Water resources and management in the Himalayas under climate constraints: case studies in Pakistan and Nepal

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Abstract

The question of the future of water resources in the Himalayan Range has been widely discussed during the recent years. But the main problem is that the statements of the debate are based on a limited number of studies and a large lack of rigorous observations. When the glacier's and their evolution is presented as the main concern, the role of the snow cover and the complex dynamic of the precipitations, including the monsoon, are less often presented as major. Even so they are probably more important in the regional water supply for the different uses (domestic, agricultural or industrial). The purpose is illustrated with two studies currently conducted in the Northern Pakistan and in the Koshi River Basin (Nepal).

Keywords: Hindu Kush-Himalaya, climate change, snow cover.

Introduction

The Hindu Kush – Himalaya mountain range (HKH) is often designed as the *Third Pole* and also as the *water tower of 1/6 of the humanity*. The first expression is justified by the fact that this mountainous region, extended from the Pamir on the East until the Gulf of Bengal on the West, and including the Tibetan Plateau, contains the largest extension and volume on the Earth of cryosphere, snow and glaciers, outside the Polar Regions. The word Himalaya means in Sanskrit "Home of the Snows". The second expression is justified by the fact that 7 of the largest Asian rivers (Brahmaputra, Ganges, Indus, Mekong, Red River, Salween and Yangtze) have their sources in these mountains and more than 1.2 billion of people is living within their basins.

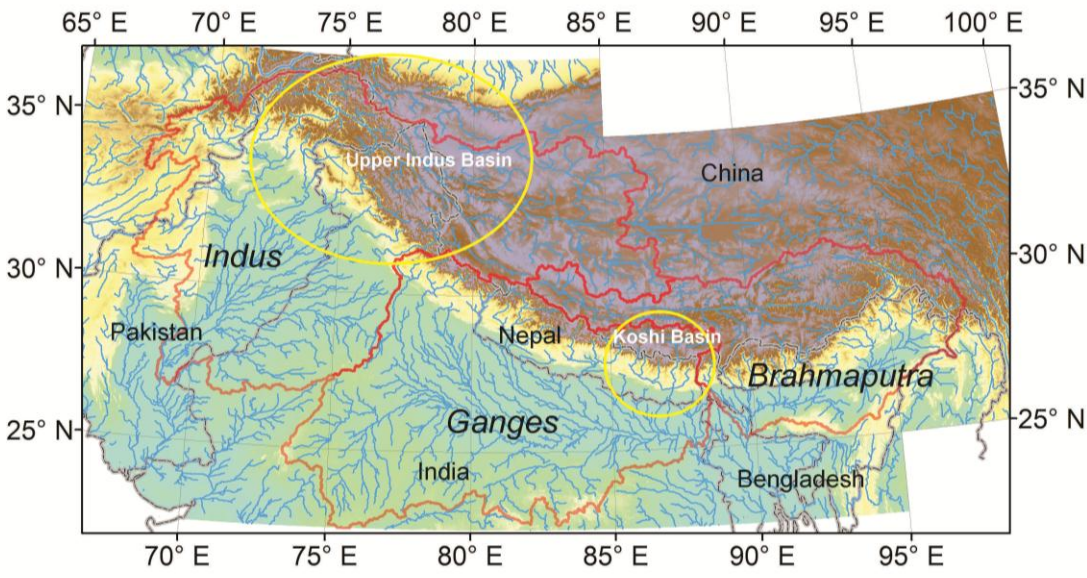

Figure 1. Map of the Hindu-Kush Himalaya range with the 3 main river basins (Brahmaputra, Ganges, Indus).

The second group of the 4th assessment report of IPCC (IPCC, 2007;Cruz et al., 2007) underlined the impact of the global warming and the consequences of the shrinking glacier, despite a misinterpretation which led to an inappropriate debate (Cogley et al., 2010).

In such context this paper presents an outlook, based on research works currently conducted by the authors in this region. After a general presentation of the Himalayan context, two study cases (fig.1) presenting different situations are introduced: (1) in the Upper Indus River Basin (Northern Pakistan) and (2) in the Nepalese part of the Koshi River Basin.

