



An indicator to map diffuse chemical river pollution considering buffer capacity of riparian vegetation – A pan-European case study on pesticides



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HIGHLIGHTS

- QuBES is a new generic indicator for the qualitative assessment of river pollution.
- QuBES allows detection of critical riverside areas in terms of water pollution by pesticides.
- Buffer permeability is modelled according to buffer width and chemical adsorption properties.
- QuBES allows assessment of a specific part of ecosystem services provided by riparian zones.

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ABSTRACT

Vegetated riparian areas alongside streams are thought to be effective at intercepting and controlling chemical loads from diffuse agricultural sources entering water bodies. Based on a recently compiled European map of riparian zones and a simplified soil chemical balance model, we propose a new indicator at a continental scale. QuBES (Qualitative indicator of Buffered Emissions to Streams) allows a qualitative assessment of European rivers exposed to pesticide input. The indicator consists of normalised pesticide loads to streams computed through a simplified steady-state fate model that distinguishes various chemical groups according to physico-chemical behaviour (solubility and persistence). The retention of pollutants in the buffer zone is modelled according to buffer width and sorption properties. While the indicator may be applied for the study of a generic emission pattern and for a chemical of generic properties, we demonstrate it to the case of agricultural emissions of pesticides. Due to missing geo-spatial data of pesticide emissions, a total pesticide emission scenario is assumed. The QuBES indicator is easy to calculate and requires far less input data and parameterisation than typical chemical-specific models. At the same time, it allows mapping of (i) riparian buffer permeability, (ii) chemical runoff from soils, and (iii) the buffered load of chemicals to the stream network. When the purpose of modelling is limited to identifying chemical pollution patterns and understanding the relative importance of emissions and natural attenuation in soils and stream buffer strips, the indicator may be suggested as a screening level, cost-effective alternative to spatially distributed models of higher complexity.

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1. Introduction

Chemical pollution from diffuse sources is identified by the current European legislation as one of the main stressors affecting the quality of rivers (EU, 2000). Most of the time, pollution has been tackled by considering individual substances more or less independently while, in practice, pollution derives from chemical mixtures of many different molecules. As a consequence, while fate and transport models can be run for individual (or a small number of) chemicals to assess environmental concentrations, quantitatively predicting the concentrations of chemical mixtures are not straightforward. It seems unlikely that we can achieve full understanding of chemical pollution through only a

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reductionist approach based on the study of individual chemicals. This has shown to generate an endless quest for more data while, for decision support, we are in need of a suitable representation of chemical pollution that makes the problem more manageable.

In addition to the complexity of chemical mixtures, another difficult task is the characterisation of chemical emissions. A direct inventorying of chemical emissions is feasible when a well-defined responsible subject can be identified (e.g. point sources), while a quantification of diffuse sources of contamination can only be made indirectly. For diffuse pollution we adopt the definition of D'Arcy et al. (2000) and Novotny (2003), who define it as pollution arising from land-use activities, dispersed over a catchment and excluding industrial, municipal sewage, deep mine or farm effluent discharge. For diffuse pollution it is often assumed that emissions are distributed according to a pre-defined pattern, e.g. population or agricultural intensity, and are quantified through appropriate "emission factors". For example, pesticide losses are reported to be in the range of 1–5% of the amount applied (Wauchope, 1978; Gaynor et al., 2001). The research question tackled in this paper focuses on the potential to support chemical pollution management by identifying the contamination patterns and priorities of action without referring specifically to individual chemicals and quantitative emission factors, but rather to the typologies of pollutants and the corresponding relevant emission patterns.

We may assume that all chemicals having a certain spatial emission pattern and sharing similar physico-chemical properties will also have similar drivers of their environmental fate. If this assumption holds, then an indicator of the relative intensity of emissions and attenuation processes may suffice to represent chemical risk. This avoids the need to characterise in detail the actual chemical mixtures involved and the fate of individual chemicals based on the specific properties.

Several indicators of chemical risk have been proposed which aim to detect priority areas for action against diffuse pollution. Many examples derive from the assessment of pesticides (Gutsche and Rossberg, 1997; Reus and Leendertse, 2000; e.g. Chen et al., 2002; Padovani et al., 2004; De Zwart, 2005; Schriever and Liess, 2007). Many other indicator approaches rely on geographic information system (GIS) based indicators, such as the attenuation factor of Rao et al. (1985), and have proven useful for decision support e.g. in water resources vulnerability mapping (Bacci, 1993; Corwin et al., 1997; Loague et al., 1998).

