Rapid Landslide Risk Zoning toward Multi-Slope Units of the Neikuihui Tribe for Preliminary Disaster Management

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Abstract. Taiwan features steep terrain and a fragile geology environment accompanied by frequent earthquakes and typhoons annually. Meanwhile, with the booming economy and rapid population growth, activities ~~are shifting~~pivot from metropolises to the Taiwan's suburban and mountain areas~~ in Taiwan~~. However, for example, the Neikuihui tribe in northern Taiwan evolves landslide disasters during extreme rainfall events. To rapidly examine landslide risk in the tribe area for preliminary disaster management, the well-known principle of Risk, which comprises Hazard, Exposure, and Vulnerability, was carefully adapted to ~~examine~~scrutinize 14 slope units around the Neikuihui tribe region. The framework of risk zoning is improved based on the previous quantified findings regarding the inventory of the deep-seated landslides in southern Taiwan. Moreover, the proposed procedures comprehensively ~~involve~~apply the susceptibility, activity, exposure, and vulnerability of each slope unit. The ~~analyses of the~~ rapid risk zoning ~~toward~~analysis of multi-slope units ~~reveal that No.11~~delivers a sloping unit with a high level of ~~slope units around the Neikuihui tribe has a relatively higher~~ landslide risk~~ level~~, and ~~the No.11~~this slope unit ~~indeed suffered~~did suffer from landslide ~~disaster during~~disasters in the 2016 typhoon event~~ in 2016~~. This study preliminarily proves that the proposed framework and details of rapid risk zoning can help identify a relatively high-risk slope unit around a tribal region and address pre-countermeasures for disaster management.

1 Introduction

Disasters due to regional landslides, soil yield, and sediment production have received more attention in recent decades (Keefer and Larsen, 2007), and one of the highly correlated causes can be global warming ~~that~~which drastically affects the climate phenomenon, as pointed out by Intergovernmental Panel on Climate Change (IPCC) (2014). For instance, rainfall concentrates in fewer ~~and~~but more violent rain events in Taiwan, where about 75% of the ~~lands are steep~~land is mountains, accompanied by steep terrains, fragile geology conditions, and seismic activities. Therefore, Taiwan suffers several geological disasters due to rainfall events annually. Nevertheless, increasing landslides expand the area of bare land in Taiwan (Chen and Huang, 2010) because of rapid economic development and population growth that ~~push~~force land use ~~to~~into mountainous areas. Taking Typhoon Ophelia in 1990 and Typhoon Herb in 1996, rainfall events caused landslides in Tomong Village (eastern Taiwan) and Nantou (central Taiwan), respectively, and led to costly restoration~~ as well~~. During Typhoon Morakot in 2009, the mountainous area in southern Taiwan formed another hot zone for landslides (Lin et al., 2008; 2011; Chen, 2016). Moreover, Nantou's mountainous regions became a spotlight after the Chichi earthquake in 1999 and Typhoon Toraji in 2001 (Lin et al., 2008).

Due to the increase ~~of~~in natural disasters, it is necessary to execute risk management to reduce losses (Chen et al., 2010) and propose an efficient risk assessment to determine where priority must initiate for governance in the case of limited time and resources (Zheng, 2018). Varnes et al. (1984) revealed a risk assessment principle as Risk = Hazard × Exposure × Vulnerability based on the requests above. Dai et al. (2002) proposed a framework for deep-seated landslide risk assessment, in which Triggering, Preparatory, and Landslide are the primary tasks. Fell et al. (2008) provided guidelines for landslide Susceptibility, Hazard, and Risk zoning for land use planning. Besides, Corominas and Mavrouli (2011) stated that a completed deep-seated landslide risk assessment must include Susceptibility, Hazard, Vulnerability, and Risk. Cantarino et al. (2021) applied the risk evaluation with Hazard, Exposure, and Vulnerability on expansive residential areas in La Marina, Spain.

In detail of Hazard, Parise and Wasowski (1999) proposed the areal frequency method to further quantify the activity area of a landslide with specified surface features such as ~~cliffs~~scarps, tension cracks, and slip marks. The equal-area can be identified and drawn from the aerial photos before and after the disaster. Then the ~~active area ratio~~Activity Area Ratio (AAR) is defined as the percentage of the active area divided by the total area and ~~used~~operated to express the activity of a landslide. Florina (2002) indicated that rock strength, topography (formation process, slope, and distribution of watersheds), soil, and vegetation are essential factors for distinguishing whether slopes are dangerous or not. Guzzetti (2005) sorted out landslide ~~susceptibility~~Susceptibility evaluations, in which five methods involve Geomorphological Mapping, Analysis of Landslide Inventories, Heuristic Zoning, Statistical Method, and Deterministic Models. Among these, Statistical Method usually collects numerous landslides to analyze the relationship between slope failure and its factors, such as topographical and geological conditions. Then these factors are weighted and ranked to objectively provide interpretations for landslide Activity~~ objectively~~.

Remondo et al. (2005) developed the method to quantitatively assess landslide hazards and risks based on the 140 km^2 study area in the lower part of the Deva River Valley, Givascua, Spain. The method incorporated the past landslide inventory frequency and intensity to convert landslide sensitivity into a quantitative hazards model. Remondo et al. (2005) further obtained Vulnerability by quantitatively appraising the damage of each exposed infrastructure, ~~buildings~~building, and land resource. ~~Comprehensive~~A comprehensive analysis of landslide Hazard and Vulnerability models can support a quantitative risk model with monetary significance. Di et al. (2008) reported a risk assessment of debris flows in Sichuan Province, China, based on the on-site interpretation from aerial photographs and satellite images. They determined the locations of the debris flows and applied GIS to build a database including Hydrology, Topography, Geology, Social and Economic. Regression analysis revealed the relationship between the 24-hour rainfall records and the abovementioned geological and topographic factors. Finally, social and economic information was ~~jointed~~joined to establish a debris flow Vulnerability model, and it was further employed to integrate with debris flow Hazard and Exposure to form a four-stage Risk map.

Fauziah Ahmad et al. (2012) also showed a quantitative risk evaluation method ~~which~~that contains nine environmental risk factors, including Casualties of people, Soil Properties, Earth Coverage, Soil Grading Characteristics, Land Use Suitability, Factor of Safety, Blasting area, Distance between Proposed Structure to Landslide. Then they implemented the method to examine Penang Island, Malaysia's development area, and the results were divided into five levels of Risk: Extremely Low, Low, Medium, High, and Extremely high. After this comprehensive analysis, relevant personnel can ~~use~~operate the environmental risk map to measure ~~development~~ feasibility of the risk assessment.

To evaluate the susceptibility areas for deep-seated landslides in southern Taiwan, Forestry Bureau initiated a project from 2012 to 2013 at Gaoping River and Zengwen River Basins (He and Lin, 2017). The high-precision digital terrain model (DTM) surveyed by the LiDAR completed the interpretation of the deep-seated landslide susceptibility area, and a total of 2,523 places were identified accordingly. In this project, a criterion that a landslide area greater than 10 hectares was defined for a susceptible deep-seated landslide. Then each slope was systematically examined using aerial photographs, ~~hill-shade~~hillshade maps via DTM, and interpretations from various geological and topographic factors. Afterward, susceptibility positions of various deep-seated landslides in the project area were carefully located, and further in-situ inspections were suggested by confirming sliding depth, local geological survey, and unfavorable hydrological factors. The related products verified the activities of slopes and scale of the landslide dam due to a deep-seated landslide. It is called the evaluation of the occurrence of deep-seated landslide susceptibility. Pan et al. (2019) established a risk assessment framework applied to a deep-seated landslide in Taiwan, including Landslide Susceptibility, Hazard, Vulnerability of protected objects, and Risk Level. They further considered the landslide Activity to ~~reveal its susceptibility to~~assist deep-seated ~~landslides~~landslides' Hazard assessment. Besides, the Vulnerability of local households, residents, and infrastructure due to landslide run-out and deposition was also advised. ~~Thus~~Therefore, a deep-seated landslide Risk assessment guide was formed based on the above project in southern Taiwan.

Although the above relevant documents have provided the basic framework required for risk assessment of deep-seated landslides in southern Taiwan, it seems like a pitfall of applying analysis for different landslide types and failure mechanisms (van Westen et al., 2008). ~~Thus~~Hence, this study refers to the previous framework and aims to provide a rapid landslide risk zoning based on the improvements, significantly contributing to a smaller scale and multiple slope units around the tribe region. After the comprehensive interpretations of the risk zoning of Neikuihui, the historical disaster event further verifies the feasibility of the proposed method for disaster management.

2 Regional details of study area

The administrative area of the Neikuihui tribe belongs to Taoyuan City, as shown in Fig. 1. The total area is around 21 hectares, and most of the residents live in the northwest of the tribe. It is located on the southern slope of the Yanshan ridge of the Kuihui Mountain, looking to the Ronghua Valley, and two kilometers northwest of Kayilan. ~~There is only a road network to~~They are the inhabitants who lived here before, named aborigines in Taiwan. Since the Neikuihui tribe~~. Most~~ has only one external road and frequent rockfall disasters, most residents have moved north to ~~the~~ Kuihui Village, and only about 15 ~~families live~~households are left in ~~a small tribe named~~the Neikuihui tribe.

To better visualize the terrain features, the 1 m x 1 m Digital Elevation Model (DEM) is employed as a basement in Fig.2. The overall slope aspect of the tribe is mainly northwest (Fig. 2a), with an average slope degree of 43.9° (Fig. 2b). Fig. 2c and Fig.2d show the CS map and Relief map based on the 1 m x 1 m DEM, respectively. The CSMapMaker plugin on QGIS produced by Asahi (2014) was applied to generate the CS map, where a topographic map is made of altitude, curvature, and slope~~. (~~ degree. Fig. 2c~~)~~ is provided with color attributes that Light Blue indicates valleys and Light Red indicates the ridge. Meanwhile, the Relief Visualization Toolbox application (Zakšek et al., 2011; Kokalj et al., 2019) is applied for generating the Relief map (Fig. 2d) with attributes that the darker the color, the closer the river valley, and the lighter color means the closer to the ridge. These maps can ~~help~~support characterize the slope features quickly.

Figure 2e ~~shows~~is a 1:25,000 geological map ~~from~~of the Central Geological Survey (2020~~) that the~~). The strata ~~are the Aoti bottom layer and~~include the Tatongshan ~~layer of~~ and the Aoti formations, of which the Tatongshan formation is composed of black hard shale and siltstone interbedded~~ sand and shale. These two layers are apparently conterminous at the Neikuihui tribe.~~, often forming steep slopes along the river bed. Aoti formation is composed of sandstone with a coal seam. Besides, there is a Ronghua Stream flowing through the Neikuihui tribe region. Figure 2f is visualized based on a hillshade map from 1 m x 1 m DEM. Figure 2f also reveals the locations of dip slopes from the Central Geological Survey (2020), and these dip slopes are geologically sensitive to the safety of the local settlements~~. This study further details terrain features for the risk zoning based on the previous 1 m x 1 m DEM map, CS map, and Relief map, resulting in eight cliffs and four erosion grooves, as shown in Fig. 2f.~~.

