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Analysis of future precipitation in the Koshi river basin, Nepal

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SUMMARY

We analyzed precipitation projections for the Koshi river basin in Nepal using outputs from 10 General Circulation Models (GCMs) under three emission scenarios (B1, A1B and A2). The low resolution future precipitation data obtained from the GCMs was downscaled using the statistical downscaling model LARS-WG. The data was downscaled for 48 stations located in the six physiographic regions in the Koshi basin. The precipitation projections for three future periods, i.e. 2020s, 2055s and 2090s, are presented using empirical Probability Density Functions (PDFs) for each physiographic region. The differences between the mean values of individual GCM projections and the mean value of the multi-model for the three scenarios allow for the estimation of uncertainty in the projections. We also analyzed the precipitation of the baseline and future periods using six indices that are recommended by the Expert Team on Climate Change Detection, Monitoring and Indices (ETCCDMI). Results indicate that not all GCMs agree on weather changes in precipitation will be positive or negative. A majority of the GCMs and the average values of all the GCMs for each scenario, indicate a positive change in summer, autumn and annual precipitation but a negative change in spring precipitation. Differences in the GCM projections exist for all the three future periods and the differences increase with time. The estimated uncertainty is higher for scenario A1B compared to B1 and A2. Differences among scenarios are small during the 2020s, which become significant during the 2055s and 2090s. The length of the wet spell is expected to increase, whereas the length of the dry spell is expected to decrease in all three future periods. There is a large scatter in the values of the indices: number of days with precipitation above 20 mm, 1-day maximum precipitation, 5-day maximum precipitation, and amount of precipitation on the days with precipitation above 95th percentile, both in direction and magnitude of the change.

1. Introduction

Global climate change is expected to have serious implications for the Earth's environment. Water is the one natural resource that is expected to be most severely affected by climate change (Minville et al., 2008). Global warming is associated with changes in a number of components of hydrological systems such as precipitation's patterns, its intensity and extremes, the widespread melting of snow and ice, increasing evaporation and atmospheric water vapour, and changes in soil moisture and runoff (Xu et al., 2011). In many parts of the world, climate change will most likely be expressed through changes in freshwater availability. Hydrological systems are anticipated to experience not only changes in the average availability of water, but also in extreme events such as floods and droughts. Changes in precipitation are expected to significantly affect cryospheric processes and the hydrology of headwater catchments in the Himalayas (Immerzeel et al., 2012). Mountainous regions are fragile and are easily affected by environmental change, which also affects important environmental services that these regions provide, such as water supply to lowlands (Buytaert et al., 2010).

To prepare adaptation strategies for changing climatic conditions, decision makers require quantitative projections on regional to local scales, depending on their purpose. Over several decades of development, GCMs have consistently provided robust information regarding climate change in response to increasing greenhouse gases (Mearns et al., 2003). However, the GCMs output remains relatively coarse in resolution and is generally considered insufficient for representing local variability necessary for climate change impact studies. Translating projections of changes made on a global scale to the regional scale is important for all water based activities. These activities include irrigation, hydropower development, and the reduction of risks related to floods and droughts. A number of methods have been used to address these scale differences; these methods range from the simple interpolation of climate model results to dynamic or statistical downscaling methods (Bates et al., 2008).

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The Long Ashton Research Station Weather Generator (LARS-WG) is a stochastic weather generator developed by Semenov and Barrow (1997) for statistical downscaling. Several studies (such as Hashmi et al., 2011) have compared the performance of LARS-WG with other statistical downscaling techniques and have concluded that LARS-WG can be adopted with confidence for climate change studies. Hashmi et al. (2009) analyzed the performance of LARS-WG for the Auckland (in New Zealand) and concluded that it prove to be an efficient tool for simulating present climate and projecting its future states in terms of complex statistics by using the information provided by a GCM. LARS-WG has been applied in climate change impact studies in many researches, such as in the Saguenay watershed in northern Québec, Canada (Dibike and Coulibaly, 2005); in Montreal, Canada (Nguyen, 2005) and different locations in Europe (Semenov and Stratonovitch, 2010). The description of the latest version of LARS-WG, called LARS-WG 5 and its capabilities is given in Semenov and Stratonovitch (2010). LARS-WG 5 incorporates climate projections from 15 GCMs used in the IPCC-AR4. LARS-WG 5 was used in the present study to downscale daily precipitation data in the Koshi river basin, which is located in the Himalayan region. To the best of our knowledge, LARS-WG has not been applied to the Himalayan region before.

Substantial uncertainty remains regarding the precise impact of climate change on water resources (Kingston and Taylor, 2010). The estimates of uncertainty present plausible future climates which would help in investigating the potential consequences of anthropogenic climate change. Such estimates are valuable for policy makers and planners (Stott and Kettleborough, 2002). These estimates are also of fundamental importance for preparing approaches to adaptation and mitigation (Deser et al., 2012).

