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Relationship Between Debris Flow and Precipitation From Nantou and Chiayi County in Taiwan

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ABSTRACT This study collected data on debris flow and precipitation from Nantou and Chiayi districts in Taiwan. According to past reports of debris flow by the Bureau of Water Conservation, there have been 19 debris flow in the Nantou area and 14 debris flow in the Chiayi area for a total of 33 reports of debris flow. Among them, 8 (42%) of the Nantou debris flow were classified potential debris flow torrents, and 11 were ordinary unclassified torrents. There were 8 events of potential debris flow torrents (57%) in the Chiayi area, and 6 ordinary unnamed torrents. According to the hydrological data from the disaster report, precipitation patterns were analyzed using effective accumulated precipitation (R), the duration of sustained precipitation, the duration of alert level precipitation, and the precipitation intensity (I) during debris flow. The precipitation patterns were analyzed using level 1 and level 2 graphs, and findings showed that there are 6 different types of precipitation patterns during debris flow. The results showed that the most significant precipitation patterns were: level 1 short-duration heavy precipitation and level 2 short-duration heavy precipitation, as short duration heavy precipitation occurred 17 times and accounted for 52%. This is in line with the current extreme climate, as short-duration torrential rain can cause disasters. The lesser-occurring mild precipitation is divided into two types: level 1 long-duration mild precipitation and level 2 short-duration long-duration mild precipitations. They occurred 2 times and accounted for 6%. A disaster prevention mechanism should be established in the future to prevent the occurrence of debris flow caused by heavy precipitation.

KEYWORDS: Debris flow; Precipitation pattern; Sustained precipitation; Mild precipitation; Heavy precipitation.
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Full article

INTRODUCTION

The world has been affected by extreme weather conditions recently as disasters have become more devastating and the frequency of them occurring has risen rapidly. Since Taiwan possesses an island-type climate, the country has abundant and unevenly distributed precipitation each year. Annually the precipitation in the mountain areas can exceed 8,000 mm, but in the lowland plains can be less than 1,200 mm, and 78% of the precipitation is concentrated in what region. The collapsing hillsides and the mud that is washed down by frequent heavy precipitation and rainstorms are called debris flow. Debris flows are most likely to occur from May to October during the rain and typhoon seasons.

Debris flow are a natural phenomenon that occur when mud, sand, gravel, and boulders are mixed with water and pulled down along slopes, rivers, ditches, and other paths by gravity from elevated locations. The Executive Yuan Council of Agriculture's Soil and Water Conservation Bureau announced that there were 1,673 potential debris flow torrents in 17 counties and cities in different watersheds (Xu et al., 2012). Nantou and Chiayi County in this research had 249 and 80 potential debris flow torrents (Qiu et al., 2012). The damage caused by debris flow in recent years has been devastating, and it is important to establish a debris flow alert system to prevent disasters and casualties. Even though Taiwan has a debris flow alert system that is defined by colors such as "red," "orange," "yellow," and "green," which mean "highly dangerous," "moderately dangerous," "slightly dangerous," and "general debris flow," respectively, the addition of an auxiliary tool working in conjunction with the debris flow alert system can surely predict the occurrence of debris flow more quickly, lowering the amount of casualties and false reports.

Based on the premise of not considering geology and topography, this study only uses hydrology (CWB, 2019) as a factor to design research to determine precipitation patterns (Chen, 2005) from past hyetographs, and determine scenarios that will cause major debris flow. Therefore, projection of future, the precipitation pattern can be clearly identified from the precipitation, allowing preparations to be carried out in advance from early warnings like Japan as examples (Chen, 2013). This will allow debris flow specialists to analyze the situation without having to be at the actual location and determine if there will be a debris flow based on the precipitation pattern, saving man power and lowering casualty rates.

RESEARCH MATERIALS AND METHODOLOGY

Geographic Locations

Nantou located in the center of Taiwan and it is the only county that does not border the coast. The mountain of Yushan, located in among of Xinyi Township of Nantou County, Taoyuan District of Kaohsiung City, and Alishan Township of Chiayi County, is the highest mountain in Taiwan. The county's many mountainous peaks block the monsoon vapor from the Southern and Eastern Pacific Ocean, providing Taiwan with abundant precipitation and allowing the island to have more annual precipitation than any other country on the same latitude. The county has two of central Taiwan's four major river systems flowing through it: the Zhuoshui River System and the Wuxi River System. The administrative district of Nantou County has one county-administered city (Nantou City), four urban townships (Puli Township, Caotun Township, Zhushan Township, Jiji Township) and eight rural townships (Mingjian Township, Lugu Township, Zhongliao Township, Yuchi Township, Guoxing Township, Shuili Township, Xinyi Township, and Renai Township). Nantou County features a subtropical humid climate as the annual average temperature of planar townships is about 23°C, and the annual average temperature for mountainous townships is 20°C. The annual average precipitation for planar townships is below 1,750 mm, the annual average precipitation in the mountainous area is more than 2,800 mm, and the annual average precipitation on hillsides is somewhere in between the two at around 2,000-2,800 mm. The county's rainy season is from April to September every year, and the dry season is from October to March (Wikipedia, 2019).

