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ANALYSIS OF SURFACE SINK OF EXPLORATION VACANCY IN GOLD MINING AREA OF ZHAOYUAN CTIY BASED ON RS AND GIS

WU Quan-yuan[1,2], AN Guo-qiang[3], BAO Wen-dong[1,3], ZHANG Zu-lu[2], XU Qiu-xiao[2], FANG Xue-mi[2]
(*1. The College of Geoscience and Engineering of Shandong, Tai'an 271019, P. R. China; 2. Shandong Normal University, Jinan 250014, P. R. China; 3. The Engineering College of Land Investigation and Layout of Shandong, Jinan 250014, P. R. China*)

ABSTRACT: Surface sink is a main geological calamity of gold mining areas and a main factor to restrict economic sustainable development of mining zone. Based on former investigations, this article draws the environment information of surface sink of exploration vacancy in gold mining area of Zhaoyuan City, Shangdong Province by RS technology. Through spatial simulation analysis and expert diagnoses on the basis of GIS technology, the article affirms the inducement factors of the surface sink. Then using these factors as distinguishing ones the authors prognosticate the criticality of other exploration vacancies. The results indicate that the surface sink area of study area in Zhaoyuan City, has already come to 0.78km^2 and it is forecasted that 0.97km^2 of the exploration vacancy belongs to high danger area. Decisive measures need taking in order to prevent this crucial problem. Another 1.57km^2 of the exploration vacancies belongs to middle danger area, which will sink when meeting some inducing factors, such as earthquake. Still another 1.53km^2 of the exploration vacancies belongs to low danger area that can not lead to surface sink when meeting common inducing factors.

KEY WORDS: surface sink; exploration vacancy; remote sensing(RS); geographic information system(GIS)

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1 INTRODUCTION

Zhaoyuan City, located in northeast of Shandong Province, is called "Gold City" and it is one of important gold production bases in China. The exploitation of the gold brought out the extensive vacant areas, leading to large-scale ground subsidence. That becomes the main geological calamity of the gold mining areas, causing great destruction to economy and eco-environment of local society. There are numerous factors to bring out subsidence in the ground, and a lot of scholars have already carried out relatively detailed research from the geological angle, but relatively rare from the research of the macroscopical space angle (DU and GUO, 2003; QIAO *et al*., 2002; WANG *et al*., 2002; WEI, 1998). This paper uses the techniques of remote sensing and geographic information system, combining ground samples and investigation, to expose the geological background of the subsidence. It offers an accurate way to analyze this kind of geological calamity.

2 STUDY AREA

Study area (37°24′00″–37°28′30″N, 120°27′28″–120°37′37″E) is located in the north of Zhaoyuan City, and adjoins Longkou City in northeast, and the Bohai Sea in northwest, with an area of 657.3km^2 (Fig. 1). It mainly includes Jiaojia Gold Mine, Xincheng Gold Mine, Huangnigou Gold Mine, Yuangtong Gold Mine, Zhaoyuan Gold Mine and so on (Fig. 1), with a total proven gold reserve of 538t and an annual ore exploiting amount of 6 250 000t. The study area belongs to continent monsoon climate, with an average annual precipitation of 635mm. Its river system is seasonal and the density of water network is relatively large. Shore plain is distributed in the northwestward and low mountain in the southeastward. Luoshan Mountain is the highest in this area, with an altitude of 757m. The rock is mainly the Archean Era granite and metamorphic rock, with relatively developed rift. The main directions of the rift structure are north-east, north-north-east and east-west,

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Biography: WU Quan-yuan (1959–), male, a native of Longkou of Shandong Province, professor, specialized in the application of RS and GIS. E-mail: wqy6420582@163.com