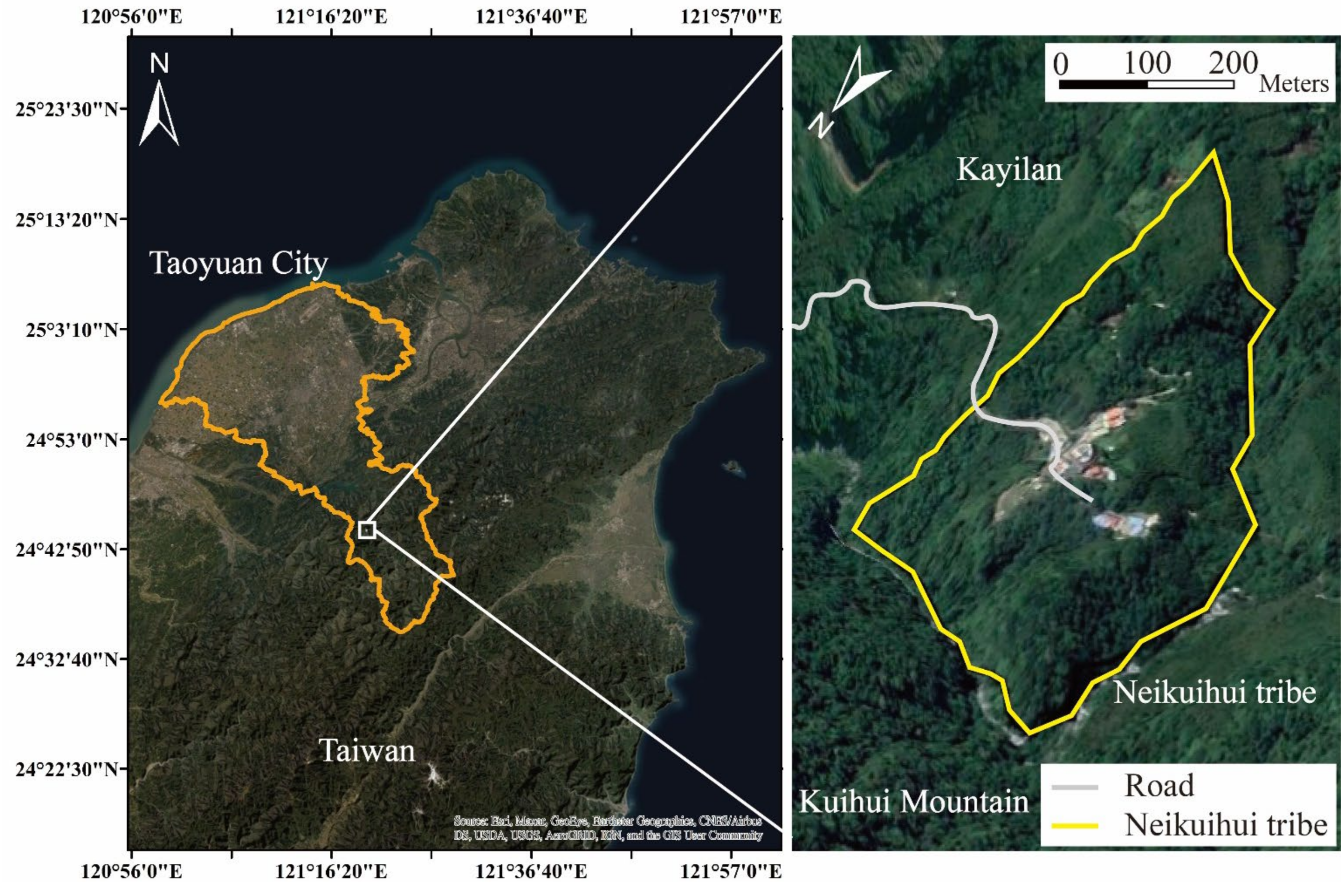

Figure 1 Location of the Neikuihui tribe (image source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID,IGN, and the GIS User Community); Aerial: ESRI ArcGIS 10.4).

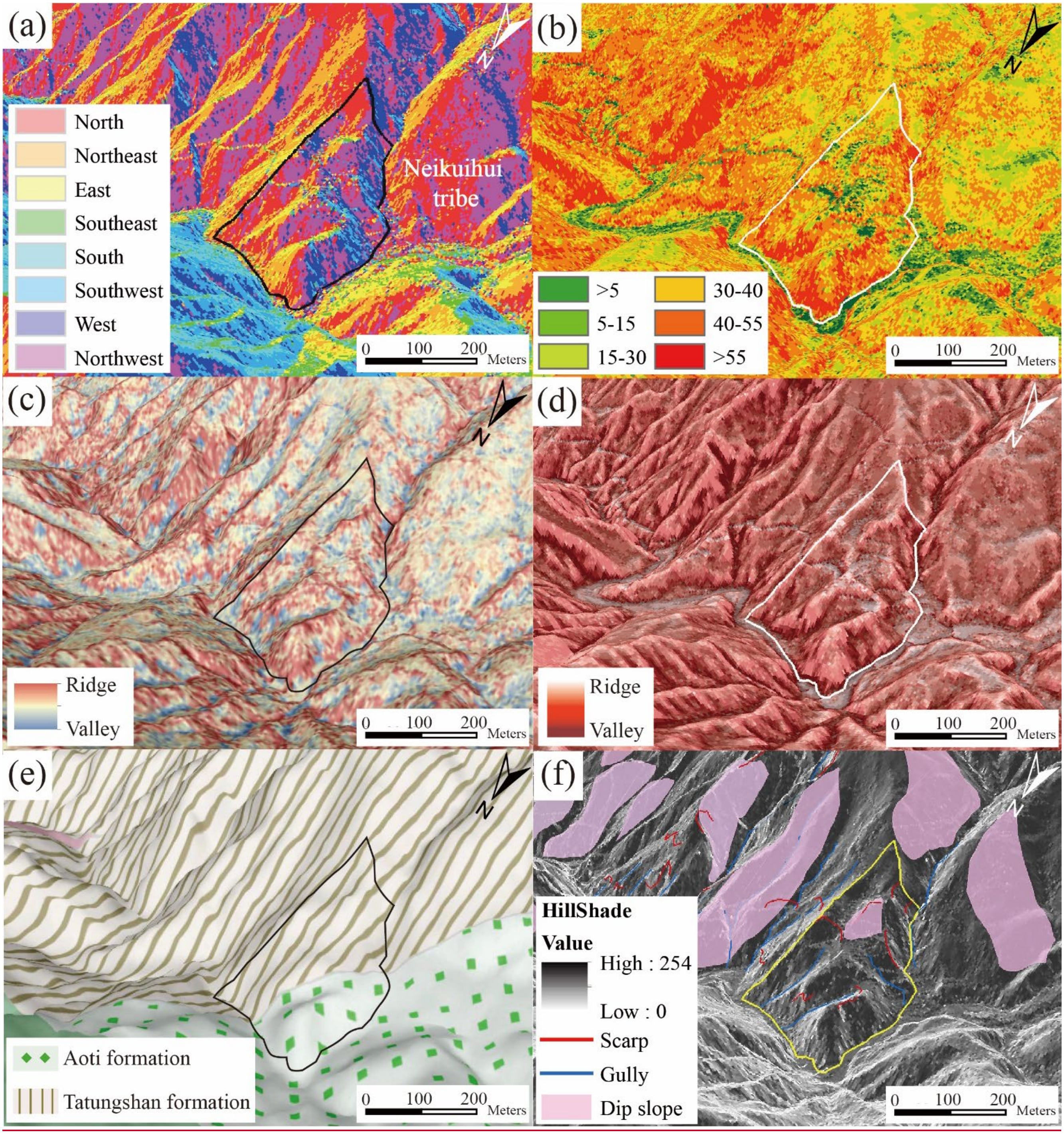

Figure 2 Basic geology and environment of the Neikuihui tribe (**a**) slope aspect (modified after Department of Lands, Ministry

of the Interior 2020); (**b)** slope map (modified after Department of Lands, Ministry of the Interior 2020); **(c)** CS map (modified after Department of Lands, Ministry of the Interior 2020); (**d)** Relief map (modified after Department of Lands, Ministry of the Interior 2020); (**e)** 1:250,000 geological map (modified after Central Geological Survey 2020); (**f)** Geologically sensitive area distribution map (modified after Department of Lands, Ministry of the Interior 2020) with a hillshade based map ; Aerial: ESRI ArcGIS 10.4.

3 Improved method for rapid landslide risk zoning

3.1 Delimited slope units

~~Among~~Quantitative geomorphological and environmental analysis requires the ~~processes of delimited slope units, grid~~ adoption of well–defined spatial domains as basic mapping units. The spatial domains provide local boundaries to aggregate environmental and morphometric variables for related analyses (Alvioli et al.,2020). Grid cells ~~units~~ and slope units are commonly adapted among the spatial domain processes of delimited slope units (Reichenbach et al., 2018). Grid cells, typically aligned with a digital elevation model, are the standard mapping unit preference (Alvioli et al.,2020). Usually, grid~~-~~ cells are directly derived through a DTM or DEM, and the resolution of the predictor variables is assumed as corresponding to that of the DEM pixels~~, as presented in Fig. 2. Thus~~. Therefore, the grid cell division is considered fast and straightforward for ~~better~~ modeling (Van Den Eeckhaut et al., 2009; Rotigliano et al., 2011; Lombardo et al., 2015; Cama et al., 2017). ~~However, the grid unit may not fully express unstable conditions due to~~Despite its ~~limited range, especially when it~~popularity and operational advantages, grid cells have apparent drawbacks for susceptibility modeling (Guzzetti et al., 1999). First, there is ~~necessary to predict a~~no physical relationship between landslides and a grid cell or a group of grid cells since landslides from slope ~~sliding on a full scale. Nevertheless, pixel-based maps frequently are hard~~processes acting at different spatial and temporal scales result in geomorphological forms of very different shapes and sizes (Malamud et al., 2004; Guzzetti et al., 2012). An alternative to grid cells is the method of slope units, which refers to ~~read and not friendly for land use. To solve the limitation,~~hydrological terrain divisions bounded by drainage and ridges (Carrara, 1983; Carrara et al., 1991, Carrara et al., 1995; Guzzetti et al., 1999). Martinello et al. (2020) ~~took~~brought the Imera Settentrionale watershed in northern Sicily, Italy, as the research scope and found ~~the best~~a better way to present the landslide susceptibility map utilizing slope units.

~~Since~~The size of the slope units can be tailored to the type and size of the landslides since a slope unit has more geomorphological and geological significance than a grid unit (Carrara et al., 1991; Alvioli et al., 2016). Accordingly, a modified method is introduced to delimit slope units and depict slope profiles based on high-resolution DEM (1 m x 1 m) via GIS in this study. The slope-unit delimiting method is supported ~~with~~by a GIS-based hydrological analysis and modeling tool, Arc Hydro, which originally incorporates DEM and reversed DEM approaches (Maidment, 2002; Xie et al., 2003; Wang et al., 2016). Based on Xie et al. (2004) classification, GIS-based hydrological analysis and modeling tools are implemented to divide the watershed into slope units ~~afterward. In order to make~~through the ~~division accuracy of risk assessment results consistent, Xiong et al. (2019) used the slope units to assess the impact of landslide risk on the operation of oil and gas long-distance pipelines. Based on the previous experience, this study completes the~~proposed processing chart of delimited slope units, as illustrated in Fig. 3.

~~The~~Figure 4a depicts the 14 delimited slope units around the Neikuihui tribe~~, as shown in Fig. 4, are determined with the steepest slope profiles~~ based on 1 m × 1 m DEM via Hydro-tool in ArcGIS (Xie et al., 2004~~).~~), and Fig.4b illustrates the slope units mapping to the aerial photo. Subsequently, related environmental factors and features were analyzed, including ~~contour,~~ slope aspect, slope degree, valley, and ridge~~.~~, as pointed out in Fig.2. Then 14 slope units accompanied with ~~cliffs~~scarps and eroded gullies are manually drawn based on Fig. ~~2f~~2f and aerial photos. According to the improved framework of risk zoning as proposed in Fig. 5, the 14 slope units were graded regarding landslide Hazard, Exposure, and Vulnerability factors. The corresponding Risk scores of each slope unit were consequently obtained. These scores are expected to support revealing the Risk level and a disaster reduction strategy for the slope unit to reduce the impact of the disaster.

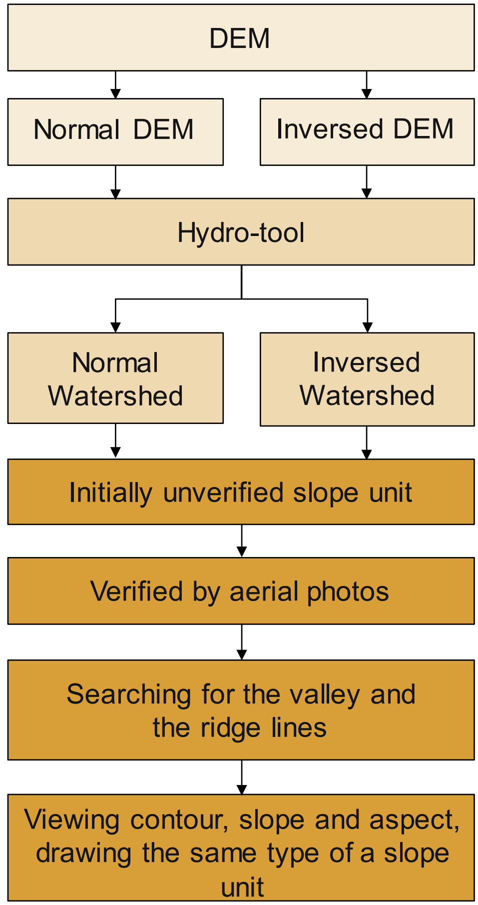

Figure 3 Process of delimited slope units (modified after Wang et al. 2016).

