Comparison of Three GIS-Based Hydrological Models
Zhi-Jia Li and Ke Zhang

Abstract: Three geographic information system (GIS)-based distributed hydrological models were developed for flood simulation and forecasting in a subbasin of the Yellow River. A grid-and-topography-based distributed hydrological physical model, i.e., the GTOPMODEL model, is described that includes vegetation and root interception, evapotranspiration, and runoff generation via the saturation excess mechanism, as well as subsurface via the Darcian approach used by TOPMODEL, runoff concentration, and flow routing. The downslope redistribution of soil moisture is explicitly calculated on a grid by grid basis. Using the isochrone curve method based on GIS, another two models are developed on the basis of the Xinanjiang and TOPMODEL models. The three developed models were applied to the Upper Lushi basin in Luohe River, one tributary of the Yellow River, with an area of 4,716 km² for flood simulation. The results show that all of these models perform well in the simulation and can be used for flood forecasting in the Yellow River basin and that GTOPMODEL performed the best among the three models.


CE Database subject headings: Hydrologic models; Hydrology; Hydrologic properties; Hydraulic networks; Geographic information systems; Comparative studies.

Introduction

From the last part of the 20th century, a large number of hydrological models (STANFORD IV, SACRAMENTO, APIC, SSARR, TANK, XINANJIANG) have been developed and put into application in practice (Singh 1996; Todini 1996). With the rapid development of spatial survey technology such as geographic information system (GIS) and remote sensing, more hydrological models are being combined with these technologies. Distributed hydrological models, which consider the spatial variability of the basin using GIS and remote sensing technology, become one of the most important tools for the present hydrological investigations. The Xinanjiang model (Zhao 1983) and TOPMODEL (Beven and Kirkby 1979; Beven 1986a,b) are two representative watershed hydrology models. They have been widely used and improved since they were developed (Zhao 1984; Zhang 1990; Zhao and Liu 1995; Sivapalan et al. 1987; Franchini et al. 1996; Jayawardena and Zhou 2000; Huang and Jiang 2002). Takeuchi et al. (1999) developed the BTOPMC model for application in some large basins by using the Muskingum–Cunge method to route the simulated block-wise TOPMODEL runoff to the downstream reaches. Although the two models have witnessed a lot of successful applications, they still belong to a class of semidistributed hydrological models, which cannot adequately consider the spatial variation of parameters and input meteorological data like the fully distributed hydrological models. However, fully physically distributed hydrological models also have their limitations due to the difficulty of large data requirement and parameter measurement (Binley et al. 1989; Beven and Binley 1992; Hornberger et al. 1991). To combine the merits of distributed hydrological models and traditional conceptual hydrological models, a grid-topography-based distributed hydrological model (GTOPMODEL) (Zhang 2005) was developed by applying the Darcy law and the topography index (Beven and Kirkby 1979) into each grid to derive a series of equations for runoff and soil moisture. This model is distributed, needs only the precipitation and pan evaporation input data, and can obtain optimal parameters by mathematical optimization methods. Meanwhile, two distributed hydrological models were developed by combining the Xinanjiang and TOPMODEL models with GIS in this study. These three models were applied to the Upper Luo River Basin, one subbasin of the Yellow River, in order to validate the reliability and applicability in similar basins.

GTOPMODEL Model

Unit Contributing Area

The GTOPMODEL model is a distributed hydrological model, which is based on the schematic representation of a watershed hydrology, as shown in Fig. 1. The watershed is divided into a series of grids to which each of the rainfall-runoff models is applied. These grids in which runoff flows into the same channel reach compose a unit contributing area (UCA). A UCA is just similar to a subbasin, however, it is different from the subbasin since it includes only one channel reach, i.e., a whole tributary which has no branches or a part of a tributary (Fig. 2). In Fig. 2, the watershed is delineated from the digital elevation model.
(DEM) and is divided into six UCAs. According to the D8 method (O’Callaghan and Mark 1984) or other methods, the flow direction at each grid can be uniquely determined (Lacroix et al. 2002). Then the grids of the watershed can be represented as a tree, which defines the order in which computations are to be carried out. On each grid of the watershed, a vertical profile is treated as four layers: vegetation and root, unsaturated soil layer, saturated soil layer, and impermeable layer (Fig. 3). Runoff is generated based on the saturation excess mechanism similar to that of the TOPMODEL model. The operations performed on each grid for each time interval are: calculate the interception, evapotranspiration and runoff production for the next one.

