Disasters Caused by Typhoon Morakot in Taiwan and the Renovation Strategy

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Abstract

The purpose of this paper is to provide the information of disasters caused by Typhoon Morakot in Taiwan and the corresponding renovation strategy. The torrential rainfall is regarded as the main cause of the disasters and hence the information of the torrential rainfall is first given in this paper. The isohyets of cumulative rainfall depth are prepared. Storm centers can be found in the isohyets. The storm centers have important meanings to disasters resulted from Typhoon Morakot, because many severe disasters occurred around the storm centers or in the downstream areas of the storm centers. Disasters induced by Typhoon Morakot include floods, landslides, landslide dams, driftwoods, and disruptions of water supply. Some of these disasters occurred simultaneously or consecutively in one place. Such disasters are defined as the compound hazard in this paper. Current warning systems for single disasters are perhaps not sufficient to handle the compound hazard. It is suggested that we need to develop a new system to early issue warnings for the compound hazard. A systematic methodology to plan the strategies to renovate the watersheds damaged during the period of Typhoon Morakot is also provided herein. The diagnosis of the problems of the damaged watersheds is the first step of the proposed methodology. From the result of the diagnosis, three factors are extracted. These three factors are used to classify the damaged watersheds into different classes. Furthermore, the regular inspection of the implementation of the strategies is suggested as a part of the proposed methodology. The strategies provide effective and efficient guidelines to allocate the limited resources to renovate the damaged watersheds during the period of Typhoon Morakot.

Keywords: Typhoon Morakot, Compound hazard, rainfall, flood, sediment-related disasters

1. Genesis of Typhoon Morakot

A tropical depression formed on the sea 1,000 km northeast to Philippines on August 2, 2009. It then turned into a typhoon on August 4, 2009 and was named as Morakot. Typhoon Morakot slowly moved westward toward Taiwan. The track of Typhoon Morakot is depicted Fig. 1 (Shieh et al., 2009; Unisys weather, 2009). The intensity of Typhoon Morakot was once equivalent to that of a Category 2 hurricane on the Saffir-Simpson

Hurricane Scale, with maximum wind speed of 85 knots. From August 7, 2009, the storm circle of Typhoon Morakot affected Taiwan. At 17:00 on August 7, 2009, Taiwan was covered within the storm circle of Typhoon Morakot. The location of the landfall of Typhoon Morakot was in the vicinity of the Hualien city located in the eastern Taiwan at 23:50 on August 7, 2009. The intensity of Typhoon Morakot gradually decreased when it moved across the Central Mountains of Taiwan. The storm circle of Typhoon Morakot left Taiwan at around 18:30 on August 9, 2009. It then turned northward and entered China. Typhoon Morakot weakened to a tropical depression on August 11, 2009 in China.

For Taiwan, Typhoon Morakot is probably the deadliest typhoon over the past fifty years. The purpose of this paper is thus to provide an overview of disasters resulted from Typhoon Morakot in Taiwan. Different kinds of disasters which include flood, landslides, landslide dams, driftwoods, and water supply disruptions, occurred during the period of Typhoon Morakot. Some of these disasters occurred almost concurrently in certain places. Such disasters are defined as the compound hazard in this paper. In the following sections, the characteristics of the heavy rainfall are first described. Then disasters, which are the flood, the sediment-related disasters, and the driftwoods, are explained. An example of the compound hazard is also described in this paper. A planning of renovation strategy to alleviate the loss of the damaged watersheds is given this paper.

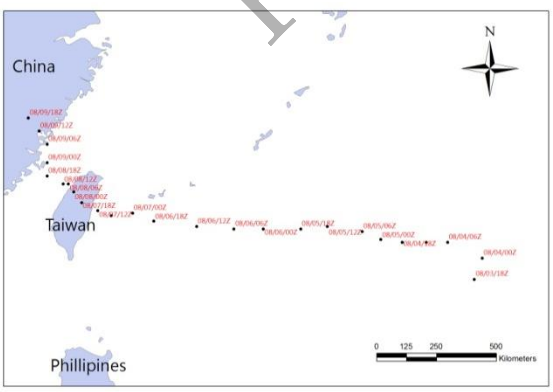

Fig. 1 Path of the center of Typhoon Morakot

2. Rainfall characteristics

2.1 Depth, duration and intensity

A critical feature of Typhoon Morakot is the rainfall. The rainfall record during the period of Typhoon Morakot which was observed at the rain gauge Yuyushan is collected. The record shows that it rained continuously from August 6, 2009 to August 10, 2009. The hyetograph is drawn in Fig. 1. The duration of the rainfall recorded at gauge Yuyushan is 91 hours and the value of the accumulated rainfall depth is 2,583 mm.

