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Environmental risk assessment of accidental releases in chemical plants through fuzzy logic

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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, in many occasions, environmental data tend to be vague and imprecise and as a consequence uncertainty is associated to any study related to it. Uncertainty in risk assessment may have essentially two origins: randomness and incompleteness. In this paper, fuzzy logic is used to manage this uncertainty in environmental data concerning accidental releases in chemical plants. The methodology developed allows assessing the environmental risk of such releases using a set of parameters treated with fuzzy logic. This method can be used as a powerful tool by both public authorities and plant managers to take decisions in situations where chemical releases can occur.

1. Introduction

The growing concern about the environment and the potential risks associated to many human activities and new technologies have arisen an increasing interest towards environmental risk assessment. In addition, the introduction of a list of ecotoxic substances by the Council Directives 96/82/EC (Seveso II Directive, 1996) and 2003/105/EC (Seveso Directive, 2003) leads to the need of assessing the environmental risk resulting from major accidents in industrial plants.

Estimating this risk involves identifying the events that imply hazards and assessing the magnitude of their consequences and frequency (Lein, 1992). However, this process is not as straightforward as one could imagine. For a complete environmental risk assessment, a great amount of data is required. In some cases, extensive statistical data may be available that can contribute to an understanding of the frequency and severity of the hazard (probabilistic approach) (Casal, 2008). Unfortunately, in many occasions, environmental data tend to be vague and imprecise and as a consequence significant uncertainty is associated to any study related to them.

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The proper management of this imprecision has become a major concern in environmental risk assessment studies (Kentel and Aral, 2007). The ability to model complex behaviors as a collection of simple if–then rules makes fuzzy logic a useful tool in risk assessment (McKone and Deshpande, 2005). Fuzzy logic techniques are used to deal with uncertainty and can be very powerful when having poorly characterized parameters. Moreover, the risk assessment results expressed in linguistic terms (fuzzy logic uses linguistic parameters) leads to an understandable approach for the decision makers and the public (Darbra et al. 2008).

Therefore, a methodology to assess the environmental risk of accidental releases in chemical plants using fuzzy logic has been developed and is presented in this paper. The main steps to feed the system are:

- the characterization of the substance involved in the industrial accident. The hazardousness of the substance depends on its mobility, its toxicity and its degradability;
- the vulnerability of the soil (e.g. permeability) and the groundwater (e.g. depth);
- the management and plant measures to protect the environment and the people in the area (i.e. level of safety that they guarantee).

Once each of these steps has been reached through fuzzy logic application, a categorization of the risk of the plant can be obtained: No risk, Low risk, Medium risk, High risk. This methodology is a useful tool for both public authorities and plant managers.

2. Fuzzy logic

The notion of an multi-valued logic took hold recently. That was in the mid-sixties when Zadeh (1965) published his seminal work Fuzzy Sets in order to provide a model for inexact concepts and subjective judgements similar to those encountered in risk assessment.

Fuzzy logic represents a significant change in both the approach to and the outcome of environmental evaluations. The key advantage of fuzzy methods is how they reflect the human mind in its remarkable ability to store and process information that is imprecise, uncertain, and resistant to classification (McKone and Deshpande, 2005).

Fuzzy logic is an alternative to the classical logic where every proposition must either be “true” or “false”. Instead, fuzzy logic asserts that things can be simultaneously “true” and “not true”, with a certain membership degree to each class (Zadeh, 1983). It is based on membership functions and linguistic parameters to express vagueness in environmental issues. Fuzzy logic has the power to handle the concept of ‘‘partial truth’’ to quantify uncertainties associated with linguistic variables (Chen and Pham, 2001). It allows defining a “degree of membership” of an element in a set by means of a membership function. For classical or “crisp” sets, the membership function only takes two values: 0 (non-membership) and 1 (membership). In fuzzy sets the membership function can take any value from the interval [0,1]. The value 0 represents complete non-membership, the value 1 represents complete membership, and values in between are used to represent partial membership (Mohamed and Cote, 1999).