**Runoff-Generation Calculation**

The watershed is divided into grids in GTOPMODEL (Fig. 2), and each grid is divided into four layers vertically (Fig. 3). The relationship between grids in the same UCA is established by the mean soil moisture deficit on the basis of the runoff-generation theory of TOPMODEL. Runoff-generation calculation is performed on grids. The soil moisture deficit of each grid, the mean soil moisture deficit of the UCA, the topography index of each grid, and the mean topography index of the UCA are related as

\[ \frac{\text{SD} - \text{SD}_i}{m} = \left[ \ln \frac{a_i}{\tan \theta_i} - \lambda \right] - \left[ \ln T_{0s} - \ln T_s \right] \]  

where \( \text{SD} \) = moisture deficit at the \( i \)th grid; \( \text{SD}_i \) = mean soil moisture deficit of the UCA; \( m \) = parameter representing the effective soil depth at the \( i \)th grid; \( \ln T_{0s} = 1/\sum A_i \ln T_{0} \) = mean value of \( \ln T_0 \) over UCA, \( \ln a_i/\tan \theta_i = \text{topographic index at the } i \text{th grid} \); and \( \lambda = 1/\sum A_i \ln a_i/\tan \theta_i \) = mean value of the topographic index over the UCA. \( T_{0s} \) = transmissivity of a full saturated soil which is regarded as a parameter. It is assumed that \( T_{0s} \) and the percentage contents of sand, clay, and silt at the soil meet the following expression (Takeuchi et al. 1999)

\[ T_{0s} = P_{\text{sand}} \times T_{0\text{, sand}} + P_{\text{clay}} \times T_{0\text{, clay}} + P_{\text{silt}} \times T_{0\text{, silt}} \]  

where \( P_{\text{sand}}, P_{\text{clay}}, \text{and } P_{\text{silt}} \) respectively, represent percentage content of sand, clay, and silt at the soil; and \( T_{0\text{, sand}}, T_{0\text{, clay}}, \text{and } T_{0\text{, silt}} \) respectively, represent value of \( T_{0s} \) at the sand, clay, and silt.

**Vegetation and Root Interception Capacity**

The type of land use on each grid can be obtained by remotely sensed images. In GTOPMODEL, the types of land use are reclassified into four groups: forest, grassland and cropland, and impermeable land. The vegetation and root interception capacity is represented by a reservoir with a capacity of \( SR_{\text{max}} \). The value of \( SR_{\text{max}} \) can be regarded as the same on the grids with the same soil type. The net rainfall \( P_0(t) \) can be obtained by subtracting interception capacity \( SR_i(t) \) from rainfall \( P_i(t) \) on the \( i \)th grid at the \( r \)th time step

\[ P_0(t) = \max(0, [P_i(t) - SR_i(t)]) \]  

**Evapotranspiration**

Evapotranspiration is calculated at two layers vertically in GTOPMODEL: the vegetation and root layer and the unsaturated soil layer. First, evapotranspiration occurs on the vegetation surface and root layer. When the water of this layer is dried up, it will occur on the soil layer. Calculation can be performed, respectively, by Eqs. (4) and (5)

\[ E_a(t) = E_{\text{fr}}(t) \left\{ 1 - \left( \frac{SR_{\text{max}} - SR_i(t)}{SR_{\text{max}}} \right)^a \right\} \]
The flow in soil includes groundwater recharge, overland flow, and saturated flow, respectively, obtained by Muskingum flow routing method.

where \( E_d(t) \) and \( E_b(t) \) = evapotranspiration on the vegetation and root layer and the soil layer, respectively; \( E_P(t) \) = pan evaporation at the \( i \)th grid at the \( t \)th time step; \( S_{w_c}(t) \) = water storage of vegetation and root layer; \( S_{w_s}(t) \) = water storage of unsaturated soil layer at the \( i \)th grid at the \( t \)th time step; \( SD_i(t) \) = moisture deficit in unsaturated soil layer of the \( i \)th grid at the \( t \)th time step; \( \alpha \) = exponential parameter; and \( \beta \) = another exponential parameter.

