Brack et al. Environ Sci Eur (2019) 31:63
https://doi.org/10.1186/s12302-019-0232-y
Environmental Sciences Europe

POLICY BRIEF

Open Access

Strengthen the European collaborative environmental research to meet European policy goals for achieving a sustainable, non-toxic environment

Werner Brack[1,2*], Selim Ait-Aissa[3], Thomas Backhaus[4], Sebastian Birk[5], Damià Barceló[6,7], Rob Burgess[8], Ian Cousins[9], Valeria Dulio[3], Beate I. Escher[1,10], Andreas Focks[11], Jos van Gils[12], Antoni Ginebreda[6], Daniel Hering[5], L. Mark Hewitt[13], Klára Hilscherová[14], Juliane Hollender[15], Henner Hollert[2], Marianne Köck[6], Andreas Kortenkamp[16], Miren López de Alda[6], Christin Müller[1], Leo Posthuma[17,18], Gerrit Schüürmann[1,19], Emma Schymanski[20], Helmut Segner[21], Frank Sleeuwaert[22], Jaroslav Slobodnik[23], Ivana Teodorovic[24], Gisela Umbuzeiro[25], Nick Voulvoulis[26], Annemarie van Wezel[27] and Rolf Altenburger[1,2]

Abstract

To meet the United Nations (UN) sustainable development goals and the European Union (EU) strategy for a non-toxic environment, water resources and ecosystems management require cost-efficient solutions for prevailing complex contamination and multiple stressor exposures. For the protection of water resources under global change conditions, specific research needs for prediction, monitoring, assessment and abatement of multiple stressors emerge with respect to maintaining human needs, biodiversity, and ecosystem services. Collaborative European research seems an ideal instrument to mobilize the required transdisciplinary scientific support and tackle the large-scale dimension and develop options required for implementation of European policies. Calls for research on minimizing society's chemical footprints in the water–food–energy–security nexus are required. European research should be complemented with targeted national scientific funding to address specific transformation pathways and support the evaluation, demonstration and implementation of novel approaches on regional scales. The foreseeable pressure developments due to demographic, economic and climate changes require solution-oriented thinking, focusing on the assessment of sustainable abatement options and transformation pathways rather than on status evaluation. Stakeholder involvement is a key success factor in collaborative projects as it allows capturing added value, to address other levels of complexity, and find smarter solutions by synthesizing scientific evidence, integrating governance issues, and addressing transition pathways. This increases the chances of closing the value chain by implementing novel solutions. For the water quality topic, the interacting European collaborative projects SOLUTIONS, MARS and GLOBAQUA and the NORMAN network provide best practice examples for successful applied collaborative research including multi-stakeholder involvement. They provided innovative conceptual, modelling and instrumental options for future monitoring and management of chemical mixtures and multiple stressors in European water resources. Advancement of EU water framework directive-related policies has therefore become an option.

*Correspondence: werner.brack@ufz.de
[1] Helmholtz Centre for Environmental Research UFZ, Permoserstr. 15, Leipzig 04318, Germany
Full list of author information is available at the end of the article

Challenge

To achieve a sustainable development and maintain welfare, distinct sustainable development goals (SDG) are consented in international policy (https://www.un.org/sustainabledevelopment/sustainable-development-goals/). The implementation of the SDG, however, faces enormous challenges at continental and global scales, including climate change [1], chemical pollution, urbanization and demographic changes [2], quantitative and qualitative shortage of freshwater for drinking water production and ecosystem functioning, and the loss of biodiversity and ecosystem services [3, 4]. Recently, the Background Report by the UN's Environment Assembly "Towards a pollution-free planet" estimated "19 million premature deaths annually as a result of the way we use natural resources and impact the environment to support global production and consumption" [5]. While chemical consumption and production are expected to double within the next 15 years [6], pesticides and other pollutants are reported to already pose significant risks to aquatic ecosystems [7] and compromise ecosystem biodiversity [8]. Environmental pollution, particularly pesticides, had been identified as drivers of the decline of insects and birds and thus compromise related ecosystem services such as pollination [9, 10]. Wildlife and humans experience lifelong continuous exposure to complex mixtures of chemicals in concert with other stressors [11]. This stands in contrast to established regulatory sectoral thinking that so far prevails in chemical safety and environmental protection, quality assessment and management. To foster sustainable chemistry development, the challenge is to overcome 'silo' thinking and to develop means to comprehensively understand, predict, and assess aggregated individual exposure (exposome) and stress profiles to identify the means for dealing with real-world complexity and dynamics. This perspective would allow new and original thinking about options to prevent and limit mixture risks and support sustainability in chemical use and land management.