Fuzzy set theory provides a way to use imprecise and uncertain information generated by the system and human judgements in a precise way. When the environmental data available does not provide proper statistical treatment, fuzzy arithmetics can solve this problem, since it works well for addressing poorly characterized parameters and linguistic variables. Fuzzy logic also can merge different kinds of parameters (e.g. environmental, health), quantitative and qualitative.

3. Methodology

The proposed fuzzy model consists of different steps. During the first stage, the inputs and outputs must be defined and then converted from values to linguistic parameters by creating fuzzy sets for each of them (fuzzification process). Secondly, a set of rules must be established. These rules will allow going from the input to the output. But now the process has to be inverted: from the linguistic parameter it is necessary to attain a crisp numeric value by the defuzzification process (centroide method). Finally, an output is obtained which is directly related with a certain level of risk. All these steps are carried out using the fuzzy toolbox present in Matlab and they are explained hereafter.

A) Inputs definition

As can be seen in Figure 1, there are many parameters involved in the risk assessment of release of ecotoxic substances in a hazard plant. Three big macro variables should be identified in order to carry out a proper risk assessment: the hazardousness of the substance, the vulnerability of the soil/groundwater and the protective/preventive measures taken in order to protect the environment.

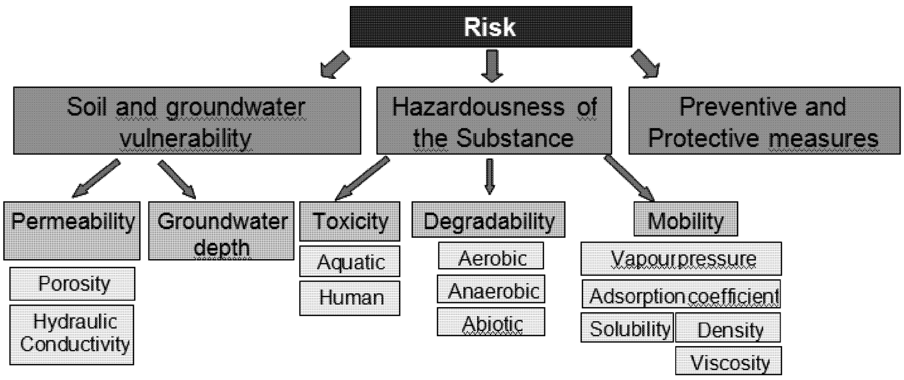

Figure 1. Risk assessment scheme for releases of ecotoxic substances in hazard plants.

These three macrovariables depend on several factors and at the same time these ones depend on others. The information required to carry out a complete risk assessment is often not available and/or expensive to obtain, both in terms of time and money. The fact that the information required by fuzzy logic is more qualitative than quantitative makes this tool the perfect candidate to be used to preliminary assess the risk of soil and water pollution in hazardous plants.

B) Outputs definition

The main output of this fuzzy model is the risk level for each of the surveyed plants and situations. A function to attain the final value of this risk can be established (1).

Risk Function

In order to assess the risk of releases of ecotoxic substances in hazard plants the risk was defined as follows:

$$R=S*V*M \qquad (1)$$

with: S, hazardousness of the substance; V, soil and ground water vulnerability; M, protective/preventive measures taken in order to minimize the environmental impact of a hypothetical accident.

It is important to notice that S and V are macro variables, since they are functions of other parameters (such as toxicity, mobility, degradability and permeability and groundwater depth, respectively). The macrovariables and their effect on the final event consequences are shown in Figure 2.

