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Water budget on the Dudh Koshi River (Nepal): Uncertainties on precipitation

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SUMMARY

Although vital for millions of inhabitants, Himalayan water resources remain currently poorly known, mainly because of uncertainties on hydro-meteorological measurements. In this study, the authors propose a new assessment of the water budget components of the Dudh Koshi River basin (3720 km^2, Eastern Nepal), taking into account the associated uncertainties. The water budget is studied through a cross analysis of field observations with the result of a daily hydrological conceptual distributed snow model. Both observed datasets of spatialized precipitations, interpolated with a co-kriging method, and of discharge, provided by the hydrological agency of Nepal, are completed by reanalysis data (NCEP/NCAR) for air temperature and potential evapotranspiration, as well as satellite snow products (MOD10A2) giving the dynamics of the snow cover area. According to the observation, the water budget on the basin is significantly unbalanced; it is attributed to a large underestimation of precipitation, typical of high mountain areas. By contrast, the water budget simulated by the modeling approach is well balanced; it is due to an unrealistic overestimation of the glacier melt volume. A reversing method led to assess the precipitation underestimation at around 80% of the annual amount. After the correction of the daily precipitation by this ratio, the simulated fluxes of rainfall, icemelt, and snowmelt gave 63%, 29%, and 8% of the annual discharge, respectively. This basin-wide precipitation correction is likely to change in respect to topographic or geographic parameters, or in respect to seasons, but due to an insufficient knowledge of the precipitation spatial variability, this could not be investigated here, although this may significantly change the respective proportions for rain, ice or snow melt.

1. Introduction

The Hindu Kush Himalaya (HKH) is the largest and highest mountain range of the world, with snow cover area (SCA) and glaciated area among the largest of worldwide mountain areas (Bolch et al., 2012). In addition to the Asian monsoon rainfalls and the precipitation originating from westerlies, the HKH cryosphere contributes significantly to water resources, which are crucial for more than 1 billion people living in the mountains and surrounding plains. The seasonal variability of flows (Hannah et al., 2005; Bookhagen and Burbank, 2010) has significant impacts on populations, not only for their livelihood (water supply, food production, hydropower) (Ives and Messerli, 1989; Viviroli et al., 2007), but also for hazards (landslides, glacial lake outburst floods – GLOF) (Cenderelli and Wohl, 2003) and sediment transport (Bookhagen, 2010). In addition, the cryosphere is particularly sensitive to climate change (Akhtar et al., 2009; Tahir et al., 2011b; Immerzeel et al., 2013).

Regarding these fundamental water issues in the HKH, several studies have been conducted to assess the water resources in this area using observation data (Kattelmann, 1991; Chalise et al., 2003; Alford and Armstrong, 2010; Thayyen and Gergan, 2010) or with hydrological conceptual models (Konz et al., 2007; Immerzeel et al., 2009; Bookhagen and Burbank, 2010; Tahir et al., 2011a; Andermann et al., 2012; Pellicciotti et al., 2012; Nepal et al., 2013). According to these studies, the significant

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variability of the Asian monsoon rainfall throughout the HKH introduces regional patterns in the distribution of the water budget components (Kansakar et al., 2004; Bookhagen and Burbank, 2010; Andermann et al., 2011). Bookhagen and Burbank (2010) estimated that monsoon rainfall is the main contribution (80% of annual discharge) in the eastern part of HKH, while in the western part of HKH snowmelt is the main contribution (60% of annual discharge).

Large uncertainties exist on hydrological component assessment in HKH (Pellicciotti et al., 2012; Immerzel et al., 2014; Ragettli et al., 2015). These uncertainties are generally minored, often ignored, in HKH and overall in mountainous areas. These difficulties stem in part from the high spatial variability of meteorological variables in mountains caused by the large differences in altitude over small distances (Immerzeel et al., 2009). In addition, the scattering of the hydro-meteorological and glaciological data network caused by the difficult access to mountain areas (Klemeš, 1990; Winiger et al., 2005; Hewitt, 2011; Pellicciotti et al., 2012; Ragettli et al., 2015) prevents researchers from accurately representing the high spatial heterogeneity of hydrological and cryospheric processes. These problems are especially pronounced when assessing precipitation volumes displaying high spatial variability with the elevations due to orographic effects (Andréassian et al., 2001; Andermann et al., 2011). In addition, the recognized undercatch of most rain gauges leads to a pronounced underestimation of measured precipitation, especially for solid precipitation for which classical rain gauges are usually not adapted (Klemeš, 1990; Gottardi, 2009; Sevruk et al., 2009). Additionally, the optimization of the spatial interpolation methods using data from precipitation ground gauge stations is a recurring problem (Hewitt, 2011). Finally, Comeau et al. (2009) recommended differentiating the water produced by icemelt (wastage) from that produced by the melt of snow accumulation on the glacier (melt). In the present study, icemelt corresponds only to the melt of the ice, i.e. wastage, and snowmelt corresponds to the melt of the snow in glaciated and unglaciated areas.

