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Attributing rapid hydrologic change in a data-scarce and strategic transboundary catchment

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The transboundary Indus river provides critical water supply to India and especially Pakistan, where agriculture consumes 60% of Indus streamflow to irrigate 80% of agriculture in Pakistan. The majority of flow in the basin originates from six headwater streams in India in the Himalayan region, where climate change and anthropogenic actions have altered hydrological processes in the region and led to concerns of declining river flow. The situation is common in arid and semiarid regions, and innovative approaches are needed to understand the drivers of hydrological change and promote sustainable water resources, especially in regions with limited data availability.

We focus on the the upper Jhelum river, a tributary to the Indus that is located in the Kashmir Valley in India. Digitized written records of streamflow from five gages along the river show a sudden, substantial (44%) and persistent decrease in annual water volume flowing out of the catchment and toward Pakistan over the last two decades. Lack of in-situ observational data, due in part to long-standing political instability in the region, forces us to exclusively rely on remote sensing data. Our analysis indicates that, while increasing temperatures, decreasing precipitation and slowing glacier melt (due to glacier recession) caused a shift in seasonal flow regimes and decreased annual flows, these effects are insufficient to account for the full extent of the observed streamflow decline. Using remote-sensing of lakes and wetlands on the valley bottom, we find strong hysteresis between surface water storage and downstream discharge. This suggests that subsurface processes play a critical role in the drainage and replenishment of these water bodies, which appear to drive downstream river discharge. The dramatic reduction in the extent of these water bodies across seasons after 2000 indicates that groundwater decline has likely played a significant role in streamflow reductions. This hypothesis is confirmed by a hydrological bucket model that reproduces the hysteresis behavior and evidence from the digitized streamflow of a transition from a gaining to losing stream along the reach that is connected to the wetlands.

This study illustrates fundamental challenges and opportunities in using remote sensing to attribute rapid hydrologic change where in-situ data is unavailable. Changes that occurred far enough into the past to allow their persistence and significance to be established typically do not allow modern remote sensing products to be leveraged to identify their drivers. Here remote-sensing observations of the extent of surface water bodies, and their relation to streamflow, allowed changes in subsurface water storage to be inferred without resorting to modern gravitational or soil moisture products.