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Geologic Hazard Risk Assessment of Slopeland Villages in Southern Taiwan Using Remote Sensing Techniques

(Penilaian Risiko Bahaya Geologi di Kampung-kampung Tanah Cerun di Taiwan Selatan menggunakan Teknik Pengesanan Jarak Jauh)

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ABSTRACT

Countering the dangers associated the present extreme climate not only requires continuous improvement of local disaster prevention engineering infrastructure but also needs an enhanced understanding of the causes of the disasters. This study investigates the geologic hazard risk of 53 slopeland villages in Pingtung county of southern Taiwan. First, remote sensing (RS) techniques were utilized to interpret environmental geology and geologic hazard zonation, including dip slope, fault, landslide and debris flow. GIS map overlay analysis was used to further identify the extent of the geologic hazard zonation. As a final step, field investigation is used to comprehend geologic, topographic conditions and the geologic hazard risk specific to each locality. Based on data analysis and field investigation results, this study successfully integrates RS, GIS and GPS techniques to construct a geologic hazard risk assessment method of slopeland village. The results of this study can be used to promote support for future disaster prevention and disaster mitigation efforts.

Keywords: Geologic hazard; landslide susceptibility; remote sensing; slopeland village

ABSTRAK

Pembilang bahaya berkaitan iklim melampau semasa bukan sahaja memerlukan penambahbaikan berterusan infrastruktur kejuruteraan pencegahan bencana tempatan tetapi juga perlu peningkatan kefahaman tentang punca berlakunya bencana ini. Penyelidikan ini mengkaji risiko bahaya geologi di 53 kampung-kampung tanah cerun di daerah Pingtung selatan Taiwan. Pertama, teknik pengesanan jarak jauh (RS) digunakan untuk mentafsir geologi alam sekitar dan pengezonan bahaya geologi, termasuk aliran cerun, gelinciran, tanah runtuh dan aliran puing. Analisis bertindih peta GIS seterusnya digunakan untuk mengenal pasti tahap pengezonan bahaya geologi. Sebagai langkah akhir, kajian lapangan digunakan untuk memahami geologi, keadaan topografi dan risiko bahaya geologi khusus untuk setiap lokaliti. Berdasarkan keputusan data analisis dan hasil kajian lapangan, kajian ini berjaya menggabungkan RS, GIS dan GPS teknik untuk menghasilkan kaedah penilaian risiko bahaya geologi untuk kampung tanah cerun. Keputusan kajian ini boleh digunakan untuk meningkatkan sokongan untuk pencegahan bencana pada masa hadapan dan usaha mitigasi bencana.

Kata kunci: Bahaya geologi; kampung tanah cerun; kerentanan tanah runtuh; teknik pengesanan jarak jauh

INTRODUCTION

When confronting the danger of intense weather, promoting and implementing investigations needed for each type of significant natural hazard can be just as important as improving hazard prevention infrastructure. Also, tabulating the causes of slopeland disasters of each locality, assists efforts to identify concrete and effective post hazard reconstruction recovery policies and can serve as an important basis for the development of future hazard mitigation plans. Additionally, the characteristics of recent rainfall patterns have changed. Sudden intense rainfall events have already drastically endangered local village safety of life and property. As a result of the sudden increase in natural hazards caused by extreme weather, Taiwan has been listed as a natural hazard hotspot by the World Bank. In order to correctly grasp the risk level of each slopeland village in Pingtung County and further develop effective counter measures, an assessment of the geologic hazard associated with each slopeland village is required.

In the past, relevant domestic and international researchs have used geologic hazard assessment to construct a data set and used remote sensing and image interpretation and field investigation methods to provide a foundation for landslide susceptibility assessment (AGS 2000; Bai et al. 2010; Saunders & Glassey 2007; UPSAG 2006), landslide influence on mountain road interruption (Yang et al. 2012) and settlement isolation susceptibility assessment (Yang 2013). The advantage of utilizing remote sensing techniques is the relatively short time needed to perform large scale geologic hazard assessments and ability to overcome difficulties associated with rough and dangerous terrain in the field (Yang et al. 2012). However, seldom studies simultaneously considered the influence of landslide, debris flow, geologic and topographic conditions on the slopeland village housing safety using remote sensing techniques.

