Risk assessment of Aeolian sand disaster on city in sandy area of Northern China based on RS, GIS and Models

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1 Introduction

China is a country with severe land degradation, dust storms and blown sand disasters (Shi et al., 2005). Dust storms mainly occur in Northern China, and can travel to south China at about 23.5^0 N (Wang et al., 2004), even far to North America (Husar et al., 2001). Statistically, there are about 70 cities, 172 county towns and 24,000 villages suffer from ASD perennially. For example, in response to serious problems with windblown sand, sand-control engineering in the Shiquanhe Basin designed and implemented (Zhang et al., 2007). Cities as centers of economic growth，technical innovation and cultural production are growth poles in contributing to developing the Western and Northern part of China (Gu and Shen, 2002). Moreover, urban development was seeing an increased growth percentage since the central government has been vigorously promoting economic development through providing wide ranges of incentives in the western region (Tian, et al., 2005). Hence, it is significant to carry out study on risk assessment of ASD to combating the disaster for sustainable cities in sandy land of Northern China. There are numerous researches concerning sandy desertification and ASD in Northern China. However, quantitative information concerning the risk of ASD on cities remains sparse in China. Such information is essential to determine where and with what intensity ASD are occurring.

The objective of present study is to set up reasonable models for comprehensive risk assessment of ASD on cities in sandy area of Northern China, from city characters detection and spatial analyses support by RS and GIS data and technology.

2 Study area and Data sources

2.1 Study area

It was estimate that there were 173.97×10^4 km^2 sandy deserts, Gobi deserts and desertified lands in the north of China before 2004, accounting for 18.12% of the country, as a part of one of four frequent occurrence regions of ASD in the world. There are totally 69 selected cities, which derived from city database of China (National Bureau of Statistics of China, 2005; NSDSP, 2006) by spatial overlay supported by GIS, according to distribution of sandy regions, the spatio-temporal distribution of ASD and the distribution of windy days (Wang et al., 2004), participated in the assessment in Northern China.

2.2 Data sources

Data used in this study include: Map of the desert and Aeolian desertification in China (Wang et al., 2005); Spatial database of soil map in China (SDBCAS, 2006); City database of China (NSDSP, 2006); Mean annual wind speed data from 1951 to 2000 (SDBCAS, 2006); Precipitation map in China (NSDSP, 2006); Landsat Thematic Mapper (TM) image (2002 – 2003). The data processing platform is ARC/GIS 9 and Erdas Imagine 8.5. Spatial data were integrated under same formation and projection in unison for spatial overlay. Land use and vegetation extracted from TM images with supervised classification method.

3 Methods

3.1 ASD system of city

According to Disaster System Theory, regional disaster system (DS) is composed of hazard-formative environments (H_E), hazard-inducing factors (H_F) and hazard-affected bodies (H_B). The stability of H_E (E), the hazard of H_F (H) and the vulnerability of H_B (V) make up of the functional system of DS. Disasters have chain characters (Shi, 2005). Based on above mentioned theory and our knowledge on ASD (Wang et al, 2000; Zhang et al, 2007), the ASD system of cities and its functional system worked out.

H_E consists of regional natural conditions (E_A) which are dry, windy with rich sand sources and local conditions (E_L) around a city such as the orientation and distance relationship between city and blown invasion sand, and vegetation. H_F includes dust storm, wind blown sand and floating dust. H_B is city, and its disaster effects (D_E) includes air pollution, economic loss, ecology breakage and harm on human health. As to function system of ASD, E results from the joint effects of E_A and E_L. E_A is the sufficient condition for H, determining the comprehensive degree of H. E_L can strengthen (weaken) H, magnify or lessen D_E at last. H behaves as the intensity of H_F, formed in an unstable environment. In theory, H should be determined by field observation of H_F, but measurement of blown sand and dust on each city in sandy area is difficult to do. Therefore, it is practical to represent H using the joint effects of E_A and E_L, which is accordant to Mileti (1999) who classified H_F and H_E as part of environment system. D_E caused by joint effect of H and V, where V is the sensitivity degree of H_B to H_F. Once H_F occurs, it will transport through certain distance before acts on H_B, in fact, E_L take effect on H just during this transporting course. In addition, the effects depend on position and distance between H_F and H_B, and the vegetation cover of ground. For instance, H_F comes from windward and adjoining area of cities is more dangerous than that from contrary direction and far away. On the other hand, more vegetation at windward and adjoining area of cities bring less dangerous because vegetation can reduce wind speed significantly.

