Mountain flooding analysis based on SCS-CN model -- A case study in Mingxi, China

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Abstract. Flood and waterlogging disaster occurs frequently, which seriously threatens people’s life and properties. The SCS-CN model takes into account the characteristics of various factors such as rainfall, soil type, land use, soil moisture and surface runoff. In this paper, the SCS-CN model is introduced to the analysis of flood inundation in mountain areas. Firstly, remote sensing data, land use status map, topographic map are used to obtain land-use type, slope and other data. Then, watershed analysis is carried out based on SCS-CN model to obtain runoff data. Finally, based on rainfall data, the inundated area is estimated, and the spatial and temporal distribution characteristics of inundation area were analyzed from the perspective of land use. The experimental results of Mingxi county in Fujian province, China show that this method is effective for the analysis of flood inundation in mountainous areas.

1. Introduction
As one of the frequent natural disasters in China, flood and waterlogging disaster is sudden and destructive, causing heavy losses to urban safety, industrial and agricultural production and residents’ life [1]. In foreign, the early stage of studies on flood and waterlogging disaster is soil and water conservation based on soil factors. In the early 1970s, studies on flood and waterlogging disaster began to gradually transition to studies on inundation analysis [2]. In the late 1990s, the combination of computer, geographic knowledge and mathematical statistics greatly accelerated the efficiency of flood and flood analysis. Domestic research is mainly based on DEM data of the research area to establish a three-dimensional terrain model. The data of different inundation periods are superimposed hierarchically to simulate the process of rising flood water level, and then the inundation area with different water levels are compared. Although three-dimensional simulation can clearly understand the regional risk, the inundation analysis based on vector data has disadvantages, such as not being able to dynamically analyze the flooded area, large data processing capacity and complex structure. In view of the characteristic, some researchers choose to use grid data structure to obtain a three-dimensional terrain model. The data of different inundation periods are superimposed hierarchically to simulate the process of rising flood water level, and then the inundation area with different water levels are compared. Although three-dimensional simulation can clearly understand the regional risk, the inundation analysis based on vector data has disadvantages, such as not being able to dynamically analyze the flooded area, large data processing capacity and complex structure. In view of the characteristic, some researchers choose to use grid data structure to obtain an accurate flow network diagram by superimposing water flows through each grid.

The SCS-CN model proposed by the soil conservation service of the United States Department of Agriculture Soil Conservation Service (USDASCS) took into account a variety of factors including rainfall, soil type, land use pattern, early soil moisture and runoff. This model can fully reflect the inundation range of the river network and has a high accuracy [3]. Therefore, this paper proposed a mountain flood submerging analysis method based on the SCS-CN model. And took Mingxi county in Fujian province as the research area to carry out verification experiments. This study can provide...
method basis and data support for accurate assessment of flood inundation range and risk assessment in mountainous areas.

2. Research Methods
In this paper, a flood inundation analysis method based on SCS-CN model was proposed for mountainous areas, which was mainly divided into three steps: data preprocessing, runoff calculation based on SCS-CN model and flood inundation analysis (Figure 1).

2.1. Data preprocessing
The flooded area is closely related to the land use, topography, soil moisture and other information of the research area. Carrying out geometric correction and image classification of satellite remote sensing data to obtain land use type information (cultivated land, garden, woodland, urban and rural construction land, transportation construction land, water, grassland, natural reserve, other agricultural land and other construction land) in the research area. Slope analysis was conducted on DEM data to obtain slope data. According to antecedent moisture condition, the soil moisture status was obtained.

2.2. Runoff calculation based on SCS-CN model
SCS-CN model is a hydrological model for studying flood water, which takes into account a variety of factors such as rainfall, soil type, land use pattern, antecedent moisture condition and runoff. According to the infiltration capacity of different land-use types in different regions, the surface runoff of the region is calculated, the flood inundation range is simulated.

The calculation expression of surface runoff based on SCS-CN model is as follow:

\[ Q = \frac{(P - I_c)^2}{P - I_c + S} \]  

where, \( Q \), \( P \), \( S \) and \( I_c \) are the surface runoff, total rainfall, rainwater consumption and possible maximum retention, respectively, all in mm.

Rainwater consumption \( I_c \) includes water absorption by trees, water storage in soil and evaporation in air. \( I_c \) has the following relationship with \( S \):

\[ I_c = \lambda S \]  

where, \( \lambda \) is the regional parameter, which mainly depends on the geographical and climatic factors, usually 0.2.

\( S \) is a spatial variable, which is related to soil texture, land use, slope and other spatial factors. The specific calculation formula is as follow:

\[ S = \frac{25400}{CN} - 254 \]  

Where, CN reflects the soil and water condition in the studied area before rainfall. This parameter also represents the maximum water storage capacity of the soil surface. In this study, the evaluation of CN value mainly based on soil moisture condition, land use type and slope. According to the statistical yearbook issued by Mingxi county, antecedent moisture condition and land use type were determined. Through the CN value lookup table listed in chapter 4 of the US national engineering manual, the CN value range of this study was determined to be 53–87.