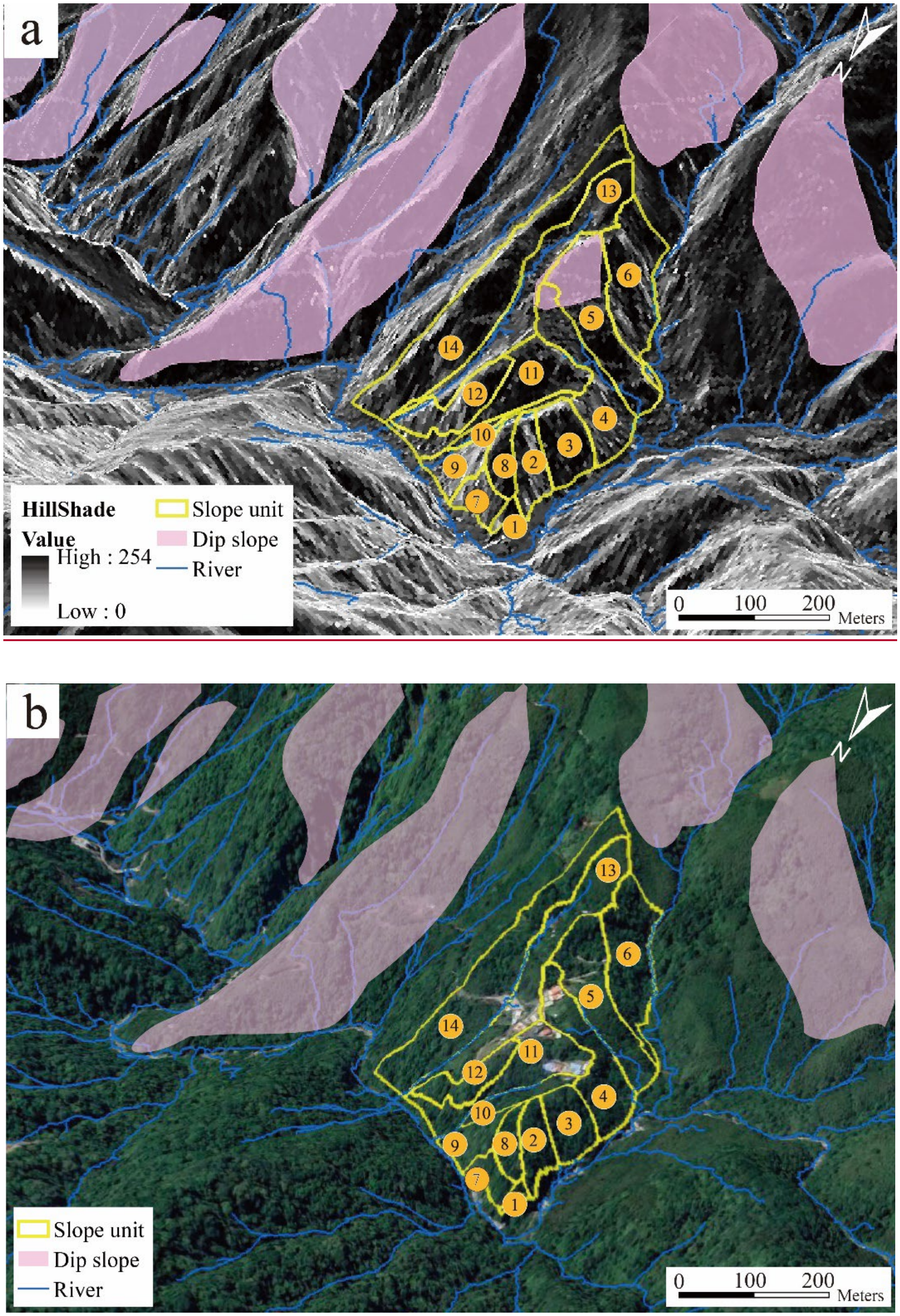

Figure 4 (a) Distributions of 14 slope units around the Neikuihui tribe (Background: modified after Department of Lands, Ministry of the Interior 2020; Aerial: ESRI ArcGIS 10.4).); (b) households distribution map (Background: modified after © Google Earth 2021; Aerial: ESRI ArcGIS 10.4)

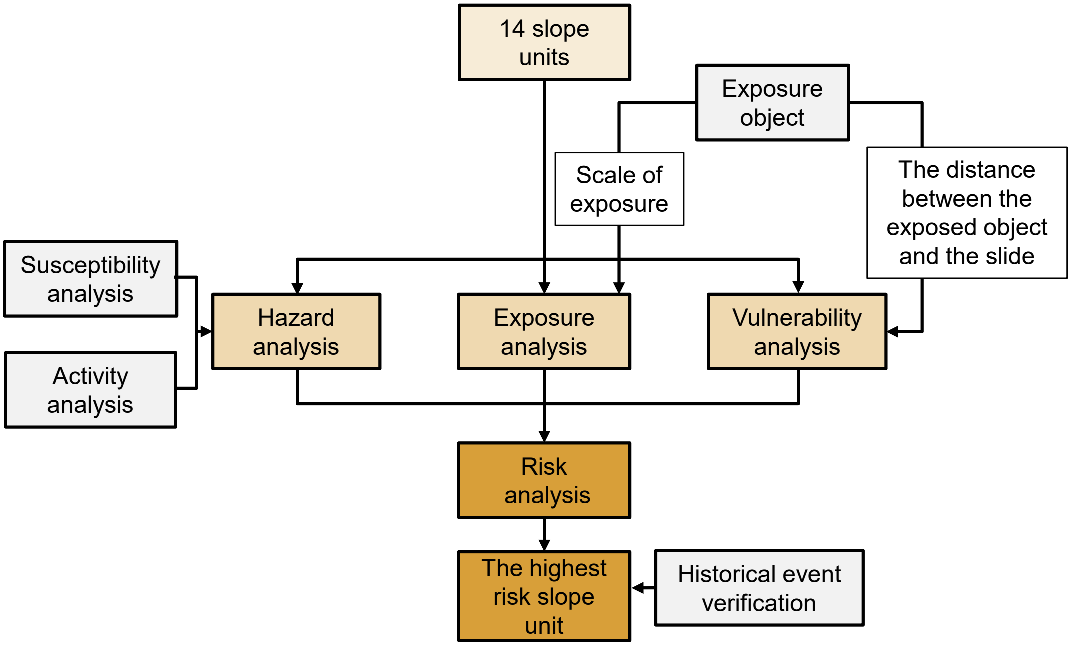

Figure 5 Improved framework of risk zoning for multi-slope units and the corresponding verification.

3.2 Hazard analysis

This study refers to the Hazard of a landslide by considering the indexes of Susceptibility and Activity to identify a landslide in spatial distribution. Although more environmental and morphometric indexes can be involved for Hazard analysis, the proposed simplified analysis ~~only required~~requires the necessary information for rapid risk zoning as described~~ following.~~:

3.2.1 Susceptibility analysis

Guzzetti (2005) sorted out the evaluation of the Susceptibility of a landslide, which can be classified into five methods: Geomorphological Mapping, Analysis of Inventories, Heuristic ~~zoning~~Zoning, Statistical Methods, and Deterministic Models. The statistical one uses numerous landslides to analyze the corresponding unstable slopes. Factors such as topographical and geological conditions were marked with weights and rankings statistically, leading to objective results in practice. Forest Bureau (2013) in Taiwan further reported the related results of the river basins in southern Taiwan by including 2523 landslide areas. Then Susceptibility of the landslide was evaluated ~~by weighting~~logistically with main factors of the slope degree~~ and distance of river channel~~, lithology, and dip slope~~. All~~, as well as the adjacent conditions to a river and fault. The aforementioned factors were proceeded in ArcGIS using the 5-meter grid-size DEM and the improved 1/5000 Gaopingxi watershed geological maps. Afterward, regional statistical results were applied to calculate the occurrence index ~~that was~~

normalized from 1 to 2. Zheng (2018) also proposed the Susceptibility assessment qualitatively and quantitatively by considering the types of past regional landslide events, geological conditions, slope, and aspect.

This study adopts the previous suggestions to classify the Susceptibility of landslides with factors and the corresponding grades. Noticeably, this study designs higher grades of slope degreedegrees larger than 45° and river cross or adjacent to the slope unit based on the previous experience. Consequently, the grades are further accumulated to evaluate the Susceptibility level of the landslide, as listed in Table 1, and Table 2 reveals the Susceptibility level of the landslide.

Table 1 Susceptibility grades of environmental factors (modified after Forest Bureau 2013).

Factor	Classification	Occurrence index	Grades
Slope degree	>45°	2	4
	30~45°	1.5	1
	<30°	1	0
River	Cross or adjacent	2	3
	No cross or no adjacent	1	1
Lithology	Slate	2	3
	Sandstone, metamorphic sandstone, schist	1.5	2
	Shale	1	1
Dip slope	Yes	2	2
	No	1	1
Fault	Cross or adjacent	2	2
	No cross or no adjacent	1	1

Table 2 Susceptibility level of landslide (modified after Forest Bureau 2013).

Summation of grades	**10~14**	**7~9**	**4~6**
Susceptibility level	High	Medium	Low

3.2.2 Activity analysis

The Activity of a slope can be obtained withSusceptibility is typically applied for the landslide risk assessment of large-scale geological conditions accompanied by common environmental factors, as mentioned previously. To rapidly assess the landslide risk of a tribe region, this study refers to the susceptibility findings of deep-seated landslide inventory and carefully includes Activity analysis, especially for a small-scale slope unit. The Activity of a slope can be obtained from long-term monitoring by examining evolutions of slopes through aerial photos of different periods. Parise and Wasowski (1999) proposed Activity Area Ratio (AAR) to quantify the Activity of a slope. AAR wasis defined as the percentage of the active area to the total area, and the active area often contains specified features such as cliffsscarps, tension cracks, and sliding traces. These features can usually be drawn from the aerial photos before and after the slide events. BaseBased on the aforementioned findings, this study applied the ~~1~~2.5 m × ~~1~~2.5 m orthophoto map and Google Earth aerial photos to identify the features mentioned above in each small slope unit around the Neikuihui tribe.

Furthermore, by referring to dip sliding and colluvium indexes proposed by Forest Bureau (2017), the dip sliding indexes include ~~cliff activity~~scarp, slope toe activity, and the relationship between rock layer orientation and slope aspect/degree. Meanwhile, the colluvium indexes were also proposed, including ~~cliff activity~~scarp, eroded gully activity, and surface features. ~~The criteria of both dip slope (~~Therefore, Activity 1~~) and~~ is modified to measure the activity level of the dip sliding along a slope unit, while Activity 2 examines the activity level of the colluvium ~~(Activity 2)~~ layer on the surface of a slope unit. The criteria of Activity 1 and Activity 2 are qualitatively modified in Table ~~2~~3 and Table 4, respectively. Then, the appraisal of activity level ~~by considering Activity 1 and Activity 2~~ is listed in Table ~~2~~5. Finally, a comprehensive activity score by integrating levels of Activity 1 and Activity 2 is proposed in Table ~~3~~6.

