

Geomorphological site classification for the Fujian province

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Abstract Geomorphological classification of the Fujian province was done based on remote-sensing imaging, digital elevation maps, and slope gradient data acquired by ArcGIS 9.2. The engineering geological units in the Fujian province were divided into five types by the geomorphologic shape and genesis. The relationship among geomorphological type, engineering geological unit, and site category was determined using engineering geological data and site category data. Then, after making a preliminary site classification adjusted by drill hole data, the site was classified into four types: I_0 , I_1 , II, and III according to site classification standards of equivalent shear-wave velocity and overburden thickness. The results showed that the site categories in the Fujian province mainly consist of type II, which accounts for 85.26 % of the land area. The percentage of I_0 was the smallest, which accounts for only 2.44 % of the total area.

Keywords Site classification · Geomorphological classification · GIS · Fujian province

1 Introduction

Studies of earthquake damage show that destruction caused by earthquakes is obviously variable from location to location due to the differences in site characteristics, such as geology and geomorphology. Site classification is

important for seismic design of buildings (Liang 2008). According to the Chinese Code for Seismic Design of Buildings (Ministry of Housing and Urban–Rural Development of People’s Republic of China 2010), construction sites are classified by equivalent shear-wave velocity and overburden thickness. Most of the studies of site classification in China were based on the standard of the Chinese Code for Seismic Design of Buildings (Yin et al. 1999; Wang et al. 2005; Cai et al. 2008).

Li and Lin (2004) proposed two methods of synthetic fuzzy evaluation for categorizing sites based on the Chinese Code for Seismic Design of Buildings, but it is not suitable for site classification over large area. Liang (2008) found that in comparison with measured data, the site category made by fuzzy isoline is consistent with site categorization defined by the Chinese Code for Seismic Design of Buildings. But, the study needs a large number of drill hole data to be successful.

Correlations between measured V_S^{30} (m/s) and topographic slope (m/m) for active tectonic and stable continental regions were studied, and a site-condition map was derived from topographic slope (Wald and Allen 2007).

As our study area is a province ($\sim 124,000$ km² in area), we do not currently have a representative quantity of drill hole data; however, there is a corresponding relationship among geomorphology, engineering geological unit, and site category; thus, site classification can be done based on geomorphological classification.

We made a geomorphological classification based on remote-sensing images and digital elevation maps (DEM). The corresponding relationship among geomorphology, engineering geological unit, and site category was constructed. Site classification was done first. The result was then adjusted according to drill hole data, and site classification was accurately made.

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2 Materials and methods

2.1 Remote-sensing image processing

ALOS PRISM data (panchromatic image, 2.5 m) and AV-NIR-2 data (multispectral images, 10 m), which cover six coastal cities in the Fujian province, were purchased. Geometric rectification of the 2.5-m panchromatic images was done based on the topographic map (1:50,000). Then, geometric rectification of the 10-m multispectral images was done based on the 2.5-m panchromatic images. Geodetic accuracy of the images was higher than 0.3 pixels. Then, the image mosaic of the multispectral images and panchromatic images were made. Pixel-level fusion of panchromatic images and multispectral images was carried out by a principal component analysis data fusion technique. The 2.5-m multispectral image covering the coastal regions of Fujian province was created. ETM (15 m) images covering three cities (Nanping, Sanming, and Longyan) of the Fujian inland were also adopted for this study.

2.2 DEM, slope gradient, and other data processing

The DEM data were classified into four grades in the order of 0–50, 50–200, 200–500, and 500 m. The terrain grade map of Fujian province was then created. The slope gradient map was created based on the DEM data and then the slope gradient was divided into five degree categories such as 0° – 7° , 7° – 15° , 15° – 25° , 25° – 35° , and $>35^{\circ}$.

Characteristics in the slope gradient map and the terrain grade map were combined into a single map by overlay analysis using ArcGIS 9.2. The gradient elevation grades map, which contains 12 grades, was then created. The 12 grades contained in the gradient elevation grades map are: 0° – 7° , 0–50 m; 0° – 7° , 50–200 m; 0° – 7° , 200–500 m; 0° – 7° , >500 m; 7° – 15° , 0–50 m; 7° – 15° , 50–200 m; 7° – 15° , 200–500 m; 7° – 15° , >500 m; $>15^{\circ}$, 0–50 m; $>15^{\circ}$, 50–200 m; $>15^{\circ}$, 200–500 m; and $>15^{\circ}$, >500 m.

