

# ECOLOGICAL RISK ZONE MAPPING FOR HIGH-SULPHUR GAS EXPLOITATION WITH GEOGRAPHIC INFORMATION SYSTEM

Minxia Zhang, Xuan Zhang, Fanghua Hao\*, Cheng Zhao, Wei Ouyang, Dan Wang

School of Environment, State Key Laboratory of Water Environment Simulation, Beijing Normal University, Beijing, 100875, China

**KEY WORDS:** Ecological Risk Analysis, Geographic Information System, Landscape, Ecosystem, Spatial Analysis, Mapping

## ABSTRACT:

The exploitation of fossil fuels is a main factor for environmental deterioration, especially the large-scale exploitation of high-sulphur gas because of the toxicity of sulphur. There exist many different types of environmental risk threats in gas exploitation, regardless of whether it is caused by human activity or natural calamity. It is impossible to control nature, but it is possible to map ecological risk zones and thereby minimize the frequency of accident, avert ecological disaster. In this paper, Puguang high-sulphur gas field was taken for a case study. Regional ecological risk assessment of high-sulphur gas exploitation was discussed through the advanced regional ecological risk assessment for the first time. A geographic information system was used as the data integration analysis platform, and the topographic data and land-use information of Puguang gas field in 2001 as the main data source. Comprehensive ecological risk index was constructed based on the topographic data, land-use structure and other different risk source factors, being calculated by assigning subjective weights to the classes of risk source factors according to their sensitivities to ecological risks or their risk-inducing capabilities. The system sampling method was applied to make the risk spatial variable. After sampling, the semi-variance analysis and block Kriging were conducted to render the map of ecological risk distribution. As a result, four categories of ecological risk ranging from very intense to light were formed according to comprehensive ecological risk index. The result indicated that almost 21.3% of the study area was predicted to be under very intense and intense-risk zones.

## 1. INTRODUCTION

Ecological risk assessment, which is based on the integrated multidisciplinary knowledge (including environmental science, ecology, geography, biology), is a new field of study for evaluating the risks associated with a possible eco-environmental hazard under uncertainty. It uses the means of risk analysis, like mathematics, and advanced space technologies like remote sensing, geographic information system (GIS) analysis, to predict, analyze and evaluate the damage that the uncertain disasters or accidents may bring for the ecosystem. Ecological risk assessment aims to provide regional risk management theoretical and technical support.

As provided by many relative studies, the large-scale exploitation of fossil energy, especially high-sulphur gas exploitation because of the toxicity of sulphur, has a dramatic impact on the health of ecological system. In the process of fossil energy exploitation, there exist many different types of environmental risk threats (accidental chemical reactions, release of hazardous gases/contamination) triggered by a probable technological mishap or a natural calamity. All these risks can lead to degradation of environment of energy exploitation region. In order to control and reduce these problems, ecological risk assessment of energy exploitation and utilization projects has become a primary study in the field of environmental protection in recent years. But most of studies paid close attention to ecological risks of hazardous chemicals and biomass fuels (like liquefied petroleum gas) during storage and transportation, only few studies covered regional ecological risk assessment of energy exploitation. This paper discussed regional ecological risk assessment of high-sulphur gas exploitation using the advanced regional ecological risk assessment for the first time, and took Puguang high-sulphur

gas field for a case study, which is the largest gas field in our country that had been found and has more ecological risks because of its specific character of high sulfur-bearing (the sulfur content in gas reached  $219.9 \text{ g/m}^3$ ).

Puguang high-sulphur gas field located in Xuanhan County, the Northeast Sichuan of China, stretched over an area of  $1116 \text{ km}^2$  (Fig. 1). This region has a complex topography, diversified ecological environment, and the higher population density, which has more potential risks for gas exploitation. It is more viable to map ecological risk zones of gas exploitation region rather than to control the natural rules, which can minimize the frequency and probability of variable ecological risks. A precise ecological risks evaluation and decisions on solutions can only be satisfactorily made when an ecological risk zone map is available. In this paper, on the basis of analysis of the factors responsible for ecological risk of gas exploitation, an attempt was made to prepare an ecological risk zone map by integrating a satellite image, topographical and other ancillary data from a GIS for the study area. And this study is an attempt to exploit the capabilities of remote sensing and GIS techniques and to suggest an appropriate methodology for ecological risk zone mapping. Such maps will help gas field manager prevent or minimize ecological risk in the process of gas exploitation.

