

Glacier-fed Himalayan rivers of India

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Whether scarcity of water is due to climate change or population explosion is a matter of debate among scientists. The demand for water resources will increase in the future. The depletion of resources in the Himalaya – the Third Pole, will have a serious effect on the major rivers of Asia that are fed from the Tibetan Plateau and the Himalaya. Scientific studies on the Himalaya and Tibetan Plateau glaciers indicate that topography and local conditions favour the long sustenance of glaciers. In large parts of the Himalaya and Tibetan Plateau, the rise in atmospheric temperature does not cause any serious impact on the glaciers, particularly in Karakorum Himalaya. The water supply from Upper Indus, Ganges and Brahmaputra rivers is likely to decrease by –8.4%, –17.6% and –19.6% respectively, and there is likelihood of an increase in mean upstream rainfall in the Indus (+25%), Ganges (+8%) and Brahmaputra (+25%), implying that the Himalayan rivers will continue to flow, with no substantial decrease in water budget and no fear of rivers to dry.

Keywords: Climate change, glacier-fed rivers, snow, water scarcity.

MOUNTAINS of the world, including Asia, are the water towers. Most of the rivers in Asia are fed from the Tibetan Plateau and the Himalaya. The melting of snow and glaciers of the Tibetan Plateau and the Himalaya form important hydrologic processes in these mountains, and any change in temperature and precipitation will seriously affect the melt characteristics and hydrologic processes. The effect of climate change on the melting of glaciers and snow will have potential consequences, mostly qualitative or local, on downstream hydrology. The impact of snow and glacial melt on Asian river basin hydrology remains largely unknown. So does the effect of climate change on the downstream water supply and food security.

Climate change is expected to multiply the threat of food and water shortage in the future. It is also believed that climate change will increase the frequency of natural calamities, more particularly, in the form of frequent storms and floods. The rise in atmospheric temperature will cause global warming which in turn may increase the melting of glaciers in Asia, the largest storehouse of freshwater. The increase in the melting of glaciers will have a cascading effect leading to high discharge initially

in the rivers and subsequently, the water budget in rivers will fall substantially leading to the drying of rivers originating from the Himalaya¹. There is another school of thought which believes that the rise in atmospheric temperature will not cause any serious impact on the glaciers in the Himalaya. There are several glaciers in the Himalaya (more particularly in Karakorum Himalaya) that are not affected by the rise in atmospheric temperature. Hence, these glaciers may not have any impact on the budget of the major rivers that originate from the Himalaya. In either case, water will be the major and significant issue that deserves attention from the perspective of climate change. Even though the water budget in Himalayan rivers may dwindle or remain unaffected due to climate change, the demand for water is likely to increase with a substantial increase in human population in the mountains in the near future. The propensity of water therefore will increase and so will conflicts related to distribution and usage of water among the states/countries.

Climate affects the hydrological cycle at both global and regional scales, and consequently the availability of, and demand for, water resources²⁻⁴. Climate change directly affects water resources through changing the quantity, variability, timing, form and intensity of precipitation, and indirectly impacts water resources through increasing water temperature, increasing evapotranspiration rate and decreasing water quality^{2,4-6}.

The pessimistic view is that a warming climate will reduce available water and, particularly if combined with rising water demand, increase the propensity for water-related conflicts among the riparian countries, while the more optimistic view is that increasing temperature causes a depletion of snow and glacier storage in high-altitude regions that translates into an additional run-off, which at least in the next few decades will avoid a deterioration of the supply–demand ratio^{7,8}.

Are the Himalaya glaciers melting?

The melting of glaciers in the Himalaya is one issue that has no conclusive answer so far. The Intergovernmental Panel on Climate Change (IPCC) in its Assessment Report IV in 2007 had projected that glaciers in the Himalaya will vanish by AD 2035, which was not accepted by a large section of scientists/glaciologists in India. A document⁹ prepared by the Ministry of Environment and Forests, Government of India, recorded the erratic behaviour of glaciers across the Himalayas⁹. The scientific

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data suggest that the Himalayan glaciers are not responding to global warming/climate change in the strictest sense. The glaciologists who have been carrying out field mass balance study of glaciers in the Himalaya are of the view that some of the glaciers have the same or increased surface area, but are thinning¹⁰. In the Gravity Recovery and Climate Experiment (GRACE) satellite mission, it has been found that the glaciers in high-altitude Asia are losing ice one-tenth as fast as the previous estimates, and glaciers in the Tibetan Plateau are growing on average¹⁰.

