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Risk Assessment as a Tool to Improve Water Resource Management

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Abstract
The examination of primary risk assessment methodologies reveals a significant expansion in recent years, particularly toward encompassing ecosystem preservation and predictive models for environmental contaminant behavior. However, alongside this progress, new challenges have surfaced, such as engineered nanoparticles, cumulative impacts, and the risks associated with emerging contaminants of concern. This research aims to uncover fresh perspectives within the realm of global environmental risk assessment concerning the stress on water resources. Based on the results, the directions for studying water pollution's environmental risks are highlighted. Special attention is given to water multi-stressor challenges with significant impact and therefore to multi-risk assessment of aquatic ecosystem components and human health. The foundational framework for the primary phases of risk assessment was delineated, taking into account the existing body of prior research. Drawing from the current state of knowledge, the notion of evaluating cumulative ecological risks (termed multi-risk) stemming from pollutant exposure, encompassing emerging contaminants among other factors, is introduced. This encompasses the phases of contaminant migration, transformation, and accumulation within the various components of the hydrosphere, specifically in surface water bodies, groundwater, and their eventual discharge into the sea and ocean, within a unified global water system. Furthermore, alternative approaches for incorporating additional factors, such as climate change, into the overarching risk assessment framework have been pinpointed, offering novel perspectives for future research endeavors in this domain.

Keywords Environmental risk assessment · Multi-risk · Pollutants · Contaminants of emerging concern · Water resources · Ecosystem services

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1 Introduction

Nowadays, water ecosystems are threatened by water pollution problems (eutrophication, micropollutants, microplastics), increasing water demand, and increased probability of extraordinary events (e.g., fish poisoning, floods). To address these issues, various methods and technologies have been applied to identify the main risks and optimise the safe management of water resources. When water bodies become contaminated, their value for fisheries diminishes, and they may no longer meet the requirements for agricultural use, thereby disrupting key ecosystem services (Dem et al., 2024).

Currently, risk assessment stands as a primary tool for informing management decisions across numerous countries globally, spanning from localized contexts (such as individual production facilities or other sources of environmental contamination) to regional and national scales (as highlighted by Barati et al. 2023). Assessing environmental risk in a river basin could start with modelling the changes in surface water status processes in the studied basin using the Geographic Information System (GIS) (Javadinejad et al. 2019; Tokatlı et al. 2024).

In the final stage of environmental risk assessment, pollutant exposure is integrated with exposure factors to assess the probability of adverse environmental effects associated with the stressor(s). The most important part of the assessment is the interpretation of risk acceptability (Carvalho et al. 2019).

Fridman et al. (2019) posit that the environmental impact on water quality encompasses the likelihood of events resulting from human activity and/or the interplay of human activity and natural hazards, which could lead to detrimental effects on the aquatic environment. Several pollutants released by human activities, their effects, and risks have been well studied, as in the case of total phosphorus, total nitrogen, and other organic matter (expressed as biochemical or chemical oxygen demands) (Li et al. 2023; Shi et al. 2023; Wang et al. 2023a).

Numerous of these contaminants have been shown to have adverse effects on both human health and aquatic ecosystems (Yadav et al. 2021), with ongoing research exploring the impacts of others. The interest in assessing the risks associated with exposure to these contaminants is constantly increasing; therefore, innovative strategies are needed to overcome the challenges in comprehensive and reliable risk assessment presented by the sheer number of substances (Johnson et al. 2020).

As per the European Water Framework Directive (WFD), the precautionary principle should guide the identification of priority hazardous substances. This involves considering the potential adverse effects of exposure to a particular product and conducting scientific risk assessments (Carvalho et al. 2019). The European Parliament and the Council have implemented targeted measures to address water pollution caused by individual pollutants or pollutant groups that present a substantial risk to the aquatic environment, including threats to water resources used for drinking water production (Halleux 2023). Individual countries support projects to implement risk analysis in water management, an example for the Czech Republic in Jašíková et al. (2022).

In a study conducted by Lopez-Herguedas et al. (2023) aimed at identifying both known and unknown contaminants in wastewater samples collected from two wastewater treatment plants (WWTPs). However, a limitation was noted in the prioritization strategy for assessing environmental risk in the region, as it solely focused on compounds identified as significant by Lopez-Herguedas et al. (2023).

Bozorgi et al. (2021) focused on developing a novel multi-hazard risk assessment framework utilizing a hybrid Bayesian network specifically tailored for agricultural water supply and distribution networks. Further research is warranted to enhance the real-time identification of the causes and magnitude of system and component failures resulting from impending hazards. Terzi et al. (2019) put forth a multi-risk assessment approach encompassing the impacts of climate change on hydro systems and interconnected natural components (water, air, soil, and biota). However, in the case of a chain of influences of many negative factors with the estimation of their synergistic effect, many boundary constraints remain. (Terzi et al. 2019).

As indicated by Zhou et al. (2019), there is still a need to move towards a more accurate risk assessment by including the full exposure scenario, which increases the complexity of calculating the corresponding risks. It's crucial to recognize that risk assessors in different regions may prioritize site-specific stressors, necessitating adaptable approaches to cumulative risk assessment.

Thus, this endeavour is impeded by gaps in understanding basic physical phenomena, challenges in comparing hazards and risks across diverse types, and notably, as the focal point of the investigation, obstacles within risk management that hinder the successful execution of required risk reduction measures (Filho et al. 2024).

These obstacles encompass a range of issues, including the lack of standardized terminology, inadequate expertise across multiple disciplines relevant to multi-risk reduction planning, limited resources, biases, and communication barriers among stakeholders from both the public and private sectors, as well as between researchers and policymakers (Spycher et al. 2024; Shi et al. 2024).

It's important to highlight that the potential "multi-risk" index might exceed the simple aggregation of single risk indices, as calculated under the assumption that each source operates independently of the others (Shafi et al. 2023; Zhang et al. 2024).

However, it is also important to note that the applicability of these models may not be easily extrapolated to regions experiencing more or less serious events.

This review centers on characterizing multi-risk assessment practices aimed at identifying the impacts of various pollutant categories on the hydrosphere (including surface water, groundwater, and oceans) within the broader biogeochemical cycle of ecosystems. The objective is to advance beyond the current state-of-the-art by offering a systematic overview of environmental risk assessment research concerning water resources. This entails evaluating multi-risks and cumulative risks on ecosystem components and human health. As part of this endeavor, the following tasks have been undertaken:

i. Review the bibliometric analysis to identify trends and clusters' modelling on the topic of the environmental risk assessment of water resources;
ii. Analyse current frameworks and the process of achieving new approaches to improve risk assessment.