Table ~~1 Susceptibility~~3 Activity grades ~~of environmental factors and Susceptibility level of landslide~~including dip slope features (referred as Activity 1) (modified after Forest Bureau ~~2013).~~2017)

Factor	**Classification**	**Grades**
Scarp activity	The scarp was significantly expanded, tension cracks appeared in the crown, and the back of the deep-seated landslide cliff was eroded.	3
	The scarp is slightly expanded.	2
	No significant changes.	1
Slope toe mobility	The river channel is significantly undercut, causing continuous erosion of the slope toe.	3
	The river course may erode the slope toe, but the slope toe does not change much.	2
	No significant changes.	1
Relationship between rock layer orientation, and slope aspect & degree	Aerial photo interpretation shows that the rock layer is exposed and has the potential of sliding forward.	3
	Aerial photo interpretation shows that rock layers may be exposed and have the potential to slide forward.	2
	No significant changes.	1

Table 4 Activity grades including colluvium features (referred as Activity 2) (modified after Forest Bureau 2017)

Factor	Classification	Grades
Scarp activity	The scarp retreat obviously, the scope expands, and the number increases.	3
	The scarp tends to retreat or expand.	2
	No significant changes.	1
Gully activity	Erosion grooves are severely cut down or up, and the number of erosion grooves increases.	3
	Aerial photos suggest that the erosion ditch may be eroded.	2
	No significant changes.	1
Surface features	No vegetation on the surface and exposed rock plates.	3
	Inclined trees and scattered vegetation.	2
	Forest is complete and dense.	1

Table 5 Activity level of landslide (modified after Forest Bureau 2017)

Summation of grades	8~9	5~7	3~4
Activity level	High	Medium	Low

Table 6 Comprehensive Activity level of landslide (Forest Bureau 2017)

Activity 2 \ Activity 1	High	Medium	Low
High	High	High	Medium
Medium	High	Medium	Low
Low	Medium	Low	Low

3.2.3 Hazard level analysis

By considering landslide Susceptibility and Activity ~~level~~levels, the combined evaluation for Hazard level is subsequently listed in ~~the upper part of~~ Table ~~4~~7. The Hazard levels are then divided into five classes~~, then~~ for the ~~corresponding~~ Hazard score ~~are~~as listed in Table ~~4~~8.

Table 7 Hazard level combined by evaluation of landslide Susceptibility and Activity (Forest Bureau 2017)

Activity \ Susceptibility	High	Medium	Low
High	Extremely high	High	Medium
Medium	High	Medium	Low
Low	Medium	Low	Extremely low

Table 8 Hazard level and score (Forest Bureau 2017)

Hazard level	Extremely high	High	Medium	Low	Extremely low
Hazard score	5	4	3	2	1

3.3 Exposure analysis

~~Among the elements of Risk zoning, an~~It is essential to calculate how many households, traffic, and public utilities are exposed ~~object is significant.~~to risk zoning. For example, a slope ~~is~~ in the mountains with no roads and no households~~, indicating~~ indicates no damage even if a landslide occurs (Zheng, 2018). ~~Thus~~Therefore, the degree of exposure can refer to the items suffering the slide slope. Finding out and classifying exposed items within the different slopes around the tribe region is crucial in this study. In other words, the degree of damage caused by the impact of a landslide should be critically quantified. This study referred to the report by Forest Bureau (2017) and redefined the Exposure degree that can be graded according to the exposed objects' importance. The exposed items include affected households in different quantities, the main roads and bridges ~~cross~~crossing the affected joint, critical public facilities, and reservoir areas. To effectively identify the Exposure level of the protected objects in the tribe region, the number of households of exposed objects is re-adjusted and enhanced, and squared values of the raw grades are presented in Table ~~5~~9. It also contains the corresponding Exposure score in Table 10.

Table 9 Grades of exposed objects~~, and Exposure level and score~~ (modified after Forest Bureau 2013~~, 2017~~)

Category	Item	Raw grades	Adjusted grades
Household	~~More than~~ 5 or more households	6	36
	~~Households~~ 3 to 4 households	5	25
	~~Households~~ 1 to 2 households	4	16
	Less than 1 household	~~3~~1	~~9~~1
Traffic	Main access roads or bridges	2	4
	Ordinary road	1	1
Public Utilities	Public facility, high-voltage towers, and river barriers related to disaster prevention	4	16
Reservoir area		4	16

Table 10 Exposure level and score (Forest Bureau 2017)

Summation of grades	36~72	12~35	1~11
Exposure level	High	Medium	Low
Exposure score	3	2	1

3.4 Vulnerability analysis

Although several factors do determine physical Vulnerability (Papathoma-Köhle et al. 2022), Vulnerability analysis in this study initially represents the degree of damage ~~of~~to the exposed object by considering the relative position from the landslide, runout, and deposition area~~.~~ for the rapid Risk zoning. The closer the distance, the greater the damage and the higher ~~vulnerability~~Vulnerability. Moreover, the weighting sometimes is considered to be added according to the attributes of the exposed items. ~~Thus,~~Therefore, the Vulnerability index proposed by Papathoma-Köhle et al. (~~2019~~2017) was adopted in this study to evaluate the Vulnerability of the Neikuihui tribe, and the details of the Vulnerability index are defined as followings:

Total Vulnerability Score of Household $VS_R = \sum_{i=1}^{NR}(VL_i \times WR)$, (1)

Total Vulnerability Score of Public $VS_f = \sum_{i=1}^{NF}(VF_i \times WF)$, (2)

where VL is the distance between the household and a ~~susceptibility~~susceptible landslide, divided into three levels (low, medium, high) ranging from 1 to 3. The closer the distance, the higher VL. Similarly, VF is the distance between the public facilities and a susceptibility landslide, divided into three levels (low, medium, high) ranging from 1 to 3. Due to the small area of the tribe slope unit, it is difficult to directly quantify the distance between the susceptible landslides and the households / public facilities. Hence, the study judges the distance by assuming that the scarp is the source of the collapse and its migration area does not exceed the scope of the slope unit. If the collapsed soil and rock encounter a river, the soil and rock will move to the river. Accordingly, High level of VL is defined as that households / public facilities are buried directly by soil and rock, Medium level is the possibility of being buried, and Low level is no chance of being buried.

WR means the impact of the potential collapse area on residents, and WF means the impact of the potential collapse area on public facilities. Here, ~~the two weights~~WR and WF are set to be one as a fixed value for the preliminary evaluation. NR is the number of households, and NF is the number of public facilities. Then the Vulnerability Score (VS) of a slope unit is the combination of $VS_R + VS_f$, and total weight $W_{total} = NR \times WR + NF \times WF$, then Vulnerability Index (VI) can be written as:

$VI = VS/W_{total}$, (3)

Consequently, the Vulnerability level and score based on Vulnerability Index (VI) are revealed in Table ~~6.~~11.

3.5 Risk analysis

As revealed in the Introduction section, Varnes et al. (1984) have defined Risk = Hazard × Exposure × Vulnerability, where Hazard, Exposure, and Vulnerability are all described in a qualitative way as mentioned above, and the overall structure of risk assessment can achieve the purpose of mutual comparison (Zheng, 2018). The Risk index (RI) of each slope unit around the tribe refers to the ratio of the Risk score (RS) to the total marks of the score (RS_{max}) as formulated ~~following~~ (Pan et al. 2019):

$$RI = \frac{\text{Scores of Hazard}\times\text{Exposure}\times\text{Vulnerability}}{RS_{max}} = \frac{RS}{RS_{max}}, \tag{4}$$

where the RS_{max} is 75 as the summation of the maximums of previous scores. Then the Risk level of a slope can be obtained from Table ~~6~~11.

Table ~~6~~11 Vulnerability & Risk index, level, and score

Vulnerability index (VI)	3≧VI>2.5	2.5≧VI>2.0	2.0≧VI>1.5	1.5≧VI≧1.0	1.0≧VI≧0
Vulnerability level	Extremely high	High	Medium	Low	Extremely low
Vulnerability score	5	4	3	2	1
Risk index (RI)	1.0≧RI>0.8	0.8≧RI>0.6	0.6≧RI>0.4	0.4≧RI≧0.2	RI<0.2
Risk level	Extremely high	High	Medium	Low	Extremely low

4 Improved method for rapid landslide risk zoning

4.1 Hazard analysis results

4.1.1 Susceptibility and Activity analysis results

Based on the classification of the slope, river distance, lithology, dip slope, and distance away from the main geological structure in Table 1 and basic information as shown in Fig. ~~2, landslide susceptibility~~2, Susceptibility levels of 14 slope units of the Neikuihui tribe are provided and depicted in Fig. 6, and the corresponding grades are listed in Table ~~7~~12. Among 14 slope units, No. 1, 2, 3, 6, 7, and 9 have high landslide susceptibility levels where the ~~slopes~~slope degrees are above 45° and are adjacent to or intersecting with the river.

~~Besides, based~~Based on the classification of ~~cliffs~~scarps, slope toes, rock formations, erosion gullies, and surface features as mentioned in ~~Tables~~Table 2, this study gives levels of Activity 1 and Activity 2 of 14 slope units around the Neikuihui tribe as detailed in Table ~~8~~13 and Table ~~9~~14, respectively. According to the comprehensive activity level as defined in Table ~~3, because~~6. Because the ~~cliff~~scarp is slightly expanded and the river channel is significantly undercut~~ and~~, it leads to continuous erosion of the slope toe. Besides, aerial photo interpretation shows that rock layers would be exposed and have the susceptibility to slide forward. ~~Such that~~Based on these observations, No. 6, 11, 13, and 14 slope units have high Activity levels, as shown in Fig. 7.

This study employs slope unit No. 11 as an example to explain how to judge the degree of change of scarp through orthophoto images of different periods. The brighter and more saturated red in the orthophoto image, as in Fig. 8, means that the planting slope is complete and lush. Then this study examines the orthophoto images of June 8, 2013, and July 14, 2015, respectively. Since some vegetation has disappeared and the soil and rocks are exposed on July 14, 2015, the No.11 example is treated as a basis to give all the slope units in the Nekuihui tribe a score for Activity.

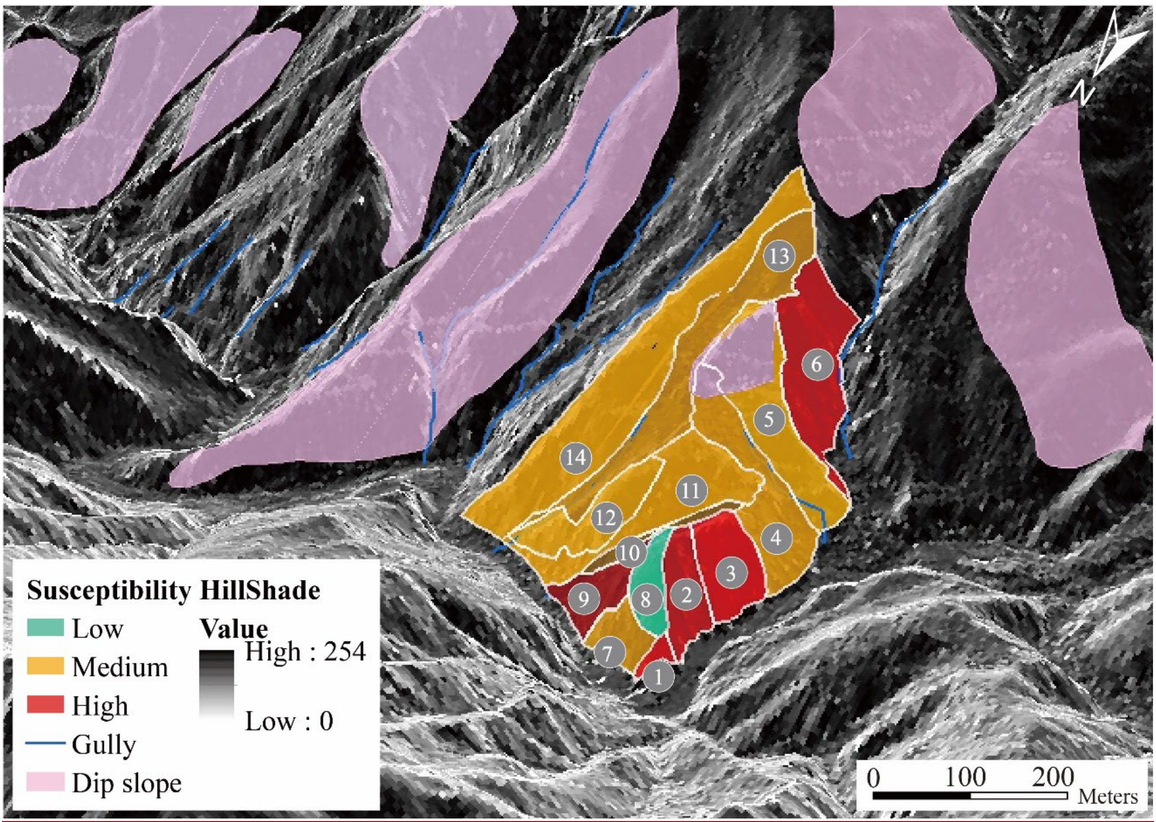

Figure 6 Susceptibility level ~~mapping of landslide~~ referred to slope units around the Neikuihui tribe (Background: modified after Department of Lands, Ministry of the Interior 2020; Aerial: ESRI ArcGIS 10.4).