\* Corresponding author: Tel: 86-10-58807937; Fax: 86-10-58807937. E-mail address: fanghua@bnu.edu.cn. Supported by the National Nature Science Foundation of China (Grant No.40771192)

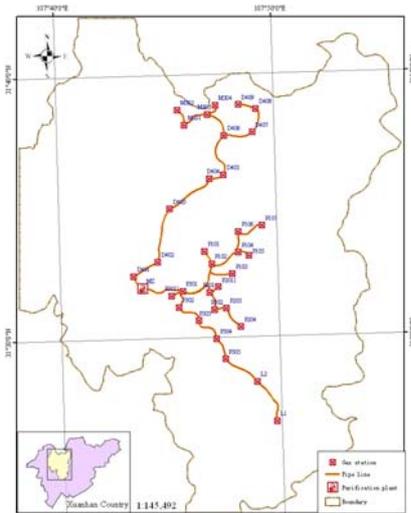


Fig. 1. Location of study area

## 2. FACTORS RESPONSIBLE FOR ECOLOGICAL RISK IN THE STUDY AREA

Considering that the resource underground is the determinant of the gas exploitation construction, the position of the gas station depends on the oil and gas storage. Therefore, the risk of accident in the exploitation is restricted not only by the technology and management of risk, but also by the surroundings of the gas field. The ecological risk proneness of any gas field depends on many factors such as characteristics of gas, topography, soil erosion susceptibility, etc. The most important factors leading to high ecological risk probability of Puguang high-sulphur gas filed are the following:

### (1) Characteristics of gas

Puguang high-sulphur gas filed has specific characteristic of high sulfur-bearing, the sulfur content in gas reached  $219.9 \text{ g/m}^3$ . As we all know, hydrogen sulfide is with severe toxicity, once there was an accident in the gas field, the sour gas would leak, which is serious danger to the ecological environment and the people around the gas field.

### (2) Complex topography

The complexity of the topography and geomorphology in the study area increases the risk of the gas exploitation. The maximum slope of this area is  $52^\circ$ . The greater the slope is, the more easily the soil and water loss may happen. Also, it would increase the risk of the accidents during exploitation. The range of the slope in the study area were classified as  $<3^\circ$ ,  $3\sim5^\circ$ ,  $5\sim10^\circ$ ,  $10\sim25^\circ$ ,  $25\sim35^\circ$  and  $>35^\circ$ .

### (3) Soil erosion susceptibility

The soil erosion may cause the geological disasters. Correspondingly, if the gas exploitation is occurred in these areas, once there was a geological disaster, it might trigger the blowout, leakage, or the pipe break accident.

### (4) Flood susceptibility

Puguang high-sulphur gas filed is located in a flood-prone area, where there were two rare catastrophic flood in consecutive years in 2004 and 2005. According to the elevation data, the area, which is higher than the highest recorded water level, is not prone to experience a flood accident, while in the gas field which is lower than the highest recorded water level, the accident risk triggered by flood is relatively high.

### (5) Distance from road

Human, vehicular movement and activities on roads provide ample opportunities for engineering accident of Puguang high-sulphur gas filed. Gas station or pipeline located near roads are therefore more ecological risk probability. The study area is traversed by many roads, allowing local people to become the cause of engineering accident of gas filed.

### (6) Proximity to settlements

High-sulphur gas filed contains hydrogen sulfide, which is hyper-toxic. The blowout and leakage accidents are always accompanied by the leakage of the sour gas. If the settlements are nearby the gas field, the pervasion of the sour gas will create grave consequence, which can raise the risk of exploitation.