The Hindu-Kush Himalayan context

The role of the glaciers

Although it is the third largest ice mass or the Earth, no long-term glacier monitoring network (over than 10 years) has ever been sustained despite the efforts of the local and international scientific communities (Young, 1993). The reasons are mainly political (many glaciers are located in restricted border areas), financial or practical (glaciers are usually not easily accessible, very large and often debris-covered which makes them less related to climate). An exhaustive state of the art regarding mass balance measurements and energy balance studies of Himalayan glaciers is done in (Wagnon et al., 2007).

Consequently, until now, our current knowledge about recent glacier trends in this part of the world and their relationship with regional climate is poor, whereas one sixth of the world population partly depends on these glaciers and on seasonal snow-cover for their water supply. In the context of global warming, (Barnett et al., 2005) warn that the HKH region is “the most critical region in which the vanishing glaciers will negatively affect water supply in the next few decades”. There is little doubt that melting glaciers as well as seasonal snow-cover provide a key source of water for the summer months at least in the North-western part of the Himalayas (Singh and Kumar, 1997;Singh and Jain, 2002;Singh and Bengtsson, 2004;Wagnon et al., 2008). It appears that some areas of the most populated region on Earth are likely to run out of water during the dry season if the current warming and glacial and seasonal snow-cover melting trends continue for several more decades.

The three main basins flowing from the Himalayan range, Indus, Ganges and Brahmaputra Rivers (fig.1, table 1) are covering a drainage area of approximately 2.7 million of km², supplying more than 700 million of inhabitants (Revenga et al., 2003;Immerzeel et al., 2010).

Table 1 Characteristics of the three basins:

River	Population	Drainage area (km²)	Mean-Annual volume of discharges (km^3) [a]	Glacierized area (km²)
Indus	180 M	1 200 000	104	44 600
Ganges	410 M	960 000	380	22 200
Brahmaputra	120 M	550 000	630	11 700
Total 3 basins	710 M	2 700 000	1 110	78 500

Table 2: Glacier contribution to the annual runoff:

River	% of glacierized area (%)	(Eriksson et al., 2009) (%)	(Bookhagen and Burbank, 2010) (%)	(Immerzeel et al., 2010) (%)
Indus	3.7	>50	67.5	51
Ganges	2.3	~9		10
Brahmaputra	2.1	~12		21

Recent studies estimate the proportion of the water issuing from glacier and snow melt in those three main river basins (Table 2). The large differences between the authors illustrate the difficulty to compute this factor. Nevertheless, the impact of the cryosphere on the flows appears as much more significant in the Indus basin than in the Ganges and Brahmaputra.

The role of the precipitations (rain and snow)

Two main climatic dynamics regulate the precipitations in this region: the Monsoon and the Westerlies (fig.1). Very schematically, the Monsoon generates summer precipitation and the Westerlies autumn or winter precipitation. Linked with the temperature, and consequently, the altitude these precipitations are liquid (rain) or solid (snow). The main difficulty is the assessment of the quantities. The large majority of the precipitation gauges are located in the plains or hills and the few located in mountainous areas are generally close from the settlements in the valley bottoms. Moreover, the gauges are almost ever not adapted to measure snowfalls.

Considering these lacks of dense field observations, spatialized data basis are available over the region. They are the result of modelling approaches and used the observations for their calibration. We used two sets of data: (1) TRMM (Kummerow et al., 1998;Bookhagen and Burbank, 2006) (resolution < 10x10 km) and (2) Aphrodite (Yatagai et al., 2009) (resolution 15'x15'). Both are showing that between 60 and 80% of the total precipitations occur in the summer months. They show also that the precipitations varying significantly: decreasing from east to west and from south to north.

In order to examine the dynamics of the snow cover, we used the MODIS/Terra Snow Cover 8-Day global 500m grid available weekly from March 2000 (Hall et al., 2002).

