Simulation of Soil and Water Loss in the Upper Huaihe River Basin using the Xinanjiang Model

Chun-Sheng Yang\textsuperscript{a}, Qiong-Fang Li\textsuperscript{b,c}, Hai-yan WEN\textsuperscript{d}, Tao CAI\textsuperscript{b,c}, \textsuperscript{b*}

\textsuperscript{a} Haerbin Bureau of Hydrology, 205 didian Road, Haerbin 150010, China
\textsuperscript{b} State Key Laboratory of Hydrology-Water Resources and Hydraulic Engineering, Hohai University, Nanjing 210098, China
\textsuperscript{c} College of Hydrology and Water Resources, Hohai University, 1 Xikang Road, Nanjing 210098, China
\textsuperscript{d} Tangqin Bureau of Hydrological & Water Resource Survey in Hebei province, 8 chaoyang Road, Tangshan 063000, China

Abstract

The Xinanjiang model is coupled with the Modified Universal Soil Loss Equation to simulate the soil and water loss in the upper Huaihe River. The outputs show that xinanjiang model can simulate runoff and sediment well, and the total runoff was generally less than 10\% for both model calibration and validation with the Nash-Sutcliffe efficiency larger than 0.78 respectively. The computed sediment graphs were in good agreement with the observed ones, i.e. the relative errors of the computed total sediment yield was generally less than 20\% for both model calibration and validation with the Nash-Sutcliffe efficiency larger than 0.62 respectively.

© 2011 Published by Elsevier Ltd. Selection and/or peer-review under responsibility of Society for Resources, Environment and Engineering Open access under CC BY-NC-ND license.

Keywords: Upper Huaihe River Basin; Xinanjiang model; MULSE model; soil erosion simulation

1. Introduction

Soil erosion is a widespread land degradation problem in many parts of the world, and the adverse influences of soil erosion on soil degradation, agricultural production, water quality, hydrological system, and environments have long been recognized as severe problems for human sustainability [1], therefore, it is essential to quantitatively assess soil erosion at a watershed scale. Recently, there has been a dramatic increase in development and use of physically based hydrological model to simulate complex hydrological process and to estimate soil erosion and non-point source pollution [2]. A number of
physical-based models including Groundwater Loading Effects of Agricultural Management Systems, and Soil and Water Assessment Tool were used to simulate soil loss and had a wide range of applicability. Although those models can provide detailed descriptions for the processes and mechanisms of soil erosion, they could not simulate soil erosion at hourly time scale during flood events. It is well recognized that rainfall events are an essential condition for soil erosion, but not all rainfall events can result in soil erosion.

The Xinanjiang model is one of rainfall-runoff models, which has been widely used in humid, semi-humid and semi-arid regions of China in flood forecasting and water resources assessment with good simulation accuracy. However, the applicability of the Xinanjiang model in soil erosion simulation by coupling with MULSE model is yet to be investigated. In this study, the Xinanjiang model was employed to simulate soil and water loss in the upper Huaihe River basin during storm events. The objective of the paper is to develop a grid-based sediment yield model by coupling the Xinanjiang model with MULSE model to simulate soil loss in the upper Huaihe River Basin at hourly time scale. With the rapid increase population and economic development, the soil and water loss in the upper Huaihe River basin has been becoming one critical environmental and ecological problem. It is urgent to understand the sediment yield characteristics in the upper Huaihe River basin during storm events by use of sediment yield models at hourly time scale.

2. Model Development

2.1. Grid-based Xinanjiang Model

A Grid-based Xinanjiang Model was developed for runoff simulation with higher spatial resolution. By using geographic information system (GIS) and the digital elevation model (DEM) data, the whole catchment is divided into an array of cells (30′× 30′, i.e. approximate 1Km ×1Km), and the runoff production in each cell was computed by the Xinanjiang model respectively. The runoff production in each cell makes a contribution to the total catchment outflow through two stages of flow concentration: the three components of the total runoff generated including the surface flow, subsurface flow and groundwater flow moving within a cell towards the cell outlet, and flow routing from the cell outlets to the whole basin outlet. The more detailed introduction of Xinanjiang model can be seen the reference [3].

2.2. Grid-based sediment yield simulation model

A sediment yield simulation model consists of two modules, i.e. soil erosion modeling within a cell and sediment routing through channel networks. The soil loss from a cell can be computed by the Modified Universal Soil Loss Equation (MUSLE). The sediment outflow at the basin outlet can be computed based on the sediment routing equations and the derived flow routing paths from each cell outlet to the whole basin outlet as above, The detailed description of grid-based sediment yield model can be seen the reference[4].

2.3. Coupling of the Xinanjiang model with the sediment yield simulation model

The coupling of the Xinanjing model with the sediment yield simulation model can be realized through the following two steps: (1) In the stage of cell sediment yield computation, the surface runoff RS computed by the runoff production module of the Xinanjiang model is taken as an input to MULSE model; (2) In the stage of sediment routing from each cell outlet to the whole basin outlet, the inflow to, and the outflow from each river reach were directly obtained by applying Muskingum method to
successive reaches.

