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Runoff predictions in ungauged catchments in southeast Tibetan Plateau

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SUMMARY

The Tibetan Plateau (TP) plays a key role on both hydrology and climate for southern and eastern Asia. Improving runoff predictions in ungauged catchments in the TP is critical for surface water hydrology and water resources management in this region. However, a detailed runoff prediction study in this region has not been reported yet. To fill the gap, this study evaluates two regionalization approaches, spatial proximity and physical similarity, for predicting runoff using two rainfall–runoff models (SIMHYD and GR4J). These models are driven by meteorological inputs from eight large non-nested catchments (4000–50,000 km^2) in the Yarlung Tsangpo River basin located in southeast TP. For each catchment, the two models are calibrated using data from the first two-thirds of the observation period and validated over the remaining period. The calibrated and validated Nash–Sutcliffe Efficiency of monthly runoff (NSE) varies from 0.73 to 0.93 for the SIMHYD model, and are similar to or slightly better than those obtained for the GR4J model. The incorporation of snowfall–snowmelt processes into the rainfall–runoff models does not noticeably improve the runoff predictions in the study area. The main reason is that monthly runoff is dominated by summer precipitation and snowfall in winter accounts for a small percentage (less than 14%). The results from both models show that the spatial proximity approach marginally outperforms the physical similarity approach and both approaches are better than random selection of a donor catchment. This is consistent with recent regionalization studies carried out in Europe and Australia. The study suggests that conceptual rainfall–runoff models are powerful and simple tools for monthly runoff predictions in large catchments in southeast TP, and incorporation of more catchments into regionalization can further improve prediction skills.

1. Introduction

The Tibetan Plateau (TP) has an average altitude of 4700 m, and is the highest plateau in the world. The TP plays a determinant role on the hydrology and climate of eastern and southern Asia. Several large rivers originate from the TP, including Yellow River, Yangtze, Mekong, Salween, Irrawaddy, Brahmaputra, Indus and Ganges. These rivers sustain the lives of hundreds of millions of people living downstream (Immerzeel et al., 2010; Yao et al., 2010). Therefore, it is important to simulate or predict runoff at large scale in the TP for a better understanding of surface water availability and management.

Conceptual and distributed hydrological models are increasingly used to simulate hydrological processes, water balance and runoff for the TP catchments (Immerzeel et al., 2009; Kite, 2001; Yang et al., 2011). Wohl (1995) estimated flood magnitude using parameters related to channel geometry in five ungauged mountain channels in Nepal, which indicated that indices from channel characteristics were useful indicators for flood peak estimation. Krause et al. (2010) estimated water balance components using a spatially distributed conceptual hydrological model (J2000), with parameters transferred from an alpine catchment in Austria, in the Nam Co basin in Tibet, and achieved reasonable water balance simulation results. Peng and Du (2010) analyzed the Xinanjiang model and the modified TOPMODEL model for flood forecasting in the Lhasa River basin. Nash–Sutcliffe Efficiency of hourly runoff varied from 0.61 to 0.83 during 1998–2001, indicating that two the models perform well in flood forecasting. Bharati and Gamage (2010) calibrated Pitman semi-distributed monthly model for the upper Koshi basin in Nepal and then transferred the optimized parameters to the Lhasa basin for runoff predictions in ungauged catchments. But they did not assess simulation results using available runoff data in the Lhasa basin. The above-mentioned runoff prediction studies were conducted at annual (Krause et al., 2010), monthly (Bharati and Gamage, 2010) or daily (Peng and Du, 2010;

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0022-1694/$ - see front matter Crown Copyright © 2014 Published by Elsevier B.V. All rights reserved.
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Wohl, 1995) scale. They either focus on one catchment or small research area. The use of multiple catchments in predicting runoff over a large region has not been reported yet.

To fill the gap, this study uses two lumped rainfall–runoff models, SIMHYD and GR4J, by applying two regionalization approaches to explore accuracy of runoff predictions in eight mountainous catchments located in the Yarlung Tsangpo River (YTR) basin which is the largest river system in the TP. Although YTR is an extremely important water source for the downstream irrigation and hydroelectric power generation in areas with chronic power shortages, it is an ungauged and poorly studied area (Yang and Zheng, 2004). The YTR has extremely rugged and remote nature of the terrain and poorly gauged river networks, which make lumped hydrological models, with few parameters and easily calibrated, more applicable. Therefore, two lumped hydrological models, SIMHYD and GR4J, are used in this study. They are widely used for regionalization and climate change impacts studies. For each model, two widely used regionalization approaches, spatial proximity and physical similarity, are used to choose a donor gauged catchment whose optimized parameter values are then transferred to model runoff for an "ungauged" catchment (Bárdossy, 2007; Masih et al., 2010; Oudin et al., 2010; Zhang and Chiew, 2009).

The main objectives of this study include (1) evaluating the accuracy of runoff predictions from the spatial proximity and physical similarity approaches for the YTR basin; (2) investigating if the two models have similar performances in model calibration and validation in 'ungauged' catchments; and (3) evaluating if the incorporation of snowfall–snowmelt processes into the two rainfall–runoff models improves the skill of runoff predictions for the YTR basin.