## 3. METHOD

Based on the factors responsible for ecological risk according to the specific characteristic of Puguang high-sulphur gas filed, the present study was confined to the following parameters: slope, soil erosion susceptibility, flood susceptibility, proximity to settlements, distance from road.

A slope map was prepared utilizing a DEM image at 1:25,000 scale of the corresponding area (Fig.2). A soil erosion susceptibility map was protracted by combining the layer data of the plant cover and sloped farmland, providing by ENVI (Fig.3). According to the highest recorded water level of the area in 2004, 2005, the area where the attitude is lower than it, which is called flood susceptible area is queried separately using Map Query of Arcview GIS. After comparing with the record about the disaster area in 2005, a precise flood susceptibility map was fixed (Fig.4). The information of settlements and roads was extracted from the 1:250000 topography data of the national fundamental geographic information centre. Create buffer utility of ARC/INFO was used to create buffer zones around the road and settlement locations. Corridors of 500, 1000, 1500, 2500 and  $>2500$  m perimeter were created around the settlement locations and digitized as polygon data. Similarly, buffer zones of 500, 1000, 1500 and  $>1500$  m perimeter were created around the roads (Fig.5, Fig.6).

(1) Considering there were great differences among the factors and their weights, the analytic hierarchy process (AHP) combining with expert evaluation method were applied to determine the weights. The experts selected to determine the weights are professionals working for ecological risk and petrochemical industry, as well as local governors. The factors and how they affect the ecological risk of high-sulphur gas filed were evaluated by these experts. The different classes in the thematic maps were labeled separately based on their sensitivity to ecological risk as very high, high, moderate or low. Then suitable weights were assigned. (Table 1).

(2) All the thematic maps (layers) were then integrated using the union process of GISs : Raster Calculator of Spatial Analyst Module. The equation used in a GIS for the ecological risk modeling and for mapping the ecological risk areas is:

$$ER=8T_{i=1-6}+5S_{j=1-4}+5F_{k=1-2}+3H_{l=1-5}+3R_{m=1-4}$$

where ER is the numerical index of ecological risk, T slope factor (with 1-6 classes), S indicates soil erosion susceptibility (with 1-4 classes), F the flood factor (with 2 classes), H indicates proximity to human habitation (with 1-5 classes), R the road factor (with 1-4 classes). The superscripts i, j, k, l, m indicate subclasses based on importance in determining the ecological risk.

(3) Finally, criterion-based analysis (Table 2) was carried out to create the ecological risk zone map showing different categories (Fig.7).

#### 4. WEIGHTING FACTORS FOR DIFFERENT GROUPS

The input information on ecological risk influencing factors is in descriptive form and reveals the parameters favoring the ecological risk. In order to achieve effective conclusions through computation and other mathematical operations in the subsequent GIS analysis, the descriptive information was converted into an ecological risk index and a rating system. The factors that influence the ecological risk in the study area were analyzed in the following order of importance: slope, soil erosion susceptibility, flood susceptibility, proximity to settlements and road network.

After determining the influence of each factor on ecological risk, the different classes of each factor were given suitable ratings. A higher rating indicates that the factor has a high degree of influence on the ecological risk in the study area. The considered factors were then integrated for calculating the ecological risk index. (Table 1)

#### 5. MODELLING FROM A GIS

Before integration, the thematic layers representing slope, soil erosion susceptibility, flood susceptibility, settlement corridors and road corridors had 187, 98, 59, 119 and 108 polygons, respectively. After integration using the ecological risk model, the final map contained 6250 polygons, each having a minimum