3. Model Application

3.1. Study Area

This paper focused on the sediment yield simulation in the upper Huaihe River basin. The Huaihe River is one of major rivers in China and located about mid-way between the Yellow River and Yangtze River, the two largest rivers in China, and like them runs from west to east. The Huaihe River has a drainage area of 270,000 km², which is situated between latitudes 31° and 35° north and between longitudes 112° and 121° east. This paper selected the upper Huaihe River above the Dapoling hydrologic station as a case study site. The Dapoling hydrological controlling station has a catchment of 1627km² (see Fig.1).

![Fig. 1. The location of Dapoling Catchment](image)

3.2. Data collection and processing

(1) The topographic data. The digital elevation model (DEM) data was downloaded from the Global Land One kilometer Base Elevation database (http://www.ngdc.Noaa.gov/mgg/global.html) with a spatial resolution of 1Km ×1Km. With use of the geographic information system (GIS), the elevation, slope, and slope length of each cell can be derived. (2) Soil data. The soil type map (1:200,000) for the study area was showd Fig.2, soil physical characteristics data including soil erodibility factor and soil texture were collected from the Xixian soil survey, and the details of soil database can be referred to Cai (2009)[5]. (3) Land-use/cover data. The national land-use map of 2000’s was used to develop the land-use map for the study area (see Fig.2). (4) Hydrological data. The daily flow discharge, rainfall, pan evaporation and sediment discharge data, and flood events data including hourly rainfall, flow discharge, sediment discharge data, etc. during 2000 to 2008 were collected.

3.3. Model calibration and validation

To calibrate the Xinanjijiang model at hourly scale, seven flood events during 2000 to 2008 were selected including large, medium and small floods. The parameters of the sediment yield simulation
model were calibrated following the same calibration procedures as the Xinanjiang model did. The calibrated values of all parameter were presented in Table 1.

Fig. 2. The map of land use, and soil

4. Discussions on simulation results

The simulation performance of model for the calibration events were presented in Tables 2 and 3 respectively. From Table 2 and 3, Table 2 shows that the computed runoff processes showed good match with the observed ones, i.e. the relative errors of the computed total runoff and the peak discharge being generally less than 10% for both model calibration and validation with the Nash-Sutcliffe efficiency ranging from 0.818 to 0.934 and 0.789 to 0.875 respectively. Table 3 shows that the computed sediment graphs were in good agreement with the observed ones, i.e. the relative errors of the computed total sediment yield and the peak sediment discharge being generally less than 20% for both model calibration and validation with the Nash-Sutcliffe efficiency ranging from 0.688 to 0.834 and 0.629 to 0.775 respectively. All the time difference between the observed flow/sediment peak and the computed one fell within one hour. This further proved that good simulation performance has been achieved. The simulation accuracy of sediment yield is closely associated with that of runoff. Both Table 2 and Table 3 indicated that the simulation performance for larger flood events is generally better than that for smaller flood events.

Table 1. Calibrated parameter values of the model on the Dapoling catchment

<table>
<thead>
<tr>
<th>Model parameter</th>
<th>Value</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Runoff simulation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SM</td>
<td>14</td>
<td></td>
</tr>
<tr>
<td>KG</td>
<td>0.3</td>
<td></td>
</tr>
<tr>
<td>KI</td>
<td>0.4</td>
<td></td>
</tr>
<tr>
<td>CG</td>
<td>0.98</td>
<td></td>
</tr>
<tr>
<td>CI</td>
<td>0.665</td>
<td></td>
</tr>
<tr>
<td>KE</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>XE</td>
<td>0.45</td>
<td></td>
</tr>
<tr>
<td>Soil eroision simulation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CUSLE</td>
<td>Pasture: 0.06</td>
<td>Woodland: 0.01</td>
</tr>
<tr>
<td>PUSLE</td>
<td>Pasture: 0.35</td>
<td>Woodland: 0.19</td>
</tr>
<tr>
<td>CH_EROD</td>
<td>0.4</td>
<td></td>
</tr>
<tr>
<td>CH_COV</td>
<td>0.3</td>
<td></td>
</tr>
</tbody>
</table>
5. Conclusion

The soil and water loss in the upper Huaihe River basin was simulated by coupling the grid-based Xinanjiang model with the MULSE model and the applicability of the Xinanjiang model in soil erosion simulation during flood events was proved by the fact that the four model performance indicators have achieved acceptable values. This study extends the scope of the application of the Xinanjiang model, which was originally developed for flood forecasting. The outputs of this paper could provide important references for soil erosion simulation in humid, semi-humid and semi-arid regions, particularly in China.

Acknowledgements

Financial support is gratefully acknowledged from National Natural Science Foundation of China (41171220), a research project funded by the Ministry of Water Resources, China (200901045, 201001069 and 201101052)

References