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A new methodology to identify surface water bodies at risk by using pesticide monitoring data: The glyphosate case study in Lombardy Region (Italy)

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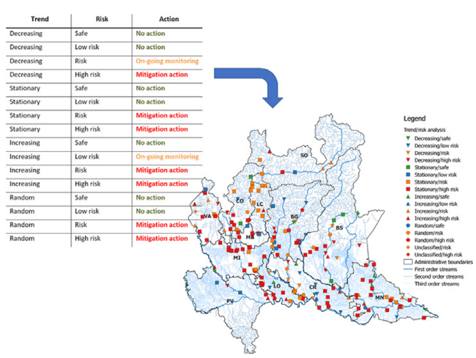
HIGHLIGHTS

- How to identify the need of pesticide risk mitigation actions for surface waters.
- Territorial analysis coupled with expert judgement.
- Decision support tool for public risk assessors
- Environmental awareness

GRAPHICAL ABSTRACT



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ABSTRACT

In the last decades, several monitoring programs were established as an effect of EU Directives addressing the quality of water resources (drinking water, groundwater and surface water). Plant Protection Products (PPPs) are an obvious target of monitoring activities, since they are directly released into the environment. One of the challenges in managing the risk of pesticides at the territorial scale is identifying the locations in water bodies needing implementation of risk mitigation measures. In this, the national pesticides monitoring plans could be very helpful. However, monitoring of pesticides is a challenging task because of the high number of registered pesticides, cost of analyses, and the periodicity of sampling related to pesticide application and use. Extensive high-quality data-sets are consequently often missing. More in general, the information that can be obtained from monitoring studies are frequently undervalued by risk managers. In this study, we propose a new methodology providing indications about the need to implement mitigation measures in stretches of surface water bodies on a territory by combining historical series of monitoring data and GIS. The methodology is articulated in two distinct phases: a) acquisition of monitoring data and setting-up of informative layers of georeferenced data (phase 1) and b) statistical and expert analysis for the identification of areas where implementation of limitation or mitigation measures are suggested (phase 2). Our methodology identifies potentially vulnerable water bodies, considering temporal contamination trends and relative risk levels at selected monitoring stations. A case study is presented considering glyphosate monitoring data in Lombardy Region (Northern of Italy) for the 2008–2014 period.

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1. Introduction

Water is widely recognized as the most essential of natural resources but nowadays freshwater systems are directly threatened by human activities (Meybeck, 2003; Vörösmarty et al., 2005). Indeed, the majority of streams and rivers are ecologically impaired or threatened and they constantly are losing biodiversity, which compromise the future provisioning of vital ecosystem services (Vörösmarty et al., 2010; Cardinale et al., 2012). According to Malaj and coworkers (Malaj et al., 2014), pesticides are mostly responsible of the threatening of non-target aquatic species in the European water bodies. These compounds can reach water bodies through different pathways such as spray drift, evaporation and deposition, or after rain events through runoff and erosion or drainage. Surface waters may also receive unwanted amounts of pesticides due to improper cleaning of spray equipment or improper applications in residential areas (Wauchope, 1978; Schulz, 2004).

The presence of pesticides residues in surface and groundwater is regulated through different directives, including the Ground Water Directive (Directive 2006/118/EC), the Drinking Water Directive (Directive 98/83/EC) and the Water Framework Directive (WFD) (Directive 2000/60/EC), which has been modified later several times (Directive 2008/105/EC; Directive 2013/39/EU). For groundwater concentration limits of 0.1 μg/L for individual pesticides and 0.5 μg/L for total pesticide must not be breached across a groundwater body to ensure that good chemical status is maintained. For surface waterbodies, the article 16 of the WFD settled out the strategy against chemical pollution. To determine the overall quality of a waterbody the chemical status assessment is used alongside the ecological status assessment. In addition, the Environmental Quality Standards (EQSs) Directive (Directive 2008/105/EC) established the maximum acceptable concentration and/or annual mean concentration for 33 priority substances and 8 other pollutants which, if met, allows the chemical status of the waterbody to be described as 'good'. These EQSs are applied to all EU Member States. In addition, the WFD also established the principles to be applied by each Member State to develop EQSs for other specific pollutants (Annex VIII substances of WFD). Compliance with EQSs for specific pollutants forms part of the assessment of ecological status. In Italy, in absence of an EQS for a specific pollutant a default value of 0.1 μg/L is utilized (MATTM, 2006, 2010).

