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Snow cover trend and hydrological characteristics of the Astore River basin (Western Himalayas) and its comparison to the Hunza basin (Karakoram region)

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HIGHLIGHTS

- Constant trend in snow cover area in Astore basin during last decade.
- Increasing trend of river discharge during last 34-years in the Astore River basin.
- Increasing winter precipitation and decreasing summer temperature at Astore.

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ABSTRACT

A large proportion of Pakistan's irrigation water supply is taken from the Upper Indus River Basin (UIB) in the Himalaya–Karakoram–Hindukush range. More than half of the annual flow in the UIB is contributed by five of its snow and glacier-fed sub-basins including the Astore (Western Himalaya — south latitude of the UIB) and Hunza (Central Karakoram — north latitude of the UIB) River basins. Studying the snow cover, its spatio-temporal change and the hydrological response of these sub-basins is important so as to better manage water resources. This paper compares new data from the Astore River basin (mean catchment elevation, 4100 m above sea level; m asl afterwards), obtained using MODIS satellite snow cover images, with data from a previously-studied high-altitude basin, the Hunza (mean catchment elevation, 4650 m asl). The hydrological regime of this sub-catchment was analyzed using the hydrological and climate data available at different altitudes from the basin area. The results suggest that the UIB is a region undergoing a stable or slightly increasing trend of snow cover in the southern (Western Himalayas) and northern (Central Karakoram) parts. Discharge from the UIB is a combination of snow and glacier melt with rainfall-runoff at southern part, but snow and glacier melt are dominant at the northern part of the catchment. Similar snow cover trends (stable or slightly increasing) but different river flow trends (increasing in Astore and decreasing in Hunza) suggest a sub-catchment level study of the UIB to understand thoroughly its hydrological behavior for better flood forecasting and water resources management.

1. Introduction and background

The agriculture-based economy of Pakistan is dependent on irrigation waters supplied by the Indus River and its tributaries (SIHP, 1990). Most of the flow abstracted from the Indus River at Tarbela (Fig. 1a) is contributed by snow and glacier melt (Bookhagen and Burbank, 2010; Immerzeel et al., 2012, 2013) of the Karakoram, Himalaya and Hindukush mountains. The Indus catchment area

