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# The magnitude and seasonal stream flow fluctuations of Hunza River, Karakoram region during 1966-2010

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The glacierized river basins with insufficient summer precipitation (rain) but abundant in snow and glacier-melt water, are highly suspected by reduction and seasonal alteration in the annual stream flows owing to climate change. However, the high altitude glacio-hydrological observations and investigations to address the linkage between the timings of glacier changes and river runoff fluctuations are still very weak and ambiguous particularly in the Karakoram region of Pakistan, which also a consequent of controversies among the scientists regarding the current status of glaciers in the region. In this context, the hydrological regime of Hunza (13,717km$^2$), a sub-catchment of Upper Indus River Basin (UIB), which is a part of Tibetan Plateau Environment (TPE) and lies in Hindukush–Karakoram–Himalaya (HKH) region, was comprehensively investigated by employing in-situ hydro-meteorological observations in combination with Satellite Remote sensing data. This study suggests that the annual basin precipitation is evenly distributed in winter and summer seasons, and depends on Westerly and summer Monsoon circulations respectively. As a consequent of very high mean basin elevation i.e. 4500m.a.s.l, more than 24% of basin area is covered by glaciers and perennial ice and with accumulated seasonal snow (estimated by temporal MODIS Imageries) it reaches 58% of the basin area. Hydrological analysis by employing basin cryosphere dynamics and observed hydro-meteorological data reveals that most of the annual basin runoff depends on melt-water produced by predominant glacier ablation and seasonal snow. As a result, the basin annual mean discharge reaches 762mm of water depth equivalent; whereas the three meteorological stations at 2810m.a.s.l (Naltar), 3669m.a.s.l (Ziarat) and 4730m.a.s.l (Khunjerab) located in Hunza basin recorded 720mm, 265mm and 200mm annual mean precipitation respectively. The separation of hydrologic flow regimes to estimate the contribution of genetic sources from both glaciated and snow melt regime, was carried out by adopting semi-qualitative approach, in which snow cover depletion curves, monthly 00 isotherm elevation level and precipitation records were employed. The hydrograph was divided into three main regimes i.e. base-flow, lower-to-mid altitude (1400-4500m.a.s.l) snow-melt regime ($S_{L-M}$; Mid-April to Mid-July), and high-altitude snow and glacier-melt regime ($S_H G_A$; Mid-July to October), and their corresponding Runoff yield was estimated as 20%, 24% and 56% of annual steam-flow respectively. Non-parametric Mann-Kendall trend test was applied on the whole time-series of hydrological data, which indicates significant decrease in discharge by 26% of the annual stream-flow magnitude during 1966-1995, however, after that point of time from 1995-2010 there is little variation in the annual discharge which was mainly associated with precipitation. As a result of the cooling in summer temperatures (Jul-Sep), the seasonal stream-flow volume in the glacier ablation period ($S_H G_A$) was significantly decreased by 29% during 1966-1995, however, afterwards from 1995-2010 even though the summer temperatures were decreasing but in-contrast there was slight increase in stream-flow volume, although it was mainly coupled with increased summer precipitation during that period. Similarly, due to increased winter precipitation accumulation and warming in basin spring temperatures collectively resulted in earlier snow-melt by 10-days and eventually caused in slightly increased spring stream-flow ($S_{L-M}$) volume during 1995-2010. Our overall analysis suggested that the glacier ablation was very high during 1970s although it was continuously declined till 1995; afterwards the glacier ablation seems constant until 2010. It is clearly evidences that the glacier retreat rate was declined during 1966-1995, followed by the stable state of glaciers during 1995-2010, these findings seems in agreement with the previous glacier studies in the Karakoram region.