論文内容の要旨

論文題目 Development of a Distributed Hydrological Model Coupled with Satellite Data for Snowy Basins
(積雪流域を対象とした衛星データを組み込んだ分布型水文モデルの開発)

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ABSTRACT

Snowmelt accounts for 50-80% of the annual stream flow in many areas of the world, including the Sierra Nevada, the Rockies, the Alps, the Andes and the Himalayan Mountains. Reliable methods of snowmelt and its runoff forecasting from the preseason extent of snow and glaciers would be a great benefit in water resources planning and management.

Snow hydrological data, especially, in rugged and remote terrain of developing countries is not fully available. It is very difficult to obtain the data of snowcover extent and snow water equivalent and to take heterogeneity in a basin into account. Satellite remote sensing and a distributed runoff modelling are very effective for addressing these issues.

The objective of the present research is the development of a distributed snowmelt runoff simulation system based on remote sensing data for better water resources forecasting and management and its application in data sparse areas. In order to achieve the objective, the following approaches are adopted from the three different standpoints:

Development of a basis for a snowmelt model using meteorological, topographical and remote sensing data and confirmation of its performance in a basin (Tone River, Japan) where data sets are fully available

Development of a distributed snowmelt runoff simulation system using meteorological, topographical and remote sensing data and checking the system performance in a basin (Upper Yellow River, China) which includes high elevation area with less availability of data

Development of a basis for a comprehensive water resources forecasting and management system in the Indus River basin, by introducing the distributed snowmelt runoff simulation system to the Karakoram and Himalaya ranges

The distributed snowmelt runoff simulation system consists of three main components: the development of a snowmelt model; the development of a distributed runoff model by coupling with snowmelt model; data preparation including meteorological, remote sensing and GIS data.

Firstly, the developed semi-energy based snowmelt model consists of shortwave and longwave net radiation, sensible heat exchange with the atmosphere, condensation of water vapour and heat input by precipitation. Due to unavailability of data, degree-hour model is applied to sensible heat and condensation component for rainy period only. Corrections for slope, aspect, latitude and season have been considered for shortwave radiation input. Effect of cloud cover and forest canopy is taken into account in the case of longwave radiations. Effect of aging snow on snow albedo has been taken into account by an albedo decay function. Snowmelt in each pixel is a function of percentage of snow area in that pixel.

Secondly, coupling of snowmelt model with a distributed hydrological model is carried out. Geomorphology based distributed hydrological model is used in the study and is termed as GBHM throughout this dissertation. A discrete flow interval-hillslope system is used and the computational unit is hillslope element. A catchment is divided into a number of flow intervals along the flow distance. The river network is lumped using the main channel. Large catchments are divided into several sub-catchments and the river network is simplified using the main rivers of sub-catchment. The hydrological model contains three main modules: (1) Spatial distribution module, (2) Hillslope module, (3) and River routing module. The spatial distribution module offers the representations of catchment spatial variations including topography (elevation, hillslope gradient, and hillslope length), land use and soil properties, rainfall, air temperature, potential evapotranspiration by one dimensional-distribution functions. The hydrological processes that occur in the hillslope elements, including interception, snowmelt, evapotranspiration, overland flow, unsaturated zone water flow, saturated zone water flow and exchange with river, are described by the physically-based governing equations within the hillslope module. The hillslope runoff is the lateral inflow into the river.

Meteorological, topographical and satellite remote sensing data is used in the development and description of the system. Meteorological forcing data of precipitation, air temperature, evaporation, and sunshine duration has been used and are downscaled from daily to hourly time scale. Precipitation is interpolated using an angular distance weighting method from point data into basin average precipitation. The temperature at a station is interpolated for each grid using an elevation corrected angular direction weighting method. The digital elevation data of 1-km resolution is obtained from the USGS HYDRO1k data set and land cover is obtained from the USGS Global Land Cover Characteristics Data Base Version 2.0. The soil type and the texture data are obtained from the Digital Soil Map of the World using the FAO-UNESCO soil classification. The soil properties used for the hydrological simulation including the porosity, the saturated hydraulic conductivity, and the other soil water parameters corresponding to each soil type are obtained from the Global Soil Data

Task. Percent snowcover area on pixel basis is estimated using NOAA/AVHRR channel-2 and channel-4 satellite data.

Large catchments are divided into several sub-catchments. The degree-day snowmelt model used in the GBHM is replaced by the semi-energy based model, which calculates snowmelt from remote sensing based snowcover and is termed as RDSRM. Precipitation from snowfall is ignored in the RDSRM. Frozen soil effects have been incorporated.

Snowmelt model performance has been tested in the upper Tone River basin Japan which is a humid region with precipitation about 1500 mm per year. This region usually has a heavy snowfall during winter (December to February). Snowmelt runoff simulation by a distributed hydrological model is conducted for 2001 and 2002. Simulated runoff is compared with the observed discharge for 2001. The results show very good performance for hydrological model. Simulated runoff matches the observed discharge and the trends are also well preserved.

Snowmelt is coupled with a distributed hydrological model and its performance has been checked in a high elevation and semi-arid region of the upper Yellow River basin where less forcing data is available. The model is calibrated from 1998 to 1999 and validated for 2000. The predicted discharges by the RDSRM are closer to the observation. The predicted discharges by GBHM are much short from observed ones during snowmelt season. These results demonstrate that remote sensing based snowmelt approach brings a major improvement over degree-day methods used in GBHM.

Based on the validation of the system in high elevation and semi-arid region of the upper Yellow River basin, the system is applied to the upper Indus Basin. High elevation upper Indus River Basin is also an arid region where 80 to 90 % of the water comes from snowmelt and remote glaciers tucked in the majestic Himalayan and Karakoram ranges.

Spatial distribution of meteorological gauges is not uniform and most of the gauges are located in valley bottom and at the medium elevation bands. The application to the catchments in Karakoram Range has been tested for the following areas; Hunza River, Gilgit River at Gilgit and Gilgit River at Alam Bridge. The model is calibrated from 1997 to 1999 and validated for 2000. GBHM does not simulate snowmelt runoff as it uses valley precipitation, which does not represent the intensity and frequency of precipitation storms at high elevation bands properly. The results show good performance of RDSRM model for both long-term and seasonal snowmelt simulations. Contribution of river discharge by summer rain is only 7%. The result of this system application to the Gilgit Basin indicates that partial energy balance approach in snowmelt yields reasonable estimates of snowmelt runoff.

The application to the Great Himalaya region has been carried out by applying the models for upper Jhelum River which is an eastern tributary of the Indus River. This is a semi-arid area with substantial Indian summer monsoon and winter snowcover. Analysis shows that 45 % Jhelum basin area is covered by seasonal snow. Hydrological simulation has been performed for 1997 and 1998. GBHM simulation is better in winter and late summer than in summer season when the model underestimates snowmelt greatly. RDSRM gives better simulation results both in winter and summer season especially in the Neelum and Kunhar River Basins.

From the above applications, it is concluded that the system is widely applicable to different topographical areas and climatic characteristics for both long-term and snowmelt simulations. By using remote sensing data and with good topographical and geomorphological representation of catchment characteristics, reasonable results can be obtained from the hydrological model simulation even when very limited in situ data is available.