In this study, GIS is used to perform a map overlay analysis of the data provided by local and regional governments. These data include the environmental geologic maps and landslide susceptibility maps provided by the central geological survey and potential debris flow torrent layers provided by the soil and water conservation bureau. In addition, this study utilized the remote sensing and image interpretation techniques and then through field investigation, obtained data immeasurable from the remote sensing images. By using the remote sensing and field collection results, the geologic hazard risk of each slopeland village was assessed. Once the slopeland village geologic hazard data has been collected, the geologic hazard data set can be expanded and this result can be used as a future disaster prevention reference. Such a reference may serve as an important basis for appropriate allocation of resources and staff for response to future hazards.

STUDY AREA

The study area covers the entire Pingtung County in southern Taiwan. The total area and length of the Pingtung County is 2775.6003 km^2 and 112 km, respectively. The shape of the county is long and narrow. The most eastern portion of the study area is Wutai township, the most western portion of the county is the western portion of Liuqiu island. The southernmost portion of the county is Hengchun township and the most northern area is Gaoshu township. The Central Mountain range defines the border between Pingtung and Taidong County. The western portion of the county borders the Taiwan strait, meanwhile the south borders the Bashi channel or Luzon strait. The northern part of the county borders the boundary of Kaohsiung city, which is defined by the upper reaches of the Kaoping river.

Pingtung County is primarily defined by an alluvial plane. The topographic map of Pingtung County is shown in Figure 1. The eastern portion of the county is the southern portion of the Central Mountain range, which is the mountain range that defines the backbone of the

