

Phase Change from Snowfall to Rainfall in the Nepal Himalaya: Observed Shifts, Hydrological Impacts and Implications for Monsoon-driven Mega-geo-disasters

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Abstract: Climate change is altering precipitation regimes across monsoon-influenced mountain regions, shifting precipitation phase from snowfall to rainfall and modifying runoff timing and extremes. Such phase changes amplify risks of flash floods, landslides, and other mega-geo-disasters during intense monsoon events by removing the buffering effect of snow and increasing instantaneous runoff.

This study, part of the APN Project CRRP2024-06MY-Pradhananga (APN 2025), “Enhancing Climate Resilience in South Asia and China: Predicting Precipitation Shifts and Their Impacts for Disaster Risk Reduction and Resource Security”, employs an interdisciplinary and participatory approach to analyze precipitation shifts and their implications. By integrating high-resolution climate data, remote sensing, modeling, and stakeholder engagement, we assess spatiotemporal precipitation trends and phase transitions across Bangladesh, Bhutan, China, India, Nepal, and Pakistan. The project fosters regional collaboration, enhances scientific capacity through training programs, and co-develops community-driven solutions to mitigate climate-related risks. The co-creation framework ensures that scientific insights translate into actionable strategies for policymakers, disaster managers, and local communities.

Special emphasis is also placed on expanding high-elevation climate and cryosphere monitoring through HIMDATA – High-Altitude Monasteries for Data Acquisition, Tracking and Awareness (Pradhananga et al., 2025) to fill critical data gaps in the high-altitude environments of the Himalayan region (Figure 1). These monastery- and school-based high-altitude observatories will provide rare insights into snowfall–rainfall transitions, precipitation gradient, temperature lapse rates, and extreme precipitation patterns. The Asian Monsoon Climate Change Adaptation Network (Terao et al., 2025) will support HIMDATA and the APN project through data harmonization, shared protocols,

capacity development, and integration into regional hazard early-warning frameworks.

Case studies include Jumla (western Nepal) and Mustang (trans-Himalayan zone), where local reports and observational trends indicate notable declines in snowfall and earlier snowmelt. Jumla shows a statistically significant increase in precipitation (trend $\approx +5.19$ mm yr⁻¹, $p < 0.01$) with concurrent, though less statistically robust, decreases in measured snowfall. Remote sensing (Landsat) indicates Nepal Himalayan snow/ice area reduction from $\sim 26,800$ km² (1990) to $\sim 16,300$ km² (2018), underscoring long-term cryospheric decline. The study uses a physically based psychrometric energy-balance model (Harder and Pomeroy, 2013) included in the Cold Region Hydrological Modelling platform (Pradhananga and Pomeroy, 2022) to partition precipitation into rainfall and snowfall.

Preliminary findings reveal increasing monsoon variability, heightened extreme precipitation in previously arid zones, and a concerning shift from snowfall to rainfall in mountain regions, reducing seasonal snow storage and weakening hydrological buffering. These insights underscore the urgency of adaptive water management strategies and enhanced early warning systems.

This merged, multidisciplinary evidence, combining model outputs, satellite products, in-situ observation trends, and participatory data, provides actionable insights for policymakers and practitioners in the Asian monsoon region to reduce the risk of monsoon-driven mega-geo-disasters in a warming climate. Recommendations include improved cryosphere monitoring, cross-border data sharing, community-engaged adaptation planning, and integration of precipitation phase information into disaster risk models.

Keywords: *Climate resilience, Precipitation phase shift, Snow-to-rain, Himalaya, Monsoon, Hydrological risk, Co-creation, AMCLAN.*

