Spatial mapping of environmental risks: state-of-the-art and perspectives *by J. Lahr*

Introduction

Traditionally, results from environmental risk assessment (ERA) have been presented in non-spatial ways. However, in reality one has to deal with pollution gradients and uneven distribution of exposure receptors. Geographical risk maps therefore provide a powerful tool for analysis and visualization of the spatial distribution of environmental stressors and their effects on humans and ecosystems. In brief, risk mapping is the visualization of the geographical distribution of risks in an area. Two types of risk mapping can be distinguished: explorative (study, analysis, method development) and communicative (inform non-scientific stakeholders, policy makers and the general public, raise public awareness). However, making risk maps for communication purpose should be done with care and in a scientific sound manner.

The NoMiracle project of the EU develops innovative methods for ERA. It focuses on cumulative risk assessment, i.e., taking into account the combined effects of stressors. This includes:

- multiple sources of emission,
- behavior and fate in multiple compartments (multimedia fate),
- multiple pathways of exposure,
- multiple receptors (notably integration of ecological & human ERA), and
- multistress (with as special case combitox, the combined effects of toxicants).

Hargrove et al. (1996) call the multivariate nature of contamination data sets a 'double-edged sword': "when presented in the appropriate spatial context, the same multidimensionality may effectively communicate nuances and lead to easier decision making". The multivariate and complex nature of modern risk assessment methods should therefore be reflected in the development of novel methods for risk mapping. In this chapter an overview of currently existing methods and the most important challenges for further development of risk maps are provided.

Literature survey

NoMiracle partner Alterra (Wageningen UR, The Netherlands) conducted a survey literature on current risk mapping methods to assess the state-of the-art of risk mapping methods for toxic substances (Lahr & Kooistra, 2006; NoMiracle deliverable D 4.4.1). Special attention was being paid to:

- risk concepts and indicators for cumulative ERA,
- integration of human & ecological risks in maps, and
- relations between map making and end users.

The focus was on peer-reviewed literature but a few reports and websites were screened as well. More than 150 documents were consulted and some 80 of them were reviewed.

Published maps differ considerably with regard to risk assessment methods, assessment level, indicators, scale, underlying data and spatial operations applied. Table 1 presents an overview and classification of the most important current methods used to map environmental contamination, exposure to pollutants and risks of single and cumulative stressors. An important distinction can be made between vulnerability maps (mapping the vulnerability to stressors based on the features of an area, often before contamination occurs) and 'true' risk maps (mapping the geographical distribution of the risk associated with stressors that are already present, often expressed as the probability that a certain toxic or health effect will occur).

State-of-the art

The results show that risk mapping is a new and rapidly developing field. But the survey also showed some major shortcomings of the reviewed maps and methods:

- True collaboration between risk assessors and GIS seems to be rare, i.e., many publications focus on either ERA or GIS methodology, not on both.
- The majority of maps deals with local scale problems. National and continental scale maps (catchment areas, pan-European, etc.) are less common, probably because they require more data and because local data sets often need to be harmonized first.
- Results of human and ecological risk assessment are hardly ever shown simultaneously in maps. No true examples of such integration were found.
- Maps of multiple and cumulative stress factors are still rare as well (an example of a simple risk map with three combined pesticide stressors is shown in Figure 1).
- Communication is seldom mentioned as the objective of the published maps. Many are published without identification of the end users for which the maps are intended. This, however, is pivotal when designing the maps and methods for communication purposes.

Perspectives

The increasing availability of environmental data in large electronic databases and the ongoing developments in GIS techniques make risk mapping relatively easy these days. As a consequence, the field of risk mapping is rapidly expanding and risk maps are increasingly used. Contamination risk maps and vulnerability maps (Table 1) are very suitable for planners and decision makers. They can be used to plan future activities in such a way that environmental risks to humans and ecosystems can be prevented or at least reduced. Maps that display existing pollution and their associated environmental risks are more appropriate to raise public awareness and to support environmental policies.

Among the principal challenges in risk mapping are:

- dealing with the multivariate nature of risks (and simplify this for use in maps),
- scale issues (upscaling from local to higher levels, spatial aggregation),
- mapping and communicating uncertainties in ERA, and
- designing and optimalising maps for communication purposes.

It is anticipated that the use of GIS and modern mapping methods will greatly improve the implementation and communication of ERA results the coming years. These developments should also lead to more international and uniform approaches and to the exchange of (national) datasets.

How to make the right maps?

Some tips for the makers of risk maps are given below.

- Identify the target audience and stakeholders for whom the map is meant.
- Formulate the objective of the map. Remember that “every map has a purpose” (Frye, 2001).
- Use the appropriate risk assessment methods. Clearly describe these methods and the indicators used or provide complete references to the methods.
- Apply appropriate cartography and spatial operations (GIS).
- Get the visualization right (scale, colours, etc.). The right cartography can be used by risk assessors to improve communication and thus to bridge the gap between experts and laypersons (Husdal, 2001).
- Suggestive use of symbols and colors (red, purple) should be avoided. See Bartels & Van Beurden (1998).
- Always provide clear legends with risk maps. People should know what they are seeing.