The EU strategy for a non-toxic environment (http://ec.europa.eu/environment/ chemicals/non-toxic/index_en.htm) responds to these challenges and provides an ambitious commitment in support of goals, geared towards the provision of food (SDG 2), clean water for humans (SDGs 3 and 6), responsible production and consumption (SDG 12), as well as safeguarding of aquatic life (SDG 14). Furthermore, as the SDGs are interconnected [12], integrated environmental policies and strategies are required to protect our natural capital, stimulate resource-efficient, low-carbon growth and innovation, safeguard people's health and well-being while respecting the Earth's natural limits [13].

Evidence-based approaches to support these strategic goals are needed. Current scientific knowledge, however, is often produced in fragmented settings based on disciplinary, small-scale studies that produce scientifically interesting results but with limited dissemination to decision makers. Moreover, since stakeholders are hardly, if ever, involved in basic research, many scientific findings remain unnoticed or are taken up for policy action only after decade-long delays [5]. Furthermore, there are limitations for national science funding schemes when it comes to large-scale multidisciplinary challenges such as understanding global processes, managing large ecosystems, e.g., river basins that cross national borders, or safeguarding environmental quality for multiple, often conflicting, purposes.

The scientific and technical means to record unparalleled amounts of data for chemical fingerprinting, toxicological profiles, biological and ecological functions in a yet unachieved resolution are emerging [14, 15]. These data offer novel insights to anticipate impacts on biodiversity and ecosystem services as basis for informed decision making. Yet, the full potential of such information can only be realized if it becomes accessible to a larger scientific community and if the digitalization is complemented with tools to derive the new knowledge and options for societal problems. The European Collaborative Projects SOLUTIONS [16], MARS [17], GLOBAQUA [18] and the NORMAN network (https://www.norman-network.net/) [19] have demonstrated how European research can provide the platforms for such large-scale data exchange between the scientific community and regulators, taking advantage of increasing digitalization and big data mining, and providing means to transform information into knowledge useful for decision making.

We are facing large-scale environmental challenges that call for transformative thinking and scientific expertise needs to be mobilized to address them adequately. The European Union organized support for excellent international research teams within their Framework Programmes to develop coherence in the European Innovation Union [20]. Such an unprecedented level of integrated European environmental research efforts is seen internationally as a major success story, because it provides scientific evidence and competitive solutions directly in support of European policies and practices on environmental protection and sustainable development. Given the current challenges, these are strong arguments to further support and strengthen European collaborative research, to address the challenges related to (1) the prediction, monitoring, assessment and management of increasingly complex contamination and multiple stressor exposure, (2) minimizing pressure on health, biodiversity and ecosystem services, (3) developing options for smart, sustainable and healthy cities and landscapes, and (4) support sustainable agriculture and industrial innovation and production.

The present paper gives recommendations for strengthening European collaborative applied research to achieve the European environmental policy goals. It has been written on the basis of the experience of the large EU-funded projects SOLUTIONS, MARS and GLOBAQUA. The extensive scientific results of the three projects are documented in about 200 publications each, accessible via the websites https://www.solutions-project.eu/, http://www.mars-project.eu/, http://www.globaqua-project.eu/en/home/, and have been exploited to derive a series of policy briefs published in this journal [21–32]. We made no attempts to summarize these results here but drew conclusions for the requirement of future European research under systematic involvement of major stakeholders using a small selection of general achievements of the projects to underline these conclusions.

Recommendations

- *Specify the needs and opportunities for science-based options in support of a non-toxic environment* Contamination of European water resources with mixtures of pesticides, biocides, pharmaceuticals, and other pollutants should be tackled as a complex, multi-dimensional challenge. The additional impact of non-chemical stressors deriving from, e.g., climate change which can alter chemical exposure and effects through water scarcity and thus decreasing dilution of pollution, or the remobilization of contaminants during more frequent flood events have to be seen in concert. Moreover, factors enhancing chemical pressures that have to be accounted for include urbanization and demographic and land use changes inducing rising emissions of pharmaceuticals and personal care products or higher demand for water reuse, respectively. Innovative chemical management in conjunction with sustainable land use and agriculture to counteract the current losses in biodiversity and safeguard ecosystems goods and services requires innovative 'out-of-the-box' thinking. EU research for the Water Framework Directive may prove an example of how collaborative European environmental research can support implementation and advancement of European policies.
- *Establish European collaborative and interdisciplinary research projects* to (i) develop options for comprehensive reduction of modern society's footprints in the nexus of growing demands on energy, food and clean water, (ii) provide the scientific underpinnings for a non-toxic environment, and (iii) protect health, biodiversity and ecosystems goods and services from being jeopardized by exposure to increasingly complex chemical mixtures and non-chemical stressors. Integrated projects should thus aim to:

