Hydrological Dependence of Ganges River on Himalayan Cryosphere

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The Gangotri group of glaciers in the Himalayas is the source of the Ganges River that provides water security to half a billion people. Serious concerns have been raised about the impact of shrinking glaciers (rate of snout retreat 30 m/year) on the hydrological regime of the Ganges River and future supply of potable water. The effect of global warming on cryosphere-river linkages can be studied by quantifying the relative proportion of glacial melt and snow melt to the total river discharge. However, the scientific community is not in agreement regarding the relative contributions of glacier, snow, rain, and ground water to the total Ganges discharge. Estimates are based either on models that were generated mostly using a combination of high-resolution, calibrated rainfall values estimated from remotely sensed data with snowmelt runoff models, or through isotope mixing models. The snowmelt runoff models undoubtedly provide invaluable insights into the influence of the Gangotri glaciers on the hydrological budgets of rivers, but also contain large uncertainties due to limited validation from field data. The $\delta^{18}O$ and δD isotope mixing models based on field data are sensitive to the end member compositions of sources that are not well constrained. As a result, estimates based on isotope data have large uncertainties. For example, our calculations reveals that if the $\delta^{18}O$ composition of the base flow increases by 2‰, the glacial and snow melt proportions will decrease by 5%. Moreover, it is difficult to separate glacial and snow melt proportions using isotope mixing models. Here, we have characterized the seasonal (pre-monsoon, monsoon, and post-monsoon) $\delta^{18}O$ and δD variability of the Ganges headwaters in 2014 and 2015, and analyzed the isotope data within a Bayesian framework. The pre-monsoonal $\delta^{18}O$ and δD varied from -15.1‰ to -9.3‰, and -105.4‰ to -61.5‰ respectively. The monsoonal $\delta^{18}O$ and δD varied from -15.5‰ to -10.7‰ and -106.7‰ to -47.1‰, respectively, whereas the post-monsoonal $\delta^{18}O$ and δD varies from -14.9‰ to -7.0‰ and -103.9‰ to -61.0‰ respectively. The Bayesian modeling using isotope data shows significant seasonal variation of glacial and snowmelt contributions to the total discharge.