In this paper we aim to map diffuse pollution through normalised indicators, derived from simplified fate and transport models, enabling the identification of pollution patterns rather than individual chemicals of concern. We refer to the case of river pollution, and we define a generic indicator for the identification and ranking of areas likely to contribute to the diffuse pollution of streams, taking into account attenuation due to riparian vegetative buffer strips. We call the proposed indicator *Qualitative indicator of Buffered Emissions to Streams* or QuBES.

QuBES surrogates a quantitative estimate of pollutant loads to streams from diffuse sources, by simplifying the mass balance equation of certain categories of chemicals in soils. The presence and the abundance of riparian vegetation alongside streams, which act as pollutant buffer, is specifically considered within this process.

This indicator is intended as a tool to identify potentially critical conditions arising from a combination of relatively high chemical loads coming from the land and a relatively low buffer capacity of riparian ecosystems. Although we demonstrate the approach referring to the case of pesticides, QuBES is intended to be rather general.

After defining the indicator and providing an example application, we discuss its limitations and advantages over more traditional approaches in certain problems of river basin management.

2. Materials and methods

A key point for the assessment of diffuse river pollution is about modelling the environmental fate and transport of the chemicals of

concern, in which the buffering effects of vegetation or structures along the river shores need to be considered. Those effects are acknowledged in the literature (Mander et al., 1997) but only in a few cases (Krysanova et al., 1998; Hattermann et al., 2006) considered in large scale hydrological models.

QuBES is the product of two independent factors representing the two main processes controlling actual contaminant loads to streams: (1) potential contaminant load to streams (Y) and (2) the riparian buffer permeability to pollution (Z), respectively:

$$\text{QuBES} = Y * Z. \quad (1)$$

Term Y [–] is designed to represent the runoff of a pollutant from soil at a given location. The buffer permeability term, Z represents the fraction of the pollutant mass flux from the land that reaches a stream after passing through the riparian zone. Factors Y and Z retain also an individual physical meaning. QuBES as well as Y and Z are all non-dimensional, normalised quantities as discussed in details below.

2.1. Potential contaminant loads (Y)

We assume steady state to compute the mass balance of a generic contaminant in soil, and we further assume (1) concentration equilibrium among the different soil phases and (2) exponential dependence of a chemical's soil degradation rate on temperature. Hence, we can represent the pollutant load L [kg m⁻² s⁻¹] to a stream that is potentially generated from the land surface as (Pistocchi, 2014):

$$L \sim E \left(1 + \mu_Q \frac{\lambda Q}{e^{qT} + \alpha'Q + \beta'E_r} + \mu_{E_r} \frac{E_r}{e^{qT} + \alpha'Q + \beta'E_r} \right) \quad (2)$$

where E [kg m⁻² s⁻¹] is the pollutant emission to the land surface, Q [m s⁻¹] is the total volumetric water discharge from the land area, of which a fraction λ [–] reaches the stream through the buffer zone, while a fraction $1-\lambda$ infiltrates the shallow aquifer (hence does not contribute directly to the pollution of the nearby stream). E_r [kg ha⁻¹ yr⁻¹] is the soil erosion rate, q is the temperature constant for the degradation rate, μ_Q and μ_{E_r} are constants representing the relative importance of loads through water discharge and erosion compared to direct emissions to water (e.g. by wind drift or dripping to tile drains), while α' and β' represent appropriate constants. A detailed derivation of Eq. (2) is provided in the Supplementary data (S1). Under these assumptions, we may represent pollution loads through a simple combination of emissions (E), landscape and climate drivers (λ , Q, T, E_r) and the physico-chemical properties of pollutants (implicitly included in the other coefficients appearing in the equation). Eq. (2) may be further simplified for different typologies of contaminants as explained in Pistocchi (2014), recalled hereafter.

For non-persistent chemicals, the term $e^{qT} \gg \alpha'Q + \beta'E_r$, hence $e^{qT} + \alpha'Q + \beta'E_r \sim e^{qT}$; very frequently removal through water discharge dominates over removal through erosion (as is the general case for soluble chemicals), i.e. $\mu_Q \gg \mu_{E_r}$, although there may be cases where the contrary is true (hydrophobic chemicals), i.e. $\mu_Q \ll \mu_{E_r}$. So, in the case of non-persistent chemicals, loads can be approximated as:

$$L \sim E \left(1 + \mu_Q \frac{\lambda Q}{e^{qT}} \right) \quad (2a)$$

$$L \sim E \left(1 + \mu_{E_r} \frac{E_r}{e^{qT}} \right) \quad (2b)$$

depending on whether liquid or erosion removal dominates.

In the case of persistent chemicals, $\alpha'Q + \beta'E_r \gg e^{qT}$; additionally, if removal through erosion dominates removal through water discharge

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