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Environmental vulnerability assessment for mainland China based on entropy method☆

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ABSTRACT

Evaluation of environmental vulnerability over large areas is a difficult and complex process because it is affected by many variables. Few research on environmental vulnerability assessment is conducted in mainland China comprehensively. In this study, indicators were selected mainly from the function of ecosystem factors and the natural environmental factors associated with the life of the residents. After collinearity diagnostics, 12 indicators remained, covering landform, meteorology, vegetation and irrigation conditions. Entropy method was used to determine the weights for indicators. Results indicate that the vulnerability degree in western China is significant higher than that of eastern China. The spatial distributions of vulnerability gradation are analyzed at national, regional and provincial scales, respectively. On the whole, areas of light vulnerability are main in the northeastern region. Potential, light and medium vulnerability occupy the largest area in the eastern and central region. Percentages of medium, heavy and very heavy vulnerability are the maximum in the western region. The change trend of vulnerability gradation showed that eco-environment has got more vulnerable since 2000. The evaluation results would provide references for the environmental protection and the formulation of related policies.

1. Introduction

In the design of regional development plans, environmental vulnerability zone identification is an essential step for a sustainable environmental protection framework (Sahoo et al., 2016). Meanwhile, it is critical challenge especially for these regions where development pressures are high and environmental threats are considerable (Yang and Chen, 2015). A comprehensive environment evaluation can provide basic data and information for sustainable development and it would be the basis for taking effective measures to implement environmental protection and management in typical zones (Hou et al., 2015; Guo et al., 2016). Over the past couple of decades, effective assessment of ecological conditions has been increasingly associated with questions of global change and hazard mitigation (Yang and Chen, 2015). Therefore, in order to achieve regional sustainable development and environmental protection, environmental vulnerability assessment is of realistic significance (Shao et al., 2015). However, because of the difference of regional environment, the mechanism of vulnerability evaluation varies from region to region. Therefore, it is difficult to develop a set of indicators that have wide adaptability. In addition, many qualitative factors enhance the difficulty of vulnerability measurement (Zou and Yoshino, 2017).

Recently, RS technology provides data support for environmental evaluation, which along with GIS has become important evaluation tools (Hou et al., 2016a) and has been widely used in vulnerability assessment (Fang et al., 2014; Pei et al., 2015). Among them, research on large-scale evaluation has emerged (Nguyen et al., 2016; Liu et al., 2017). For example, Li et al. (2006) obtained land use and vegetation indicators from Landsat images by user-computer interactive interpreting method to evaluate the environmental vulnerability in mountainous region. In virtue of RS data, Shao et al. (2014) analyzed temporal and spatial variations of ecological vulnerability of the Anning River Basin. Enete et al. (2010) adopted RS and GIS technologies and evaluated the environmental vulnerability with indicators of land-use, vegetation and slope. Zhang et al. (2015) extracted the indicators of land use and vegetation coverage from Landsat-7 ETM image and constructed an index system together with other factors for urban ecological vulnerability assessment. Nandy et al. (2015) utilized Landsat TM images to calculate environmental vulnerability for the 1990, 2000 and 2010 periods. Hou et al. (2015, 2016a,b) also based on

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Landsat TM images and acquired land use and other indicators in the process of vulnerability assessment of Loess Plateau. Similarly, Kumar et al. (2016) calculated the land use change on basis of Landsat data and presented a spatial assessment of climate change vulnerability patterns at city scale. Jin and Wang (2016) assessed ecological vulnerability in western China based on time-integrated NDVI data.

The selected indicators vary greatly according to different research object. For example, Hong et al. (2016) aimed at spatial recognition and management in highly urbanized regions and established vulnerability assessment index system containing 12 indicators, such as soil condition, natural-social pressure and vegetation condition. Guo et al. (2016) introduced many interdisciplinary factors, such as landscape pattern indices and extreme climate factors to establish the evaluation system and evaluate vulnerability changes. Liu et al. (2017) took the same region as study area and analyzed the long-term dynamic changes of environmental vulnerability based on the indicators of vegetation, landscape, terrain, soil, hydrothermal condition and social economy. From the perspective of the relationship between landscape pattern and environmental vulnerability, Zang et al. (2017) explored the influence of landscape pattern on environmental vulnerability, including the emissions of CO_2, CH_4 and N_2O, elevation, climate and soil indicators.

However, most studies were conducted on a certain region or river basin, and researches on assessment of environmental vulnerability at national scale are still rare. Evaluation of environmental vulnerability over large areas is a difficult and complex process because it is affected by many variables (Nguyen et al., 2016), and a variety of high-precision basic data is not readily available. Up till now, there have been no studies on environmental vulnerability assessment for mainland China. Moreover, the evaluation indicators are different from region to region, so spatial comparison between different regions cannot carry on directly. Therefore, supported by RS data and GIS technology, our study built the model of environmental vulnerability assessment for mainland China.

