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Editorial

Changing monsoon patterns, snow and glacial melt, its impacts and adaptation options in northern India: Setting the stage

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ABSTRACT

To set the stage of this special issue this paper gives a short introduction to the sensitivity to climate change of the main bio-physical processes in the Hindukush–Karakoram–Himalayas. It also describes the socio-economic setting of the Ganges basin in northern India as the main focal point of the impact and adaptation studies in this special issue.

1. Introduction

The hydrological system of northern India is based on two main phenomena, the monsoon precipitation in summer and the growth and melt of the snow and ice cover in the Himalaya, also called the "Water Tower of Asia" (e.g. Immerzeel et al., 2010; Immerzeel and Bierkens, 2012). However, climate change is expected to affect snow cover, glaciers and its related hydrology, which will in turn alter water resources and the human wellbeing and economy on the Indian subcontinent (e.g. Sachs et al., 2002; Gupta and Deshpande, 2004; Hussain et al., 2007; Gautam et al., 2013). The perennial rivers in the north, Ganges, Indus and Brahmaputra, are particularly susceptible to climate change as they originate from the Himalayas, as snow and glacier melt run-off represents a substantial proportion of their total flow (e.g. Singh and Jain, 2002; Singh and Bengtsson, 2004; Kumar et al., 2007). The impacts of climatic changes are projected to have short-term and long-term consequences on the hydrological system of the region. On the short term, discharge of rivers in the north is expected to increase because of the melting of snow and glaciers. On the longer term, however, much of the perennial snow and the glaciers will have been wasted and their contribution to river flow will likely decrease (Eriksson, 2006; Immerzeel et al., 2013).

In the Fourth Assessment Report (AR4) of the Intergovernmental Panel on Climate Change (IPCC), Working Group 1 (WG1) concludes that "there is a tendency for monsoonal circulations to result in increased precipitation due to enhanced moisture convergence, despite a tendency towards weakening of the monsoonal flows themselves. However, many aspects of tropical climatic responses remain uncertain" (Christensen et al., 2007). In the same report, it is concluded that the observed maximum rainfall during the monsoon season is still poorly simulated by many models. The most likely cause being the coarse resolution of the models preventing a good representation of the steep geography of the area. Three-member ensembles of baseline simulations (1961–1990) from a RCM (PRECIS) at 50 km resolution have confirmed that significant improvements in the representation of regional processes over South Asia can be achieved (e.g., Kumar et al., 2006; Lucas-Picher et al., 2011; Srinivas et al., 2013).

Besides climate change, socio-economic development will also have an influence on the use of water resources, the agricultural economy and the adaptive capacity, with the level of the latter being in turn influenced by the socio-economic development itself. It is a challenge to find appropriate adaptation strategies with stakeholders for each of the sectors including agriculture, energy, health and water supply by assessing the impact outputs of the hydrological and socio-economical models.

The urgency of these changes and possible threats were recognized in 2007, when the impact of climate change on water resources was identified as one of the important areas for EU–India research collaboration. As a result, funds within the Seventh Framework Program of the European Union (EU-FP7) research programme were made available to initiate the HighNoon project (also see www.eu-highnoon.org for details). The focus of the HighNoon project, a collaborative effort between European, Indian, and Japanese partner institutions, was on the development of adaptation measures in northern India and of an

