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An investigation of correlations between different environmental assessments and risk assessment

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Abstract

The increasing deterioration of environment is affecting our entire word. Environmental management plays a crucial role in maintaining environmental sustainability. While environmental management is complicated due to the complex natural ecosystem which is poorly understood and ill-structured, and significant uncertainties. A variety of environment assessment processes, e.g., environmental impact assessment (EIA), regional strategic environmental assessment (R-SEA), the precautionary principle, sustainability assessment (SA) etc., widely used in environmental management are reviewed and their correlations with human health risk assessment (HHRA) and ecological risk assessment (ERA) are investigated. The results of this paper facilitate the decision makers selecting proper assessment framework and/or some combinations of them in environmental management.

Keywords: Environmental management; environmental impact assessment; human health risk assessment; ecological risk assessment; strategic environmental assessment; the precautionary principle; sustainability assessment.

1. Introduction

Environmental management is complicated due to the complex natural ecosystem which is poorly understood and ill-structured problems, many stakeholders with different objectives, and significant uncertainty. A variety of frameworks of environmental assessment and risk assessments such as environmental impact assessment (EIA), human health risk assessment (HHRA), ecological risk assessment (ERA), strategic environmental assessment (SEA), the precautionary principle, and sustainability assessment (SA) etc. were promulgated and are widely used in different scenarios of environmental management. These frameworks were designed for different purposes and were used in different ways. Usually the EIA practicers may not be familiar with the algorithms of the HHRA and ERA, thus the HHRA and ERA results which are useful for EIA cannot be used. Even the risk assessors in human health risk assessment may not be familiar with the ecological risk assessment. Over the past three decades, considerable interests have been paid to the development of tools and techniques to protect human and ecosystem health. Unfortunately, such approaches ignore the relationships amongst ecology, society, and economic concerns which are

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three pillars of SA, while the SA addresses human health issue poorly. As facing more environmental threads, in some cases, the integrated methods are required which include human health, economic, social, and ecological parts. Thus the investigation of the correlations amongst different types of environmental assessments and their merits and demerits is necessary for integrated environmental assessment and facilitates decision makers selecting proper assessment framework and/or some combinations of them. It is the subject of this paper.

2. Human health risk assessment and ecological risk assessment

Human health risk assessment (HHRA) is evaluation of potential adverse health effects on humans exposed to environmental hazards together with uncertainties [1]. Four major components are included in a risk assessment process [2]: (1) Hazard identification: This step identifies whether the contaminants present lead to adverse effects on human health; (2) Exposure assessment: This step estimates the intensity, frequency, and duration of exposure; (3) Dose-response assessment; This step determines the relationship between dose and the adverse effects based on animal experiments and epidemiological studies; and finally, (4) Risk characterization. This four-step process is used to describe the nature and magnitude of risk for each exposure pathway and derive the total risk.

Ecological risk assessment is defined as a process that evaluate the likelihood of adverse ecological effects may occur or are occurring caused by exposure to multiple agents (e.g., physical disturbances, and toxical chemicals [3], which must be based on sound ecological theory and not the simple extension of the human health risk assessment to non-human receptors [4]. Assuming protection of human health then will protect non-human receptors is not sufficient as some chemicals will cause serious effects for aquatic organisms like chlorines, ammonia, and aluminium while pose no risk or negligible risk to humans [5]. Suter II (2006) [5] presented that human health risk assessment is a complement of ecological risk assessment. Thus integration of human health risk assessment and ecological risk assessment is necessary for environmental management in some cases. For example, Zhang et al. (2009) [6] developed a ranking system for contaminated sites by using the multicriteria Preference Ranking Organization METHod for Enrichment Evaluation (PROMETHEE) methods, where the criteria were identified based on the factors that potentially contributed to human health and ecological risk posed by contaminated sites. While there are significant differences between human health risk assessment and ecological risk assessments [4]: (1) the human health risk assessment has determined receptors, i.e., humans, while there are no universal ecological risk assessment endpoints; (2) ecological risk assessment considers the effects on population, communities, or system level while the human health risk assessment most often focuses on a hypothetical adult (e.g., an adult with average weight is 70 kg and life time is 70 years for cancer risk assessment etc.); (3) usually ecological risk assessment has to capture the effects caused by the interactions among multiple agents such as physical disturbances and toxical chemicals; (4) it is easy to determine the exposure pathways for human health risk assessment, e.g., ingestion, inhalation, and dermal contact, while exposure analysis in more complicated in ecological risk assessment as an agent will act periodically and has significantly variation in exposure sites, or take different alternatives in the future. It is not easy to track the fate and transport of contaminants in ecosystems; (5)For human health risk assessment, dose-response assessment is based on the animal test in the laboratory and then extrapolated to the humans. This extrapolation will induce significant uncertainty. For ecological risk assessment, dose-response relationship for a given species can be determined with better accuracy under the set conditions in the laboratory. Nonetheless, multiple species and complex exposures will be involved in the paradigm of ecological risk assessment such that the stressors-response analysis becomes more difficult (the dose-response analysis focuses on the single species which the stressors-response analysis focuses on the community and system level). Pastorok (2002) [7] pointed that most practices of ecological risk assessment simply rely on the simple calculation without incorporating basic ecological information derived from comprehensive ecological models. As time cost and a lack of specific site information, a comprehensive human health risk assessment or ecological risk assessment which includes the capture of hazards, contaminant transport in ecosystem and human and animal bodies, effects on human and ecosystem health, and uncertainty and variability is not easy to develop and seldom used in practical projects. Zhang (2009) [8] developed a comprehensive framework which includes contaminant transport models, exposure assessment models, physiologically-based pharmacokinetic (PBPK) model, and dose-response models to evaluate the risk posed by TCE contaminated groundwater under uncertainty. As aforementioned, in most cases, comparative risk assessment (CRA), which is a methodology facilitating decision-making when sufficient information is not available, is widely used in environmental management [6] [9].