**Flow Calculation**
The flow in soil includes groundwater recharge, overland flow, and saturated flow, respectively, obtained by Muskingum flow routing method.

The flow in each grid can be calculated one by one according to the D8 method, the drainage network can be extracted and the matrix of the basin and endow the current calculation order.

On the basis of the flow direction at each grid determined by the D8 method, the drainage network can be extracted and the matrix of the basin and endow the current calculation order.

As shown in Fig. 4, the flow discharge at grids \( a, b, \) and \( c \) will flow into grid \( d \). Their outflow discharge at center of grid \( d \) are \( Q'_d \), \( Q''_d \), and \( Q'''_d \), respectively, obtained by Muskingum flow routing method.

\[
Q_a(t) = \sum_{i \in A} q_{ai}(t) = \sum_{i \in A} A_i K_0 \exp\left( -\frac{SD_i(t)}{m_i} \right)
\] (10)

When \( SD_i(t) \) is less than zero, i.e., the unsaturated soil layer is saturated, there will be overland flow \( q_{ai}(t) = |SD_i(t)| \).

**Flow Routing**
On the basis of the flow direction at each grid determined by the D8 method, the drainage network can be extracted and the matrix for the order of calculation can be established by the following steps: (1) find the grid with the largest drainage area, i.e., the outlet of the basin and endow the current calculation order \( n \) with the value of 1; and (2) add 1 to \( n \) cumulatively \((n=n+1)\) and seek each one of the neighboring eight grids from the north clockwise. If the flow of the neighboring grid can flow into the current grid, the neighboring one is endowed with the current calculation order \( n \); (3) repeat step 2 until all grids have been endowed with the calculation order; and (4) start the calculation orders contradictorily and obtain the result.

As shown in Fig. 4, the flow discharge at grids \( a, b, \) and \( c \) will flow into grid \( d \). Their outflow discharges are \( Q'_d \), \( Q''_d \), and \( Q'''_d \), respectively, obtained by the Muskingum flow routing method [Eq. (11)]

\[
Q^{n+1}_d = C_1 Q^n_d + C_2 Q'^{n+1}_d + C_3 Q''^{n+1}_d
\] (11)

where

\[
C_1 = \frac{0.5 \Delta t - x \kappa}{(1-x) \kappa + 0.5 \Delta t}, \quad C_2 = \frac{0.5 \Delta t + x \kappa}{(1-x) \kappa + 0.5 \Delta t},
\]

and

\[
C_3 = \frac{(1-x) \kappa - 0.5 \Delta t}{(1-x) \kappa + 0.5 \Delta t}
\]

and \( x \) and \( \kappa \) = two parameters of the Muskingum flow routing method.

Therefore, the outflow \( Q_d \) of the grid \( d \) is the sum of \( Q'_d, Q''_d, \) and the runoff \( Q_{d0} \) produced at grid \( d \) [Eq. (12)]

\[
Q_d(t) = Q'_d(t) + Q''_d(t) + Q'''_d(t) + Q_{d0}(t)
\] (12)

The flow of each grid can be calculated one by one according to the method until the outflow of the outlet is obtained.
Improved GIS-Based TOPMODEL and Xinanjiang Model

Model Structure

Combining the TOPMODEL and Xinanjiang models with GIS, two distributed hydrologic models are developed. The watershed is divided into several subbasins. The runoff of every subbasin is calculated by the TOPMODEL and Xinanjiang models. However, the flow routing of each subbasin is calculated by the GIS-based isochrone curve method. Finally, the outflow process of each subbasin as the inflow of drainage network is routed by the Muskingum flow method. Then the discharge hydrograph of the outlet can be obtained. Fig. 5 shows the calculation process of the models.

