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A moni-modelling approach to manage groundwater risk to pesticide leaching at regional scale

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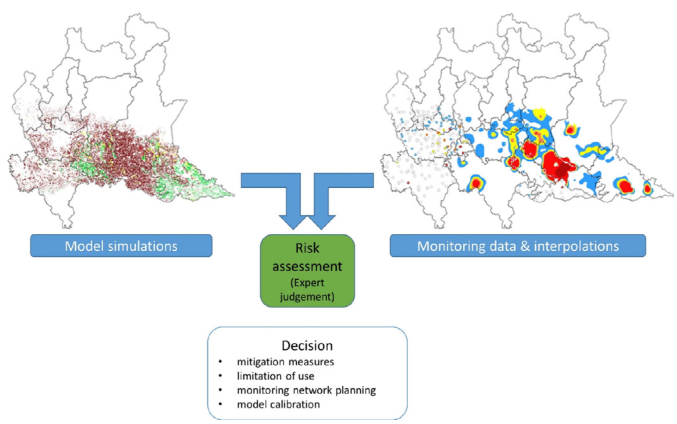
HIGHLIGHTS

- A novel methodology to identify vulnerability areas to pesticides
- Coupling information from fate models and monitoring programmes
- Decision support tool for public risk assessors
- Environmental awareness

GRAPHICAL ABSTRACT



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ABSTRACT

Historically, the approach used to manage risk of chemical contamination of water bodies is based on the use of monitoring programmes, which provide a snapshot of the presence/absence of chemicals in water bodies. Monitoring is required in the current EU regulations, such as the Water Framework Directive (WFD), as a tool to record temporal variation in the chemical status of water bodies. More recently, a number of models have been developed and used to forecast chemical contamination of water bodies. These models combine information of chemical properties, their use, and environmental scenarios. Both approaches are useful for risk assessors in decision processes. However, in our opinion, both show flaws and strengths when taken alone. This paper proposes an integrated approach (moni-modelling approach) where monitoring data and modelling simulations work together in order to provide a common decision framework for the risk assessor. This approach would be very useful, particularly for the risk management of pesticides at a territorial level. It fulfils the requirement of the recent Sustainable Use of Pesticides Directive. In fact, the moni-modelling approach could be used to identify sensible areas where implement mitigation measures or limitation of use of pesticides, but even to effectively re-design future monitoring networks or to better calibrate the pedo-climatic input data for the environmental fate models. A case study is presented, where the moni-modelling approach is applied in Lombardy region (North of Italy) to identify groundwater vulnerable areas to pesticides. The approach has been applied to six active substances with different leaching behaviour, in order to highlight the advantages in using the proposed methodology.

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1. Introduction

Groundwaters are the most sensitive and largest body of freshwater all over the world; very frequently, they are characterized by a very long mean retention time, and thus the consequences of potential pollution have long time scales (Haarstad, 1998). This is obviously of particular concern, since groundwater supplies the vast majority of drinking water. In Europe almost about 65% of water is taken from underground (Bouraoui, 2007), reaching peaks in some countries, such as in Italy, where more than 85% of the drinking water is extracted from aquifers (Onorati et al., 2006). In this context, the European Water Framework Directive (WFD — 2000/60/EC) has represented a first and important framework for developing measures for the conservation, protection and improvement of the quality of water as limited and vulnerable resource (European Commission, 2000). The environmental protection of groundwater is explicitly acknowledged by the Directive 2006/118/EC, also known as the "daughter Directive" to the Framework Directive (European Commission, 2006).

Agricultural activity is the most significant factor and the main cause of chemical pollution in many surface waters and aquifers (i.e. nitrates and Plant Protection Products). For instance, since the early analytical evidences of Plant Protection Products (PPPs) contamination of surface water and aquifers (Leistra and Boesten, 1989; Hallberg, 1989; Funari and Vighi, 1995), there have been increasing evidences of contamination of water resources from pesticides and their metabolites (Guzzella et al., 2006; Hildebrandt et al., 2008; Reemtsma et al., 2013; Bozzo et al., 2013; Stehle and Schulz, 2015). Directive 2006/118/EC has set to 0.1 μg/L and 0.5 μg/L the maximum allowable concentrations in drinking water for each individual pesticide and for their sum, respectively. This value has been also included in the EU Regulation 1107/2009/EC (formerly 91/414/EEC), concerning the placing in the market of PPPs. In Europe, PPPs regulation has been further strengthened by the recent promulgation of the Directive on Sustainable Use of Pesticides (2009/128/EC). According to this directive the EU Member States have to establish National Action Plans (NAPs) to reduce risks of PPPs use and to identify vulnerable areas (or sensible areas), in which a minimization or a prohibition of pesticide use should take place. This Directive represent a major challenge for water quality managers and environmental risk assessors and the availability of supporting information systems and methodologies useful to identify vulnerable areas or to define risk mitigation actions on the territory would be very helpful in their decisions (European Commission, 2009).