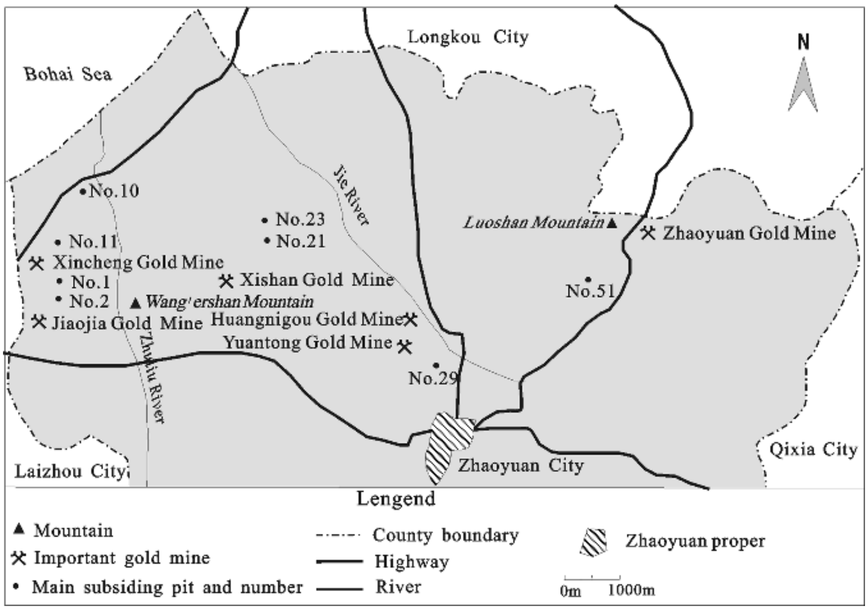

Fig. 1 Location sketch of study area and distribution of mines and subsiding pits

and the structure controls the growth of physiognomy and the distribution of the stratum of the whole region.

3 METHOD

3.1 Technological Route

The subsidence of the vacant lot is the result of the synthesis of natural and social key elements (LIU *et al*., 2002; WU *et al*., 2004; ZHOU, 2003). The pictures of remote sensing are carriers of these key elements. They include not only the visible environmental information, but also invisible infrared and far infrared environmental information, and can reflect the marks of human activities on the earth surface, conceal the indirect information of earth's crust to a certain extent (FULI and ROSEN, 1998; TOWNSHENG, 1990). So remote sensing technology is the most effective technological means to obtain ground subsidence (ZEBKER and GOLDSTEIN, 1986; WANG and LU, 2001). Geographic information system can analyze the subsidence and the natural and social information that related to ground subsidence form, driving factors, structure, etc. So it is the most effective technological method to analyze ground subsidence (GAN *et al*., 2000; HU and TANG, 2002). Under this consideration, the study adopts the following technological route: Firstly, on the basis of former research, ground subsidence information was drawn by remote sensing technology; secondly, combining on-the-spot testing and verifying, the subsiding area was positioned and measured by adopting GPS technology; thirdly, after transferring the remote sensing information into geographic information system, the key factors bringing about land subsidence was analyzed by using space analysis module; and finally combining expert's diagnose, the important and less important factors causing land subsidence were determined so as to decide the possibility of the ground subsidence of the other exploration vacancies.

3.2 Data Source and Management

3.2.1 Data source

The data source includes grid data and text data. Grid data include the digital remote sensing images and the thematic maps. Information source includes SPOT satellite pictures with a resolution of 2.5m in May 2001 and the aviation photos of December 1999. The thematic maps used include 1:10 000 topographic maps of gold mining area, 1:50 000 geologic maps, 1:10 000 land-use maps, 1:25 000 gold mine distribution map, 1: 25 000 geological calamities' investigation map and 1: 25 000 surface flows contours map. The text data refer to various kinds of study reports, experimental data and the illumination of the maps.

3.2.2 Projection, correction and integration of raster data

There are relatively great differences in collected grid data, such as projection, the scale and precision of geometries, so geometric correction and accurate registration must be carried out. The 1: 10 000 topographic maps were used for geometry correction, and the geometry correction method is cubic multinomial with 10 geometry control points (GCP). The accurate error must be smaller than 0.5 pixels in order to guarantee high-precision overlaying analysis of multi-source information. Aviation correction was conducted by using positive emendation method, with original space resolution. The integration of the data of remote sensing is a kind of advanced image dealing technology and its purpose is to synthesize wave band information of the single sensor or different classes of information that sensor offers, to dispel the redundant and contradiction that may exist between the information of sensors, to improve the promptness and reliability of data extraction, and to raise the space resolution, the spectrum resolution and efficiency of data use (MASSONNET *et al*., 1997; SHIRAZA, 1984). Taking SPOT and aviation picture as examples, we firstly used HIS (Hue-Intensity-Saturation) transformation to merge pan-spectrum wave band with the resolution 2.5m and multi-spectrum wave bands with the resolution 10m, and then get an artificial multicolor image. Second, we adopted Bayes transformation to merge the aviation pictures with the resolution 0.5m and the just merged artificial multicolor image, and the final image not only keeps the high resolution, but also has abundant spectrum information.

