

SIMULATION OF FLOOD INUNDATION OF GUIYANG CITY USING REMOTE SENSING, GIS AND HYDROLOGIC MODEL

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ABSTRACT:

This paper illustrates an example of developing a grid-based distributed hydrologic model for storm-inundation simulation using GIS and remote sensing for flood emergency planning, and the feasibility of the model was explored in the mountainous urban area of Guiyang city of the Guizhou Province, China. The research was based on four major steps. The first step was to prepare data for the model, such as the grids of the city, land cover/land use of each grid from Landsat ETM+ image, and DEM from the 1:500 digital maps. The second step involved the calculation of the land overflow caused by rainstorm using SCS TR-55 model and routing the spatially distributed land overflow with a D_{∞} algorithm and Manning equation. The third and the final steps concern implementing of the simulation and mapping based on the simulation respectively. The model was validated using in situ water level measurements on July 11th 2005 when storm occurred over the city and a correlation coefficient of 0.67 is attained, so the model can be applicable to mountainous cities like Guiyang. The result of the research show that remote sensing, GIS and hydrological models can be integrated to solve hydrological problems.

1. INTRODUCTION

As is well known, water resource relates to the sustainable development of economy and society. In China, spatial and temporal distribution of water resources is imbalanced. According to statistics, 2/3 of the total 600 cities in China endure droughts frequently. On the other hand, urban impervious area has been increased drastically in the past two decades, and most urban drainage systems can't match the normal storms. As a result, urban inundation occurs frequently and causes huge damage and great losses. The forecast and simulation of floods is therefore essential for planning and operation of civil protection measures and for early flood warning (Cheung, 2003; Hsu, 2000).

While remote sensing is a useful tool to rapidly acquire land surface information over large scale area and the derived data such as DEM and LULC can be used as input for hydrologic models, the geographic information systems (GIS) provides a platform for simulation of hydrologic models (Gambolati, 2002; Knebl, 2005). With recent advances in remote sensing technology and GIS, scientists have developed various distributed hydrological models such as SWMM (Storm Water Management Model) to simulate physical hydrological processes within the drainage area. This paper is another attempt to develop a grid-based hydrologic model for storm-flood simulation using GIS and remote sensing for flood emergency planning. The feasibility of the model is explored in the mountainous urban area of Guiyang city, which is the capital of Guizhou province, China.

2. STUDY AREA AND DATA

The study area locates at Guiyang city, which is located on the east slope of Yunnan-Guizhou Plateau, in the middle of Guizhou Province, with the east longitude 106°07'~107°17' and the north latitude 26°11'~27°22'. The landform of Guiyang belongs to the hill-plateau basin, the main part of the city is mountainous and hilly. Guiyang falls within the monsoon climate in subtropical zone that is temperate and humid without severe winters or hot summers, characterized by abundant rainfall and longer frost-free period. Annually, the temperature averages 15°C, the rainfall is 1197 mm, the sunshine time is about 1278 hours, the relative humidity is 76.9% and the frost-free period is about 270 days. But drought or waterlogging occurs frequently because of the rainfall unbalance among different seasons.

The input data for the modeling include the grids of the city, land cover/land use and elevation of each grid, and the data of the draining pipelines. The grids of the city were generated from a Landsat ETM+ image with a horizontal resolution of 30 meters (on November 23, 2001). With such a resolution, there are totally 201 samples and 233 lines over the study area. The land cover/land use data of the grids is obtained using Maximum Likelihood Classification (MLC) method from the ETM+ image. Each grid of the city was classified as one of the following five types: bare soils, developed lands, grass lands, forest lands, and aquatic systems (Figure 1.a). The 1:500 digital maps were adopted to generate DEM of the city (Figure 1.b). Elevation of each grid was calculated using a Kriging interpolation method from contours and elevation points on the maps. The data of the urban draining pipelines along the main roads were also extracted from the digital maps. Taking such drainage pipelines into account can describe the spatial-

temporal variation of anthropogenic effects to the hydrological process in more detail. All kinds of data were referenced to a local coordinate system of Albers Equal Area Conic map projection. The standard parallels of the projection are 25° and 30° north separately and the longitude of origin is 107° east.