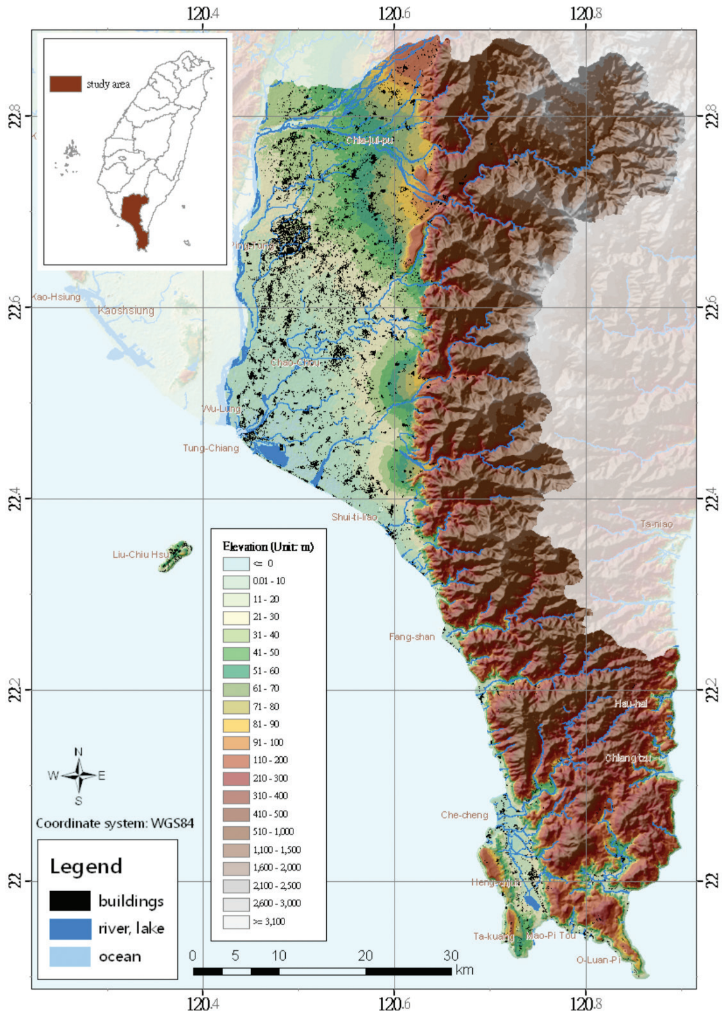

FIGURE 1. Topographic map of Pingtung County

Taiwan island, a layered, highly broken mountain chain that encroaches upon a vast plane. The west portion of the county is a fertile expanse of plains and along the border of the county is the upper reach of the Kaoping river that flows through folded layers of bedrock. The boundary of the mountains and plains are defined by the Chaojhou fault. The primary controls of the on topography in the county are rivers, which originate in the Central Mountains and have formed the alluvial plane. Over 42.1% of the county is below 100 m and only 15.05% is above 1000 m.

The primary rivers in Pingtung County are Pingtung, Donggang, Cishan, Laonong, Ailiao and LinBian. The wet season is from May to October and this season, in terms of total annual flow, accounts for 85.7% of the flow in the Kaoping river, 86.3% of the Donggang river and 96.8% of the Linbian river. The wet season to dry season flow ratio is 9:1 for the Pingtung plain, which clearly illustrates the rainfall characteristics of the area.

Regarding the climate, Pingtung County is the most southern area of Taiwan and has a tropical, monsoon climate. The difference in temperature between the southern and northern portion of the county is small and average temperature is 24.4°C. Low elevation and high elevation temperature difference is more significant. The average difference in temperature though the year is 5.3°C, with the winter and summer seasons having a mean difference of 7.2°C and 7.9°C, respectively. Regarding the rain, about 91% falls during the summer season, with the most of summer season rain falling in July and August. Rainfall patterns include Meiyu, the rainfall that occurs during the transition from spring to summer season, afternoon thunder storms, which occurs between July and September, as well as the summer and fall south westerly airflows derived heavy rains, which often occurs between June and September. Finally, there are the summer typhoons, which often occur between July and September.

METHODS

This study was implemented using both office and field techniques. In the office, satellite images and aerial photos were used to digitize characteristics of Pingtung County slopeland villages. Then remote sensing techniques were used to identify and locate the boundaries of geologic hazards zone near the slopeland villages. Also, remote sensing techniques were utilized to identify the geologic and topographic characteristics of each village. In particular, dip slopes, ancient landslides and debris flows were spatially identified. After that, GIS map overlay analysis was used to analyze the environmental geologic maps and landslide susceptibility layers provided by the Central Geological Survey, and the potential debris flow torrent layers provided by the Soil and Water Conservation Bureau. Field techniques included both field investigation to very office recon results and obtain measurements undetectable using remote sensing image interpretation, such as geologic hazard indicators in field such as tension cracks, subsiding structural foundations, cracks in retaining walls, recently exposed slopes and un-remediated debris flow channels. A flow chart of research program is shown in Figure 2.

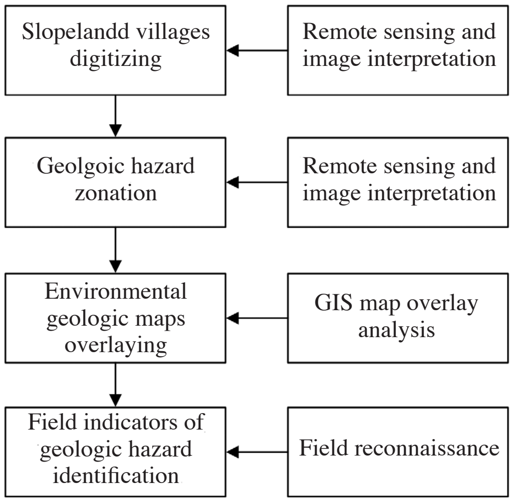

FIGURE 2. Flow chart of research program

This study divides the collected data into three sections including: General information (Table 1); Geologic hazards, which are primarily acquired by remote sensing techniques and GIS map overlay analysis of multiple layers (Table 2); and geologic hazard indicators in field (Table 3), which is populated with the data collected in the field.