weighting of 40 and maximum weighting of 163. Ecological risk zones were delineated by grouping the polygons of the integrated layer into different risk zones. A criterion-based analysis has been performed for demarcating the upper and lower limits of the ecological risk index (Table 2). The criterion analysis was applied to classify this map into four ecological risk zone classes. The area of very high ecological risk was delineated by grouping the polygons that have weights >102 in the final integrated layer. The lower weight limit (102) of the very high ecological risk zone was derived by adding together the very high risk prone weight of slope, moderate risk prone weight of soil erosion susceptibility, high risk prone weight of flood susceptibility and high risk prone weight of road/settlement corridors. The polygon corresponding to the high ecological risk zone was obtained by grouping polygons having weights between 90 and 101. The lower weight limit (90) was derived by adding very high risk prone weight of the slope layer, high risk prone weight of flood susceptibility layer and moderate risk prone weight of all other layers. The polygon corresponding to the moderate ecological risk zone was obtained by grouping polygons having weights between 60 and 89. The lower limit (60) for the moderate ecological risk zone was derived by adding low risk prone weight of flood susceptibility layer and moderate risk prone weight of all other layers. Polygons having a weight of <60 were categorized under low ecological risk zones. These were classified separately on the final ecological risk zone map (Fig.7)

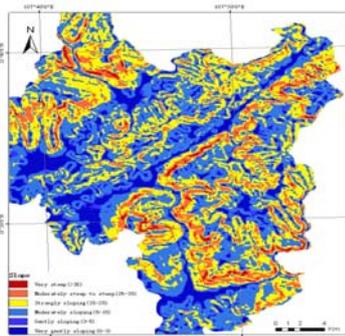


Figure 2. Slope map of study area

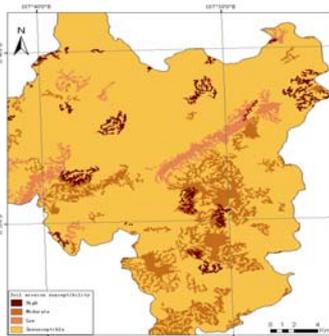


Figure 3. Soil erosion susceptibility of study area

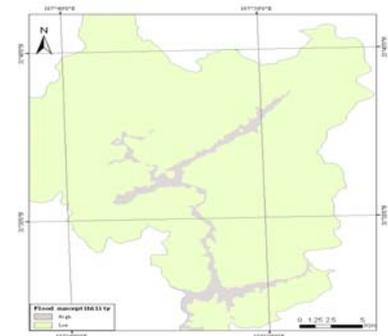


Figure 4. Flood susceptibility map of study area

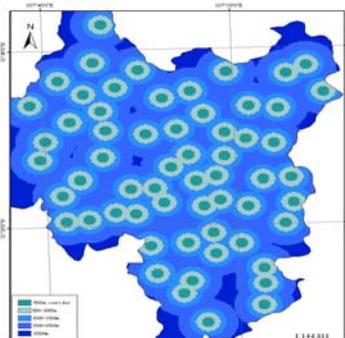


Figure 5. Settlement buffer map of study area

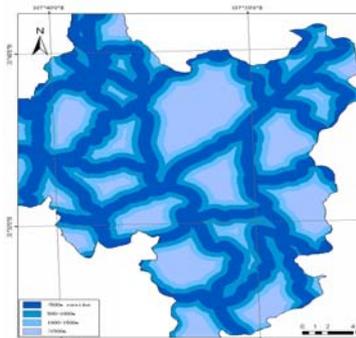


Figure 6. Road buffer map of study area

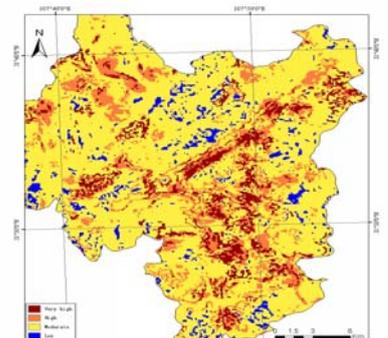


Figure 7. Ecological risk map of study

#### 6. RESULTS AND CONCLUSION

As a result, four categories of ecological risk ranging from very intense to light were derived according to the order of

integrative ecological risk index. And the ecological risk zones of Puguang high-sulphur gas exploitation region were delineated in the light of categories of ecological risk. Table 3 describes the resultant ecological risk zones and the

corresponding degree of ecological risk. Out of the total area of 1116km<sup>2</sup>, 7.8% falls in the category of ' very high ' ecological risk zone, followed by 13.5, 71.1 and 7.6%, respectively, in the categories ' high ', ' moderate ' and ' low '. The result indicated that almost 21.3% of the study area was predicted to be under very intense and intense-risk zones.

