Nationwide Landslide Hazard Analysis and Mapping in Taiwan

169

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Abstract

In the past, landslide susceptibility analysis was generally limited to a small area and research purpose. A susceptibility model established for on specific region could not be applied to other areas. This has led to technological stagnation in the research and testing phase. Based on actual demand, Taiwan started a research program, the Central Geological Survey, in 2003, for the execution of nationwide landslide hazard maps. By the end of year 2013, the whole of Taiwan has been mapped with good results. This paper discusses the success of landslide susceptibility/hazard analysis and mapping over a wide region and shares the experience with society. For hazard analysis and mapping one needs to take into account heterogeneous features present in a wide area and the consistency of results from different regions. These challenges require the following two methods to be resolved: (1) division of homogeneous zones so that a reliable hazard model can be established for a zone; (2) a consistent hazard level must be chosen so that the results for different regions will be consistent. Also, it is important to select an event-based landslide susceptibility analysis method that will ensure the consistency of results from different analyses.

Keywords

Event landslide inventory • Landslide susceptibility • Landslide hazard • Hazard mapping

169.1 Challenges

To extend local statistical landslide susceptibility analysis to a wide and heterogeneous region leads to many problems and challenges, as has been shown in previous studies (Lee and Fei 2011; van Westen et al. 2006). Common problems previously involved in median scale mapping are discussed below.

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169.1.1 Previously Limited to a Small Area

Previously landslide susceptibility analysis has generally been limited to a small area, and a susceptibility model established in a region cannot be applied to other areas. This is a complex issue, the main problem being the heterogeneous features in a wide region. It may be necessary to restrict effective analysis to a homogeneous area.

169.1.2 Consistency of Results from Different Regions

If analysis is conducted region by region, the problem of inconsistency of results would rise, because the susceptibility values for a study region only represent the relative likelihood that a landslide will occur in the region, and equal value does not mean equal possibility of landslide occurrence. This creates matching problems among adjacent

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susceptibility maps. A consistent hazard level must be chosen when mapping of a wide region.

169.1.3 Variety in Types of Landslides

Shallow slides (and falls) are the most common type of landslides. The random occurrence of this type of landslides makes them easy for statistical susceptibility analysis. The flow-type landslides (debris flows) are also feasible to be analyzed. Deep-seated slides, which are frequently facilitated by weak layers, tectonic structures, and local hydrological conditions, are more complicated and must be investigated case by case. Different models and maps would be needed for different types of landslides in a susceptibility analysis.

169.1.4 Multi-temporal Landslide Inventory

Single-period landslide inventories for susceptibility analysis may be biased. However, it may not be feasible to use a multi-temporal landslide inventory in some regions. There are still problems such as incompleteness of the inventory, insufficient length of historical records, and a possible mixing of extreme events and/or earthquake disturbance that need to be considered. This is especially true in Taiwan (Lee and Fei 2011), and therefore, makes this project a big challenge.

169.2 Solutions

One solution to solving the above-mentioned challenges is discussed below. The goal is to make landslide susceptibility mapping in a wide region feasible.

169.2.1 Division of Homogeneous Zones and Construction of a Susceptibility Model for a Zone

Since the complexity of the geological conditions and the effective landslide factors may be different among regions, an effective susceptibility model might not be suitable for a wide region, where division into homogeneous zones is necessary. The concept of a homogeneous zone depends on the similarities of characteristics as shown in the landslide statistics and their control factors. Homogeneous zones were classified by the ISODATA algorithm using the factor layers including the slope gradient, topographic roughness, slope roughness, elevation of crest, total slope height, relative height and total curvature. The divisions of homogenous areas for Taiwan are shown in Fig. 169.1. A susceptibility model was built for a homogenous area in a river basin in Taiwan.

169.2.2 Event-Based Landslide Susceptibility Model

The high spatial and temporal resolution satellite images that are available nowadays make it easy to produce an event landslide inventory. With this kind of inventory together with the triggering factors and causative factors, it is feasible to perform an event-based landslide susceptibility analysis (Lee et al. 2008). This can avoid the bias of an analysis that depends on one period landslide inventory. It also avoids the difficulty of preparation of a long-period multi-temporal landslide inventory.

The event-based landslide susceptibility model is capable of landslide prediction and hazard mapping. In actual cases, it is also possible to use multi-event landslide inventories, using a wider range of rainfall values in construction of the model, facilitating the application to a wider rainfall range.

169.2.3 Hazard Mapping Based on the Probability of Landslide Failure

A consistent hazard level must be chosen so that the results among regions will be consistent. Reichenbach, et al. (2007) have carried outdone this kind of testing for in Italy.