TABLE 1. General information

Location	County Township Village	
Name		
Number of households	□ <20 □20 - 40 □40-60 □>60	
TW97 coordinates	X:	Y:
Date		
Investigator(s)		

TABLE 2. Geologic hazards

	Landform	Included	Not included
Local characteristics	1. Slopeland		
	2. River terrace		
	3. Gully or fan		
Geology and topography	4. Dip slope		
	5. Slope greater than 30°		
	6. Fault or discontinuity		
Hazard type	7. Potential debris flow torrent		
	8. Debris slide		
	9. Rock slide		
	10. Rock fall		

TABLE 3. Geologic hazard indicators in field

Evaluated items	Included		explanation
	yes	no	
Geologic hazard evidence			
1. Tension cracks			
2. Subsided foundations			
3. Cracks in retaining walls			
4. Exposed slopes			
5. Potential debris flow torrent remediated?			

Finally, all slopeland village data was analyzed using GIS and geologic hazard tables were constructed.

RESULTS AND DISCUSSION

In this study, remote sensing, GIS and field investigation were conducted to evaluate the presence of geologic hazard risk of 53 slopeland villages in Pingtung County. The results of Xiadanlu village and Fenshuiling village were discussed. Figure 3 is Xiadanlu village satellite image and photos of the village taken in the field. Through interpretation of satellite images, primary topographic features defining the Xiadanlu village have been identified as river terrace and gullies. Through GIS map overlay analysis, no geologic hazards were included in the village. From field investigation, it was found that tensions cracks exist in the slopes around Xiadanlu village and foundations have subsided and retention walls were cracked. All other hazard characteristics were not observed during the field investigation.

Figure 4 shows the Fenshuiling village satellite images and field photos. From image interpretation it was found that the Fenshuiling village is located in slopeland area and on a river terrace that resulted from historicly high sediment flows. Both sides of the village show evidence of land sliding and the whether or not the landslides pose any risk to village will be determined by future observation and assessment. Also, as a result of field investigation, it was realized that Fenshuiling village has cracked retaining walls, subsided foundations and tension cracks. All other hazards were not observed.

To further analyze the data collected from the 53 slopeland villages of Pingtung County, the hazards and causes of those associated with each village, were discussed and analyzed relative to village location, geology, topography and geologic hazard type.

VILLAGE LOCATION

The village location and geologic hazard type has a close relationship. Statistical analysis of village location showed

