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Performance assessment of the BTOPMC model in a Nepalese drainage basin

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Abstract BTOPMC, a physically-based distributed hydrological model based on the block-wise use of TOPMODEL with Muskingum-Cunge flow routing method, was selected to evaluate the applicability in a Nepalese basin. Model performance was judged by a range of quantitative and qualitative measures of fit applied to both the calibration and validation periods. BTOPMC can be successfully used as a tool for integrated water resources investigation in a large watershed, the mountain physiographic region, Nepal.

Key words BTOPMC model; Nepalese river basin; performance assessment; Sun Kosi River; water balance

INTRODUCTION

Nepal, with an area of 147 181 km^2, has more than 6000 rivers stretching from the Great Himalayas with an elevation of more than 8800 m, to the southern plain called "Terai" with an elevation of 100 m, within a 200 km width. This provides a dense network of rivers with steep topographical conditions and 80% of the total annual rainfall concentrates in a relatively short period of about four months. These peculiar characteristics lead to a set of hazards, including frequent floods. The country has been regarded as one of the richest nations of the world in water resources, having annual average surface water availability of 1 521 934 m^3 km^2 and 11 200 m^3 per capita. Nepal is a country with vast hydroelectric resources. The total hydropower potential of Nepal is estimated to be 83 000 MW. Moreover, Nepal is an agriculture-based country.

In view of the important role that the water resource can play in Nepal and the need to harness it in a sustainable manner, it is essential to know the various facets of the water resources. Depending on the situation, different approaches to its use is needed to be designed, sometimes to "keep the water away from the people", and at other times "keep the people away from the water". Suitably selected models can help to identify issues which are useful for planning various development projects with minimum risk of flood disasters, alerting people to keep away from such disasters in time, and providing planners with information about water for use in various development projects like hydropower, irrigation, etc. Until now, quite a few such models have been tested in Nepal. With the advancement of technology, GIS and satellite images have played a vital role for the easy access of a wide range of data. The model, which can incorporate such data, is very fruitful for a country like Nepal, where only a few scattered and less reliable data sources are available.

The inability of lumped type models to explicitly handle land-use changes and water-use systems modification make them unsuitable, without extensive modification, for the present requirements. More suitable types of models include distributed models, but most of them are data demanding and not yet practical for large ungauged basins. Thus, to overcome all the complexities and difficulties stated above, BTOPMC (Ao *et al.*, 1999b; Takeuchi *et al.*, 1999)—a physically-based distributed hydrological model based on the block wise use of TOPMODEL (Beven & Kirkby, 1979) with Muskingum-Cunge flow routing method—was selected to evaluate the applicability in a Nepalese catchment. In contrast to other models, in TOPMODEL the catchment is not divided into homogeneous units, but natural heterogeneity (i.e. topography) and its effects on hydrological processes are represented by distribution functions (Seibert, 1999).

MODEL DESCRIPTION

The component models for BTOPMC are as follows:

(a) Runoff Generation Model: The block-wise use of TOPMODEL is adopted. The model parameters and the average soil-topographic index are calibrated or computed for each block, respectively.

(b) Routing Model: The variable coefficient Muskingum-Cunge routing method is used by which the river reach characteristics can be considered, and the velocity and discharge for any grid can be obtained simultaneously.

(c) Terrain Model: A river stream network is produced from the DEM with an automatic sink removal algorithm developed by the authors.

(d) Precipitation Model: the Thiessen method is adopted to give rainfall for each grid cell in which rainfall is given the value of the nearest raingauge. Basin-averaged rainfall can also be used.

(e) Evapotranspiration Model: The Penman method is used to estimate monthly evapotranspiration and the estimated values are provided to BTOPMC model.

STUDY AREA

The study area, the Sun Kosi River basin, lies within the Kosi basin. The study area is located in the eastern part of Nepal. The Kosi basin is one of Nepalese three major river systems and lies between latitudes of 26°50′N and 28°N and longitudes of 85°30′E and 88°12′E. The drainage basin area within Nepal is estimated to be 33 000 km^2. The Kosi basin is divided into three major topographic and ecological areas: the Mountain area in the north, the hill area in the midland and the Terai area in the south. The Sun Kosi basin lies between the mountain area and the hill area. The mountain area is situated at an altitude exceeding 3000 m, with the highest point reaching more than 8000 m. The hill area lying between 3000 and 300 m consists of high ridges and steep slopes including the Mahabharat range and Siwalik Hills. The Terai area, lying below 300 m, forms the southern belt extending along the Indian border.