Other EU measures to control pesticides in the environment are also well established. For instance, Council Directive 91/414/EEC (Council of the European Union, 1991), repealed and replaced by Regulation (EC) No 1107/2009 on 14 June 2001 (European Commission, 2001), laid down the authorization procedures of pesticides to be marketed within the European Union. During the authorization process, possible entries and resulting concentrations in the edge of field water bodies are predicted based on available fate models and using a tiered approach, which was developed by the FOCUS (i.e., Forum for the Coordination of Pesticide Fate Models and their Use) group (FOCUS, 2001). The PECs (Predicted Environmental Concentrations) are then compared with a predetermined list of ecotoxicological endpoints on selected aquatic non-target species (algae, *Daphnia*, fish) for estimating acute and chronic risks. If unacceptable risk is indicated, restrictions on the use are required (Schulz, 2004; EFSA, 2013a, Alix et al., 2017).

More recently, the Directive 2009/128/EC of the European Parliament and of the Council of 21 October 2009, commonly referred to as "the Sustainable Use of Pesticides Directive", (European Commission, 2009), established a framework for Community action to achieve the sustainable use of pesticides. Among the requirements of the Directive, one obliges Member States to adopt a National Action Plan (NAP). The plan should define a national strategy to set down objectives, quantifiable measures and timeframes to reduce the risks associated with the use of pesticides. This Directive asks Member State to pay particular attention to water resources by taking appropriate risk mitigation measures on the territory to avoid pesticides contamination of water resources. An inventory of the risk mitigation tools for pesticides being implemented or in development in European countries is reported in the work of Alix et al. (2017). In this framework, one of the challenges to manage pesticides risk at territorial scale is the identification of reaches of water bodies where to implement risk mitigation measures. In this, the national pesticides monitoring plans could be very helpful; usually, they are carried out at regular intervals and series of both spatial and temporal data are available and often published in national environmental reports such as those regularly published by the Italian Environmental Protection Agency (i.e. ISPRA, 2016). In the last years several attempts to use pesticide monitoring data alone or in combination with predictive models have been proposed for setting risk mitigation measures to preserve aquatic systems (Finizio et al., 2011; Bozzo et al., 2013; Di Guardo and Finizio, 2016).

In this paper, we discuss and propose a new methodology useful to provide indications to risk managers about where to implement pesticides risk mitigation measures at the territorial scale by using public and already available data derived from national monitoring plans of pesticides residues in surface water. The approach relies on the spatialisation of monitoring data and the definition of an automated expert system for the identification of trends of contaminations in specific areas. In addition, by using different GIS layers (crops distribution, highways and trains networks, urban areas) it could be used to identify different potential sources of pesticides emissions and areas where risk assessors should further investigate.

The proposed approach is described and discussed by using, as a case study, surface water monitoring data of the herbicide glyphosate in Lombardy Region (North of Italy).

2. Materials and methods

2.1. Overview

This paper describes a methodology to address the environmental risk analysis for surface water bodies by using pesticide monitoring data as suggested by European regulations and in particular the National Action Plan drafted by Member States in the frame of the Sustainable Use of Pesticides Directive (European Commission, 2009). Its final target is to help risk assessors to identify waterbodies mainly at risk and to prioritise vulnerated areas on the territory. The methodology could be implemented using a spreadsheet for statistical analysis or in alternative a statistical software such as R (R Core Team, 2012) and a GIS application for distributing data on the territory (the freely available Quantum GIS tool (Quantum GIS Development Team, 2017) has been used in the test case here presented)..

The methodology shall be applied for a single pesticide and foresees two distinct steps (Fig. 1):

- **Phase 1**: acquisition of the available monitoring data (MECs: Measured Environmental Concentrations) and calculation of statistical parameters (MEC_{mean}, MEC_{median} and $MEC_{95th\ percentile}$ for each monitoring station and available year). In addition, the ratios MEC/EQS or MEC/PNEC are calculated, where MEC is one of the above described statistical parameters and EQS and PNEC are the Environmental Quality Standard and the Predicted No Effect Concentration respectively.
- **Phase 2**: expert analysis and rules for the identification of areas at risk.

Both phases are better described in the following paragraphs.

2.2. Phase 1: monitoring data analysis and indices calculation

Monitoring data are generally provided by public authorities in charge of environmental data surveys; our methodology makes use of