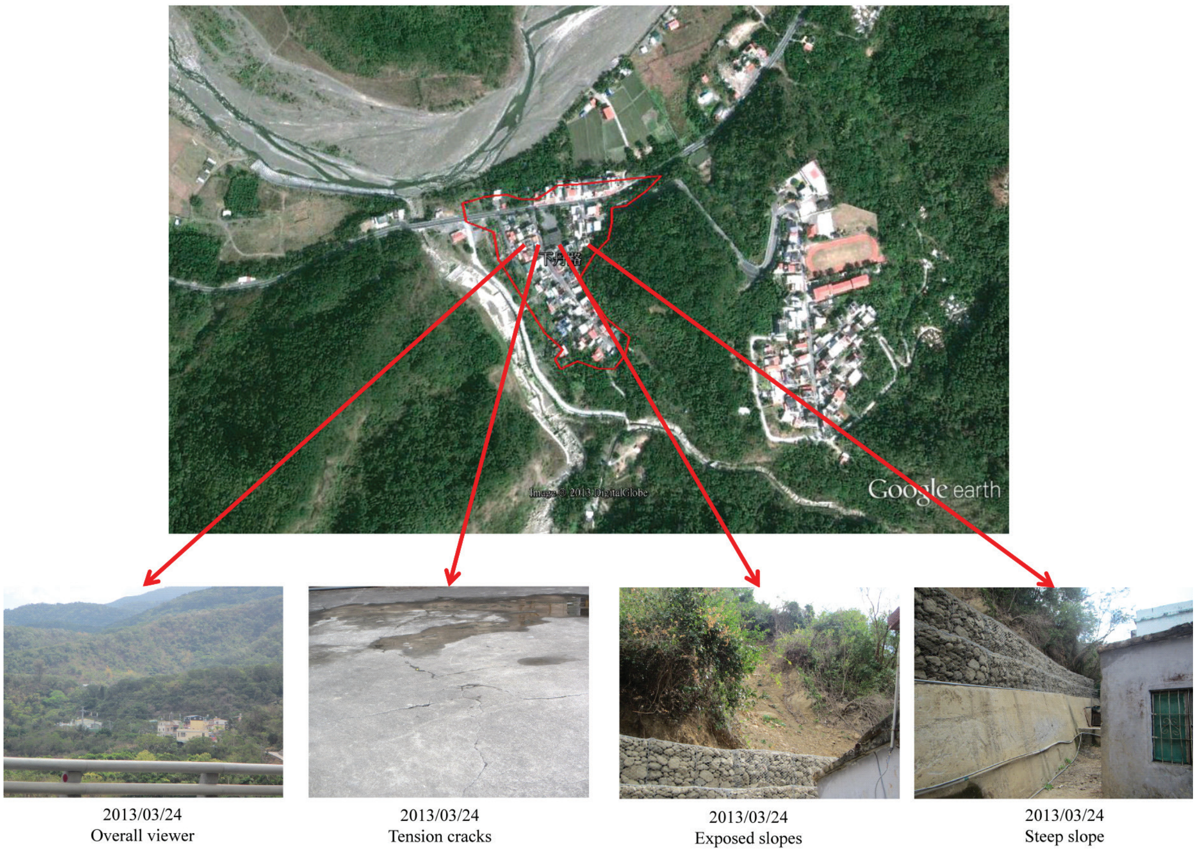

FIGURE 3. Xiadanlu village satellite image and field photos

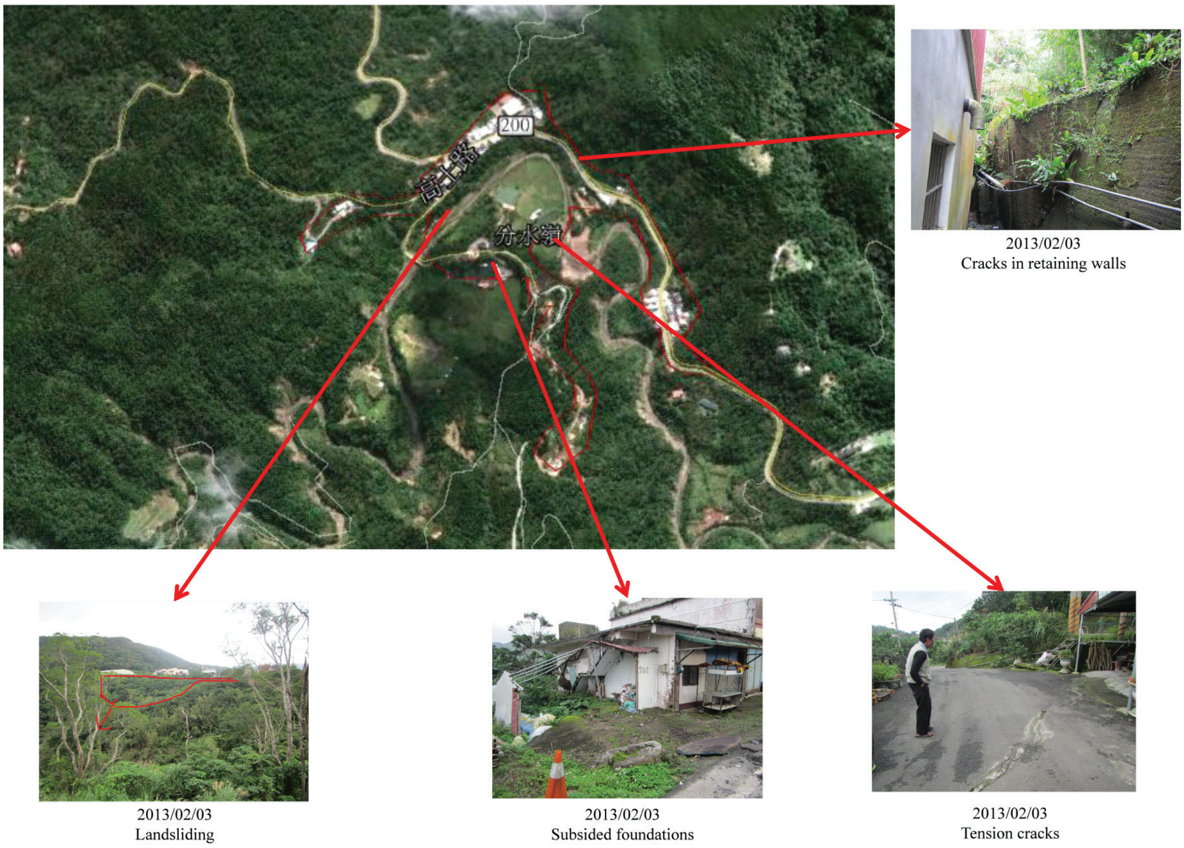

FIGURE 4. Fenshuiling village satellite image and field photos

that of the 53 villages, 31% are located on slopelands, 31% are located on river terraces and 38% are located in river valleys, as shown in Figure 5. The distribution of topography types is nearly even. However, some villages had two landform types such as the Cingshan, Cingye, Saijai and Xiamudan villages. Other villages actually had three types of landforms such as the Laiyidong, Laiyixi and Haichian villages.

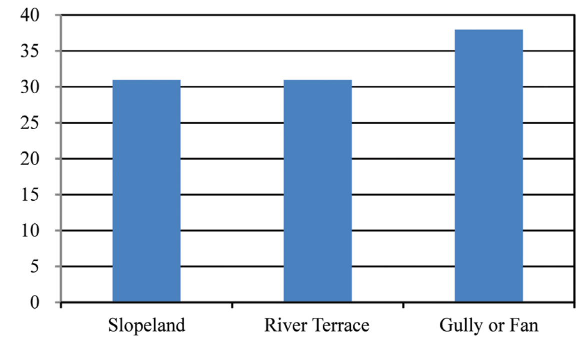

FIGURE 5. Village location statistics

GEOLOGY AND TOPOGRAPHY

Figure 6 shows the geology and topography statistics of the villages. Of the villages, 21% of them are located on dip slopes. The remaining 79% are on other, non-dip