3.2 Character detection and spatial analysis

Local characters of city area include prevailing wind direction, geomorphology (mountain and river), position-distance between sandy area and city, vegetation coverage and position-distance between vegetation and city. Such characters were identified using Man-Machine Interaction Technology from Landsat Thematic Mapper(TM) images of assessed cities, which extracted according to buffer zones created by GIS based on population size and scale of cities. By anglicizing these characters, eight typical modes of sandy area cities were worked out. Regional environmental factors such as mean annual wind speed, types of desertification, soil types and mean annual precipitation, from multi sources are converted into $1\times1\text{km}^2$ grids with support of spatial analysis function of GIS, for the purpose of calculating ASD in regional scale.

3.3 Models

As mentioned above, E, H and V cause actual hazard and loss of the ASD, namely the risk of disaster (R) $R = E \cap H \cap V$. As for H is the sufficient condition produces disaster and V is the essential condition of enlarging or weakening the disaster. So, R *is* usually regarded as a product of H (or variable can express H) With V (or variable represent V) in practical application, namely $R = H \times V$ (Wisner et al, 2003). Similar models have seen in several other literatures (Wang et al, 2000). In this study, Wisner's model is adopted but revised for integrated risk assessment of ASD, considering the fact that H is derived from E_A and E_L as pointed out previously, and the idea of H and E all belongs to environment system (Mileti, 1999). The model expressed as

$$R = (\frac{E_A + E_L}{2}) \times V \text{ ,} \qquad (1)$$

Where V is vulnerability of cities itself, E_A is the effect of regional hazard-formative environments and E_L is the influence of local conditions around cities. In the present study, E_A and E_L calculated as follows

$$E = 100\sum_{j=1}^{m}\prod_{i}^{n} W_i \text{ ,} \quad (n \subset (1,\infty), \ m \subset (1,\infty)) \qquad (2)$$

Where W_i is the weight to its previous layer index of an index, i is the layers of index; j is the number of factors participated in risk assessment of ASD on a certain cities. *R* divided into 5 grades by standardization and grading through the standard deviation method. They are the slightly dangerous (D_1), the middle dangerous (D_2), the serious dangerous (D_3), the intense dangerous (D_4) and the extremely dangerous (D_5).

4 Results and discussions

4.1 Results

Risk assessment of ASD on 69 cities carried out according to above-mentioned method, and the map worked out (Fig.1, Fig.2). Result shows: 12 cities are grading D_1, accounting for 17.4% of the total cities; 14 are D_2 and D_3 grades, accounting for 20.3%; 20 are D_4 grade, accounting for 29%; nine are D_5 grade, accounting for 13%. In a word, 62.3% of the cities receive the hazards of ASD and 42% cities are serious affected. The results suggest that a large number of cities faced with the severe dangerous situation of aeolian sand, and they urgently need to take the safety countermeasures.