Chiayi County is located in the southwestern part of Taiwan, bordering the Taiwan Strait to the west, Alishan Mountains and the Yushan's main peak to the east, Nantou County to the northeast, Tainan City to the south, and Kaohsiung City to the southeast. The Beigang River and Yunlin County border the north of Chiayi County while Bazhang River and Tainan City border the south. The administrative district of Chiayi County is divided into two county-appointed cities (Taibao City and Puzi City), two townships (Bubao Township, Dalin Township) and 14 other townships: Minxiong Township, Xikou Township, Xingang Township, Liujiao Township, Dongshi Township, Yizhu Township, Lucao Township, Shuishang Township, Zhongpu Township, Zhuqi Township, Meishan Township, Fanlu Township, Dapu Township, and Alishan Township). The County features a subtropical humid climate as the temperature is the highest in July and the lowest in January with an annual average temperature of 22.6°C. Although the County is located in southern Taiwan (south of Zhuoshui River), the strong radiative cooling effect of the Jianan Plain during winter cold spells has Chiayi County often seeing temperatures below 10°C. There were even subzero temperature recordings before the establishment of the Chiayi Weather Station, but no observation was recorded for those temperature readings. Chiayi County's winter is dry as the Northeast Monsoon is the primary contributing factor. The prevalent Southwest Monsoon gently blows during the summer wind to combine with high temperatures for frequent convections and afternoon thunderstorms. Typhoons often occur from July to September, and the annual average precipitation in Chiayi County is 1696.9 mm (Wikipedia, 2019).

The geographical areas of this study in Nantou County are Renai Township's Wanfeng Village, Xinyi Township's Shenmu Village, Xinyi Township's Wangmei Village, Shuili Township's Yufeng Village, Xinyi Township's Fengqiu Village, Renai Township's Nanfeng Village, Puli Township's Qilin Village, Xinyi Township's Tannan Village, Renai Township's Fazhi Village, Shuili Township's Shang'an Village, Xinyi Township's Tongfu Village, and Yuchi Township's Riyue Village. The geographical areas of this study in Chiayi County are Meishan Township's Taihe Village, Alishan Township's Chashan Village, Dapu Township's Jiadong Village, Meishan Township's Ruili Village, Zongpu Township's Zhonglun Village, Alishan Township's Lijia Village, Alishan Township's Laiji Village, Alishan Township's Fengshan Village, and Alishan Township's Shanmei Village as shown in Figure 1.

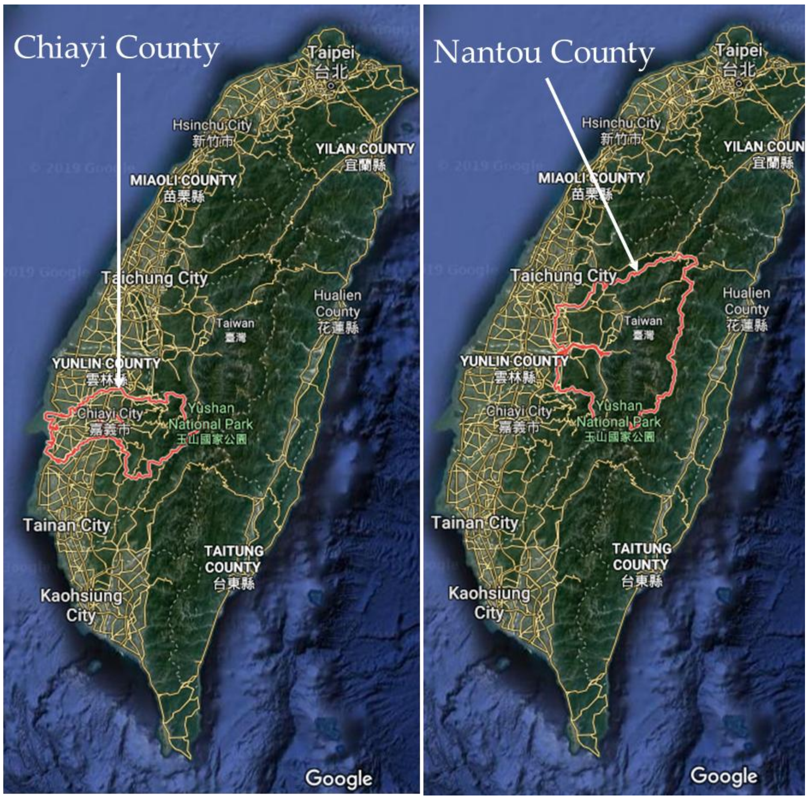

Figure 1. Geographical Locations Map of Chiayi and Nantou County (Google Map, 2019)

Data Collection

The data was collected from the Executive Yuan Council of Agriculture Soil and Water Conservation Bureau - Debris flow Disaster Prevention Information Network from Nantou County area to Chiayi County area.

Nantou County Area Information

This study analyzes the relationship between debris flow and precipitation based on the 19 events of Nantou County rapid disaster reports' hyetographs (1. Renai Township's Fazhi Village, 2. Xinyi Township's Tannan Village, 3. 4. Puli Township's Qilin Village, 5. Renai Township's Nanfeng Village, 6. Renai Township's Nanfeng Village, 7. Xinyi Township's Fengqiu Village, 8. Shuili Township's Yufeng Village, 9. Xinyi Township's Tongfu Village, 10. Xinyi Township's Wangmei Village, 11.12.13.14. Xinyi Township's Shenmu Village, 15. Xinyi Township Fengqiu Village, 16.

Renai Township's Wanfeng Village, 17. Xinyi Township's Shenmu Village, 18. Yuchi Township's Riyue Village, 19. Shuili Township's Shang'an Village). The numerical data in Figure 2 shows the hyetographs of the 19 debris flow incidents in Nantou County.