slopes. Faults or other discontinuities cross 8% of the villages. Additionally, a GIS analysis of slope showed that the average slope for all 53 villages does not exceed 30 degrees.

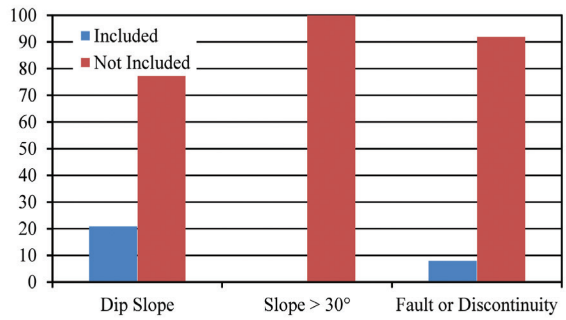

FIGURE 6. Village geology and topography statistics

GEOLOGIC HAZARD TYPE

Figure 7 shows the village geologic hazard statistics. From Figure 5, 68% of the villages were located near a potential debris flow channel while the other 32% were not near a potential debris flow channel. In addition, debris slides account for 36% of the villages while the other 64% show no evidence of debris slides. None of the 53 villages have recorded evidence of rock slides. Rock fall was found in 6% of the villages. 92% had no sign of rock fall potential. These results showed that slopeland villages in Pingtung County are primarily at risk of debris slides and debris flows.

