Simulation Experiment of TOPMODEL to the Binggou Catchment, Heihe River Basin, Northwest China

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Abstract

This paper describes a distributed modeling approach applied to stimulate the stream flow on a 30.06 km^2 Binggou watershed on the North Slope of the Tuolai Mountains in Heihe Basin, Northwest China. The simulation process has assembled a modeling system centered on TOPMODEL, simulation of saturated excess runoff was mainly based upon topography, the other components deemed relevant to the hydrologic processes in the basin, however, were simulated not only upon the topography but also the Geographic Information System (GIS) data . Precipitation was spatially interpolated from five rain gauges using linear interpolation on Delauney triangles and scaling by an annual rainfall surface to represent orographic effects. The model included the following components: 1) reference evapotranspiration estimation by following Maident D.R. (1993); 2) interception and throughfall, an unsaturated zone soil layer that delayed water inputs to the saturated zone and provided infiltration excess runoff generation capability, and a kinematic wave channel routing component. Procedures were developed to generate model input files from digital elevation model and land resource inventory GIS data. Model elements are subwatersheds automatically extracted based upon the channel network generated from the Digital Elevation Model (DEM) and a specified stream order threshold. Model element parameters are linked to GIS information averaged over each subwatershed. Totally 9 subwatersheds were subdivided, and the model was calibrated using an interactive calibratioing package with the Gauss-Marquardt method. The calibration uses scale multipliers to retain GIS landcover derived relative differences between parameters across subwatersheds. Model parameters were first calibrated for one year then independently tested there for the following years. The calibration used precipitation measured at this small watershed while the validation exercised the precipitation interpolation methodology. The results indicate that streamflow estimates are sensitive to uncertainty in the precipitation due to variability and orographic effects, and this precipitation uncertainty takes prodominate role among all the sources.

Introduction

Orginally developed at the Leeds University, UK in the mid-1970s, topography based hydrological model (TOPMODEL) has been widely used in predicting or estimating catchment water discharge, spatial soil water saturation pattern, temporal-spatio distribution of soil moisture, geochemical flux, evaporation, erosion and deposition … etc. (Beven, 1986; Quinn and Beven, 1993) in its recent development based upon precipitation and evapotranspiration time series with topographic information. The objective of TOPMODEL was to establish a physically based rainfall runoff model that only requires simple parameters as input to predict various hydrological responses (Ambroise et al., 1996; Beven and Kirkby, 1979; Beven, 1997). A minimum of four effective catchment parameters need to be estimated to characterize the discharge dynamics of the catchment. The parameters are fitted from the discharge predictions. Neither horizontal or vertical soil parameters need to be supplied. However, to estimate water table or soil moisture content from the saturation deficit requires soil information. A correct estimation of evaporation is critical for model performance. Evaporation is most frequently estimated by using the Penman-Monteith methods, However, Shuttleworth method (Maident D.R. 1993) was found much practical since it need less input parameters. Indeed, TOPMODEL is not a hydrological modeling package. It is rather a set of conceptual tools that can be used to reproduce the hydrological behaviour of catchments in a distributed or semi-distributed way, in particular the dynamics of surface or subsurface contributing areas (Beven et al., 1995). The simplicity of TOPMODEL comes from the simplification of physical mechanism of hydrological processes. The detailed model describation can be found elsewhere (Zhang et al., in submitting), the oral presentation on the detail of the model will be give in the conference.This summay was given in two part. First of all, the basic geographical, meteorologic conditions and the ecologic informaion was described with GIS or remote sensing data analyses with the brief description of the model. Then the calculation of hydrological parameters using digital elevation model (DEM) of the Bingguo Basin, as well as the simulation results and discussions was followed with the end of simple conclusion.