A relief amplitude map of the Fujian province was created using ArcGIS 9.2 based on DEM data (resolution

of 30 m). The relief amplitude was classified into two grades, <30 and >30 m, respectively.

The geomorphological classification was carried out based on basic data such as remote-sensing images, DEMs, slope grade maps, terrain grade maps, slope–elevation grade maps, administrative area maps, and relief amplitude grade maps.

2.3 Principle of geomorphological classification

The study area was divided into two parts: a plain and platform region, and a mountain and hilly region; depending on the slope gradient. Slope gradient of the former was lower than 7° and the latter was higher than 7° . Mountainous and hilly regions were divided by elevation: mountains were considered to be higher than 500 m, and hills less than 500 m. Plains and platforms were divided by the relief amplitude of 30 m, the former is lower than 30 m, while the platforms are considered to be higher than 30 m (Zhou et al. 2009). As actual situation of the Fujian province, the elevation of the plain is mainly lower than 50 m. The slope gradient of intermontane basins, mountain valleys, and river valleys was lower than 7° .

There are two methods of geomorphological classification based on geomorphologic shape and genesis, or the combination of two methods (Su and Li 1999). In this study, the method based on geomorphologic shape was selected. Geomorphology of a specific site was classified by the slope gradient, aspect, and the combination of the two properties (Table 1). Slope gradient and aspect consist of the mean taken at a map spot (Institute of Geographic Sciences, Chinese Academy of Sciences (CAS) 1987; Zhou et al. 2009).

2.4 Process of geomorphological classification

Previous geomorphological data (resolution of 500 m) and other basic data such as physical atlas of Fujian (Editorial Board of Fujian Local Chronicles 1998) and relief

Table 1 Slope classification of different geomorphological types (Institute of Geographic Sciences, CAS 1987)

Slope surface types		Basic character	Difference
Plain	Flat	Inclined to a aspect or center, slope gradient $<2^{\circ}$, commonly	Relief amplitude <30 m
	Tilted	Inclined to a aspect or center, slope gradient $>2^{\circ}$, commonly	
Platform	Fluctuant	With slopes inclined to the same and opposite aspects, slope gradient $>2^{\circ}$, commonly	Relief amplitude >30 m
Mountain	Gentle	Slope gradient 7° – 15° , commonly	Elevation >500 m
	Relatively gentle	Slope gradient 15° – 25° , commonly	
Hilly	Steep	Slope gradient 25° – 35° , commonly	Elevation <500 m
	Very steep	Slope gradient $>35^{\circ}$, commonly	

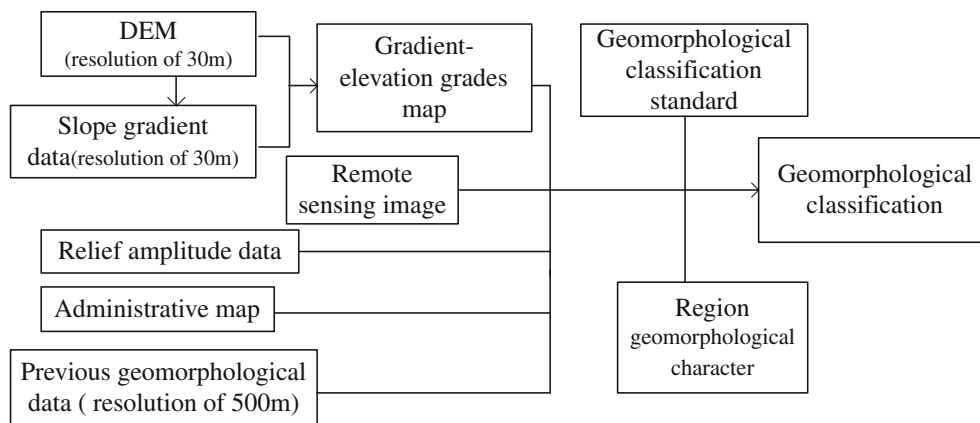


Fig. 1 Processes of geomorphological classification in Fujian province

amplitude data were consulted. Gradient elevation maps and remote-sensing images were combined to classify the geomorphological types based on the criteria mentioned above. The classification process is shown in Fig. 1.

To ensure accuracy requirements (1:100,000), the geomorphological classification in the coastal region of the Fujian province was performed using a scale of 1:10,000, and a scale of 1:15,000 in the inland region. In some complex geomorphological areas, classifications were achieved using even larger scale. The interpretation methods are described in the following sections.