3. Environmental impact assessment

Environmental impact assessment (EIA) cannot be considered as an alternative of risk assessment as it is not another way to evaluate and manage the hazards to humans and environment [5]. EIA is often required by government agencies for some projects with potential higher environmental impacts, while risk assessment is often voluntarily by agencies to facilitate decision making [5]. EIA emphasizes the compliance with the regulation requirements, while risk assessment can be used in two ways: (1) to determine whether the risk posed by agents meet the regulation requirements; (2) given the predefined risk (usually the regulation requirements) to determine the thresholds of disturbances on ecosystem or set the remediation target. The second one is used to determine the remediation criteria for pollutants in contaminated sites in a lack of regulation requirements. EIA is often criticized due to its lack of rigid quantitative methods to predict the probability of the potential effects on environment [10]. While in risk assessment, a more rigid measurement framework for risks posed by agents exist and more quantitative methods such as contaminant transport and transformation models, exposure assessment models, dose-response models are used. Uncertainties involved in the process of risk assessment have to be properly represented and transparently incorporated into the risk assessment. Uncertainty analysis must be implemented in each step of risk assessment and their cumulative influences on final risk evaluation have to report to the risk managers. Uncertainty assessment can be used to explain the implications and limitations of the risk assessment results reported to the risk managers. While in environmental impact assessment, uncertainty representation and propagation are not discussed transparently. Thus Andrew (1988) [11] presented how the environmental impact assessment and risk assessment can learn each other. The methodology involved in risk assessment, e.g. stress-response analysis, can be used to evaluate the potential environmental impacts caused by the projects (stresses caused by the projects, e.g. construction of a dam on a river). From this point of view, risk assessment can be considered as a complement of environmental impact assessment.

4. Regional Strategic environmental assessment (R-SEA)

Regional strategic Environmental Assessment (R-SEA) is defined as "*a process designed to systematically assess the potential environmental effects, including cumulative effects, of alternative strategic initiatives, policies, plans, or programs for a particular region*" [12]. The framework of R-SEA includes both biophysical and human components and their interactions and the final objective of R-SEA is to ensure the sustainability of a region and to get a desired level of environmental quality. Environmental impact assessment is a project-based environmental assessment which focuses on finding ways to migrate adverse effects such that the environmental quality of the target project to comply with the regulation requirements without considering “whether the proposed undertaking is the most appropriate form of development or whether the cumulative environmental effects of such development are in conflict with broader regional environmental goals or desired future conditions” [12]. SEA is a flexible method rather than a precise analytical methodology as different types of futures studies (scenario exercises), systems analysis, risk assessments, life−cycle assessments, economic appraisal tools, and multi−criteria analysis might be involved in this process [13]. The significant difference between R-SEA and project-based environmental impact assessment is that the former is a proactive methodology and tries to answer the questions “what is the preferred option?” and “what is the preferred attainable end(s)?”, while the project-based EIA tries to predict the most likely outcomes of a given project [12]. The evaluation of cumulative effects on biophysical and human components is required by the R-SEA, human health risk assessment and ecological risk assessment can be used as quantitative methods to predict these effects once sufficient information is available under a given scenario.