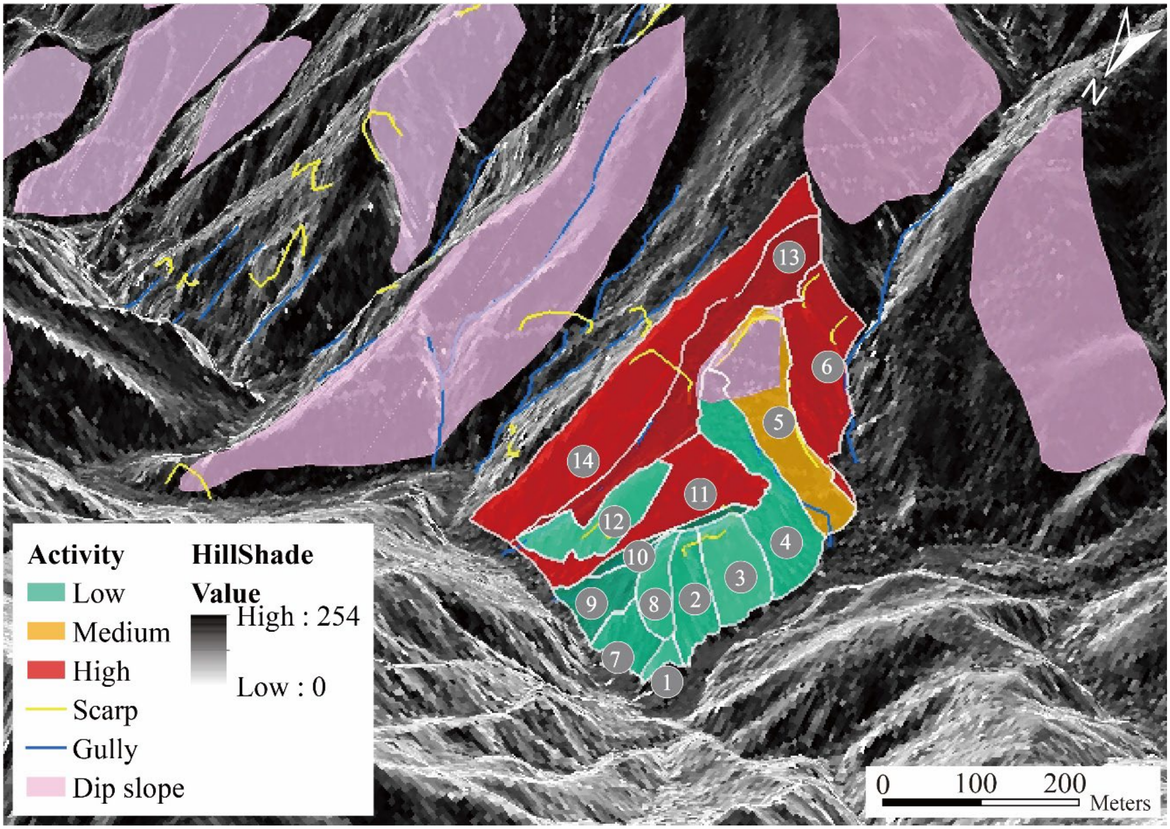

Figure 7 Activity level ~~mapping of landslide~~ referred to slope units around ~~The~~the Neikuihui tribe (Background: modified after Department of Lands, Ministry of the Interior 2020; Aerial: ESRI ArcGIS 10.4).

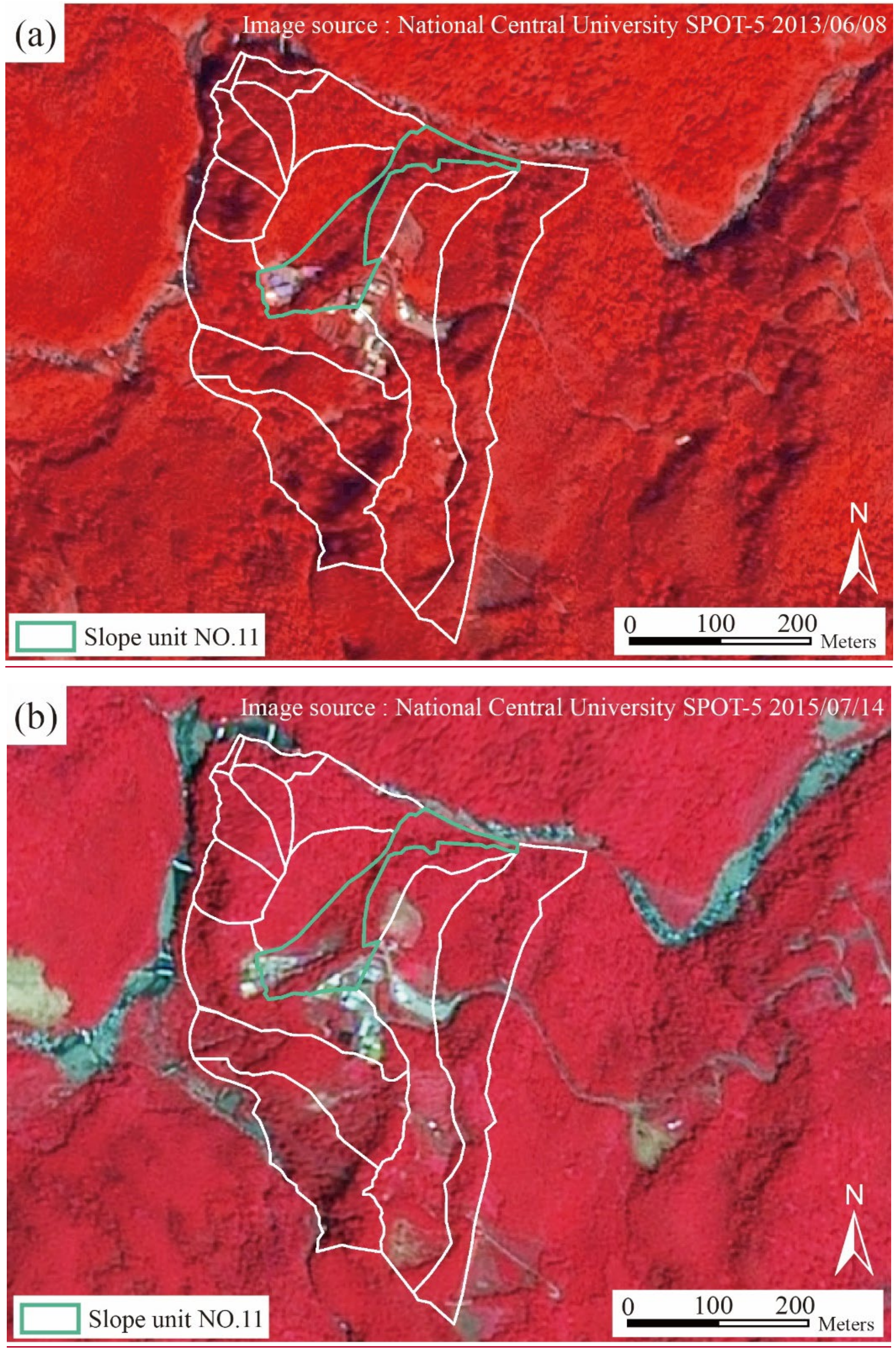

Figure 8 Comparison of the terrain features in **(a)** 2013 and **(b)** 2015 orthophoto maps at No. 11 slope unit (modified after National Central University SPOT-5 2015); Aerial: ESRI ArcGIS 10.4.

Table ~~7~~12 Grades and levels of landslide Susceptibility of slope units around the Neikuihui tribe

<table>
<tr><th rowspan="2">Slope unit</th><th colspan="2">Slope</th><th colspan="2">River cross or adjacent</th><th colspan="2">Lithology</th><th colspan="2">Dip slope</th><th colspan="2">Fault cross or adjacent</th><th rowspan="2">Total grades</th><th rowspan="2">Susceptibility level</th></tr>
<tr><th>Degree</th><th>Grade</th><th>Attributes</th><th>Grade</th><th>Attributes</th><th>Grade</th><th>Attributes</th><th>Grade</th><th>Attributes</th><th>Grade</th></tr>
<tr><td>No.1</td><td>63.2°</td><td>4</td><td>Yes</td><td>3</td><td rowspan="14">Sandstone, metamorphic sandstone, schist</td><td>2</td><td>No</td><td>1</td><td rowspan="14">No</td><td>1</td><td>11</td><td>High</td></tr>
<tr><td>No.2</td><td>54.0°</td><td>4</td><td>Yes</td><td>3</td><td>2</td><td>No</td><td>1</td><td>1</td><td>11</td><td>High</td></tr>
<tr><td>No.3</td><td>47.1°</td><td>4</td><td>Yes</td><td>3</td><td>2</td><td>No</td><td>1</td><td>1</td><td>11</td><td>High</td></tr>
<tr><td>No.4</td><td>32.7°</td><td>1</td><td>Yes</td><td>3</td><td>2</td><td>Yes</td><td>2</td><td>1</td><td>9</td><td>Medium</td></tr>
<tr><td>No.5</td><td>31.8°</td><td>1</td><td>Yes</td><td>3</td><td>2</td><td>Yes</td><td>2</td><td>1</td><td>9</td><td>Medium</td></tr>
<tr><td>No.6</td><td>46.5°</td><td>4</td><td>Yes</td><td>3</td><td>2</td><td>No</td><td>1</td><td>1</td><td>11</td><td>High</td></tr>
<tr><td>No.7</td><td>61.2°</td><td>4</td><td>Yes</td><td>3</td><td>2</td><td>No</td><td>1</td><td>1</td><td>11</td><td>High</td></tr>
<tr><td>No.8</td><td>37.4°</td><td>1</td><td>No</td><td>1</td><td>2</td><td>No</td><td>1</td><td>1</td><td>6</td><td>Low</td></tr>
<tr><td>No.9</td><td>47.6°</td><td>4</td><td>Yes</td><td>3</td><td>2</td><td>No</td><td>1</td><td>1</td><td>11</td><td>High</td></tr>
<tr><td>No.10</td><td>39.0°</td><td>1</td><td>Yes</td><td>3</td><td>2</td><td>No</td><td>1</td><td>1</td><td>8</td><td>Medium</td></tr>
<tr><td>No.11</td><td>31.1°</td><td>1</td><td>Yes</td><td>3</td><td>2</td><td>No</td><td>1</td><td>1</td><td>8</td><td>Medium</td></tr>
<tr><td>No.12</td><td>55.4°</td><td>4</td><td>No</td><td>1</td><td>2</td><td>No</td><td>1</td><td>1</td><td>9</td><td>Medium</td></tr>
<tr><td>No.13</td><td>30.3°</td><td>1</td><td>Yes</td><td>3</td><td>2</td><td>No</td><td>1</td><td>1</td><td>8</td><td>Medium</td></tr>
<tr><td>No.14</td><td>37.6°</td><td>1</td><td>Yes</td><td>3</td><td>2</td><td>No</td><td>1</td><td>1</td><td>8</td><td>Medium</td></tr>
</table>

Table ~~8~~13 Grades and levels of Activity 1 of slope unit around the Neikuihui tribe.

Slope unit	~~Cliff activity1~~Scarp activity		Slope toe mobility		Relationship between rock layer orientation, and slope		Total grades	Activity1 level
	Attributes	Grade	Attributes	Grade	Attributes	Grade		
No.1	No significant changes	1	The river course may erode the slope toe	2	No significant changes	1	4	Low
No.2		1		2		1	4	
No.3		1		2		1	4	
No.4		1		2	The rock layer may be exposed and slippery	2	5	Medium
No.5	Slightly expanded	2		2		2	6	
No.6	Significantly expanded	3	The river channel is significantly undercut	3		2	8	High
No.7	No significant changes	1	No significant changes	1	No significant changes	1	3	Low
No.8		1		1		1	3	
No.9		1		1		1	3	
No.10		1	The river course may erode the slope toe	2		1	4	
No.11	Significantly expanded	3	The river channel is significantly undercut	3	The rock layer may be exposed and slippery	2	8	High
No.12	No significant changes	1	No significant changes	1	No significant changes	1	3	Low
No.13	Significantly expanded	3	The river channel is significantly undercut	3	The rock layer may be exposed and slippery	2	8	High
No.14		3		3		2	8	

Table ~~9~~14 Corresponding grades and levels of Activity 2 of slope units around the Neikuihui tribe.