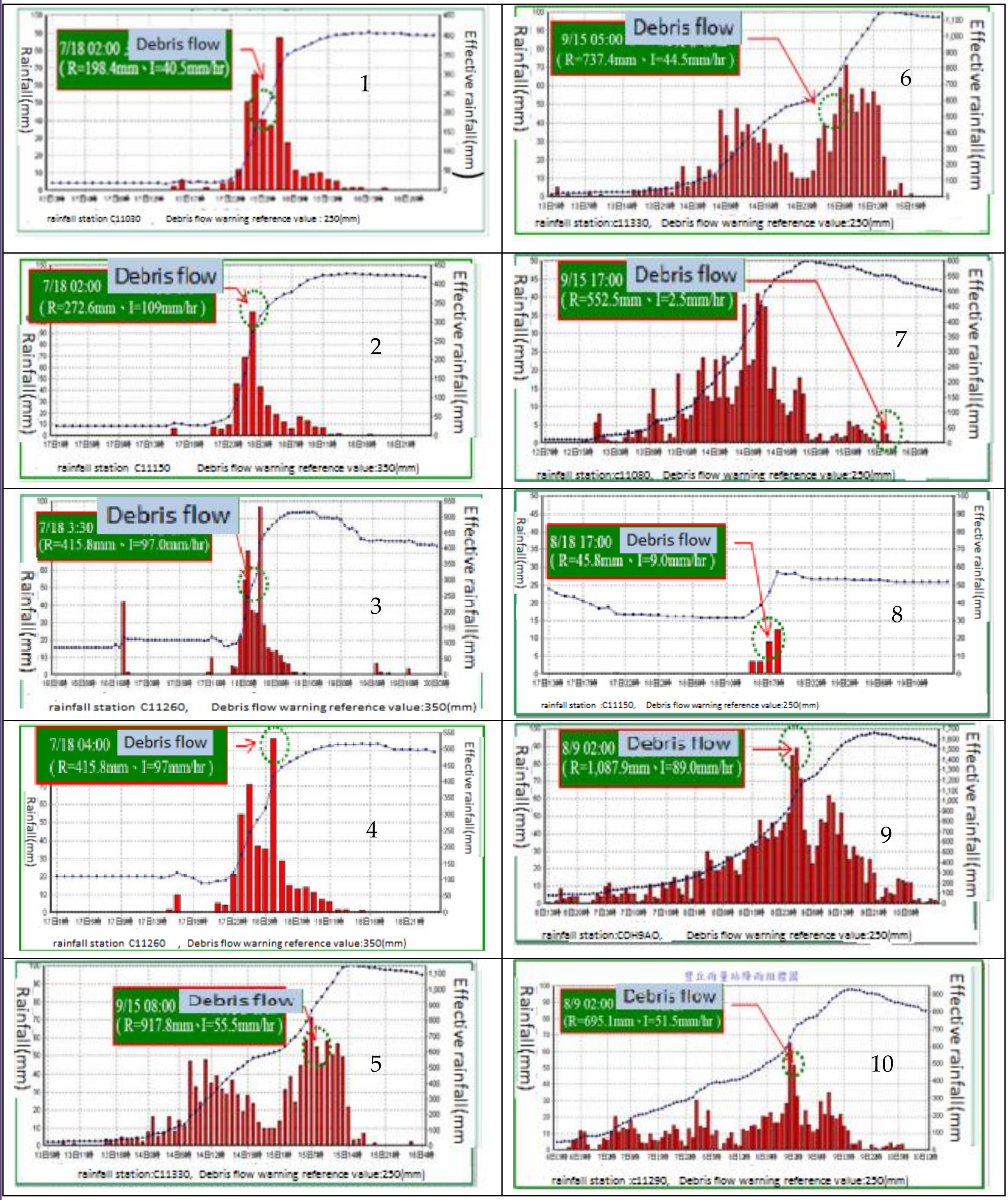

Figure 2. The Hyetographs of the 19 Debris flow Incidents in Nantou County (**Source:** Debris Flow Disaster Prevention Information Network, 2019).

