Uncertainty Analysis of Flash-flood Prediction using Remote Sensing and a Geographic Information System based on GcIUH in the Yeongdeok Basin, Korea

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ABSTRACT : This paper focuses on minimizing flood damage in the Yeongdeok basin of South Korea by establishing a flood prediction model based on a geographic information system (GIS), remote sensing, and geomorphoclimatic instantaneous unit hydrograph (GcIUH) techniques. The GIS database for flash flood prediction was created using data from digital elevation models (DEMs), soil maps, and Landsat satellite imagery. Flood prediction was based on the peak discharge calculated at the sub-basin scale using hydrogeomorphologic techniques and the threshold runoff value. Using the developed flash flood prediction model, rainfall conditions with the potential to cause flooding were determined based on the cumulative rainfall for 20 minutes, considering rainfall duration, peak discharge, and flooding in the Yeongdeok basin.

KEY WORDS: DEM, Flash Flood Prediction Model, Geographic Information System, GcIUH, Remote Sensing

1. INTRODUCTION

The relationship between rainfall and runoff is an important but challenging issue in surface hydrology. Geographical information systems (GISs) and hydrological modeling are closely connected. A GIS can represent the spatial features of the Earth, while hydrological modeling is concerned with the flow of water and its constituents over the land surface and in the sub-surface environment. The hydrological system in most areas is quite complex. To understand a hydrological regime, all influencing factors must be coherently analyzed (Saraf et al. 2004)

However, few studies have examined in detail the reference systems for flood alarms, and no specific foundation for flood alarm systems is available. Therefore, we focused on the characteristics of small stream flash flood potential in the Yeongdeok basin, which has an existing flood prediction and alarm system. Using a hydrological flash flood prediction model based on a GIS, rainfall with the potential to generate flash flooding in the Yeongdeok basin was characterized.

2. STUDY AREA

Yeongdeok County is located in the easternmost part of North Gyeongsang Province, South Korea, between 36°15′ and 36°40′N and 129°09′ and 129°27′E. The Landsat image in Figure 1 shows the location and present land uses of the research area.

3. METHODOLOGY

3.1 Surface hydrological modeling based on a digital elevation model (DEM)

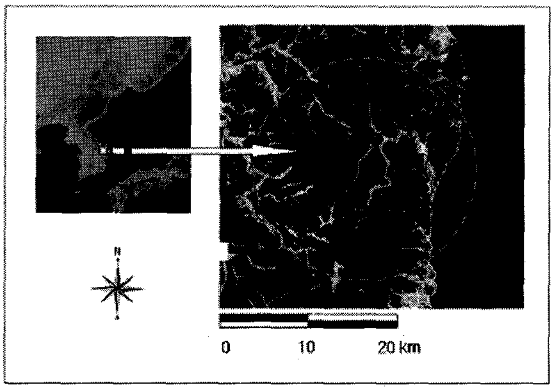

Figure 1. Landsat TM image of the Yeongdeok watershed.)

DEMs are indispensable for many analyses such as those requiring topographic feature extraction, runoff analysis, slope stability analysis, and landscape analysis (Saraf & Choudhury 1997, Choudhury 1999).

This grid is synonymous with the aspect grid except that the aspect grid has some flat pixels (cells). The output grid has values of 1 to 128 around the center cell, as shown in Figure 2.

Flow direction data are used to create the flow accumulation grid, for which each cell is assigned the value of the number of cells flowing to it. Cells having flow accumulation values of zero generally correspond to local topographic highs, whereas cells with high flow accumulation values correspond to stream channels. This approach was followed in this study (Figure 3). The flow accumulation was used to produce a drainage network, applying a suitable threshold. The threshold value indicates the minimum upstream drainage area (threshold area) necessary to maintain a stream. Different threshold values would result in stream networks with different total stream lengths, and consequently, different drainage density values.

32 (↖)	64 (↑)	128 (↗)
16 (←)	×	1 (→)
8 (↙)	4 (↓)	2 (↘)

Figure 2. . Hydrologic flow direction encoding.

