Summary

Millions of people rely on river water originating from snow- and ice-melt from basins in the Hindukush-Karakoram-Himalayas (HKH). One such basin is the Upper Indus Basin (UIB), where the snow- and ice-melt contribution can be more than 80%. Being the origin of some of the world's largest alpine glaciers, this basin could be highly susceptible to global warming and climate change. Precise predictions of future water availability for resource planning under a changing climate depends on significantly improved hydrological modelling, and is vital for the food and energy needs of downstream population. However, hydrological modelling has not received due attention in the HKH region. This study critically assesses available hydro-climatic data, and identifies five major drawbacks in the published hydro-climatic studies reviewed, even these appearing in well-reputed international journals. The main weaknesses in these studies are: i) use of over-estimated basin areas; ii) use of under-estimated precipitation data; iii) use of incorrectly-defined glacier boundaries; iv) use of under-estimated snow-cover data; and v) use of biased melt factors for snow and ice during the summer months. These inputs have either produced under-estimated modelled flows, implying severe water scarcity in the region, or have over-estimated modelled flows by over-estimating glacier melt contributions to total flows, although the proportions vary in different sub-basins of the UIB. These forecasts cannot therefore be used in policy making or to inform water resource development.

This study, therefore: provides the best estimates of basin area for the UIB; identifies the best available gridded data out of twelve datasets analyzed, and provides a precipitation distribution that can be used for future improved hydrological modelling and bias correction of other precipitation datasets; evaluates various causes of incorrect definition of glacier boundary, and identifies the best available glacier datasets; indicates sources of bias in raw MODIS snow-cover data and provides remedial measures for these; provides spatial-altitudinal variation of weighted melt rates in various sub-basins; together with developing and improved reference hydrological model based on the best available datasets and precise calibration. This study then evaluates the sensitivity of output predictions to different input datasets and calibration parameters, using the reference temperature-based hydrological model. An over-estimation of modelled flows has been noticed wherever an icorrect basin has been used which exaggerates the basin area, while under-estimated precipitation produces significant under-estimation in modelled flows in various sub-basins of the UIB. Modelled flows of sub-basins in the Karakoram region are found to be more sensitive to snow-cover

and melt-rates, compared to sub-basins in the Himalayas and Hindukush regions, where precipitation is the main source of variability in modelled flows. The current research also provides estimates of flow components, based on improved hydrological modelling, hydrograph separation and constant ablation gradient methods. This results in significantly improved understanding of the UIB hydro-climatology. The research will therefore provide assistance for future water resource forecasting, policy making and sustainable water resource development, together with the strong recommendation to avoid use of over-estimated basin areas, under-estimated precipitation data, incorrect definition of glacier boundaries, biased snow-cover data and biased calibration parameters in future hydrological modelling in the study area. This study also suggests the need for critical analysis of other datasets for the HKH region not included in the research reported here and for further analysis of existing hydrological modelling studies and their improvement in other regions of the world. The methods developed in this research are robust, and can be adopted in other regions of the world, especially with similar hydro-climatology.