2 Materials and Methods

In this review, bibliometric data from the Scopus and WoS databases were used. To analyse the data in publications, online tools (to track, analyse and visualise research) were used to process the query results (Figure A1) for different combinations of keywords.

These online analysis tools are presented with an initial example of the results obtained.

i. Analysing publication sources identifies influential journals that affect the scientific dissemination environment in the field of water body pollution risk assessment.
ii. Examination of trends in publication activity over time provides an opportunity to observe the evolving dynamics of global interest in the field of study.
iii. The typological analysis of the articles allows for the categorical differentiation of a core range of publication formats.
iv. A systematic assessment of the application and direction of thematic distribution serves to further clarify sectoral developments within environmental risk assessment.

The top-down ranking of the keyword series was used (Table A1). We took into account the realisation of an integral approach to the consideration of migration of the totality of polluting substances in different water systems as a single water body. One global water body includes surface water bodies, groundwater, and the ultimate outlet to the sea and ocean, i.e., it is considered as a single hydrosphere system. Therefore, the selection of keywords had such a character that took into account the migration of pollutants in different water bodies.

A VOSviewer analysis was conducted on word combinations and their co-occurrence, with a focus on visualizing semantic relationships between words. In addition, based on bibliometrics, an exhaustive exploration of literature was also used.

3 Results and Discussion

3.1 Review of Trends and Clusters Modelling on the Topic of Environmental Risk Assessment of Water Resources

The statement highlights the growing significance of risk assessment, evident from the exponential rise in publications over the last two decades. According to data obtained from the Scopus and Web of Science (WoS) databases, there was a substantial increase in the number of publications, reaching a total of 15,354 in Scopus and 9,965 in WoS as shown in Figure A2a. The topic is also relevant to different fields of research (Figures A1a and A2b). This is consistent with both Scopus and WoS databases. The Environmental Science research area accounts for 45–50% of the publications on this topic as searched in the two databases (Figures A2b and A2c).

In the analyzed publications, numerous studies have been dedicated to exploring the risks associated with contaminants of emerging concern (CEs), which comprise organic chemicals currently not regulated by environmental legislation. These include pharmaceuticals, heavy metals, microplastics, illegal drugs, personal care products, and emerging organic pollutants, as highlighted by Geissen et al. (2015); Zhang et al. (2022); Oyege et al. (2024); Chen et al. (2024a).

However, proposed revisions to the EU Urban Wastewater Treatment Directive aim to address this issue by mandating quaternary treatment in urban wastewater treatment plants, aimed at removing the "largest possible spectrum of micropollutants" (European Commission 2022), including per- and polyfluoroalkyl substances (PFAS) (Bil et al. 2023) and pesticides (European Commission, Food Safety, 2023). Additionally, microplastics have garnered significant attention in recent years, as evidenced by studies conducted by Everaert et al. (2018), and Shi et al. (2023).

Indeed, traditional approaches to chemical analysis often involve low-resolution mass spectrometry with target chemical analysis. However, recent advancements in high-resolution mass spectrometry, coupled with both target and non-target approaches, have significantly expanded the capabilities for identifying and screening a broader range of contaminants of emerging concern (CECs). This includes not only the parent compounds but also their various (bio)transformation products, providing a more comprehensive understanding of their presence and potential impacts on the environment (Starling et al. 2024; Nusair et al. 2024; Zhao et al. 2024).

However, the latter is more costly and time-consuming concerning data processing.

Geissen et al. (2015) highlight, based on data provided by the NORMAN network, that over 700 substances categorized into 20 classes have been detected in the aquatic environment of Europe. Similarly, a recent assessment conducted in 2019 within the Danube River basin, Europe's second-largest river basin, identified 586 contaminants of emerging concern (CECs) present in its aquatic environment (Ng et al., 2023). New methodologies are needed to assess the cumulative risks stemming from the collective impacts of diverse stressors, encompassing mixtures of emerging contaminants, using a multi-step approach. The multi-scale approach considers the impacts of chemical exposure across various levels.

It's evident that individuals and ecosystems frequently face simultaneous exposure to multiple chemicals or stressors. Therefore, conducting a joint analysis and quantification of all anthropogenic and natural risks that may impact an area (adopting a multi-risk approach) is essential for achieving a comprehensive evaluation and promoting sustainable environments. This approach also facilitates effective water and land use planning and enables competent emergency management both before and during catastrophic events (Shafi et al. 2023).

Furthermore, the combined effects of exposure to multiple stressors or hazards as in the case of pollutants must be also considered (cumulative-risk approach). However, gathering data on multiple exposures and their interactions is challenging, as it requires a significant amount of information about various stressors, their toxicity, and their exposure levels. The interactions and synergistic effects among different stressors are complex and their modelling provides uncertainties that make accurate risk estimation difficult (Nativio et al. 2022).

These examples highlight the complex challenges associated with emerging pollutants in aquatic ecosystems and the pressing need for innovative solutions:

1. **Estrogens**: Wojnarowski et al. (2021) underscore the limited understanding of estrogen's negative effects on animal health, the challenges in removing them from the environment, and the ongoing development of suitable removal technologies. They advocate for identifying estrogens as new pollutants to prioritize scientific research on addressing their current threats.

2. **Fungicides**: Zubrod et al. (2019) discuss the presence of fungicides in aquatic ecosystems and the impracticality of empirically testing all species for individual fungicides, especially when considering mixtures. They propose enhancing efforts in effect modeling to predict toxicity under changing environmental conditions and minimize reliance on animal testing.
3. **Perfluoroalkyl and Polyfluoroalkyl Substances (PFAS)**: Bil et al. (2023) suggest exploring modes of action and adverse outcome pathways to address data deficiencies and gain insights into species consistency regarding PFAS toxicity. As noted in (Xu et al. 2024), the Pielou uniformity index can be effectively used to quantify anomalous sources of PFAS pollution along rivers.
4. **Dichlorophenolindophenol (DCIP)**: Wang et al. (2023a) studied the multi-risk aspects of health effects through oral and inhalation exposure in raw and treated water to this type of contaminant. Its presence as an industrial by-product and difficult removal by conventional treatment processes indicate the need to control sources of contamination in the aquatic environment (Wang et al. 2023a).
5. **Pharmaceuticals**: Richmond et al. (2018) acknowledge the detection of numerous biologically active pharmaceuticals in surface waters worldwide but highlight the lack of understanding regarding their impacts and integration into aquatic food webs. The study conducted by Hanna et al. (2023) focused on identifying antibiotic residue levels that are prone to selecting for resistance and the relative contributions from various aquatic sources. This highlights the need for further research to assess the potential ecological impacts of pharmaceutical residues in aquatic ecosystems (Castellano-Hinojosa et al. 2023).
6. **Microplastics**: Jeyasanta et al. (2023) conducted a risk assessment study on microplastic pollution in Tamil Nadu, India, emphasizing the need to anticipate potential adverse effects on ecosystems. However, they did not perform a risk assessment using available predicted effect concentration values for aquatic and terrestrial environments. Everaert et al. (2018) also conducted an assessment of the environmental risk posed by microplastics in marine environments. However, additional ecotoxicological studies are needed to verify these conclusions. Rybalova and Artemiev (2017) introduce a method for evaluating the risk of impairing the condition of a water body. However, this method cannot be applied directly to assess the impact of pollution on a watercourse. The Ganie et al. (2024) study estimated the contamination and accumulation of microplastics in freshwater hydrobiotic systems.