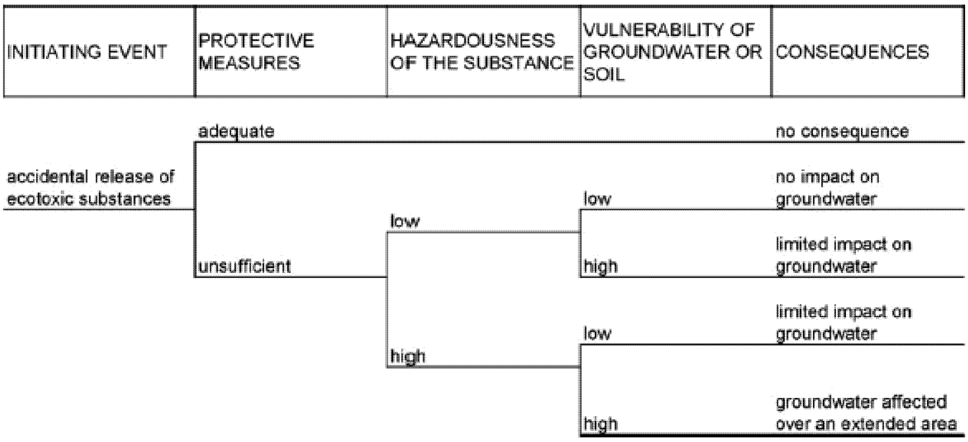

Figure 2. Event tree describing the effects of the model variables in case of accidental release of ecotoxic substances.

C) *Fuzzy sets and intervals*

For all the inputs and outputs, the fuzzy sets must be established to convert numeric values to linguistic parameters. This is called fuzzification process. In most cases the fuzzy sets have been: Low, Medium and High, associated with a quantitative description ranging from 0 to 10. In the case of the final output four categories have been established: Inert, Low, Medium and High as seen in figure 3.

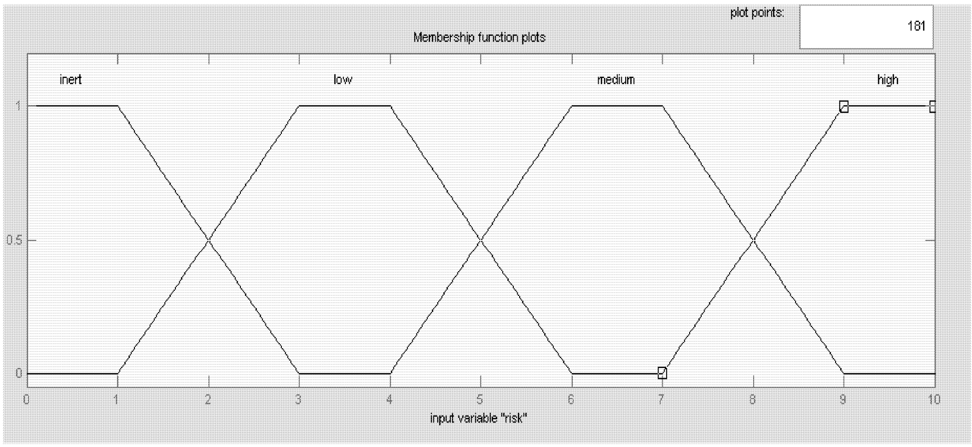

Figure 3. Fuzzy subsets and membership functions for the risk output.

D) *Membership functions*
To define the grade of membership of each element X to a given fuzzy set A, membership functions are required. They are characteristic of the data set under analysis and can take on many forms: Triangular, Trapezoidal, Gaussian, etc. In the present work, trapezoidal functions are used (see Figure 3).

E) *Setting up the rules*
Fuzzy logic is a decisional system based on linguistic rules. These rules connect the inputs with the output (e.g. if hazardousness of the substance is high and vulnerability is high and measures low, then risk is high) and they activate certain area of the membership functions.

F) *Defuzzification*
This is the conversion of the fuzzy output set (an area) to a crisp number. Finally, an output is obtained which is directly related with a certain level of risk (e.g. inert, low, medium, high). All these steps are carried out using Matlab fuzzy toolbox.

4. Application of the methodology to the process industry

The process industry uses and handles many hazardous substances that, in the event of a loss of containment, can be harmful for people and for the environment.

