Human and Ecological Risk Assessment, 21: 297–306, 2015

ISSN: 1080-7039 print / 1549-7860 online
DOI: 10.1080/10807039.2014.913441

A GIS-Based Ecological Safety Assessment of Wushen Banner, China

Donghua Pan,[1] Huicong Jia,[2] and Yi Yuan[1]
[1]National Disaster Reduction Center of China, Ministry of Civil Affairs of the People's Republic of China, Beijing, P.R. China; [2]Key Laboratory of Digital Earth Science, Institute of Remote Sensing and Digital Earth, Chinese Academy of Sciences, Beijing, P.R. China

ABSTRACT

Eco-environmental sensitivity assessment as a new research field on sustainable development is the foundation for establishing early warning systems for ecological safety and environmental management. Many scholars have started to study national and social safety from an ecological point of view. Wushen Banner, which is located in the transitional area between Ordos Plateau in Inner-Mongolia and Loess Plateau in the north of Shanxi Province, is in the center of the Mu Us Desert, an area with a fragile environment. From the perspective of regional ecological safety, the regional eco-environmental sensitivity assessment index system was established, including sensitivity to soil erosion, land desertification, bioinhabitation, and human settlements. Based on the grid module supported by the geographical information system (GIS), changing the spatial data into a 30 m × 30 m grid, through grid average weight calculation, the eco-environmental sensitivity assessment distribution map of Wushen Banner was compiled. The results show that an acute sensitivity area, located in the northwest area of Wushen Banner, represents about 29.1%. The main features of the physical environment are very poor. Soil salinization and grassland desertification are serious. This research could provide a scientific basis for exploring sustainable development of regional resources and environment as well as guiding local development construction and ecological risk management.

Key Words: Wushen Banner, grid, spatial analysis, ecological safety, eco-environmental sensitivity assessment.

Received 2 November 2013; revised manuscript accepted 22 March 2014.
Address correspondence to Huicong Jia, Key Laboratory of Digital Earth Science, Institute of Remote Sensing and Digital Earth, Chinese Academy of Sciences, No. 9 Dengzhuang South Road, Haidian District, Beijing 100094, P.R. China. E-mail: jiahc@radi.ac.cn
Color versions of one or more of the figures in the article can be found online at www.tandfonline.com/bher.

INTRODUCTION

Eco-environmental security is an important part of state security as well as global security and economic security. A natural ecological system, composed of water, soil, air, forest, and grassland, marine and biological life, is the material base for humans. When a natural ecological environment around a country or a city can meet the demands of sustainable development for society and economy, the situation has security; otherwise, it does not have security (Hu *et al.* 2012). Eco-environmental sensitivity is the degree of sensitivity of ecosystems reacting to various environmental variations and human activities. It reflects the possibility to assess ecology unbalance and eco-environmental problems. Under a natural state, various ecology processes maintain a correspondingly steady coupling relation in order to ensure a correspondingly steady ecosystem. When outside interferences exceed an ecosystem's limit, this coupling relation is broken, and some serious problems may happen that result from expansion of some ecology processes. Therefore, the essence of eco-environmental sensitivity assessment is the probability assessment of potential ecological environment problems in specific ecological processes under natural conditions (Liu *et al.* 2003).

As a key area of desertification research in China, the Mu Us Desert is located in the agro-pastoral transitional zone in northern China. There are many studies of the Mu Us Desert (Li *et al.* 1998; Wu and Ci 1999, 2002; Wang *et al.* 2013). Currently, the study of ecological sensitivity is more concentrated on a particular ecological problem or a provincial scale (Liu *et al.* 2002; Zhong *et al.* 2003; He *et al.* 2004; Jin *et al.* 2004); while there are few small-scale regional studies that focus on the eco-environmental sensitivity assessment. Based on geographical information system (GIS), the eco-environmental sensitivity was assessed through use of a single-factor analysis and multi-factor integrated combination, yielding eco-environmental sensitivity distribution and geographical differences. This outcome is expected to provide a basis for regional ecological construction and environmental protection planning programs.