These examples underscore the importance of advancing scientific research and developing effective strategies to mitigate the impacts of emerging pollutants on aquatic ecosystems and human health. However, they did not perform a risk assessment using the available predicted effect concentration values for aquatic and terrestrial environments.

To maintain good chemical and ecological status, EU Member States are mandated to monitor priority substances and chemicals flagged as substances of concern at both the European Union and local/basin/national levels in surface water bodies. They are also required to report any exceedances of environmental quality standards. However, there remains a gap in the classification of the ecological status of surface water bodies, as highlighted by previous studies (Freshwater 2023; Law and Environment Assistance Platform (UNEP-LEAP), 2023).

From the studies reviewed (Rybalova and Artemiev 2017; Chandellier and Malacain 2021; Ullah Bhat and Qayoom 2022; Anthonj et al. 2022; Ullah et al. 2022; Barati et al. 2023; Jonjev et al. 2024), two primary types of environmental risk can be summarized:

1. **Risk of Ecosystem Disruption**: This type of risk pertains to the potential disruption of the stability and functioning of ecosystems due to environmental pollution. It encompasses threats such as habitat degradation, loss of biodiversity, and disturbances to ecological processes caused by various pollutants and stressors.
2. **Risk to Public Health**: This risk refers to the probability of adverse health effects occurring in human populations as a result of exposure to environmental contaminants. It encompasses risks associated with waterborne diseases, exposure to toxic chemicals, and other hazards that may compromise public health and well-being.

As evident from our analysis, significant emphasis is placed on assessing the risk of water pollution, particularly in countries with developed economies. A notable shift in focus is observed towards addressing pollution caused by Contaminants of Emerging Concern (CECs). However, it's noteworthy that EU policy initiatives, such as the Urban Wastewater Treatment Directive, have primarily targeted inorganic pollutants like nutrients, indicating a gap in addressing the emerging challenge posed by CECs. This highlights the need for policy adaptation and regulatory frameworks to address evolving environmental risks associated with emerging contaminants in water systems.

The cluster modelling is shown in Fig. 1.

Thus, clusters enable us to identify research trends in this area, and they are modelled using special software. Clustering is the identification of major trends in risk research based on keyword sampling in bibliometric analysis. In addition, we have considered the distribu-

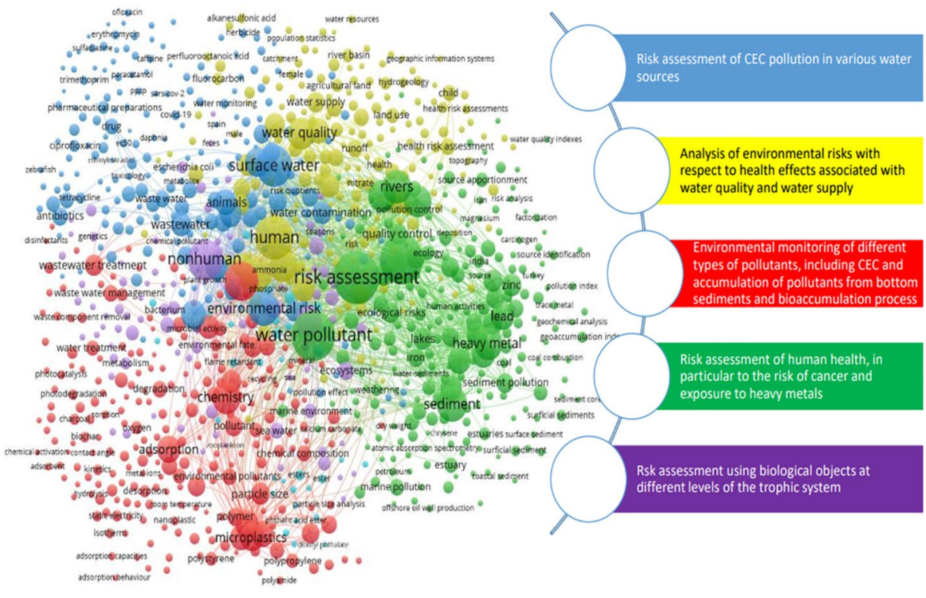

Fig. 1 Cluster modelling (VOSviewer) of the environment risk assessment for water resources (items 968, clusters 6, links 188743, total link strength 649799)

tion of risks, e.g. human or ecosystem, behind the object of research. This is not a cluster modelling, but an expert opinion based on the analysis of previous studies.

3.2 Existing Framework and the Process of Reaching a New Risk Assessment Approach

Various ecotoxicological methods have been developed to determine Predicted No-Effect Concentration (PNEC) values and construct dose-response curves, owing to the diverse ecotoxicological mechanisms and biological effects of chemicals on living organisms (Smid et al. 2006; Lian et al. 2021). The environmental behaviour of organophosphorus esters (OPEs) in water and sediment samples was investigated (Li et al. 2023) to identify their concentrations, spatial and temporal changes, and environmental risks. The relations between environmental risk assessment and the issues of climate change and greenhouse gas emissions are discussed in another study (Barati et al. 2023).

The main approaches to risk assessment are summarised below (Table 1).

Analysis of publications indexed in Scopus and Web of Science (WoS) databases reveals a knowledge gap in assessing the effects of certain types of contaminants and in conducting multi-risk assessments across various categories of pollutants. Research commonly focuses on specific types of pollutants and subsequently evaluates the environmental risk associated with their release into water bodies on an individual basis. While multiple risk assessment approaches are prevalent, particularly in assessing the complex impacts of natural hazards.

3.3 Suggestion for Updating the Multi-Risk Assessment Approach

Figure 2 presents the concept of assessing the aggregate environmental risks (as multi-risk) of the impact of CECs during the stages of migration, transformation, and accumulation in the components of the hydrosphere, namely in surface water bodies, groundwater and the final entry into the sea and ocean, all in one global water system.