2.3. Flood inundation analysis
Calculation of runoff based on SCS-CN model, combined with rainfall data, flood inundation analysis was carried out. The runoff is related to water level, grid area and grid elevation. The specific calculation formula is as follow:
where, $Q$ is the regional runoff, $H$ is the flood level in the flood zone, $V$ is the Grid area of each discrete unit in the Grid model data, $h_i$ is the elevation of the $i$-th Grid, and $n$ is the total number of grids.

3. Research area and data

3.1. Research Area
Mingxi county is located in the northwest of Sanming city, Fujian province, China. The geographical scope is (26°08’-26°39’N, 116°47’-117°35’E), with an area of 1705.6 square kilometers. The specific location is shown in Figure 2. The terrain of the county is high in the north and low in the south, with a large elevation difference between the north and the south. The terrain is mainly mountainous and hilly but few plains, accounting for 91.91% and 6.98%, respectively, of the total area.

3.2. Data
The data used in this paper mainly include satellite remote sensing image, DEM data, administrative zoning map and precipitation of Mingxi county. The data obtained was from April 12 to April 30, 2019. Satellite remote sensing images are used to extract the status quo of land use, DEM data are used for slope analysis and hydrological analysis, and precipitation data are used for SCS-CN model processing.

4. Experimental results and analysis

4.1. Experimental results
Image classification, slope analysis and hydrological analysis were carried out on satellite remote sensing data, DEM data and water body data. These data processing can obtain the land use type map, slope data and river grid data.

It can be seen from Figure 3 that the woodland occupies the largest area in Mingxi county, and the
water area is mostly located in the southeast and northwest. Urban and rural construction land, transportation and water conservancy construction land are mostly located in the central and southeast of Mingxi county. Northwest of Mingxi county has the high altitude and steep slope. The terrain is relatively flat in the southeast of Mingxi county. Affected by topographic partition, the river network is fractured and no coherent river system flows through Mingxi county.

The Moisture content of soil before precipitation and the loss of vegetation root system will have a certain impact on runoff. According to Antecedent Precitation Index (API), Antecedent Moisture Condition (AMC)\(^{[10]}\) was divided into 3 levels, which were A (drought), B (normal) and C (Moisture), respectively. The specific classification basis is shown in table 2.

**Table 2 AMC classification of study area**

| AMC | Growing Period | Fallow Period | Month       |
|-----|----------------|--------------|-------------|
| A   | <36.2          | <13.9        | 12, 1, 2, 3 |
| B   | 36.2-54.6      | 13.9-31.2    | 7, 8, 9, 10, 11 |
| C   | >54.6          | >31.2        | 4, 5, 6     |

It can be seen from the table that low rainfall from December to January results in low surface water content, which is prone to drought. From April to October, the surface water content was higher and the vegetation growth was better.

The permeability of 10 land types were investigated to obtain the CN value corresponding to each type of land (Figure 4). It can be seen from the figure that the CN value of urban and rural construction land is relatively high, which has the worst infiltration effect and the poor surface storage capacity. The CN value of cultivated land, garden land, grassland and natural reserve is not much different. The CN value of woodland is also relatively high due to the loss of rain water caused by tree canopy and natural evaporation. Based on the precipitation data of each month, formula (1) is used to calculate the runoff data of each month of different land use type, and the result is shown in Figure 5.

It can be seen from Figure 5 that the surface runoff in Mingxi county presents a trend of "increasing - decreasing", and the precipitation being the most in April to August. From the analysis of land use type, the runoff in the natural reserve is the largest and other construction land is the smallest.

![Figure 4. CN values of different land uses.](image)

![Figure 5. Surface runoff in 2016.](image)

According to the surface runoff of 12 months, the flooded area of Mingxi county was simulated based on SCS-CN model, and the results were shown in Figure 6.

![Figure 6. Flooding simulation.](image)
According to the simulation results of flooded areas, it can be seen that:

1. The precipitation was less in December and February, and the irrigation area located in the low-lying farmland suffered from severe drought.
2. More rainfall in March-June, and the possibility of flood disaster is high. It can be seen from Figure 6 that the inundation area is mainly located in the southeast and northwest of Mingxi county. And the terrain around the southeast is flat, the residential areas are concentrated, and the river system is rich, suitable for farmland irrigation. When the rainfall is large, the water surface rises and flooding is easy to occur. The elevation in the northwest is slightly higher than in the southeast. and the slope in the northwest is larger, which will prone to landslides, debris flow and other disasters.
3. Combined with the land use type map, the highest proportion of submerged area is other agricultural land.

5. Conclusion
In this paper, SCS-CN model is introduced into the analysis of flood inundation area in mountainous areas, the main conclusions are as follows: (1) the technical process of mountain flood inundation area analysis based on SCS-CN model is designed; (2) the risk and scope of flood in each month and various land use types in Mingxi county of Fujian province, China were analyzed through simulation. The study discussed the response of various land use types to flood inundation range. The next research direction of this paper is to analyze the economic loss caused by flood inundation from GDP and other indicators.

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