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Editorial: Hydrosphere-cryosphere interactions in the Himalayas under climate change

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Editorial on the Research Topic
Hydrosphere-cryosphere interactions in the Himalayas under climate change

Himalayan cryosphere, aptly known as "Third Pole" comprises voluminous quantity of ice and snow cover, large glaciers, and permafrost areas. It is a major and fresh source of water flow of regional and transboundary river systems (e.g., Indus, Ganges, and Brahmaputra) and groundwater in these catchments and regulates the hydro-bio-geo-chemical processes (Mir et al., 2018; Immerzeel et al., 2020). This ice resource is essential to human society and economic development of the region. However, the Himalayan cryosphere and its interactions with the hydrosphere are severely impacted by the rapid human-induced and natural climatic changes from small scale to large scale. Such changes are recognized by certain indicators like a loss of net ice-mass, reduced snow-cover extent, and observable fluctuations in river-flow patterns. These changes could significantly impact the regional water resources and affect the economic and food security of more than 1.4 billion humans and their livelihoods in this sector (Mir et al., 2017; Azam et al., 2021). Several natural disasters are directly or indirectly related with this interactive hydro-cryosphere that has resulted in severe catastrophes in the Himalaya during recent years (e.g., Shugar et al., 2021). Several such hazardous disasters like glacial lake outburst floods (GLOFs), avalanches, landslides and catastrophic floods etc. have been noticed in this fragile mountain system frequently. Moreover, the recent climatic variability supplemented with wide anthropogenic interventions have caused over-exploitation, contamination, and degradation of essential bio-geo-resources that are detrimental to the future water availability, food supply, energy production, tourism and cultural landscape development, economic balance, securable environment, and human health in the region. Thus, it is essential to understand the intricate hydro-cryosphere dynamics and the association it shears with other sub-systems in the Himalayas to plan long-term adaptive and management approaches in terms of climate change, water and food security, and coupled disasters for a sustainable future of the region. For this, a careful and comprehensive assessment is needed to understand the climatic and hydrologic response, disaster initiation, land management, and social fabric etc. Nevertheless, the human-driven climate change has the potential to alter the regional characteristics of a climate hazard by changing its magnitude, intensity, frequency, occurrence timing and duration, as well as spatial extent. Therefore, the adaptive measures shall also promote climate services with a provision of climate information to assist decision-making and appropriate engagement from users and providers based on scientifically credible information and expertise (Zhongming et al., 2021). Additionally, it shall promote climate risk information to allow decision makers to better tailor adaptation, mitigation and risk management strategies (Hewitt et al., 2012).

The present Research Topic (RT) was based on the objective to improve the understanding in these directions so that the readers could make an assessment on how the ice and glaciers influence the water resources, regulate the hydrogeological, biological, and chemical processes, and emphasize the factors like the natural and human-induced changes, disasters, and other risks that degrade these vital resources across the Himalaya. With the goal, papers on multiple topics were received and only five research papers, after thorough review, were included in this collection that focused on five aspects like to (a) understand the relationship between past glaciations and fluvial systems, (b) model the glacier mass balance–energy flows, (c) understand the spatio-temporal variations of snow cover extent, (d) impress upon the challenges that obstruct the research of the cryospheric processes and its influence on water resources of the region, and (e) understand the transferability and usability of parameters between different snowmelt and runoff/discharge models in the Himalayan basins. The articles essay a spectrum of processes in Himalayan hydro-cryosphere and its impacts and discussed various approaches to report them. All the topics are relevant to understand the dynamics of Himalayan hydro-cryosphere from past to recent times and cover interestingly typical issues in the research, development, and policy making domains. The papers are briefly summarized below.

The first paper by Dar et al., investigates the response of riverine system to cryospheric melting from late quaternary time period using glacio-fluvial landforms, tectonic indicators, and satellite data. The authors have selected the Rambiara stream (major tributary of the Upper Jhelum Basin) located in the NW Himalaya, for this investigation. The fluctuating climate causes an imbalance of the Himalayan mountain glaciers that modulates the geomorphic configuration and the upliftment of the mountain ranges. The wide fluvial-glacial landforms of the Rambiara basin indicated the erosion capacity of previous glaciers in the area. These glaciers have been ∼200 m in thickness and spread to >10 km down slope from the preserved cirque marks of today since Last Glacial Maximum (LGM). The rock-glaciers are more than the clean-glaciers and the glacial lakes are prominently developed in the higher elevations whereas in downstream areas, the prominent features are wide drainage channels, irregular sinuosity, braided stream flow, and unpaired slope terraces. After the LGM episode, the glaciers declined that lead to a significant decrease of river discharge. The current trends of climate warming in the region have considerably reduced the glaciers in the area. These and similar studies carried out for other catchments would generate information that could help to model the historical glaciations and subsequent climate fluctuations and human interferences.

The second paper by Srivastava and Azam focuses on modeling the glacier mass-energy-balance in the Himalayas. The simulation of the annual glacier-wide mass balance (B_a) was generated using the bias-removed ERA5 time series data of 1979 to 2020. For this study, two benchmark glaciers have been investigated; Dokriani Bamak Glacier, DBG located in central Himalaya and Chhota Shigri Glacier, CSG, of NW Himalaya. The model calibration and validation was performed using *in-situ* geodetic altitudinal mass-balance data. The mean B_a reported here of DBG and CSG are −0.27 and −0.31 mw.e.a^{-1}. These results provide an insight on how the regional disparities in glacier mass-wastage govern the surface energy balance fluxes. Similar studies based on sublimation and T-index models are recommended to understand the glacier–climate interactions and mass balance reconstructions in other glaciated river basins of the Himalayan region as well as other regions of the world.