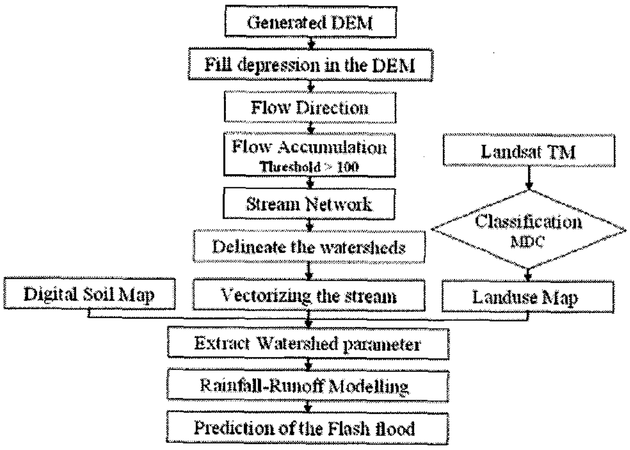

Figure 3. . Methodology for predicting flash floods using a GIS based on the DEM. [Change 'modelling' to 'modeling'; change 'vectorizing' to 'vectorize'; define 'MDC'; consistently capitalize words in the boxes.]

3.2 Conceptual GcIUH based on relationships between hydrologic responses and watershed characteristics

Using the kinematics wave approximation for flow routing along first-order streams and a derived distribution approach, Rodriguez-Iturbe et al. (1982) obtained analytical expressions for the probability density functions of the time to peak, tp, and the peak discharge, qp, for a GIUH that depended on the mean rainfall intensity; hence, the term GcIUH was used.

For individual storm events, the above equations can be manipulated to obtain expressions for the peak discharge and time to peak as functions of the particular storm intensity and duration. These expressions lead to

The GcIUH establishes a link among climate, watershed geomorphology, and the hydrologic response of the basin. Furthermore, the GcIUH allows an estimation of the IUH for a given particular rainfall input, so that problems associated with nonlinear basin behavior are avoided. For example, runoff from a given rainfall event can be computed using an IUH derived from the given storm event characteristics, thereby avoiding the well-known errors incurred when using an IUH based on a different event.

$$q_p = \frac{0.871}{\Pi^{0.4}} \tag{4}$$

$$t_p = 0.585\Pi^{0.4} \tag{5}$$

$$\Pi_i = \frac{L_\Omega^{2.5}}{i A_\Omega R_L \alpha_\Omega^{1.5}} \tag{6}$$

4. RESULTS

4.1 Basin character

A digital elevation model of the research area (Figure 4) was created based on a 1:50,000 topographic map for the basin-sharing and basin-network maps of the GIS.

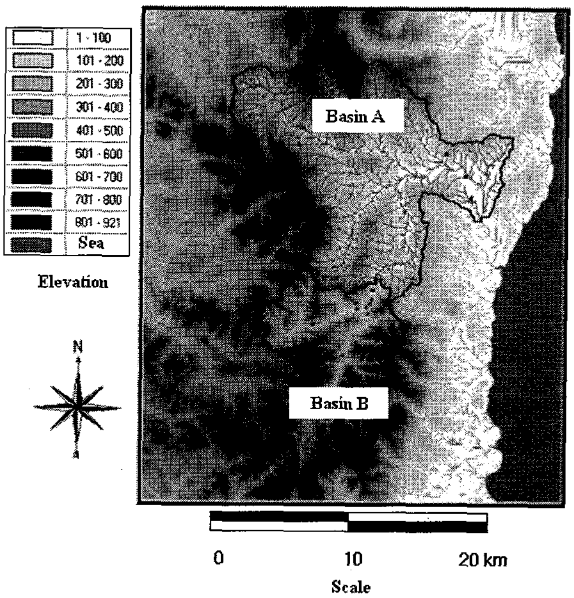

Figure 4. Digital elevation model of the study area.