Six hyetographs are compared to the hyetograph which was recorded at rain gauge Yuyushan during the period of Typhoon Morakot (Fig. 2). The hyetograph of Typhoon Isewan, which struck Japan in 1959, is also compared. The selection of the comparative hyetographs is based on two criteria. The first criterion, denoted as Criterion 1 herein, is based on the maximum accumulated rainfall depth. The record of rain gauge where the maximum accumulated rainfall depth was observed is selected. Four hyetographs are selected in accordance with Criterion 1. These hyetographs were recorded during the periods of Typhoons, Kalmaegi, Toraji, Herb, and Isewan. The second criterion (Criterion 2) for selecting hyetographs is based on remarkable disasters. For example, the hyetograph for Typhoon Aere is selected from the rain gauge adjacent to a severe landslide occurred at Taoshan village, Hsinchu County, Taiwan. Fifteen persons were killed by the landslide. The other hyetograph for Typhoon Winnie is also selected according to Criterion 2.

It can be observed from Fig. 2 that the duration of the rainfall during Typhoon Morakot is significantly longer than those of other typhoons. The accumulated rainfall depth of Typhoon Morakot is far larger than that of others as well (Fig. 3). The intensity-duration curves corresponding to the seven hyetographs are depicted in Fig. 4. Fig. 4 shows that the peak of rainfall of Typhoon Morakot is not the largest. The largest peak of rainfall is found in the hyetograph of Typhoon Kalmaegi. The second large peak of rainfall is in the hyetograph of Typhoon Herb.

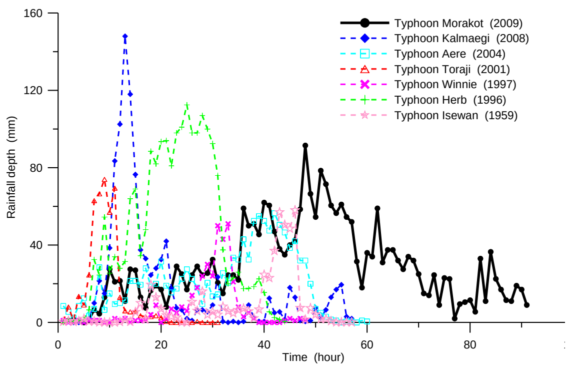

Fig. 2 Comparison of hyetographs of seven typhoons

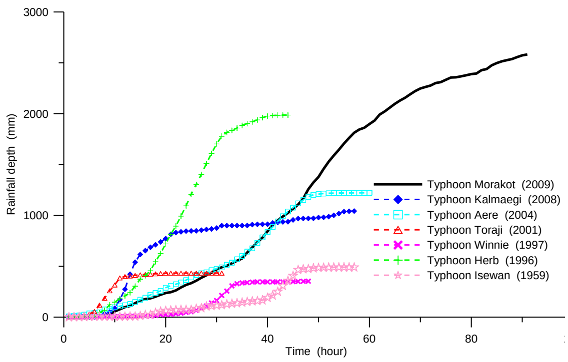

Fig. 3 Comparison of curves of the accumulated rainfall depth of seven typhoons

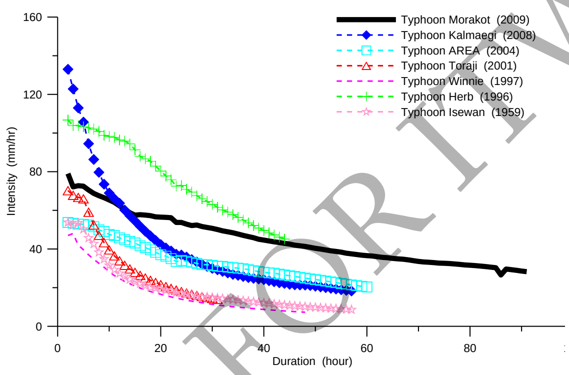

Fig. 4 Intensity-duration curves for the selected hyetographs

2.2 Isohyet

The isohyets of cumulative rainfall depth for Taiwan during Typhoon Morakot are depicted in Fig. 5. From Fig. 5, it can be found that the heavy rainfall covered whole Taiwan during Typhoon Morakot. Therefore, it is said that one characteristics of the rainfall of Typhoon Morakot is large-extent.

Storm centers can be observed in the southern area of Taiwan from Fig. 5. The locations of the storm centers have strong connections with the disasters. Most of severe disasters, including landslides and landslide dams, occurred surrounding the storm centers. Flood occurred in the downstream areas of the storm centers as well.