Risk-based water resource planning operates under the principle that water managers should allocate resources to mitigate risk until the marginal benefit of risk reduction equals the marginal cost of achieving it. Here, risk is quantified as the expected annual cost of water use restrictions, while reliability is understood as the capacity of a water resource system to sustain performance, measured as the acceptable risk of water use restrictions across various future scenarios. By connecting risk attitudes to resilience, stakeholders can consciously balance incremental enhancements in resilience with investment expenses for a specified risk level (Borgomeo et al. 2018; Nusair et al. 2024; Fernandes et al. 2023).

Integrating climate considerations into risk assessment for aquatic contaminants involves several strategies:

1. **Climate Scenario Analysis**: Incorporating climate projections to anticipate alterations in climate variables over time and assessing their impact on the behavior and consequences of contaminants in aquatic ecosystems during risk evaluation.
2. **Modeling Approaches**: Utilizing modeling techniques to forecast how climate change may influence the concentration, dispersion, and accessibility of contaminants in aquatic environments, allowing for a more comprehensive understanding of potential risks.

Table 1 Overview of risk assessment approaches

Type of approach	Basic aspects
Ecological risk index (ERI)	ERI functions as a diagnostic tool for managing water pollution, aiding in the identification of lakes or basins and substances that require specific attention and prioritization in pollution control endeavors. It is one of the diagnostic tools for aquatic ecosystem assessment (Ma and Han 2020; Suchi et al. 2024). Key operational aspects of the Potential Ecological Risk Index (PERI) assessment, as outlined by Fiori et al. (2013), include: • Collection of surface sediment samples from low-energy areas where sediment accumulation occurs. • Determination of natural levels of toxic substances using geological landmarks or pre-industrial levels identified through sediment cores. • Inclusion of metals such in the model. Polychlorinated biphenyls and arsenic should also be included if possible. • Utilization of a simple index with a limited number of variables as a tool for environmental management in degraded areas.
Species sensitivity distribution and Probabilistic risk assessment	Insufficient chronic toxicity data are available for most chemicals to construct appropriate sensitivity distributions. Conversely, acute toxicity data are more abundant. Species Sensitivity Distributions (SSDs) and assessing the effectiveness of estimated Hazardous Concentrations (HCs) in protecting freshwater aquatic ecosystems. A comprehensive analysis is used to construct SSD curves to collect data on the toxicity of a substance (Albarano et al. 2024). Probabilistic risk assessment necessitates a wealth of data compared to other approaches. By utilizing existing distributions of exposure data collected at various locations and times and juxtaposing them with toxicological responses, it becomes possible to pinpoint locations or periods when risks are elevated. An extrapolation method is also used to overcome the lack of toxicity data to improve the reliability of deriving water quality criteria and reduce the uncertainty of the risk assessment (Zhou et al. 2024).
Multi-risk assessment and cumulative risk assessment	Indeed, both multi-risk assessment and cumulative risk assessment are integral tools within the realm of risk assessment. Both provide information to support decision making and risk management and help policy makers and stakeholders prioritise actions to reduce risks, although they have different purposes. While multi-risk assessment assesses and compares risks from multiple hazards or stressors to prioritise and manage them effectively, cumulative risk assessment focuses on evaluating the combined effects of exposure to multiple stressors or hazards (e.g., chemicals, pollutants) on a specific population or environment (Shafi et al. 2023). Multi-risk assessment can encompass a wide range of risks, including natural hazards (e.g. floods, extreme climate events), technological hazards (e.g., chemical spills), and societal risks (e.g., economic instability). An environmental risk assessment procedure that includes multi-hazard synergy risk (He and Weng 2020) can be illustrated by identifying the main steps that need to be followed to estimate a multi-risk index (Figure A3). Cumulative risk assessment (Figure A4) is more focused on a specific endpoint (e.g. human health or environmental impact) (Chen et al. 2024a, b). The first approach involves the independent evaluation of multiple distinct risks without necessarily considering their interactions to identify and rank risks based on their individual characteristics. The second approach considers additive, synergistic, or antagonistic interactions between different stressors, and it often involves the summation or integration of risks from various sources to assess the overall risk. Both approaches can be complex because they need to deal with multiple stressors or hazards and require the integration of data and expertise from various disciplines. Consequently, the cumulative risk considered within this approach is not evaluated within the confines of conventional risk assessments. Furthermore, it allows for the possibility of a semi-quantitative or qualitative analysis or result, unlike most previous assessments, which were predominantly quantitative in nature (Huang et al. 2024). However, limitations in its applicability stem from factors such as insufficient data on combined effects, the complexity of the models involved, and the uncertainty associated with the intricacies of the interactions.

Table 1 (continued)

Type of approach	Basic aspects
Fuzzy logic based approach	Fuzzy logic is a mathematical framework that can be useful in risk assessment and decision-making processes where uncertainty and imprecision are present. This approach is based on fuzzy decision logic and is applicable to various case studies (Bahadur et al., 2018). Traditional risk assessment methods often rely on crisp, binary values (e.g., true/false, yes/no) which may not adequately capture the complexity and uncertainty of real-world scenarios. Fuzzy logic, on the other hand, allows for a more flexible approach to risk assessment by representing variables and relationships with degrees of membership in fuzzy sets. Several methods exist for implementing fuzzy principles, with one of the most widely used being the Fuzzy Inference System (FIS). FIS enables the assignment of output variables to input variables using fuzzy logic, allowing for the modeling of complex systems with uncertain or imprecise inputs (Civan Çavuşoğlu et al. 2023). The basic steps for implementing a fuzzy model with FIS are depicted in Figure A5. The main limitations of this approach are (Yadav et al. 2018): (i) lack of precision since it deals with uncertainties, (ii) subjectivity since fuzzy logic relies on variables, sets, and statements which are often subjectively defined, (iii) high data requirement, sensitivity to parameter tuning, and (iv) limited modeling capabilities and scalability.
Toxic Unit	As per the European chemicals legislation REACH, this information is summarized in a Predicted No Effect Concentration (PNEC) for the specific ecosystem under consideration. The PNEC is derived by identifying the most sensitive biotest, which represents the most sensitive trophic level, and then applying an appropriate Assessment Factor (AF). A further study by Chepchirchir et al. (2024) investigated the processes of occurrence, removal, and potential risk of CECs found in rivers and wastewater treatment plants. Crustaceans were shown to have a significant potential risk of toxicity, which was mainly caused by diazinon and dichlorophos in rivers.

3. **Stressor Interaction Studies**: Researching to explore additional stressors that may affect the vulnerability of aquatic organisms to contaminants, recognizing that climate change interacts with various environmental stressors to shape ecological responses.

