Ecological Indicators 51 (2015) 53–58

Contents lists available at ScienceDirect

Ecological Indicators

journal homepage: www.elsevier.com/locate/ecolind

Dynamic assessment of environmental damage based on the optimal clustering criterion – Taking oil spill damage to marine ecological environment as an example

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ARTICLE INFO

Article history:
Received 28 April 2014
Received in revised form 15 September 2014
Accepted 20 September 2014

Keywords:
Environmental damage
Optimal cluster
Dynamic evaluation
Marine oil spill
Consistency check

ABSTRACT

Aim: ng at the evaluation of environmental damages, we proposed a dynamic evaluation approach based on the optimal cluster criterion. Firstly, a method for sample data standardization was introduced. After determining the measurement of damage grade, we applied the system cluster analysis approach to classify the grades of corresponding environmental pollution events. Then, the optimal cluster level was evaluated based on the optimal clustering criterion. By using the marine environmental damages caused by 17 marine oil spill events as a sample, we tested the dynamic evaluation method proposed in this article with its practicability. Further, by comparing it with some traditional damage evaluation methods, we found that their evaluation results were consistent. All these have shown that the dynamic evaluation approach proposed in this paper can meet the requirement of environmental damage evaluation. Finally, directions of future researches were pointed out.

1. Introduction

Along with the entry of social economy into fast industrialization stage, contradictions between human beings and the environment gradually appeared. Environment pollution incidents happened from time to time (Peng et al., 2013), which would definitely make damages to the environment. Environmental damage refers to various kinds of disasters happening during or after environmental pollution events, including direct damages to regional ecological environment and natural resource and indirect damages of expenses occurred for taking necessary and proper measures to prevent expansion of the pollutions, repairing or recovering damaged ecological environment, and so on (Gastineau and Taugourdeau, 2013; Martin-Ortega et al., 2011). Damage evaluation is the first question to be faced after the occurrence of environmental damages. It is the basis for a series of issues such as compensation and pollution treatment afterwards (Burger, 2008). Therefore, we need to find out an effective method for environmental damage evaluation which can be used to dynamically grade environmental damages in different environmental areas and for corresponding environmental pollution events. Hence, dynamic evaluation of environmental damage has become a hot research subject at present.

In current studies, the scholars introduced different methods to make environmental damage evaluations. For example, Hanson et al. (2013) introduced the Habitat Equivalence Analysis (HEA) into the environmental damage evaluation. They proposed a compensation quantity model, a damage model and a compensation scale model. These models can be used to simulate marine oil spill accidents, analyze the evaluation scope and the damage ways. Although HEA is a good tool to measure the materialized loss and evaluate ecological value loss, it cannot rank the environmental damage events and decide damage grades (Ma and Qiang, 1988). Vaissiere et al. (2013) introduced the equivalence analytical method into the environmental damage evaluation and carried out a case study to the environmental damages caused by unexpected water pollutions to a river. They tried to evaluate environmental damage through constructing simulated equivalent ecology, but rationality of this method still needs to be further proved (Rodríguez-Labajos and Martínez-Alier, 2013). Gilbuena et al. (2013) adopted the utility function method and the shadow projection approach when evaluating environmental damage. However, utility function method is likely to be affected by subjective factors and shadow projection approach can be greatly affected by the values of damaged marine areas and water depth when evaluating environmental damages caused by oil spill accidents (Fallah-Mehdipour et al., 2011). Brody et al. (2012) carried out a preliminary evaluation to the ecological environmental damages resulted from coal mining in Shanxi province by using the economic loss coefficient of ecological

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http://dx.doi.org/10.1016/j.ecolind.2014.09.033
1470-160X/

environment and preliminarily predicted the possible damages resulted from coal mining to the environment in the future. However, the method mentioned in this literature was only used to evaluate the economic losses resulted from environmental damages. The marine ecological service function evaluation model put forward by Kennedy and Cheong (2013) is weakly operable because value and time of ecological function loss are hard to decide. Also, there are some statistical methods can be used to make environmental damage evaluation. For example, matter-element analysis, the entropy method and the main component method. All these statistical method can rank the environmental pollution events effectively, but they all cannot dynamically figure the disaster levels of the environmental pollution events. Hence, high effectiveness and accuracy of evaluation cannot be guaranteed.

