

Study on Identification of Areas Susceptible to Mountain Torrent Disasters in Small Basin of Deficient Data

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Identification of areas susceptible to mountain torrent disasters is the basis of decision making for river basin flood control and flood disaster loss analysis, and analysis for those areas in small basin lacking data is key and difficult points of our study. Gulu small basin is chosen as the research object of the present work. According to the combination of rational formula and GIS technology, we propose a method for fast identification of areas susceptible to mountain torrents in small basin short of geological data. Based on the Digital Elevation Model (DEM) extracted from the characteristics of small basin in mountain torrent disasters prevention areas utilizing hydrological analysis tools, rational formula is used to calculate peak discharge and runoff volume at each outlet. Manning formula is adopted to compute each outlet water depth, then GIS spatial interpolation technology is used to calculate flood submerged areas. Through exploring technology and method in identification of areas susceptible to mountain torrents in small basin short of geological data, we have made breakthrough in integration research theory, and created a new way for mountain torrents disaster prediction.

1. Introduction

Mountain torrent disasters are those caused by flash floods, including casualties, property loss, infrastructure damage and environmental resources destruction resulting from river flooding, debris flow and landslide (Liu et al (2014), Liu et al (2011)). Identification of areas susceptible to mountain torrent disasters is the basis of decision making for flood control and flood loss estimation. Japan, America, Austria, Sweden and Germany are among countries in the world which started to develop risk zoning and prediction of mountain torrent disasters fairly early (Ahmed (2011), Versini et al (2010), Amutha et al (2009)). California Nevada River Forecast Center (CNRFC) adopts a scoring method, establishing the basic framework of risk prediction and evaluation for mountain torrent, which utilizes factors overlay analysis and weighted average method to calculate the relevant Flash Flood Potential Index (FFPI), exponentially scaled from 1 to 10, simultaneously considering main impact factors topographic feature, soil properties, vegetation cover and land utilization, in order to predict and estimate the degree of mountain torrent risk. Sweden uses danger area diagram to identify the type of mountain torrent disasters and estimate the corresponding disaster scale, and areas susceptible to mountain torrent are divided into four different danger areas, each of which are further divided into 1 to 5 sub-regions; therefore, determining flood occurrence areas (Wen (2013), Su (2012), Liu (2012)). However, these methods generally apply to areas with plentiful geological data, where potential types, extent and scope of influence of mountain torrent disasters can be analyzed on the basis of investigation on historical mountain torrent disasters. Then danger areas can be reasonably delimited according to historical flood level, which can help government and residents to carry out specific measures, reaching the goal of early warning. While rainfall in hilly regions with high and steep mountains and rivers of high density can transfer into runoff rapidly, the relevant confluence is fast and the velocity is high (Wei and Fan (2004)). Consequently, disasters could happen 1 to 2 hours or even half an hour later; therefore, the effective response time is short and the level of difficulty of early warning is high. Most of mountainous areas belong to areas of deficient data, where monitoring data is in shortage or lacking, and forecasting approaches for storm-flood are in deficiency, which cannot satisfy the need for preventing storm-flood and mountain torrent disasters in small and medium-sized river basins (Sandra (2003), Yang (2001), Hapuarachchi (2001)). As to watercourses in mountainous areas, calculation and analysis of watercourse flood cannot be developed with uncontrollable hydrologic section.

Currently, research papers on mountain torrent disasters in small basin areas of deficient data are fairly few, and no relatively developed theory has been formed. Therefore, it is of high importance and impendency to do the relevant research, aiming at minimizing disaster loss caused by storm-flood (Mohammed (2001), Joy (2005), Magesh (2011)). The present work abstracts the features of small basins in mountain torrent disasters prevention and control areas, utilizing Digital Elevation Model (DEM) and Geographic Information System (GIS), explores the corresponding identification method for areas susceptible to mountain torrent disasters, and technically create new methods for preventing mountain torrent disasters.

2. Overview of research object

Gulu is a small basin located at South of Henan province with northern subtropical, monsoon-type and continental climate, where the average annual precipitation is above 800 mm. Gulu River is a tributary of Huangya River, one part of hydrographic net of Tangbai River in Yangze River basin, originating from Dongnan Ping Village at the Western foothill of Da Sheng Ren Duo of Funiu Mountain in Henan province. The basin area is 88.7km², and the altitude of Da Sheng Ren Duo is 1508m. The distance from the corresponding watershed to estuary entrance is 26.4km, and the relative altitude difference between two places is about 1000 m, with characteristics of wide top and narrow bottom, and high fall head, as shown in Figure 1. In the 50s, 70s and 80s of last century, this area had encountered flood current or debris flow several times, resulting in casualties and properties loss. Mountain torrent disasters seriously threatens the safety of residents along Gulu River Banks, especially 950 people of 230 families from 7 village-groups in Cangfang and Dongnan Ping villages. Mountain torrent disasters along Gulu River have become protruding problems which seriously restrict local economic and social development, hinder residents from shaking off poverty and attaining prosperity as well as restrain the improvement of ecological environment.