2.4.1 Interpretation of plain and platform

Plain and platform areas are mainly distributed in the coastal region of the Fujian province, with slope gradient lower than 7° . The plains are characterized by flat terrain, located along the southeastern coast, with slope gradient lower than 7° , and elevation lower than 50 m. There are occasionally monadnocks located in the plains. The platforms are mainly dry land with relatively flat terrain. Shallow ravines have become well developed in the platform region. The boundary of the plain and platform region were marked according to elevations lower than 200 m and slope gradient lower than 7° . The boundary between the plain and platform region was marked according to 30 m relief amplitude.

2.4.2 Interpretation of the mountainous, hilly areas

Hilly areas are classified as areas lower than 500 m in elevation with slope gradient higher than 7° , and are commonly covered by vegetation. The geomorphologic shape of the mountainous regions is the same as the hilly regions. The slope gradient of both areas is larger than 7° . The difference between them is the elevation: the peak elevation of hilly regions is lower than 500 m, but

mountainous regions exceed this elevation. Peak elevations in the mountainous areas were found using the images, and the geomorphological type was determined by the elevation. The elevation of the mountains and hills was determined by the gradient elevation grade maps and the remote-sensing images. The boundary of the mountainous hilly region was drawn manually using ArcGIS 9.2.

2.4.3 Interpretation of intermontane basins and mountain and river valleys

Intermontane areas with slope gradients lower than 7° were interpreted as intermontane basins, and mountain and river valley regions. The difference among them is that basins have a broad morphology, while mountain and river valleys are long and narrow. River valleys contain active rivers, while mountain valleys do not have flowing water. Their area was delineated manually using ArcGIS 9.2.

2.4.4 Interpretation of water systems and islands

We used ArcGIS 9.2 to turn the previously collected 1:100,000 scale water system data from polyline format into polygon format. Then, automatic extraction of natural river system from remote-sensing images was performed. The boundary of the water system was modified manually according to both the previous data, as well as automatic extraction data. Geomorphology of islands larger than 200,000 m² was classified according to the principle mentioned above. Geomorphology of islands smaller than 20,000 m² was not classified.

2.5 Site classification based on geomorphology

Engineering geological units were classified according to geomorphologic shape and genesis. Engineering geological

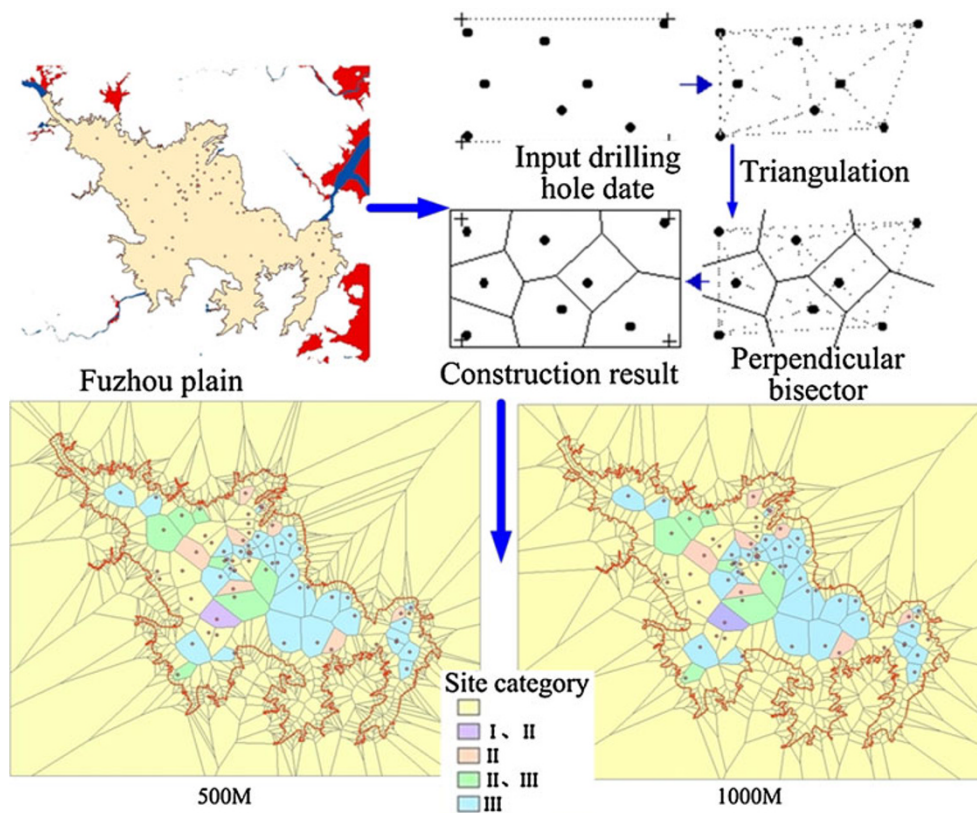


Fig. 2 Tessellation polygon analysis

data and site category data were collected and analyzed, and the relationship among geomorphological type, engineering geological unit, and site category was constructed. As a preliminary step, site classification was carried out.