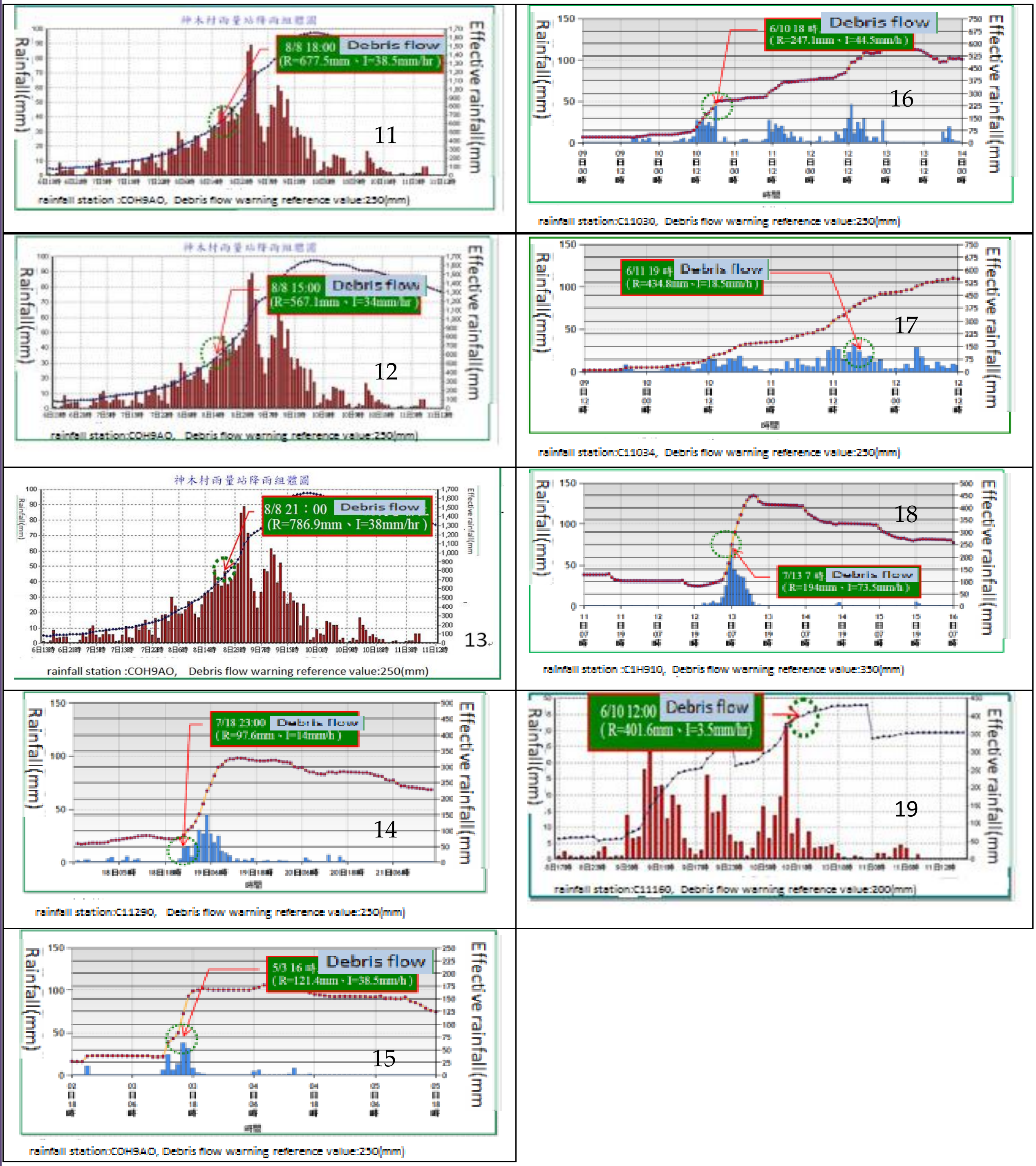

Figure 2. The Hyetographs of the 19 Debris flow Incidents in Nantou County (continue).

Chiayi County Area Information

This study analyzes the relationship between debris flow and precipitation based on the 14 numbered events of Chiayi County rapid disaster reports' hyetographs (1-3: Meishan Township's Taihe Village; 4: Alishan Township's Chashan Village; 5: Alishan Township's Shanmei Village; 6: Dapu Township's Jiadong Village; 7: Zhongpu Township Zhonglun Village; 8- 13: Alishan Township Lijia Village; 9 Meishan Township's Ruili Village, Alishan Township Laiji Village, 14. Alishan Township Fengshan Village). The data is collected from the Executive Yuan Council of Agriculture Soil and Water Conservation Bureau - Debris flow Disaster Prevention Information Network. The numerical data in Figure 3 shows the hyetographs of the 14 debris flow incidents in Chiayi County.