Although there are many researches on evaluation of environmental damage, but there is still not a systematic method which can comprehensively evaluate the environmental damage in a dynamic manner. To solve this problem, this article is written with efforts to dynamically classify the grade of environmental damage and identify the degree of damage to the to-be-evaluated environmental pollution event under corresponding conditions. The optimal cluster approach (Mulder, 2013; Li et al., 2013) is introduced into the environmental damage evaluation in this article. By incorporating this approach, problems about dynamic evaluation of environmental damage can be effectively solved. Further, some other statistical methods are also incorporated into our evaluating approach, the matter-element analysis method corporate with the proposed cluster analysis are used to make comprehensive analysis of the environmental pollution events, specifically they can be used to identify the disaster grade of the environmental pollution events. The entropy method and the main component method are incorporated to rank the damages of the environmental pollution events. Additionally, marine ecological environmental damages caused by 17 oil spill accidents is set up to test this environmental dynamic evaluation method. Results of optimal cluster approach, matter-element analytical method, entropy evaluation method and principal component evaluation method are compared to check the consistency of the proposed comprehensive environmental damage evaluation method.

2. Data standardization

We need to standardize the sample data of marine ecological environmental damages resulted from oil spill accidents before handling them, because it's meaningless to compare data when the dimensions of index vectors are different or quantity levels vary greatly. For convenience, we assume that all acquired samples were expressed by matrix X.

$$X = \begin{bmatrix} x_{11}\ldots x_{1j}\ldots x_{1m} \\ \ldots\ldots\ldots\ldots\ldots \\ x_{i1}\ldots x_{ij}\ldots x_{im} \\ \ldots\ldots\ldots\ldots\ldots \\ x_{n1}\ldots x_{nj}\ldots x_{nm} \end{bmatrix} \quad (1)$$

The matrix means that the sample size is n and each sample contains m damage index. x_{ij} refers to the value of the jth damage index of the ith sample. Then, to each kind of index with the same type, its sample variance will be as shown in Formula (2):

$$S_j = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}(x_{ij} - \overline{x_j})^2} \quad (2)$$

$\overline{x_j} = \frac{1}{n}\sum_{i=1}^{n} x_{ij}$ refers to the mean value of index value of the jth type.

Based on the above assumption, following formula is put forward to standardize the acquired sample data:

$$x_{ij}^{*} = \begin{cases} \dfrac{x_{ij} - \overline{x_j}}{S_j} & S_j \neq 0 \\ 0 & S_j = 0 \end{cases} \quad (3)$$

Through the above changes, mean value of data is 0 and the standard deviation is 1. Thus, the effect of dimension can be eliminated. Even though samples are changed, results can stay stable.

3. Measurement of damage grades based on optimal cluster

We will put forward the measurement of damage degree at first and then propose the corresponding cluster analysis method to classify environmental damages caused by each accident and decide the number of categories of marine ecological environmental damages caused by oil spill accidents.

3.1. Measurement of damage grade and system cluster analysis

Before carrying out system cluster method analysis, we need to decide the measurement of environmental damage grade. The

Table 1
Indexes for marine ecological environmental damages caused by oil spills.

Event number	Economic loss (unit: RMB 100 million yuan)		Fishery disaster (unit: 10,000 ha)		Pollution-affected population (unit: 10,000 persons)
	Direct economic loss	Fishery industry economic loss	Polluted ocean area	Polluted fishery industry area	
1	237.5314	72.7394	216.1040	77.2733	2047.3200
2	65.9884	83.1057	52.5333	10.4000	220.0000
3	184.8036	83.3782	217.4188	48.4222	1464.9000
4	214.3930	65.3519	105.0759	39.574	1148.0000
5	85.9619	100.1141	68.8140	12.4867	464.8400
6	101.1890	94.5755	16.5000	3.0000	196.0000
7	86.6274	87.2703	163.9000	24.8000	1377.0000
8	229.5515	78.7274	286.3800	89.9100	2393.6700
9	51.1839	89.4617	23.7800	0.0000	387.8700
10	158.7388	76.0180	153.5000	40.5700	1640.1000
11	51.4421	98.0325	59.2480	15.1140	640.1100
12	116.2253	72.9618	161.6700	55.4500	1881.9200
13	160.8527	65.8988	67.8100	11.1400	814.6000
14	110.0926	99.4163	38.2600	4.3700	644.3400
15	83.7927	87.8358	108.4000	13.4000	1288.7000
16	64.8935	107.1756	6.1200	3.0400	538.7000
17	32.8705	122.9369	32.3500	0.0000	398.5500