Rainfall distribution in the Sun Kosi basin is in a concentric circular pattern. Maximum annual rainfall in the Sun Kosi is 3500 mm with a minimum of 2000 mm

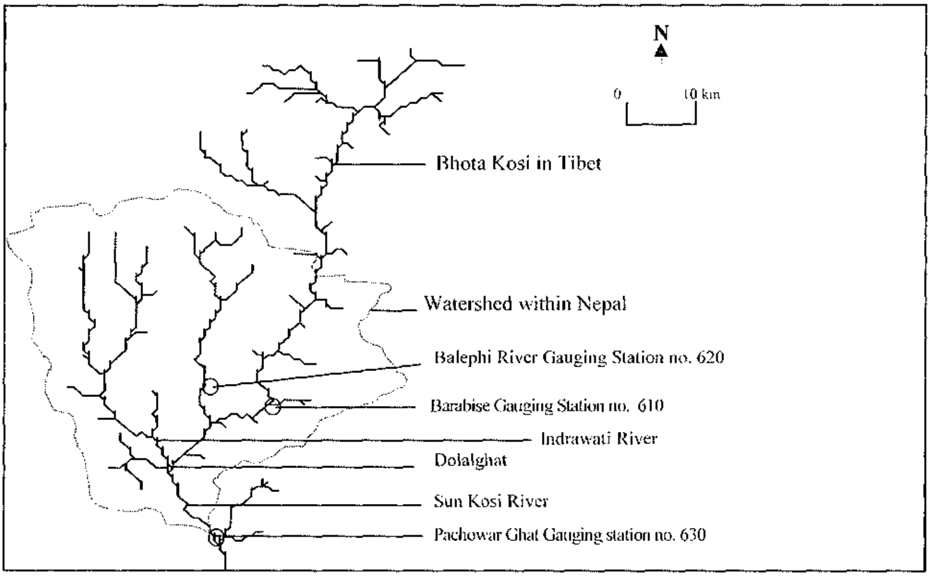

Fig. 1 Sun Kosi drainage basin above Pachowar Ghat gauging station no. 630.

and rainfall is particularly heavy in the upper reaches of the Sun Kosi along the Bhote Kosi basin where annual rainfall exceeds 3500 mm.

The total length of the Sun Kosi River is approximately 330 km, of which 280 km lies in Nepalese territory (Japan International Co-operation Agency, 1985). The river gradient is approximately 1/210 throughout the entire length of its course in Nepal and 1/450 between Tribeni and Dolalghat. The Sun Kosi, the Tamur and Arun rivers meet at Tribeni and the Indrawati River joins the Sun Kosi River at Dolalghat. The Sun Kosi study area was taken above Pachowar Ghat gauging station no. 630 (see Fig. 1).

DISCUSSION

Of the 330 km total length of the Sun Kosi River, 280 km lies in Nepalese territory and the rest lies in the Tibetan Plateau where data information was not available (see Fig. 1). To cope with this problem, the observed discharge is given as a boundary condition so that the drainage basin above that gauging station can be removed. Thus the observed discharge of Barabise gauging station no. 610 (see Fig. 1) is given as input for the calibration and validation periods.

The whole drainage basin area under study was approximately 5000 km^2. This study area was divided into eight blocks. The basin is described by a digital terrain model of resolution 30 arc second downloaded from GTOPO30 (USGS, US Geological Survey internet site). Despite of the coarse resolution, topographic data and inconsistency in observed hydro-meteorological data, the simulation results of the model were promising. The simulation results from calibration for the year 1991 are shown in Table 1. The results were good enough with 80% Nash efficiency. Figure 2 shows the comparison of hydrographs for this calibration period in 1991.

Table 1 Calibrated simulation results for year 1991.

