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Evaluation of geologic bearing capacity of coastal zones taking coastal area of Laizhou Bay as an example

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ABSTRACT

The estuarine and coastal vulnerability around the world is increasing day by day, due to climate warming and sea level rise. And the resource-environmental pressure, caused by population expansion, also has been increasing. In a word, human interventions have caused lots of irreparable damages to the sensitive ecosystems in estuarine and coastal regions. Therefore, to carry out evaluations about ecological state and environmental bearing capacity is of great significance for environmental protection, as well as resource utilization. In this study, we constructed an indices system, which was based on a PSR model, to be used for the geologic bearing capacity assessment in coastal zones. There is no doubt that determination of indices weights is very important in the evaluation process, even it is a key factor restricting the ecological evaluation accuracy. Based on the above, we proposed a new weight determining method by fusing non-structural fuzzy number weighting and triangular fuzzy number weighting in the basis of the theories of fuzzy mathematics and named it as unstructured triangular fuzzy number weight determining method. In this new method, judgment matrix is used to calculate the relative importance among those indices included in the evaluation system with unstructured binary tone operators and rules of triangular fuzzy number. Therefore, this new method accords with the cognitive law of decision makers from macro to micro, and that three different experience attitudes (pessimistic, neutral, and optimistic) are fully considered can make the one-sidedness caused by a single attitude be avoided effectively. In addition, a new consistency test method entitled hierarchical sorting consistency test method was proposed to check the consistency of judgment matrix. This study took the coastal area around Laizhou Bay in Shandong Province of China for example and assessed the geologic bearing capacity here. The results indicate the geologic bearing capacity here is gradually increasing from the coast to the inland, and that the proposed weighting model is effective for eco-geological environment evaluation.

1. Introduction

Estuarine and coastal zones are important areas for human survival and socio-economic development. There is about 25% of population living in estuarine or coastal zones in the world (Syvitski et al., 2005). In recent years, with population expansion and climate warming, the pressure of eco-geological environment in coastal zones has been increasing. It is of great significance to carry out evaluations about ecological state and environmental bearing capacity in estuarine and coastal zones. The EU Climate Change Research Center has analyzed a series of cases about the sea level rise caused by climate changes all over the world, and has summarized a variety of evaluation methods aimed at the environmental vulnerability of coastal zones (Ramieri et al., 2011). The Coastal Zone Management Group of the Strategic Working Group of the Intergovernmental Panel on Climate Change (IPCC/RSWG/CZMS) also took steps to evaluate the environmental vulnerability of coastal areas in 1991, and has carried out the related assessments about coastal environments for 7 regions and 27 countries (Organization, 1994; Li, 2012; Li et al., 2013). In addition, France, New Zealand, America, and other countries have begun to pay attention to the sustainable development of eco-environment in

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estuarine and coastal areas (Leujak and Ormond, 2007; Sowles, 2005; Levrel et al., 2009; Hughey et al., 2004; Ferreira et al., 2007). The existing ecological environment evaluations of estuarine and coastal zones mainly focus on the vulnerability evaluation (Yan, 2005; Liu, 2004 . Rao et al., 2008; Diez et al., 2007; Abuodha and Woodroffe, 2010; Ramieri et al., 2011); the geological disaster loss evaluation (Birkmann et al., 2014; Thompson and Schlacher, 2008); and the coastal engineering suitability evaluation (Xie et al., 2014). However, studies on the geologic bearing potential evaluation of coastal zones are fewer in number (Li, 2013).

The geological environment bearing capacity is used to describe the support ability of a regional geological environment to carry objects (human activities), as well as the adjustment recovery ability for its own geological disasters. It is also an important index for judging whether the geological environment can successfully meet the regional social development. In recent years, a series of geological disasters have occurred in some major coastal and estuarine regions of China, like landslide deformations, collapses, and so on. And these disasters have attracted the attention of domestic environmental protection agencies, experts, and research teams. As we all know, there are many land reclamation projects, important ports, as well as water conservancy and hydropower facilities in coastal and estuarine regions. Once the geological disasters appear, the consequences would be unimaginable. The coastal area of Laizhou Bay is one of the most potential regions in eastern coastal China, as there are rich resources here. When Guo Han [2011] introduced the No.1 document entitled *Shandong Peninsula Blue Economic Zone Development Planning*, the State Council considered this region to be the key area of the Yellow River Delta Economic Zone, and Shandong Peninsula Blue Economic Zone (Baidu encyclopedia, 2014). However, the region's economic status increasing along with the advancement of industrialization and urbanization, has caused lots of problems such as ecological pressure increasing, surface subsidence, seawater intrusion, and coastal erosion. It is of great significance to carry out the assessment about ecological state and environmental bearing capacity here for environmental protection. And it is necessary for the regional economic development plan making.