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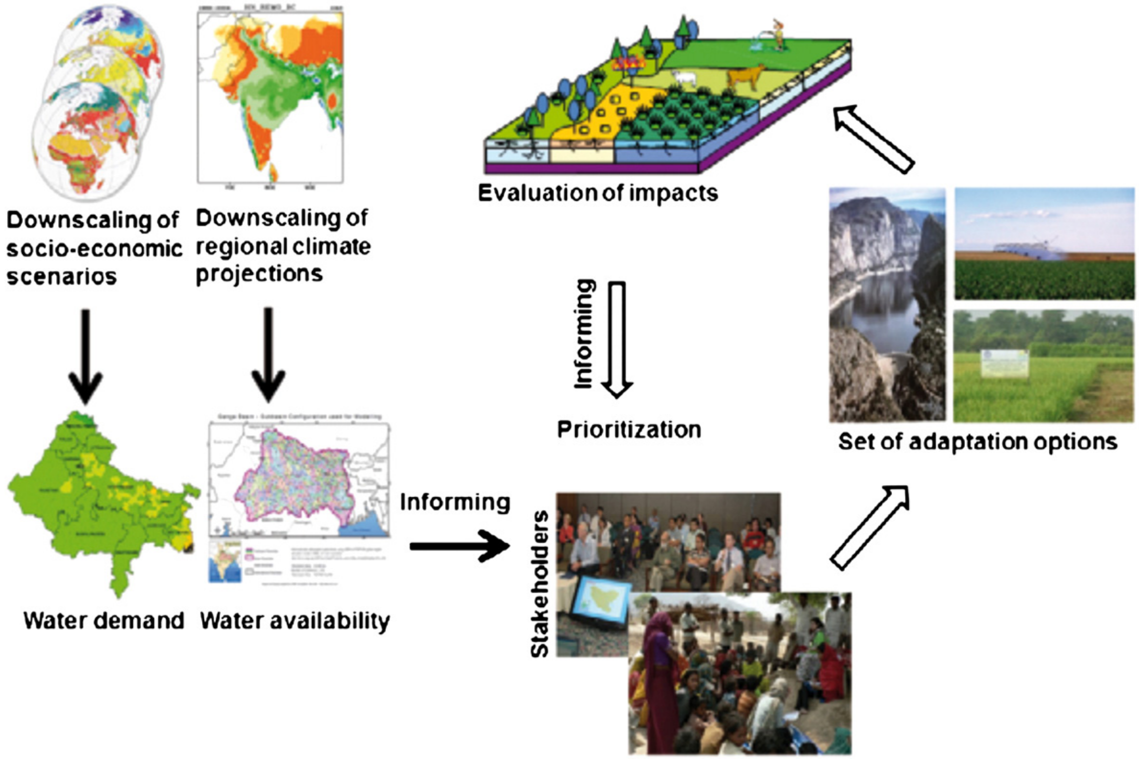

Fig. 1. Graphical representation of the research approach applied in the HighNoon project to determine impact, vulnerability and adaptation options for climate change and socio-economic changes in the Ganges basin.

improved understanding of the current and future biophysical and social systems (Fig. 1). Through the involvement of stakeholders at different levels, ranging from individual farmers to national government agencies, adaptation options were selected.

The objective of this special issue is to highlight the key research findings of HighNoon related to the above described challenges in a coherent way.

2. Description of the region

Fig. 2 shows the main phenomena driving snow and glacier processes of accumulation and melt and points to the significant differences in the processes and seasonality driving precipitation between the East and the West. The illustration also shows that glacier wasting is depending either on temperature changes, variability in precipitation or on