OVERVIEW OF RESEARCH AREA

Wushen Banner is in the southwest of Ordos City in the Inner Mongolia Autonomous Region, southernmost of the Inner Mongolia Autonomous Region, in the center of the Mu Us Desert, between 37°38′54″～39°23′50″N, 108°17′36″～109°40′22″E. Wushen Banner belongs to a region of temperate continental monsoon climate. Its characteristics are drought, strong wind, much sand, dry climates, strong solar radiation, and great temperature difference between day and night. The average rainfall is 347.5 mm. The average temperature is 6.4 to 7.5°C. The average wind speed is 2.7～3.5 m/s; the wind direction is mainly to the northwest. The wind is blowing in the spring. Aeolian sandy soil is the main soil type. Natural vegetation mainly includes sandy, meadow, and dry grassland vegetation. Sandstorms, drought, and soil erosion are the three natural disasters affecting Wushen Banner (Water Power Bureau of Wushen Banner 1999).

RESEARCH METHODS

Ecological risk identification and ecological sensitivity comprise the elements of ecological risk assessment, while ecological health includes three aspects, *i.e.*, ecological completeness, ecosystem vigor, and ecosystem resilience. In the studies of ecological security assessment, the rational combination of ecological risk and ecological health and the establishment of an integrated measure index system based on a spatial scale are needed. Vulnerability refers to the potential for loss (Cutter *et al.* 2008) and more specific definitions qualify the potential for loss by factoring in the likelihood of exposures and susceptibility to damage. Etkin *et al.* (2004) define vulnerability as the propensity to suffer some degree of loss from a hazardous event. Ecological sensitivity is the degree of response to environment changes that are caused by the integrative action of internal and external factors (Huang *et al.* 2013).

Assessment of sensitivity should first aim at a specific eco-environmental problem and then undertake a comprehensive analysis, analyse the features of regional eco-environmental sensitivity distribution. Several affecting factors for each ecological issue are then selected, under an ArcGIS environment, using spatial analysis algebra functions, to provide a comprehensive analysis of the impact of various factors, yielding an eco-environmental sensitivity distribution map was obtained. Then through further integration, the regional eco-environmental sensitivity distribution map is developed by combining the corresponding status assessment standards. These results in the development of five grades of eco-environment sensitivities: acute, high, medium, low, and none (Table 1). Factor sensitivity ratings were scored from high to none as 9, 7, 5, 3, and 1, respectively.

Data Source and Processing

Soil erosion sensitivity

The rainfall erosion value was obtained by using the simple formula put forward by Wang (1987), which is suited for application to drought regions. Based on the region and the surrounding weather station data, through a spline interpolation function of ArcGIS, a regional *R*-value distribution map was obtained. Using undulating topography degrees for assessment of soil erosion terrain assessment, we used a 1:250,000 DEM (digital elevation model) raster grid point as a target. An undulating topography of the raster matrix was built based on the grid module FOCALRANGE function of ArcGIS. The soil texture factor was processed from a soil texture map (1:3,000,000), which was compiled in 1992 by the Soil Survey Office of the Inner Mongolia Autonomous Region. The vegetation factor was derived from the TM Image for Wushen Banner. A Thematic Mapper (TM) is one of the Earth observing sensors introduced in the Landsat program.TM is a whisk broom scanner that takes multi-spectral images across its ground track. It does not directly produce a thematic map. The Thematic Mapper has become a useful tool in the study of albedo and its relationship to global warming and climate change. Landsat 7 carries an enhanced TM sensor known as the Enhanced Thematic Mapper Plus (ETM+). Finally, according to the classification standards of Rainfall Erosion, Soil texture,

Table 1. Assessment factors and grade of eco-environmental sensitivity in the Wushen Banner.