The Target Area

Located in the middle part of the Hexi Corridor in Gansu Province, northwestern China, the Heihe River Basin takes the rank of the second largest inland river basin in the arid regions of China. Its geographic location lies from 96°42'-102°00'E and 37°41'-42°42'N encompassing a catchment area of about 128,700km^2. Administratively, it trans 11 counties / cities including Qilian County in Qinghai Province, some northwestly cities / counties in Gansu Province, and part of Ejin Banner in Inner Mongolia Autonomous Region. Some quite noticeable and characteristic landscapes in the whole catchment of the Heihe region can be viewed evidently, which exhibates three major geomorphologic units from south to north. These geomorphologic units are entitled as the Southern_Qilian_Mountains type, the Middle_Hexi_Corridor type and the Northern_Alxa_plateau type. Each geomorphologic unit has its own unique geologic, geomorphologic, hydrologic, meteorologic, soil and vegetation characteristics. Owing to its relatively rich land resources, abundant sunshine and longer cultivation history, the Heihe River Basin has become an important commodity grain base of northwest China and an inland region with more rapidly socioeconomic development and denser population. However, on the other hand, the shortage of water resource seriously hinders the further development of the region's secioeconomy and leads to severe deterioration of the eco-environment in the downstream sections of the basin. Furthermore, since the river system flows through two administrative areas of Gansu Province and Inner Mongolia Autonomous Region, the water shortage also stirs up serious troubles among people with different nations. The water resource distribution in the region has dramatically constrained to the sustainable development and caused serious social problems in the surrounding area (Cheng, 1996; Feng and Cheng, 1998; Feng et.al., 1999). Accordingly, in such an area with diversty geomorphologic units, complex water resource conversion relations, fragile eco-environment, and acute water shortage, classifying the relations of water resource conversion among different geomorphologic units to rationally utilize and effectively allocate water resources in the basin so as to coordinate the contradictions between socioeconomic development and environmental protection are all crucial and urgent problems that require the policy-makers to handling. Under such a cirsumstance, several pronounced scientific projects has been carried out in recent decade under the leadership of the Cold and Arid Regions Environment and Engineering Research Institute, Chinese Academy of Sciences. Some in-depth studies of hydrology and water resources have been undertaken on arid regions of northwestern China. In these projects, many water circulation and sustainability-oriented studies have been conducted, and some significant results have been obtained. In the present study, a distributed modeling in hydrology using digital data and GIS systems to a 30.06 km^2 Binggou watershed on the north slope of the Tuolai Mountains in Heihe Basin, Northwest China is attempted. The Binggou Basin is a small watershed located in 100°11'-100°18'E and 38°00'-38°04'N at the altitude with elevation span ranging from 3433 to 4406 m. Figure 1 schamatically shows the drainage system of the Heihe River Basin with the target modelling catchment of Binggou sub-basin exhibated. As an ideal place for the studies of water balance and runoff formation mechanism in the alpine frozen soil region, the Lanzhou Institute of Glaciology and Geocryology, Chinese Academy of Sciences has conducted hydrological experiments since the 1980s in the basin (Yang et al., 1992).

