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Seasonal Precipitation Modeling for Glacial-Fed Indus Basin of Pakistan under Projected Climate Using Contemporary Statistical Downscaling Framework

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The transboundary Indus River Basin System is the twelfth largest river basin in the world and covers nearly 54 % of the area of Southeast Asian region (1.12 million km2). The river system originates from the Tibetan Plateau and traverses about 3200 km to descend into the Arabian Sea in Southern Pakistan. The Upper Indus Basin (UIB) has seven of the world's highest peaks after Mount Everest and contains the second largest perennial ice reserves (22000 km2) after Poles and Greenland regions. However, the extent of winter snow cover is even 10 times of this permafrost area. The climate across the basin is highly variable from subtropical arid and semi-arid to temperate sub-humid in alluvial plains, to alpine in the mountainous highlands of the north. Annual precipitation ranges between 100 and 500 mm in the lowlands to a maximum of 2000 mm on high mountains. The Western Disturbances and Indian Summer Monsoon are the main sources of precipitation across the Basin. The Monsoon incursions into the Upper Indus Basin (UIB) are limited by the Himalayans and they mainly produce precipitation in the southern foothills.With respect to river discharges glacial and snow melt primarily control the hydrological regime of the Indus river system.

Considering the high vulnerability of the Indus Basin under projected climate change and due to its millions of inhabitants relying on the Indus water resources, the present study assesses precipitation using updated datasets (including high altitude stations of UIB) and statistical downscaling approaches. The statistical projections on regional to local scales are done to provide a scientific basis for localized adaptions across the basin, particularly in a water management context.

A total of 58 meteorological stations were selected across the Basin, of which 42 stations were located only in the UIB, in order to account for topographic complexity and importance for water supply. Based upon monthly precipitation analysis, three seasons i.e. pre-monsoon (Apr-Jun), monsoon (Jul-Sept) and winter (Dec-Mar) were identified. Considering the high temporal and spatial climatic variability precipitation regionalization was carried out using K-Means Cluster Analysis. The regional representative stations were selected by considering correlation coefficients with the regional mean, data quality, and completeness and time series length. ERA-Interim reanalysis was selected as predictor data to identify atmospheric circulation governing precipitation variations. S-Mode PCA was carried out to identify important centers of variation for the selected atmospheric variables over appropriate domains.

Precipitation in the observational period for all seasons was modeled using GLM framework with Gamma and Tweedie distributions. Model development was done within a cross validation framework using root mean squared error (RMSE) as criterion. Robust and stable model selection was made through maximizing the root mean squared error skill scores (RMSESS) in calibration and validation. The final models demonstrated significant skills for all seasons across the Basin including the complicated UIB. The output from General Circulation Models was taken as new predictors in the statistical models in order to assess possible future changes of precipitation during the 21st century.