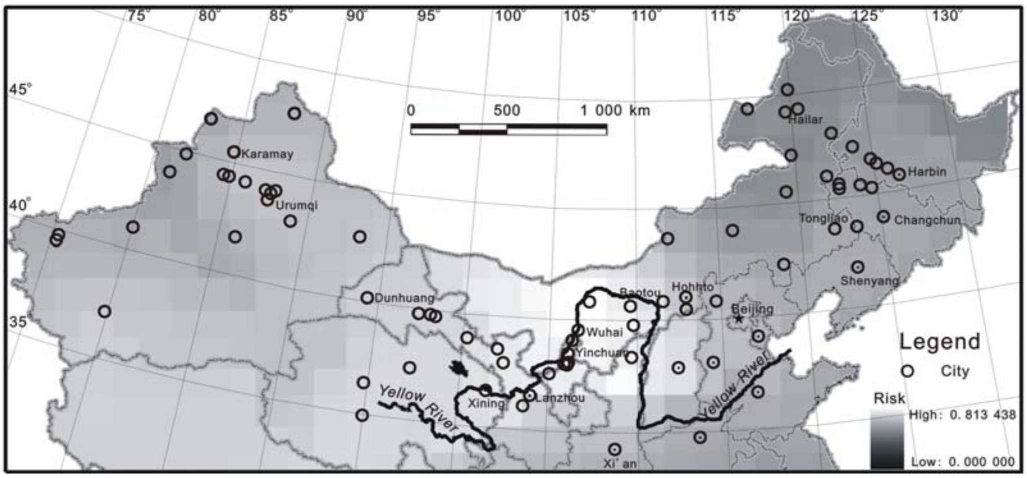

Fig.1 Output of regional risk assessment of ASD in sandy area of Northern China

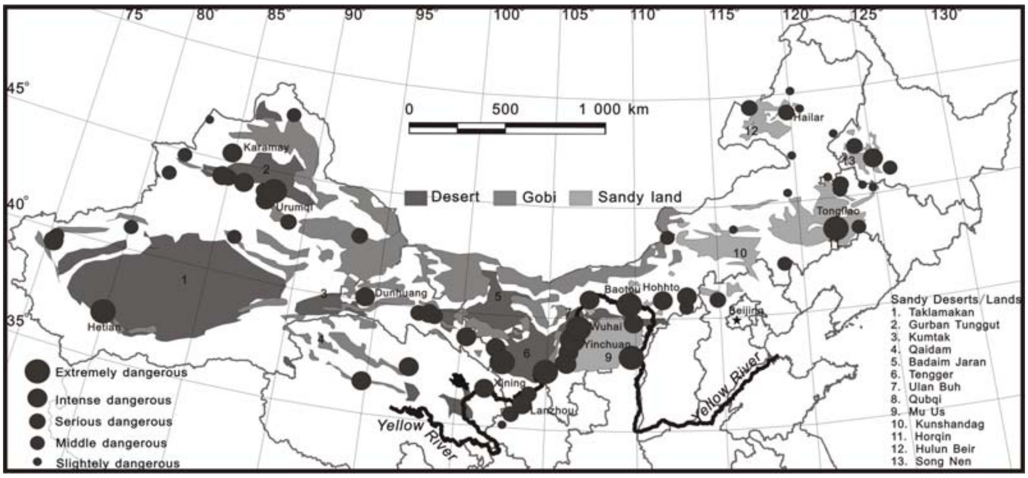

Fig.2 Output of risk assessment of ASD on cities in sandy area of Northern China

4.2 Discussions

Generally, the risk grades increase gradually with increasing desert and sandy land mobility, with decreasing precipitation from east to west, considering physical geography condition and economic development. The extremely and intense dangerous cities lie in the middle part and the western region mainly, slightly and middle dangerous cities are distributed in Xinjiang and Songlun sandy land. According to quantity and dangerous grade of cities, the middle part of Northern China is key area that ASD on cities occurs. It suggests that population increase and human disturbance such as over cultivation and over grazing in this area are largely responsible for current desertification and ASD on cities, under the background of global climate change. A significant reduction of ASD may require a comprehensive approach, which deals with the entire urban area and its immediate surroundings, particularly to reducing the availability of erodible particles by means of planting or paving all exposed land surfaces.

5 Conclusions

According to disaster system theory, the risk of Aeolian sand disasters (ASD) on cities in sandy area of Northern China assessed, with the two-layer model from city characters detection supported by RS and GIS data and technology. Results show that nearly 70% cities are in serious condition under aeolian sand threat, which demand urgently to take safety countermeasures. Generally, extremely and intense dangerous cities lie in the middle part and the western region mainly, slightly and middle dangerous cities are distributed in Xinjiang and Songlun sandy land. According to quantity and dangerous grade of cities, the middle part of Northern China is key area that ASD on cities occurs. Such research will be beneficial to understanding and managing the ASD for ecological security and sustainable development of cities in arid and semi-arid sandy regions.

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