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A holistic approach is key to protect water quality and monitor, assess and manage chemical pollution of European surface waters

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Abstract

Chemical pollution of surface waters is a societal concern around the globe. Key problems in current water quality protection, assessment and management are the narrow focus on a small fraction of the chemicals in commerce, concerns for increasingly diverse chemical emissions, and lack of effective diagnosis and management approaches. In reply, three key concepts to address these challenges were developed and tested. The approaches were developed in the context of the European Union Water Framework Directive, based on principles such as the DPSIR-causal framework (Drivers, Pressure, Status, Impact and Response) and the basic feature that water protection and management should be based on a water-system level approach. Collaborative actions of researchers and stakeholders resulted in: (1) an operationalization and implementation of the solution-focused risk assessment paradigm as proposed in 2009, to improve the utility of risk assessments, (2) the provision of a large set of tools and services to prevent, monitor, assess and manage complex mixture pollution problems, and (3) a strategy and a database on intervention options. These three elements were recognized as core elements to help protecting and improving water quality. Although the methods were developed in the context of water quality problems in Europe, the three elements can be applied globally in water quality protection and management.

Challenge

Chemical pollution of surface waters is a societal concern around the globe [1–3]. Key problems in current water quality protection, assessment and management can be identified as a too narrow focus on a small fraction of the chemicals in commerce, concerns for increasingly diverse chemical emissions, and lack of effective diagnosis and management approaches [4] (see Additional file 1). The present paper is a Policy Brief that considers three overarching concepts to address these challenges. It is based on a broad evaluation of the results the EU-Integrated Project "SOLUTIONS" (http://www.solutions-project.eu). Other Policy Briefs from this project published in the present journal provide further information on specific subjects. The research specifically considered the problem of chemical pollution of surface waters in Europe [5], being evaluated in the context of the European regulation (the EU-Water Framework Directive [6]). Despite this, the results can be applied globally in water quality protection and management.

Considering chemical pollution, the Water Framework Directive (WFD) defines 'pollution' (Article 2.33) as the human-caused introduction of substances into the air, water or land which may be harmful to human health or the quality of aquatic ecosystems, including the services provided to humanity by water resources of good quality. Water quality protection, assessment and management is faced with an extremely complex problem, given the more than 145,000 chemicals registered in the EU Classification and Labeling Inventory of New and Existing substances in the EU, and the rising chemical diversity and production masses [7–9]. Water quality can, thus, be threatened by an infinite number

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of local, specific mixtures of these. Global strategies to prevent and limit chemical pollution threats focus on products (improve chemical safety), emissions (limit) and the receiving environment (reduce mixture exposures). EU-Regulations and Directives such as REACH [10] and the WFD [6] have been cited as global examples of modern, comprehensive regulatory approaches [11]. Although the WFD was published in 2000, a good water quality status was not yet reached in 2012 and 2018 in a large fraction of Europe's surface waters [5, 12]. Chemical pollution poses a lasting and diversifying problem to surface water quality [7], together with the aforementioned other stressors [13].

In this Policy Brief, we address four major challenges: (1) to respond to the currently observed issue of insufficient chemical and ecological status, (2) to develop a holistic view on assessing and managing chemical pollution of complex mixtures, (3) to operationalize that view in the formats of a conceptual framework for protection, assessment and management of complex mixtures and associated tools and services, and (4) to address the problem that the wide diversity of mixture problems asks for an intervention measures database and -strategy that can be used to identify abatement options and select the best approach to solving the diversity of pollution problems. The overall challenge was to characterize chemical pollution in a comprehensive way with limited resources, such that the likelihood of impact of chemical pollution can be diagnosed, that risks to ecosystems and human health and resources for drinking water production can be prevented and limited at minimal treatment costs, and that optimized programs of measures can be derived.

Recommendations

- Start addressing chemical pollution problems from a holistic, water-system level viewpoint.
- Consider that any water body can be exposed to a unique set of specific pollutants, beyond the obligatory priority substances (PS) and the river basin-specific pollutants (RBSP), which act as mixture.
- Utilize the SOLUTIONS conceptual framework and intervention database and -strategy to assist water quality assessment practices in diagnosing mixture problems and to select measures that optimally prevent and reduce impacts of chemical pollution.
- Apply the set of SOLUTIONS tools and services for the so-called *Analysis of Impacts*-step that is described in the WFD-Annex II, to diagnose the likelihood that chemical pollution threatens water quality of a water body.
- Support the application of the aforementioned tools and services by expanding the current guidance and by establishing communities of practice.