Basin A was divided based on an installed flood control station, and included two alarm stations, two control stations, and two rainfall stations. Basin B had eight alarm stations, two rainfall stations, a mediating station, and a base station. The basin area directly affects the flood size. Given the same rainfall amount, a basin with a larger area may experience a larger flood than a basin with a smaller area. Basins A and B had calculated areas of 343.132 and 101.446 km2, respectively.

The altitude difference refers to the height difference between the highest and lowest points within the basin, and the basin slope is defined as the altitude difference divided by the river extension. The altitude difference of basin A was relatively high (900 m), and the basin slope was 0.0197 indicating a fairly steep aspect. Basin B also had a relatively high altitude difference and steep basin slope (816 m and 0.0328, respectively). The average basin width was determined as the basin area divided by the river extension. Conceptually, the basin was regarded as a rectangle and was divided by the river extension; the average width of the basin thus does not have a physical meaning.

4.2 Classification

Table 1 lists the percentages of land use types in the basins. Land uses were classified by the maximum likelihood classification (MLC) method using supervised classification of a Landsat image.

Table 1. Land use in each basin

Basin	Landuse categories							
	Water	Build-up	Barren	Wetland	Rangeland	Forest	Agricultural	Total
A	0.11%	1.22%	0.33%	0.03%	3.15%	86.95%	8.20%	100%
B	0.01%	0.43%	0.14%	0.01%	2.66%	89.23%	7.52%	100%

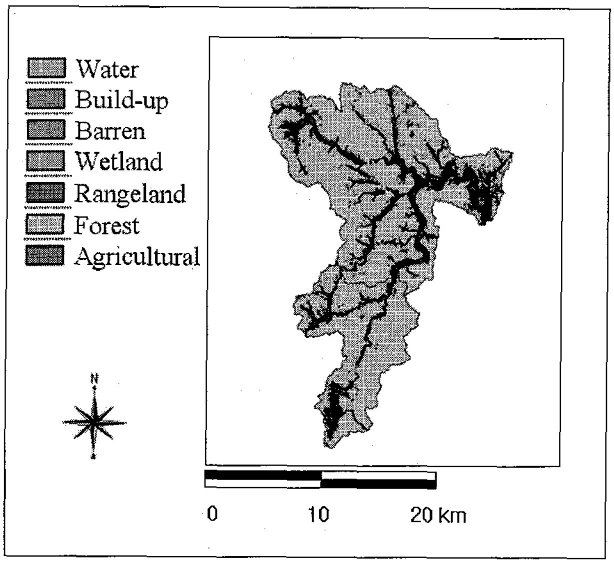

Figure 5.. Land use map, Yeongdeok County, 2000.

4.3 Soil Conservation Services-Curve Number (SCS-CN) generation procedure

The Soil Conservation Services Curve Number (SCS-CN) method was used to estimate water loss by rainfall runoff processes (Hydrologic Engineering Center [HEC], 1981). Precipitation loss was calculated based on the CN and the initial surface moisture storage capacity, as shown in Eq. 10. The standard SCS-CN method is based on the relationship between rainfall depth (P in millimeters) and runoff depth (Q in millimeters):

$$Q = \frac{(P - 0.2S)^2}{(P + 0.8S)} \tag{10}$$

The potential maximum retention (S in millimeters) represents an upper limit in the amount of water that can be abstracted by the watershed through surface storage, infiltration, and other hydrologic abstractions. For convenience, S is expressed in terms of the CN as follows:

$$S = \frac{25400}{CN} - 254 \tag{11}$$

The CN describes the runoff production behavior of a catchment in the SCS runoff model, where higher CNs generate more runoff. SCS-CN values have been suggested for various land covers and soil types. Table 2 shows the SCS composite curve numbers for the study basins in normal and high antecedent soil moisture conditions (AMC-II and AMC-III, respectively). Figure 7 features a map of CNs for AMC-II conditions.

