How to measure uncertainties in environmental risk assessment

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Environmental risk assessment is an essential element in any decision-making process in order to minimize the effects of human activities on the environment. Unfortunately, often environmental data tends to be vague and imprecise, so uncertainty is associated with any study related with these kind of data.

Essentially, uncertainty in risk assessment may have two origins – randomness and incompleteness. There are two main ways to deal with these uncertainties – probability theory and fuzzy logic.

Probability theory is based on a stochastic approach, using probability functions to describe random variability in environmental parameters.

Fuzzy logic uses membership functions and linguistic parameters to express vagueness in environmental issues.

We discuss the best way to deal with uncertainties in the environmental field and give examples of probabilistic and fuzzy-logic approaches applied to environmental risk assessment.

Keywords: Environmental risk assessment; Fuzzy logic; Monte Carlo; Probability theory; Uncertainty

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1. Introduction

The growing concern about the environment and the potential risks associated with many human activities and new technologies have created increasing interest in environmental risk assessment, which is a critical, essential part of any decision-making process. It offers sound bases for assessing and ranking potential pollution of the environment, so the evaluation of environmental risk due to anthropic activities is an important step in mitigating their impact on natural resources and in recreating the co-evolutionary process between human and natural components of the environment [1].

Decision makers of ecological policy and management require sound scientific information on the environmental risk associated with many different activities in order to arrive at and to justify their decisions [2], so there is a need to evaluate all potential risks that can cause environmental damage. The results of this environmental risk assessment should be communicated to the decision makers and regulators in a common, sound language to allow them to take the most appropriate decisions.

Estimating risk involves identifying the events that present hazards and produce risk, communicating the magnitude of the consequences associated with these events, and estimating the likelihood of a given risk [3]. However, this process is not so straightforward as one might imagine. For a complete environmental risk assessment, a great amount of data is required. In some cases, extensive statistical data may be available and can contribute to an understanding of the frequency and the severity of the hazard. However, it is very common that environmental data is qualitative, vague or imprecise, especially in the case of newly emerging contaminants.

As stated by Uricchio et al. [4], incomplete information is notoriously common in environmental issues. This imprecision of the environmental data, together with the randomness of the events and the role that human judgment plays in determining the risk and communicating its significance, means that there is uncertainty associated with risk assessment.

The proper management of this uncertainty has become a major concern in studies of environmental risk assessment [5]. In response, research is under way to explore techniques that can incorporate uncertainty and imprecision into the assessment process [3].

It has been found from the literature review that stochastic and fuzzy-set techniques have been commonly used to accommodate uncertainties associated with risk-modeling inputs and outputs. Stochastic techniques may be known as a

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''scientific reasoning model'', based on probability theory, and the fuzzy-set techniques may be known as a ''human reasoning model'', based on linguistic parameters and qualitative assessment.

In this article, we discuss the suitability of both methodologies to deal with uncertainty, and provide applications of these approaches to environmental risk assessment.

2. Risk assessment and risk management

According to Varnes [6], *risk* is generally defined as the combination of *hazard* and *vulnerability*; hazard represents the probability that a potentially detrimental event of given characteristics occurs in a given area, for a time period; vulnerability is the degree of intrinsic weakness of the system.

Risk can be measured by pairing the probability of occurrence of an event, and the outcomes or consequences associated with that occurrence. This pairing is not a mathematical operation, a scalar or vector quantity, but a matching of the probability of the event occurring with the expected consequence [7].

Risk assessment can be defined as the process of estimating the possibility that a particular event may occur under a given set of circumstances [2]. But *risk management* is the process whereby decisions are made about whether an assessed risk needs to be managed, and the means for accomplishing that management, for the protection of public health and environmental resources [8].