On the Dudh Koshi River basin (3720 km^2, Eastern Nepal, southern Mount Everest range), two studies have already been published on the water budget, and their results highlighted the uncertainties described above. Andermann et al. (2012) found that the snowmelt, icemelt, rainfall, and groundwater represent 6%, 4%, 24%, and 67%, respectively, of annual Dudh Koshi River discharge from 1987 to 2006. Nepal et al. (2013) found that the snowmelt, icemelt, and rainfall correspond to 8%, 5%, and 87%, respectively, of annual discharge from 1986 to 1997. The real evapotranspiration (RET) accounts for 14% and 20% of annual precipitation, respectively, according to Andermann et al. (2012) and Nepal et al. (2013).

To improve the knowledge on the water resources in the Dudh Koshi River basin, the aim of this study was to analyze the water budget of this basin with a specific focus on the associated uncertainties. For this analysis, we computed the water budget with (1) observation data and (2) a hydrological model.

2. Study area

The Dudh Koshi River basin is located in the central part of the HKH range in Nepal (Fig. 1). It is an affluent of the Koshi River, itself flowing into the Ganges River. The area of this basin, upstream of Rabuwabazar (460 m.a.s.l.) covers 3720 km^2. Its relief is generally steep, with a high orographic gradient from south to north. The elevations extend from 460 m.a.s.l. to 8848 m.a.s.l., Mount Everest's summit. About 50% of elevations are higher than 4000 m.a.s.l. (Fig. 2). The main geological units are the High Himalayan Crystalline series and Proterozoic sediments of the Lesser Himalayas (Andermann et al., 2012).

The runoff seasonality of the Dudh Koshi River at Rabuwabazar, where discharge is monitored by the Department of Hydrology and Meteorology of Nepal (DHM), is significant, with discharge often ten times higher in monsoon season than in winter (Hannah et al., 2005). In this study, the seasons are defined as follows: (1) pre-monsoon in April and May, (2) monsoon from June to September, (3) post-monsoon in October and November, and (4) winter from December to March. The hydrological year used in this study starts in April and finishes in March according to the DHM definition.

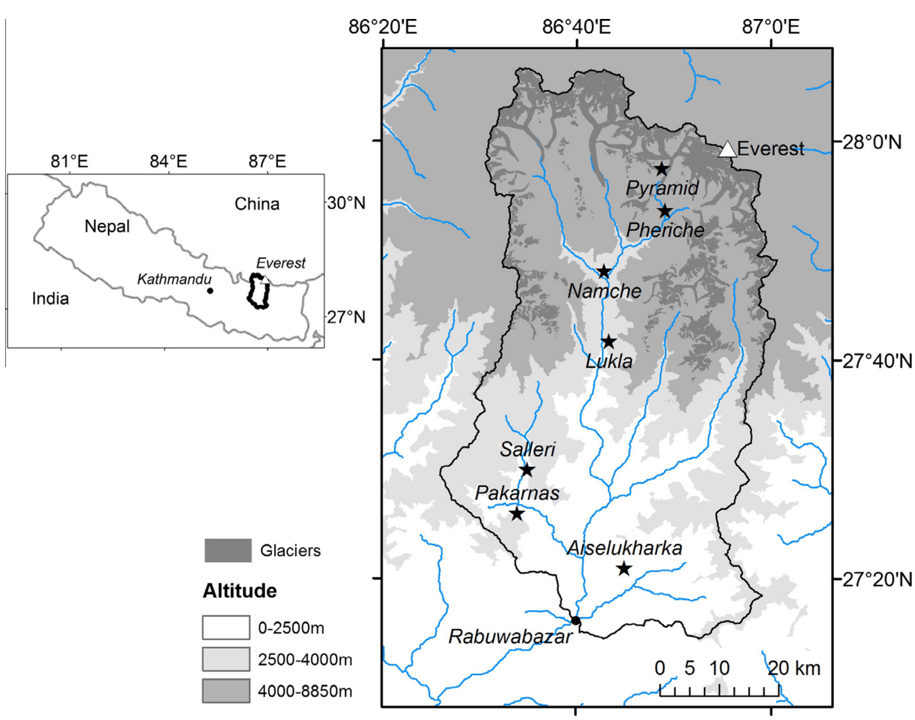

Fig. 1. Map of the Dudh Koshi River basin showing the precipitation gauges used in this study (stars) and the Rabuwabazar gauging station (dot).