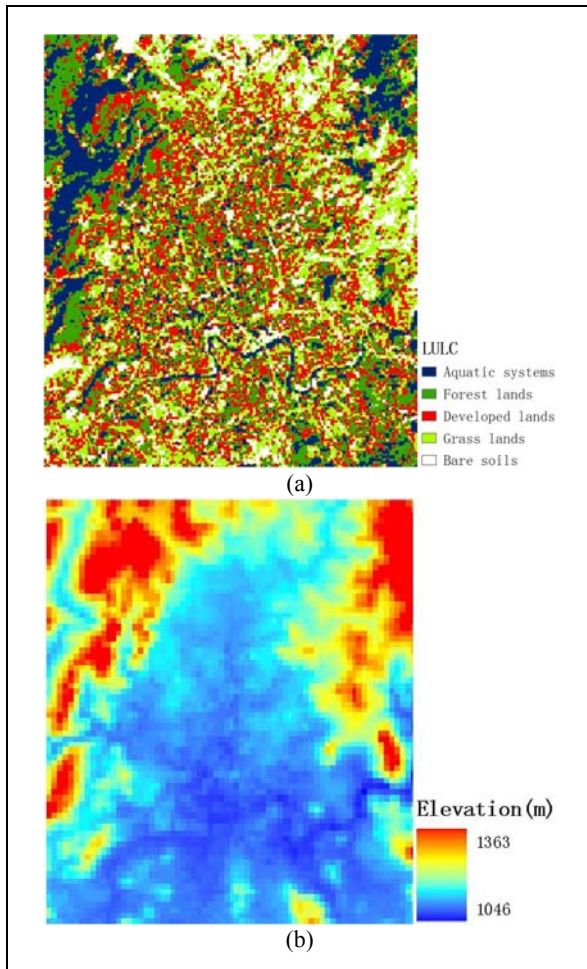


Figure 1. (a) The land use/land cover and (b) the elevation of Guiyang city.

3. METHODOLOGY

The inputs of the model include rainfall observation data besides the prepared data in part 2. The output is the overflow within each grid at the simulating time. The process of model is shown in a flowchart (Figure 2). As it is driven by rainfall observations during the simulation period, what directly result in the final overflow of each grid include four parts ---- the runoff brought on by rainfall, the overflow velocity, runoff along the main drainage system, and the ET_0 at the time.

3.1 Estimating runoff

With the supporting of RS and GIS, we adopt Soil Conservation Service Technical Release 55 (SCS TR-55) model to calculate storm runoff volume within each grid. The model is developed by National Resources Conservation Services (NRCS) and is the most common method for predicting storm runoff. The main parameters of the model depend on the factors of the underlying

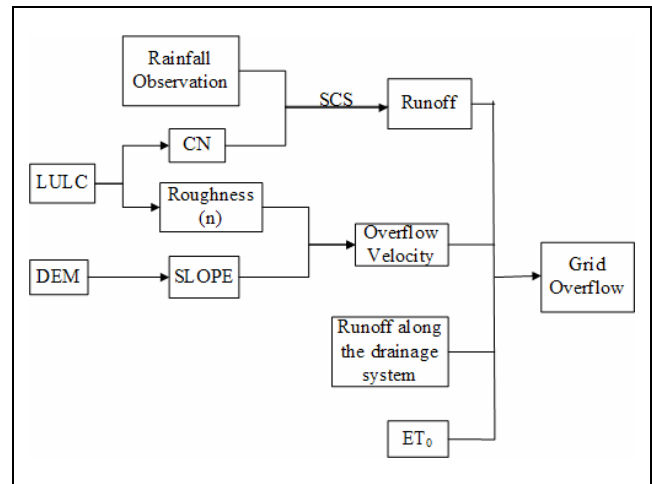


Figure 2. The flowchart of the Model.

surface such as land use and soil, so it is important to apply remote sensing information to the model. The model is described as

$$R = \frac{(P - 0.2S)^2}{P + 0.8S}, (P \geq 0.2S) \quad (1)$$

and

$$R = 0, (P < 0.2S) \quad (2)$$

where R is the overland flow (mm), P is the rainfall (mm), and S is the potential maximum soil retention (mm). S is related to soil and land covering conditions of the area through the Curve Number (CN). And CN is a function of many physical properties of each grid before the rain, such as soil moisture condition, slope, vegetation type and density, land use type of the grid. CN values vary from 0 to 100. S is calculated from CN by

$$S = \frac{25400}{CN} - 254 \quad (3)$$

During the experiment, the CNs corresponding to each land cover/land use type of Guiyang city are shown in Table 1.