Slope unit	~~Cliff activity2~~Scarp activity		Gully activity		Surface features		Total grades	Activity2 level	Comprehensive Activity level
	Attributes	Grade	Attributes	Grade	Attributes	Grade			
No.1	No significant changes	1	The erosion ditch may be eroded	2	Forest is complete and dense	1	4	Low	Low
No.2		1		2		1	4		
No.3		1		2		1	4		
No.4		1		2		1	4		
No.5	The ~~cliff~~scarp tends to retreat or expand	2		2	Inclined trees and scattered vegetation	2	6	Medium	Medium
No.6		2	Erosion grooves are severely cut down or up	3		2	7		High
No.7	No significant changes	1	No significant changes	1	Forest is complete and dense	1	3	Low	Low
No.8		1		1		1	3		
No.9		1		1		1	3		
No.10		1	The erosion ditch may be eroded	2		1	4		
No.11	The ~~cliffs~~scarps retreat obviously	3	Erosion grooves are severely cut down or up	3	Inclined trees and scattered vegetation	2	8	High	High
No.12	No significant changes	1	No significant changes	1	Forest is complete and dense	1	3	Low	Low
No.13	The ~~cliffs~~scarp retreat obviously	3	Erosion grooves are severely cut down or up	3	Inclined trees and scattered vegetation	2	8	High	High
No.14		3		3		2	8		

4.1.2 Hazard level and score results

By combining the evaluation results of landslide Susceptibility and Activity levels as ~~referring~~referred to Table ~~4,~~12, 13, and 14, the Hazard scores of each slope unit can be obtained as listed in Table 4~~1~~5, leading to analyzed results of landslide Hazard levels of 14 slope units around the Neikuihui tribe~~ as detailed in Table 10~~, as well as the corresponding illustration map as depicted in Fig. ~~8~~9. The No. 6 slope unit has an Extremely High level of landslide ~~hazard~~Hazard, and No.11, 13, and 14 have High levels of landslide ~~hazard~~Hazard. It can be reasoned that No.6 is next to the river channel and significantly undercut, as shown in Fig. 8.

Table 15 Hazard levels and scores of slope units around the Neikuihui tribe

Slope unit	Susceptibility Level	Activity level	Hazard Level	Hazard Score
No.1				3
No.2	High		Medium	3
No.3		Low		3
No.4	Medium		Low	2
No.5		Medium	Medium	3
No.6	High	High	Extremely high	5
No.7			Medium	3
No.8	Low	Low	Extremely low	1
No.9	High		Medium	3
No.10			Low	2
No.11		High	High	4
No.12	Medium	Low	Low	2
No.13		High	High	4
No.14				4

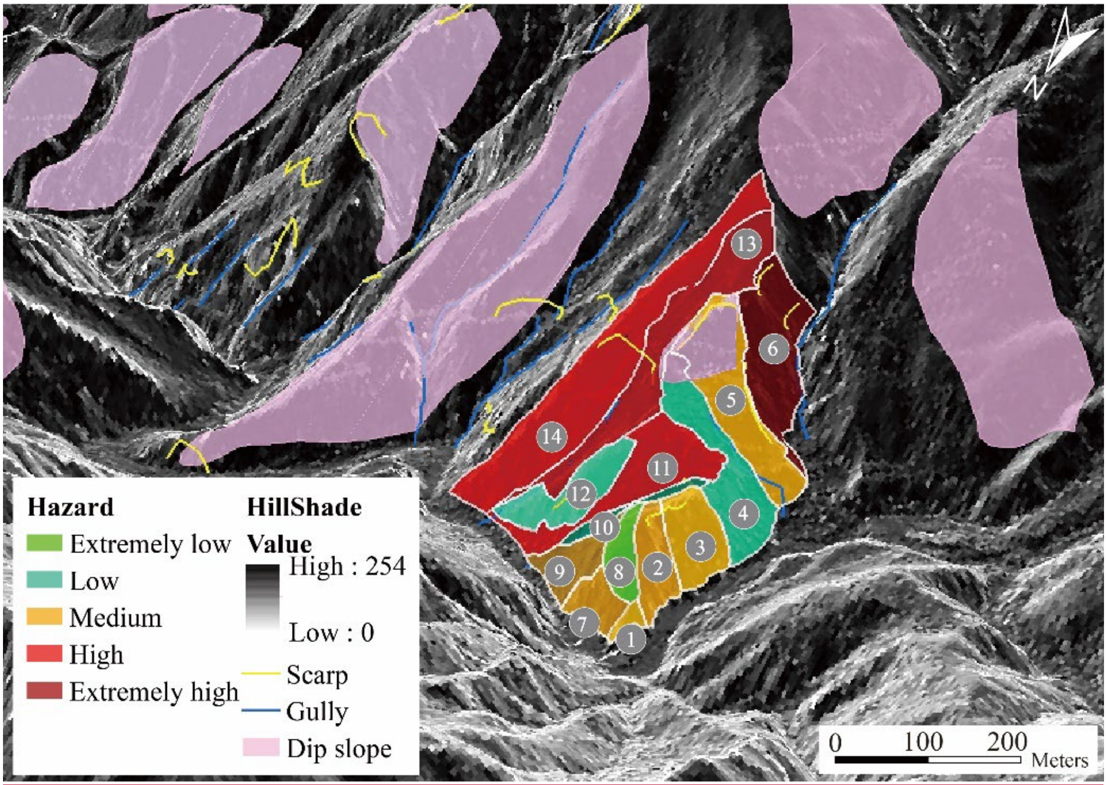

Figure 9 Hazard level mapping of landslide referred to slope units around the Neikuihui tribe (Background: modified after Department of Lands, Ministry of the Interior 2020; Aerial: ESRI ArcGIS 10.4).

4.2 Exposure analysis results

Based on the classification of households, transportation, and essential facilities as listed in Table ~~5~~9, this study determined Exposure levels of 14 slope units around the Neikuihui tribe as detailed in Table ~~11~~16, and the corresponding mapping ~~as~~are shown in Fig. ~~9~~10, which is based on the aerial photo to visualize the resident locations better. Results indicate that No. 4, 5, ~~6,~~ 11~~, 13,~~ and ~~14~~13 slope units have higher Exposure levels. Noticeably, the residents of the Nekuihui tribe mainly live in the No. 4 and No. 11 slope units, as shown in Fig. 4b. Besides, landslides may block the major external road leading to the outside, causing evacuation and material transportation difficulties. Consequently, these two units have the highest Exposure levels.

Table 16

~~Table 11~~ Exposure levels and scores of slope units around the Neikuihui tribe.

Slope unit	Household		Traffic		Public utilities		Total grades	Exposure level	Exposure score
	Attributes	Grade	Attributes	Grade	Attributes	Grade			
No.1		~~9~~1		0		0	~~9~~1		1
No.2	< 1 household	~~9~~1	No	0		0	~~9~~1	Low	1
No.3		~~9~~1		0		0	~~9~~1		1
No.4	≥~~>~~ 5 households	36		4		0	40	High	3
No.5	Households 1 to 2	16	Main access roads or bridges	4		0	20	Medium	2
No.6		~~9~~1		4		0	~~13~~5	Low	~~2~~1
No.7		~~9~~1		0		0	~~9~~1		1
No.8	< 1 household	~~9~~1	No	0	No	0	~~9~~1	Low	1
No.9		~~9~~1		0		0	~~9~~1		1
No.10		~~9~~1		0		0	~~9~~1		1
No.11	≥~~>~~ 5 households	36	Main access roads or bridges	4		0	40	High	3
No.12	< 1 household	~~9~~1	No	0		0	~~9~~1	Low	1
No.13	Households 3 to 4	~~9~~25	Main access roads or bridges	4		0	~~13~~29	Medium	2
No.14	< 1 household	~~9~~1		4		0	~~13~~5	Low	~~2~~1

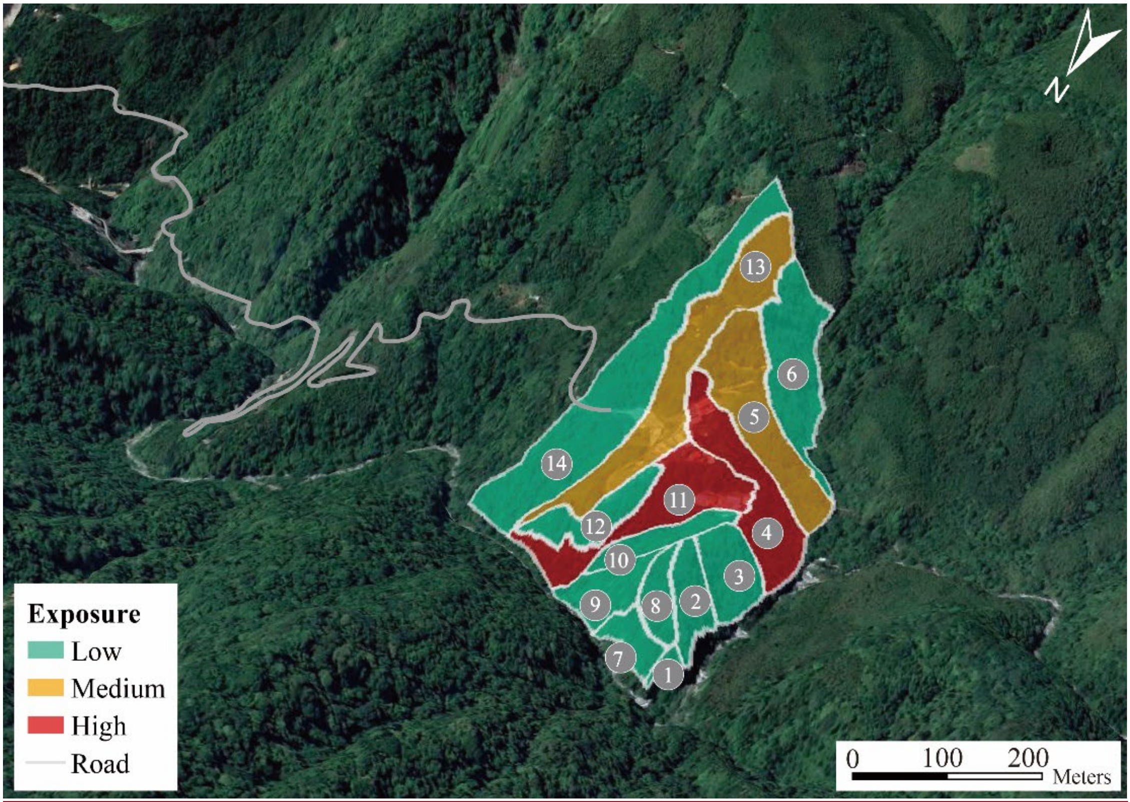

Figure ~~9~~10 Exposure level mapping of landslide referred to units around the Neikuihui tribe (Background: modified after © Google Earth 2021; Aerial: ESRI ArcGIS 10.4).

4.3 Vulnerability analysis results

With the description of the Vulnerability assessment method in the previous section, this study used 1 m × 1 m DEM to manually interpret the ~~cliffs~~scarps and erosion ditches around the Neikuihui tribe, as shown in Fig. 2f. Zheng (2018) proposed that the possible impact range of the landslide is interpreted based on the principle of the landslide area and the farthest run-out distance, and the transport of landslides will not be blocked by the terrain if there is no high or steep terrain. Besides, the landslide transport's distance and direction are kept in the origin state, indicating that the influence range would cover the source area and landslide path. However, the ~~path of the~~ landslide path should not exceed the ridgeline of the slope. ~~After entering the flat ground,~~The landslide gradually spreads after entering the flat ground, and deposits accumulate. According to the above principles, this study judges the possible impact range of the soil and rock ~~if the susceptibility collapse area collapses. The~~from the calculation process of the Vulnerability index proposed by Papathoma-Köhle et al. ~~(2019) is applied to analyze~~(2017). The difference in impact weights in the Vulnerability analysis is based on the landslide extent and path to the households and public facilities. This study utilized the 1*1 dem map to identify the possible locations of the collapse and then judged the Vulnerability by the slope aspect and settlement distribution for the burry effect.