  - Develop concepts, approaches and methods to close knowledge gaps for chemical mixtures and multiple stressors assessment, e.g., through adverse outcome networks. Emerging and promising methods for a more holistic diagnosis and impact assessment should be advanced including chemical and bioanalytical non-target screening, high-throughput (eco)toxicological profiling, OMICs methods, and human and ecological health monitoring programmes;
  - Survey the 'universe of chemicals' that our societies deal with, currently and in the foreseeable future as a basis for a systematic understanding, and management of exposure to and effects of this chemical universe at different scales;
  - Identify vulnerable species, ecosystems and human populations and prioritize human activities and source regions for abatement. This includes inventories of stress and pollution patterns as well as the development of comprehensive data repositories, computer tools and models to diagnose and predict stress profiles in space and time;
  - Develop long-term strategies for the integrated monitoring, assessment and management of chemical and non-chemical stressors on a European scale and test them in model landscapes in close collaboration between academia and public bodies, industry, agriculture, environmental associations and citizens;
  - Provide a coherent framework for sustainable chemistry comprising chemical invention ('benign by design'), production, distribution, use, waste, fate and effect management across all chemical uses including a dynamic process perspective for progress in knowledge (i.e., accommodate for cross-talk between monitoring and prospective risk assessment);
  - Integrate ecosystem services into environmental management and planning to facilitate a more comprehensive assessment of environmental quality. This provides options to become a driver of societal acceptance and associated policy formulation. In support of this concept, a participatory Ecosystems Services approach for pressure prioritization that enables the integration of Ecosystem Services into River Basin Management Plans would allow a systematic way to prioritize pressures with metrics

that directly match with matters that are important for people [33].
- Develop strategies for urban water and pollution management to support smart, sustainable and healthy cities including the assessment of transboundary chemical footprints [34], advancing on the concept of source-related discharge signatures [35] and fingerprints [14];
- Foster science–policy interaction for strengthening policy coherence and harmonized cross-compliance of regulations on chemical, water, energy and environmental conservation and to anticipate upcoming transition pathways, e.g., for implementing a circular and bio-based economy.

- *Foster the involvement of non-EU partners in European collaborative research* The realization of the UN SDGs is a global challenge. Mounting environmental deterioration on a global scale will also affect health and welfare of European citizens. For many developing and emerging economies, European regulation and research on chemicals and environmental protection provide valuable options as solutions for environmental problems and thus also assist in keeping anthropogenic impacts within planetary and regional boundaries as a safe operating space for humanity [36]. Common funding instruments and encouraging collaboration with research groups from the United States, Canada, Australia, Japan, China, Brazil as well as developing countries on applied environmental science and pollution research will more efficiently identify major drivers, mobilize additional resources and expertise towards a non-toxic environment and sustainable development on a relevant scale.
- *Complement European research with targeted national scientific funding* to provide incentives for inventions regarding specific scientific questions and to support the evaluation, demonstration and implementation of novel concepts and approaches on a regional scale. The projects SOLUTIONS, MARS and GLOBAQUA may serve as examples, as they developed novel consistent approaches for protection, monitoring, assessment and management of water quality, chemical contamination and multiple stressors. National projects provided follow-up on approaches for regional and national water bodies and river basins in close collaboration with stakeholders from agencies, water supply, wastewater treatment, agriculture, fishing industry and municipalities, NGOs, and others. This collaboration of science and stakeholders on a regional level will provide new opportunities of implementation of protection, monitoring, assessment and management options identified in European research. In addition, specific scientific questions fostering detailed process understanding and specific instrumentation can be addressed efficiently at national levels.
- *Provide incentives for solution-oriented approaches* that allow becoming more creative in chemical innovation and management. We need to depart from the route of one-dimensional thinking of current individual chemical risk assessment and generate more flexibility, e.g., by allowing for weight-of-evidence-based approaches. Collaborative European environmental research is a powerful tool to identify options and alternative trajectories in a world changing to bio-based and circular economy approaches. Management action could often be taken before final conclusive statements about a single chemical's hazards and risks are available. Assessing different a priori abatement options for challenging problems rather than producing finite a posteriori status assessments may often be more efficient to derive sustainable solutions [37]. Strategies to develop smart solutions based on sparse data are needed. Emerging transition pathways such as repurposing of waste, which involve fundamental changes in chemical life cycles need incentives.
- *Encourage multi-stakeholder involvement in EU collaborative projects to capture added value and address complexity* Solution-oriented research needs to go beyond the scientific community and needs to engage with the private sectors, governments, citizen groups and environmental organizations [12]. Multiple stakeholder participation in ambitious integrated research projects can play several roles. They function as emphatic safeguards regarding the project's principal objectives. They facilitate the necessary development of overall objectives into operational issues. They foster a science–society dialogue and they help to communicate and translate project findings for non-scientific audiences. Moreover, they are crucial to develop and conduct demonstration projects, pilot and case studies as well as wider acceptance for necessary actions. Crucially, they serve to explore and define a far wider 'solution space' in which innovative transition scenarios can be defined beyond disciplinary boundaries. Stakeholder involvement helps finding solutions for complex problems, as long as the different roles of scientists and stakeholders are acknowledged. Scientists work from scientific facts, while solutions additionally require specific attention to governance issues and transition pathways, which can be anticipated by stakeholders. Thus, for collaborative projects, intensive stakeholder dialogue is often highly beneficial, as long as

stakeholder participation is professionally organized from the very beginning of a project. Deciding on options provided by research projects is a policy issue and close interaction with stakeholders significantly enhances the chances of actually implementing the solutions provided by a project in a relevant time frame.

