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OPINION

Observational gaps leave global assessment of riverine heatwaves lagging across inland waters

Sebastiano Piccolroaz[1*], **Senlin Zhu**[2]

1 Department of Civil, Environmental and Mechanical Engineering, University of Trento, Trento, Italy,
2 College of Hydraulic Science and Engineering, Yangzhou University, Yangzhou, China

* s.piccolroaz@unitn.it

Recent scientific evidence – often confirmed by our own experience – has identified riverine heatwaves as a growing threat to river systems under climate change. In their recent *Perspective*, van Hamel *et al.* [1] effectively synthesize the current state of knowledge on riverine heatwaves, while clearly outlining key research and practical needs to guide future scientific work, policymaking and management in this field. Here, we echo the authors' call to establish a strong international working community on river temperature, starting from a first, essential step: addressing the persistent scarcity and fragmentation of river water temperature observations at the global scale.

Continuous, long-term and high-frequency records of river water temperature are sparse, unevenly distributed and often difficult to access. These limitations have been noted in general for river observations, pointing to persistent structural gaps in current monitoring efforts [2]. This is critical for the study of extremes, which require relatively complete and long-term time series to robustly quantify the frequency, duration and severity of such events. As a result, existing studies of riverine heatwaves are necessarily limited to a small number of well-monitored regions (e.g., the USA [3,4]; Central Europe [5,6]), introducing a geographical bias that restricts our ability to assess how riverine heatwaves develop and evolve across a broader range of climatic and hydrological contexts.

This observational gap is far less evident for another inland-water environment that is strongly impacted by heatwaves, namely lakes. Over the past decade, coordinated international initiatives and satellite-based products have enabled near-global assessments of lake surface water temperature and lake heatwaves, substantially advancing our understanding of thermal extremes in these lentic systems [7,8]. Clearly, the spatial heterogeneity and limited width of rivers pose challenges for their remote sensing, contributing to their poor representation in global temperature datasets. But this is only one facet of a broader challenge, where the limited global harmonization and accessibility of long-term *in situ* river temperature observations represent the fundamental obstacle to large-scale analyses.

At the same time, global modelling frameworks have demonstrated the value of coordinated, multi-model approaches for assessing climate impacts on inland waters. Initiatives such as ISIMIP (Inter-Sectoral Impact Model Intercomparison Project) have

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enabled consistent global projections of hydrological and water-quality variables, providing a common basis for intercomparison and risk assessment [9]. However, river water temperature remains only partially represented in these frameworks – unlike for lakes – particularly owing to insufficient temporal and spatial resolution, constraining the representation of extremes. As a result, the robust representation of heatwaves and other extremes across the full inland-water domain remains challenging within current global modelling frameworks.

The challenge extends beyond temperature alone. The impacts of riverine heatwaves are often mediated or amplified by concurrent changes in other water quality variables, including dissolved oxygen, ecosystem metabolism and contaminant toxicity, with cascading ecological and socio-economic consequences, particularly during low-flow conditions. Yet high-frequency, long-term observations of these variables in rivers are even more limited than those of temperature, severely constraining the characterization of extreme compound events and leading to an underestimation of cumulative impacts.

In this context, there are also encouraging signs: recent data synthesis efforts such as the OLIGOTREND database provide an instructive example [10]. OLIGOTREND compiles multi-decadal in situ observations of temperature and key water quality variables across rivers, lakes and estuaries, demonstrating the feasibility and scientific value of harmonized, openly accessible inland-water datasets. Although not specifically designed to study thermal extremes, such initiatives illustrate how coordinated data collation can enable cross-system and cross-region analyses that remain impossible when observations are fragmented or inaccessible.

Along similar lines, recent work has pointed to key elements needed to advance coordinated river observation networks towards the establishment of a global River Observation System (RIOS), including standardization and long-term continuity [2]. We therefore advocate building on this (or similar) recent community effort to develop a global, openly accessible river water temperature database. By nesting future initiatives within ongoing discussions on global river observation and monitoring, we avoid reinventing structures and instead refine and extend ideas that have already gained international scientific traction, creating a more efficient pathway toward implementation while limiting redundancies and further fragmentation.

More broadly, and to conclude, research on aquatic heatwaves has progressed unevenly across system types. While riverine heatwaves are increasingly studied at local to regional scales, globally consistent assessments have advanced more rapidly for marine systems [11] and, more recently, for lakes [7,8]. This imbalance primarily reflects differences in observational coverage and data availability rather than a lack of conceptual development for rivers. Interestingly, however, despite the strong emphasis placed on advances in hydrological and environmental monitoring and digital water technologies in recent international priority-setting exercises led by the International Association for Hydro-Environment Engineering and Research [12], river water temperature and thermal extremes are not considered explicitly, suggesting that their relevance has yet to be fully recognized within broader global water agendas. This lack of explicit consideration is particularly relevant because rivers, lakes and estuaries form a connected inland-water continuum, thermal extremes may propagate, interact or compound across system boundaries. Developing a system-wide understanding of inland-water heatwaves therefore requires observational foundations that are comparable across system types – just in case focusing on a single inland-water environment did not already seem challenging enough.

We echo once again the call for the development of a centralized, openly accessible global database of river water temperature observations, ideally integrated with concurrent measurements of other water quality variables. This call is primarily addressed to the international river science community, funding agencies, and institutions responsible for hydrological monitoring, who are uniquely positioned to coordinate, support and sustain such an effort beyond individual projects or regions. We suggest that building on existing collaborative frameworks and looking at the experience of the lake research community could provide a useful pathway forward. After all, closing this observational gap would benefit the entire limnological community, broadly defined as those studying, managing and experiencing the full inland-water domain.

Author contributions

Conceptualization: Sebastiano Piccolroaz, Senlin Zhu.

Writing – original draft: Sebastiano Piccolroaz.

Writing – review & editing: Senlin Zhu.

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