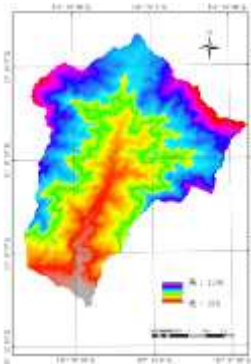


Figure 1: Gulu small basin DEM and relief map



Figure 2: Determine catchment units

3. Research method

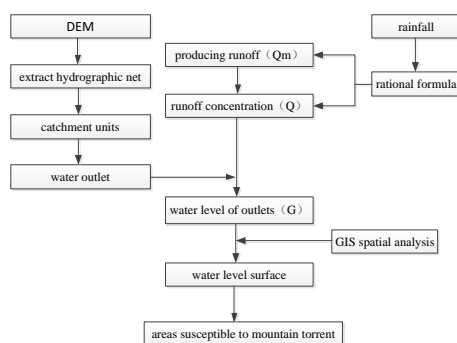


Figure 3: Technology roadmap for identification of areas susceptible to mountain torrent

Firstly, extract hydrographic net utilizing DEM, and determine stream order using hydrology analysis module, based on which flow units can be divided, then water outlets of discrete and different levels of rivers and the

relevant elevation at each water outlets can be obtained; Secondly, calculate peak discharge at individual outlet of each flow units (Q_m) and the corresponding runoff volume at each water outlets (Q) according to rational formula derived in "Design storm and flood atlas of small basins in Henan Province"; Thirdly, get the conversion of water depth from runoff volume at individual water outlet according to Manning's equation; Fourthly, obtain water level through summing water depth and water elevation at each water outlet, forming water level surface using water level interpolation based on spatial interpolation tools of ArcGIS; Fifthly, intersect water level surface and terrain elevation surface, and points on water level surface higher than that on terrain elevation surface are grouped into incidence of mountain torrent, then abnormal data will be deleted after data error checking; Finally, areas susceptible to mountain torrent related to specific rainfall. The research method and technology roadmap is shown in Figure 2.

4. Prediction of areas in small basin susceptible to mountain torrent

4.1 Grade river using Strahler method

Investigation on fluid motion and confluence modes are the basis for exploring mountain torrent disasters. According to Strahler grading of ArcGIS hydrological analysis, group segmental arcs in hydrographic net without tributary hydrographic net into first order, then the confluence of two first order segmental arcs are grouped into second order, the rest can be done in the same manner until reaching hydrographic net outlets.

4.2 Determine catchment units according to stream order

Catchment unit, also named as catchment zone, is a place where current and other materials flow through discharge via a communal water outlet, thus forming a concentrated catchment area. Determine all interconnected grids which are located in the same drainage basin through data analysis of flow direction. In ArcGIS, catchment units are calculated using basin tool of hydrology module, which can be adopted to compute catchment units of different stream order, and the results are presented in Figure 3.

4.3 Determine outlets of rivers with different order utilizing hydrological analysis tool

Outlets are the lowest position of a whole catchment unit. The position of outlets can be searched through SnapPourPoint tool of hydrology tool sets under the tool boxes of Spatial Analyst Tools in ArcGIS.

4.4 Calculate outlets peak discharge of individual catchment unit

As detailed historical flood disasters and hydrological data are in shortage, complex hydrodynamics model of the basin hydrology cannot be built. Therefore, rational formula for small basin in mountainous areas recommended by "Design storm and flood atlas of small basins in Henan Province" is adopted to calculate peak discharge related to different return periods. We calculated five particular flood with 5-year, 10-year, 20-year, 50-year, 100-year of return periods, respectively. The method of rational formula to calculate peak discharge is based on rainfall, the fundamental form is as follows,

$$Q_m = 0.278\psi \frac{S \cdot F}{\tau^n} \quad (1)$$

$$\psi = 1 - \frac{\mu}{S} \cdot \tau^n \quad (2)$$

$$\tau = 0.278 \frac{L}{m \cdot J^{1/3} \cdot Q^{1/4}} \quad (3)$$

Where, Q_m is design peak discharge, m^3 / s ; ψ is peak runoff coefficient; τ is peak concentration-time, h; F is drainage area, km^2 ; L is main-stream length, km; J is average main stream length gradient (in decimals); S is design average rainfall intensity within 1h, namely design frequency of 1h-rainfall, mm/h; n is decline factor of design rainstorm, counted according to corresponding to catchment travel time; μ is average infiltration rate, mm/h; m is catchment coefficient.

The peak discharge at outlets of each catchment unit is calculated via trial method based the abovementioned formula and parameters, then watercourse flood routing is achieved adopting Muskingum-Cunge method, thus obtaining catchment volume at each catchment unit outlet.

4.5 Calculate water level at outlets

Assuming that the current in studied area to be constant flow, so we use stable relationship between water level and flux, detailed equation is as follows,

$$Q = \frac{1}{n} \cdot A \cdot J^{\frac{1}{2}} \cdot R^{\frac{2}{3}} \tag{4}$$

Where Q is section discharge capacity (m^3 / s), which is runoff volume at each catchment unit outlet after flood routing,

A is discharge section area (m^2);

J—slope, expressed as $\tan \theta$;

n—roughness coefficient, set as 0.035 referring to “Roughness Coefficient Table”;

R—section hydraulic radius.