However, the knowledge of the temperature is also needed for sharing the snow and rain precipitations, on the one hand, and for assessing the impact of the global warming on the water balance. The field data are registered at the same station than for precipitation. But globally the quality of the data is significantly better, considering that the errors in the measurement are negligible. It allows establishing gradient of temperature in the studied regions. The analyse shows that this gradient varies in the Himalaya not only with the zone, but also with the season within the range 0.4-0.8 °C/100m. At a large scale the NCEP-NCAR reanalysis data (resolution 2.5°x2.5°) are available at various levels of pressure (Kalnay et al., 1996;Kistler et al., 2001).

In a previous study (Bolgov et al., 2010;Chevallier et al., 2010) realised in the Pamir Alay range located at the north-west extremity of the HKH region (fig.1) we shown that the main effect of the increasing temperature was the decreasing of the area available for interception of the snow cover (fig. 2.) leading to a change in the flow regimes.

More recently, we developed this analysis in two other regions of the HKH region, where the potential impacts of a change in the flow regime could have huge impacts on the human activities.

Case study in the Upper Indus Basin (Northern Pakistan)

The first case study evocated in this paper concerns the Upper Indus Basin, uphill from the Tarbela reservoir, located 50 km north from the Pakistan's capital, Islamabad (fig.2). The research project was developed in a PhD thesis conducted by Adnan Tahir in the Laboratoire Hydrosciences – Montpellier France, with the collaboration of the Laboratoire des Transferts en Hydrologie et Environnement – Grenoble France and to be defended in the University of Montpellier in September 2011 (Tahir et al., 2011, submitted-a;Tahir et al., 2011, submitted-b).

The assessment of the water resources in this basin is explored following the main following steps:

- Analysis of the snow cover extent from March 2000 until March 2009;
- Calibration and validation of the SRM modeling (Martinec, 1975;Martinec et al., 2007) at the scale of the sub-basin of the Hunza River at Daynor Bridge (13 700 km²)
- Extension of the modeling at 4 other sub-basins (Gilgit River at Gilgit), Astore River at Doyian and Shiok River at Yogo)
- Simulation of the water resources availability at the different sub-basins for reasonable scenarios of temperature and precipitations in 2020, 2050 and 2070.
- Assessment of the impacts of this water availability for the management of the Tarbela Dam and of the future Diameer Basha Dam, especially used for irrigation and domestic water supply.

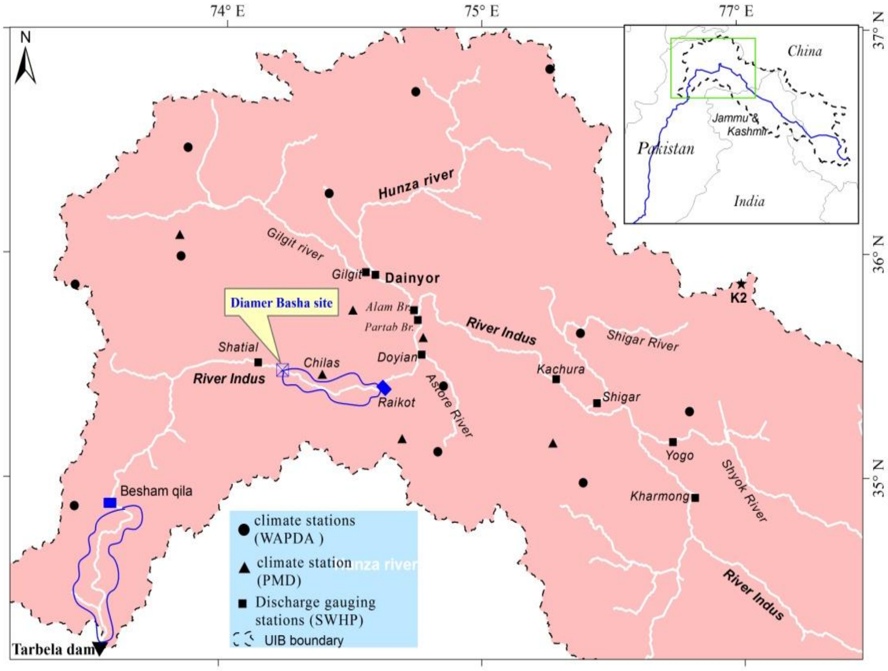

Figure 2: The Indus River basin at Tarbela Dam. Hydrometeorological observation network. Location of the future Diameer Basha Dam

The obtained results are showing the essential influence of the snow in the Upper Indus Basin. It is basically due to the high extension of the areas located at an elevation above 5000 m, which is not significantly affected by the increase of the temperature. By the contrary, an increase of the precipitations observed during the last years led to a slight increase of the snow cover accumulation and cover. As a consequence, the glaciers are not shrinking in this area and the water resource availability seems not really threatened.