GIS-Based Isochrone Curve Method

This method is applied to each subbasin. Therefore, the whole watershed is divided into several subbasins. Then the area-distance curve or area-time curve of each subbasin is gained according to the DEM data. According to the area-distance curve or area-time curve, the confluence process of runoff on each subbasin can be calculated. Supposing that the outlet discharge of one subbasin is \( Q(t) \) at time \( t \), and the average runoff of the subbasin at time \( \tau \) is \( R(\tau) \), then only the flow of the runoff which arrives at the outlet for \((t-\tau)\) time steps constitutes the discharge \( Q(t) \). Thus

\[
dQ(t) = \frac{\partial A(t-\tau)}{\partial \tau} R(\tau) d\tau
\]  

(13)

Since all the runoff from the 0 to \( t \) time step contributes to the outlet discharge \( Q(t) \) at time \( t \), then \( Q(t) \) can be obtained by the integral

\[
Q(t) = \int_0^t \frac{\partial A(t-\tau)}{\partial \tau} R(\tau) d\tau
\]  

(14)

The subbasin is divided into \( m \) parts, according to the average flow path. The upper contributing areas are accumulated by each contributing part. Then the percentage of the accumulated area from the first to the \( i \)th contributing area to the total area of the subbasin is \( P_A(i) \). The average flow path \( L(i) \) of the \( i \)th part is the mean distance from the \( i \)th contributing part to the outlet. The average flow velocity of the \( i \)th part is \( v(i) \), which is provided as empirical data in this study. Thus the confluence time of each contributing area is

\[
t_i = \left\{ \begin{array}{ll}
L(i) & i = 1 \\
v(i) \\
\sum_{k=0}^{i-1} (L(i-k) - L(i-k-1))/v(i-k) & i > 1
\end{array} \right.
\]  

(15)

If the time step is \( \Delta t \), the flow on the first contributing area first arrives at the outlet. The lag number of time step is \( j_1 = \text{int}(t_1/\Delta t + 0.5) \). In the same way, the lag number of time step of the flow on the farthest contributing area is \( j_m = \text{int}(t_m/\Delta t + 0.5) \). When the confluence time is greater than the time step, i.e., \( t_m \) is greater than \( \Delta t \), the runoff produced during the \( k \)th time step will arrive at the outlet in succession from \( k+j_1 \) to \( k+j_m \). Supposing that the runoff of the subbasin is \( R_k \) at the \( k \)th time step and that the proportion arriving at the outlet from \( k+j_1 \) to \( k+j \) \( j = j_1+1, \ldots, j_m \) is \( P(j) \)

\[
P(j) = P_A(i) - \frac{(P_A(i) - P_A(i-1))(t_j - j \cdot \Delta t)}{t_i - t_{i-1}}
\]  

subject to \( t_{i-1} < j \cdot \Delta t \leq t_i \)

During the \((k+j)\)th time step, the proportion of the runoff arriving at the outlet is \( \Delta P(j) = P(j) - P(j-1) \). Then, part of the discharge of the \( k+j \) time step at the outlet formed by the runoff of \( k \) time step is
where \( A = \text{total area of the subbasin.} \)

The outlet discharge hydrographs of each subbasin can be gained, respectively, by calculating the discharge process at the outlet formed by runoff at each time step and adding them up. Finally, the outflow process of each subbasin as the inflow of drainage network is routed by the Muskingum flow method. Then the discharge hydrograph of the outlet can be obtained.

**Models Application**

In order to verify the applicability of the three models and compare them, the three models were applied to the upper area of Lushi Station located in the Luo River which is one of the tributaries of Huanghe River (Figs. 6 and 7). Luohe River is one of ten main tributaries of the Yellow River. The control area of Lushi Hydrological Station is 4,716 km\(^2\). The length of the main stream is 140 km. The altitude increases gradually from west to east and is between 800 and 2,747 m. The watershed has the characteristics of warm temperature zone and mountain monsoon climate. The annual rainfall is between 500 and 1,100 mm.

