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RESEARCH PAPER

Modelling snowmelt runoff in Lidder River Basin using coupled model

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ABSTRACT
A major proportion of discharge in the Lidder River is contributed by snowmelt runoff in its catchment which is situated in the West Himalayan region. It is, therefore, quite essential to estimate the contribution of snowmelt runoff to discharge along with other hydrological components. The MIKE SHE-MIKE-11 integrated coupled model along with the moderate resolution imaging spectroradiometer (MODIS) remote sensing snow cover products was selected and used in the Lidder Basin to ascertain the snowmelt contribution to runoff along with baseflow and drainage, as well as the percentage of snow-covered areas in the Basin around the year. The model was calibrated by trying to match simulated discharge against observed stream flow discharge at the Sheeshnag gauging station. Sensitivity analysis was carried out by varying three unknown parameters, viz., degree day coefficient, temperature lapse rate and precipitation lapse rate. The three parameters were unknown in the region. The cumulative volume of the simulated runoff was further validated with the observed runoff which showed an excellent comparison. The snow-covered areas obtained from the output of the model were validated with the data obtained from MODIS data sets. The data showed an excellent comparison. The ET losses at Sheeshnag represented 19.65% of the total rainfall, while the runoff at the Sheeshnag catchment of the Lidder Basin represented 40% of the total rainfall. Snowmelt contribution to the total streamflow in the Lidder River at Sheeshnag was found to be 54.19%. The total error percentage of the model was about 0.11 of the total rainfall, indicating a good interaction among different hydrological components of the model. The results obtained suggest that the MIKESHE-MIKE-11 integrated coupled model can be used efficiently in the sub-catchments of the upper Indus Basin in which snowfall and snowmelt runoff are significant.

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Snowmelt runoff modelling; high altitude Basin; distributed model; MIKESHE

Introduction

The Himalayas is the largest mountain range in the world, extending over a length of 2500 km. Snowmelt runoff is one of the major sources of freshwater for many regions in the world. Snowpacks fulfill 33% demand of irrigation water in the world (Brooks *et al.* 1997). An estimation of snowmelt runoff is very important in the Western Himalayan rivers in India where it is required to plan for hydropower generation and water management during the non-monsoon season (Agrawal *et al.* 1983, Singh and Singh 2001, Adam *et al.* 2009, Bookhagen and Burbank 2010).

Complex climatic and topographical conditions in remote areas of watersheds make an assessment of snowmelt contribution very difficult. Snowmelt, along with the baseflow, is an important contributor to discharge in the Himalayan rivers. The seasonal water availability depends not only on precipitation but also on snow and glacier melt (Gillan *et al.* 2010, Moors *et al.* 2011). Rainfall with strong rainfall gradients along the foreland is dominated by its topography (Bookhagen and Burbank 2010).

Physically based distributed models have many advantages compared to traditional lumped parameter models in simulating hydrologic response to water management (Sun *et al.* 2007). Distributed models can simulate the interactions between precipitation, geomorphology, vegetation, land use, and anthropogenic influences using a Geographic Information System (GIS) and remote sensing technology (Ciarapica and Todini 2002, Singh and Woolhiser 2002).

The distributed watershed hydrologic simulation model, MIKE SHE, originally derived from the SHE model (Abbott *et al.* 1986), has been widely used for examining hydrological responses to land use, land cover change and climate variability (Graham and Butts 2005, Lu 2006, McMichael and Hope 2007). Other areas of study on MIKE SHE include sensitivity analysis and spatial scale effects (Xevi *et al.* 1997, Vazquez and Feyen 2007), model parameterization, calibration, and validation (Singh *et al.* 1997, Andersen *et al.* 2001, Henriksen *et al.* 2003, Madsen 2003), and the evaluation of the potential evapotranspiration (PET) methods (Vazquez and Feyen, 2003).

Snowmelt runoff modelling studies have been carried out using physics-based energy budget models or temperature index based snowmelt calculation approach based models (Immerzeel *et al.* 2009, Bookhagen and Burbank 2010). Degree-day-based methods are commonly used in hydrology because these models require less additional data and are relatively simple to calibrate (Connell *et al.* 1998; Singh *et al.* 1998, Illangasekare 2001, Thompson *et al.* 2004, Nazrul *et al.* 2006, Sahoo *et al.* 2006, Stisen *et al.* 2008). Energy balance methods are also widely used, but require considerably more detailed input data. Further, the energy balance methods are often layer based (i.e. multi-layered snow models) and the energy balance is often calculated implicitly.

It has been observed that previously researchers had mostly used lumped models, i.e. model input parameters

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