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Adapting ecological risk valuation for natural resource damage assessment in water pollution

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ABSTRACT

Ecological risk assessment can address requirements of natural resource damage assessment by quantifying the magnitude of possible damages to the ecosystem. This paper investigates an approach to assess water damages from pollution incident on the basis of concentrations of contaminants. The baseline of water pollution is determined with not-to-exceed concentration of contaminants required by water quality standards. The values of damage cost to water quality are estimated through sewage treatment cost. To get a reliable estimate of treatment cost, DEA is employed to classify samples of sewage plants based on their efficiency of sewage treatment. And exponential fitting is adopted to determine the relation between treatment cost and the decrease of COCs. The range of damage costs is determined through the fitting curves respectively based on efficient and inefficient samples.

1. Introduction

Natural Resource Damage Assessment (NRDA) mainly concerns ecological injuries resulting from human actions and aims to restore injured natural resources and services or acquire equivalent compensation (Bascietto, 1991; Bascietto, 1993). To guarantee the equivalency between injuries and restoration or compensation, it generally requires monetization of ecological assessments to integrate all estimates of ecological injuries into one determinate number. Most ecological assessments only compare ecological states to regulatory standards and prescribe a concentration of contaminants that cannot be exceeded. The regulatory standards are widely used indicators for the public in risk communication and can aid government agencies in conveyance of information (Johnson, 2008). But monetary value cannot be reasonably assigned according to the statement whether a regulatory standard is exceeded. To facilitate the assignment of monetary values, specific ecological changes should be estimated on aspects of both spatial and temporal scales.

Ecological Risk Assessment (ERA) is a promising way to evaluate natural resource damages and to scale the scheme of environmental restoration (Munns et al., 2009a; Sanders et al., 2016). It can address the requirements of monetization by quantifying the severity of each adverse effect or the magnitude of possible damages to the ecosystem (Andretta, 2014). Given an ecological pollution incident, risk assessment considers all potential hazardous scenarios and evaluates the probability of occurrence and associated consequence for each scenario (Gardoni and Murphy, 2014). Ecological changes quantified through these specific risk estimates can be readily related to a monetary value reflecting the loss from injured resources and services.

Ecosystem services are suggested as an appropriate and convenient tool to quantify the level of risk in monetary terms (Forbes and Calow, 2013). Ecosystem services are the focus of environmental policies and can provide a natural link between NRDA and ERA (Chapman, 2008; Munns et al., 2009b). There is considerable overlap in the elements of ERA and NRDA, such as collecting and assessing environmental data. ERA and NRDA both would benefit by focusing on ecosystem services that correspond most directly to restoration and damage compensation decisions. Moreover, existing researches of ERA mainly concentrate on risk ranking and priorities setting for a Superfund contaminated site (Špačková and Straub, 2015; Schulz and Griffin, 2001; Long and Fischhoff, 2000). Though ERA is used to capture most aspects of environmental damages, it lacks the capacity to quantify their economic values. Methods for valuating ecosystem services are well developed (Chee, 2004), which would facilitate the monetization of risk estimates.

Based on ecosystem services, this paper endeavors to combine NRDA and ERA and evaluate damages to resources and services through risk assessment. Specifically, the paper investigates an approach to assess water damages from pollution incident on the basis of water quality standards for drinking. Drinking water mainly provides provisioning service to people and its concentration of contaminants (COCs) should

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not exceed certain standards. Any exceedance might cause risk to human health as well as ecosystem services. Excessive contaminants should then be disposed to restore the healthy supply of drinking water. The cost of disposal can be viewed as the value of this provisioning service which provides a reference to risk monetization and damage assessment.

The paper is organized as follows. Section 2 presents the relation of ERA and NRDA in water pollution incidents based on water quality standards. Section 3 investigates the method to evaluate water damage costs in a pollution incident through samples of sewage treatment costs. In Section 4, the damage evaluation method is illustrated through a pollution case in Guangxi province of China. Finally, Section 5 concludes the paper and proposes directions for future research.

2. Relation of era and nrda in water pollution incidents

In water pollution incidents, the basic ERA considers the potential negative impact on water quality or the hazard of contaminants intake on human health. Water quality is determined based on COCs in the water by regulatory legislations. There are four levels of regulatory legislations in Chinese water conservation framework: the Chinese Constitution, laws approved by the National People's Congress, administrative regulations, measures, decisions, and rules enacted by the State Council and ministerial bodies, and national standards issued by the Ministry of Environmental Protection (Deng et al., 2016). National standards specify detailed COCs that should not be exceeded for each level of water quality. These specifications of COCs are set to monitor increased threats of hazardous contaminants to ecosystem and human health.

NRDA is conducted to determine the extent of injury to natural resources and to calculate compensatory monetary damages. The degradation of water quality reflects injuries caused by the pollution incident to water environment. The higher COCs are in the polluted water, the severer the water is injured. As COCs are used as risk indicators, NRDA is closely related to ERA. To make decisions of damage restoration or risk remediation, the pre-incident condition of COCs is required for setting a baseline in both ERA and NRDA. Due to the randomness and suddenness of pollution incidents, it is difficult to acquire the exact baseline state of an ecosystem. Usually, the baseline state is inferred from COCs of similar sites or previous statistical documents. For water environment, the not-to-exceed concentrations set by water quality standards provide a convenient baseline or reference for setting remediation and restoration goals (Johnson, 2008; Schulz and Griffin, 2001; Yao et al., 2015; Pease, 1992).