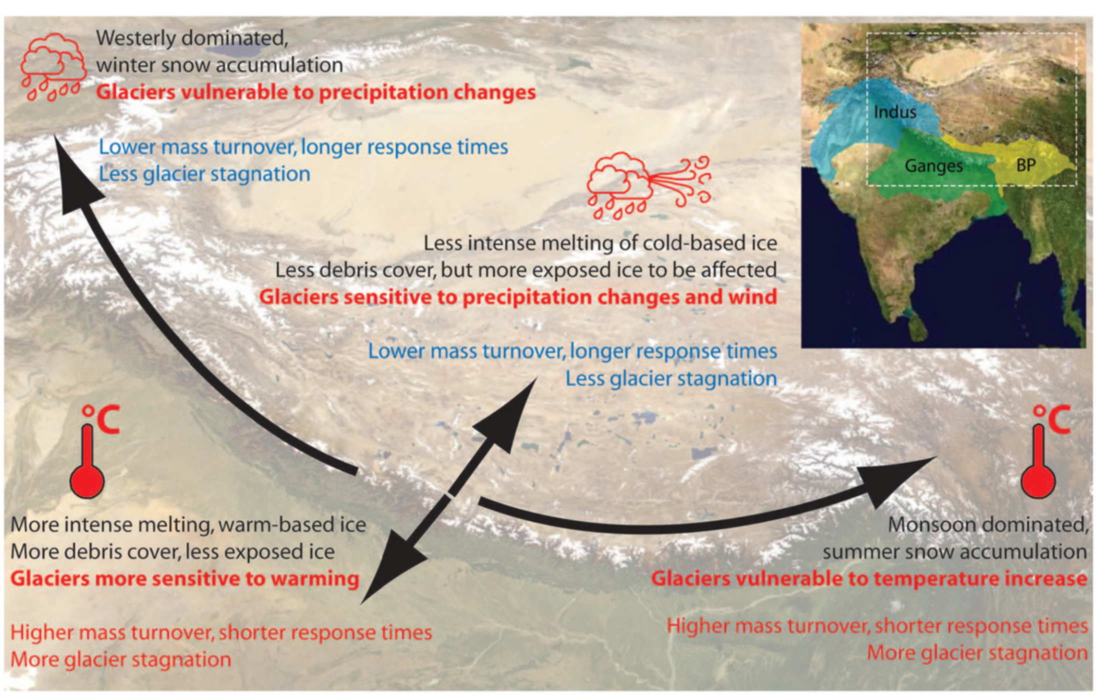

Fig. 2. Climate, glaciers and snow in the Hindukush–Karakoram–Himalayas and their sensitivity to changes in climate (inspired from Kargel et al., 2012). The regional setting of the major streams of the Indian subcontinent (Brahmaputra, Ganges, and Indus) is shown in the inset map.

changes in wind, and that the current status of glaciers and their "health" will depend strongly on their geographic location (Bolch et al., 2012; Kargel et al., 2012; Sorg et al., 2012). The presence of a snow cover and the timing of snow fall in the Himalayas and the Tibetan plateau may in turn also influence the circulation patterns leading to the onset and determining the intensity of monsoon. Cold, wet winters have been shown to cause less severe monsoons as the snow cools down the air in summer (Wang et al., 2005) Excessive snowfall in winter/spring has been demonstrated to delay the build-up of the monsoonal temperature gradient as solar energy is used to melt the snow or reflected by the snow. As a consequence, the heat low in the northwest of India will be less strong during such situations and result in a weak monsoon and decrease in precipitation.

The Ganges basin can be divided into 3 physiographic regions, namely the Himalayan fold mountains and Central Indian highlands, the Peninsular shield and the Gangetic plain. The total drainage area of the Ganges is 1.086×106 km^2 and extends over Tibet, Nepal, India and Bangladesh (see inset map in Fig. 2). The stream originates as the Bhagirathi at the snout of the Gangotri glacier at an elevation of 3892 m above sea level. The waters of the Ganges flow to the east over a distance of 2525 km before they merge with the Brahmaputra in Bangladesh, and before the latter discharges into the Bay of Bengal. Approximately 80% of the Ganges basin is located in India, where it flows through the territories of 11 different Indian states hosting 652×10^6 inhabitants, corresponding to approximately 54% of the total population of India (Census of India, 2011). Land use in the states is dominated by agriculture in general and by wheat, sugarcane, sorghum, millet, and rice production in particular (GOI, 2012).

3. Questions addressed

This special issue is aimed to encourage interdisciplinary exchange and interaction on the topics addressed above and presents a set of papers that seek to understand, model and quantify some of these interactions, the impact of Himalayan glaciers retreat and possible changes of the Indian summer monsoon on the spatial and temporal distribution of water resources in northern India. In addition, it merely tries to provide recommendations for appropriate and efficient response strategies that might eventually strengthen the cause for adaptation to hydrological extreme events. The papers published in this special issue address the following set of questions:

- Using a higher spatial resolution (i.e. 25×25 km) is expected to lead to better results especially for the Indian subcontinent in general and the Ganges basin in particular with the latter being influenced by the extreme topography of the Himalayas. What are the skills and uncertainties of the most recent, state-of-the-art high-resolution Regional Climate Model (RCM) runs?
- Does an improved consideration of interactions between the atmosphere and cryosphere enhance the capabilities of the RCMs to simulate monsoon-related precipitation patterns and quantities?
- How will glaciers respond to climate changes and altered monsoon circulation?
- How can poor and contradictory rainfall simulations be improved?
- How can the prediction of river flow responses be improved by modelling interacting processes (e.g., timing of snow fall, effective melt, human influences)?
- What are realistic regional water demand scenarios based on socio-economic scenarios for the Ganges basin and how can changing water resources be assessed with regional models?
- What are possible impacts of climate change on different sectors such as agriculture and health and what are possible response strategies?
- What new methods could be implemented for the prioritisation of adaptation measures to be used as a design tool in the selection of adaptation options?
- How can the participative development of specific multi-sector adaptation measures in consultation with stakeholders be used to increase the success of adaptation?