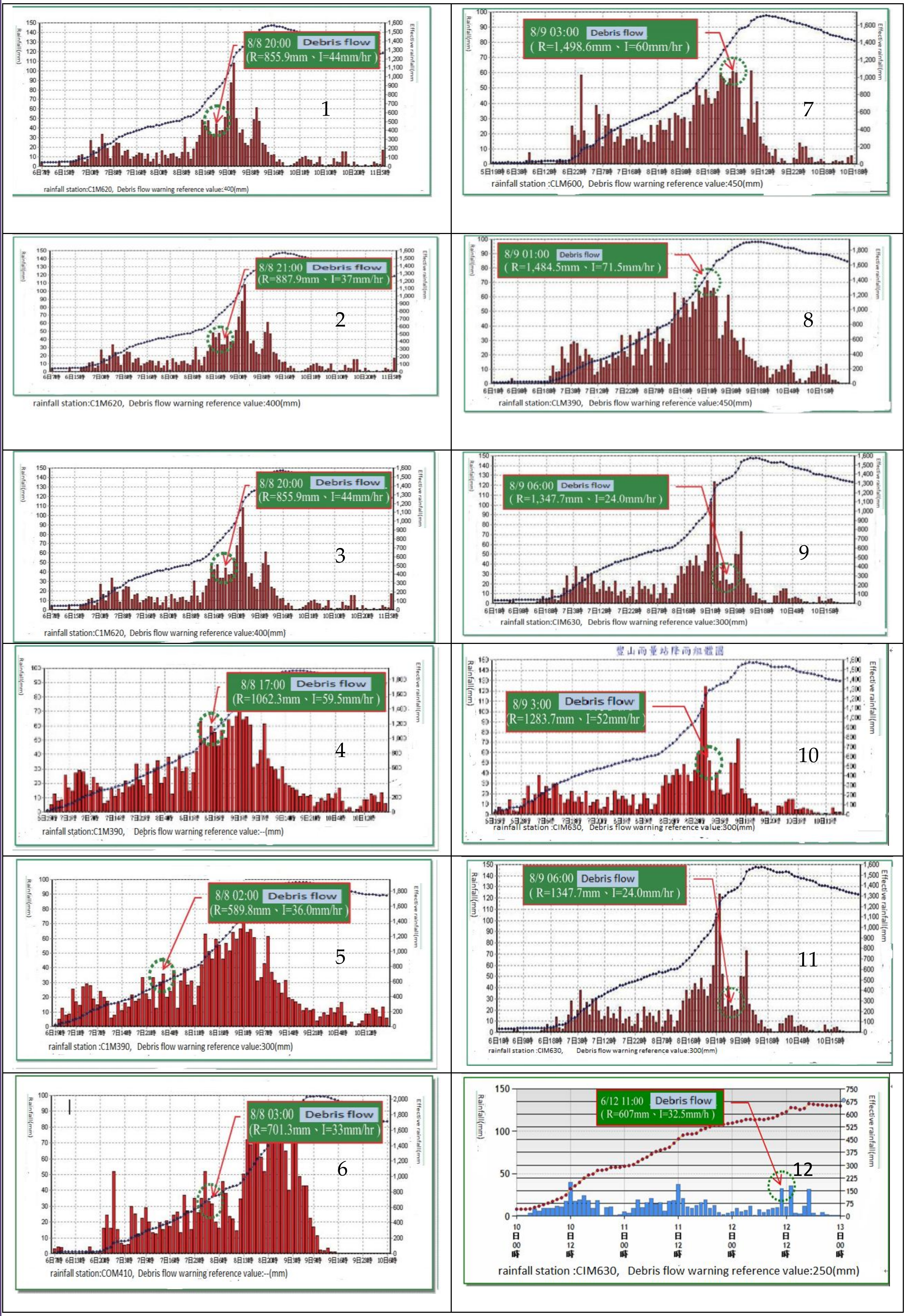

Figure 3. The Hyetographs of the 14 Debris flow Incidents in Chiayi County (**source:** Debris Flow Disaster Prevention Information Network, 2019).

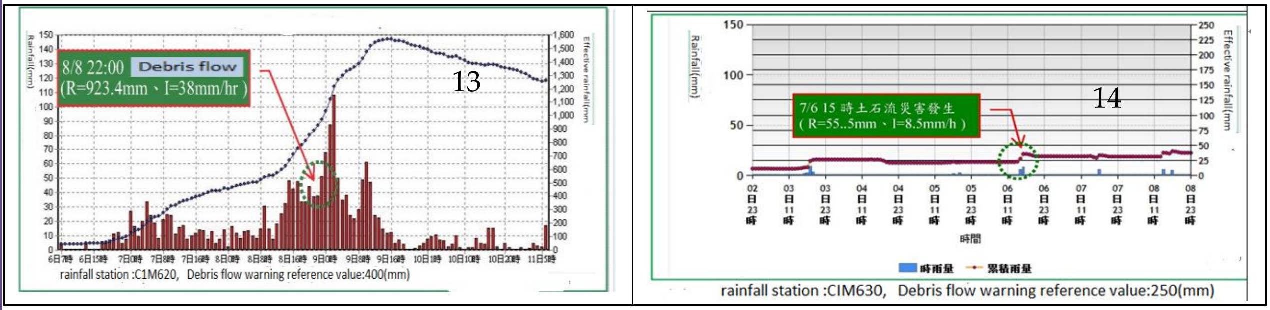

Figure 3. The Hyetographs of the 14 Debris flow Incidents in Chiayi County (continue)

Analysis Table of Consolidated Data

The hydrological data of each area in Figure 2 and 3 were integrated into the comparative analysis table exploring the relationship between debris flow and precipitation in Table 1 and Table 2 as mentioned at Lin (2008). The duration of continuous precipitation and precipitation patterns cannot be found in Figure 2 and Figure 3, therefore the values for these two factors were determined through interpretation of the data. The duration of continuous precipitation was calculated from the occurrence of the debris flow to the time of initial precipitation. The precipitation pattern representation is split into Level 1 and Level 2 based on the hyetographs in Figure 2 and 3. Level 1 represents only one peak during precipitation and continuous precipitation till conditions became moderately calm. Level 2 has clear high-low fluctuations and has two peaks as precipitation was continuous without any stoppage. The data from Figure 2 and 3 was interpreted as a comparative analysis table of earth and stone flow and precipitation in Tables 1 and 2.

Table 1. Comparative analysis of the relationship between debris flow and precipitation in 19 Nantou County debris flow disasters

