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An integrative water balance model framework for a changing glaciated catchment in the Andes of Peru

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In the Santa River catchment [SRC] (Cordillera Blanca, Andes of Peru), human livelihoods strongly depend on year-round streamflow from glaciers and reservoirs, particularly in the dry season and in adjacent arid lowlands. Perennial glacial streamflow represents a buffer to water shortages, annual discharge variability and river contamination levels. However, climate change impacts, consecutive glacier shrinkage as well as new irrigated agriculture and hydropower schemes, population growth and thus water allocation might increase water scarcity in several areas of the SRC. This situation exerts further pressure and conflict potential over water resources and stresses the need to analyze both water supply and demand trends in a multidisciplinary and interlinked manner.

In this context, an integrative glacio-hydrological framework was developed based on the Glacier and Snow Melt (GSM) and SOil CONTribution (SOCONT) models using the semi-distributed free software RS MINERVE. This water balance model incorporates hydroclimatic, socioeconomic and hydraulic objects and data at daily scale (with several gaps) for the last 50 years (1965-2015). A particular challenge in this context represents the poor data availability both in quantity and quality. Therefore, the hydroclimatic dataset to be used had to be carefully selected and data gaps were filled applying a statistical copula-based approach. The socioeconomic dataset of water demand was elaborated using several assumptions based on further census information and experiences from other projects in the region. Reservoirs and hydropower models were linked with additional hydraulic data. In order to increase model performance within a complex topography of the 11660 km^2 SRC, the area was divided into 22 glaciated (GSM) and 42 non-glaciated (SOCONT) subcatchment models. Additionally, 382 elevation bands at 300 m interval were created and grouped into 22 different calibration zones for the whole SRC. The model was calibrated using the Kling-Gupta efficiency indicator and the Coupled Latin Hypercube with Rosenbrock optimization algorithm.

A first simulation run suggests increasing water scarcity particularly in the middle and lower catchment where population and agricultural growth are increasingly competing with less continuous river streamflow. On the one hand, relative glacier contribution to river discharge which is highest in the upper catchment is diminishing on the long term with ongoing glacier shrinkage. On the other hand, water demand from hydropower schemes and population centers in the middle catchment and water withdrawals from irrigation schemes (e. g. Chavimochic, Chinecas) further downstream are increasing.

The developed hydrological model framework represents a progress in integrative modeling at daily time step. Furthermore, it provides a useful tool for water management and thus future adaptation and risk reduction. Local stakeholders and decision makers increasingly have to put into practice Integrated Water Resources Management plans in the context of Peru's institutional transformation process. Nonetheless, institutional obstacles persist and high uncertainty partially limits the results due to data inconsistencies and a complex interplay of multiple drivers of change within a steep topography and diverse climatic setting. Therefore, future research must deal with data scarcity, uncertainty and foster water management and adaptation plans in close collaboration with science, society and policy.