The complete results will be available soon in the Tahir's thesis.

Case study in the Koshi River basin (Nepal)

The second case study started recently and is still in progress. No conclusive results are available at the present time.

The study concerns the Koshi River basin at Chatara (57 700 km²) located half/half in Nepal and China (Tibet) (fig.3). The Everest summit (8848 m) is approximately located in the center of the basin, which contains 4 others 8000m-peaks (Cho-Oyu, Kanchenjunga, Lhotse and Makalu). Even with high mountain austerity and disadvantages, all the main valleys are inhabited, with agriculture of subsistence developed in traditional terraces installed along the slopes and widely depending of the water resources issued from the glaciers, snow cover and ground water storages. Another important fact is the fast growth of the touristic economy, especially in the Solukhumbu district (Nepal), which attracts trekkers and climbers from the all world, with special requirements on accommodation, food and energy, all them impacting directly the water use.

Finally, this high basin is also close from the large industrial cities of southern Asia and directly influenced by the aerosols emitted by this activity. These aerosols are impacting not only the chemistry of the atmosphere and the dynamic of the local climate, but also, when deposited on the snow and ice covers, they modify the albedo and the melting processes.

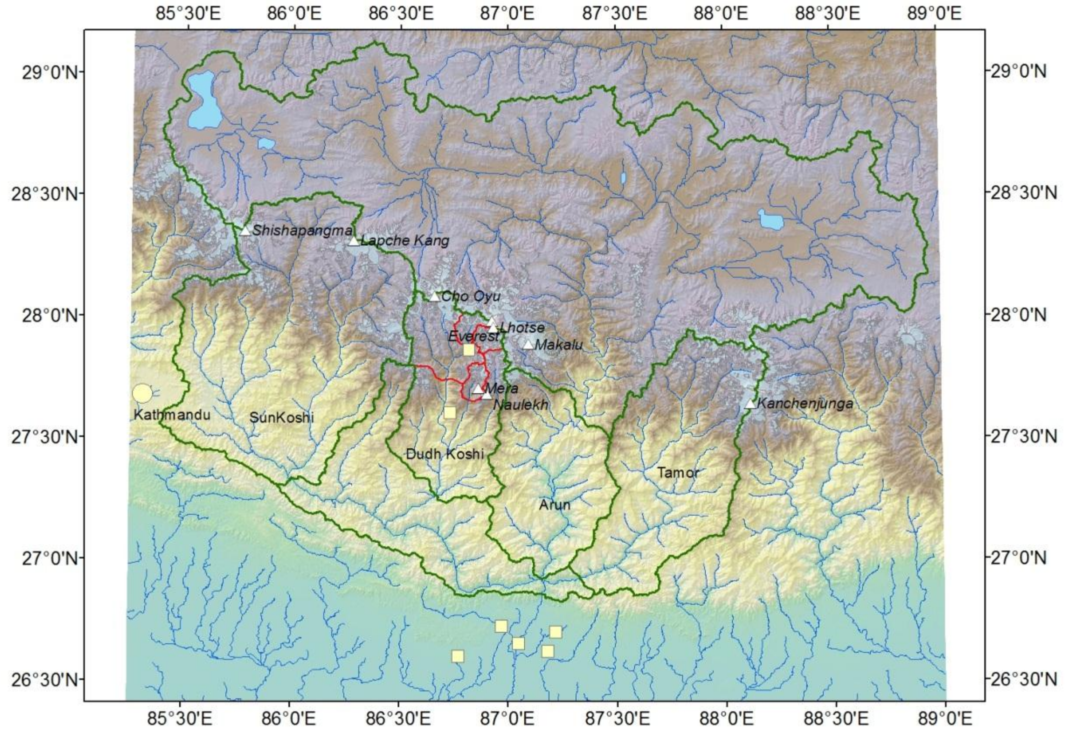

Figure 3. The Koshi River Basin with its main tributaries and the research sub-basins (in red). The small squares represent the villages where the water impact of the environmental changes on the human activities is studied.