By integrating these factors, risk assessments can provide a more holistic understanding of the potential impacts of contaminants in aquatic systems under changing climate conditions. Adaptation to climate change, including water risk management, is becoming an important consideration (Pham et al. 2023; Simeoni et al. 2023).

Therefore, the research conducted by Adib et al. (2023) examined how climate change affects runoff quality within the Maroun watershed, which is recognised as one of the most significant watersheds (Adib et al. 2023).

4 Conclusions

The conceptual apparatus of the main stages of risk assessment was formed, considering the available base of previous studies. We considered the realisation of an integral approach for the migration of the totality of polluting substances in different water systems as a single water body. The concept of assessment aggregate ecological risks (as multi-risk) of CEC pollutant exposure at the stages of migration, transformation, and accumulation in the components of the hydrosphere, namely in surface water bodies, groundwater, and the final entrance to the sea and ocean, all in one global water body, was presented. Indeed, it's crucial to acknowledge that risk assessors in different regions may encounter site-specific

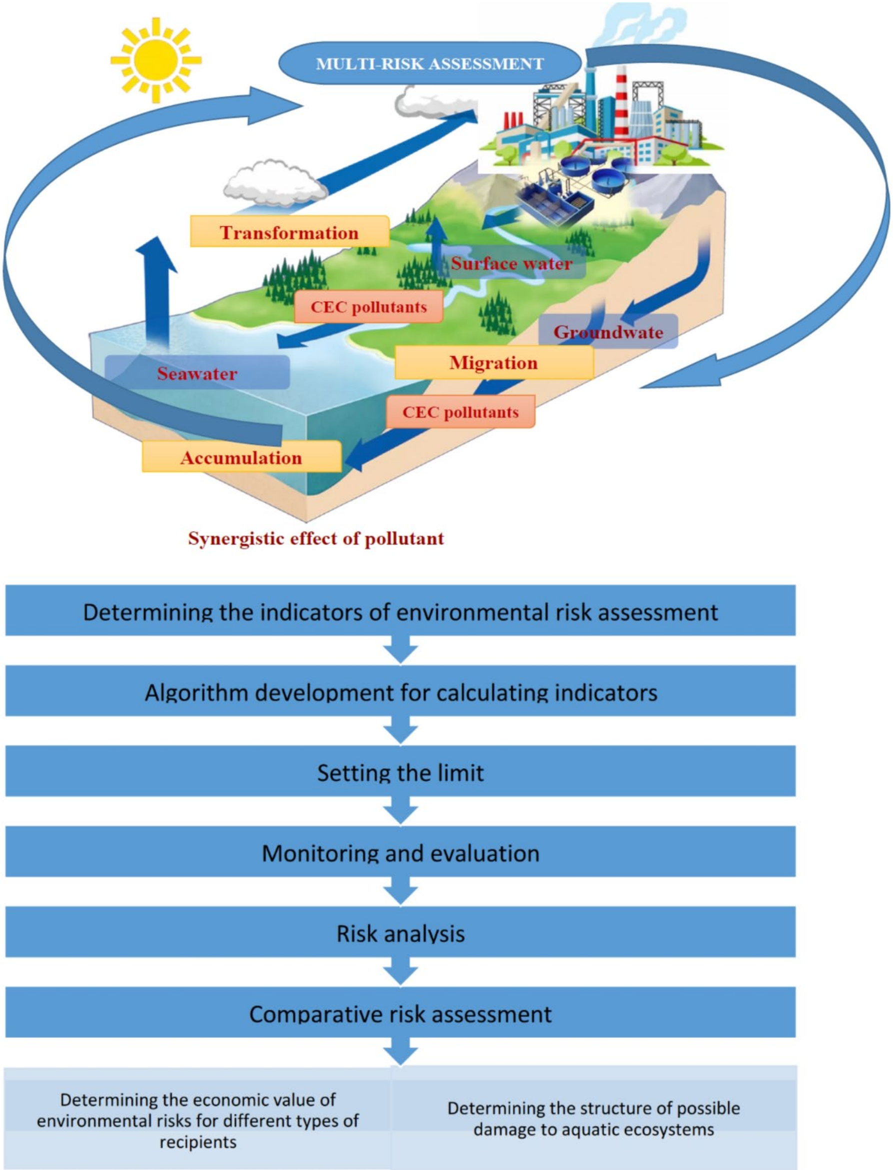

Fig. 2 Approach to aggregation of environmental risks of hydrosphere pollution as a multi-risk assessment

stressors. This requires flexible approaches to assess the ecological risk of aquatic ecosystem pollution and its implications for biota, including human health. By adopting adaptable methodologies that can accommodate regional differences in stressors, we can better tailor risk assessment strategies to address the unique challenges facing by different ecosystems and communities. Further research will be aimed at improving the implementation of the approach to assessing environmental risks (under multi-risk assessment) on the synergistic basis of the interaction of pollutants in the ecosystem with an impact on human health on a global scale.

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Data Availability Data will be made available on request.

Declarations

Conflict of Interest The authors declare no conflict of interest.

References

Adib A, Haidari B, Lotfirad M, Sasani H (2023) Evaluating climatic change effects on EC and runoff in the near future (2020–2059) and far future (2060–2099) in arid and semi-arid watersheds. Appl Water Sci 13(6):122. https://doi.org/10.1007/s13201-023-01926-1

Albarano L, Maggio C, Marca AL, Iovine R, Lofrano G, Guida M, Vaiano V, Carotenuto M, Pedatella S, Spica VR, Giovanni Libralato G (2024) Risk assessment of natural and synthetic fibers in aquatic environment: a critical review. Sci Total Environ 934:173398. https://doi.org/10.1016/j.scitotenv.2024.173398

Anthonj C, Setty KE, Ferrero G, Yaya A-MA, Mingoti Poague KIH, Marsh AJ, Augustijn EW (2022) Do health risk perceptions motivate water - and health-related behaviour? A systematic literature review. Sci Total Environ 819:152902. https://doi.org/10.1016/j.scitotenv.2021.152902

Barati AA, Zhoolideh M, Azadi H, Lee J-H, Scheffran J (2023) Interactions of land-use cover and climate change at global level: how to mitigate the environmental risks and warming effects. Ecol Ind 146:109829. https://doi.org/10.1016/j.ecolind.2022.109829

Bil W, Govarts E, Zeilmaker MJ, Woutersen M, Bessems I, Thomsen C, Ma Y, Haug LS, Lignell S, Gyllenhammar I, Palkovicova Murinova L, Fabelova L, Snoj Tratnik J, Kosjek T, Gabriel C, Sarigiannis D, Pedraza-Diaz S, Esteban -L,´opez M, Casta˜no A, Rambaud L, Riou lM, Franken C, Colles A, Vogel N, Kolossa-Gehring M, Halldorsson TI, Uhl M, Schoeters G, Santonen T, Vinggaard AM (2023) Approaches to mixture risk assessment of PFASs in the European population based on human hazard and biomonitoring data. Int J Hyg Environ Health 247:114071