Simulated average discharge ($m^3 s^{-1}$)	211.3
Observed average discharge ($m^3 s^{-1}$)	229
Nash efficiency (%)	80.0
Volume ratio of simulated and observed average discharge	0.9
Simulated water balance (m)	–0.2
Peak time of simulation (day)	229
Peak time of observation (day)	222
Simulated maximum peak discharge ($m^3 s^{-1}$)	1162.6
Observed maximum peak discharge ($m^3 s^{-1}$)	1360

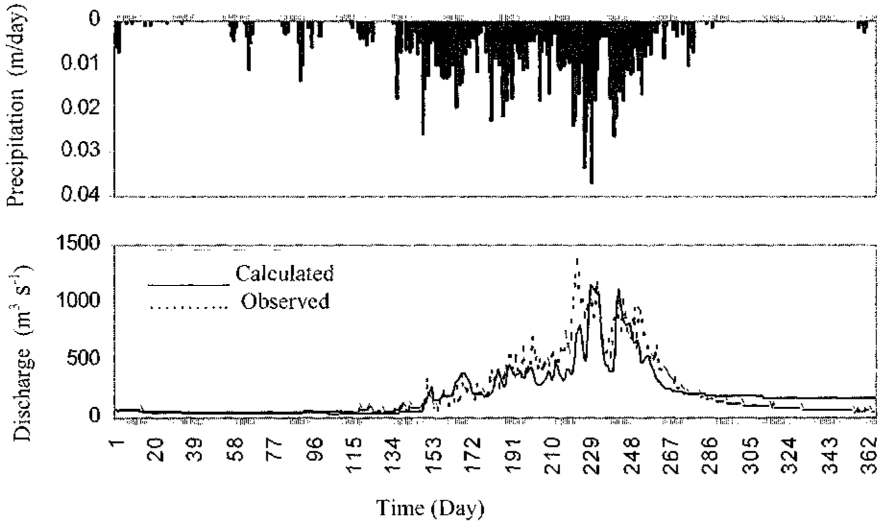

Fig. 2 BTOPMC Model calibration for Sun Kosi River in 1991 at Pachowar Ghat gauging station no. 630.

The same parameters were used for verification for the year 1990. The result was good enough with 75.8% Nash efficiency. The simulation results from validation year 1990 are shown in Table 2. Figure 3 shows the comparison of hydrographs for this validation period in 1990.

In the calibration period, the rate of recession for the groundwater flow was too low, which gave poor water balance for the later dry season of the year (refer Fig. 2). In TOPMODEL, the saturation deficit controls the discharge from the local area. The groundwater discharge, $q_b(i,t)$, is determined by the local saturation deficit, $SD(i,t)$, the gradient of the local surface, $\tan\beta i$, and the parameters relating to transmissivity of the block, T_o and m, as follows:

$$q_b(i,t) = T_o \, e^{-SD(i,\,t)/m} \tan\beta i \qquad (1)$$

Thus saturation deficit variation with respect to time was analysed. In Fig. 4, the saturation deficit gradually decreased and from day 229 onwards the soil is completely

Table 2 Validated simulation results for year 1990.

Simulated average discharge ($m^3 s^{-1}$)	284.1
Observed average discharge ($m^3 s^{-1}$)	253.7
Nash efficiency (%)	75.8
Volume ratio of simulated and observed average discharge	1.1
Simulated water balance (m)	-0.2
Peak time of simulation (day)	226
Peak time of observation (day)	199
Simulated maximum peak discharge ($m^3 s^{-1}$)	1597.9
Observed maximum peak discharge ($m^3 s^{-1}$)	1410