Acknowledgements.

This presentation benefited of contributions from Yves Arnaud and Patrick Wagnon (Laboratoire des Transferts en Hydrologie et Environnement, Grenoble, France), Olivia Aubriot, Ornella Puschiasis et Joëlle Smadja (Centre d'Etudes Himalayennes, Villejuif, France), François Delclaux, Luc Neppel and Adnan Tahir (Laboratoire Hydrosciences, Montpellier, France) and Bijay Pokhrel (Department of Hydrology and Meteorology, Kathmandu, Nepal). The author thanks the providers of data used in this study: MODIS from NASA (USA), Aster-GDem from NASA (USA) and METI (Japan), the Water and Power Development Authority (Pakistan) and the Department of Hydrology and Meteorology (Nepal). A special thank is addressed to Bodo Bookhagen (University of California at Santa Barbara, USA).

References

Barnett, T. P., Adam, J. C., and Lettenmaier, D. P.: Potential impacts of a warming climate on water availibility in snow-dominated regions, Nature, 438, 303-309, 10.1038/nature04141, 2005.

Bolgov, M., Agaltseva, N., Chevallier, P., Pouyaud, B., Trubetskova, M., and Mojaisky, M.: Impact of climate change on the run-off formation zone, in: Interstate water resource risk management - Towards a sustainable future for the aral Basin (JAYHUN), edited by: Olsson, O., and Bauer, M., IWA, London, UK, 33-48, 2010.

Bookhagen, B., and Burbank, D. W.: Topography, relief, and TRMM-derived rainfall variations along the Himalaya, GEOPHYSICAL RESEARCH LETTERS, 33, L08405, 10.1029/2006GL026037, 2006.

Bookhagen, B., and Burbank, D. W.: Toward a complete Himalayan hydrological budget: Spatiotemporal distribution of snowmelt and rainfall and their impact on river discharge, Journal of Geophysical Research-Earth Surface, 115, 10.1029/2009jf001426, 2010.

Chevallier, P., Pouyaud, B., and Mojaïsky, M.: Couverture neigeuse et régime hydrologique dans les montagnes d'Asie Centrale, La Houille Blanche, 26-31, 10.1051/lhb/2010030, 2010.

Cogley, J. G., Kargel, J. S., Kaser, G., and Van der Veen, C. J.: Tracking the Source of Glacier Misinformation, Science, 327, 522-522, 2010.

Cruz, R. V., Harasawa, H., Lal, M., Wu, S., Anokhin, Y., Punsalmaa, B., Honda, Y., Jafari, M., Li, C., and Ninh, N. H.: Asia., in: Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, edited by: Parry, M. L., Canziani, O. F., Palutikof, J. P., Linden, P. J. v. d., and Hanson, C. E., Cambridge University Press, Cambridge, UK, 469-506, 2007.

Eriksson, M., Jianchu, X., Shrestha, A. B., Vaidya, R. A., Nepal, S., and Sandström, K.: The Changing Himalayas. Impact of climate change on water resources and livelihoods in the greater Himalayas, ICIMOD, 28, 2009.

Hall, D. K., Riggs, G. A., Salomonson, V. V., DiGirolamo, N. E., and Bayr, K. J.: MODIS snow-cover products, Remote Sensing of Environment, 83, 181-194, 2002.

Immerzeel, W. W., van Beek, L. P. H., and Bierkens, M. F. P.: Climate Change Will Affect the Asian Water Towers, Science, 328, 1382-1385, 10.1126/science.1183188, 2010.

IPCC: Climate Change 2007 - Synthesis Report. Contribution of working groups I, II and III to the Fourth Assesssment Report of the Intergovernmental Panel on Climate Change, edited by: The Core Writing Team, Pachuri, R. K., and Reisinger, A., IPCC, Geneva, Switzerland, 104 pp., 2007.