The landslide hazard level used here is the ratio of landslide pixels to the total pixels in a susceptibility index; this is called the proportion of landslide cells in Jibson et al. (2000), and the probability of (landslide) failure in Lee et al. (2008). We first establish the relationship between the susceptibility value and the probability of failure, and then use the relationship to transfer a susceptibility value into the probability of failure.

An example of a landslide probability map for the Shihmen Reservoir catchment basin is presented in Fig. 169.2. The susceptibility model was constructed by using logistic regression and using the 2004 Typhoon Aere event landslide inventory as the training data set.

169.2.4 Separation of Analysis for Different Types of Landslide

Landslide types were identified from a satellite image or an aerial photograph, with necessary field checks. In the present study, the landslide susceptibility models were trained from shallow landslides (and rock falls), so the model is used for hazard mapping of shallow landslides only.

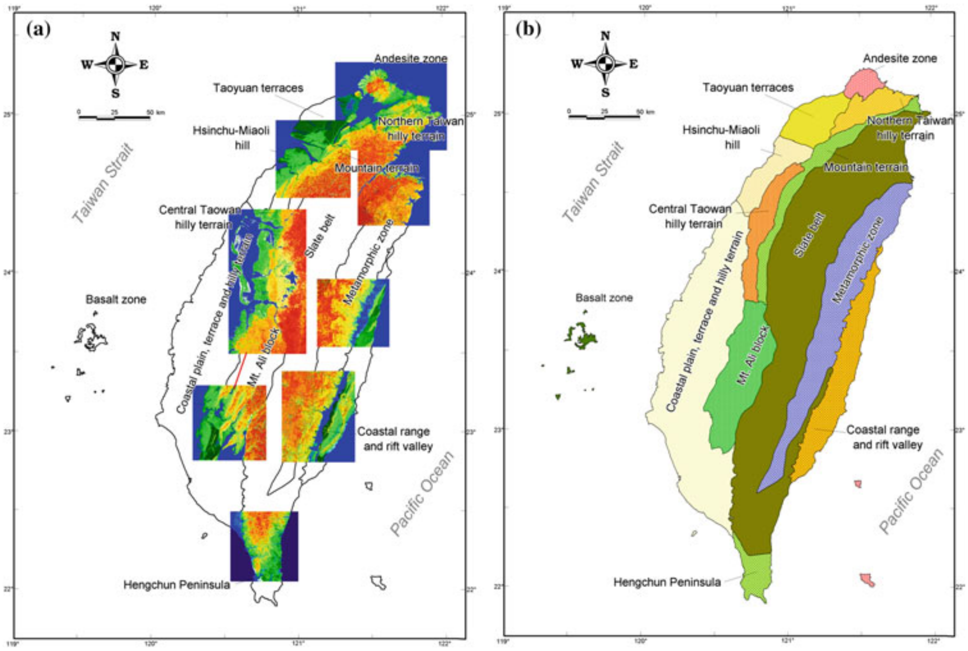

Fig. 169.1 Homogenous area division for Taiwan: **a** geomorphologic classification using the ISODATA method; **b** homogenous area division for Taiwan