R can be described as follows,

$$R = \frac{1}{2} \cdot h \cdot \cos \theta \tag{5}$$

$$X = \frac{h}{\sin \theta} \tag{6}$$

Therefore, Manning’s Formula can be expressed as,

$$Q = AV_c = \left[\frac{1}{n} \cdot \left(\frac{1}{2}\right)^{\frac{2}{3}} \cdot \left(\frac{1}{\tan \theta}\right)^{\frac{1}{2}} \cdot (\cos \theta)^{\frac{2}{3}} \right] \cdot h^{\frac{8}{3}} \tag{7}$$

Then the relationship between water depth and flux can be described as,

$$h = \left[0.0556 \cdot \frac{Q \cdot (\tan \theta)^{\frac{1}{2}}}{(\cos \theta)^{\frac{2}{3}}} \right]^{\frac{3}{8}} \tag{8}$$

In ArcGIS, each outlet elevation E can be extracted through DEM, then each outlet water level G is summation of E and h,

$$G = E+h$$

4.6 Areas susceptible to mountain torrent

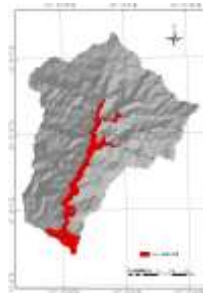


Figure 4: 5-year return period flood inundation Range Figure Figure 5: 50-year return period flood inundation Range Figure

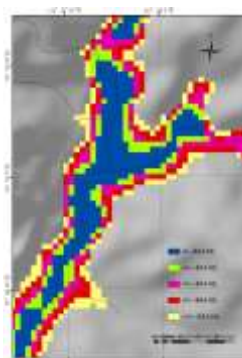


Figure 6: 100-year return period flood inundation Range Figure Figure 7: Different return periods inundation area comparison chart

The areas under investigation is mountainous areas with steep slope. The flood in watercourse is treated as inclined plane, then the problem concerning submerged areas calculation boils down to intersection of DEM elevation surface with water level surface. Firstly, each outlet water level is used for Kriging interpolation to form water level surface, then the surface generated is subtracted by elevation surface, consequently grids above zero are grouped into areas affected by mountain torrents, and grids below zero are grouped into areas not affected by mountain torrents. The relevant areas obtained through abovementioned method is theoretical areas submerged by mountain torrents. However, the precision of the water level surface resulting from interpolation is limited by the number of discrete points used for interpolation, leading to certain error; therefore, error checking is essential. Error checking is to further group the results calculated, deleting abnormal results, and finally the areas susceptible to mountain torrents under certain rainfall can be obtained. Based on high-precision DEM data, GIS spatial analysis is utilized to analyze areas submerged by mountain torrents, and the corresponding diagrams of submerged areas are plotted, as shown in Figures 4 to 6, representing relevant cases with 5-year, 50-year, 100-year of return periods, respectively; as shown in Figures 7, This is different return periods inundation area comparison chart; thus, different grade of danger areas can be determined. It is observed that the occurrence frequency of cases with return period less than 5-year is fairly high, which are graded as areas with extreme danger; cases with return period more than or equal to 5-year but less than 20-year are graded as high risk areas; the areas with occurrence frequency of maximum historical flood level with return period more than or equal to 20-year is very rare, which are graded as danger areas. The area danger degree is listed in Table 1.

Table 1 Grade of danger areas

Grade of danger areas	Flood return period(year)	Occurrence frequency
Extremely high danger	< 5	Fairly high
High danger	≥ 5 & < 20	Medium
danger	≥ 20 to Probable Maximum Flood (PMF)	Rare

5. Conclusions

As to small basin watercourse in hilly areas with deep undercut and large gradient, the rainstorm and mountain torrents are characterized by short lasting, intense rainfall, and steeply rising and dropping. Gulu small basin is chosen as the research object of the present work. Based on rational formula for rainstorm and mountain torrents, local rainstorm diagrams with 5-year, 50-year, 100-year of return periods are analyzed, respectively. Digital elevation of small basin in hilly areas was extracted utilizing GIS to form DEM database, then rational formula for rainstorm and mountain torrents was combined with GIS to calculate water depth at each catchment unit outlet. Areas submerged by flood corresponding to different return periods is calculated using GIS spatial interpolation; therefore, the danger grade of areas susceptible to mountain torrents can be determined, and areas susceptible to mountain torrents in small basin of deficient data can be rapidly identified. The method proposed is well combined with traditional flood calculation, based on which areas susceptible to mountain torrents can be quickly figured out according to practical basin characteristics. Our method with clear thinking is convenient to be applied. In the meanwhile, our method can enrich research works in identification of areas susceptible to mountain torrents in small basin short of geological data, and can provide theoretical basis and value of popularization and application for areas short of geological data to take out measurements to prevent mountain torrents disasters.

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