The risk to human health is calculated based on the toxicity of contaminants and directly related with intakes of contaminants (Fujinaga et al., 2012; Carlon et al., 2008). Human intake of a particular contaminant is estimated from exposures at the contaminated site and largely depends on COCs in the water. For non-carcinogenic contaminants, risk (R) is calculated as the intake (I) of contaminants divided by the reference dose (RfD). For carcinogenic contaminants, risk is calculated as the intake times the cancer slope factor of a contaminant (Sf). That is, $R = I/RfD$, or $R = I \times Sf$. The intake of the j^{th} contaminant is predicted through $I = k_j C_{0j}$ where C_{0j} is the concentration of the j^{th} contaminant after a pollution incident and k_j represents all the influencing factors including ingestion rate, exposure frequency, exposure duration, body weight, and other parameters. Risk from the j^{th} contaminant is then $R_j = f_j C_{0j}$ where $f_j = k_j/RfD_j$ or $f_j = k_j \times Sf_j$.

Denote C_{ij} the upper-bound concentration of the j^{th} contaminant set for the i^{th}-level water quality by water standards. The pollution incident then increases the possible human intake of the j^{th} contaminant from $k_j C_{0j}$ to $k_j C_{ij}$. The increased risk from the j^{th} contaminant is $f_j(C_{0j} - C_{ij})$. Obviously, $f_j C_{ij}$ can be identified as the acceptable risk level for human health and C_{ij} the concentration requirement of water quality. Therefore, they can be directly used as goals of risk environmental remediation. They can also support the NRDA in environmental restoration by monetizing the cost of risk remediation.

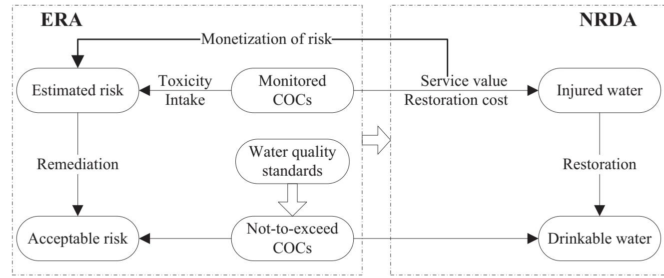

Fig. 1. Relation Framework of ERA and NRDA in water pollution incidents.

Generally, natural resource and environmental damage is measured on the basis of restoration costs or foregone use values (Ulibarri, 1997). Use values depend on the demand for beneficial uses of natural resources and services and are often estimated through market data of actual payments. This valuation method is not applicable to most of the natural resources as they do not have a trading market. Restoration costs are a useful way of approximating resource values under specific conditions. This method determines damages for natural resources based on the cost to restore, rehabilitate, or replace the resource or resource services. Denote Q_j the quantity of water polluted by the j^{th} contaminant and u_j its unit restoration cost. The damage cost to the water can then be estimated through $D = \sum_j (C_{0j} - C_{ij}) Q_j u_j$.

The relation of ERA and NRDA is summarized in Fig. 1. ERA and NRDA in water pollution incidents are both based on baseline COCs provided by water quality standards. The not-to-exceed COCs can be viewed as goals of both risk remediation and damage restoration. Originally, COCs indicate the extent of risk to ecosystem and human health in combination with many nondeterministic components such as body weights, water intake, reference doses of contaminants, and interaction forms of contaminants (Mishra et al., 2016; Ryker and Small, 2008). ERA actually considers the likelihood of a physiological response to the contaminant by simulating possible values for these uncertain parameters (Yao et al., 2015; Thayer et al., 2003). But remediation decisions usually require cost and benefit analysis of risk reduction and monetization of risk estimates (Špačková and Straub, 2015). On one hand, the increase of risk also reflects the extent of damages to water that is not qualified for drinking. On the other hand, NRDA mainly focuses on the valuation of damages and provides a convenient measure for costs of risk remediation.

3. Water damage valuation based on sewage treatment

3.1. Overview of the damage valuation method

NRDA based on restoration cost requires a sample of cost information from similar restoration activities. In the instance of water pollution, damage cost can be valued through the disposal of chemical contaminants. And water treatment cost of sewage plants can provide a sample based on which the most likely range of expected restoration costs can be estimated. This valuation method is suitable for all common resources that can find a sample of restoration costs.

Fig. 2 shows the flowchart of water damage assessment based on samples of treatment cost. First, the extent of damage is assessed by comparing the baseline condition of the water and the injured condition. The baseline condition can refer to the not-to-exceed COCs required by water quality standards, and the injured condition is determined through emergent monitoring activities. Then the damage should be valued in monetary terms which requires information of service values or restoration costs. This paper focuses on the estimation of restoration costs based on samples of sewage treatment cost.

While the water treatment cost can assemble a large number of