Requirements

Investing in EU collaborative projects in the field of research on sustainable use of chemicals, the environment and its services to humanity calls for:

- Recognition that it is required to employ novel concepts and approaches to comprehensively address, assess and manage the 'universe of chemicals' which modern societies rely on for various services and simultaneously reaching the SDGs;
- Acknowledgement that our current rate of innovation and trends in consumption require tools that adequately help to evaluate the likelihood of harm imposed by complex mixtures (both predictive and preventive as well as diagnostic and curative);
- Realization of the needs to be inclusive of human and environmental health, and provide for dynamic changes in human–environmental interactions, as well as account for the relevance of potential interaction between different stressors in a climate change context;
- Establishment of funding instruments for collaborative projects that explore and develop novel routes of solution-oriented assessment and management to safeguard biodiversity, ecosystem services, and human health;
- Consideration of the specific characteristics of collaborative environmental research that have less focus on marketable products and business development but strives for providing scientific evidence for the achievement of the policy and societal goals of the EU concerning public goods;
- Awareness that understanding, and advanced monitoring, assessment and management of chemical mixtures and non-chemical stressors in European water resources may change our knowledge on causes and sources of risks and thus will support low-footprint cities, sustainable food, industrial and energy production not the least by avoiding costly remediation of contamination;
- Effective demonstration and evaluation in case studies involving stakeholders at different spatial scales and covering regional differences in geographies, land use and cultural context.

Achievements

Applied, collaborative, interdisciplinary research on a European scale

The EU-funded projects SOLUTIONS, MARS, and GLOBAQUA with a total funding volume of over 20 million Euro and comprising 80 leading scientific institutes from 23 European countries together with partners from Australia, Brazil, China, Turkey and Morocco provided the critical mass to successfully overcome the interdisciplinary challenges of monitoring, assessment and protection of European water resources as established in the WFD and the EU strategy for a non-toxic environment. The balance between individual objectives and approaches of the projects and intensive exchange and collaboration between the projects allowed for overarching conclusions directly informing decision making in the catchments and in European regulation. That is, MARS developed an overarching concept to assess how multiple stressors affect surface water and analysed stress data at the European, at the catchment and at the water body scale, providing methods to support improving ecological status in a multiple-stress context. SOLUTIONS contributed a comprehensive picture of contamination and toxic stress in European catchments using predictive modelling based on emission data as well as monitoring of complex mixtures and effects at the watershed scale in major European river basins including those of the Rivers Danube, Rhine and Ebro. GLOBAQUA studied multiple stressor effects in rivers of southern Europe such as the Adige, Evrotas and Sava, providing methods to tailor the aforementioned approaches to water systems under water scarcity scenarios. Together, the projects provided methods to monitor, assess and manage chemical mixtures and other stress that allow for advanced assessment of both chemical safety and ecological status. Collaborative modelling and monitoring data assessments across the three projects revealed that chemical mixtures occur as one of the prevailing factors for determining the ecological status in many rivers. Pollutants collectively contribute in multiple stressor settings to a similar degree as nutrients, hydrology and riparian land use, with a spatiotemporal variability that relates to land use and season. To better understand toxic stress under water scarcity as an increasing challenge under climate change, SOLUTIONS and GLOBAQUA closely collaborated on the Iberian Peninsula and were able to demonstrate the intensifying role of climate change on the environmental impact of chemicals. These results, which emerge from collaborative, interdisciplinary European research, suggest that the separate consideration of chemical contamination (status) and ecological status needs to and can be overcome to achieve the goals of the Water Framework Directive (WFD).

Although strongly focused on fulfilling societal and regulatory demands, applied research, as it has been performed in the three European projects, addresses the full chain of knowledge from basic understanding of scientific processes via monitoring and assessment tools to the formulation of recommendations for protection and management efforts by all stakeholders, supported by a comprehensive set of policies. This may be illustrated by the monitoring of toxic stressors in European water bodies as performed in SOLUTIONS. Starting with the collation and investigation of modes of action and toxicogenomics of known water contaminants [38, 39], an effect-based monitoring strategy and the corresponding toolbox [24] were developed, rigorously evaluated and adapted using selected chemicals [40], mixtures [41] and field samples [42]. Through extensive stakeholder dialogue, policy-related working groups, workshops, via scientific and popular publications plus close collaboration with relevant science–policy interaction networks such as NORMAN, the new concepts were discussed, refined and integrated in the decision-making processes regarding the review of WFD [43].