The global DEM data at a resolution of 30\(^\circ\) x 30\(^\circ\) provided by USGS (2005) were used to extract the subbasins (in Fig. 6 the basin area threshold is 200 km\(^2\)). Fig. 7 shows a map of UCAs in the upper area of Lushi Station used by GTOPMODEL. The land use data are obtained from IGBP of USGS at a resolution of 30 x 30 in. The types of land use are reclassified into four main types: forest, shrubbery, grassland and cropland, and impermeable land. The soil composition data are gained from the RS image of NOAA at a resolution of 1 x 1\(^\circ\). The land use map and soil composition map at this basin are shown as Fig. 8.

Parameters of the three models were calibrated and optimized by the Rosenbrock mathematical optimization method with the following objective function

\[
\min \text{Obj} = \left[ \sum_{i=1}^{n} (Q_{\text{Obs},i} - Q_{\text{Cal},i})^2 \right]^{1/2}
\]

where \( Q_{\text{Obs},i} \) and \( Q_{\text{Cal},i} \) respectively, =observed and simulated discharges at time step \( i \); and \( n = \text{number of time intervals.} \) Eight out of 13 hourly event floods were used for calibration and the left five floods were used for verification. To simplify computation, subbasins were grouped to optimize some parameters according the elevations of the subbasins and their topological relationships. The calibrated parameters are listed in Tables 1–4. The results of calibration and verification of the three models for the event flood data are listed in Table 5

**Discussion**

The statistic values obtained from the application of the three models to 13 flood events are shown in Table 5. The flood events were classified according to peak flow. When the peak flow is larger than 1,400 m\(^3\)/s, the flood is regarded as a major flood. When the peak flow falls between 1,000 and 1,400 m\(^3\)/s, the flood is classified as a moderate flood. The remaining floods are considered as minor floods. Therefore, the 13 flood events, including five major floods, four moderate floods, and four minor floods, have good coverage from small to large floods. The statistics values include the relative runoff error, the relative peak flow error, the peak time error, and the Nash coefficient, i.e., the coefficient of determination.

For all three models, peak flows were underestimated for over 50% of simulated flood events, especially major floods. This may be due to the theory of runoff production, since the three models all assume full saturation of the unsaturated soil layer before the generation of overland flow. This theory might not fit well for heavy rains or steep ground topography which may exist in the test catchments. In most cases, all three models overestimated the amount of runoff. This can be mainly caused by human activity and hydraulic works, because there are many farm lands and small water conservancy projects in the catchments such as small water storage dams and reservoirs. They work like the interception of vegetation which decreases the runoff depth. On the other hand, irrigation and hydraulic works may also contribute to the underestimates of peak flows in some sense. Except for Nos. 4 and 7 flood events with known data missing problems, all three models had small peak time errors. Relative to other models, GTOPMODEL performed better in simulation of peak time. As far as simulation of flood processes was concerned, all the models had high Nash coefficients and captured most of the variation in flood processes. Relatively, GTOPMODEL and GIS-based Xinjiang models performed better.

**Table 1.** Calibrated SR\(_{max}\) and \( T_0 \) of GTOPMODEL Model Using Eight of 13 Flood Events

<table>
<thead>
<tr>
<th>Subbasin No.</th>
<th>SR(_{max}) (m)</th>
<th>( T_0 ) (m(^3)/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3–6, 8–10</td>
<td>0.06</td>
<td>0.04</td>
</tr>
<tr>
<td>2, 7, 11–14</td>
<td>0.011</td>
<td>0.110</td>
</tr>
<tr>
<td>1, 15–19</td>
<td>0.015</td>
<td>0.104</td>
</tr>
</tbody>
</table>

**Table 2.** Other Calibrated Parameters of GTOPMODEL Model Using Eight of 13 Flood Events

<table>
<thead>
<tr>
<th>Subbasin No.</th>
<th>( \kappa )</th>
<th>( m ) (m)</th>
<th>( X )</th>
</tr>
</thead>
<tbody>
<tr>
<td>3–6, 8–10</td>
<td>0.3</td>
<td>0.02</td>
<td>0.45</td>
</tr>
<tr>
<td>2, 7, 11–14</td>
<td>0.6</td>
<td>0.0103</td>
<td>0.15</td>
</tr>
<tr>
<td>1, 15–19</td>
<td>0.8</td>
<td>0.0105</td>
<td>0.01</td>
</tr>
</tbody>
</table>