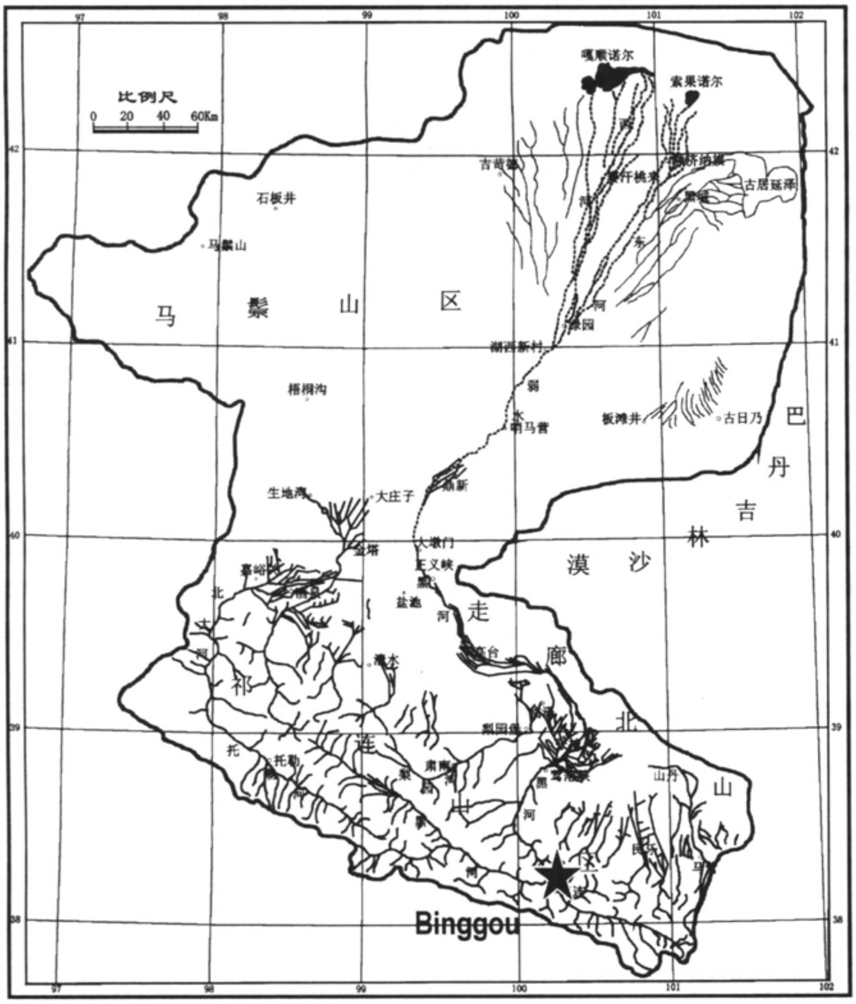


Figure1. Schematic map of geographic location of the Heihe River Basin showing the basic channel sysyem with the Binggou watershed location exhibated

Principles of the TOPMODEL model

The basic hypotheses (Beven, 1997) of the TOPMODEL can be sumarized as followings:

(1). The dynamical changes of water table can be approximated by uniform subsurface runoff production per unit area.

(2). The hydraulic gradient of the saturated zone can be approximated by the topographic slope.

Based on the above hypotheses, the topographic index is used as basic input in TOPMODEL (Kirkby and Weyman, 1974) and is defined as:

$$k = \ln(\alpha / \tan \beta) \qquad (1)$$

Where α is the area draining through a point from upslope and β is the slope angle. The topographic index is used as an index of hydrological similarity. All points with the same value of the index are assumed to respond in a hydrologically similar way (Beven, 1997). The spatial component requires a high quality DEM (digital elevation model) without sinks. Surface runoff is computed based on variable saturated areas, subsurface flow using a simple exponential function of water content in the saturated zone. Channel routing and infiltration excess overland flow are considered in the model. The structure of the model with regard to interception and root zone storage compartments is variable, allowing much flexibility to simulated different systems. Time steps should be in the range of day to represent surface runoff peaks. The length of the simulation period depends on the availability of precipitation and evapotranspiration input data. The spatial component requires a high quality DEM (digital elevation model) without sinks. Parameters scaled by GIS average properties is assigned to each subwatershed. Kinematic wave routing of streamflow was treated through channel network.

Many methods have been developed to calculate the topographic index (Quinn et al., 1997). It is worth to notice that its accuracy depends upon the DEM resolution. Generally, the DEM resolution should be at least larger than the length of the mountain slope, the higher the DEM resolution, the more reliable the calculated result of topographic index. We also developed a program for calculating topographic index using the hydrological analysis programs in the hydro.avx, which is an extension run in the ArcView Spatial Analyst (ESRI, 1996).