Kalnay, E., Kanamitsu, M., Kistler, R., Collins, W., Deaven, D., Gandin, L., Iredell, M., Saha, S., White, G., Woollen, J., Zhu, Y., Chelliah, M., Ebisuzaki, W., Higgins, W., Janowiak, J., Mo, K. C., Ropelewski, C., Wang, J., Leetmaa, A., Reynolds, R., Jenne, R., and Joseph, D.: The NCEP/NCAR 40-Year reanalysis project, Bull.Am.Meteorological Soc., 77, 437-471, 1996.

Kistler, R., Kalnay, E., Collins, W., Saha, S., White, G., Woollen, J., Chelliah, M., Ebisuzaki, W., Kanamitsu, M., Kousky, V., Doul, H. v. d., Jenne, R., and Fiorino, M.: The NCEP/NCAR 50-Year reanalysis, Bull.Am.Meteorological Soc., 2001.

Kummerow, C., Barnes, W., Kozu, T., Shiue, J., and Simpson, J.: The Tropical Rainfall Measuring Mission (TRMM) Sensor Package, Journal of Atmospheric and Oceanic Technology, 15, 809-817, doi:10.1175/1520-0426(1998)015<0809:TTRMMT>2.0.CO;2, 1998.

Martinec, J.: Snowmelt Runoff Models for stream flow forecasts, Nordic Hydrol., 6, 145-154, 1975.

Martinec, J., Rango, A., and Roberts, R.: Snowmelt Runoff Model (SRM) user's manual., New Mexico State University, Las Cruces, NM 88003, USA, 2007.

Revenga, C., Nackoney, J., Hoshino, E., Kura, Y., and Maidens, J.: Watersheds of the world_CD, IUCN, IWMI, Ramsar, World Resources Institute, Washington, 2003.

Singh, P., and Kumar, N.: Impact assessment of climate change on the hydrological response of a snow and glacier melt runoff dominated Himalayan river, J.Hydrol., 193, 316-350, 1997.

Singh, P., and Jain, S. K.: Snow and glacier melt in the Satluj River at Bhakra Dam in the western Himalayan region, Hydrological Sciences Journal, 47, 93-106, 2002.

Singh, P., and Bengtsson, L.: Hydrological sensitivity of a large Himalayan basin to climate change, Hydr.Processes, 18, 2363-2385, 10.1002/hyp.1468, 2004.

Tahir, A. A., Chevallier, P., Arnaud, Y., and Ahmad, B.: Snow cover dynamics and hydrological regime of the Hunza River basin, Karakoram Range, Northern Pakistan, Hydrology and Earth System Sciences, 2011, submitted-a.

Tahir, A. A., Chevallier, P., Arnaud, Y., Neppel, L., and Ahmad, B.: Modeling of snowmelt-runoff under climate scenarios in the Hunza River basin, Karakoram Range, Northern Pakistan J.Hydrol., 2011, submitted-b.

Wagnon, P., Kumar , R., Arnaud, Y., Linda, A., Sharma, P., Vincent, C., Pottakal, J., Berthier, E., Ramanathan, A., Hasnain, S. I., and Chevallier, P.: Four years of mass balance on Chhota Shigri Glacier (Himachal Pradesh, India), a new benchmark glacier in the Western Himalaya, J.Glaciol., 53, 603-612, 2007.

Wagnon, P., Chevallier, P., and Arnaud, Y.: La source himalayenne se tarit, La Recherche, 421, 48-51, 2008.

Yatagai, A., Arakawa, O., Kamiguchi, K., Kawamoto, H., Nodzu, M. I., and Hamada, A.: A 44-Year Daily Gridded Precipitation Dataset for Asia Based on a Dense Network of Rain Gauges, Sola, 5, 137-140, 10.2151/sola.2009-035, 2009.

Young, G. J.: Snow and Glacier Hydrology - Proceedings of the International Symposium held in Katmandu, Nepal, 16-21 November 1992, IAHS Publication No. 218, IAHS Press, Wallingford, UK, 410 pp., 1993.