**Table 3.** Calibrated Parameters of GIS-Based TOPMODEL Model Using Eight of 13 Flood Events

<table>
<thead>
<tr>
<th>Subbasin No.</th>
<th>( m ) (m)</th>
<th>( T_0 ) (m(^3)/s)</th>
<th>SR(_{max}) (m)</th>
<th>( \kappa )</th>
<th>( x )</th>
<th>( v ) (m/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1–5</td>
<td>0.011</td>
<td>0.110</td>
<td>0.060</td>
<td>1.0</td>
<td>0.45</td>
<td>2.22</td>
</tr>
<tr>
<td>6–10</td>
<td>0.016</td>
<td>0.108</td>
<td>0.055</td>
<td>1.0</td>
<td>0.20</td>
<td>1.94</td>
</tr>
<tr>
<td>11–15</td>
<td>0.015</td>
<td>0.104</td>
<td>0.050</td>
<td>1.0</td>
<td>0.10</td>
<td>1.67</td>
</tr>
</tbody>
</table>

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Table 4. Calibrated Parameters of GIS-Based Xinanjiang Model Using Eight of 13 Flood Events

<table>
<thead>
<tr>
<th></th>
<th>$B$</th>
<th>$C$</th>
<th>$W_M$ (m)</th>
<th>$W_M$ (m)</th>
<th>$W_M$ (m)</th>
<th>$I_M$</th>
<th>$S_M$</th>
<th>$E_X$</th>
<th>$K_G$</th>
<th>$K_I$</th>
<th>$C_G$</th>
<th>$C_I$</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.3</td>
<td>0.08</td>
<td>0.13</td>
<td>0.02</td>
<td>0.05</td>
<td>0.01</td>
<td>6</td>
<td>1.2</td>
<td>0.3</td>
<td>0.4</td>
<td>0.998</td>
<td>0.8</td>
<td></td>
</tr>
</tbody>
</table>

Note: The values of $k$, $x$, and $v$ are the same as those of the GIS-based TOPMODEL model.

Table 5. Comparison of Application of Three Models

<table>
<thead>
<tr>
<th>Flood No.</th>
<th>Start time</th>
<th>Peakflow ($\text{m}^3/\text{s}$)</th>
<th>Relative error of peak flow ($%$)</th>
<th>Relative error of runoff ($%$)</th>
<th>Peak time error (h)</th>
<th>Nash coefficient</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>1982073009</td>
<td>2,070</td>
<td>$-19.1$</td>
<td>$-18.0$</td>
<td>$-11.1$</td>
<td>19.6</td>
</tr>
<tr>
<td>11</td>
<td>2003082708</td>
<td>1,988</td>
<td>$-4.9$</td>
<td>$-18.6$</td>
<td>$-35.1$</td>
<td>16.6</td>
</tr>
<tr>
<td>5</td>
<td>1984091812</td>
<td>1,520</td>
<td>19.7</td>
<td>8.4</td>
<td>18.8</td>
<td>16.0</td>
</tr>
<tr>
<td>10</td>
<td>1994070715</td>
<td>1,480</td>
<td>5.9</td>
<td>9.0</td>
<td>11.9</td>
<td>4.5</td>
</tr>
<tr>
<td>9</td>
<td>1992091309</td>
<td>1,440</td>
<td>$-15.0$</td>
<td>$-22.7$</td>
<td>$-5.8$</td>
<td>$-0.1$</td>
</tr>
<tr>
<td>4</td>
<td>19830000208</td>
<td>1,390</td>
<td>$-8.0$</td>
<td>5.4</td>
<td>10.8</td>
<td>6.6</td>
</tr>
<tr>
<td>12</td>
<td>2003090507</td>
<td>1,260</td>
<td>$-2.9$</td>
<td>$-7.2$</td>
<td>$-5.1$</td>
<td>3.1</td>
</tr>
<tr>
<td>8</td>
<td>1989070907</td>
<td>1,160</td>
<td>$-13.0$</td>
<td>$-9.9$</td>
<td>6.8</td>
<td>13.7</td>
</tr>
<tr>
<td>1</td>
<td>1981090908</td>
<td>1,110</td>
<td>$-5.4$</td>
<td>9.9</td>
<td>11.0</td>
<td>8.6</td>
</tr>
<tr>
<td>7</td>
<td>1987060413</td>
<td>980</td>
<td>$-31.2$</td>
<td>$-43.5$</td>
<td>$-6.8$</td>
<td>19.1</td>
</tr>
<tr>
<td>6</td>
<td>1985091312</td>
<td>687</td>
<td>19.3</td>
<td>14.2</td>
<td>9.4</td>
<td>3.1</td>
</tr>
<tr>
<td>13</td>
<td>2003010108</td>
<td>615</td>
<td>5.9</td>
<td>9.0</td>
<td>11.9</td>
<td>$-7.8$</td>
</tr>
<tr>
<td>3</td>
<td>1982081220</td>
<td>480</td>
<td>$-4.0$</td>
<td>$-19.1$</td>
<td>$-2.8$</td>
<td>7.2</td>
</tr>
</tbody>
</table>

