAL DIMENSION VALUES OF DIFFERENT GEOLOGICAL HAZARDS IN HUOXI COALFIELD

	Debris flow	***Collapse***	***Landslides***	***Slopes***	***Ground collapse***
Box-counting dimension	0.5128	0.6744	0.8805	1.1129	1.2854
Information dimension	0.6538	0.7023	0.9149	1.1976	1.3986

In terms of the fractal dimension values, the fractal dimension value of the spatial distribution of the ground collapse points have the highest performance, second is unstable slope, then is landslide, collapse and debris flow.

IV. DISCUSSIONS

The box dimension is used to reflect the ability of the points occupying some space, and the larger the box counting dimension, the greater the degree of spatial occupation of geological hazards, contrarily the smaller the box counting dimension, the smaller the space occupying degree of geological hazards.

Compared with the box dimension, the information dimension not only care about the state of the box in different scales which is "empty" or "non empty", but also the quantity of the information is considered which is provided by the "non empty" lattice at different scales. It reflects the degree of non-uniformity of spatial distribution of geological hazards points, and the high information dimension indicates that the distribution of geological hazards points is more uneven, numerous and highly aggregated.

The two fractal dimension value of the ground collapse and unstable slope has the highest performance, means that the ground collapse and unstable slope in the study area is more developed, numerous and aggregated than other geological hazards due to the underground mining which causes the existence of the mine goaf.

V. CONCLUSIONS

Through the fractal theory we have been able to analyze the spatial distribution of geological hazards wholly in Huoxi Coalfield. The results shows that the fractal dimension value of ground collapse and unstable slope points are greater than the landslide, collapse and debris flow points, and accounts for the underground mining which causes the existence of the mine goaf that the ground collapse and unstable slope in the study area is more developed, numerous and aggregated.

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References

[1] Ensan Jiang, Guangming Ren, Jintao Chen, 2016. “The fractal characteristics of the geological hazards development of Pugh county Sichuan province”, The Chinese Journal of Geological Hazard and Control, 2016, 27 (3) :122-126

[2] Wang Zhiwang, Ma Shuishan, 2001. “Fractal dimension pattern of landslide and its significance for forecasting”, Chinese Journal of Rock Mechanics and Engineering, .2001(S1):1699-1701

[3] Wu Shuren, Shi lin, Tan Chenxuan et.al, 2000. “Fractal analysis of landslides in Three GorGes, ChangJiang River, China”, Earth Science-Journal of China University of Geosciences,2000,25(1):61-65

[4] Xiao H P. Important geological hazards of coal-mine and its prevention measures in China [J]. The Chinese Journal of Geological Hazard and Control. 2001, 12 (1): 51-54.

[5] Zhai W J, Zhong Y Z, Jiang D L, et al. Prediction of Geological hazard in West open pit of Fushun coal mine[J]. Journal of Natural Hazardss, 2006, 15(4) : 132-137.