Requirements

Implementing a holistic approach to assess and manage chemical pollution of European surface waters requires:

- Recognition that chemical pollution problems need to be assessed and managed in a holistic way, covering all substances and their mixtures:
  - Consider priority substances (European scale).
  - Consider river basin-specific pollutants (basin scale).
  - Consider sub-basin and local pollution (see [14]).
- Recognition that mixture exposures and potential effects are common.
- Recognition that current per-chemical assessments provide too limited information for comprehensive impact assessment and derivation of programs of measures to reduce chemical pollution.
- Development of, and agreement on, a set of diagnostic approaches with which water quality assessors can be assisted in determining pollution hot spots and priority pollutants and -mixtures, to help formulating and focusing programs of measures to the sites and compounds mattering most.
- Development and implementation of a user-oriented decision tree with which the optimal diagnostic approach can be derived for the specific context of a water quality problem.
- Development of effective methods to communicate the results of chemical pollution assessments, such that water quality experts can interpret and handle the results of the diagnostic approaches in their daily practice.
- Adoption and expansion of the intervention database and -strategy, to enable water quality managers to explore the optional solutions for the water quality problem, given the results of the diagnosis.

Achievements

Overview

The research addressed the main goals of the European Innovation Partnership for chemical pollution of Europe's water systems [4] (compare Additional file 1: Material) and achieved to provide:

1. A conceptual framework for the protection, monitoring, assessment and management of chemical pollution in European surface waters.
2. A wide array of methods with which water managers can diagnose whether, where, and due to which compounds chemical pollution poses threats to water quality.
3. A strategy for and an overview of potential measures, to provide water quality professionals with insights in the 'solution space' to reduce the water pollution problems, and thus to support deriving (cost)effective programs of measures.

All three achievements were developed with an eye on the holistic principle on which the WFD is based. This contrasts to the current practices in chemical pollution assessments, which have evolved into approaches that often focus on individual chemical measurements, with neglect of the water system context [15]. The diagnostic methods were developed because the current guidance is very limited in this respect (see WFD-Annex II text [6], and [14]). The attention was focused on intervention measures because current approaches are often focusing on describing the problem rather than on (also) providing solutions that can be implemented to improve water quality. Other closely related achievements, describing, e.g., the wide array of specific diagnostic methods, are presented in other Policy Briefs of the SOLUTIONS project.

The conceptual framework

The WFD assessment and management cycle is based on the DPSIR-causal framework. This consists of a systematic analysis of the Driving forces (D), the resulting Pressures on the environment (P), the Status characteristics of the water bodies (S), and finally the impact to water quality (I), which triggers a management Response (R) to protect or restore water quality [14].

In line with the DPSIR-cycle and combining that with the solution-focused risk assessment paradigm [16], a conceptual framework was developed for the protection, monitoring, diagnostic assessment and management of chemical pollution problems. The solution-focused risk assessment paradigm was proposed to improve the utility of chemical and environmental risk assessments [16]. This paradigm was operationalized, resulting in the comprehensive solution-focused framework shown in Fig. 1.

The figure shows four 'corner-stone' elements, their mutual relationships and the management-relevant outputs that are generated when the framework is applied. The outer ring shows that and how—in principle—chemical pollution can be reduced, such as (top) via the sustainable use of chemicals. In essence, the conceptual framework describes the transfer from a *problem-oriented* approach ('what is the risk') to the realm of the *solutions-focused* outcomes ('what can be done if there is a risk or an effect'). The diagnostic tools and services (provided by the RiBaTox tool, see below) were designed for the key elements of the conceptual framework. The intervention database and -strategy (for technical and non-technical abatement options) was a specific product, positioned separately (lower left) in the framework.

Versatile tools and services

The research provided a variety of tools and services to assist in the process of assessing the likelihood that chemical pollution threatens water quality (cf. WFD-Annex II). This is referred to as 'diagnosis' in this paper.

The diagnostic methods are summarized and characterized in the other SOLUTIONS Policy Briefs. For example, methods can be selected for early-stage exploratory assessments on the presence of chemicals [19], via refined component- and effect-based diagnostic approaches of impacts [20, 21] to specific biological quality elements [22] and the ecological status [13], up till integrated modeling [23]. The methods cover the full array of the DPSIR-causal approach (Fig. 1). An assessor can derive the likelihood of chemical pollution to pose harm by combining the information from integrated modeling of expected threats associated to societal activities (Drivers), via wide-ranging non-target screening results on the presence of chemicals up to information gained by targeted component- and effect-based diagnostic and monitoring methods. The assessor can select the tools and services that are relevant to their local problem definition, using the decision tree approach of the RiBaTox-webtool (https://solutions.marvin.vito.be/). If needed, the methods can be applied in a tiered way.

The intervention database and -strategy

The research resulted in an intervention database and -strategy to help assessors to solve chemical pollution problems [18]. The strategy to identify options to derive programs of measures and thus to explore the 'solution space' is a key part of the conceptual framework (Fig. 1), and stresses the idea of paying early attention for the Response-step of the DPSIR-cycle.