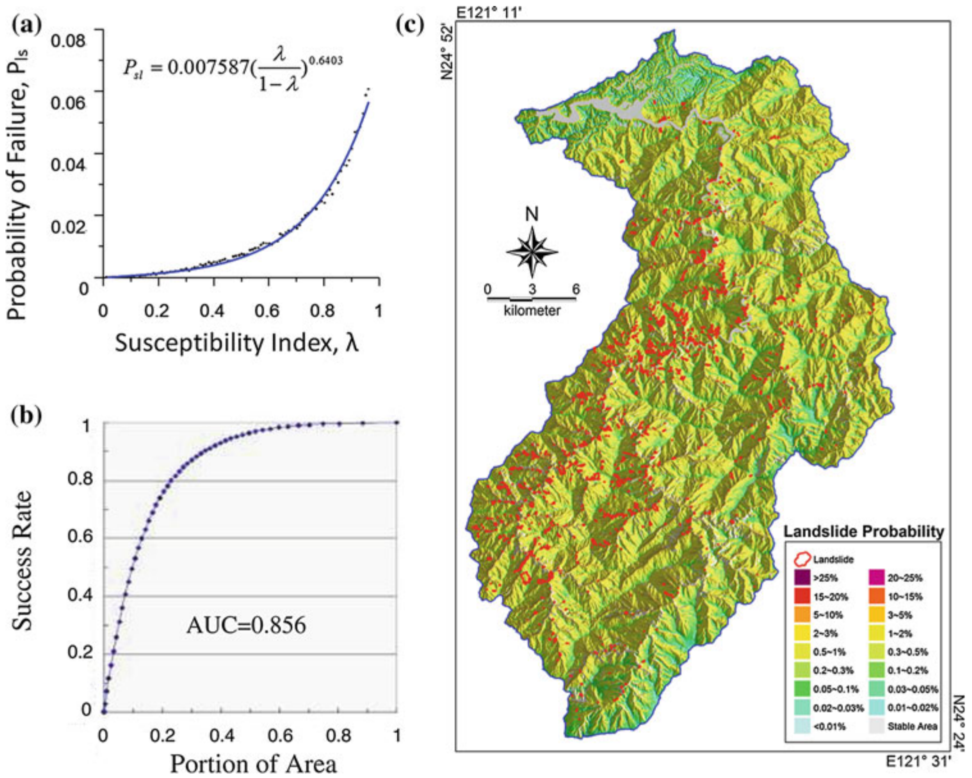

Fig. 169.2 An example of landslide susceptibility analysis at the Shihmen Reservoir catchment basin: **a** probability of failure curve; **b** success rate curve, and area under curve (AUC); **c** landslide probability map for the Typhoon Aere event

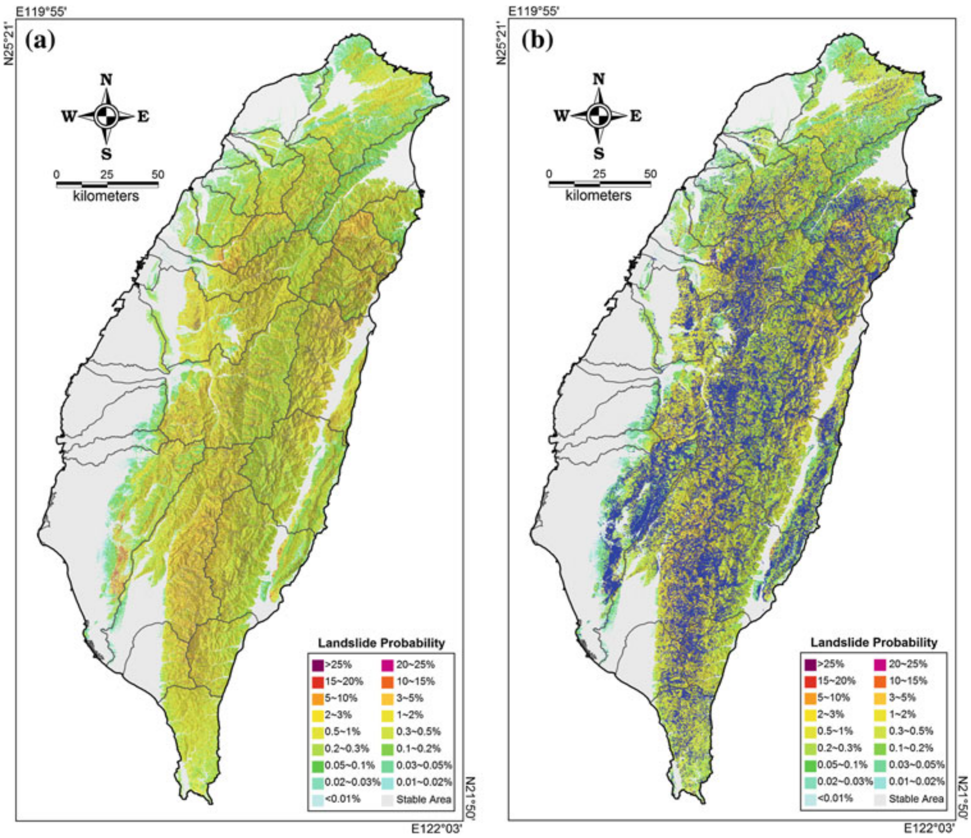

Fig. 169.3 **a** 100-year landslide probability map for the whole of Taiwan; **b** overlay of multi-temporal aerial-photo landslide inventory from year 2004 to 2009

Debris-flow susceptibility was built in different models in the same project, but is not present here. Deep-seated landslides were mapped and studied case by case in a separated project of the Geological Survey.

169.3 Achievements and Further Work

A total of 16 river basins and 26 susceptibility models, as well as probability of failure curves, have been built during the past 7 years. For consistent mapping, a rainfall return-period must be selected. We adopt the 100-year return-period rainfall for the triggering factors and use them in the hazard mapping. A 100-year landslide probability map for the whole of Taiwan (1:50,000 scale and total area 35,873 km^2) is shown in Fig. 169.3a. It shows a consistent hazard level (landslide spatial probability) in the region. An overlay of multi-temporal aerial-photo landslide inventory from 2004 to 2009 is shown in Fig. 169.3b to demonstrate that the pattern of landslide distribution can be interpreted by the landslide probability map.

We also complete a nationwide debris-flow probability map in the same project. Deep-seated landslide hazard mapping is actively ongoing. These maps will be applied for the zoning of the landslide sensitive areas based on the newly announced Geology Act of Taiwan. The methodology and work procedure are still improving, especially for hazard of a slope unit and landslide size prediction.

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