An accidental release can follow diverse sequences and lead to different scenarios, depending on the condition –liquid, gas/vapour, two-phase flow– of the hazardous substance released. Fig. 4 is a simplified scheme of the diverse possibilities which can occur. The final consequences on the environment can be the pollution of soil and/or ground water, the pollution of water, atmospheric pollution and, furthermore, those related to blast and thermal radiation. The methodology discussed in this communication deals essentially with the soil and ground water pollution, although it could also be applied to the other situations (which are much more dynamic and less persistent).

This methodology is now being tested through its application to chemical plants located in Catalonia.

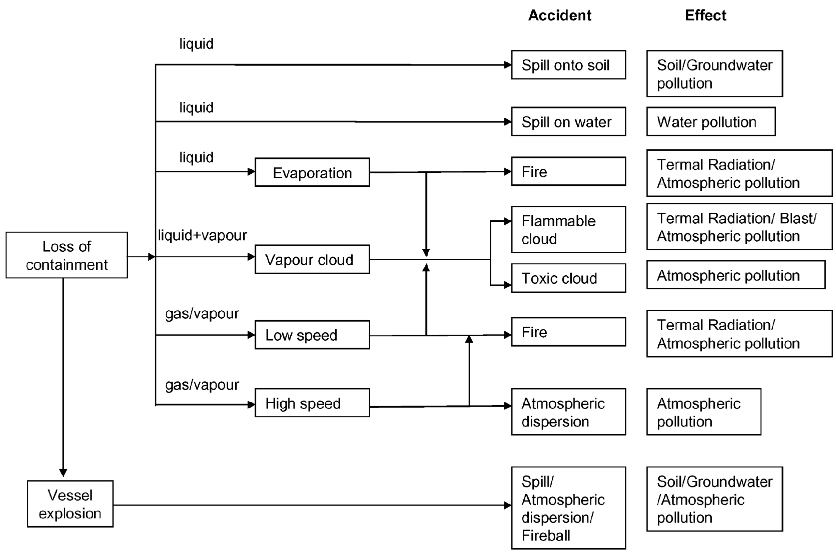

Figure 4. Simplified schematic representation of the accidents that can occur following a loss of containment and their potential associated damage.

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References

Casal, J., 2008. Evaluation of the effects and consequences of major accidents in industrial plants. Elsevier, Amsterdam.

Chen, G. and Pham, T., 2001, Introduction to Fuzzy Sets, Fuzzy Logic and Fuzzy Control Systems. CRC Press, Boca Ratón, Florida.

Darbra, R.M., Eljarrat, E., Barceló, D., 2008. How to measure uncertainties in environmental risk assessment. Trends in Analytical Chemistry, vol. 27, n. 4.

E. Kentel, M.M. Aral, Risk tolerance measure for decision-making in fuzzy analysis: A health risk assessment perspective. Stochastic Environmental Research and Risk Assessment 21(4) (2007) 405.

Lein, J.K., 1992. Expressing environmental risk using fuzzy variables: a preliminary examination, Environ Prof 14, 257.

McKone, T.E. and Deshpande, A.W., 2005. Environ. Sci. Technol. 39 (2) 42A.

Mohamed, A.M.O. and Cote, K. 1999. Waste Manage 19, 519.

Seveso II Directive, 1996. Council Directive 96/82/EC of the European Parliament on the control of major-accident hazards involving dangerous substances, Official Journal No. L 010 of 14 January 1997.

Seveso III Directive, 2003. Council Directive 2003/105/EC of the European Parliament amending Council Directive 96/82/EC on the control of major-accident hazards involving dangerous substances, Official Journal No. L 345 of 16 December 2003.

Zadeh, L.A., 1965. Inf. Control 8, 338.

Zadeh, L.A., 1983. The Role of Fuzzy Logic in the Management of Uncertainty in Expert Systems, Fuzzy Sets and Systems 11, 199.