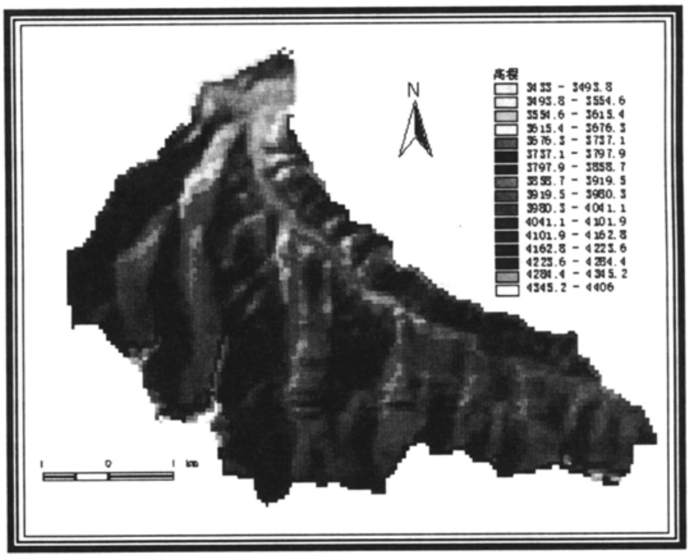


Figure 2. Digital Elevation Model (DEM) of the Binggou watershed with spatial resolution of 60 meter.

DEM was also used to calculate the hydrological parameters such as flow direction, flow accumulation, and flow length. Furthermore, it can be used to extract channel network, drainage divides and sub catchment (Jenson and Domingue, 1988; Tarboton et al., 1991; Band, 1986; Marks et al., 1984; O'Calllaghan and Mark, 1984; Lu et al., 1988a; Lu et al., 1988b). These basic hydrological parameters are essential to any distributed hydrological models. For example, above parameters is the basic input of the distributed hydrological model TOPMEDEL.

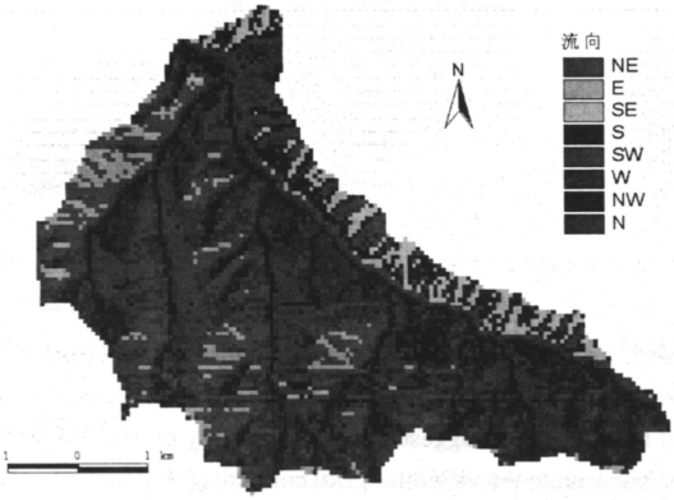


Figure 3. Simulated flow direction of the Biggou watershed.

To calculate the topographic index as well as topography-dependent hydrological parameters of the basin, we firstly digitized 1:50000 topographical map of the Binggou Basin and the DEM of the basin with a resolution of 60m was generated (Figure 2). Then, by using the hydrological extension in ArcView, we mapped a series of hydrological parameters such as flow direction (Figure 3), flow accumulation (Figure 4), channel network (Figure5) and sub-catchment polygons (the threshold for extracting sub-catchment is 500 grids) (Figure 6). Finally, we obtained the topographical index based on the above results (Figure 7). The calculation of topographic index lays a basis for the further use of TOPMODEL and for the development of a distributed hydrological model of the Heihe River Basin.