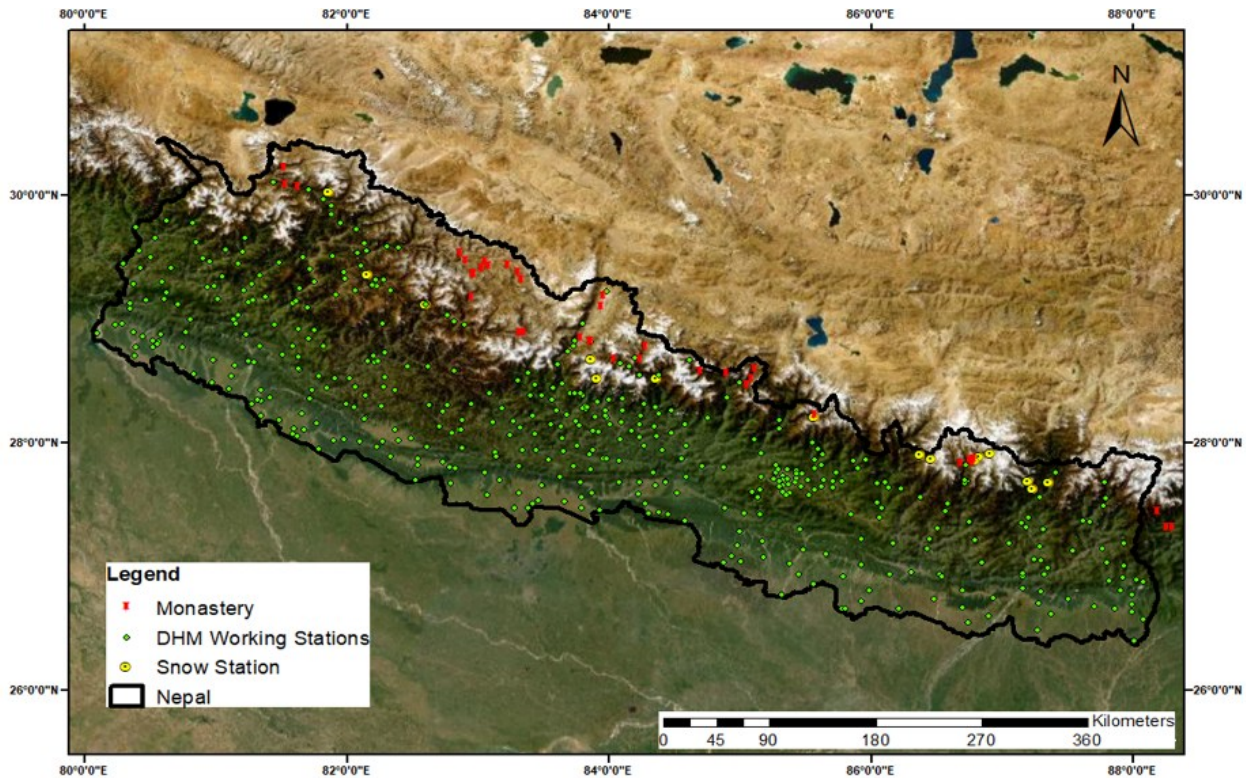


Figure 1, Monasteries (and Schools) as Potential Site for High-Altitude Meteorological Stations.

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References

Asia-Pacific Network for Global Change Research. (2025). Enhancing climate resilience in South Asia and China: Predicting precipitation shifts and their impacts for disaster risk reduction and resource security (Project CRRP2024-06MY-Pradhananga). Available at: <https://www.apn-gcr.org/project/enhancing-climate-resilience-in-south-asia-predicting-precipitation-shifts-and-their-impacts-for-disaster-risk-reduction-and-resource-security/>

Harder, P., and Pomeroy, J. (2013). Estimating precipitation phase using a psychrometric energy balance method. *Hydrological Processes*, 27(13), 1901–1914. <https://doi.org/10.1002/hyp.9799>

Pradhananga, D., and Pomeroy, J. W. (2022). Diagnosing changes in glacier hydrology from physical principles using a hydrological model with snow redistribution, sublimation, firnification and energy balance ablation algorithms. *Journal of Hydrology*, 608, 127545. <https://doi.org/10.1016/j.jhydrol.2022.127545>

<https://doi.org/10.1016/j.jhydrol.2022.127545>

Pradhananga, D., Smith, J., Crowe, M., Bharati, L., Aryal, K., Kayastha, D., and Manandhar, S. (2025). Filling critical data gaps in high-altitude environments of the Himalayan region. *The Small Earth Nepal*; Tribhuvan University; ICWRGC.

Terao, T., Dutta, S., Hossain, A. T. M. S., and Pradhananga, D. (2025). Agenda for establishment of the Asian Monsoon Climate Adaptation Network (AMCLAN). International Consortium for Earth and Development Sciences (ICEDS), Kagawa University. AAEH 2025 Conference Document, 30 September 2025. Available at:

<https://www.icedes.net/aaeh/aaeh2025/>