$G$ denotes GTOPMODEL model.

$T$ denotes GIS-based TOPMODEL model.

$X$ denotes GIS-based Xinanjiang model.

In these flood events, some rainfall gauges missed some data.

In these flood events, some rainfall gauges missed some data.

Conclusions

The results show that all the three models performed well in the catchments in most cases. Relatively, GTOPMODEL performed a little better and had lower errors in most cases than did GIS-based TOPMODEL. Although the GIS-based Xinanjiang model had lower relative peak flow errors and lower relative runoff errors than did GTOPMODEL in many cases, GTOPMODEL had lower peak time errors and had better simulated hydrographs in most cases. For all three models, the runoff production theory, human activities, and hydraulic works brought out some limitations to their performance. To improve these models, these factors should be considered and be incorporated into the models.

Although GTOPMODEL did not show better performance than the other two models as expected, the coarse-resolution DEM, the land use map, and soil composition mapping should assume partial responsibility. In this study, the resolution of DEM and land use map was only 30 ft (close to 1 km) and the resolution of soil composition was even worse, only 1°. Once higher resolution data (especially DEM data) are used, GTOPMODEL and GIS-based TOPMODEL should perform better.

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Notation

The following symbols are used in this paper:

- $a$ = contributing area per unit contour length;
- $E_u$ = evapotranspiration of vegetation and root layer;
- $E_b$ = evaporation of soil layer;
- $E_p$ = pan evaporation;
- $i, j, k, n$ = subscripts or numbers that define symbol’s application;
- $L$ = length of channel reach or flow path;
- $m$ = parameter, i.e., effective soil depth;
- $P$ = precipitation;
- $P_A$ = percentage of accumulated contributing areas to total area;
- $P_r$ = percentage;
- $Q$ = flow discharge;
- $Q_b$ = base flow;
- $Q_v$ = groundwater recharge;
- $q_b$ = base flow per grid;
- $q_s$ = overland flow per grid;
- $q_r$ = groundwater recharge per grid;
- $R$ = runoff;
- $S_{v}$ = water storage of vegetation and root;
- $S_{w}$ = water storage of unsaturated soil;
- $S_D$ = moisture deficit;
- $SD$ = mean soil moisture deficit;
- $SR$ = interception of vegetation and root;
- $SR_{\text{max}}$ = interception capacity of vegetation and root;
- $T_e$ = mean transmissivity of soil;
\[ T_0 = \text{transmissivity of the saturated soil}; \]
\[ t = \text{time}; \]
\[ v = \text{flow velocity}; \]
\[ x = \text{one parameter of Muskingum flow routing method}; \]
\[ \alpha, \beta = \text{exponential parameters for evapotranspiration}; \]
\[ \Delta t = \text{time interval}; \]
\[ \theta = \text{degree of slope}; \]
\[ \kappa = \text{other parameter of Muskingum flow routing method}; \]
\[ \lambda = \text{mean topographic index}; \]
\[ \tau = \text{time}. \]

References