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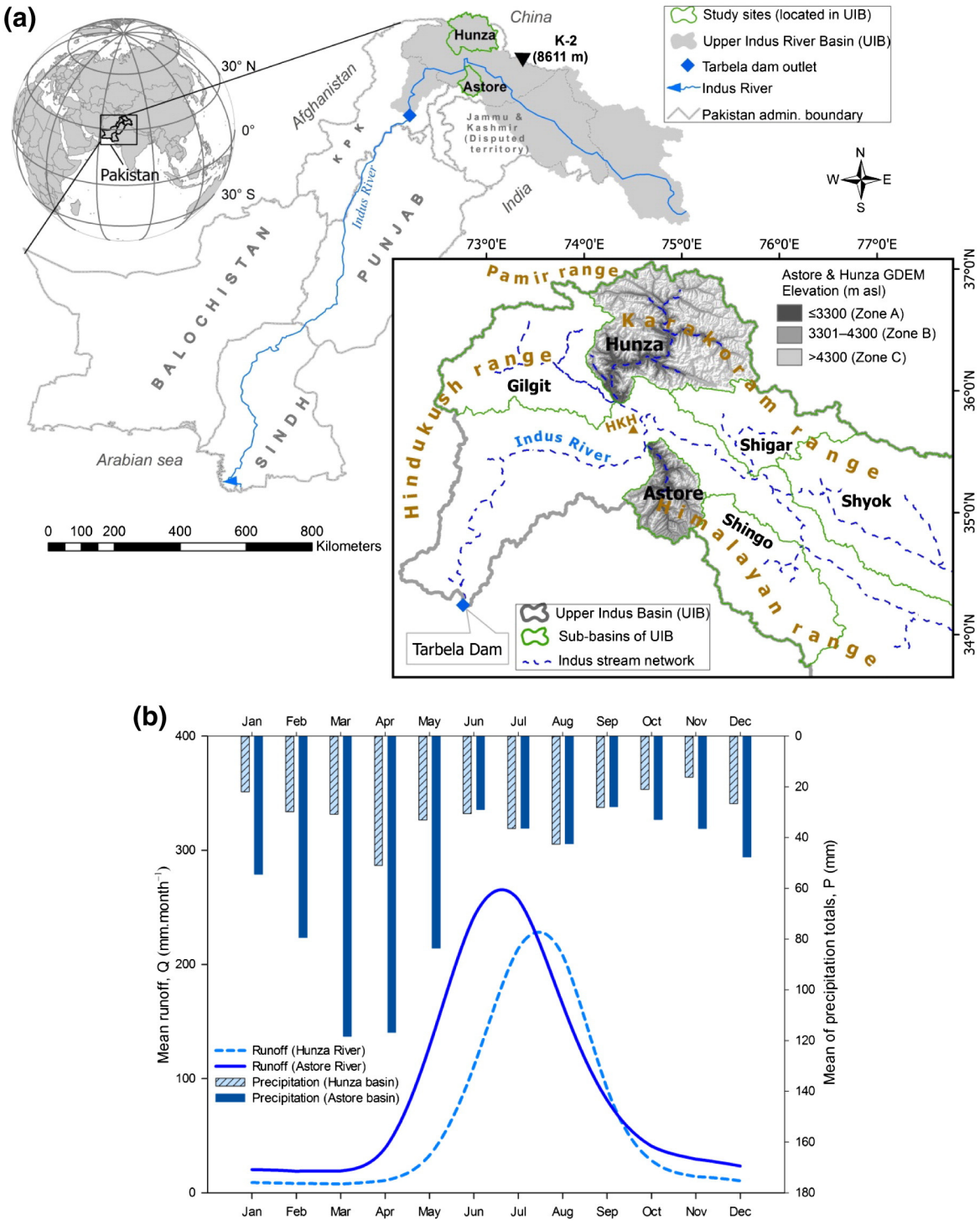

Fig. 1. (a) Map of Pakistan including the Upper Indus River Basin (UIB) area, its sub-basins, Tarbela dam and study sites (Astore and Hunza sub-basins with their Global Digital Elevation Models GDEM) and (b) mean monthly recorded precipitation totals (1974–2010) and mean monthly runoff (1974–2008) of both study sites. Precipitation records are the average totals of all three climate stations (Astore, Rama and Rattu CS for Astore basin; Khunjerab, Naltar and Ziarat CS for Hunza basin) situated in the both catchments.

upstream of Tarbela, Upper Indus River Basin (UIB) (Fig. 1a), is the main contributor to the Indus River. Tarbela reservoir was constructed in 1974 on the Indus River to supply irrigation water to the Indus Irrigation System through a large network of canals, and so to supply the agricultural lands of Punjab and Sindh (Pakistan) (Fig. 1a), the main producers of agricultural products in the country. The mean annual inflow to Tarbela is $\approx$2410 $m^3 \cdot s^{-1} \pm 309$ $m^3 \cdot s^{-1}$, as estimated from the 40-year (1969–2008) SWHP (Surface Water Hydrology Project) flow record.

The Upper Indus River Basin has a total catchment area of >200,000 km^2 (Bookhagen and Burbank, 2010; Forsythe et al., 2012b; Immerzeel et al., 2009; Tahir et al., 2011a) and almost 12% of the total area ($\approx$22,000 km^2) is covered by glacier ice (Hewitt, 2001; Hewitt, 2007). There are many discrepancies in the estimated catchment area reported by Khan et al. (2014) that may be a result of different datasets, methodologies and assumptions used to estimate this area by different authors. Within the UIB, five catchments, the Shyok, Shigar, Astore, Gilgit and Hunza rivers (Fig. 1a), contribute more than 60% of the total