- Clearly communicate and display any uncertainties associated with the ERA methods, its outcome and the data in the maps.
- Use the right communication channels and techniques.
- Be aware that risk perception of the general public is different from that of the specialists (Holtzhauer et al., 1998)!

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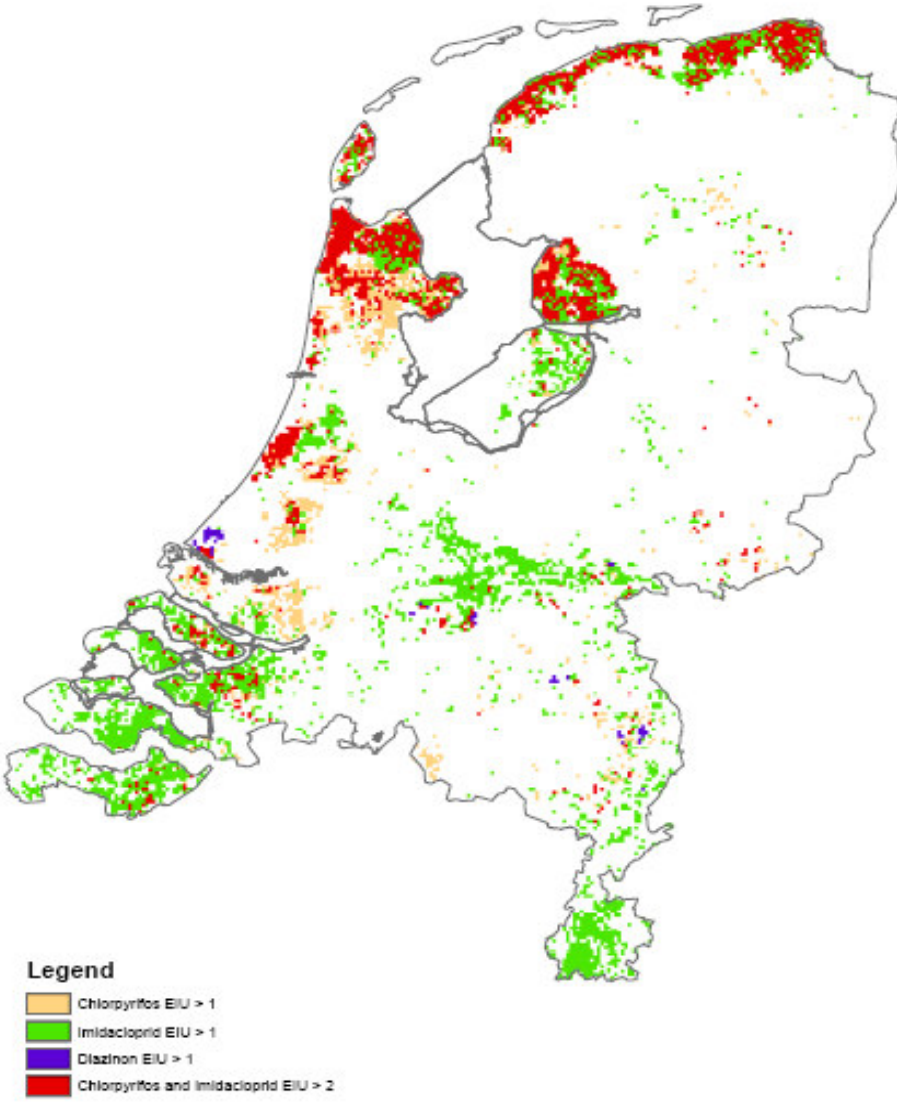

Figure 1: Example of a map displaying combined risks. Aquatic and terrestrial, human and ecological risk for three insecticides in The Netherlands in 1998. Environmental Indicator Units (EIU) are calculated by dividing Predicted Environmental Concentrations by threshold concentrations (Alterra, unpublished data). Please note that the map is a test version for development purposes. It is not necessarily accurate or complete.

Table 1: Summary of the current approaches used for mapping contamination and risks.

Map category	How to make them?
Contamination	Display the distribution of measured or predicted (modeled) concentrations in a geographical area
Contamination risk	Use the physical and geographical features in an area to map the likelihood of (potential) contamination
Vulnerability	Use the presence and geographical distribution of sensitive receptors of environmental stress to map more and less vulnerable areas
(Potential) exposure	Combine (measured or predicted) contamination levels with the geographical distribution of (ecological or human) exposure receptors
Risk of single stressors	• Compare (measured or predicted) environmental concentrations to simple environmental threshold levels and map the results • Map results of extensive modeling/simulation of contamination, exposure and effects ('model train' approach) • Combine maps of vulnerability and maps of (potential) stress/environmental pressures (e.g., by overlaying)
Risk of multiple stressors	• Calculate combined risk from single stressors using cumulative stress principles and algorithms (e.g., concentration-addition) • Use multivariate statistical analysis to reduce dimensionality and map the resulting statistical parameter values • Present risk assessment results in more dimensions (e.g., a map with a matrix legend or visualization in 3D or 4D)

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