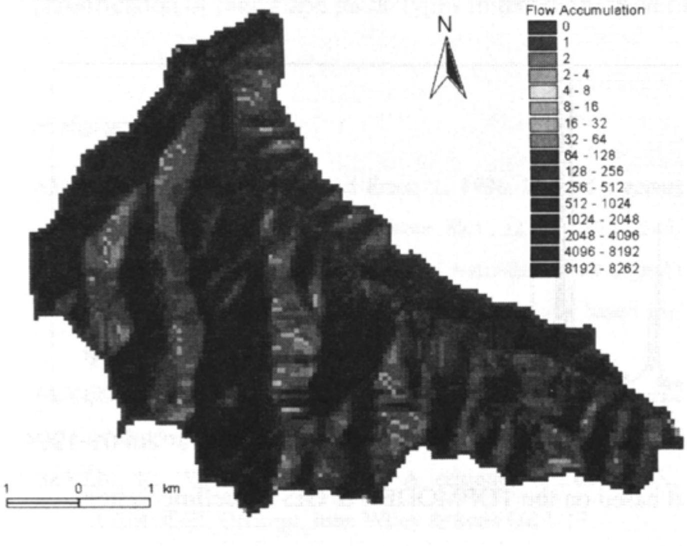
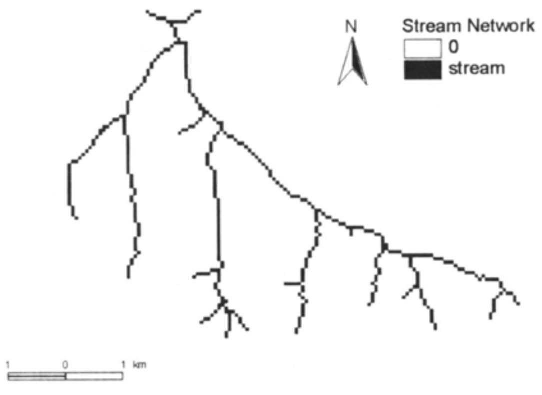


Figure 4. Simulated flow accumulation for Binggou watershed

Figure 5. Simulated stream net work based on 8D methodology.



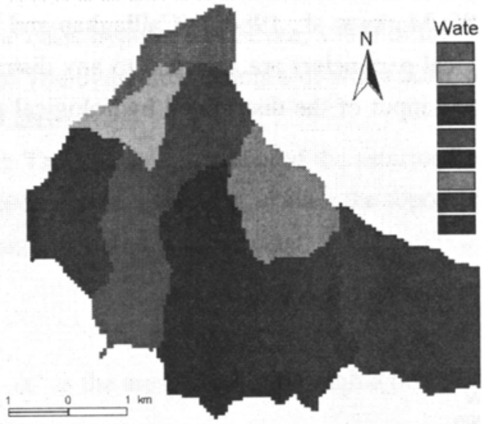


Figure 6. Subwatershed delination by order 5 for the studied basin.

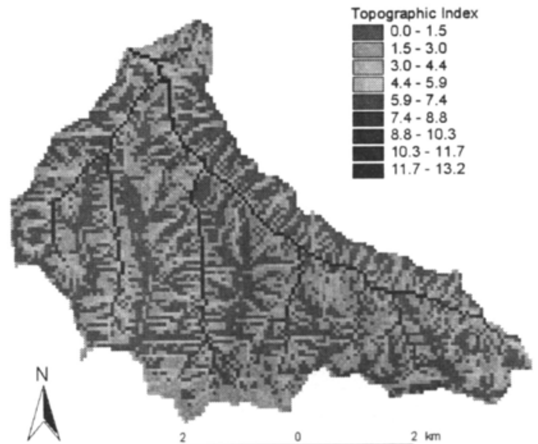


Figure 7. Topographic index generated with 60 m resolution DEM of Binggou watershed.

Results and Discussions

Modeling system centered on TOPMODEL for representation of spatially distributed water balance based upon topography and GIS data (vegetation and soils) has been successfully developed in the present study. The preliminary results are very encouraging, and the simulation suggested the applicability of the TOPMODEL in predicting the water balance and hydrological response to the meteorological conditions. Figure 8 shows the the performance of the modelling system in Binggou watershed hydrological simulations. The simulation process involved several parameter verifications, however, at present physical interpretation of calibrated parameters is still problematic. Moreover, large scale water balance problem due to difficulty in relating precipitation to topography have to be resolved using rather empirical adjustment method.