Type	S factors	No S	Low S	Medium S	High S	Acute S
Soil Erosion S	Rainfall Erosion	<25	25–100	100–400	400–600	>600
	Soil texture	Gravel, Sand	Sand, Clay	Sand, Loam	Sandy loam, Salty clay, Loam	Clay, Sandy silt, Silt
	Hypsography/m	0–20	20–50	51–100	101–300	>300
	Vegetation	Water, Swamp	Forest, Meadow	Sparsely fruit plain	Hungriness	No Vegetation
Desertification S	Humid index	>0.65	0.5–0.65	0.20–0.50	0.05-0.20	<0.05
	>6 m/s gale days	<15	15–30	30–45	45–60	>60
	Soil texture	Bedrock	Viscidity	Gravel	Loam	Sandiness
	Vegetation cover	Dense	Moderate	Less	Sparsely	Bare Land
Habitat S	Groundwater salinity/(g/L)	<1	1–3	3–10	10–25	>25
	Distance to road/km	>20	20>R>10	10>R>5	<5	0.5
	Function of surface water	Unrelated	Low function	Transition	Source	Fetch Region
Grade Value		1	3	5	7	9
Grade Standards		1.0–2.0	2.1–4.0	4.1–6.0	6.1–8.0	>8.0

S = Sensitivity.

Hypsography and Vegetation shown in Table 1, sensitivity distribution maps of soil erosion for each sensitivity factor was developed.

Desertification sensitivity

According to multi-year rainfall and evaporation data for the meteorological sites, river basin rainfall and evaporation (30 m × 30 m grid) were obtained through interpolation. The humid index map resulted by computing the ratio. Days of wind speed greater than 6 m/s day during September to May were obtained through geostatistical interpolation. The vegetation cover used a TM image in 2005 as the data source, extracting NDVI, then graded into grid. The Normalized Difference Vegetation Index (NDVI) is a simple graphical indicator that can be used to analyze remotesensing measurements, typically but not necessarily from a spaceplatform, and assess whether or not the target being observed contains live green vegetation. The soil texture factor refers to the soil erosion sensitivity extraction methods. Finally, according to the classification standards of humid index, >6 m/s gale days, soil texture, and vegetation cover given in Table 1, sensitivity distribution maps of desertification for each sensitivity factor were obtained.

Habitats sensitivity

Groundwater salinity was used as the quantitative index for degree of regional salinity. The groundwater salinity data came from hydrogeological maps compiled by the Geological Bureau of Inner Mongolia No. 1 Hydrological Team in 1973 (1:500,000). Using the Buffer wizard module of ArcGIS software, the main roads' buffer zones in the research region were analyzed based on classification standards of groundwater salinity, distance to road and function of surface water given in Table 1. According to water environmental function zone of the Erdos Plateau, the surface water function was spatial analyzed based on the relationship between lakes, rivers, and people's production and daily life around and self-function. Finally, according to classification standards shown in Table 1, sensitivity distribution maps for the eco-environment of each sensitivity factors were obtained. The water function zoning is not only the basis for water resource management but also a basic work of the exploitation and protection of water resources. The aims of water function zoning are to carry out the environment quality management and the water pollution control based on the natural attributes of water, the social demand, and the target requirements of water functional zone (Yuan 2001). It makes the water resources create the biggest economic, social, and environmental benefits. At the same time, it promotes the development of society and economy without destructing the protection target of water resources (Han *et al.* 2001).

Assessment Model

A calculation model for soil erosion assessment is $di = \sum_{i=1}^{4} Si \times Pi$, in which di stands for soil erosion degree (%), Si: ratio of various levels of average erosion and the sum of such grades of average erosion modulus. Pi stands for percentage of erosion area for each grade accounting for statistical administrative region area.

Table 2. Results of eco-environmental sensitivity in the Wushen Banner.