Solution-based approaches in monitoring, assessment and management of risks of complex chemical mixtures and multiple stressors

While current evaluations of chemical pollution in European surface waters focus on problem description and water quality classification, the projects SOLUTIONS, MARS and GLOBAQUA put emphasis on early exploration of prevention and abatement options considering the remedial space within the Drivers–Pressure–State–Impacts–Response (DPSIR) causal approach [32]. To facilitate solution-focused risk assessment [37], a conceptual framework has been developed [16]. The early consideration of possible responses is supported by a database on technical abatement options [44] and a systematic evaluation of non-technical abatement options. SOLUTIONS-focused assessment of multiple stressors is supported by the SOLUTIONS' Tools and Services for River Basin Toxicants Assessment and Management accessible through the web-based guidance tool RiBaTox (https://solutions.marvin.vito.be/ [29]) and by a living database architecture for the exchange of chemical and effect-based monitoring data [30]. Moreover, a scenario analysis tool developed by MARS provides indications on how stressor intensity and ecological status will develop under given scenarios of human impact at the European scale and broken down to more than 100,000 sub-catchments in Europe (https://mars-project-sat.shinyapps.io/mars-sat). In addition, a diagnostic tool developed by MARS assists water managers to identify the main stressors affecting the ecological status, and to derive appropriate management measures (http://freshwaterplatform.eu/index.php/mars-diagnostic-tools.html). GLOBAQUA developed ESPRES (Efficient Strategies for anthropogenic Pressure Reduction in European waterSheds, http://www.globaqua-project.eu/en/content/ESPRES-tool.94/), a web-based decision support tool that can be employed to explore management options for achieving environmental targets of European water bodies. The user-friendly web interface supports multi-criteria river basin analyses via DPSIR-based causal analysis steps to identify efficient pressure reduction strategies and reflecting the perception of stakeholder efforts, which includes monetary costs, political difficulty, and social acceptability of available solutions. Monitoring and assessment of ecosystem goods and services such as river ecosystem functioning have been addressed by GLOBAQUA and recommended as a crucial module to be included in the existing river monitoring and assessment schemes [45]. The resultant toolbox is accessible (http://www.globaqua-project.eu/en/content/Toolbox-for-ecosystem-functioning.50/).

Success measures towards a non-toxic environment and sustainable cities and landscapes

While global boundaries have been defined as the safe operating space for humanity [36], ecological, energy, carbon and water footprints have been introduced to quantify the appropriation of natural resources by humans within these boundaries [46, 47], typically at a regional scale. Chemical footprints as applied in SOLUTIONS were likewise developed as an indicator of the cumulative impacts of chemical mixtures on biodiversity and represent the approximation or exceedance of a contamination level considered as safe [48]. They are recommended to be used to evaluate trends in chemical contamination and may help selecting best options for abatement scenarios, as well as to communicate complex data sets on mixture exposures and effects [32]. To anticipate the effectiveness of interventions, the perspectives of the water cycle and the chemical life cycle were connected by providing a mitigation database coupled to hydrological models [44].

River basin scale case studies were instrumental to benchmark performance of modelling and measurement tools for water contamination assessment, provided data necessary to identify river basin-specific pollutants, demonstrated the benefits of the technical upgrade of wastewater treatment plants, specified the potential for targeted remediation of pollution sources, and demonstrated the interactions between contamination and situations of water scarcity that need to be acknowledged. In particular, we sought to conceptually provide links for bridging between chemical and ecological water status measures [49–51]. This includes the identification and ranking of environmental hazards with ecosystem vulnerability distributions [52]. Thus, we overcame a major hurdle in current water quality assessment, where ecological and ecotoxicological assessments and recommendations are derived independently, based on different principles (protection vis a vis protection and impacts) leading to diverging, if not contradictory advice for river basin management.

Science–policy interaction and stakeholder dialogue

Starting in the proposal phase, a systematic and structured dialogue with diverse stakeholders was established in the three collaborative projects SOLUTIONS, MARS and GLOBAQUA. It involved major stakeholders in the fields such as DG Environment, European Environmental Agency (EEA), European Chemical Agency (ECHA), European Food Safety Authority (EFSA), International River Commissions such as International Commission for the Protection of the Danube River (ICPDR) and the Rhine (ICPR), national environmental and chemical agencies, water industry, and NGOs. The structured stakeholder dialogue led to joint activities and developed new options. For example, SOLUTIONS provided the compilation of river basin-specific pollutants suggested for the Danube River Basin Management Plan and provided conceptual and technical input as well as case study evidence to the sub-group for effect-based methods of the CIS Working Group Chemicals under DG Environment. MARS with stakeholder participation developed conceptual models on how the relevant multiple stressors affect water body status in sixteen case study catchments and subsequently used the outcome for producing predictive models. The results were discussed in a specific workshop with the Common Implementation Strategy (CIS) Working Group ECOSTAT of DG Environment. A moderated e-learning course for policy makers and river basin managers was provided to translate scientific understanding for end users (http://www.globaqua-project.eu/en/content/E-Learning.93/).