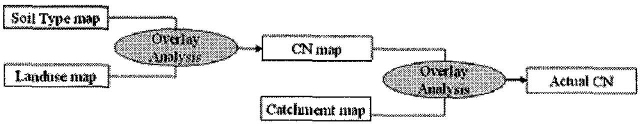

Figure 6. Soil Conservation Services curve number (CN) generation procedure [Change "catchmemt" to "catchment"]

Table 2. SCS composite curve numbers (CN) at two different antecedent soil moisture conditions (AMC)

Basin	CN	
	AMC-II	AMC-III
A	65	83
B	67	82

4.4 Roughness coefficients and river widths

Because no pertinent water level data were available for the calculation of a roughness coefficient, a higher value among roughness coefficients estimated by the Cowan (1956) method was mainly used for this investigation. Roughness coefficients for basins A and B were estimated as 0.031 and 0.091, respectively. When using a GcIUH, the width of the stream significantly affects the determination of the flood level. The average river widths for basins A and B were 183.8 and 47.5 m, respectively.

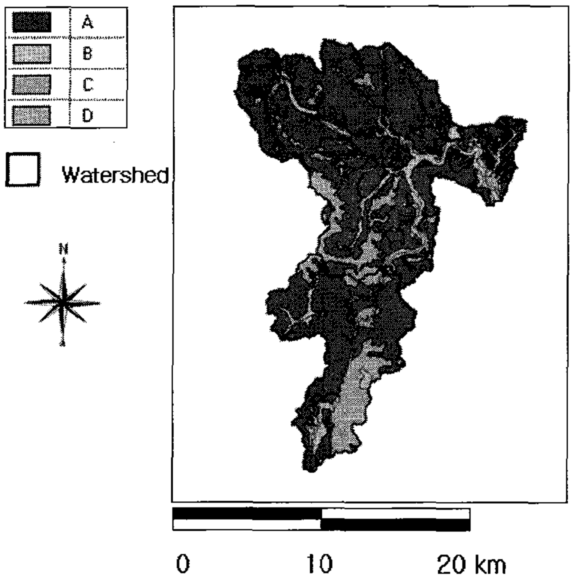

Figure 7. Curve number map (AMC-II).

4.5 Calculations of the critical depth and flood level

To calculate the critical depth and flood level, the river cross section was assumed to be spherical, and critical discharge was determined based on the range of rapid shelter locations available in the event of a flash flood, set at the standard maximum depth (Y) of 0.5 m. Table 3 shows the calculation results.

Table 3. Analysis of fluid-flow limit constraints (Y=0.5m).

Basin	Fluid flow (m/sec)
A	11.78
B	16.03

The Manning equation was used to calculate the critical discharge (Q_d), as shown in Equation 12.

$$Q_d = \frac{1.486}{n} S_c^{0.5} B_b [\frac{Y_b}{M+1}]^{0.38} \tag{12}$$

where S_c is basin relief (m/m), B_b is river width, Y_b is critical depth, and n is Manning's roughness coefficient. By applying the GcIUH, the runoff calculation equation for determining critical flow was obtained. The basin maps of the research area, Horton stream order, DEM, and the present rainfall stations and alarm stations were also included in the analyses, and the following terms were determined: basin characteristics, the GcIUH parameters, danger alarm flow, and the rainfall necessary to raise a flood alarm.

5. CONCLUSIONS

Using a GIS, flash flood prediction was analyzed for the study area. To create an effective alarm system, the amount of runoff producing flash floods and the relationship between rainfall and runoff were examined using GcIUH techniques. Flood standards were determined based on flood danger depths of 0.5, 0.7, and 1.0 m that can lead to loss of lives. Further, a flood escape guideline was proposed by making a flood chart of rainfall duration and amount. The results of this investigation provide a more suitable alarm standard for the basins, as compared with the conventional uniform alarm systems. The results and methods can also be used to create other alarm networks based on GIS.

A precise flood-alarm standard requires long-term predictions of hydrological data, surveys of channel cross sections, and rainfall prediction using meteorological radar. A flood-alarm project must also be supported and understood by residents and related organizations. People entering mountain areas should be educated on the flood alarm system and its management.

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