The third article by Khali et al., investigated the spatio-temporal changes in snow cover extent in response to current climate change and its disparity. The snow cover extent generally affects the glacier nourishment and impacts the melting dynamics. However, the meteorological data is scarcely available commonly in the mountain regions. Therefore, the utilization of remote sensing data has become very crucial to understand the snow cover dynamics. Using the freely available Moderate Resolution Imaging Spectro-radiometer (MODIS) 8-day snow cover dataset (MOD10A2), the spatiotemporal variability and trends in snow cover extent have been investigated during 2001 to 2021 in Zanskar valley of NW Himalaya. The average annual snow cover extent is 68%, with a maximum extent in the month of March (96%) and minimum extents in August (32%). The results indicate that the snow cover proportion has not decreased to any significant level during the last 20 years. No change in snow cover percentage was found below an altitude of 3,500 m asl but changes occurred mainly between an altitude of ∼4,500 and 5,500 m asl. The results were validated against the data from Climatic Research Unit's (CRU). These findings encourage similar studies using long-term time series snow cover extent data to better understand its influence on hydrological and climatic processes in the Himalayas.

The fourth paper by Vishwakarma et al., reviewed the role of different methodologies, current status of knowledge on different dimensions of glaciers, snow cover extent, permafrost, and future directions for assessing hydro-cryospheric dynamics based on different methodological approaches and modeling. Climate change and rapidly increasing human disturbances like, land use land cover change, abstraction of groundwater, and alteration of hydrology through reservoir or dam construction have significantly impacted the water availability in the area. Moreover, a lack of *in-situ* time series measurements, complexity of hydro-climatic and limited collaboration create knowledge gaps in understanding the hydro-cryosphere dynamics. The work is an outcome of the workshop "*Water sEcurity assessment in rIvers – oriGinating from Himalaya* (WEIGH)," during which intense discussions and deliberations attempted to synthesize the current understanding of the topic and highlight the essential research breaks and the preferences required for studying water availability and accessibility in the area. The recommendations provide very interesting and comprehensive documentation toward ensemble scientific studies required to capture real time estimates and assessment of hydro-cryospheric components and management of emerging impacts and issues.

The fifth paper by Vinze and Azam, is a case study on snowmelt runoff and discharge modeling in the Chandra-Bhaga Basin, NW Himalaya wherein a practical explanation about the snowmelt runoff modeling and the constrains in transferability of its parameters were discussed. The snowmelt runoff has an important role in the glacierized and snow-covered basins. Therefore, to quantify its contribution, modeling is the most helpful tool. But, the scarcity of ground observations makes the model calibration very difficult task. The study investigated and applied the Snowmelt Runoff Model (SRM) in reference to Chhota Shigri Glacier catchment and the Chandra-Bhaga Basin, NW Himalaya to understand the transferability of model parameters. Three model parameters [temperature, lapse rate, and recession coefficients (x and y)] among the nine model parameters were constrained. Subsequently, the model was validated and calibrated against the observed discharge data. The daily discharge was simulated over 2003-2018 for the study basins using snow cover area (SCA), precipitation, and temperature as inputs. The decadal comparison showed an increase and early onset of maximum monthly discharge over 2011-2018 compared to 2003-2010 in the area. The reconstructed discharge is mainly controlled by summer temperature and summer SCA and summer precipitation. The model output is almost equally sensitive to the degree day factor and runoff coefficient for snow. The study concluded that the application of SRM parameters is not transferable in the same basin depending upon the scale. Thus, the observations and recommendations highlighted that an extreme care is required to be taken while using SRM parameters from other basins in the Himalayan and other mountainous regions of the world.

In general, the papers presented in this issue highlight the need to consider comprehensive scientific, environment, and society oriented research in future studies to develop robust projections of climate change, its effects and future consequence of declining nature, dynamics, and evolution of hydro-cryosphere and to design sustainable adaptation measures. But, specifically, the papers attempted to answer certain essential science questions that are very critical for understanding the Himalayan hydro-cryospheric dynamics under past, present, and future scenarios. The RT discussed elaborately the linkage between the cryospheric changes and subsequent landform evolution and development and its influence on the river morphology, hydrology, and reduction in glacier cover. An understanding of surface energy mass balance of glacier resources, analysis of snow cover extent, its relation with the ongoing climatic variability, snow melt runoff modeling and overall, it's possible impacts and implications on the hydrology of the Himalayan river catchments has been documented very precisely. The RT included an essential and detailed account on the knowledge gaps, data scarcity, uncertainties of methods in studying the hydro-cryospheric resources of the Himalayan region and provided elaborately, necessary recommendations to improve these issues and future studies in the region. Basically, the individual papers compiled will provide a baseline dataset in this direction and in better understanding the dynamic behavior of Himalayan hydro-cryosphere and its governing processes. The collection will provide critical future research directions for hydro-cryospheric monitoring vis a vis disaster risk reduction efforts for its sustainable development and management in the region. More comprehensive research is required to cover other aspects such as atmospheric pollutants. These atmospheric impurities reduce the surface albedo and increase the temperature from net shortwave radiation absorption and promoting faster ice melting. We believe that understanding the role of atmospheric pollutants and their effects on climate and hydro-cryospheric systems is still a challenge in climate and cryospheric studies in the region.

We are persuaded that the research articles under this topic have presented recent findings in the field of hydro-cryosphere at local to regional scale. This will improve the understanding of the hydro-cryosphere interactions under changing climate, which is important to frame sustainable strategies for effective climate change and water resources management and to solve broad spectrum of water-related and environmental issues in trans-boundary catchments in near and far future in the Himalayan region.

Author contributions

RM wrote the first draft of the manuscript. FD and KG revised it. All authors made a direct and substantial contribution to the manuscript and approved the final version for publication.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

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