Borgomeo E, Mortazavi-Naeini M, Hall JW, Guillod BP, Risk (2018) Robustness and water resources planning under uncertaint. Earth's Future 6:468–487

Bozorgi A, Roozbahani A, Hashemy Shahdany SM (2021) Development of multi-hazard risk assessment model for agricultural water supply and distribution systems using bayesian network. Water Resour Manage 35:3139–3159. https://doi.org/10.1007/s11269-021-02865-9

Carvalho L, Mackay EB, Cardoso AC, Baattrup-Pedersen A, Birk S, Blackstock KL, Borics G, Borja A, Feld CK, Ferreira MT, Globevnik L, Grizzetti B, Hendry S, Hering D, Kelly M, Langaas S, Meissner K, Panagopoulos Y, Penning E, Solheim AL (2019) Protecting and restoring Europe's waters: an analysis of the future development needs of the water framework directive. Sci Total Environ 658:1228–1238. https://doi.org/10.1016/j.scitotenv.2018.12.255

Castellano-Hinojosa A, Gallardo-Altamirano MJ, González-López J, González-Martínez A (2023) Anticancer drugs in wastewater and natural environments: a review on their occurrence, environmental persistence, treatment, and ecological risks. J Hazard Mater 447:130818. https://doi.org/10.1016/j.jhazmat.2023.130818

Chandellier J, Malacain M (2021) Biodiversity and Re/insurance: an ecosystem at risk. Research report. Muséum National d'Histoire Naturelle, Paris

Chen Z, Zhao Y, Liang N, Yao Y, Zhao Y, Liu T (2024b) Pollution, cumulative ecological risk and source apportionment of heavy metals in water bodies and river sediments near the Luanchuan molybdenum mining area in the Xiaoqinling Mountains, China, Marine Pollution Bulletin. 205:116621. https://doi.org/10.1016/j.marpolbul.2024.116621

Chen Y, Li M, Gao W, Guan Y, Hao Z, Liu J (2024a) Occurrence and risks of pharmaceuticals, personal care products, and endocrine-disrupting compounds in Chinese surface waters. J Environ Sci 146:251–263. https://doi.org/10.1016/j.jes.2023.10.011

Chepchirchir R, Mwalimu R, Tanui I, Kiprop A, Krauss M, Brack W, Kandie F (2024) Occurrence, removal and risk assessment of chemicals of emerging concern in selected rivers and wastewater treatment plants in western Kenya. Sci Total Environ Volume 948:174982. https://doi.org/10.1016/j.scitotenv.2024.174982

Civan Çavuşoğlu F, Özçelik G, Özbek C et al (2023) Fe_3O_4 supported UiO-66 (zr) metal–organic framework for removal of drug contaminants from water: fuzzy logic modeling approach. Environ Sci Pollut Res 30:44337–44352. https://doi.org/10.1007/s11356-023-25378-x

Dem P, Hayashi K, Fujii M, Tao L (2024) Resources time footprint indicator extension for evaluating human interventions in provisioning ecosystem services supply. Sci Total Environ 946:173852. https://doi.org/10.1016/j.scitotenv.2024.173852

European Commission (2022) Proposal for a directive of the European parliament and of the council concerning urban wastewater treatment. COM, 541 final 2022/0345 (COD). Brussels

Everaert G, van Cauwenberghe L, de Rijcke M, Koelmans AA, Mees J, Vandegehuchte M, Janssen CR (2018) Risk assessment of microplastics in the ocean: modelling approach and first conclusions. Environ Pollut 242:1930–1938. https://doi.org/10.1016/j.envpol.2018.07.069

Fernandes F, Malheiro A, Chaminé HI (2023) Natural hazards and hydrological risks: climate change-water-sustainable society nexus. SN Appl Sci 5:36. https://doi.org/10.1007/s42452-022-05214-6

Filho WL, Fedoruk M, Eustachio JHPP, Splodytel A, Smaliychuk A, Szynkowska-Jóźwik MI (2024) The environment as the first victim: the impacts of the war on the preservation areas in Ukraine. J Environ Manage 364 121399. https://doi.org/10.1016/j.jenvman.2024.121399

Fiori C, da Rodrigues FS, Santelli AP, Cordeiro RE, Carvalheira RC, Araújo RG, Castilhos PC, Bidone ZC (2013) Ecological risk index for aquatic pollution control: a case study of coastal water bodies from the Rio De Janeiro State, southeastern Brazil. Geochim Brasiliensis 27(1). https://doi.org/10.21715/gb.v27i1.386

Fridman KB, Novikova YA, Belkin AS (2019) On the issue of health risk assessment techniques for hygienic characteristics of water supply systems. Hygiene Sanitation 96(7):686–689. https://doi.org/10.18821/0016-9900-2017-96-7-686-689

Ganie ZA, Mandal A, Arya L, Sangeetha T, Talib M, Darbha GK (2024) Assessment and accumulation of microplastics in the Indian riverine systems: risk assessment and implications of translocation across the water-to-fish continuum, aquatic toxicology. 272:106944. https://doi.org/10.1016/j.aquatox.2024.106944

Geissen V, Mol H, Klumpp E, Umlauf G, Nadal M, van der Ploeg M, van de Zee SEATM, Ritsema CJ (2015) Emerging pollutants in the environment: a challenge for water resource management. Int Soil Water Conserv Res 3(1):57–65. https://doi.org/10.1016/j.iswcr.2015.03.002

Halleux V (2023) Pollutants in EU waters Update of chemical substances listed for control. EPRS European Parliamentary Research Service

Hanna N, Tamhankar AJ, Stålsby Lundborg C (2023) Antibiotic concentrations and antibiotic resistance in aquatic environments of the WHO Western Pacific and South-East Asia regions: a systematic review and probabilistic environmental hazard assessment. Lancet Planet Health 7(1):e45-e54. https://doi.org/10.1016/S2542-5196(22)00254-6

He Z, Weng W (2020) Synergic effects in the assessment of multi-hazard coupling disasters: fires, explosions, and toxicant leaks. J Hazard Mater 388:121813. https://doi.org/10.1016/j.jhazmat.2019.121813

Huang D, Pang T, Bai X et al (2024) Evaluating the surface water pollution risk of mineral resource exploitation via an improved approach: a case study in Liaoning Province, Northeastern China. Environ Monit Assess 196:750. https://doi.org/10.1007/s10661-024-12899-2

