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Editorial: Exploring the combined effect of climate change and pollution on freshwater ecosystems

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Editorial on the Research Topic
Exploring the combined effect of climate change and pollution on freshwater ecosystems

Aquatic ecosystems worldwide are impacted by the simultaneous action of multiple pressures, both anthropogenic and environmental. In particular, pollutants including nutrients, pesticides, metals, persistent organic pollutants, and anthropogenic particles affect the environmental compartments (water, sediment, biota) which is further exacerbated by climate change impacts on water quality and quantity. The origins of these anthropogenic pollutants range from agriculture and livestock activities to industrial emissions, to daily activities from the general population including use of personal care products and fast fashion. Pollutants may cause a variety of ecosystem impacts when considered individually, but they also show complex interactions with one another as well as with other environmental stressors which manifest as mixture effects. For instance, pollutant impacts are concurrent with global environmental change due to increasing greenhouse gas emissions, resulting in increasing water temperatures, alterations in water flow regimes, and changes in biodiversity and ecosystem resilience. Global climate change effects could exacerbate the potential impacts of pollutants on freshwater ecosystems, but this is not typically factored into standard ecotoxicity testing or environmental risk assessments. For example, temperature can change the chemical characteristics of toxicants, including solubility and degradation rates, thereby altering bioavailability, mobilisation, and persistence in the environment. Moreover, the increase of extreme hydrological events (i.e., floods and drought) can re-mobilise toxicants that were previously buried in sediments and were altered due to changing redox conditions. Temperature can also affect biodiversity and change the food web dynamics and other biological interactions. For instance, an increase of temperature can reduce the oxygen concentration in water, thus favouring species that are more tolerant to low-oxygen conditions, some of which may be non-native.

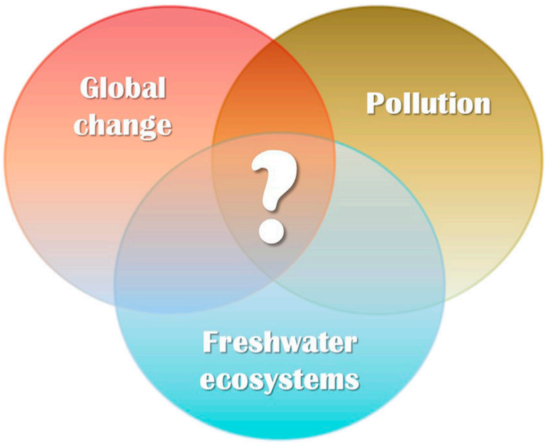

FIGURE 1
Gaps to address and understand the impacts of combined stress from global change and anthropogenic pollution in freshwater ecosystems, from different perspectives.

This Research Topic draws together studies unified by the goal of understanding the impacts of combined stress from global change (in particular temperature effects) and anthropogenic pollution, from different perspectives (Figure 1). The focus of the collected works is on freshwater ecosystems, with the aim of highlighting approaches for assessing and quantifying the combined impacts of global change and pollution on ecosystem resilience (Bank et al., 2022), functioning, evolution and adaption.

Roth et al. investigated the combined effects of pesticides and heatwaves on freshwater zooplankton communities using indoor microcosms. The results indicated direct effects of the heatwaves on the zooplankton community in the form of increased abundance, particularly for smaller taxa with shorter reproductive cycles. The zooplankton community exposed to the herbicide terbuthylazine treatment was marginally different in community structure and abundance from the other treatments, likely due to indirect effects from changes in the phytoplankton community due to the action of the herbicide. However, the combination of the two stressors did not have a significant impact on the zooplankton community over the observed timescale of 3 weeks, despite inferred changes in the phytoplankton community abundance/composition. The observations were explained by the relative increase in the cyanobacterial abundance due to the selective inhibition of palatable phyotoplankton by the herbicide and stimulated cyanobacterial metabolism from the heatwave. Overall, these results highlight the challenges in disentangling the effects of combined stressors on freshwater biological communities and demonstrates the need to explore their mechanisms and long-term impacts.

Moving beyond the lab into field studies, Pander et al. investigated how thermal changes affect macroinvertebrate community compositions, comparing the responses of native vs. non-native gammarids (*Gammarus roeselii* and *Dikerogammarus villosus*) in three differentiated thermal regions within a single stream system. They used a standard Surber sampling in spring and summer with in-stream cross-exposure experiments (using Salmonid-egg floating boxes) over 71 days, during which a heatwave occurred and resolved. Macroinvertebrate species composition was highly dependent on temperature, with indigenous gammarids preferring colder sites and invasive species preferring warmer temperatures. Macroinvertebrates play a key role in regulating functional processes in streams and are an essential food source for higher trophic levels. Therefore, macroinvertebrate community changes may have consequences for food webs and ecosystem resilience. Moreover, increasing mean temperatures and increasing temperature fluctuations in streams can generate novel macroinvertebrates communities. Thus, Pander et al. highlight that the consideration of shifts in community composition, driven by temperature increase, needs to become integrated with assessment of biological response patterns related to morphological and flow degradation, chemical pollution, and fine sediment. Such an approach is crucial for the effective conservation and restoration of native biodiversity and for a realistic prediction of the ability to reach policy targets for aquatic ecosystems.