	Soil erosion S		Desertification S		Habitats S		Integrated S	
S grade	Area/ km^2	Proportion	Area/ km^2	Proportion	Area/ km^2	Proportion	Area/ km^2	Proportion
No S	826.2	7.1%	477.4	4.1%	2882.1	24.8%	1464.1	12.8%
Low S	2561.6	22.0%	2398.8	20.6%	7725.1	66.3%	1289.2	11.1%
Medium S	2432.5	20.9%	6552.5	56.3%	616.0	5.3%	1649.6	14.2%
High S	882.9	7.6%	1321.7	11.4%	408.7	3.5%	3853.8	33.1%
Acute S	4941.5	42.4%	882.7	7.6%	10.5	0.1%	3388.0	29.1%

S = Sensitivity.

The models for desertification and eco-environmental sensitivity are $DS_j = \sqrt[4]{\prod_{i=1}^{4} Ci}$ and $BS_j = \sqrt[3]{\prod_{i=1}^{3} Ci}$, respectively, in which, DS_j and BS_j stand for desertification and eco-environmental sensitivity index of No. j space unit (a 30 m × 30 m grid), respectively, Ci stands for sensitivity degree value of No. i factor of desertification and eco-environmental sensitivity. The integrated regional eco-environmental sensitivity assessment model is $MSj = \sum_{i=1}^{3} Si \times Wi$, in which MSj stands for integrated index of eco-environmental sensitivity of No. j space unit, Si stands for sensitivity degree value of No. i factor, Wi stands for weight of influencing eco-environmental sensitivity factors. According to regional characteristics of Wushen Banner and data integration, using the expert evaluation method, the weights of soil erosion sensitivity, desertification sensitivity, and eco-environmental sensitivity are 0.4, 0.4, and 0.2, respectively.

RESULTS AND ANALYSIS

Eco-Environment Sensitivity Spatial Distribution Characteristics

Soil erosion sensitivity

Wushen Banner is located in a sandstorm region. Most of the soil is aeolian sandy soil and contains less physical clay, loose and poor corrosion resistance, coupled with low vegetation cover. Soil erosion is sensitive, high and acute sensitivity areas accounted for 7.6% and 42.4%, respectively. The main form of erosions is wind erosion and wind–water erosion crisscross the region. Wind erosion is mainly northwest of the arid grassland. Wind–water erosion crisscrosses the region mainly located in the loess ridges of the Wuding River Basin and bottomland of rivers and lakes that are in the east and south of Wushen Banner (Table 2). Here loess is homogeneous, porous, friable, pale yellow or buff, slightly coherent, typically non-stratified and often calcareous. In several areas of the world, loess ridges have formed that are aligned with the prevailing winds during the last glacial maximum. These are called paha ridges in the United States and greda ridges in Europe. The form of these loess dunes has been explained by a combination of wind and tundra conditions.

Desertification sensitivity

Desert sand on the land surface is an important characteristic of land degradation; Wushen Banner is located in the center of the Mu Us Desert. Drought, sparse vegetation, and land desertification are extremely sensitive; high and acute sensitivity areas accounted for 11.4% and 7.6%, respectively, with moderate desertification sensitivity areas as high as 56.3%. The desertification sensitivity area is located northwest of the arid grassland in the banner (Table 2).

Habitats sensitivity

Habitat sensitivity assessment takes the land salinization, motor vehicle traffic, and surface water function into consideration. The respective rates of high and