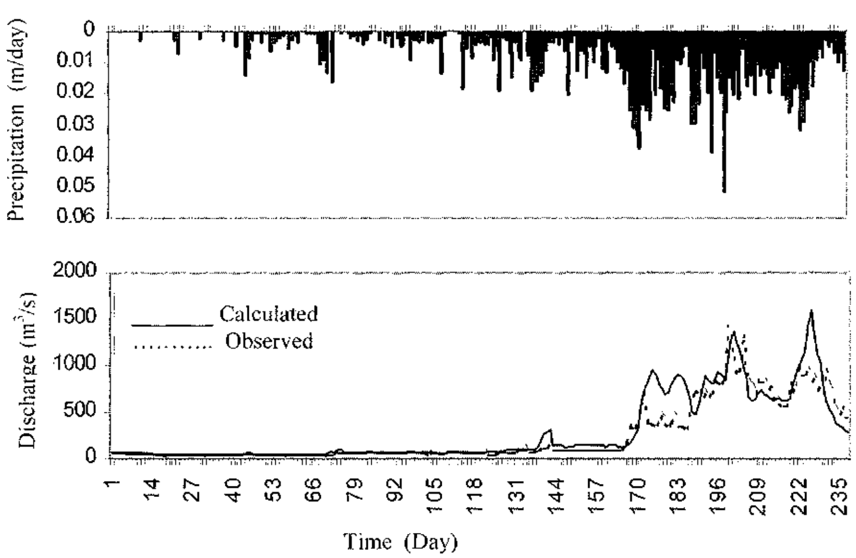

Fig. 3 BTOPMC Model verification for Sun Kosi River in 1990 at Pachowar Ghat gauging station no. 630.

saturated leading to low recession rate of groundwater flow. This is why the model failed to give satisfactory water balance for the later dry season of the year shown in Fig. 2. Thus, in validation period, the later dry season of the year was not taken into account (see Fig. 3).

All the parameter calibration was done by the trial-and-error method. Apart from the distributed soil topographic index, eight sets of parameters were estimated for the drainage basin divided into eight blocks shown in Table 3. Regarding the volumetric analysis, lateral transitivity played the most important role whose increment highly changed the base flow during the rainy season. On the other hand lateral transitivity and saturation deficit of the soil influenced each other in water balance analysis. The rate of recession of the groundwater flow in the later dry season is very low (see Fig. 2).

Hence, in the calibration by trial and error process the values of lateral transitivity were kept very low, as shown in Table 3. The increment of Manning's roughness coefficient decreased the peaks by shifting them backward.

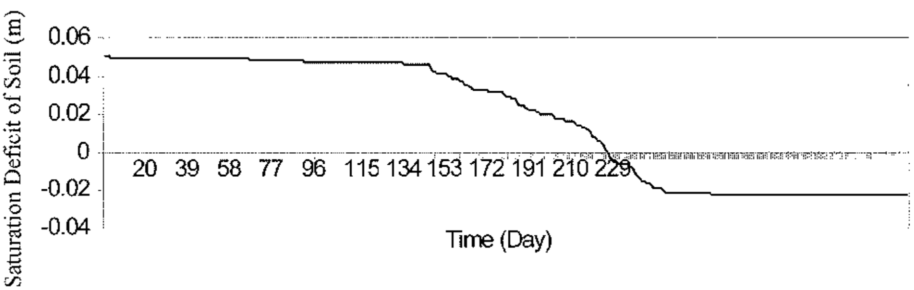

Fig. 4 Variation of saturation deficit of soil with respect to time for block 8.

Table 3 BTOPMC calibrated parameters for year 1991 and used in verification for year 1990.

Block Number	To ($m^2 h^{-1}$)	m (m)	Sr_{max} (m)	$S_{bar}0$ (m)	n ($m^{-1/3} s^{-1}$)
1	0.51	0.03	0.008	0.501	0.01
2	0.10	0.013	0.004	0.21	0.01
3	0.15	0.015	0.003	0.06	0.01
4	0.03	0.01	0.002	0.021	0.05
5	10.05	0.02	0.002	0.82	0.02
6	10.02	0.02	0.003	0.81	0.01
7	2.50	0.023	0.002	0.01	0.01
8	0.01	0.05	0.002	0.051	0.01

T_o: saturated transmissivity of soils;
m: decay factor of T_o;
Sr_{max}: capacity of root zone storage;
$S_{bar}0$: initial saturation deficit of soil;
n: Manning roughness coefficient.

On overall analysis of the performance, the BTOPMC model can be successfully used as a tool for integrated water resources investigation in a large watershed, mountain physiographic region, in Nepal.

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