Land cover/land use type	CN	Roughness coefficient (n)
Bare soils	86	0.03
Developed lands	95	0.1
Grass lands	80	0.04
Forest lands	79	0.07
Aquatic systems	100	0.03

Table 1. The Curve Numbers (CN) and roughness coefficient (n) corresponding to land cover/land use type of Guiyang city

3.2 Routing procedures

The overflow from a grid propagates to the adjacent grids with lower elevations and the proportions of the flow are calculated using the D_∞ algorithm (Tarboton, 1997). The algorithm calculates the proportions of influx according to the angle between the flowing directions and the steepest direction down-slope (Figure 3).

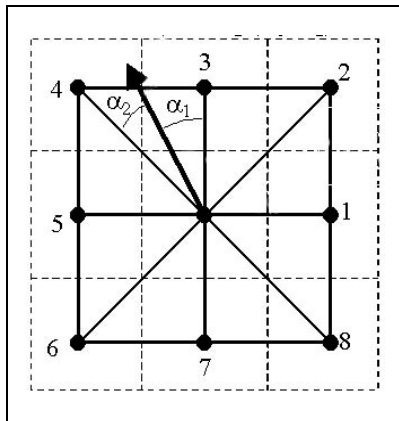


Figure 3. The D_∞ algorithm: Proportion flowing to neighboring grid cell 4 is $\alpha_1/(\alpha_1+\alpha_2)$; Proportion flowing to neighboring grid cell 3 is $\alpha_2/(\alpha_1+\alpha_2)$.

3.3 Overflow velocity

The velocities of the overflow between grids were calculated using the Manning equation (Zhan, 2005). That is

$$v = \frac{1}{n} R^{2/3} S^{1/2} \quad (4)$$

where R is hydraulic radius and it can be substituted by current water level; S is the slope of the water surface; n is the roughness coefficient. The magnitudes of n were chosen according to the land cover/land use type of the grid, which was shown in Table 1.

3.4 Drainage system runoff

The flood accumulation through the draining systems were calculated with a rectified Manning equation (Maidment, 2002)

$$Q_t = 24S^{1/2} y^{5/3} T \quad (5)$$

where S is the slope of the draining pipeline, y is the water level, and T is the top-width of the channel.

3.5 Evapotranspiration

The Penman-Monteith equation is adopted to compute the Reference evapotranspiration (ET_0) from the water surface from standard climatological records of sunshine, temperature, humidity and wind speed (Allen, 1998). The daily ET_0 of Guiyang city are shown in Table 2. As the evapotranspiration amount is small compared with the flood runoff, it even may be omitted in the model.

Month	ET_0	Month	ET_0
Jan.	1.2	Jul.	3.9
Feb.	1.5	Aug.	3.8
Mar.	2.2	Sep.	3.0
Apr.	3.0	Oct.	2.3
May	3.1	Nov.	1.7
Jun.	3.0	Dec.	1.4

Table 2. The daily ET_0 (mm) of Guiyang city

4. RESULTS AND ANALYSIS

The model was implemented using Visual Basic programming language. To display result of the simulation, a GUI program was developed using the ESRI MapObjects ActiveX control.

The variation of the water level at each grid during the rainstorm was represented graphically with different colors. The change of the precipitation was depicts with a dynamic line, which was shown in Figure 4. The simulations at any time spot can be exported as ESRI shape files to be used in other GIS softwares such as ESRI ArcView or ESRI ArcGIS to generate inundation maps.

To validate the model, we adopted metrological rainfall records on July 11th 2005 of the Guiyang city. At that day, the daily rainfall amounted to 113.6 mm and many parts of the city were inundated. The hourly rainfall of the day is shown in Figure 5(a). The inundation map according to the model simulation of water levels at 22:00 o'clock is shown in Figure 5(b).

The water levels at 24 observing stations were measured at 22:00 o'clock of the day. When comparing the simulated water levels with the in situ measurements, a correlation coefficient of 0.69 is attained (Figure 6). As some other hydrological factors such as soil infiltration and plants interception are not considered in this model, and the anthropogenic effects during the actual flood are difficult to be parameterized, the simulation result is satisfactory.

