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Cryosphere-fed rivers in a warming climate, 1950-2050

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Cryosphere-fed rivers drain glacier, snow, and permafrost landscapes and are characterized by glacial, nival, pluvial and mixed hydrological regimes. Such river systems originate from high-mountain areas and transport water, sediment, nutrients, and organic carbon downstream, underpinning the freshwater and coastal ecosystems and supporting the lives of more than one-third of the world's population.

In response to the amplified climate change, accelerating glacier-snow melt and permafrost thaw, the cryosphere-fed rivers are overall becoming warmer, wider and muddier associated with markedly increasing river turbidity and suspended sediment concentration. For instance, observational data from 28 headwater rivers in High Mountain Asia reveal that the river suspended sediment loads have been increasing at a rate of ~13% per decade since the 1950s, much faster than rate of increase of river water discharge (~5% per decade). Leveraging over 120 in-field observations and a sediment-climate elasticity model, we estimate that the present-day river suspended sediment load in High Mountain Asia is nearly two billion metric tons per year, and could more than double by 2050 under an extreme climate change scenario. Beyond High Mountain Asia, such warming-driven increases in river turbidity and suspended sediment concentrations have also widely featured in other cryospheric basins such as the Arctic, European mountains, and Andes.

The muddier rivers carry pollutants, nutrients, and organic carbon, thus affecting water quality and aquatic ecosystems in the cold regions and beyond. Increases in sediment-driven river turbidity can threaten river biotic conditions by blocking sunlight from reaching the streambed,

limiting respiration, and deteriorating feeding conditions of benthic macroinvertebrates and fishes, thereby affecting habitat availability. Elevated turbidity can disturb habitats of macroinvertebrates and fishes by filling interstitial spaces between pebble and cobbles on the riverbed, thereby reducing the flow of oxygenated water through bed sediment that is essential to the survival of their eggs. The increased sediment supply especially the coarse sediment further magnifies river channel instability and migration, affecting fish habitats and carbon storage and release.

To better assess the impacts of changing climate on the functions and services of river ecosystems in strategically important cold regions, we highlight the pressing need to integrate multiple-sourced river observations, to develop empirical, physics-based, and AI-based river flux models, and to promote interdisciplinary scientific collaboration. The innovative system approach would best come from the creation of an interdisciplinary collaborative initiative, where climatologists, ecologists, glaciologists, permafrost scientists, hydrologists, civil engineers, and geomorphologists work together to establish an integrated cryosphere–water–sediment–carbon-ecology observation platform that facilitates the mechanism understanding and development of novel and powerful models. Furthermore, dialogues and collaboration between international scientists, stakeholders, local communities, and policymakers would help to bridge the gaps between state-of-the-art scientific findings and practicable adaptation strategies.