References

Bolch T, Kulkarni A, Kääb A, Huggel C, Paul F, Cogley JG, et al. The state and fate of Himalayan Glaciers. Science 2012;336:310–4.

Census of India. http://censusindia.gov.in/2011census/, 2011. [retrieved 7 July 2013].

Christensen JH, Hewitson B, Busuioc A, Chen A, Gao X, Held I, et al. Regional climate projections. In: Solomon S, Qin D, Manning M, Chen Z, Marquis M, Averyt KB, Tignor M, Miller HL, editors. Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press; 2007. p. 996.

Eriksson M. Climate change and its implications for human health in the Himalaya. ICIMOD newsletter No. 50; 2006. [Summer].

Gautam MR, Timilsina GR, Acharya K. Climate change in the Himalayas: current state of knowledge. World Bank, Policy Research Working Paper 6516; 2013. p. 47.

GOI. Directorate of economics and statistics. Department of Agriculture and Cooperation, Ministry of Agriculture, Government of India; 2012 [http://eands.dacnet.nic.in/].

Gupta SK, Deshpande RD. Water for India in 2050: first-order assessment of available options. Curr Sci 2004;86:1216–24.

Hussain I, Turral H, Molden D, Ahmad M. Measuring and enhancing the value of agricultural water in irrigated river basins. Irrig Sci 2007;25:263–82.

Immerzeel WW, Bierkens MFP. Asia's water balance. Nat Geosci 2012;5:841–2.

Immerzeel WW, Beek LPH, Bierkens MFP. Climate change will affect the Asian water towers. Science 2010;328:1382–5.

Immerzeel WW, Pellicciotti F, Bierkens MFP. Rising river flows throughout the twenty-first century in two Himalayan glacierized watersheds. Nat Geosci 2013;6:742–5.

Kargel JS, Alho P, Buytaert W, Célleri R, Cogley JG, Dussaillant A, et al. Glaciers in Patagonia: controversy and prospects. EOS Trans Am Geophys Union 2012;93(22):212.

Kumar KR, Sahai AK, Kumar KK, Patwardhan SK, Mishra PK, Revadekar JV, et al. High-resolution climate change scenarios for India for the 21st century. Current Science 2006;90:334–45.

Kumar V, Singh P, Singh V. Snow and glacier melt contribution in the Beas River at Pandoh dam, Himachal Pradesh, India. Hydrol Sci J 2007;52(2):376–88.

Lucas-Picher Philippe, Christensen JH, Saeed F, Kumar P, Asharaf S, Ahrens B, et al. Can regional climate models represent the Indian monsoon? J Hydrometeorol 2011;12:849–68.

Sachs JD, Bajpai N, Ramiah A. Understanding regional economic growth in India. Asian Econ Pap 2002;1:32–62.

Singh P, Bengtsson L. Hydrological sensitivity of a large Himalayan basin to climate change. Hydrol Process 2004;18:2363–85.

Singh P, Jain SK. Snow and glacier melt in the Satluj River at Bhakra dam in the western Himalayan region. Hydrol Sci J 2002;47(1):93–106.

Sorg A, Bolch T, Stoffel M, Solomina O, Beniston M. Climate change impacts on glaciers and runoff in Tien Shan (Central Asia). Nat Clim Change 2012;2:725–31.

Srinivas CV, Hariprasad D, Bhaskar Rao DV, Anjaneyulu Y, Baskaran R, Venkatraman B. Simulation of the Indian summer monsoon regional climate using advanced research WRF model. Int J Climatol 2013;33(5):1195–210.

Wang P, Clemens S, Beaufort L, Braconnot P, Ganssen G, Jian Z, et al. Evolution and variability of the Asian monsoon system: state of the art and outstanding issues. Quat Sci Rev 2005;24:595–629.