And the ecological risk zone map in our study reflects both the likelihood of ecological risk and the severity of risk consequences. This GIS-based ecological risk analysis method of the study area can provide regional risk management theoretical and technical support for Puguang high-sulphur gas filed and any other regional energy exploitation project.

## REFERENCES

- Ashford NA. Industrial safety: the neglected issue in industrial ecology. In: Ashford NA, Cote RP, editors. *Industrial ecology [ special issue ]*. *J Cleaner Prod.* 1997, 5(1/2):15-21.
- Zheng Hui, Liu Guojun. Analysis of regional ecological risk based on landscape structure[J]. *China Environmental Science.* 1999,19(5):454-457.
- Bartell SM, Lefebvre G, Kaminski G, Carreau M, Campbell KR. An ecosystem model for assessing ecological risks in Quebec rivers, lakes and reservoirs. *Ecol Model.* 1999, 124:43-67.
- Maxwell T, Costanza R. Distributed modular spatial ecosystem modelling. *Comput Simul Special Issue Adv Simul Methodol.* 1995, 5(3): 247-262.
- Campbell KR, Bartell SM. Ecological models and ecological risk assessment. In: Newman MC, Strojan CL, editors. *Risk assessment: logic and measurement*. Chelsea, MI: Ann Arbor Press. 1998, 69-100.
- Ortigosa GR, De Leo GA, Gatto M. VVF: Integrating modeling and GIS in a software tool for habitat suitability assessment. *Environ Model Softw.* 2000,15:1-12.
- Thomas Kistemann, Friederike Dangendorf, Martin Exner. A Geographical Information System (GIS) as a tool for microbial risk assessment in catchment areas of drinking water reservoirs. *Int.J.Hyg.Enviro.Health.* 2001,203:225-233.
- PamelaJ. Sydelko, Ihor Hlohowskyj, KimberlyMajerus, etc. An object-oriented framework for dynamic ecosystem modeling: application for integrated risk assessment. *The Science of the Total Environment.* 2001,274:271-281.
- AnilK.Gupta, Inakollu V. Suresh, Jyoti Misra, Mohammad Yunus. Environmental risk mapping approach: risk minimization tool for development of industrial growth centres in developing countries. *Journal of Cleaner Production.* 2002, 10: 271-281.
- Anderson, R.P., Lew, D., Peterson, A.T. Evaluating predictive models of species' distributions: criteria for selecting optimal models. *Ecological Modelling.* 2003, 162:211-232.
- Tor-Gunnar Vagen. Remote sensing of complex landuse change trajectories— a case study from the highlands of Madagascar. *Agriculture, Ecosystems and Environment.* 2006, 115: 219-228.
- WilliamE. Banks, Francesco d'Errico, A. etc. Human ecological niches and ranges during the LGM in Europe derived from an application of eco-cultural niche modeling. *Journal of Archaeological Science* xx. 2007, 1-11.
- Carola Alexandra Schriever, Matthias Liess. Mapping ecological risk of agricultural pesticide runoff. *Science of the Total Environment.* 2007, 384:264-279.
- Huang Shengbiao, Wang Zijian, Qiao Min. Ecological risk assessment (ERA) at the regional scale[J]. *Journal of Environmental Sciences.* 2007, 27(5):705-713.
- Antunes SC et al. Contribution for tier 1 of the ecological risk assessment of Cunha Baixa uranium mine ( Central Portugal ): II. Soil ecotoxicological screening. *Science of the Total Environment* (2007), doi: 10.1016/j.scitotenv.2007.07.053.