NU	Hydrological Event Typhoon	Location	Debris flow	Warning value (mm)	Effective cumulative rainfall(mm)	Disaster occurrence time	Continuous heavy rainfall period	warning value/ rainfall delay	Intensity (I) (mm)	Rainfall pattern
1	2008 / Kalmeagi Ty	Ren-ai/ fa-chih	-	250mm	198.4mm	7/8 02:00	6hrs	40mm/ 3hrs	40.5 mm	1st-order heavy rainfall short delay
2	2008 / Kalmeagi Ty	Shin-yi/ tan-nan	-	250mm	272.6mm	7/18 02:30	6hrs	40mm/ 3hrs	109 mm	1st-order heavy rainfall short delay
3	2008 / Kalmeagi Ty	Pu-li/ chin-lin	DF045	350mm	415.8mm	7/18 03:30	6hrs	40mm/ 3hrs	97.0 mm	1st-order heavy rainfall short delay
4	2008 / Kalmeagi Ty	Pu-li/ chin-lin	-	350mm	415.8mm	7/18 03:30	8hrs	40mm/ 5hrs	97.0 mm	1st-order heavy rainfall short delay
5	2008 / Sinlaku Ty	Ren-ai/ nan-feng	DF013	250mm	917.8mm	7/18 04:00	41hrs	30mm/ 7hrs	55.5 mm	1st-order heavy rainfall short delay
6	2009/ Morakot Ty	Shuei-li/ yu-feng	-	250mm	737.4mm	9/15 08:00	38hrs	40mm/ 4hrs	44.5 mm	2nd-order heavy rainfall short delay
7	2009/ Morakot Ty	Skin-yi/feng-chiu	-	250mm	552.5mm	9/15 05:00	69hrs	3mm/ 46hrs	2.5 mm	2nd-order heavy rainfall short delay
8	2009/ Morakot Ty	Shuei-li/ yu-feng	-	250mm	45.8mm	8/15 17:00	4hrs	5mm/ 2hrs	9.0 mm	2nd-order heavy rainfall long delay
9	2009/ Morakot Ty	Shin-yi/ tung-fu	DF202	250mm	1087.9mm	8/9 02:00	51hrs	40mm/ 10hrs	89.0 mm	2nd-order heavy rainfall short delay
10	2009/ Morakot Ty	Shin-yi/ wang-mei	-	250mm	695.1mm	8/9 02:00	19hrs	30mm/ 3hrs	51.5 mm	2nd-order weak rainfall short delay
11	2009/ Morakot Ty	Shin-yi/ shen-mu	-	250mm	677.5mm	8/8 18:00	42hrs	30mm/ 13hrs	38.5 mm	1st-orderweak rainfall short delay
12	2009/ Morakot Ty	Shin-yi/ shen-mu	-	250mm	567.1mm	8/8 15:00	40hrs	30mm/ 12hrs	34.0 mm	1st-order heavy rainfall long delay
13	2009/ Morakot Ty	Shin-yi/ shen-mu	DF200	250mm	786.9mm	8/8 21:00	45hrs	40mm/ 4hrs	38.0 mm	1st-order heavy rainfall short delay
14	2011/ 07/19 / Heavy rain	Shin-yi/ shen-mu	DF226	250mm	97.6mm	7/18 23:00	2hrs	5mm/ 2hrs	14.0 mm	1st-order heavy rainfall short delay
15	2011/ 05/04 / Heavy rain	Shin-yi/ feng-chiu	DF190	250mm	121.4mm	5/3 16:00	5hrs	30mm/ 7hrs	38.5 mm	1st-order weak rainfall short delay
16	2012/ 06/10 / Heavy rain	Ren-ai/wan-feng	-	250mm	247.1mm	6/10 18:00	14hrs	20mm/ 7hrs	44.5 mm	2nd-order heavy rainfall short delay
17	2012/ 06/10 / Heavy rain	Shin-yi/shen-mu	DF190	250mm	434.8mm	6/11 18:00	39hrs	20mm/ 3hrs	18.5 mm	2nd-order weak rainfall short delay
18	2013/Soulik Ty	Yu-chih/ R-yue	DF202	350mm	194mm	7/13 07:00	10hrs	40mm/ 3hrs	73.5 mm	1st-order heavy rainfall short delay
19	2006/6/9/ Heavy rain	Shui-li/ shang-an	DF080	250mm	401.6mm	6/10 12:00	44hrs	5mm/ 1hrs	3.5 mm	2nd-order weak rainfall long delay

Table 2. Comparative analysis of the relationship between debris flow and precipitation in 14 Chiayi County debris flow disasters

NU	Hydrological Event Typhoon	Location	Debris flow	Warning value (mm)	Effective cumulative rainfall(mm)	Disaster occurrence time	Continuous heavy rainfall period	warning value/ rainfall delay	Intensity (I) (mm)	Rainfall pattern
1	2009/ Morakot_Ty	Mei-shan/ tai-ho	DF008	400mm	855.9mm	8/8 20:00	51hrs	40mm/ 6hrs	44 mm	2nd-order heavy rainfall short delay
2	2009/ Morakot_Ty	Mei-shan/ tai-ho	DF048	400mm	887.9mm	8/8 21:00	51hrs	40mm/ 5hrs	37 mm	2nd-order heavy rainfall short delay
3	2009/ Morakot_Ty	Mei-shan/ tai-ho	DF040	400mm	887.9mm	8/8 20:00	51hrs	40mm/ 6hrs	44 mm	2nd-order heavy rainfall short delay
4	2009/ Morakot_Ty	Alishan/ Cha-shan	-	250mm	855.9mm	8/8 17:00	45hrs	40mm/ 10hrs	59.5 mm	1st-order heavy rainfall long delay
5	2009/ Morakot_Ty	Alishan/ shan-mei	DF057	300mm	1062.3mm	8/8 02:00	30hrs	30mm/ 4hrs	36 mm	1st-order heavy rainfall short delay
6	2009/ Morakot_Ty	Da-bu/ jia-dung	DF053	450mm	589.8mm	8/8 03:00	31hrs	30mm/ 4hrs	33 mm	1st-order heavy rainfall short delay
7	2009/ Morakot_Ty	Mei-shan/ jia-dung	-	400mm	701.3mm	8/8 22:00	53hrs	40mm/ 8hrs	38 mm	2nd-order heavy rainfall short delay
8	2009/ Morakot_Ty	Jung-bu/ jung-luen	-	450mm	923.4mm	8/9 03:00	52hrs	40mm/ 14hrs	60 mm	1st-order heavy rainfall long delay
9	2009/ Morakot_Ty	Alishan/ li-jia	-	300mm	1498.6mm	8/9 01:00	54hrs	40mm/ 14hrs	71.5 mm	1st-order heavy rainfall long delay
10	2009/ Morakot_Ty	Alishan/ lai-chi	-	300mm	1347.7mm	8/9 06:00	55hrs	40mm/ 13hrs	24 mm	2nd-order heavy rainfall long delay
11	2009/ Morakot_Ty	Alishan/ lai-chi	DF042	300mm	1283.7mm	8/9 03:00	52hrs	40mm/ 11hrs	52 mm	2nd-order heavy rainfall long delay
12	2009/ Morakot_Ty	Alishan/ lai-chi	-	300mm	1347.7mm	8/9 06:00	56hrs	40mm/ 16hrs	24 mm	2nd-order heavy rainfall long delay
13	2002/6/10 Heavy rain	Alishan/ lai-chi	DF042	250mm	607mm	6/12 11:00	47hrs	25mm/ 10hrs	32.5 mm	2nd-order heavy rainfall long delay
14	2003/other	Alishan/ feng-shan	DF039	250mm	55.5mm	7/6 13:00	72hrs	25mm/ 10hrs	8.5 mm	2nd-weak rainfall long delay

RESULTS AND DISCUSSION

Precipitation Patterns

Precipitation Patterns in the Nantou Area

In this study, precipitation warning values greater than or equal to 30 mm are classified as heavy precipitation; values less than 30 mm are classified as mild precipitation. Durations of continuous precipitation greater or equal to 10 hours are classified as long duration, and durations less than 10 hours are classified as short durations. Table 1's comparative analysis on the relationship between the debris flow and precipitation for Nantou County's 19 previous debris flow were placed into eight categories (I, II, III, IV, V, VI, VII, VIII) and tallied as shown in detail in Table 3.