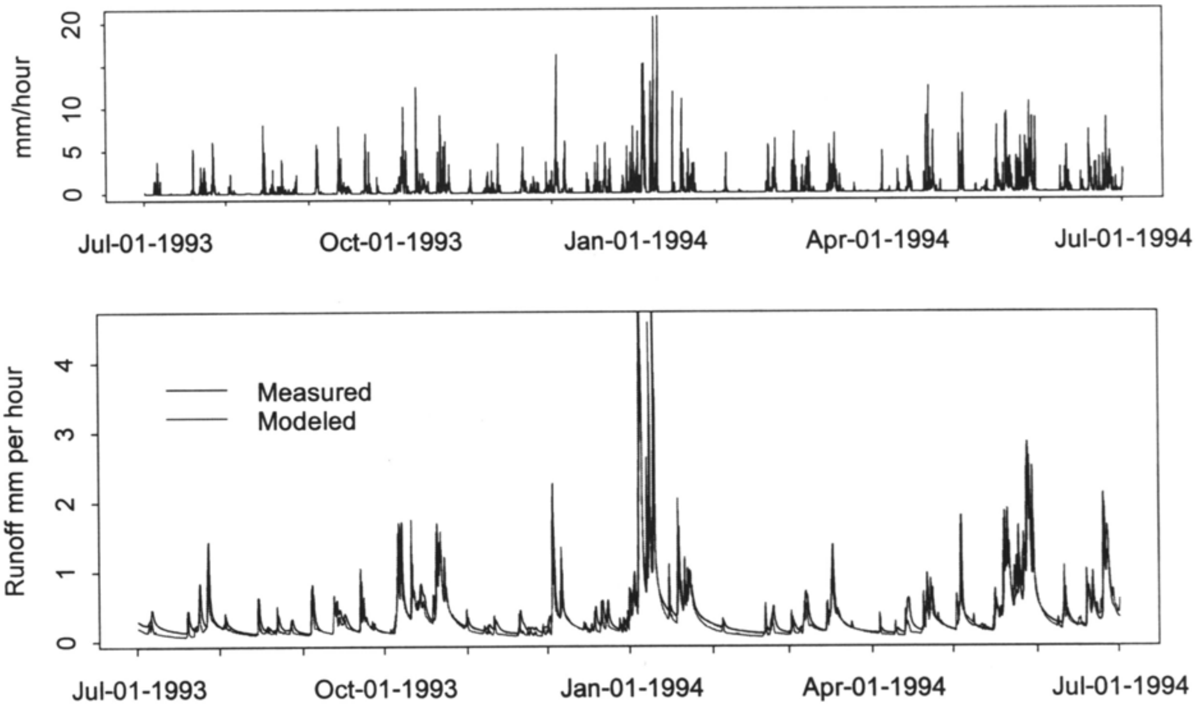


Figure 8. Simulation result of Binggou watershed based on the TOPMODEL & GIS modelling system.

Despite a wealth of data already stored in the water resource information system of the Heihe River Basin, our application study is still in the initial stage. The planned application emphases include: (1) to develop distributed hydrological model suited to arid inland river basin of northwest China, because of sparse meteorological and hydrological stations and limited observation and experiment data in the Heihe River Basin, such model should be a simplification of the existing distributed models, in the meanwhile, combined with existing one-dimension model, it is characterized by definite physical mechanism and clear model structure (Kang Ersi, 1999). It can simulate and calculate the spatial distribution of the hydrological processed such as precipitation, runoff, groundwater and evapotranspiration etc. It is also fully visual and hence the data and results have better direct-vision display ability. (2) to calculate surface water volume, evapotransipiration, ground surface temperature, reflectance and radiation etc, using remote sening data. With the help of new EOS-AMI-borne sensors such as ASTER and MODIS etc, many parameters associated with hydrological processes can be directly obtained (Running et al., 1998). Although the reversion methods of these parameters have been successfully developed, they still require further examination so as to be used in the actual distributed hydrological models. In addition, for those parameters that cannot be determined by remote sensing or limited by remote sensing spatial-temporal resolution, such as the spatial distribution of air temperature and precipitation, spatial analytical method and DEM might be the possible mean to calculate them.

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