Fig. 2 Local ground subsidence image before management

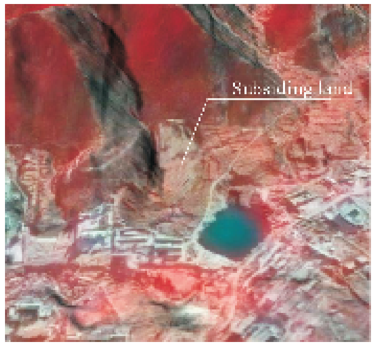

Fig. 3 Local ground subsidence image after management

3.3 Information Extraction

3.3.1 Subsidence information

The remote sensing images imply two-dimension spatial information, but surface subsidence is a three-dimension phenomena (LIU *et al*., 2003; ZHOU and WANG, 2002). The existing ground subsidence is generally 1000–4000 m^2, but some are only several hundred square meters. In addition, the natural environment in the subsidence area is quite complicated, causing the great difficulties to interpret. In order to improve the dependability of the information being drawn, Virtual GIS technology is used to overlay and analyze remote sensing picture and DEM in ENVI system, thus forming three-dimension images. According to the experimentation, enlarging perpendicular scale four to six times can effectively show spatial images character of subsidence (Fig. 2 and Fig. 3).

3.3.2 Environmental elements information

The method combining principal component analysis with merging dealing method is used in the drawing of the information of stratum and rock quality. Using principal component analysis method to transform the picture of remote sensing linearly can reflect the characteristics of ground form of different stratum districts relatively clearly, but the stratum border is still unable to be defined accurately. The method to merge the data of remote sensing with geologic map can easily discern the distribution characteristics of the border. The strengthening of geological structure can strengthen the image's characteristics. This study uses Texture Analysis to analyze the module and chooses the 5×5 window to conduct image processing, then overlays and analyzes the geological structure maps to draw the structure information.

3.3.3 Vancant lot information

The distribution of vancant lots is closely related to the stratum. We fold the distribution pictures of the gold mines, the distribution pictures of stratum and the remote sensing pictures to analyze and confirm the distributing extension. Then on this basis the spectrum testing of this stratum district was conducted. The existence of the vancant lots will certainly result in the variation of the hydro-geological conditions. The variation will be reflected by stratum surface, especially by the different vegetation growing state of the vacant lot and other districts. The vancant lot information was extracted by using inquire cursor function in ERDAS system to sample the stratum of gold ore, counting its surface spectrum characteristic, and choosing the favorable wave bands and proper logic expression.

3.3.4 Geomorphologic information

Ground subsidence relates to the geomorphologic conditions, especially to the slope, wash ditch and cut ditch. The study firstly transfers the 1: 10 000 vector contours of the study area to GIS system, then using Surface Analysis Function, draws slope, gathered water area and ridge, mountain valley, wash ditch, cut ditch, stream ditch, etc.

4 ANALYSIS OF COLLAPSE OF GROUND SUBSIDENCE

4.1 Current Situation of Main Vacant Lots

(1) No.51 mine ore subsidence (Fig. 1): Its area is 59 160 m^2, and the average elevation of ground before subsidence is 445m a. s. l. After subsiding the ground sank 28m on the average, and reached 60m in the deepest place. Fault and joint of the subsidence developed relatively and the hanging wall is main subsidence part. The mine ore extends from north to west and it is one of the backbone mineral ores in the north of the city. According to the materials, this ore vein began to subside on a small scale at the beginning of the 1990s, and then by 1993, subsided on a large scale after the heavy rain, and the hillock turned into a gully immediately.

(2) No. 1–3 mining areas subsidence: This subsidence lies in the western hills, with an area of more than 13 640 m^2. The subsidence depth of the hole is 5–15m. The subsidence hole extends along the direction of NE65° and the north wall is 325°, with the inclination of 69°; the south wall is 320°, with the inclination of 85°. The subsidence causes near rocks to collapse on a large scale, the collaps walls take the form of wedge and the subsidence area accounts for 31% of the vancant lot.