In summary, the three projects SOLUTIONS, MARS and GLOBAQUA provided well-structured and complementary contributions to the EU policy goals on sustainable management of water resources. Acknowledging a growing world population with growing demands for agricultural, industrial and energy production under conditions of climate change, land use changes and urbanization pressures and management needs emerge at a novel scale. We need to jointly address toxic pressure by complex mixtures of chemicals and multiple stressors from various sources across compartmental and regulatory borders and enable their prediction, monitoring, assessment and abatement. Accounting for associations and nexus between SDGs is a major challenge for which scientific as well as practical solutions are sought that circumvents undue trade-offs between SDGs. The water quality-related projects GlobAqua, MARS and SOLUTIONS may serve as examples for the performance of collaborative projects in supporting a rational European policy on sustainability, environmental protection, and for safeguarding of ecosystem services for “living well, within the limits of our planet” [13].

Abbreviations

CIS: Common Implementation Strategy; DG: Directorate General; DPSIR: Drivers–Pressure–State–Impacts–Response; ECHA: European Chemical Agency; EEA: European Environmental Agency; EFSA: European Food Safety Authority; EU: European Union; ICPDR: International Commission for the Protection of the Danube River; ICPR: International Commission for the Protection of the Rhine; NGO: Non-Governmental Organisation; SDG: sustainable development goals; UN: United Nations; WFD: Water Framework Directive.

Acknowledgements

The consortia of SOLUTIONS, MARS and GLOBAQUA are acknowledged for the excellent collaboration and fruitful discussions that prepared the ground for this policy brief.

Authors’ contributions

RA 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.

Funding

This article has been prepared as an outcome of the projects SOLUTIONS (European Union’s Seventh Framework Programme for research, technological development and demonstration under Grant Agreement No. 603437), GLOBAQUA (European Union’s Seventh Framework Programme for research, technological development and demonstration under Grant Agreement No. 603629) and MARS (European Union’s Seventh Framework Programme for research, technological development and demonstration under Grant Agreement No. 603378).

Availability of data and materials

Not applicable; presented information is based on previously published data only.

Ethics approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

Competing interests

The authors declare that they have no competing interests.

Author details

[1] Helmholtz Centre for Environmental Research UFZ, Permoserstr. 15, Leipzig 04318, Germany. [2] Department of Ecosystem Analysis, Institute for Environmental Research, ABBt - Aachen Biology, RWTH Aachen University, Aachen, Germany. [3] Institut National de l’Environnement Industriel et des Risques (INERIS), 60550 Verneuil-en-Halatte, France. [4] University of Gothenburg, Carl Skottsbergs Gata 22B, 40530 Göteborg, Sweden. [5] Centre for Water and Environmental Research and Faculty of Biology, University of Duisburg-Essen (UDE), Duisburg, Germany. [6] Department of Environmental Chemistry, IDAEA-CSIC, Jordi Girona 18-26, 08034 Barcelona, Spain. [7] ICRA, Carrer Emili Grahit 101, Girona, Spain. [8] Atlantic Ecology Division, National Health and Environmental Effects Research Laboratory, Office of Research and Development, US Environmental Protection Agency, Narragansett, RI, USA. [9] Stockholm University, Stockholm, Sweden. [10] Environmental Toxicology, Center for Applied

Geosciences, Eberhard Karls University Tübingen, 72074 Tübingen, Germany. [11] Alterra, Wageningen University and Research Centre, P.O. Box 47, 6700 AA Wageningen, The Netherlands. [12] Foundation Deltares, Potbus 177, 277 MH Delft, The Netherlands. [13] Water Science and Technology Directorate, Environment Climate Change Canada, Burlington, ON, Canada. [14] Faculty of Science, RECETOX, Masaryk University, Kamenice 753/5, 625 00 Brno, Czech Republic. [15] Eawag, Swiss Federal Institute of Aquatic Science and Technology, 8600 Dübendorf, Switzerland. [16] Institute of Environment, Health and Societies, Brunel University, Uxbridge UB8 3PH, UK. [17] National Institute for Public Health and Environment RIVM, Bilthoven, The Netherlands. [18] Department of Environmental Science, Radboud University, Nijmegen, The Netherlands. [19] Institute of Organic Chemistry, Technical University Bergakademie Freiberg, 09596 Freiberg, Germany. [20] Luxembourg Centre for Systems Biomedicine, University of Luxembourg, 4367 Belvaux, Luxembourg. [21] University of Bern, Bern, Switzerland. [22] Flemish Institute for Technological Research VITO, Mol, Belgium. [23] Environmental Institute, Koš, Slovak Republic. [24] University of Novi Sad, Novi Sad, Serbia. [25] University of Campinas, Limeira, Brazil. [26] Centre for Environmental Policy, Imperial College London, London SW7 1NW, UK. [27] Institute for Biodiversity and Ecosystem Dynamics, University of Amsterdam, Amsterdam, The Netherlands.