Site classification is mainly based on the equivalent shear-wave velocity and overburden thickness. In China, the equivalent shear-wave velocity at 20-m depth was chosen (Ministry of Housing and Urban–Rural Development of People’s Republic of China 2010), but the standard in the USA is the depth of 30 m (Building Seismic Safety Council 2004). In Europe, the equivalent shear-wave velocity in the depth of 10 or 20 m was chosen according to the different site categories (Committee European de Normalization 1998).

Data from about 5,000 drill holes were collected from more than 400 projects. Representative drilling holes were chosen from every project. Sites were classified by equivalent shear-wave velocity and overburden thickness according to the Chinese Code for Seismic Design of Buildings. Soil types, overburden thickness, and equivalent shear-wave velocity of the drilling holes were analyzed, and then the site category of the drilling holes was confirmed. The drill hole data were overlain on the engineering geological unit data. The relationship between site categories defined by the drill holes and the engineering

geological units was confirmed, and site classification within the Fujian province was done according to these relationships. It should be noted that the boundary of site category III was determined by automatic extraction by tessellation polygon analysis based on the drill hole data (Fig. 2). Sites in Fujian were classified into four categories: types I₀, I₁, II, and III.

3 Results

3.1 Geomorphological classification

Geomorphology in the Fujian province was classified into seven types: mountainous, hilly, plains, platforms, intermontane basins, and mountain and river valleys (Fig. 3). Geomorphology types in the Fujian province are dominantly mountainous and hilly, which account for 85.74 % of the area. Previous studies showed that mountainous and hilly regions accounted for 82.39 % of the area in the Fujian province (Editorial Board of Fujian Local Chronicles 1998), which is similar to our result. Thus, results of this study are dependable. Plains in the Fujian province are narrow, and mainly located in coastal regions south of the Minjiang river. North of the Minjiang river, mountains and

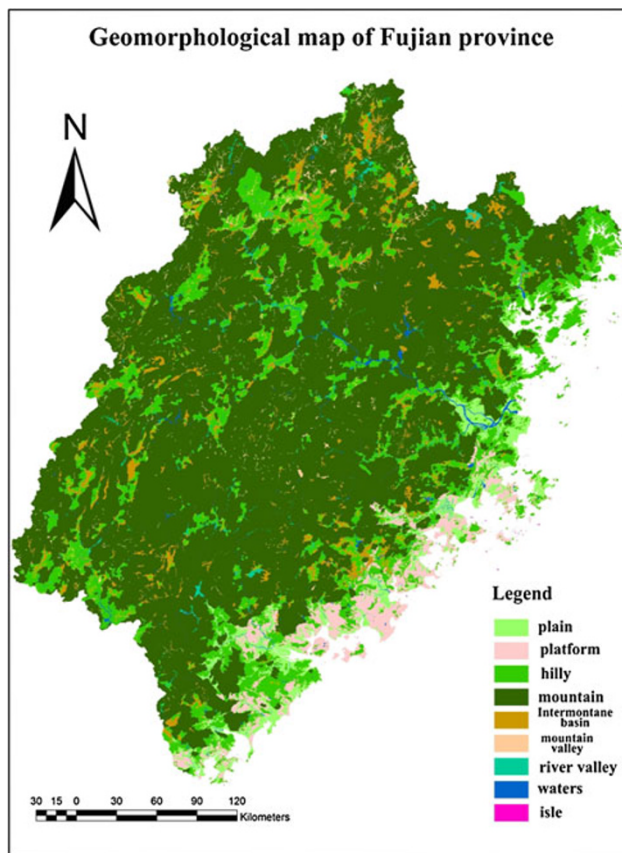


Fig. 3 Geomorphological classification of Fujian province

hills stretch straight to the coast. Therefore, plains cover a smaller area in this coastal region. Platforms are distributed mainly in the coastal region from the Longjiang river in

Fuqing county south to Zhaoan county. The platforms cover a small area in Fujian province. Intermontane basins, and mountain and river valleys are distributed mainly in flat areas between mountains or hilly areas.