Increasing the ecological relevance using a river system and assessing plastic pollution, Van Emmerik et al. present a simple harmonization approach to estimate floating plastic item numbers and mass transport from data collected using different methods. They applied their approach to the Mekong-Tonlé/Sap-Bassac river system around the city of Phnom Penh, Cambodia. The authors estimated the floating plastic item count and mass transport in the wet and dry seasons by combining data from 1) net sampling (August and September 2019 during the wet season) and 2) visual counting (February and March 2022, during the dry season). Moreover, they also estimated the city's role as an entry point of plastic pollution into the Mekong delta. River plastic transport dynamics are highly variable over time and space, especially near confluences, bifurcations and urban areas. The mass balance suggests that during the wet season, more plastic enters the river system from Phnom Penh than during the dry season (Haberstroh et al., 2021). Likewise, in other urban areas connected to natural rivers, it has been found that during periods of increased rainfall and discharge, more plastic are mobilized and transported into rivers (Treilles et al., 2022; Tasseron et al., 2023), from soil run-off (agricultrual plastics), road run-off (debris from road markings, tyre-wear etc.) and potentially from storm drain overflows. These results show that combining the data collected during the wet and dry season confirms the strong seasonality of plastic transport. Thus, to better quantify and understand sources of riverine plastic, the seasonality of entry processes should be considered in future studies. Indeed, previous papers have shown that transport of plastic items can vary by two orders of magnitude during the year (van Calcar and van Emmerik, 2019; Schirinzi et al., 2020; Cesarini et al., 2023). Moreover, the results underscore the role of Phnom Penh as a potential major entry point of plastic pollution, especially during the wet season. Improved data Research Topic is key to better understanding and quantification of the plastic sources, sinks, and pathways to enable further harmonization and development of plastic pollution monitoring and mitigation strategies in aquatic systems.

Finally, Addo-Bediako explored the extent of metal (loids) pollution in the sediment at basin level, in the Lower Olifant River Basin in South Africa, using samples from four sampling campaigns undertaken during 2018-2019. Specifically, the contamination of As, Cr, Cu, Fe, Mn, Ni, Pb, and Zn in the sediments collected at the upstream, midstream and downstream of four rivers of the Lower Olifants River Basin (the Blyde, Mohalpitsi, Ga-Selati, and Steelpoort rivers) was assessed. Two pollution indices were used in this paper: the enrichment factor (EF) was used to evaluate the extent of trace metal (loid) contamination in the sediments (Zahra et al., 2014); and the geoaccumulation index (Igeo) matrix was used to assess aquatic toxicity in the sediments. The results showed that concentrations of Cr, Ni, and Mn in all the rivers, and As concentration in the Blyde River are of great concern, as they exceeded sediment quality guidelines (Canadian Environmental Quality Guidelines, 2002). Generally, the midstream and downstream sites were more polluted compared to the upstream sites of the rivers due to increasing human activities (i.e., mining, agricultural activities and domestic waste emmissions) in the midstream and downtream. Using EF and Igeo, some of the sediments were severely enriched and extremely contaminated with As, Cr, and Ni. Climate change is also likely to increase metal concentrations in sediments of rivers in semi-arid countries such as South Africa, where a prolonged dry season may increase the risk of flash flooding and pollutnat remonilisation and redistribution when rains arrive.

In this Research Topic, we have integrated contributions that highlight important aspects of the convergence of global climate change and anthropogenic pollution, such as 1) plastic and 2) metal pollution and 3) the loss of biodiversity, mainly derived by increased temperature and extreme hydrological events. The diversity and magnitude of pollutants, combined with the complexity of the global changes caused by the warming of the planet, presents a complex environmental management challenge. Moreover, the combination of pollution and global change will affect water quality and ecosystems services in freshwater ecosystems across spatial and temporal scales. Thus, quantifying their combined effects on aquatic ecosystems, as presented in the composite studies, is crucial to improve risk assessment and implement measures to alleviate the impacts of anthropogenic pollution and climate change, and to ensure environmental and human health in the long term. We expect that this important Research Topic will gain traction in the research and regulatory communities over the next years and propose to follow-up on this Research Topic in due course.

Author contributions

BB: Writing–original draft, Writing–review and editing. AC: Writing–review and editing. SK: Writing–review and editing. TH: Writing–review and editing. DM: Writing–review and editing. IL: Writing–review and editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

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