



Economic losses from changing hydrology under future climate change, glacier shrinkage and growing water demand in the Tropical Andes

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In the Tropical Andes, glaciers play a fundamental role for sustaining human livelihoods and ecosystems in headwater areas and further downstream. However, current rates of glacier shrinkage driven by climate change as well as increasing water demand levels bear a threat to long-term water supply. While a growing number of research has covered impacts of climate change and glacier shrinkage on the terrestrial water cycle and potential disaster risks, the associated potential economic losses have barely been assessed.

Here we present an integrated surface-groundwater assessment model for multiple water sectors under current conditions (1981-2016) and future scenarios (2050) of glacier shrinkage and growing water demand. As a case, the lumped model has been applied to the Santa river basin (including the Cordillera Blanca, Andes of Peru) within three subcatchments and considers effects from evapotranspiration, environmental flows and backflows of water use. Therefore, coupled greenhouse gas concentration (RCP2.6 and RCP8.5) and socioeconomic scenarios are used, which provide a broad range of the magnitude of glacier and water volume changes and associated economic impacts. Finally, net water volume released on the long term due to deglaciation effects is quantified and by multiple metrics converted into potential economic costs and losses for the agriculture, household and hydropower sectors. Additionally, the potential damages from outburst floods from current and future lakes have been included. Results for the entire Santa river basin show that water availability would diminish by about 11-16% ($57\text{-}78 \cdot 10^6 \text{ m}^3$) in the dry season (June-August) and by some 7-10% ($103\text{-}155 \cdot 10^6 \text{ m}^3$) during the wet season (December-February) under selected glacier shrinkage scenarios until 2050. This is a consequence of diminishing glacier contribution to streamflow which until 2050 would reduce from about 45% to 33% for June-August and from 6% to 4% for December-February. A first rough estimate suggests associated economic losses for main water demand sectors (agriculture, hydropower, drinking water) on the order of about $300 \cdot 10^6 \text{ USD/year}$ by 2050. Additionally, with ongoing glacier shrinkage and the formation of new lakes, about 45,000 inhabitants and 30,000 buildings are expected to be exposed to the risk of outburst floods in the 21st century.

The pressure on water resources and interconnected socio-environmental systems in the basin is already challenging and expected to further exacerbate within the next decades. Currently, water demand levels are considerably increasing driven by growing irrigated (export) agriculture, population and energy demand which is in a large part sustained by hydropower. A coupling of potential water scarcity driven by climate change with a lack of water governance and high human vulnerabilities, bears strong conflict potentials with negative feedbacks for socio-economic development in the Santa basin and beyond. In this context, our coupled hydro-glacial economic impact model provides important support for future decision-making and long-term water management planning. However, uncertainties are relatively high (uncertainty range to be estimated) due to a lack of (good) hydro-climatic and socio-economic information at appropriate spatiotemporal scales. The presented model framework is potentially transferable to other high mountain catchments in the Tropical Andean region and beyond.