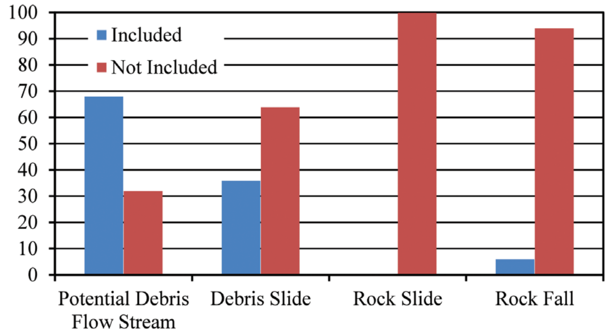

FIGURE 7. Geologic hazard statistics around village

PORTENTS OF SLOPELAND HAZARDS

Figure 8 shows the slopeland hazard portents statistics. Of the villages investigated, 47% had tension cracks and 19% had foundations that had subsided. Cracked retaining walls were found in 34% of the villages and recent exposed slopes were found in 14% of the villages. 32% of the villages had debris flow channels that had not yet been remediated. Comparing field evidence with the GIS layers showed that 47% of the villages have evidence of some form of rockslide. This value is much higher than that indicated in the landslide susceptibility maps provided by the Central Geological Survey. The primary reason for this difference is that the GIS layers were created before the Typhoon Morakot disaster. After Typhoon Morakot, large rockslides were found near many Pintung county villages. Form this finding, it was clear that this study has aided in updating the list of geologic hazards.

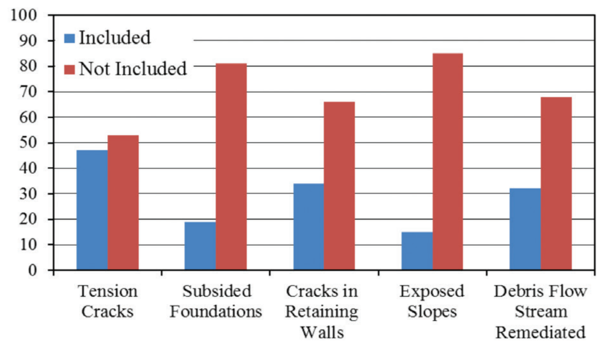

FIGURE 8. Slopeland disaster portents statistics

HIGH RISK VILLAGES

Villages that showed three or more portents of a geologic hazard are listed in Table 3. This study has identified these villages as high risk villages. Such villages include Dewen, Xiaolu, Taiwu, Caobu, Shuifenling, Majia, Jilu, Ali and Jiujiamu. All other villages are considered safe. After the addition of field reconnaissance results, analysis results represented the conditions in the villages. For example, Ali, Taiwu and Jilu villages have portents of severe geologic hazard. Structures and retaining walls show signs of serious damage. This field evidence agrees with the listing of the

FIGURE 9. Landslide caused damage in Ali village

FIGURE 10. Major landslide in Taiwu village

FIGURE 11. Major landslide in Jilu village

village in the high risk list. Field investigation photos are shown in Figures 9 through 11. It can be seen that a crack was visible in the wall (Figure 9), the retaining wall has a large crack (Figure 10) and tension cracks are visible on the ground surface (Figure 11).

CONCLUSION

This study successfully integrated remote sensing techniques, GIS map overlay analysis and field investigation to evaluate the geologic hazard risk of 53 slopeland villages in Pingtung County and develop a slopeland village geologic hazard and safety assessment methods. The results of this study showed that before Typhoon Morakot, the primary geologic hazards affecting the 53 villages were debris slides and debris flows. After the disaster, 47% of the villages had susceptibility of large rock slides. Also, this research successfully clarified the definition of a high risk village. High risk villages include Dewen, Xiaolu, Taiwu, Caobu, Shuifenling, Majia, Jilu, Ali and Jiujiamu. All other villages are considered safe.

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