Received: 24 May 2019 Accepted: 17 July 2019
Published online: 30 September 2019

References

1. Intergovernmental Panel on Climate Change (IPCC) (2018) Global Warming of 1.5 °C. https://www.ipcc.ch/sr15/
2. The Royal Commission of Environmental Pollution (2011) Demographic change and the environment
3. WWF (2018) Living Planet Report 2018: Aiming Higher. https://www.worldwildlife.org/publications/living-planet-report-2018
4. Food and Agriculture Organization of the United Nations (2019) Commission on Genetic Resources for Food and Agriculture, Biodiversity for food and agriculture
5. United Nations Environment Programme (2017) Towards a pollution-free planet. Background report. Nairobi. https://www.unenvironment.org/resources/report/towards-pollution-free-planet-background-report
6. United Nations Environment Programme (2019) Global Chemicals Outlook II. From Legacies to innovative solutions. Implementing the 2030 agenda for sustainable development
7. Malaj E et al (2014) Organic chemicals jeopardise freshwater ecosystems health on the continental scale. Proc Natl Acad Sci 111(26):9549–9554
8. Beketov MA et al (2013) Pesticides reduce regional biodiversity of stream invertebrates. Proc Natl Acad Sci USA 110(27):11039–11043
9. Sanchez-Bayo F, Wyckhuys KAG (2019) Worldwide decline of the entomofauna: a review of its drivers. Biol Cons 232:8–27
10. Mineau P, Whiteside M (2013) Pesticide acute toxicity is a better correlate of us grassland bird declines than agricultural intensification. PLoS ONE 8(2):e57457
11. Rappaport SM (2011) Implications of the exposome for exposure science. J Eposure Sci Environ Epidemiol 21(1):5–9
12. Voulvoulis N, Burgman MA (2019) The contrasting roles of science and technology in environmental challenges. Crit Rev Environ Sci Technol 49:1–28
13. European Commission (2016) Living well, within the limits of our planet. 7th EAP—the new general Union Environment Action Programme to 2020, accessible via https://ec.europa.eu/environment/efe/themes/economics-strategy-and-information/here-2020-eu%E2%80%99s-new-environment-action-programme_en
14. Brack W et al (2018) Towards a holistic and solution-oriented monitoring of chemical status of European water bodies: how to support the EU strategy for a non-toxic environment? Environ Sci Eur 30(1):33
15. Hering D et al (2018) Implementation options for DNA-based identification into ecological status assessment under the European Water Framework Directive. Water Res 138:192–205
16. Brack W et al (2015) The SOLUTIONS project: challenges and responses for present and future emerging pollutants in land and water resources management. Sci Total Environ 503–504:22–31
17. Hering D et al (2015) Managing aquatic ecosystems and water resources under multiple stress—an introduction to the MARS project. Sci Total Environ 503:10–21
18. Navarro-Ortega A et al (2015) Managing the effects of multiple stressors on aquatic ecosystems under water scarcity. The GLOBAQUA project. Sci Total Environ 503:3–9
19. Dulio V et al (2018) Emerging pollutants in the EU: 10 years of NORMAN in support of environmental policies and regulations. Environ Sci Eur 30(1):5
20. European Commission (2010) The "Innovation Union"—turning ideas into jobs, green growth and social progress. Press release IP/10/1288. http://europa.eu/rapid/press-release_IP-10-1288_en.htm
21. Posthuma L et al (2019) A holistic approach is key to monitor, assess and manage chemical pollution in European surface waters. Environ Sci Eur. https://doi.org/10.1186/s12302-019-0243-8
22. Brack W et al (2019) High resolution mass spectrometry to complement monitoring and track emerging chemicals and pollution trends in European water resources. Environ Sci Eur. https://doi.org/10.1186/s12302-019-0230-0
23. Posthuma L et al (2019) Improved component-based methods for mixture risk assessment are key to characterize complex chemical pollution in surface waters. Environ Sci Eur. https://doi.org/10.1186/s12302-019-0246-5
24. Brack W et al (2019) Effect-based methods are key. The European Collaborative Project SOLUTIONS recommends integrating effect-based methods for diagnosis and monitoring of water quality. Environ Sci Eur 31(1):10
25. Van Gils J et al (2019) The European Collaborative Project SOLUTIONS developed models to provide diagnostic and prognostic capacity and fill data gaps for chemicals of emerging concern. Environ Sci Eur. https://doi.org/10.1186/s12302-019-0248-3
26. Posthuma L et al (2019) Mixtures of chemicals are important drivers of impacts on ecological status in European surface waters. Environ Sci Eur. https://doi.org/10.1186/s12302-019-0247-4
27. Faust M et al (2019) Prioritisation of water pollutants: the EU Project SOLUTIONS proposes a methodological framework for the integration of mixture risk assessments into prioritisation procedures under the European Water Framework Directive. Environ Sci Eur. https://doi.org/10.1186/s12302-019-0239-4
28. Kortenkamp A et al (2019) Mixture risks threaten water quality. The European Collaborative Project SOLUTIONS recommends changes to the WFD and better coordination across all pieces of European chemicals legislation to improve protection from exposure of the aquatic environment to multiple pollutants. Environ Sci Eur. https://doi.org/10.1186/s12302-019-0245-6
29. Kramer KJM et al (2019) The RiBaTox web tool: selecting methods to assess and manage the diverse problem of chemical pollution in surface waters. Environ Sci Eur. https://doi.org/10.1186/s12302-019-0244-7
30. Slobodnik J et al (2019) Establish data infrastructure to compile and exchange environmental screening data on a European scale. Environ Sci Eur. https://doi.org/10.1186/s12302-019-0237-6
31. Munthe J et al (2019) Increase coherence, cooperation and cross-compliance of regulations on chemicals and water quality. Environ Sci Eur. https://doi.org/10.1186/s12302-019-0235-8
32. Posthuma L et al (2019) Exploring the 'solution space' is key: SOLUTIONS recommends an early-stage assessment of options to protect and restore water quality against chemical pollution. Environ Sci Eur. https://doi.org/10.1186/s12302-019-0253-6
33. Giakoumis T, Voulvoulis N (2018) A participatory ecosystems services approach for pressure prioritisation in support of the Water Framework Directive. Ecosyst Serv 34:126–135
34. Ramaswami A et al (2016) Meta-principles for developing smart, sustainable, and healthy cities. Science 352(6288):940–943
35. de Zwart D et al (2018) Aquatic exposures of chemical mixtures in urban environments: approaches to impact assessment. Environ Toxicol Chem 37(3):703–714
36. Rockström J et al (2009) A safe operating space for humanity. Nature 461(7263):472–475
37. Zijp MC et al (2016) Definition and use of Solution-focused Sustainability Assessment: a novel approach to generate, explore and decide on sustainable solutions for wicked problems. Environ Int 91:319–331