Table 3. Precipitation Pattern Classification Table in the Nantou Area

Level	Precipitation Warning Value	Precipitation Duration Before Debris flow	Category	Occurrences	NU
1	Heavy Precipitation ≧30 mm	Long Duration≧10 hr	I	3	9*, 11, 12
		Short Duration<10 hr	II	7	1, 2, 3*, 4, 13*, 15*, 18*
	Mild Precipitation <30 mm	Long Duration≧10 hr	III	0	–
		Short Duration<10 hr	IV	2	8, 14*
2	Heavy Precipitation ≧30 mm	Long Duration≧10 hr	V	0	–
		Short Duration<10 hr	VI	4	5*, 6, 10, 16
	Mild Precipitation <30 mm	Long Duration≧10 hr	VII	2	7, 19
		Short Duration<10 hr	VIII	1	17*

According to the classification results in Table 3 and disregarding Level 1 or Level 2, 14 out of 19 debris flow had heavy precipitation (73%), and the remaining five debris flow had mild precipitation (27%). This means that most of the debris flow occurred when precipitation was greater than or equal to 30mm. When precipitation duration before the debris flow is brought into the discussion, it can be seen that long duration (≧10 hr) heavy precipitation (≧30 mm) occurred three times (16%), while short duration (<10 hr) heavy precipitation (≧30 mm) occurred 11 times (58%), which proves that the Nantou area is more prone to debris flow when there is short duration (<10 hr) heavy precipitation (≧30 mm). As a result, disaster prevention measures in Nantou's mountainous areas should have inhabitants evacuating immediately when precipitation has achieved values (≧30 mm).

Using the most frequent occurrences for Levels 1 and 2 to explore the relationship between debris flow and precipitation, Level 1 short duration (<10 hr) heavy precipitation (≧30 mm) occurred seven times (36%), while Level 2 short duration (<10 hr) heavy precipitation (≧30 mm) occurred four times (21%). From a natural science perspective, the Level 2 graph has two peaks, which means that the chance of debris flows occurring is twice as likely as a Level 1. As the first peak's accumulated precipitation has reached a state of saturation, a debris flow will occur if precipitation continues after it briefly calms down. A possible reason for this is that when Level 1 precipitation pattern occurs in the Nantou area, oversaturation of accumulated precipitation can cause debris flow; when level precipitation patterns have reached saturation during the first peak and there is a buffer time before the next peak, a debris flow may occur due to the second peak reaching saturation as well.

It can be seen in Table 3 that numbers followed by an asterisk are potential debris flow torrents, and debris flow occurred at numbered debris flow torrents with heavy precipitation (≧30 mm) six times (75%) and short duration (<10 Hr) heavy precipitations occurred five out of six times (83%). The total number of Level 1 and 2 short duration heavy precipitation was 11 times, and heavy precipitation occurred at numbered torrents five times (83%), which proves that one out of every two occurrences of short duration (<10 hr) heavy precipitation (≧30 mm) may have a debris flow at a potential debris flow torrent.

Precipitation Patterns in the Chiayi Area

Table 2's comparative analysis on the relationship between debris flow and precipitation in Chiayi County is placed into eight categories (I, II, III, IV, V, VI, VII, VIII) and tallied as shown in detail in Table 4. In addition, it falls within the meaning of each precipitation pattern.

Table 4. Precipitation Pattern Classification Table in the Chiayi Area

Level	Precipitation Alert Value	Precipitation Duration Before Debris flow	Category	Occurrences	NU
1	Heavy Precipitation ≧30 mm	Long Duration≧10 hr	I	3	4, 8, 9
		Short Duration< 10 hr	II	2	5*, 6*
	Mild Precipitation <30 mm	Long Duration≧10 hr	III	1	14*
		Short Duration< 10 hr	IV	0	–
2	Heavy Precipitation ≧30 mm	Long Duration≧10 hr	V	3	10, 11*, 12
		Short Duration< 10 hr	VI	4	1*, 2*, 3*, 7
	Mild Precipitation <30 mm	Long Duration≧10 hr	VII	1	13*
		Short Duration< 10 hr	VIII	0	–

According to the classification results in Table 4 and disregarding Level 1 or Level 2, 12 out of 14 debris flows had heavy precipitation (86%), and the remaining two debris flow had mild precipitation (14%). This means that most of the debris flow occurred when precipitation was greater or equal to 30mm. When precipitation duration before the debris flow is brought into the discussion, it can be seen that long duration (≧10 hr) heavy precipitation (≧30 mm) occurred six times (43%), while short duration (<10 hr) heavy precipitation (≧30 mm) also occurred six times (43%), which proves that both types of precipitation can cause debris flow in the Chiayi area. As a result, disaster prevention measures in Chiayi's mountainous areas should have inhabitants evacuating immediately when precipitation has achieved values (≧30 mm).