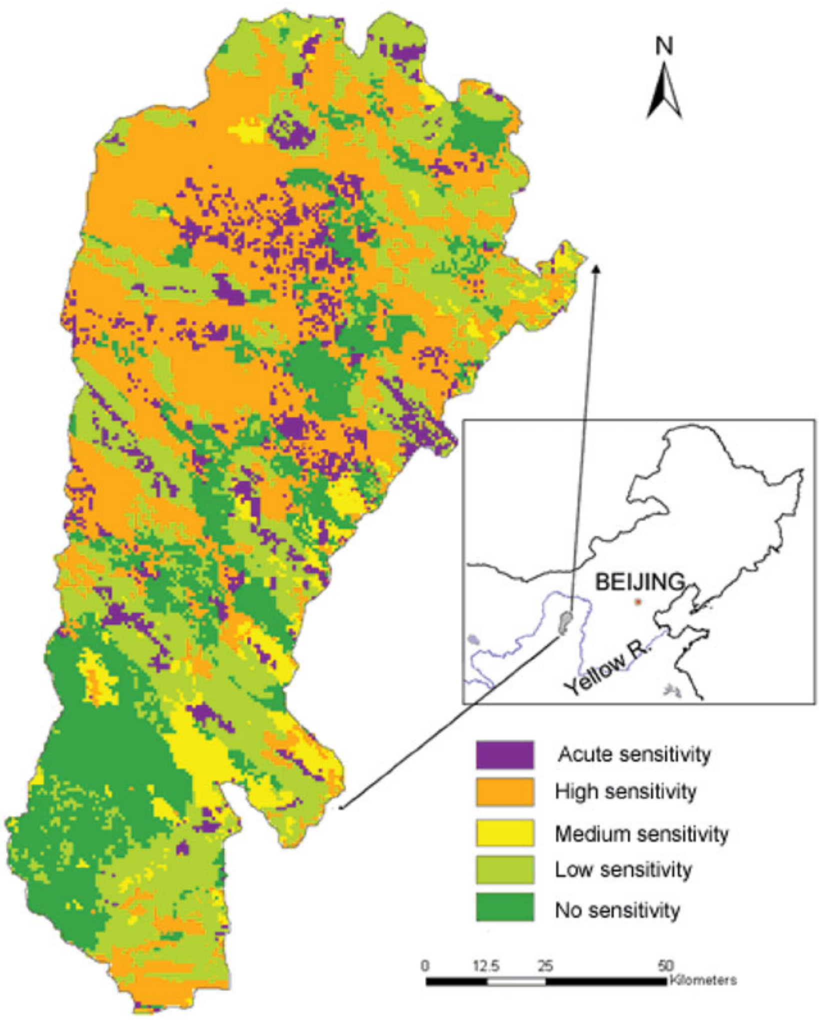

Figure 1. Eco-environmental integrated sensitivity grade in the Wushen Banner.

acute sensitive areas are 3.5% and 0.1%, respectively. Land salinization is extensively distributed in the south terrace of the Yellow River, which is the limiting factor for development of agriculture. The surface water resource here has uneven distribution. The major function of the river is to provide groundwater sources and drinking water for people and livestock. The environment function requirement is high and pollutants released into the water should be strictly controlled (Table 2). A function is the reason some object or process occurred in a system that evolved through a process of selection or natural selection. Thus, function refers forward from the object or process, along some chain of causation, to the goal or success. Compare this to the mechanism of the object or process, which looks backward along some chain of causation, explaining how the feature occurred.

Comprehensive Assessment

Regional comprehensive eco-environmental sensitivity assessment takes into account soil erosion sensitivity, land desertification sensitivity, and habitat sensitivity. Using GIS overlay capabilities, the Wushen Banner region can be divided into areas of five grades of eco-sensitivity: no sensitivity, low sensitivity, medium sensitivity, high sensitivity, and acute sensitivity. The no sensitivity area is mainly in valley beach in the south of Wushen Banner, about 12.6%. The main characteristics of this area are rich in sunlight, heat and water, river crossings, and good vegetation cover. An acute sensitivity area, located in the northwest area of sand, represents about 29.1%. The main features of the physical environment are very poor. Soil salinization and grassland desertification are serious (Figure 1, Table 2).

Ecological safety evaluation research is a long-term process and once changes occur in some conditions, the total safety level may change heavily. Therefore, it is essential that there should be a detection mechanism for dealing with emergencies, and strengthens the relationship between enterprises of environmental planning and protection management department of China (Li *et al.* 2011).