The Vulnerability level of 14 slope units around the Neikuihui tribe~~. The relevant results~~ are listed in Table ~~12~~17. For example, W_{total} of the No. ~~5~~4 slope unit equals ~~9~~4, and VS = 1 × (3 × 1) + 4 × (1 × 1) = 7 because one household has a High VL level (3~~ × 1) + 6 × (1 × 1) = 15. Thus~~) and four households have Low VL levels (1). Therefore, the Vulnerability index of the No. ~~5~~4 slope unit is ~~15 / 9 = 1.67.~~ 7 / 4 = 1.75. Compared to other slope units, No.11 slope unit is the most vulnerable because some residents on No.11 slope unit are close to the landslide, and some are within the potential coverage of the landslide. If the cliff collapses, the foundations of the four households in No. 11 slope unit will collapse. Therefore, these four households will be considered for High VL levels when calculating Vulnerability. Accordingly, ~~No.~~ W_{total} of the No. 11 slope unit equals 6, and VS = 4 × (3 × 1) + 2 × (1 × 1) = 14, leading to the Vulnerability index of the No. 11 slope unit is 14 / 6 = 2.3. In summary, No. 4, 5, 11, 13, and 14 slope units can be found with apparent Vulnerability levels because these slope units have residents, as shown in Fig. ~~10. Compared with other slope units, the No.11 slope unit has the highest Vulnerability level because the residents living on slope unit No. 11 are the closest to the susceptibility collapse and are within the range that the collapsed soil and rock may cover~~11.

Table ~~12~~17 Vulnerability rating of slope units around the Neikuihui tribe.

Slope unit	Household	VL WR=1 High (3)	VL WR=1 Medium (2)	VL WR=1 Low (1)	Total Vulnerability grades of household	Public facilities	VL WF=1 High (3)	VL WF=1 Medium (2)	VL WF=1 Low (1)	Total Vulnerability grades of public utilities	Sum of W	Total Vulnerability score	Vulnerability index	Vulnerability level	Vulnerability score
No.1	0	0	0	0	0	No	0	0	0	0	0	0	0	Extremely low	1
No.2	0	0	0	0	0	No	0	0	0	0	0	0	0		1
No.3	0	0	0	0	0	No	0	0	0	0	0	0	0		1
No.4	~~9~~5	~~3~~1	0	~~6~~4	~~15~~7	No	0	0	0	0	~~9~~4	~~15~~7	1.~~67~~75	Medium	3
No.5	~~9~~2	~~3~~0	~~0~~2	~~6~~0	~~15~~4	No	0	0	0	0	~~9~~2	~~15~~4	~~1.67~~2		3
No.6	0	0	0	0	0	No	0	0	0	0	0	0	0	Extremely low	1
No.7	0	0	0	0	0	No	0	0	0	0	0	0	0		1
No.8	0	0	0	0	0	No	0	0	0	0	0	0	0		1
No.9	0	0	0	0	0	No	0	0	0	0	0	0	0		1
No.10	0	0	0	0	0	No	0	0	0	0	0	0	0		1
No.11	~~5~~6	~~5~~4	0	~~0~~2	~~15~~14	No	0	0	0	0	~~5~~6	~~15~~14	2.3	~~Extremely high~~High	~~5~~4
No.12	0	0	0	0	0	No	0	0	0	0	0	0	0	Extremely low	1
No.13	~~1~~3	0	0	~~1~~3	~~1~~3	No	0	0	0	0	~~1~~3	~~1~~3	1	Low	2
No.14	1	0	0	1	1	No	0	0	0	0	1	1	1		2

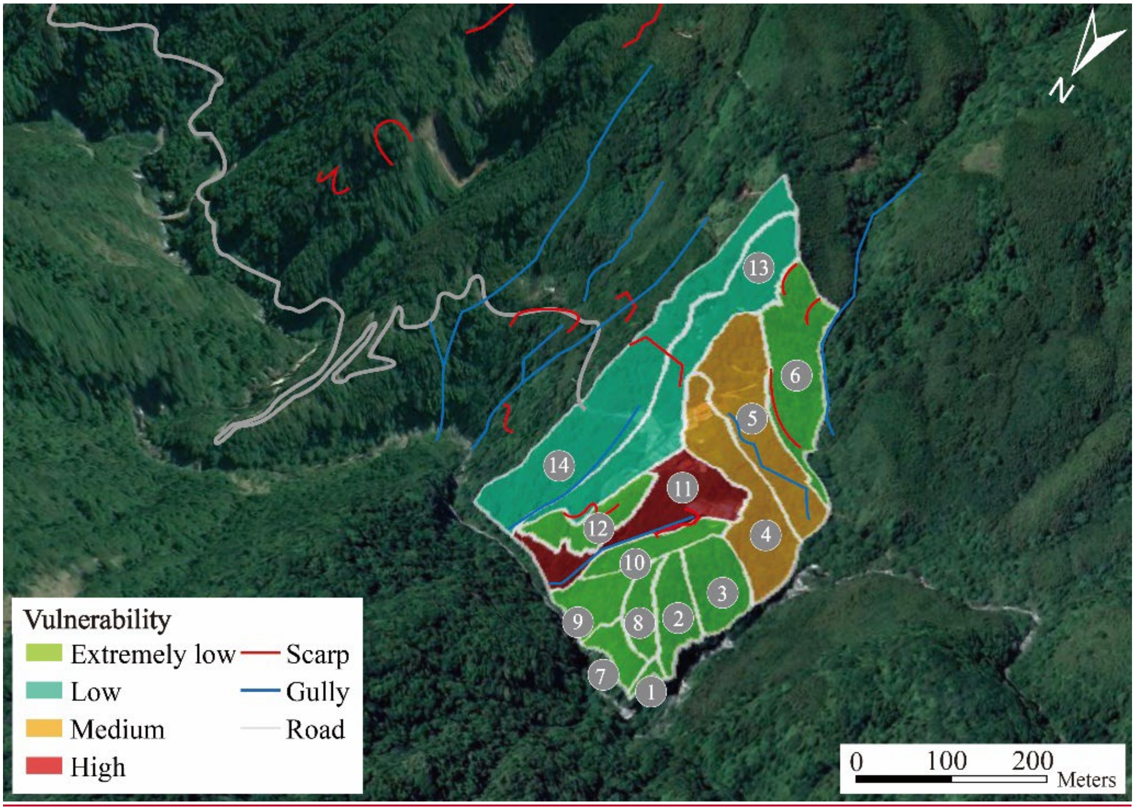

Figure ~~10~~11 Vulnerability level mapping of landslide referred to units around the Neikuihui tribe (Background: modified after modified after © Google Earth 2021; Aerial: ESRI ArcGIS 10.4).

4.4 Risk analysis results

By combining the scores of Hazard, Exposure, and Vulnerability of each slop unit around the Neikuihui tribe, Risk levels were then obtained by score summation as listed in Table ~~13~~18. The No.11 slope unit is High ~~of~~ Risk level, and No. 4, 5~~, 13,~~ and ~~14~~13 slope units are Low ~~of the~~ Risk level. The corresponding mapping result of the landslide Risk is shown in Fig ~~11~~12. Since slope unit No. 6 is steep and tangent to the river, it is ~~judged that its hazard level is~~apprised with the highest Hazard level as processing ~~hazard~~Hazard analysis at the beginning. However, no one ~~living~~lives there, and the landslide has few impacts on human lives and public facilities nearby. Thus, the Risk level is not as high as the No. 11 slope unit~~ No. 11~~. Through ~~these three main elements to do~~ Risk zoning toward slope units, ~~we~~this study can quickly identify which areas need to be prioritized in disaster prevention.

Table ~~13~~18 Risk levels of slope units around the Neikuihui tribe

Slope unit	Hazard score	Exposure score	Vulnerability score	Risk score	Risk index	Risk level
No.1	3	1	1	3	0.04	
No.2	3	1	1	3	0.04	Extremely low
No.3	3	1	1	3	0.04	
No.4	2	3	3	18	0.24	Low
No.5	3	2	3	18	0.24	
No.6	5	~~2~~1	1	~~10~~5	0.~~13~~06	
No.7	3	1	1	3	0.04	
No.8	1	1	1	1	0.01	Extremely low
No.9	3	1	1	3	0.04	
No.10	2	1	1	2	0.02	
No.11	4	3	~~5~~4	~~60~~48	0.~~80~~64	High
No.12	2	1	1	2	0.02	Extremely low
No.13	4	2	2	16	0.21	Low
No.14	4	~~2~~1	2	~~16~~8	0.~~21~~10	Extremely low

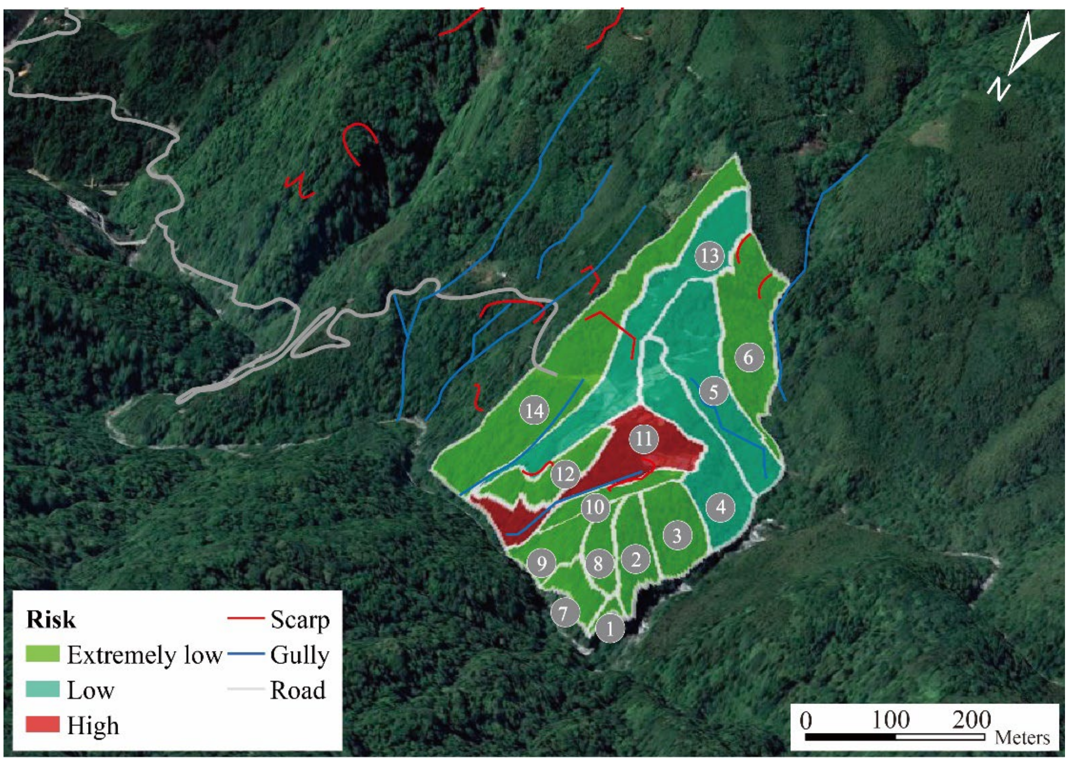

Figure ~~11~~12 Risk level~~ mapping of landslide~~ referred to slope units around the Neikuihui tribe (Background: modified after © Google Earth 2021; Aerial: ESRI ArcGIS 10.4).