Jašíková L, Prchalová H, Fojtík T, Nováková H, Picek J, Zbořil A, Vyskoč P, Semerádová S, Dlabal J (2022) Risk assessment as a comprehensive approach to protection of drinking water sources. Vodohospodářské technicko-ekonomické Informace 64(4):59–60. https://www.vtei.cz/en/2022/08/risk-assessment-as-a-comprehensive-approach-to-protection-of-drinking-water-sources/

Javadinejad S, Hannah D, Ostad-Ali-Askari K et al (2019) The impact of future climate change and human activities on hydro-climatological drought, analysis and projections: using CMIP5 climate model simulations. Water Conserv Sci Eng 4:71–88. https://doi.org/10.1007/s41101-019-00069-2

Jeyasanta KI, Laju RL, Patterson J, Jayanthi M, Bilgi DS, Sathish N, Edward JK (2023) P. Microplastic pollution and its implicated risks in the estuarine environment of Tamil Nadu, India. Sci Total Environ 861:160572. https://doi.org/10.1016/j.scitotenv.2022.160572

Johnson AC, Jin X, Nakada N, Sumpter JP (2020) Learning from the past and considering the future of chemicals in the environment. Science 367(6476):384–387. https://doi.org/10.1126/science.aay6637

Jonjev M, Miletić Z, Pavlović D et al (2024) Health risk assessment of potentially toxic elements in the riparian zone of the Sava River (southeastern Europe): effects of high and low water events. Environ Sci Eur 36:133. https://doi.org/10.1186/s12302-024-00952-3

Law and Environment Assistance Platform (UNEP-LEAP) (2023) URL: https://leap.unep.org/countries/pl/national-legislation/regulation-classification-ecological-status-ecological-1 (accessed on 12 July 2023)

Li W, Yuan Y, Wang S, Liu X (2023) Occurrence, spatiotemporal variation, and ecological risks of organophosphate esters in the water and sediment of the middle and lower streams of the Yellow River and its important tributaries. J Hazard Mater 443:130153. https://doi.org/10.1016/j.jhazmat.2022.130153

Lian M, Lin C, Wu T, Xin M, Gu X, Lu S, He M (2021) Occurrence, spatiotemporal distribution, and ecological risks of organophosphate esters in the water of the Yellow River to the Laizhou Bay, Bohai Sea. Sci Total Environ 787:147528. https://doi.org/10.1016/j.scitotenv.2021.1475

Lopez-Herguedas N, Irazola M, Alvarez-Mora I, Orive G, Lertxundi U, Olivares M, Zuloaga O, Prieto A (2023) Comprehensive micropollutant characterization of wastewater during Covid-19 crisis in 2020: suspect screening and environmental risk prioritization strategy. Sci Total Environ 873:162281. https://doi.org/10.1016/j.scitotenv.2023.162281

Ma L, Han C (2020) Water quality ecological risk assessment with sedimentological approach', water quality - science, assessments and policy. IntechOpen Jul 29. https://doi.org/10.5772/intechopen.88594

Nativio A, Kapelan Z, van der Hoek JP (2022) Risk assessment methods for water resource recovery for the production of bio-composite materials: literature review and future research directions. Environ Challenges 9:100645. https://doi.org/10.1016/j.envc.2022.100645

Nusair A, Madelyn Barber M, Avijit Pramanik A, Ethridge C, William C, Alkhateb H, Ucak-Astarlioglu M (2024) Paresh Chandra Ray, Matteo D'Alessio, Graphene-coated sand for enhanced water reuse: impact on water quality and chemicals of emerging concern. Sci Total Environ Volume 945:174078. https://doi.org/10.1016/j.scitotenv.2024.174078

Oyege I, Katwesigye R, Kiwanuka M, Mutanda HE, Niyomukiza JB, Kataraihya DJ, Kica S, Egor M (2024) Temporal trends of water quality parameters, heavy metals, microplastics, and emerging organic pollutants in Lake Victoria and its basin: knowns, knowledge gaps, and future directions, vol 22. Environmental Nanotechnology, Monitoring & Management, p 100962. https://doi.org/10.1016/j.enmm.2024.100962

Pham HV, Barco MKD, Marco Cadau, Harris MCR, Furlan E, Torresan S, Rubinetti S, Zanchettin D, Rubino A, Kuznetsov I, Barbariol F, Benetazzo A, Sclavo M, Critto A (2023) Multi-model chain for climate change scenario analysis to support coastal erosion and water quality risk management for the Metropolitan city of Venice, Science of the total environment. 904:166310. https://doi.org/10.1016/j.scitotenv.2023.166310

Richmond EK, Rosi EJ, Walters DM et al (2018) A diverse suite of pharmaceuticals contaminates stream and riparian food webs. Nat Commun 9:4491. https://doi.org/10.1038/s41467-018-06822-w

Rybalova O, Artemiev S (2017) Development of a procedure for assessing the environmental risk of the surface water status deterioration. Eastern-European J Enterp Technol 5(89):67–76. https://doi.org/10.15587/1729-4061.2017.112211

Shafi M, Jan R, Gani KM (2023) Selection of priority emerging contaminants in surface waters of India, Pakistan, Bangladesh, and Sri Lanka, Chemosphere. 341:139976. https://doi.org/10.1016/j.chemosphere.2023.139976

Shi M, Zhu J, Hu T, Xu A, Mao Y, Liu L, Zhang Y, She Z, Li P, Qi S, Xing X (2023) Occurrence, distribution and risk assessment of microplastics and polycyclic aromatic hydrocarbons in East lake, Hubei, China. Chemosphere 316:137864. https://doi.org/10.1016/j.chemosphere.2023.137864

Shi H, Du Y, Li Y, Deng Y, Tao Y, Ma T (2024) Determination of high-risk factors and related spatially influencing variables of heavy metals in groundwater. J Environ Manage 358 120853. https://doi.org/10.1016/j.jenvman.2024.120853

Simeoni C, Furlan E, Pham HV, Critto A, de Juan S, Trégarot E, Cornet CC, Meesters E, Fonseca C, Botelho AZ, Krause T, N'Guetta A, Cordova FE, Failler P, Marcomini A (2023) Evaluating the combined effect of climate and anthropogenic stressors on marine coastal ecosystems: insights from a systematic review of cumulative impact assessment approaches. Sci Total Environ 861:160687

Smid R, Kubasek M, Klimes D, Dusek L, Jarkovsky J, Marsalek B, Hilscherova K, Blaha L, Cupr P, Holoubek (2006) I. web portal for management of bioindication methods and ecotoxicological tests in ecological risk assessment. Ecotoxicology 15(8):623–627. https://doi.org/10.1007/s10646-006-0097-x