Serial no.	Variables	Classes	Ratings	Risk sensitivity
1	Slope (weight=8)	(1)0-3°	2	Low
		(2)3-5°	3	Low
		(3)5-10°	4	Moderate
		(4)10-25°	5	High
		(5)25-35°	6	Very High
		(6)>35°	10	Very High
2	Soil erosion susceptibility (weight=5)	(7)High	8	High
		(8)Moderate	4	Moderate
		(9)Low	3	Low
		(10)Insusceptible	1	Low
3	Flood susceptibility(weight=5)	(11)High	6	High
		(12)Low	2	Low
4	Habitation(weight=3)	(13)<500m corridor	7	Very High
		(14)500-1000m	5	High
		(15)1000-1500m	3	Low
		(16)1500-2500m	2	Low
		(17)>2500m	1	Low
5	Road(weight=3)	(19)<500m corridor	8	Very High
		(20)500-1000m	6	Very High
		(21)1000-1500m	4	Moderate
		(22)>1500m	2	Low

Table 1 Weights and ratings assigned to variables and classes for ecological risk modelling

Slope weighting category (T)	Soil erosion weighting category (S)	Flood susceptibility weighting category (F)	Settlement buffer weighting category (H)	Road buffer weighting category (R)	Ecological risk weighting category	Ecological risk index ( $8T_{i=1-6} + 5S_{j=1-4} + 5F_{k=1-2} + 3H_{l=1-5} + 3R_{m=1-4}$ )
V <sub>T</sub>	H <sub>S</sub>	H <sub>F</sub>	V <sub>H</sub>	V <sub>R</sub>	V	163
V <sub>T</sub>	H <sub>S</sub>	H <sub>F</sub>	H <sub>H</sub>	V <sub>R</sub>	V	156
V <sub>T</sub>	H <sub>S</sub>	H <sub>F</sub>	H <sub>H</sub>	V <sub>R</sub>	V	147
H <sub>T</sub>	H <sub>S</sub>	H <sub>F</sub>	V <sub>H</sub>	V <sub>R</sub>	V	139
H <sub>T</sub>	M <sub>S</sub>	H <sub>F</sub>	V <sub>H</sub>	H <sub>R</sub>	V	135
H <sub>T</sub>	M <sub>S</sub>	H <sub>F</sub>	H <sub>H</sub>	H <sub>R</sub>	V	128
V <sub>T</sub>	M <sub>S</sub>	M <sub>F</sub>	V <sub>H</sub>	M <sub>R</sub>	V	112
V <sub>T</sub>	M <sub>S</sub>	H <sub>F</sub>	H <sub>H</sub>	H <sub>R</sub>	V	102
V <sub>T</sub>	M <sub>S</sub>	L <sub>F</sub>	M <sub>H</sub>	M <sub>R</sub>	H	90
M <sub>T</sub>	M <sub>S</sub>	L <sub>F</sub>	M <sub>H</sub>	M <sub>R</sub>	M	60
M <sub>T</sub>	M <sub>S</sub>	L <sub>F</sub>	M <sub>H</sub>	L <sub>R</sub>	L	53
L <sub>T</sub>	L <sub>S</sub>	L <sub>F</sub>	L <sub>H</sub>	L <sub>R</sub>	L	40

Subscript: T : Slope factor, S: Soil erosion factor, F Flood susceptibility factor, H: human habitation, R: road factor. Letter: V: very high, H: high, M: moderate, L: low.

Table 2 Criterion-based analysis for ecological risk zoning of Puguang high-sulphur gas field

Ecological risk zones	Degree of ecological risk	Description of ecological risk zones	Propn of total area (%)
I	Very high	Area with steep topography, and very high soil erosion susceptibility. Meanwhile, these zones are over the highest recorded water level. It is with great risk to gas exploitation.	7.8%
II	High	Area with relatively steep topography, high soil erosion susceptibility. The gas fields in these zones are nearby roads, which can be affected by human impact and natural disasters. The risk is relatively high.	13.5%
III	Moderate	Area with gently slope, and moderately soil erosion susceptibility. The ecological risk belongs to middle level for gas exploitation.	71.1%
IV	Low	There are rarely natural disasters in these zones, and far from the settlements and roads. It is less risky to exploit gas there.	7.6%

Table 3 Extent of ecological risk zones