CONCLUSIONS

Wushen Banner is located in an arid and semi-arid region, with drought, strong wind, much sand, and farming-pastoral. The whole ecosystem has the characteristics of high vulnerability and instability, and lower output. Natural conditions and human factors seriously influence land reuse. Self-regulation of the ecosystem is weak. Once destroyed, it is very difficult to rebuild. According to sensitivity analysis, there exists the need to strengthen the ecological construction and protection, including the southern Wuding River Basin Soil Erosion Area, the central valley and large blown sand beach area, the northern lake-beach shelter, and wind erosion and desertification control area. To strengthen the protection of water resources, there is need for optimizing the use of model development, reducing water evaporation excretion, and exploring ways for optimal use of water resources and salinity ecological optimization. Attention should also be paid to the protection of historical sites and cultural relics.

ACKNOWLEDGMENT

The authors thank all those who have given them help while preparing the article.

FUNDING

This article was supported by the National Natural Science Foundation of China (41301593) and the National Basic Research Program of China (973 Program) (No. 2012CB955402).

REFERENCES

Cutter SL, Barnes L, Berry M, *et al.* 2008. A place-based model for understanding community resilience to natural disasters. Glob Environ Change 18(4):598–606

Etkin D, Haque E, Bellisario L, *et al.* 2004. An Assessment of Natural Hazards and Disasters in Canada. The Canadian Natural Hazards Assessment Project. Public safety and emergency preparedness Canada and environment Canada, Ottawa, ON, Canada

Han SJ, Hou CY, and Peng H. 2001. Study on classification water system functions and water functions. J Heilongjiang Hydraulic Engineering College 28(1):16–7

He YF, Zhang B, Ma CQ, *et al.* 2004. The study on the susceptibility of agricultural drought hazard in Songnen plain based on GIS. System Sciences and Comprehensive Studies in Agriculture 20(4):291–6

Hu YD, Fudan GN, and Lu J. 2012. Research on evaluation system of urban ecological safety. Advanced Materials Res 468:2959–62

Huang T, Cheng SG, and Hu ZX. 2013. The urban ecological sensitivity analysis of Enshi city based on GIS and analytic hierarchy process model. Advanced Materials Res 671:2599–603

Jin YH, Zhao DS, Yang QS, *et al.* 2004. A study on distribution and division of sensitivity to ecological environment in Jilin Province. J Northeast Normal Univ 36(2):68–74

Li BS, Jin HL, Lu HY, *et al.* 1998. Processes of the deposition and vicissitude of Mu Us Desert, China since 150 ka BP. Sci China Series D–Earth Sci 41:248–54

Li HW, Lv M, and Ye S. 2011. The Research and practice of ecological safety evaluation method (II): Ecological evaluation. Procedia Environ Sci 11:1211–9

Liu K, Ouyang ZY, Wang XK, *et al.* 2003. Eco-environmental sensitivity and its spatial distribution in Gansu Province. Acta Ecological Sinica 23(12):2711–8

Liu K, Xu WH, Ouyang ZY, *et al.* 2002. GIS-based assessment on sensitivity to land desertification in Gansu Province. Bull Soil Water Conserv 22(5):29–31

Wang N, Xie JC, and Han JC. 2013. A sand control and development model in sandy land based on mixed experiments of arsenic sandstone and sand: A case study in Mu Us Sandy Land in China. Chinese Geograph Sci 23(6):700–2

Wang WZ. 1987. Study on index of erosivity (R) of rainfall in loess area. Soil Water Conserv China 12:34–8

Water Power Bureau of Wushen Banner. 1999. Soil and Water Conservation and Ecol Environ Construction in Wushen Banner, Inner Mongolia (1999–2050), Ordos City, Wushen Banner

Wu B and Ci LJ. 1999. Developing stages and causes of desertification in the Mu Us Sandland. Chinese Science Bulletin 44:842–9

Wu B and Ci LJ. 2002. Landscape change and desertification development in the Mu Us Sandland, Northern China. J Arid Environ 50:429–44
Yuan HR. 2001. Water function area system in China and its corresponding classification. China Water Resources 7:1–5
Zhong XH, Liu SZ, Wang XD, *et al.* 2003. Eco-environmental fragility and ecological security strategy in Tibet. J Mountain Sci 21(suppl):1–6