5. The precautionary principle

The precautionary principle can be traced to Germany in the late 1970s when appropriate actions were required to deal with a series of large-scale environmental problems such as acid rain, pollution of the North Sea, and global climate change. The application of the Precautionary Principle in environmental planning and management [14], persistent organic pollutants (POPs) risk management [15], and fisheries management [16] were presented recently. Other applications of the Precautionary Principle such as in genetic modified crops, global warming, endocrine-disrupting chemicals, manganese in gasoline etc., were reported in [17] and [18]. The statement of the Precautionary Principle from the Wingspread conference (held in January, 1998) was widely used: ‘When an activity raises threats

of harm to human health or the environment, precautionary measures should be taken, even if some cause and effect relationships are not fully established scientifically.' [18]. Four elements are involved in the Precautionary Principle, i.e., (1) There is a threat of harm, either credible or known, (2) The situation presents a lack of scientific certainty or evidence, (3) Cause and effect relationships are not yet proven, and (4) There is a necessity or duty to act [18].

Environmental problems are characterized as (a) a wide spatial dimension, (b) time-lag between the causes and the corresponding effects, (c) the quantitative side of matters (e.g., the single behaviour may be harmless, the effects caused by combined behaviours will be disastrous), (d) the cumulative effects, and (e) the irreversibility for some effects (e.g., the extinction of species) [19]. As significant uncertainties exist in the aforementioned five characteristics, the prediction of the effects caused by the anthropogenic actives on environment becomes difficult for some complex ecological systems. Generally, inherent uncertainties exist in causes, effects, and the cause-effect relationships [20] which are three components in the framework of risk assessment. Uncertainty associated with cause-effect relationships is induced due to the lack of knowledge. The precautionary principle (PP) is invoked in the process of risk management in a case where the cause and effect relationships are uncertain or indeterminate, and where the likelihood of outcome is also uncertain, if not unknown [21]. Thus the PP has emerged in response to the need for an effective method for dealing with a plausible risk scenario where sufficient supporting evidence is not available (i.e., significant uncertainties exist in the cause-effect relationships), especially when outcomes are irreversible and/or widespread [22] [23].

Whether the conventional risk assessment (human health and ecological risk assessment) or precautionary principle will be used depends on the degree of uncertainty inherent in determination of the harm-hazard relationship. If uncertainty is small, conventional risk assessments will be employed; if the degree of uncertainty is significant, the implementation of conventional risk assessment then becomes difficult or impossible, the precautionary principle is then be carried out to indentify the appropriate risk management actions [20]. From this point of view, the PP is a means in dealing with significant scientific uncertainties and it is only one of several responses to risk [22]. Thus the implementation of PP should start with the evaluation of the degree of uncertainty in harm-hazard relationship [24]. The PP should operate at all time in the recognition of uncertainties associated with hazard, exposure, and harm-hazard relationship. When more information is available, the degree of uncertainty will change and the basis for the PP may alter positively or negatively. Thus the PP plays a temporary role in risk management which is emphasized by the Agreement on the Application of Sanitary and Phytosanitary Measures (SPS) of the Final Act of the Uruguay Round of Multilateral Trade Negotiations [25].

Conventionally, risk assessment focuses on predicting the potential adverse impacts caused by specified hazards [26]. Risk assessment tries to answer where we are and to predict where we will be in the future, while the PP approach set the target of where society (or country, ecosystem etc.) should be first and then work backward to identify steps and measures toward this goal [26]. Risk assessment only focuses on the pre-defined hazards, while "the process of applying the Precautionary Principle must also involve an examination of the full range of alternatives, including no action." stated at Wingspread on January 23-25, 1998. The precautionary principle tries to complement the limitations of risk assessment-based regulatory policy by finding better alternatives whenever a potentially hazard is identified [27].

Risk assessment provides a sound basis answering the questions such as "What level of risk is acceptable"; and "How much contaminants and stresses can humans or ecosystems tolerate without inducing adverse effects", i.e., identifying the thresholds, while the PP answers the questions such as "How much contamination can be avoided while still maintaining necessary values" [26]. Thus, risk assessment should not be considered as a means of implementing the PP [28]. Traditional risk assessment presume that the chemicals (or genetically modified crops etc.) to be safe until they are proven to be harmful, whereas, based on the precautionary principle, these chemicals etc. are presumed harmful until they are proven to be safe [29]. Renn et al. (2004) [30] developed a general model for the implementation of precaution in European risk reduction where the PP is defined as a general principle employed in the screening of threats for properties of seriousness or uncertainty in order to determine their subsequent treatment in regulatory appraisal and management.