The studies of 112 glaciers in Pakistan, Nepal and India suggested fluctuations between AD 1810 and 1970 (refs 11, 12). They further suggested that the glaciers located in the trans-Himalaya have been in the mode of advance since AD 1850 compared to those located in the other parts of the Himalaya, and that the fluctuation in glaciers shows no relation to the variation in monsoon except for the period between AD 1900 and 1909 that coincided with the peak in monsoon¹³. However, remote sensing studies suggest that glaciers in many parts of the Himalaya are advancing and also growing thick. This positive change in the Himalayan glaciers is ascribed to the enhanced monsoon precipitation associated with global warming¹³.

The scientific study of glacier fluctuations in the Himalaya for the last 100 years significantly emphasizes the difficulty in establishing any relationship between the climate factors and glacier fluctuation¹³. The improving health conditions of glaciers during the early Holocene (~11,000 yrs BP) due to the insolation maxima provide a perfect analogy to the present-day changes in glaciers of the Himalaya¹³. The large extent of advance, in some of the Himalayan glaciers, during the early Holocene is a consequence of the increased insolation and intensified monsoon activity¹⁴.

The glaciers in some other parts of the Himalaya have not shown a large extent of advance during the same period. This is obviously because the maritime type of Himalayan glaciers respond to the fluctuation in monsoon, whereas the sub-polar type of glaciers are situated in arid regions of the Himalaya and are not affected by fluctuations in monsoon¹³. A study of the cause of termini fluctuation of 286 glaciers located between Hindukush and Bhutan Himalaya with lengths varying from 2 to 70 km, revealed astonishing facts¹⁵. It is inferred that 65% of maritime type of glaciers are in the process of retreat, whereas 50% of sub-polar type of glaciers are either advancing or stable. The glaciers in Karakorum Himalaya show least impact of climate change on them due to the following:

- (a) More moisture is transported to this part of the Himalaya due to the strengthening and shifting of Westerlies to lower elevations¹⁶.
- (b) The winter precipitation has increased in the 20th century¹⁷.

- (c) There is a marginal decrease in summer temperature in the second half of the last century¹⁸.

A study on the impact of climate change on precipitation¹⁹ reveals that PDD/SDD (prolonged dry days/short dry days) have significant increasing/decreasing trends for all ranges and altitudes in the Western Himalayan region. This indicates that the rainy days have decreased and the duration of dry spell has increased over the Western Himalayan region. The PDD do not show a clear trend for all ranges and altitudes, whereas SDD indicate an alternately decreasing and increasing trend in all ranges and altitudes. The study further reveals that no significant correlation has been observed for precipitation events in terms of intensity with El-Niño, while SDD show a significant positive correlation with El-Niño for the Great Himalaya and middle altitude. Except for the Great Himalaya, NAO (North Atlantic Oscillation) shows a positive correlation with low precipitation events for all ranges and altitudes.

The debris-covered glaciers in the Himalaya, almost 20%, are interesting to study as far as the meltwater discharge due to climate change is concerned, as the rate of melt in glaciers with debris thickness exceeding a few centimetres reduces the rate of melting considerably despite the change in the climate^{20,21}. Nevertheless, glaciers in the Indian Himalaya⁹, and Qilian and Tian Shan in China²² have retreated since the middle of the 19th century by about 5–10%. With about 16% of stable glacier fronts in the Hindukush, 28% in southern Central Himalaya, 10% in northern Central Himalaya and very low (1.5%) in the Western Himalaya, it is proposed that the Himalayan glaciers are not necessarily responding to climate change and instead are responsive to the topography and local climatic oscillations¹⁵.

Will the Himalaya rivers continue to flow?

The decrease in Hunza river run-off in the Indus Basin has been attributed to the cooling trend of the regional temperature, in general, and reduction in summer temperature and strengthening of winter precipitation, in particular¹⁸. As a consequence, there is a reduction in ablation and an increase in the accumulation with a consequential effect on the decrease in river run-off. On the other hand, a study of river run-off in the Upper Indus basin presents a complex scenario with no significant change in the flow of the main Indus and Jhelum rivers between 1922 and 2004. The flow in the Chenab increased, whereas that in the Kabul river decreased during the same period²³.