3.2 Relationships between geomorphological types, engineering geological units, and site categories

Fujian province can be divided into five types of engineering geological units, that is plain zones (include river valleys), intermontane basin zones (including mountain valleys), platform zones, hilly zones, and mountain zones. The five zones were also divided into 13 subzones (Table 2). The islands smaller than 2,000 m² are mainly reefs, and were defined as bedrock zones. The relationship among geomorphological type, engineering geological unit, and site category is listed in Table 2. The number of drill holes in all geomorphological types is given as well. Site category coincidence rates between results calculated by drill hole data, and results classified by geomorphological types and/or engineering geological units, were above 85.7 % (Table 2).

3.3 Site classification in the Fujian province

Fujian can be divided into four site categories: type I₀, I₁, II, and III (Fig. 4). The cover area of different site categories is in the order of II > III > I₁ > I₀ (Table 3). Fujian dominantly consists of category II areas, which account for 85.26 % of the total area. These areas are mainly distributed in the mountain and hilly zones. The area of category accounts for 15.36 % of the area in Fujian, which is far less

Table 2 Relationship among geomorphological types, engineering geological units, and site categories

Geomorphological types	Engineering geological units	Site category	Amount of drilling holes	Site category coincidence rates (%)
Mountain	Erosion denudation middle mountain	I (slope gradient $\geq 25^\circ$)	61	100
	Erosion denudation low mountain	II (slope gradient $< 25^\circ$)		
Hilly	Erosion denudation high hilly	II	50	86
	Erosion denudation low hilly			
Basin	Intermontane basin	II	21	85.7
Mountain valley				
Platform	Residual diluvium platform	II	56	85.7
Plain	Alluvial–proluvial plain	II	135	99.3
	Alluvial plain	II–III		
	Sea–proluvial plain	III		
	Sea–alluvial plain	III		
	River valley plain	II		
	River valley plain	II		
River valley	River valley plain	II	20	100
Isle	Bedrock zone	I	–	–

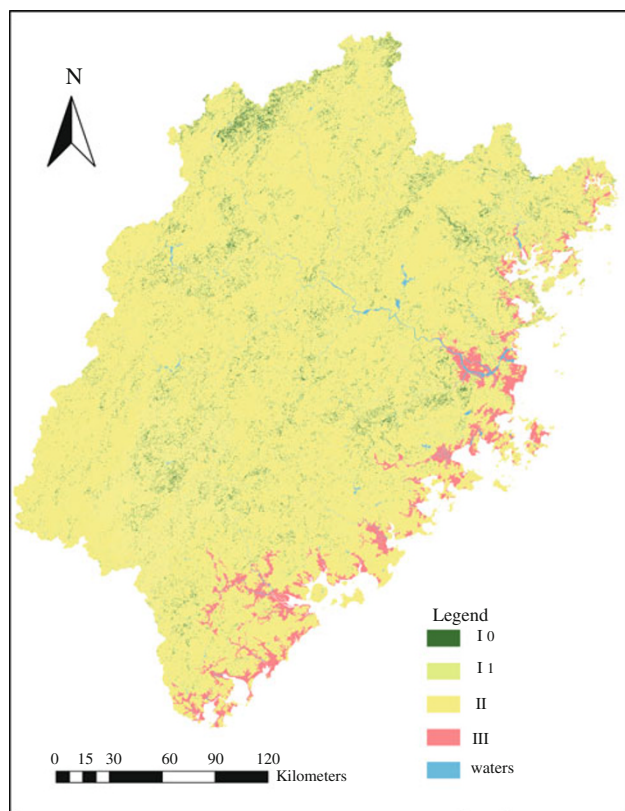


Fig. 4 Site classification of Fujian province

Table 3 Surface area of different site categories in Fujian province

Site category	Area (km ²)	Percentage (%)
I ₀	3,284	2.44
I ₁	14,511	10.77
II	114,892	85.26
III	2,070	15.36

than that of category II. Category III is mainly located in plain regions. Category I is the smallest, and accounts for only 13.22 % of the total area. The area of category I₀ is only 3 284 km², accounting for a total of 2.44 % of the area.

4 Conclusions

1. Geomorphology types in the Fujian province are dominantly mountainous and hilly regions, other geomorphology types only account for 14.26 % of the surface area. The result is similar to previous results.
2. Drill hole data were collected and analyzed with the engineering geological units and site categories. Corresponding relationships among them were accurate,

thereby indicating that our method for site classification is dependable.

3. Fujian is mainly covered by site category II terrain. The area of category I₁ and category III are smaller than that of category II. The area of category I₀ is the smallest.

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