6. Sustainability assessment

The term *Sustainability* becomes the catchword in most fields and its importance has gained wordwidely. *Sustainability* is defined as the capacity to endure (Wiki). *Sustainable development* means balancing the ecological development and environmental protection in a manner such that the current needs are met without compromising

the ability of future generations to meet their own needs [31]. Sustainable assessment is a process used to evaluate the implications of *sustainability* of long-term and short-term economic, environmental, and social consequences caused by our policies, plans, programmes, projects, pieces of legislation, or a current practice or activity, which is considered as an important role facilitating the shifts to sustainability [32]. As the complexity of the sustainability assessment with multiple –scale, multi-dimensions (economic, environment, and society) and its depth and breadth, the current environmental assessments such as environmental impact assessment, human health and environmental risk assessments, strategic environmental assessment, and some integrated environmental assessments cannot cover the context of sustainability assessment [33]. The subject of environmental impact assessment (EIA), strategic environmental assessment (SEA), and sustainability assessment (SA) is the projects with potential significant environmental impacts; plans and programmes (some time policies) with potential considerable environmental impacts; strategies, plans, programmes policies and projects, respectively [34]. The scope of these three assessments is environmental impact; environmental impacts (sometime with social-economical impacts); and economic, environmental, and social impacts, respectively [34]. Obviously, the SA has a wide assessment range compared to the conventional environmental assessments. Gibson, (2001) [35] and Verheem (2002) [36] considered that the EIA and SEA can be extended to include the SA concerns (e.g., social and economic issues). This means that environmental assessments can contribute to the sustainability by extending their assessment scopes, e.g. including social and ecological concerns which result in EIA-driven and objectives lead integrated environmental assessments [32]. Pope et al (2004) [32] presented that the EIA-driven integrated assessment fails to address the social dimension in SA, while the objectives lead integrated assessment only measure the positive and negative contributions to sustainability in the future, i.e. describing the "the direction to the target". Whether the initiative is sustainable or not is not answered in these two assessments. Actually, in practice, it is difficult to determine a system is functioning "sustainably" as the system failure is the only sustainability indicator [37]. Mehta (1997) [37] also suggested that using the definition of "sustainable risk" as a measure to identify and mitigate factors that leads to system failure. Reinert et al. (2006) [38] considered the risk assessment as an integral part of sustainable development and suggested using risk assessment to facilitate and enhance the movement to sustainability. Nonetheless, the principles of risk assessment cannot cover three pillars of sustainability assessment, i.e. economy, environment, and society. While the conventional SA paradigm poorly address the human health issue. Rotmans (2006) [33] presented a higher and much more strategic level of sustainability assessment paradigm, i.e. Integrated Sustainability Assessment (ISA) which involves a long-term comprehensive assessment of international and national policy programmes against sustainability targets and criteria. The investigation of impacts on ecosystem functioning and human health is required in this advanced sustainability assessment paradigm. Integration of risk assessment in sustainable development is necessary in order to comply with the target of sustainability.

7. Concluding comments

Human and ecological risk assessments use quantitative methods to estimate the human and ecosystem risks posed by agents or stressors. Thus both of them can be used in each assessment framework to enhance the evaluation of the effects caused by a variety of stressors on human and ecosystem health. Uncertainties involved in each step and their cumulative on final results are represented and transparently propagate through the whole risk assessment paradigms. The methodologies developed for handling uncertainty in risk assessment can also be used in other environmental assessments. Which assessment paradigm and/ or some combinations will be selected or not for a specific situation depends on the scope and objective of the projects, plans, programs, and policies and also depends on the information available. For example, the framework of human health risk assessment, ecological risk assessment, and comparative risk assessment can be used to identify the criteria to be used in ranking contaminated sites, when more information is available, sustainability indicators derived based on the paradigm of sustainability assessment can also be used as new criteria to prioritize contaminated sites. Sustainability assessment is more comprehensive compared with others. Nonetheless, there is a lack of advanced theories to capture the correlations between ecology, economy, and society. More approaches such as life-cycle assessment, adaptive environmental management were promulgated and were used in environmental management, the relationships and their applications combining the assessment frameworks aforementioned will be investigated in future work.

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