5 Discussions

Since the Risk level of the No.11 slope unit is High, as illustrated in Fig. ~~11~~13, this study further compared the results with historical disaster events for validation. According to the 2016 report ~~(~~of Bureau of Soil and Water Conservation of the Agriculture~~)~~,, the No. 11 slope unit~~ area~~ was affected by the torrential rainfall during Typhoon Meiji on September 27, 2016. A landslide disaster occurred at 14:00 on the same day. Referring to the historical data of the Fuxing Rain Gauge Station closest to the disaster location, the hour rainfall record ~~at this time ~~was 45.5 mm, as depicted in Fig. ~~12~~13. The road's foundation was scoured by rainwater, resulting in a landslide with a length of 8-10 meters and a depth of 30-60 cm, as shown in Fig. ~~13a~~14a. The soil yields moved down and rushed into the ~~No. 8 ~~residential house (Fig. ~~13b~~14b), and trees and telephone poles were seriously inclined at the No. 11 slope unit (Fig. ~~13c~~14c). Through the evidence of landslide disaster at No. 11 slope unit, the rapid risk zoning method toward multi slope units around the tribal region is ~~proven~~confirmed preliminarily.

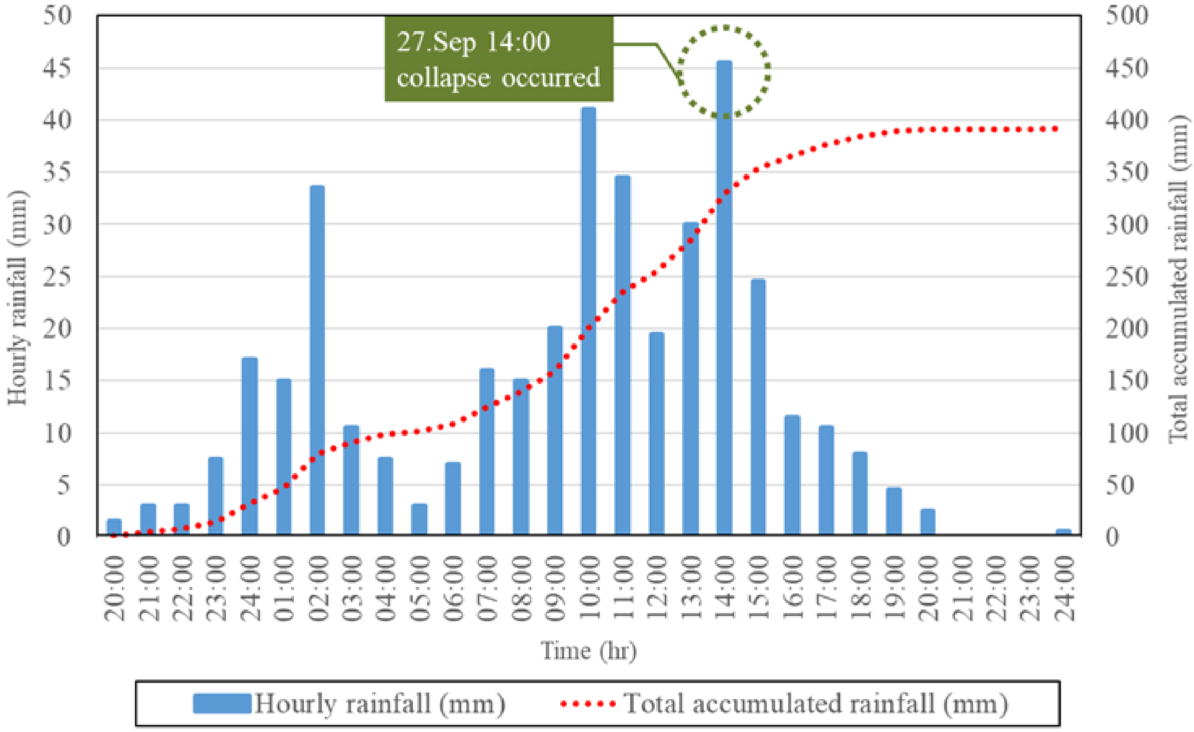

Figure ~~12~~13 Rainfall records during Typhoon Meiji (September 26 to September 27, 2016).

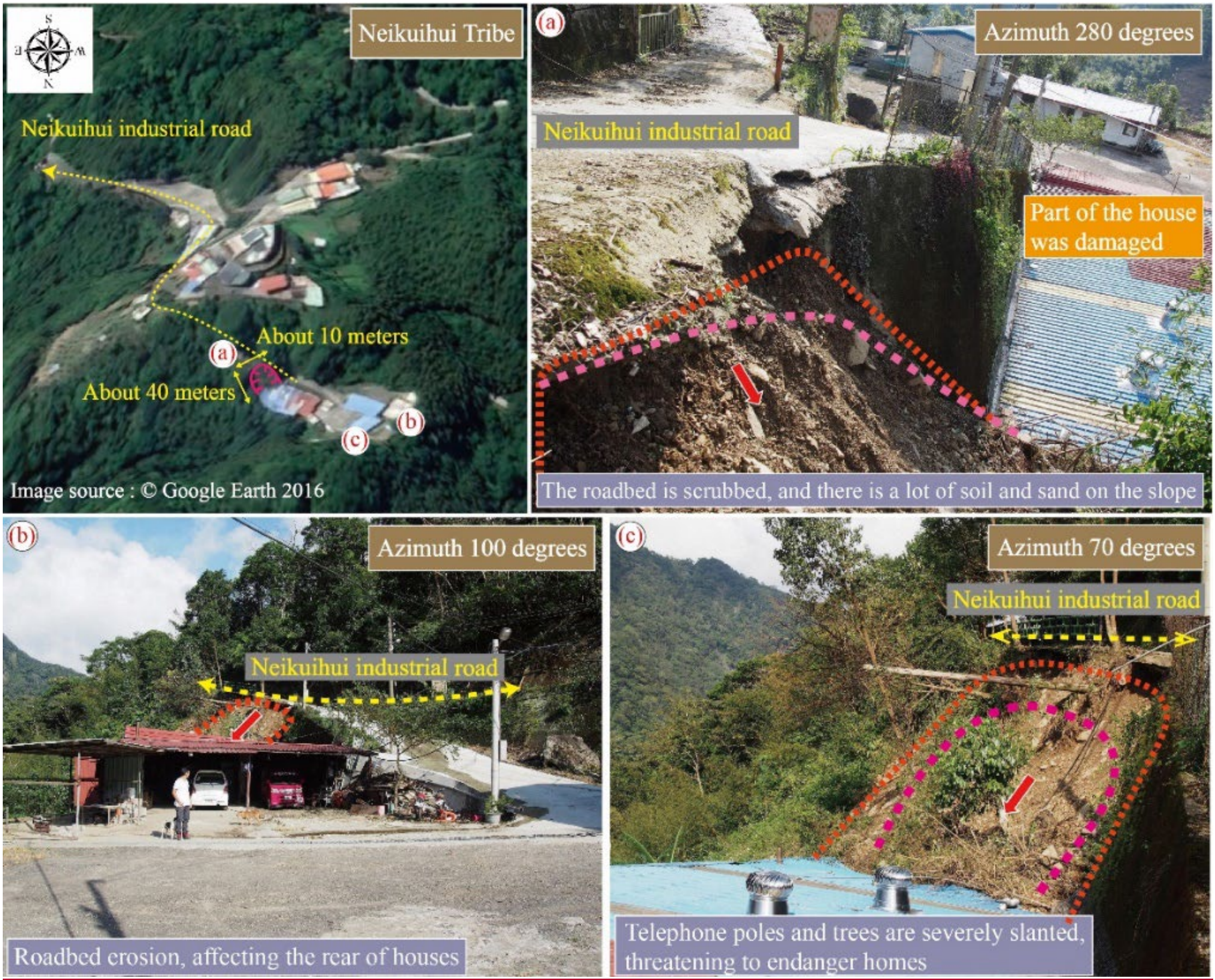

Figure ~~13~~14 Historical disaster event at No.11 slope unit during Typhoon Meiji 2016 (Picture source: 2016 Water and Soil Conservation Bureau; Aerial: ESRI ArcGIS 10.4).

The primary purpose of this research is to establish a simple risk assessment framework for quickly interpreting the collapse of multi-slope units in settlements. ~~Through the primary concepts referred to previous relevant findings, the~~The proposed method can quickly assess the risk of slope collapse in various regions through the concepts referred to as previous relevant findings. The advantages and limitations summarized by this research are as follows:

1. The proposed landslide Risk zoning ~~of collapse~~toward small slope units covers the assessments of Hazard, Exposure, and Vulnerability, in which ~~both~~ the object of resident preservation and its value are carefully considered. If the Risk zoning is implemented in a large-scale collapse, the above concepts are still necessary accompanied by extended methods.

For ~~example~~Vulnerability assessment, the effect of the more prolonged runout distance of the very large-scale landslide should be re-considered in terms of semi-experienced statistical prediction (Zheng, 2018). This study recommends refining Risk zoning with a variety of data integrity and alternative methods based on sufficient materials and process time.

2. Risk zoning can be expressed in qualitative ~~or~~and quantitative methods. The quantitative method is introduced, but it requires very detailed site information and statistics of various parameters, often taking a lot of time and cost. A qualitative description does not need to quantify each factor, which is described hierarchically. Although the qualitative method is less accurate, it can initially manifest the differences and ranks of the various sites, which is helpful to ~~quickly~~ provide a reference for subsequent risk management quickly. Therefore, the initial risk assessment is more suitable with qualitative descriptions.
3. The Risk zoning framework designed in this study ~~include~~includes the Activity assessment when grading the Hazard, which can make up for the lack of time change in the Susceptibility assessment and represent the actual site activities. However, it requires little time to analyze visually.
4. ~~At present, this~~This research assumes that one-time mass destruction will occur in the ~~susceptibility~~susceptible area. However, some susceptibility areas may be damaged by local erosion and erosion repeatably. If different types of damage ~~(~~, such as corrosion or falling rocks~~)~~, can be classified in the future, resulting in a complete ~~risk~~Risk zoning.
5. In order to quickly assess the Vulnerability, it may be simplistic but efficient to judge the vulnerability score by considering the possible impact area of the landslide and the distance from the household / public facilities with the limited geological and geomorphological data. However, there are still households in this area, and the economic conditions are disadvantaged. According to the developed methodology in this study, when the survey resources are limited, the administration can easily and quickly remind people in higher-risk areas to relocate to a safe place.
6. ~~5.~~6. After conducting Risk zoning, those slopes with higher Risk levels can be subsequently evaluated by straightforward methods, such as on-site surveys, geological drilling, and numerical simulations, and the results can be practiced as a reference for further governance.

7. Since this study aims to quickly analyze the slope collapse risk in a region through indicators, it is suggested that after the follow-up assessment of the landslide risk in a specific region, the analysis results and the corresponding disaster event should be verified by interviewing residents, experts and scholars for plausibility.

6 Conclusions

Due to Taiwan's steep terrain and fragile geology, coupled with the frequent occurrences of typhoons and earthquakes, tribes ~~at~~in mountainous areas accompanied by rapid economic development and activity might evolve into landslide disasters. This study draws up a framework of rapid Risk zoning toward multi-slope units around the tribal region and integrates qualitative~~/~~

and semi-quantitative concepts ~~with~~to form indicators of landslide Susceptibility, Activity, Exposure, and Vulnerability. Then the Neikuihui tribe in northern Taiwan was taken as an example for validation.

Research results indicated that the No. 11 slope unit has a high landslide Risk level. At the same time, it is verified by a historical disaster event, indicating that the modified Risk zoning is feasible for multi-slope units around the tribal region. The proposed procedure can benefit government agencies for rapidly conducting preliminary analysis of the risk of tribe regions and prioritizing the disaster mitigation countermeasures. For example, by revealing the risk zoning for residents as a reference, the government can guide residents to voluntarily inspect the community environment and plan evacuation during the disaster. More importantly, the government can strengthen disaster prevention and relief awareness, and promotes regular emergency disaster relief drills at the usual time. This modified process of Risk zoning is further suggested to be validated comprehensively with other cases of tribe regions.

Data availability

The information referring to risk map (in shp files) can be obtained from fromhttps://www.dropbox.com/sh/r5z0ecxqm5tmtsd/AAAM8wnDeVY5ZTigAMgWCh39a?dl=0. Further information can be made available upon request to the corresponding author.

Author contributions

All authors contributed to ~~conceptualisation~~conceptualization, led by CCC, who also conducted the formal analysis and initial draft. ~~JSPJ~~CCC had a leading role on risk zoning perspective. ZYL contributed to validation and data ~~visualisation~~visualization. CCC critically reviewed the paper and contributed to the preparation of the final version.

Competing interests

The authors declare that they have no conflict of interest.

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