Uncertainty in climate projections comes mainly from GCMs, SRES scenarios, downscaling methods and the innate internal variability of climate (Hawkins and Sutton, 2010; Hu et al., 2012). In this study the difference between different GCM outputs are considered to be GCM uncertainty. This uncertainty arises because of differences in the numerical and physical formulations of GCMs (e.g. spatial resolution, vertical layers, the representation of clouds, the convection process, the boundary layer, etc.). GCMs may yield different responses to the same external conditions and this results in differences in their output (Fowler et al., 2007). The differences in GCM outputs also come from the inadequate representation of land surface and its features like vegetation and soil characteristics. Besides, GCMs cannot fully represent the effects of an enhanced level of CO_2, or parameters like atmospheric chemistry, interactive biogeochemistry, aerosols, dynamic vegetation, ice sheets, etc. The difference in the mean values of all GCMs for each of the three scenario (here B1, A1B and A2) is considered to be scenario uncertainty, in this study. Scenario uncertainty arises because of different assumptions of external factors like GHG emissions, which influence a climate system. In addition, there is internal variability, the natural variability of the climate system that occurs due to the basic atmospheric system itself (Deser et al., 2012). Uncertainties also arise from the incorporation of climate model results into hydrological models mainly because of different spatial scales. Countries like Nepal, which are dependent on rainfall and snow-fed rivers, may face greater problems as far as climate change is concerned because uncertainty in precipitation (magnitude, timing and frequency) increases.

Many parts of Nepal are currently experiencing changes in precipitation patterns (Shrestha et al., 2000; Baidya et al., 2008; Bartlett et al., 2010). Earlier assessments of the impact of climate change on water resources in the Koshi basin were based on one or two climate models, for example, Gosain et al. (2010) used HadRM2 and HadRM3 and WWF (2009) used HadCM3. On the other hand the present study considered outputs from ten GCMs for three SRES scenarios. We analyzed precipitation in the Koshi basin by dividing the basin into six physiographic regions based on elevation differences. Furthermore, we analyzed the baseline and future period's precipitation data to study the changes that may occur in the various indices for precipitation extremes. The main objective of this study was to assess precipitation projections for the Koshi river basin in Nepal and to analyze uncertainty in these projections by taking into account the differences between different GCM projections as well as between different future emission scenarios. This study focus on analysis for three periods over the 21st century: an early-century period of 2011–2030 (2020s), a mid-century period of 2046–2065 (2055s), and a late-century period of 2080–2099 (2090s).

2. Study area and data

2.1. Study area

This study was conducted in the Koshi river basin, in Nepal. The Koshi flows through China, Nepal and India and is one of the largest tributaries of the Ganges. The Koshi River, along with its tributaries, drains a total area of 69,300 km^2 up to its confluence with the Ganges in India (WWF, 2009; Gosain et al., 2010). In Nepal, Koshi is the largest river basin, covers 18 districts (administrative boundaries in Nepal) and nearly 30,000 km^2 of land from the Himalayas to the agricultural lowlands of the Terai Plains. It consists of seven major sub-basins (Sun Koshi, Indrawati, Dudh Koshi, Tama Koshi, Likhu, Arun and Tamor), all originating from the Himalayas. The basin area lies within latitudes 26°51′ and 29°79′N, and longitudes 85°24′ and 88°57′E. The altitude of the basin ranges from 65 mamsl (meters above mean sea level) in the Terai Plains to over 8000 mamsl in the High Himalayas (Dixit et al., 2009). Given the significant altitudinal variation in the basin, it was divided into six distinct physiographic regions: the Terai Plains (<700 mamsl), the Low River Valleys (<700 mamsl), the Siwalik Hills (700–1500 mamsl), the Mountains (1500–2700 mamsl), the High Mountains (2700–4000 mamsl) and the Himalayas (>4000 mamsl) following Shrestha and Aryal (2011). The area below 700 mamsl was divided into two regions (Fig. 1): the Low River Valleys, which are low valleys upstream of Chatara station (located along the Siwalik Hills) and the Terai Plains downstream of Chatara (located in the south of the Siwalik Hills). As shown in Fig. 1, the majority of the area in the Koshi basin falls under the Mountains, followed by the Hills, Himalayas, High Mountains, Terai Plains and Low River Valleys.

The climate of the Koshi basin ranges from tropical in the Terai Plains and Low River Valleys to arctic conditions on mountain peaks, and passes through warm temperate, cool temperate and alpine conditions as elevation increases (Dixit et al., 2009). The mean annual temperature is 20 °C in the Hills and 16 °C in the Mountains. In general, the temperature decreases from South to North. Precipitation in the Koshi basin increases from the Low River Valleys to the Mountains and then decreases in regions of higher elevation like the High Mountains and Himalayas. Maximum precipitation is observed in the Mountains while minimum precipitation is observed in the Himalayas. The majority of the population (almost 70%) in the basin is dependent on rainfed agriculture for its livelihood (Dixit et al., 2009). The Hills and the Terai Plains contribute the maximum area to agriculture in the basin. Water stress during the dry season and frequent floods during the monsoons are the biggest challenges in the Koshi basin (NCVST, 2009).

2.2. Observed precipitation data

The daily observed precipitation data for all the stations located in the Koshi basin were collected from the Department of