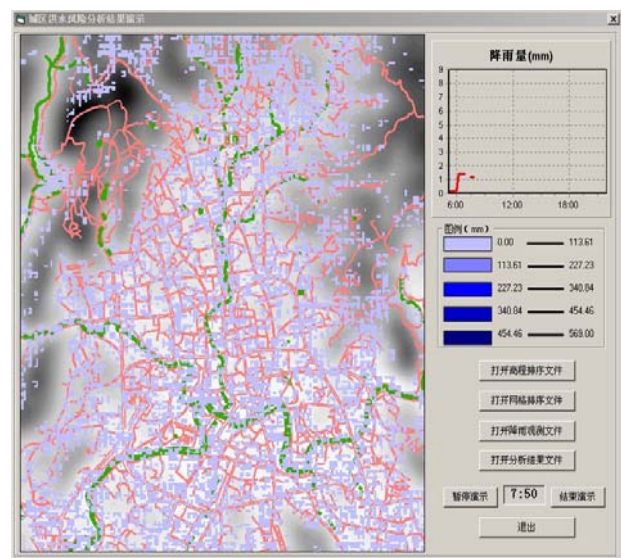


Figure 4. The GUI program to visualize the water level of each grid during the storm period

5. CONCLUSIONS

With the support of remote sensing and GIS, we can calculate varying water level at each grid of the research area with common hydrological models including SCS and Manning equation. The result of this study shows that the integration of GIS, RS and hydrologic model is an efficient way to estimate probable maximum flood, to obtain flood information for emergency response planning and evaluation of the degree of risk posed to local urban area. As the research area of Guiyang city has its specific mountainous landform, further study is required to carefully validate and calibrate the model for flood inundation simulations of other cities.

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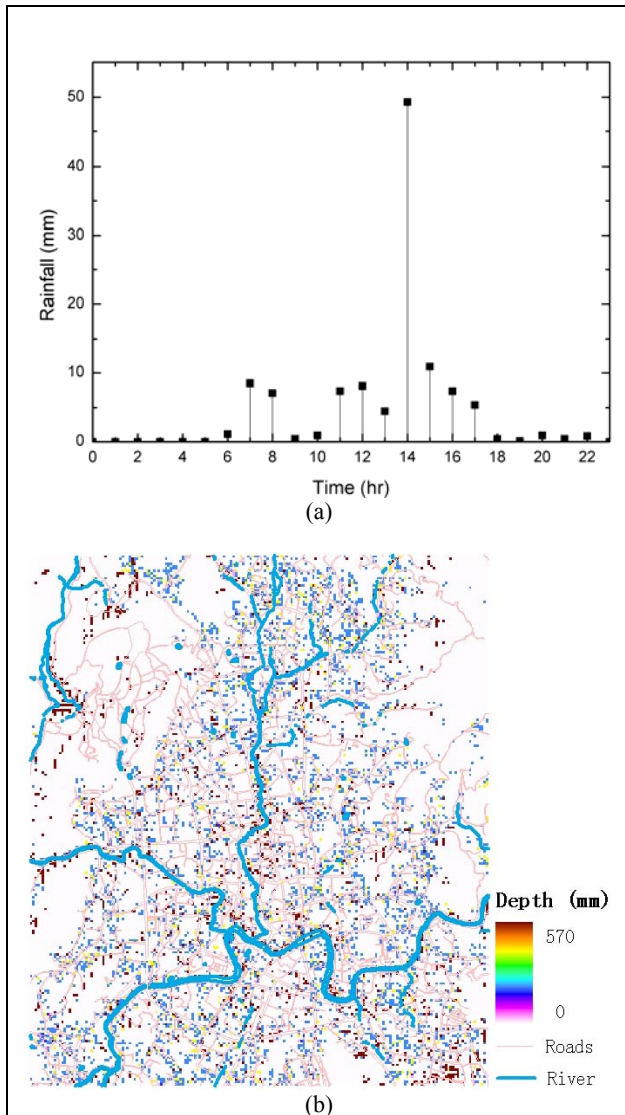


Figure 5. (a) The hourly rainfall on July 11th 2005 over Guiyang city; (b) the inundation map according to simulation result at 22:00 o'clock

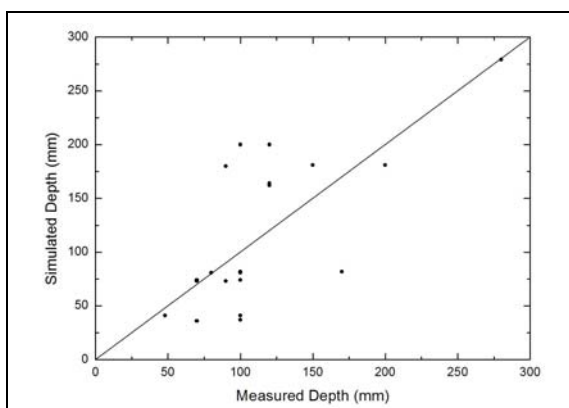


Figure 6. Scatter plot between the in situ measurements and the simulated water levels at 22:00 o'clock on July 11th 2005.