2. Study catchments, data and models

2.1. Catchment and data

The YTR basin (called Brahmaputra in India, Fig. 1) originates from the Gyima Yangzoin Glacier at an elevation of 5590 m in south-central Tibet, and it is the highest river in the world with an average elevation of over 4000 m above sea level (Yang and Zheng, 2004). The average annual surface streamflow of the YTR is about 166 billion m^3, with the annual average runoff depth ranging from 99 mm in the upper-middle reaches to 421 mm in its low reaches (Table 1). The climate in the YTR basin is characterized by intense solar radiation, low air temperature, and highly daily variations in air temperature but low yearly air temperature fluctuations with distinct dry (from October to May) and wet (from June to September) seasons (Yang and Zheng, 2004). Mean annual precipitation varies from 200 mm in the upper reaches to 5000 mm in the easternmost part, and most of the rain falls between June and September (You et al., 2007).

Table 1 summarizes the major attributes of the catchments used in the study, and corresponding record periods used for model calibration and validation. The catchment area varies from 3761 km^2 to 49,739 km^2, with the median area of 12,549 km^2. The median mean elevation for the eight catchments is about 4880 m. Most of the catchments are located in semi-arid regions, with annual precipitation varying from 288 mm to 583 mm and the aridity index (ratio of mean annual potential evaporation (ETp)/mean annual precipitation (P)) ranging from 4.3 to 8.7. The forest cover in most catchments is lower than 10%, and the main soil type is high-mountain soil accounting for 68–99% catchment area, followed by semi-hydromorphic soil. These catchments all exhibit a single annual hydrograph peak, with a maximum in July to September, generally resulting from a single rainy season, June to September. Snowfall occurs in winter and spring because of high elevation and low air temperature in the TP.

Monthly runoff data for the eight catchments for the period of 1960s to 2000/2002 were obtained from the Hydrology and Water Resource Survey (HWRS), the Tibetan Autonomous Region (TAR) of China (Table 1). Note that daily runoff data for the eight catchments were not provided. Shigatse and Gyantse catchments are subject to irrigation diversion; the other six are unregulated. The streamflow data for the Shigatse and Gyantse catchments are considered as natural flows, because they are estimated as the sum of actual flows and regulated flows used for irrigation.

The forcing dataset for the two hydrological models was extracted from 0.5 degree resolution grid dataset for whole China, which includes daily precipitation, mean and maximum temperature from 1962 to 2002. This data was provided by the National Climate Center of China Meteorological Administration (http://ncc.cma.gov.cn). The gridded daily precipitation dataset was spatially interpolated using observations from over 2200 stations across East Asia, including 751 across China; the gridded mean and maximum temperature were spatially interpolated from the same 751 stations. The gridded precipitation and temperature climatology was first calculated and interpolated with the optimal interpolation method, and then a gridded daily anomaly was added to the climatology to obtain the daily time series. To correct the bias caused by orographic effects, the daily anomaly of precipitation and temperature were adjusted by daily/monthly climatology,

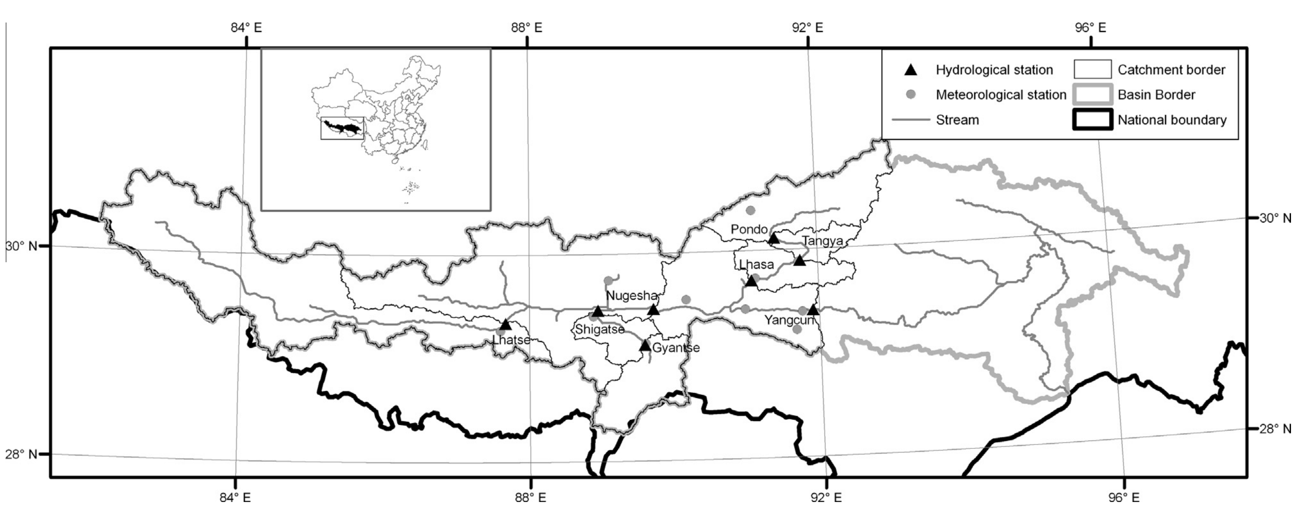

Fig. 1. Locations of catchments used in the study.