(3) No.10 mining area subsidence: It is a kind of typical stratum subsidence of the Quarternary System, and ground slope is gentle. Average elevation above sea level is 35m, the subsidence area is more than 1450m^2, and the depth of the subsidence is 5–10m.

(4) The old cave of gold mine of Xincheng subsidence: It lies in the northeast of Xincheng Village and is composed of two holes, i.e. No.1 hole and No.2 hole. No. 1 hole subsided in the middle ten days of July in 1987, extending in a circle, with a depth of less than 3m and a diameter of about 300m. No. 2 hole subsided in early April in 1993; its upper and lower mouths were in round shape; the diameter of upper mouth was 160m, and the below mouth was 110m; and depth of the hole was 5–6m.

(5) Gangue storehouse subsidence of the Wang'ershan Mountain: It lies in the northeast of Wang'er Gold Mine. The gangue storehouse was put into production in 1980, and abandoned in March 1992, then cultivated again. Two times of subsidence appeared near the gangue storehouse on May 31, 1993 and July 1995. The subsidence hole's diameter was 90–110m and the depth was 4–5m, with 30–100m of ground crack around it.

(6) No.11 ground subsidence of Matang vacant lot: This subsidence lies in northeast of Matang Village of Jincheng Gold Mine, only 3m away from highway. The subsidence hole's diameter was 60–90m. The coverage was relatively large, and the building nearby was destroyed greatly. The hole was 8–9m deep, and its influencing depth reached 110m, with dozens of 60–100m long ground cracks around it.

(7) No. 29 ground subsidence of Yuantong vacant lot: It took place at northeast of No. 2 main vertical shaft of Yuantong. Two times of large scale subsidence took place on May 13, 1995 and July 24, 1996. This subsidence was composed of 13 holes, with a total area of more than 4800m^2, the deepest hole reached 20m, and the distribution was the same as the ore vein. The nearby ground slope is 5–10°, with 2–3m of loose Quarternary System stratum. The coefficient of surface infiltration was large.

4.2 Factors Influencing Ground Subsidence of Vacant Lot

4.2.1 Forming process of ground subsidence

After the exploiting of the ore body, the vacant lot of the cover rock stratum may bend under the action of gravity. Rising and falling leads to subsidence. According to the destruction degree of the rock, from the vacant lot to earth surface it can be divided into three different distorted influence zones, i.e. rising and falling zone, crack expanding zone and crooked distortion zone. As rising and falling zone influences the earth's surface, the earth's surface will subside. If crack expanding zone only develops to the earth's surface, ground cracks appear only on the earth's surface. When the three zones appear at the same time, crooked zone always forms subsidence basin with the largest center and the smallest edge. Because the angle formed by broken surface and the horizon is relatively big, the area of the subsidence basin is slightly greater than that of the vacant lot.

4.2.2 Influence factors of vacant lot

(1) Ore bed and geologic structure condition

The ore bed condition refers to its deposit condition, thickness and inclination, etc. Under the general situation, exploiting vacant lot with thick ore bed and shallow deposit is more easily to subside on a large scale, thus causing great danger. The distortion extending to earth surface takes less time. With the constant enlargement of the vacant lot, the extent of earth surface to subside increases gradually. However, in the deep exploiting vacant lot, the distortion needs much more time to reach surface, causing small-scale subsidence and less damage. The size of the diggings inclination has mainly controlled the characteristics of the vacant lot of the earth's surface. The subsidence of the vacant lot with little inclination often takes basin shape, and it will form a banding or round tube-shape subsidence hole on the contrary.

In the stratum of geologic structure, the crack is relatively developed. The whole of the rock is bad, and its supporting ability is greatly weakened, thus promoting the course of distortion and increasing the range of the distortion. Moreover, the relation of the scale, form and structure of the subsidence is intimate. If the rift and the crack lie in the middle of the vacant lot, the subsidence influence and its distractive power are relatively weak, and the subsidence hole always takes the "V" form. If the rift and the crack lie on the edge of the vacant lot, it is easy to cause extensive subsidence, with strong destructive power and wide influence, and the subsidence hole takes the " U" form.

