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Ecological risk assessment of hydropower dam construction based on ecological network analysis

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Abstract

Dam construction is regarded as one of the major factors contributing to significant modifications of the river ecosystems, and the ecological risk (ER) assessment of dam construction has received growing attention in recent years. In the present study, we explored the potential ecological risk caused by dam project based on the general principles of the ecological risk assessment. Ecological network analysis was proposed as the usable analytic method for the implement of ecological risk assessment, thus contributing to the modelling of dam-induced risk process. Applying ecological network analysis to the ecological risk assessment of river ecosystems after dam construction, this study may provide important insights into the understanding of how an affected river ecosystem reacts to the artificial perturbation on a whole-ecosystem scale.

Keywords: Ecological network analysis; Ecological risk; Dam project.

1. Introduction

Dam project is regarded as one of the most critical factors contributing to changes of river ecosystem. It is reported that approximately 70% of the world's rivers is intercepted by large reservoirs. It has been well documented that dam project results in changes of hydrology, river morphology and habitat, thus disturbing the biota associated with the changed environment. The eco-environment impact of dam project has been the center of attention due to its important role in balancing environmental protection and dam operation, maintaining the river ecosystem health and promoting regional sustainable development.

However, most studies were focused on the environmental impact of single factors. Ecological network analysis (ENA) is a promising technique for analyzing the eco-environmental impact of certain disturbed ecosystem as a

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whole in that it is concerned with interrelations of material, energy and information among system components instead of the individual organisms and populations themselves. In this sense, ENA seems to be capable of meeting the need of multi-sources/factors/destinations Ecological risk assessment (ERA) to accomplish the evaluation and prediction in a more holistic and rational way. Combining ENA with ERA, this paper provides a new way to perform such research.

2. Potential dam-induced risk assessment

The adverse, and often irreversible effects on eco-environment induced by dam construction, which is generally the most controversial and wide-debated issue. They have become so notable that the removal of dams and reservoirs had emerged mainly in the U.S. during the past few years. A series of studies have been reported in *science* recently, making it clear that dams can disrupt the natural seasonal flow patterns to which aquatic animals are adapted, block and destroy spawning grounds and migratory paths fragment their habitats, erode inhabited island and sap the rivers' ability to detoxify and flush out pollutants, thus worsening the plight of terrestrial biodiversity and aquatic fauna as well [1]. More studies concerning the potential ecological risk caused by dam project directly or indirectly on different scales are needed.

Ecological risk assessment, focusing on the rational evaluation of potential damages and the prediction of ecological risk, is a relatively new field of study for evaluating the risks associated with a possible eco-environmental hazard under uncertainty [2]. The goal of ERA is to quantify the distribution of possible ecological effects arising from ecosystem exposure to one or more stressors (risk factors) [3]. Additionally, the process of ERA was characterized by the concept of 'sets of triplets', i.e. the scenario, the likelihood, and the consequence. have. Actually, it is well known that a formal decomposition of risk can be given by three queries—what can happen; how likely things are to happen; and what are the end point's measures from sets of occurrences, which has become a standardardized approach for predicting the risk.

In order to further illustrate the characteristics of ERA in the context of environmental management, we compare ERA with the conventional environmental impact assessment (EIA) in five aspects such as origin time, goal, process, methods, application (mainly for decision making), predictability and timeliness (Table1). Apparently, when compared with EIA, ERA is mainly focused on the prediction of the potential impact by means of modeling the ecosystem associated with the risks, which has a relatively high predictability and a good timeliness, which is helpful for decision makers to deal with certain ecological hazards under uncertainty. In this sense, ERA seems to address the challenge of evaluating and predicting the ecological risk caused by dam projects with these inherent advantages.

Table 1 Comparison between EIA and ERA on different aspects

	EIA	ERA
Origin	1970s-	1990s-
Goal	Evaluate potential adverse environmental effects by disturbance empirically (mainly human-induced).	Estimate the risks associated with a possible eco-environmental hazard under uncertainty (natural or human-induced).
Process	Observed impacts- ecological effects- avoid, minimize, or compensate.	Potential damages- probability and magnitude- predict and control the possible threatens.
Methods	Cause-impact analysis based on a case-by-case study	Source-factor-probability-impact analysis based on a model of the ecosystem
Application	Reactive control of existing impact by human.	Management of potential eco-environmental impact along with decision support systems.
predictability	Very low	High (although inconsistent sometimes)
Timeliness	Often too late to consider for a project	Can be implemented long before a project.

3. ERA and ENA for analyzing dam-induced risk.

Dam-induced ecological risks act stochastically and cumulatively or synergistically, and often difficult to forecast without an appropriate analytical modeling method. And more or less, the researchers or managers are inevitably confronted with multi-process, i.e., multi-source, multi-factor and multi-destination scenarios when preceding the risk identification and assessment. Thus, a rational, quantitative, and preferably succinct methodology (model) is essential for accomplishing ecological risk assessment (ERA). A few studies succeed in establishing a proper model for ERA, most of which were mainly focused on the biology of species and population on the microcosm or regional scale[4], including the comprehensive aquatic systems model (CASM) for assessing ecological risks posed by toxic chemicals in generic aquatic ecosystems [5] and the small-scale model for evaluating the ecological risk of regional streams wildlife [4], a five-step process of regional ERA for indentifying risks of the wetland system [6]. More related to the study here, environmental risk index was constructed as a tool to assess the safety of leachate dams considering dam breaking [7]. Traditionally, these models used in ERA have tended to be restricted to single hazard assessments with a weak calculation of its uncertainty [8]. In quest of a solution to this conundrum, network model has been introduced into ecological risk assessment, in the form of cross-validated holographic neural networks and Bayesian networks (Bns), etc. [3,9].

Jɔrgensen [10] questioned why more ecologists do not apply ecosystem theory and ecological network analysis (ENA) to their studies. ENA, which is focused on the interrelations of material, energy and information among different components instead of the individual organisms and populations themselves, is a promising technique for analyzing the ecological risk of certain disturbed ecosystem as a whole. Therefore, ENA may be capable of meeting the need of multi-sources/factors/destinations ERA to accomplish the evaluation and prediction in a more holistic and rational way. Here we introduce network structural analysis and network functional analysis (including throughflow analysis, ascendancy analysis, utility analysis and control analysis) and elicit the corresponding risk interpretation rationally to further demonstrate the application of ENA to the assessment of ecological risk caused by dam construction (Table 2).

Table 2 ENA methodology potential for ER assessment

Analytic methods	Basic information	Risk interpretation
Structural analysis	To identify the different compartments, flows and cycles of the concern system.	Risk sources, factors and destinations.
Throughflow analysis	To calculate the flow parameters of material and energy of each compartment within the ecosystem.	Risk transaction and accumulation
Ascendancy analysis	To quantify the performance (like development status, diversity and maturity) of the system as a whole at processing material and energy.	Risk effecting efficiency, system degradation.
Utility analysis	To analyze the direct and indirect relationships between components and the mutualism they perform of the concerned ecosystems.	Risk interactions among compartments, system mutualism.
Control analysis.	To analysis the control each component exerts in the overall system configuration.	Risk distribution, key risk factors.

4. Conclusion

This paper first elucidated the potential ecological risk of river ecosystem when exposed to dam projects, and then a comparison between ecological impact assessment and ecological risk assessment was made to decide the proper method for the evaluation of dam-induced risk. Ecological network analysis was proposed as the usable and strong analytic method to model the ecological risk and thereby accomplish ecological risk assessment. Finally, the main methods derived from ENA were elicited to further support the connecting of ecological network analysis and ecological risk assessment.

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