At the time being, the approach used by water quality managers to implement risk mitigation measures for PPPs on the territory falls within two categories:

a) monitoring studies, as a mean to disclose the present contamination status and assess the impact of newly implemented measures (Finizio et al., 2011; Bozzo et al., 2013);
b) use of models to predict the environmental distribution and fate of PPPs.

Both approaches show pros and cons. For instance, monitoring campaigns are very useful for regulatory purposes to verify whether the concentration of a chemical (or more) exceeds predetermined trigger values (e.g. 0.1 μg/L in groundwater). On the other hand, the main limitation of the monitoring approach is referred to the informative content of the obtained data. As matter of fact, they represent a snapshot of what is happening (in terms of concentrations) while sampling. In other words, they represent a single point in space and time (static), in a situation in which different dynamic processes act at the same time; consequently, the future state of the environment cannot be forecasted from monitoring data (Suzuki et al., 2004). Furthermore, they do not provide information on the origin of contamination (point and non-point source pollution). Finally, a preliminary set of information are needed to plan monitoring campaigns, both for selecting pesticides to be included in the list of monitored substances (leaching potential, loading rates, availability of analytical techniques) and to define the number and the spatial distribution of sites to be monitored and the sampling frequency (hydrogeology, agronomic practices, climate and soil properties). However, such information is not always easily available. In addition, the high economic costs of monitoring often limit the density of monitoring sites and influence a proper implementation of monitoring plans.

In alternative to monitoring, water quality managers can use predictive approaches. In recent years, many researchers have developed numerous spatially distributed fate and transport models of PPPs. According to Pistocchi (2008), the main advantage of such models is related to their capability of allowing spatially explicit representations (maps) of contaminants from a given spatial distribution of sources (Brown et al., 2002; Suzuky et al., 2004; Bachmann, 2006; Gusev et al., 2005). Advent of GIS has facilitated the development of this approach. For instance, very recently, a new software tool, named VULPES (VUlnerability to PESticide — Di Guardo and Finizio, 2015) has been suggested as a tool to identify groundwater vulnerable areas in Lombardy and Veneto regions (North of Italy). However, in literature there are a number of papers in which the integration of GIS systems and predictive models have been proposed, both for surface and groundwaters (Wilson et al., 1993; Burkart et al., 1998; Manguerra et al., 1998; Burkart et al., 1999; Tiktak et al., 2002; Verro et al., 2002; Holman et al., 2004).

Undoubtedly, the existing spatially explicit models provide a valuable analytical tool to identify vulnerable areas and to forecast the probable consequences of risk mitigation actions taken from risk managers on a territory. Yet they tend to be rather complex when spatial resolution increases, requiring high computation time. In addition, according to the golden role "garbage in garbage out", if the input data are incorrect or uncertain, the resulting outputs can be wrong or debatable. For instance, the spatial variability of environmental data (i.e. soil properties, climatic conditions, crop distributions, irrigation and management patterns) cannot be easily and finely described at regional scale. In addition, other information such as period of treatments, rate of application, and typologies of pesticides mostly utilized on a particular crop are not always available. This leads to the introduction of biases and uncertainties in the spatial estimation of pesticide transport toward water resources; consequently, this could hamper the correct implementation of risk mitigation actions on the territory, even if the model has been previously validated in other geographical context.

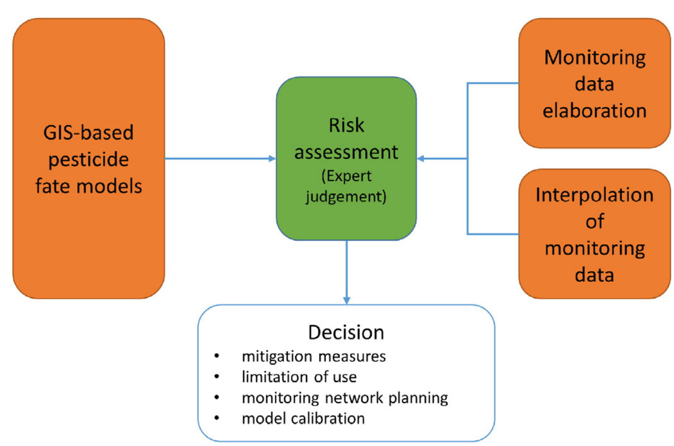

Fig. 1. Flux diagram of the proposed methodology. Colours represent different spatial levels of each action (in orange at regional level, in green at local level). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)