The contribution of snow and glacier water to the Ganges (10%), Yangtze (8%) and Yellow (8%) rivers is limited owing to comparatively large downstream areas, limited upstream precipitation, smaller glaciers and/or wet monsoon-dominated downstream climate. In the Indus and Ganges basins, about 40% of the meltwater

originates from glaciers, whereas in the other basins the glacial melt contribution is much less due to the low contribution of snow and ice as a consequence of limited upstream precipitation, smaller glaciers, wet monsoon and dominated downstream climates²⁴. The normalized melt index (NMI) study to quantify the importance of both glacier and snow meltwater for five major river basins in Asia (the Indus, Ganges, Brahmaputra, Yangtze and Yellow) revealed very large differences among the basins, ranging from 46% snow and 32% glacier contributions in the Indus to 6% snow and 3% glacier contributions in the Ganges, which is largely dependent on the summer monsoon²⁵. Results from Variable Infiltration Capacity (VIC) model to assess the Yellow, Yangtze, Mekong, Salween, Brahmaputra and Indus rivers showed that all except Indus river were primarily dependent on rainfall run-off²⁶.

Decrease in snow accumulation of Qomolangma (Mt Everest) from AD 1534 to 1889 is due to reduction in northward incursion of summer South Asian monsoon as a consequence of change in dynamics of the summer South Asian monsoon²⁷. The trend in the rate of accumulation of snow at Dasuopu (125 km from Qomolangma) is opposite for the same period²⁸. This confirms that the variation in snow accumulation in the higher Himalaya is a factor of seasonal variation in monsoon systems versus westerly moisture systems that give rise to complex mountain meteorology²⁷. Summer South Indian monsoon, the major contributor of precipitation to Himalaya, holds a key factor to the glacier hydrological system that still has not been well understood^{29,30}. Studies suggest that 5000 m amsl, 90% of precipitation is in the form of snow, and in the lower parts of the Himalaya, snow contributes no more than 10% of the total rainfall²⁹. The upstream water supply from Upper Indus, Ganges and Brahmaputra rivers is likely to decrease by -8.4%, -17.6% and -19.6% respectively, and at the same time there is a likelihood of an increase in mean upstream rainfall in Indus (+25%), Ganges (+8%) and Brahmaputra (+25%), implying that the rivers originating from the Himalaya may not show any substantial decrease in their run-off²⁴.

Discussion and conclusion

The recent controversy about overestimated melting rates of the Himalayan glaciers suggests, however, that our knowledge of high-altitude snow/ice and its response to climate forcing is still incomplete³¹⁻³⁴. A 2010 study using measurements taken by the GRACE satellite mission indicated that the Third Pole is shedding roughly 50 Gt of ice per year. An unpublished inventory of Tibetan glaciers led by Liu Shiyin at the Cold and Arid Regions Environmental and Engineering Research Institute in Lanzhou, China, shows that more than 70% of the glacier in the Tibetan Plateau are retreating. However, an analysis of GRACE data suggests that overall, high-altitude Asian glaciers are losing ice only one-tenth as fast as the previ-

ous estimates and that those in the Tibetan Plateau are growing on average. The 46,000 or so glaciers in the Hindukush Himalaya region, also known as the Third Pole, supply water to southern and Central Asia, and although many climate studies suggest that the ice is disappearing fast, not all measurements are in support.

The scarcity of water in the world is not attributed to change in climate alone, but also to a manifold increase in the population, particularly in developing countries³⁵. The severity of water shortage will largely be due to socio-economic developments and only 20% will depend on climate change³⁶. The change in intensity, timing will affect the scarcity of water^{37,38}. It is therefore a point of debate whether the change in the glacial hydrology is a factor of natural or anthropogenic climate change or overpopulation in mountain ecosystems that are seriously telling upon the increasing demand and not decreasing supply^{39,40}. The variation in climate between mountain valleys and mountain tops, between aspects and orientations, and different locations further complicates the mountain ecosystems³⁰. The large uncertainty associated with the future precipitation projections as shown with the comparison of different general circulation models⁴¹ further compounds the issue of understanding glacier hydrology in mountain systems. Environmental researchers now see the supposed Himalayan crisis as partly due to political and social factors⁴²⁻⁴⁵ rather than the result of proven and tested physical processes.

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