It can be seen in the numbers from Table 4 that the numbered debris flow currents had six debris flow (75%) when there was heavy precipitation (≧30 mm), and debris flow happened during short duration (<10 hr) heavy precipitation five times (83%). The total number of Level 1 and 2 short duration heavy precipitation was six times, and heavy precipitation occurred at numbered torrents five times (83%), which proves that one out of every two short duration (<10 hr) heavy precipitations (≧30 mm) may have a debris flow occur at a potential debris flow torrent.

Comparison of Precipitation Patterns in the Nantou and Chiayi Areas

Looking at Tables 3 and 4 analyzing the precipitation patterns of the Nantou and Chiayi areas, the differences and total of the two areas were tallied and compared in detail in Table 5. In addition, the overall discussions of the areas' comparison results are as follows:

Table 5. Comparison Table of Precipitation Patterns in the Nantou and Chiayi Areas

Level	Precipitation Alert Value	Precipitation Duration Before Debris flow	Category	Occurrences in the Nantou Area	Occurrences in the Chiayi Area	Total Occurrences
1	Heavy Precipitation ≧30 mm	Long Duration≧10 hr	I	3	3	6
		Short Duration<10 hr	II	7	2	9
	Mild Precipitation <30 mm	Long Duration≧10 hr	III	0	1	1
		Short Duration<10 hr	IV	2	0	2
2	Heavy Precipitation ≧30 mm	Long Duration≧10 hr	V	0	3	3
		Short Duration<10 hr	VI	4	4	8
	Mild Precipitation <30 mm	Long Duration≧10 hr	VII	2	1	3
		Short Duration<10 hr	VIII	1	0	1

This study collected data from the Nantou and Chiayi areas. According to past major debris flow disaster reports by the Soil and Water Conservation Bureau, there have been 19 debris flow reports from the Nantou area and 14 debris flow reports from the Chiayi area, making a total of 33 documented debris flow reports. The results showed that the most significant occurrence patterns were: Level 1 short-duration heavy precipitation occurred nine times (27%), and Level 2 short-duration heavy precipitation occurred eight times (24%) for a total of 17 short-duration precipitations (51%). This is consistent with extreme climates as torrential rain in a short period of time causes disasters: debris flow during Level 1 long-duration mild precipitation and Level 2 short-duration mild precipitation only occurred two times (6%). A disaster prevention mechanism should be established in the future to prevent the occurrence of debris flow caused by heavy precipitation.

Taking out the three highest values in Table 5 comparing the precipitation patterns in the Nantou and Chiayi areas, the results show that Nantou area's three highest values are Level 1 long-duration (≧10 hr) heavy precipitation (≧30 mm), short-duration (<10 hr) heavy precipitation (≧30 mm), and Level 2 short-duration (<10 hr) heavy precipitation (≧30 mm); Chiayi area's three highest values are Level 1 long-duration (≧10 hr) heavy precipitation (≧30 mm), Level 2 long-duration (≧10 hr) heavy precipitation (≧30 mm), and Level 2 short-duration (<10 hr) heavy precipitation (≧30 mm). This proves that debris flow occur during heavy precipitation, and the difference in duration and peak height determines whether accumulated precipitation has achieved saturation or oversaturation. Oversaturation of precipitation will cause debris flow immediately, and saturation of precipitation will require one more peak of precipitation to reach oversaturation.

The distribution of the potential debris flow torrents' precipitation patterns explored in Tables 3 and 4 found that numbered debris flow in the Nantou area and the Chiayi area with heavy precipitation (≧30 mm) happened six times (75%), with five of them being short-duration (<10 hr) precipitations (83%). As the total for Level 1 and Level short-duration precipitations was different, both Levels had debris flow occurring once out of every two short-duration (<10 hr) heavy precipitations (≧30 mm) at a potential debris flow torrent. Therefore, residents living near numbered debris flow should be on higher alert compared to other mountainous residents to keep themselves safe.

The probability of debris flow occurring discussed using Level 1 and 2 graphs shows that debris flow can easily occur during long durations, whether with heavy precipitation (≧30 mm) or mild precipitation (<30 mm). Precipitation that continuously rises by the hour can easily become a Level 1 precipitation pattern, therefore evacuation and disaster prevention procedures should be carried out as soon as possible to prevent casualties. In Level 2 graphs, the key value to look at is the accumulated precipitation in the first peak: as long as saturation is achieved during short-duration (<10 hr) or long-duration (≧10 hr) precipitations, people should be wary of a possible debris flow.

CONCLUSIONS AND RECOMMENDATIONS

The most significant precipitation patterns found in this study are: Level 1 short-duration heavy precipitation and Level 2 short-duration heavy precipitation had 17 debris flow (52%), which is consistent with today's extreme climate as torrential rain in a short period of time can cause disasters. Mild precipitation is divided into two lesser-occurring types: Level 1 long-duration mild precipitation and Level 2 short-duration mild precipitation only happened two times (6%). A disaster prevention mechanism should be established in the future to prevent the occurrence of debris flow caused by heavy precipitation.

This study explores the occurrence probability of debris flow and Level 1 graphs show that debris flow easily occur regardless of heavy (≧30 mm) or mild (<30 mm) precipitation. Precipitation that continuously rises by the hour can easily become a Level 1 precipitation pattern, therefore evacuation and disaster prevention measures should be carried out immediately to prevent casualties. In Level 2 graphs, the key value to look at is the accumulated precipitation in the first peak: as long as saturation is achieved during short-duration (<10 hr) or long-duration (≧10 hr) precipitations, people should be wary of a possible debris flow.

Only 33 pieces of data from two areas were explored in this study and if there is a requirement for more accurate conclusions, more data must be included to achieve better results and sufficient reliability. On the other hand, it is plausible to screen multiple pieces of data regionally to understand precipitation patterns, which aids in the establishment of standards for different areas.

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