Risk assessment could be considered as the most important step in the risk-management process (i.e. decision-making process). It provides a scientific, sound basis for making decisions. Managing risks should involve making decisions based on the information collected in risk assessment. However, it is important to remember that the final decision of how to manage risk is generally human in nature. This means that, apart from the results gathered in the risk assessment, social and cultural values, economic realities and political factors are borne in mind. According to Barnthouse [9], the role of science in risk assessment is to ensure that the actions implemented by environmental managers achieve the goal and the objectives defined by society.

Fig. 1 presents the steps in environmental risk management. The first step is to establish the context in which environmental risk is assessed (e.g., river water or groundwater). After this, it is necessary to identify the potential sources of environmental risk (e.g., releases of chemical products into a river). At the third step, predictions of the frequency and the consequences of the event are required. There are different techniques to assess these parameters [10,11] (e.g., event trees, historical analysis and HAZOP). From these results, a risk categorization and a final risk assessment of the situation can be obtained. Steps 1–4 provide the basis for the rest of the process of risk management, known as risk assessment. Once the risk assessment has been conducted, an environmental risk plan has to be developed in order to establish targets, means and timeframe to reduce the risk that has been identified and assessed. After this, the plan must be implemented and finally reviewed to check that it works properly.

Despite the unquestionable appropriateness of risk assessment as a tool to help in the decision-making process, it can be the part of the whole risk-management process that is most difficult and prone to error, mainly because uncertainty in the measurements of hazard and vulnerability is often large. Insight about risks is limited by the randomness inherent in nature and the lack of sufficient information about the chances of a risk occurring and the potential consequences of such an occurrence. As a result, uncertainty is inherent in risk assessment [12,13].

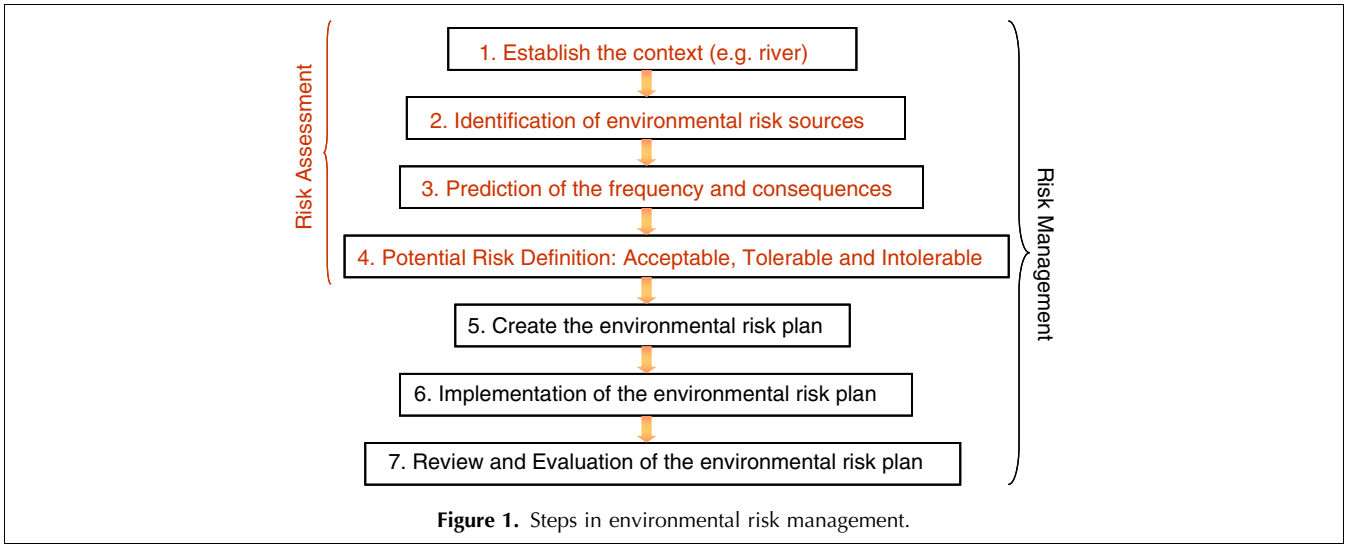

Figure 1. Steps in environmental risk management.