The 'solution space' has been identified as large. That is, solutions can vary widely, ranging for example from operational changes in the technical designs of a waste water treatment plant facility up to strategic improvements in the design of chemicals ('safe by design'). Measures can also be non-technical, such as via 'zonation' between the land use that causes the emissions of compounds and the water bodies. The overview of technical and non-technical abatement strategies provides end-users with

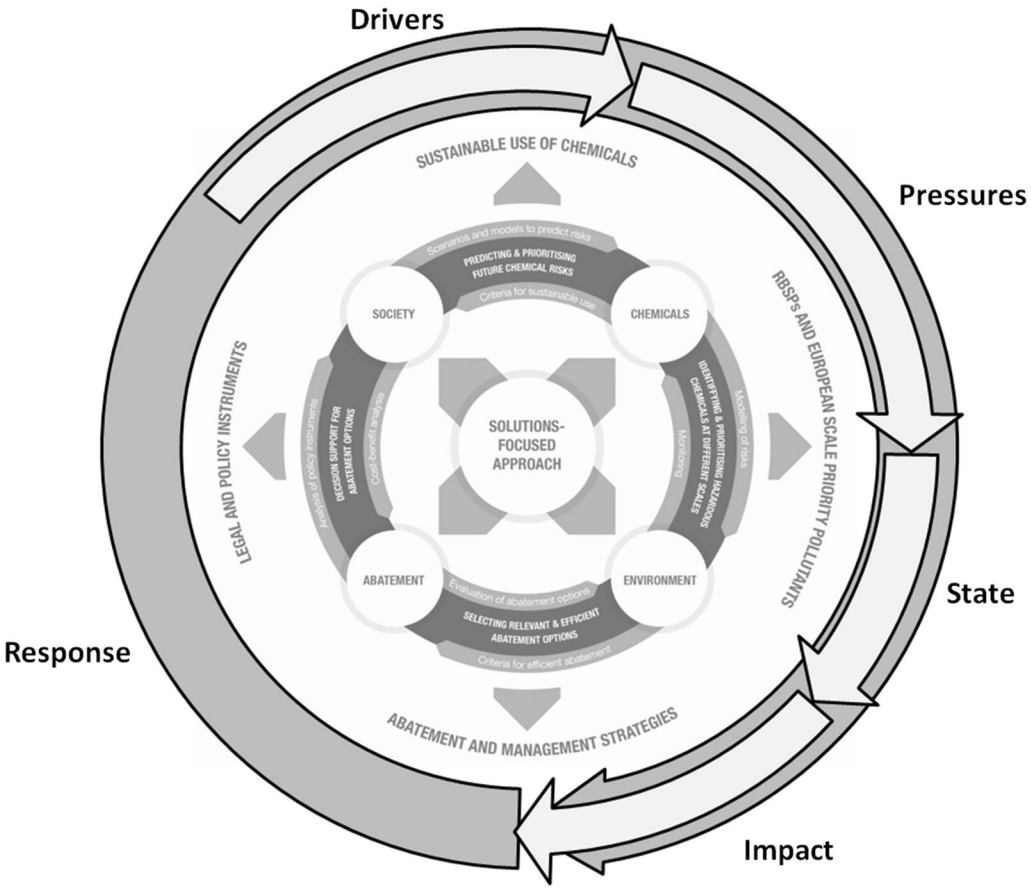

Fig. 1 The SOLUTIONS conceptual framework (center) [17] is an overlay of the DPSIR-causal framework [14] (outer circle) and the solution-focused risk assessment paradigm [16]. DPSIR's "R" closely relates to the solution-focused approach, and shows opportunities to protect and limit pollution via all management options [18]. The 3rd WFD-management cycle (planned for 2022–2027) can define Responses based on the outcomes of monitoring data and other insights gained from the 2nd DPSIR-cycle (2016–2021)

a practical but not limiting basis for derivation of (cost-) effective management plans. Users can select the options that could apply to their pollution problem. Integrated modeling [23] can be used not only to explore threats of current emissions, but also to evaluate future emission scenarios and the effects of abatement measures.

It is recommended to apply intervention tools and -strategies in the earliest stages of a WFD DPSIR-cycle. Various risk prevention and management solutions may be simple to implement and of a *no regret* kind.

Utility of the achievements

Recommended methods should have practical utility [4]. Therefore, the achievements were tested and evaluated in case studies, with intensive contacts with the stakeholders.

In their final evaluation of the project, the stakeholders expressed their positive attitude to the three main elements of the holistic and comprehensive set of approaches to prevent, monitor, assess and manage chemical pollution of European surface waters [24]. They recognized the value and utility of the comprehensive principles (the conceptual model and the intervention database and -strategy). They also valued the large set of versatile tools to address the problem of complex mixtures in aquatic ecosystems. The utility relates not only to tools and services, but also to the wide array of chemicals and mixtures that can be identified, and of which the likely impacts can be characterized [19, 21]. The number of chemicals for which diagnostic solution-focused assessments can be made is vastly expanded as compared to the current number, of approx. 300 compounds considered separately [25], whilst including their mixtures.

Supplementary information

Supplementary information accompanies this paper at https://doi.org/10.1186/s12302-019-0243-8.

Additional file 1. Research requirements formulated under the European InnovationPartnership (2010).

Abbreviations

DPSIR: Drivers, Pressure, Status, Impact and Response; PS: priority substance; REACH: Registration, Evaluation, Authorisation and Restriction of chemicals; RBSP: river basin-specific pollutant; WFD: Water Framework Directive.

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LP and WB conceptualized and drafted the manuscript. All other authors helped to further elaborate the manuscript and contributed specific aspects. All authors read and approved the final manuscript.

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