In the process of an ecological environment evaluation, determination of indices' weights is very important, and the misjudgment can be a key factor to restrict the evaluation accuracy. Now weight determining methods used in the ecological environment evaluation mainly can be divided into two types—subjective and objective methods. Subjective methods play a role in the basis of prior knowledge and expert experience, while objective weight determining methods mainly depend on data characteristics. The most commonly used objective weight determining methods mainly include: entropy method, principal component analysis method, mean variance method (deviation method), variation coefficient method, and CRITIC method (Chen et al., 2013). Due to the complex calculation process, objective weight determination methods have stronger data dependency, i.e. this kind of methods demands high data's contrast intensity and discreteness and quantification. However, in the process of an ecological environment evaluation, the indices included in the evaluation system are diversified, and most of them are qualitative, so the application of objective weight determining methods is limited. At the present time, the perfect evaluation system based on objective weight determination methods has not yet been formed.

The existing conventional subjective weight determining methods mainly include: the AHP (analytic hierarchy process); expert investigation method (Delphi method), direct scoring method, contrast sorting method, and relational matrix method (Klee method) (Guo et al., 2012; Ma, 2011). Due to the advantage that the AHP can make complex problems hierarchical and simplified, and also make qualitative problems quantitative, this method is considered to be more consistent with the actual system evaluations. Therefore, The AHP is the most widely applied to kinds of evaluations. Although this method is intuitive and simple, many disadvantages, such as using a single attitude to treat the complex whole, and thinking far from comprehensive, also exist. As one of the conventional subjective weight determining methods, non-structural fuzzy number weight determining method conforms the cognitive process of decision makers from macroscopic to microscopic (Zhang et al., 2013); and triangular fuzzy number weight determining method is used with comprehensive attitudes (Cai, 2004). So how to integrate the advantages of these two methods is the key to overcome the above-mentioned problems.

In this study, we proposed a new weight determining method by fusing non-structural fuzzy number weighting model and triangular fuzzy number weighting model, and named it as unstructured triangular fuzzy number weight determining method. We then applied this new weight determining method to evaluate the geological environment bearing capacity of the coastal area around Laizhou Bay.

2. Study area overview and methods

2.1. Study area overview

Laizhou Bay is located in the southern Bohai Sea and the northern Shandong Peninsula, and stretches from the Yellow River Estuary in the west, to Qimujiao of Longkou in the east. It is a north-north-east trending bay, which is controlled by the Tan-Lu fault zone, and was formed by faulted- block depression. The terrain tilts gently from south to north, and the average gradient is 0.47‰. The landform types transit from the southern piedmont plain, to the middle alluvial and coast plain, and the northern coastal plain. The coast type is silty mud coast, and the buried depth of the main aquifer is 5–30 m, with multilayer structures. The lithology includes various types of sand and sandy gravel. The coastline is 319.06 km long. The Yellow, Xiaoqing, and Weihe Rivers, as well as other rivers inflow, and the water depth is within 10 m, with the deepest point of up to 18 m located in the west. The average tidal range (Longkou) is 0.9 m, and the maximum possible tidal range is 2.2 m. The coastal terrain is monotonous and flat, and there are many sandy soil shoals. This area is affected by the Yellow River sediment so that the tidal flat of the west section has been 6–7 km in width, while the tidal flat of the east section is only 500 to 1000 m wide (Baidu encyclopedia, 2014). There is a vast beach with rich organic matter around Laizhou Bay. And this region is an important fishing and sea salt production base of China, and there are abundant oil and gas resources here. Besides, Weifang, Dongying, Longkou, and Yangjiaogo are important ports in Shandong Province (see Fig. 1).

2.2. Study methods

Referring to the research status of ecological-social environment evaluation both at home and abroad (Ferreira et al., 2007; Bowen and Riley, 2003; Antunes and Rui, 1999; Liu et al., 2011), we selected the PSR (the pressure-state-response) (Levrel et al., 2009; Xiao and Yang, 2007) as the basic model to evaluate the geologic environment bearing capacity of study area. The data processing is divided into three steps: 1. Construction of the geologic bearing capacity evaluation indices system; 2. Weights determination based on the non-structural triangular fuzzy number; 3. Calculation and expression of the geologic bearing capacity. The data processing flow is as shown in Fig. 2.