38. Busch W, et al (2015) What are relevant compounds from an effect perspective? Mode of action considerations for compounds and mixtures detected in different European rivers. In: Poster TU366 at SETAC Europe 2015, Barcelona, Spain
39. Schuettler A et al (2017) The transcriptome of the zebrafish embryo after chemical exposure: a meta-analysis. Toxicol Sci 157(2):291–304
40. Neale PA et al (2017) Development of a bioanalytical test battery for water quality monitoring: fingerprinting identified micropollutants and their contribution to effects in surface water. Water Res 123:734–750
41. Altenburger R et al (2018) Mixture effects in samples of multiple contaminants—an inter-laboratory study with manifold bioassays. Environ Int 114:95–106
42. König M et al (2017) Impact of untreated wastewater on a major European river evaluated with a combination of in vitro bioassays and chemical analysis. Environ Pollut 220:1220–1230
43. Brack W et al (2017) Towards the review of the European Union Water Framework Directive: recommendations for more efficient assessment and management of chemical contamination in European surface water resources. Sci Total Environ 576:720–737
44. van Wezel AP et al (2017) Mitigation options for chemicals of emerging concern in surface waters; operationalising solutions-focused risk assessment. Environ Sci 3(3):403–414
45. von Schiller D et al (2017) River ecosystem processes: a synthesis of approaches, criteria of use and sensitivity to environmental stressors. Sci Total Environ 596:465–480
46. Fang K, Heijungs R, de Snoo GR (2014) Theoretical exploration for the combination of the ecological, energy, carbon, and water footprints: overview of a footprint family. Ecol Ind 36:508–518
47. Hoekstra AY (2008) Water neutral: Reducing and offsetting the impacts of water footprints. Value of water, in Research Report Series. UNESCO-IHE, Institute for Water Education
48. Zijp MC, Posthuma L, van de Meent D (2014) Definition and applications of a versatile chemical pollution footprint methodology. Environ Sci Technol 48(18):10588–10597
49. Rico A et al (2016) Relative influence of chemical and non-chemical stressors on invertebrate communities: a case study in the Danube River. Sci Total Environ 571:1370–1382
50. Altenburger R et al (2019) Future water quality monitoring: improving the balance between exposure and toxicity assessments of real-world pollutant mixtures. Environ Sci Eur 31:12
51. European Environment Agency (2018) Chemicals in European waters, in EEA Report
52. Zijp MC et al (2017) Identification and ranking of environmental threats with ecosystem vulnerability distributions. Sci Rep 7:9298

Publisher's Note