(2) Characteristics of upper slate

The intensity and thickness of upper slate, and the width of exploiting vacant lot have considerable influence on the ground subsidence. The ground subsidence takes longer time in the exploiting vacant lot with hard rock stratum that possesses high intensity and thick cover, and even there is not distortion for a long time. If gentle rocks and rigid rocks alternate in the upper terrane, they are easy to cause continuous subsidence. First is gentle rock, then the rigid rock.

(3) Exploitation condition and meteorological factor

Exploitation condition is the important factor to produce the vacant lot subsidence. The adoption of the filling approach can reduce and prevent the emergence of the subsidence in the ground effectively. According to the investigation, most state-owned large-scale gold mine adopt the filling measure to prevent the ground from subsiding basically. However, the local gold mines seldom or never take such measure, often resulting in ground subsidence. Meteorological factors cause remarkable influence on subsidence of exploiting vacant lot with the Quarternary System cover. Precipitation infiltration reduces the intensity of the terrane, and increases the weight of the rock stratum, which has certain facilitation to subsidence. So a large scale of ground subsidence happens within 24 hours after the rain.

4.3 Subsidence Prediction of Vacant Lot

4.3.1 Analytical method

The GIS special analysis module was used to analyze the factor influencing the subsidence. First, we set up corresponded layers, and analyzed the influence power of various kinds of influence factors at current situation according to subsiding. The result was given to experts, especially the geological experts to diagnose to determine the size of the influencing factors. Later, according to the influencing degree the buffering analysis was conducted. If the result accords with the current situation, it indicates that the number value of the definite influence factor is effective. Otherwise, feedback must be analyzed, until it becomes satisfactory. Then according to the size of the influencing factors, we assign the table (Table 1) and topological calculation is given to superpose, calculate and examine the index of each polygon. The calculating formula is:

$$K=\sum P_i \times 100/\max(P_i) \quad i=1,2,3,\cdots,18$$

In the formula, K represents the influencing index; P_i is the number values of the influencing degree of the influencing factors.

Finally we use K to divide sub-area of the gold mining vacant lot (Table 2) to distinguish the criticality of the subsidence of other vacant lots (Fig. 4).

Table 1 Inducing factors appraisal of ground subsidence

Item	Vacant lot	Rift structure	Quanlity of upper rock formation			Slope of the ground			
			Hardness	Middle	Looseness	>60°	60°–30°	30°–10°	<10°
Value	10	10	4	7	10	4	6	8	10

Item	Mining manner		Thickness of upper rock formation			Coefficient of ground flow			
	Filled	Unfilled	Thick	Middle	Thin	>0.4	0.4–0.3	0.3–0.2	<0.2
Value	0	10	3	6	10	4	6	8	10

4.3.2 Subsidence prediction of vacant lot

(1) High danger areas are mainly distributed near the Zhaoyuan Gold Mine, Xincheng-Jiaojia and Huangnigou-Yuantong. The area is 0.97km², of which the residential area is 0.06km², the cultivated land 0.45km², the water area 0.01km², and the area of the vegetation 0.29km². So those areas need close monitoring and tightly controlling to manage to reduce the emergence of the geological calamity.

(2) Middle danger area is mainly distributed nearby the high danger area and the distributed area is 1.57km². If

Table 2 Ground subsidence sub-area of gold mining vacant lot of Zhaoyuan City

Sub-area	Code of sub-area	*K* value
High danger zone	A	60–100
Middle danger zone	B	30–60
Low danger zone	C	0–30

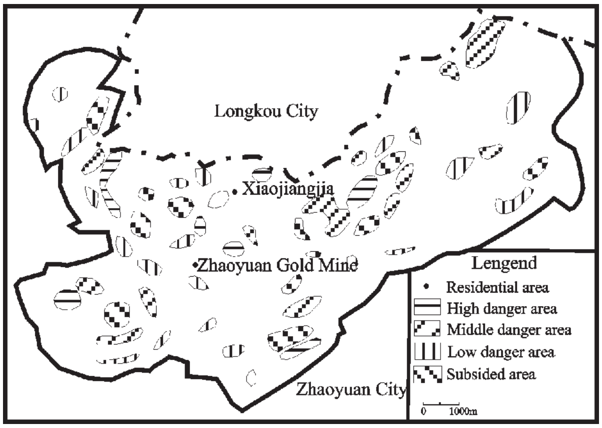

Fig. 4 Prognosticating result of vacant lot (local)

this district meets earthquake and explosion, it may subside. The way of filling mine should be taken into account.