Spycher S, Kalf D, Lahr J et al (2024) Linking chemical surface water monitoring and pesticide regulation in selected European countries. Environ Sci Pollut Res 31:43432–43450. https://doi.org/10.1007/s11356-024-33865-y

Starling MCVM, Rodrigues DAS, Miranda GA, Jo S, Amorim CC, Ankley GT, Simcik M (2024) Occurrence and potential ecological risks of PFAS in Pampulha Lake, Brazil, a UNESCO world heritage site. Sci Total Environ Volume 948:174586. https://doi.org/10.1016/j.scitotenv.2024.174586

Suchi PD, Shaikh MAA, Saha B, Moniruzzaman M, Hossain MK, Afroza Parvin A, Parvin A (2024) Comprehensive index analysis approach for ecological and human health risk assessment of a tributary river in Bangladesh, Heliyon, Volume 10, Issue 13, e32542, https://doi.org/10.1016/j.heliyon.2024.e32542

Technical Guidance Document of European Chemicals Bureau (TGD), European Communities (2003) https://echa.europa.eu/documents/10162/987906/tgdpart2_2ed_en.pdf/138b7b71-a069-428e-9036-62f4300b752f

Terzi S, Torresan S, Schneiderbauer S, Critto A, Zebisch M, Marcomini A (2019) Multi-risk assessment in mountain regions: a review of modelling approaches for climate change adaptation. J Environ Manage 232:759–771. https://doi.org/10.1016/j.jenvman.2018.11.100

Tokatlı C, Varol M, Uğurluoğlu A (2024) Ecological risk assessment, source identification and spatial distribution of organic contaminants in terms of mucilage threat in streams of Çanakkale Strait Basin (Türkiye), Chemosphere. 353:141546. https://doi.org/10.1016/j.chemosphere.2024.141546

Ullah Z, Xu Y, Zeng X-C, Rashid A, Ali A, Iqbal J, Almutairi MH, Aleya L, Abdel-Daim MM, Shah M (2022) Non-carcinogenic health risk evaluation of elevated fluoride in Groundwater and its Suitability Assessment for drinking purposes based on Water Quality Index. Int J Environ Res Public Health 19(15):9071. https://doi.org/10.3390/ijerph19159071

Ullah Bhat S, Qayoom U (2022) Implications of Sewage Discharge on Freshwater Ecosystems, Sewage - Recent Advances, New Perspectives and Applications. *IntechOpen*https://doi.org/10.5772/intechopen.100770

Wang C, Guo Q, Zhang B, An W, Wang Z, Zhang D, Yang M, Yu J (2023a) Solvent-like bis (2-chloro-1-methylethyl) ether occurrence in drinking water: multidimensional risk assessment integrated health and aesthetic aspects. J Hazard Mater 453 131446. https://doi.org/10.1016/j.jhazmat.2023.131446

Wang W, Lin C, Wang L, Jiang R, Huang H, Liu Y, Lin H (2023b) Contamination, sources and health risks of potentially toxic elements in the coastal multimedia environment of South China. Sci Total Environ 862:160735. https://doi.org/10.1016/j.scitotenv.2022.160735

Website European Comission (2023) Food Safety. State of play on the assessment of risks caused by the presence of multiple pesticide residues in food https://food.ec.europa.eu/plants/pesticides/maximum-residue-levels/cumulative-risk-assessment_en (accessed on 10

WISE Freshwater (2023) URL https://water.europa.eu/freshwater/data-maps-and-tools/water-framework-directive-surface-water-data-products/surface-water-ecological-status WISE Freshwater resource catalogue https://water.europa.eu/freshwater/data-maps-and-tools/metadata (accessed on 12 July 2023)
Wojnarowski K, Podobiński P, Cholewińska P, Smoliński J, Dorobisz K (2021) Impact of estrogens present in environment on health and welfare of animals. Anim (Basel) 11(7):2152. https://doi.org/10.3390/ani11072152PMID: 34359280; PMCID: PMC8300725
Xu N, Pan Z, Guo W, Li S, Li D, Dong Y, Sun W (2024) Impacts of rapidly urbanizing watershed comprehensive management on per- and polyfluoroalkyl substances pollution: based on PFAS diversity assessment, Water Research. 261:122010. https://doi.org/10.1016/j.watres.2024.122010
Yadav HB, Kumar S, Kumar Y, Yadav DK (2018) A fuzzy logic based approach for decision making. J Intell Fuzzy Syst 35(2):1531–1539
Yadav D, Rangabhashiyam S, Verma P, Singh P, Devi P, Kumar P, Hussain CM, Gaurav GK, Kumar KS (2021) Environmental and health impacts of contaminants of emerging concerns: recent treatment challenges and approaches. Chemosphere 272:129492. https://doi.org/10.1016/J.CHEMOSPHERE.2020.129492
Zhang J, Li Y, You L, Huang G, Xu X, Wang X (2022) Optimizing effluent trading and risk management schemes considering dual risk aversion for an agricultural watershed. Agric Water Manage 269:107716. https://doi.org/10.1016/j.agwat.2022.107716
Zhang W, Liu G, Ghisellini P, Yang Z (2024) Ecological risk and resilient regulation shifting from city to urban agglomeration: a review. Environ Impact Assess Rev Volume 105:107386. https://doi.org/10.1016/j.eiar.2023.107386
Zhao Q, Zhang Y, Li X, Hu X, Huang R, Xu J, Yin Z, Gu X, Xu Y, Yin J, Zhou Q, Li A, Shi P (2024) Evaluating a river's ecological health: a multidimensional approach. Environ Sci Ecotechnology 21:100423. https://doi.org/10.1016/j.ese.2024.100423
Zhou S, Di Paolo C, Wu X, Shao Y, Seiler T-B, Hollert H (2019) Optimization of screening-level risk assessment and priority selection of emerging pollutants – the case of pharmaceuticals in European surface waters. Environ Int 128:1–10. https://doi.org/10.1016/j.envint.2019.04.034
Zhou X, Shi Y, Lu Y, Song S, Wang C, Wu Y, Liang R, Qian L, Xu Q, Shao X, Li X (2024) Ecological risk assessment of commonly used antibiotics in aquatic ecosystems along the coast of China. Sci Total Environ 935:173263. https://doi.org/10.1016/j.scitotenv.2024.173263
Zubrod JP, Bundschuh M, Arts G, Brühl CA, Imfeld G, Knäbel A, Payraudeau S, Rasmussen JJ, Rohr J, Scharmüller A, Smalling K, Stehle S, Schul Rz, Schäfer RB (2019) Fungicides: an overlooked pesticide class? Environ. Sci Technol 53:7, 3347–3365

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