In terms of evaluation system, the previous researches established the index system mainly from the view of natural environmental conditions and pressures of human activity on both the resources and ecological environment, presented by the indicators of population and GDP. However, the positive effects of humans on improving the living conditions are rarely included, such as irrigation condition. In our study, we selected indicators mainly from the view of production activities and daily life of local residents. Meanwhile, ecological function was also took into account. We aimed at exploring the environmental stresses from which inhabitants are suffering and highlighted the effect of human improving natural conditions in the relationship of human-environment. The assessment results would provide reference basis for government to fully understand the living condition and formulate appropriate subsidy policies. In addition, it serves for regional sustainable development. Consequently, an assessment index system was constructed to evaluate the environmental vulnerability in association with 12 variables, which covered landform, meteorology, vegetation and irrigation conditions.

Besides establishing vulnerability index system, another important issue for vulnerability assessment is to assign a weight to each factor according to its relative effects on the environmental vulnerability (Guo et al., 2016; Song et al., 2010). A variety of methods have previously been employed and developed for vulnerability assessment. The analytic hierarchy process (AHP) is one of the most popular methods. However, it is based on an expert scoring method to determine the indicator weight, which is not objective, and the results are greatly influenced by expert level and knowledge (Li et al., 2006; Aryafar et al., 2013; Shao et al., 2014, 2015). Moreover, subjective evaluation has been recognized to often overestimate or underestimate the environmental effects (Basso et al., 2000; Guo et al., 2016). There have been many quantitative methods used environmental vulnerability evaluation (Fedeski and Gwilliam, 2007; Li et al., 2007; Xiong et al., 2007; Li et al., 2009), such as fuzzy evaluation method (Adriaenssens et al., 2003; Enea and Salemi, 2001), grey evaluation (Hao and Zhou, 2002) and artificial neural-network evaluation method (Park et al., 2004). Nevertheless, the variables used in the model are not always easily acquired and employed (Wang et al., 2008; Hou et al., 2016a). Moreover, in terms of principal component analysis (Shao et al., 2014), although it is a combination of qualitative analysis and quantitative analysis, part of the information is removed in the process of selecting principal components so that it affects the results of the evaluation (Shao et al., 2015). In addition, the meaning of principal component is ambiguous and not as clear as the original variables. Entropy method is also an important method to assign the indicator weight (Shi et al., 2013). The objective method determines the weight of the index based on the information provided by the observation value of each indicator, which has been applied in many research fields (Zhou and Wang, 2005; Li et al., 2011; Ye et al., 2011; Li et al., 2014; Zhang et al., 2014a) and the results are satisfied (Yu et al., 2015).

2. Materials

2.1. Study area

The mainland China with a vast territory varies in natural environment. For example, it lays across three steps in terms of topography, and also forms a huge difference in hydrothermal conditions of the coastal and inland areas. In consideration of the considerable spatial differentiation, this study evaluated the environmental vulnerability of mainland China. Furthermore, to capture regional differences, the study area was divided into eastern, central, northeastern and western region (Fig. 1).

2.2. Data and preprocessing

Five basic categories data were used in this study, covering meteorological data, vegetation data, digital elevation model (DEM) data, karst distribution data and irrigation data.

The daily meteorological data (including temperature (°C), precipitation (mm), relative humidity (%), wind speed (m/s), sunshine duration (h)) from 1951–2016 were collected from China Meteorological Data Service Center (http://data.cma.cn/). The vegetation coverage index for the years of 1985 and 1995 were originated from GIMMS (global inventory modelling and mapping studies) NDVI data (Tucker et al., 2004), and the vegetation coverage index for the years of 2005 and 2015 were derived from the MODIS China composite EVI data supported by International Scientific & Technical Data Mirror Site, Computer Network Information Center, Chinese Academy of Sciences (http://www.gscloud.cn). DEM data with a resolution of 90 m was also obtained from the website of gscloud. The distribution of karst was derived from the digitized *Karst Environment Geological Map of China* published by Geology Publishing House. Finally, the irrigation data was downloaded from International Water Management Institute (IWMI) with spatial resolution of 10 km. The detailed description information were summarized in Table 1.

Further processing the collected data mainly included the following three steps: (1) Meteorological data stored in text format was imported into the database with the help of SQL Server 2008 R2 to facilitate the calculation of indicators. (2) Projection transition was used for all spatial data and Albers equal area projection was regarded as the target projection. (3) Raster data was converted with grid size of 1 km × 1 km. All the spatial data were processed and mapped with the help of the software of ArcGIS (version 10.2). The bar graphs were drew using the software of Microsoft Excel 2013.