(3) Low danger area is about 1.53km². It mainly refers to the vacant lot filled insufficiently or the small vacant lot that is covered with thick rocks. Generally speaking, those two areas are unlikely to subside at present situation.

REFERENCES

DU Pei-jun, GUO Da-zhi, 2003. The means investigation of the distill of mining subside on the basis of GIS [J]. *Journal of Image and Graphics*, 8(2): 231–235. (in Chinese)

FULI Wara S, ROSEN P A, 1998. Crustal deformation measurements using repeat-pass JERS-1 Sythetic Radar interferomaetry near the Izu peninsula [J]. *Geophysical Research*, 103: 2411–2426.

GAN Fu-ping, WANG Run-sheng, JIANG Si-hong, 2000. The technology and application of spectrum RS rock mine distinguishing on the basic of completely spectrum quality [J]. *Scientia Geologica Sinica*, 35(3): 376–384. (in Chinese)

HU Xin-li, TANG Hui-ming, 2002. The frame design of grade geologic disaster forecast by GIS [J]. *Geologic Science and Technology Information*, 21(1): 99–103. (in Chinese)

LIU Li-min, LIU Hang-long, LIAN Chuan-jie, 2003. Evaluation system of mining subsidence damage based on GIS [J]. *Journal of Disaster Prevention and Mitigation Engineering*, 23(1): 69–73. (in Chinese)

LIU Zeng-liang, LIU Zuo-cai, MAO Shan-jun, 2002. The application discussion of GIS in subside of mine [J]. *Surveying and Mapping of Geology and Mineral Resources*, 18(2): 10–11. (in Chinese)

MASSONNET D, HOLZER T, VADON H, 1997. Land subsidence caused by the Eest Mesa geothermal filed,California,observed using SAR interferometry [J]. *Geophysical Research Letters*, 23(19): 2677–2680.

QIAO Yan-xiao, LI Mi-wen, ZHANG Wei-chen, 2002. The appraise of geologic disaster and disaster environment on the basic of RS [J]. *The Chinese Journal of Geological Hazards and Control*, 13(4): 83–87. (in Chinese)

SHIRAZA M A, 1984. Land classification used to select abandoned hazardous waste study sites [J]. *Environment Management*, 8(4): 281–286.

TOWNSHENG A L, 1990. Monitoring vegetation changes in Al Medinah, Saudi Arabia, using TM data [J]. *International Journal of Remote Sensing*, 12(2): 191–194.

WANG Juan-le, DAI Zi-qiang, WU Kan, 2002. Decision-making in the prevention of subsidence by GIS and ES [J]. *Surveying and Mapping of Geology and Mineral Resources*, 18(2): 7–15. (in Chinese)

WANG Zhi-hua, LU Jie-tang, 2001. To recognize the coast of Tibet Yigong from planet images [J]. *Journal of Remote Sensing*, 5(4): 312–316. (in Chinese)

WEI Yi-ming, 1998. The analysis of the complexity of natural calamity [J]. *Sicentia Geographica Sinica*, 18(1): 21–31. (in Chinese)

WU Li-xin, GAO Jun-hai, GE Da-qing, 2004. The analysis of remote sensing of subside in coal mine on the basis of D-InSAR [J]. *Geography and Geo-information Science*, 20(2): 22–25. (in Chinese)

ZEBKER H A, GOLDSTEIN R M, 1986. Topographic mapping from interferometric Synthetic Apertur Radar observations [J]. *Geophysical Research*, 91: 4993–4999.

ZHOU Ke-ping, 2003. The application of GPS and GIS in the calamity supervision of mine [J]. *Mining Techonology*, 3(2): 5–9. (in Chinese)

ZHOU Yun-xuan, WANG Lei, 2002. The investigation of terrain analysis of the realization on the basic of DEM [J]. *Application Study of the Computer*, 12: 50–53. (in Chinese)