Fig. 5 Isohyets of Taiwan during Typhoon Morakot. Isohyets are in mm depth of total rainfall

2.3 Frequency analysis

In Taiwan, the design of water resource systems is based on the frequency analysis of rainfall. The design level of major rivers is different from that of minor rivers. For major rivers, the design level is determined using the design storm for 200-year return period; for minor rivers, the design level is determined using the design storm for 50-year return period. Once the loading of a system exceeds its capacity, which is determined by the design level, the system may fails.

The frequency analysis of the cumulative rainfall depths of 24-hour, 48-hour, and 72-hour for many rain gauges during Typhoon Morakot is given in Table 1 (Water resource agency, 2009). It can be seen that the return periods of many cumulative rainfall depths during Typhoon Morakot exceed 200 years. Some of the return periods are even more than 2,000 years. Most of these cumulative rainfall depths were observed at the rain gauges that were around the storm centers. Therefore, during Typhoon Morakot the loadings of many water resource systems might exceed their capacities. The failures of these systems caused disaster.

Table 1 Result of frequency analysis

Rain gague	Duration (hour)					
	24		48		72	
	Observed rainfall depth (mm)	Return Period (year)	Observed rainfall depth (mm)	Return Period (year)	Observed rainfall depth (mm)	Return Period (year)
Alisan	1624	> 2000	2361	> 2000	2748	> 2000
Dadonsan	759	> 2000	1181	> 2000	1467	> 2000
Tsengwen	1089	489	1644	> 2000	1914	> 2000
Mucha	828	> 2000	1105	> 2000	1191	> 2000
Wueiliaosan	1415	> 2000	2216	> 2000	2564	> 2000
Chiasen	1078	> 2000	1601	> 2000	1856	> 2000

3. Disasters

3.1 Flood

During Typhoon Morakot, the torrential rainfall mainly fell on the areas around the storm centers and hence the corresponding downstream areas were flooded. As shown in Fig. 6, the blue-shaded areas are the flooded areas during Typhoon Morakot. These areas are in the downstream of the storm centers. The downstream areas of two watersheds, which are the Tsengwen River watershed and the Kaoping River watershed, were severely damaged by the flood. The cause of the flood is that the loadings of flood-prevention systems are greatly larger than their capacities. The loadings came from the torrential rainfall.

3.2 Landslides

During Typhoon Morakot, the torrential rainfall induced many landslides all over Taiwan. One notorious landslide is the one that occurred in Siaolin village. Over four hundred people were killed by the landslide. The location of the deadly landslide was close to the storm centers. The cumulative rainfall depth that was observed in a rain gauge near the landslide is 2,583 mm with the duration of 91 hours.

Landslides, which occurred during Typhoon Morakot, are recognized using satellite imageries. The result of the recognition is overlaid with the isohyets of cumulative rainfall depth (Fig. 7). It can be observed that numerous landslides occurred within the regions where the cumulative rainfall depths are more than 800 mm.

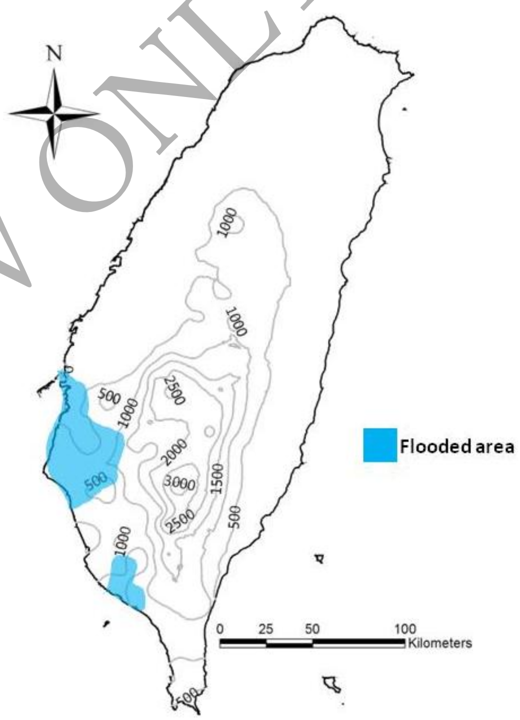

Fig. 6 Flooded area

The landslide rate l in this paper is defined as:

$$l = \frac{A_L^r}{A^r} \tag{1}$$

where A_L^r is the area of landslides within a region r; A_r is the area of the region r. The region r indicates a region within which the observed cumulative rainfall depths are in a specific interval.

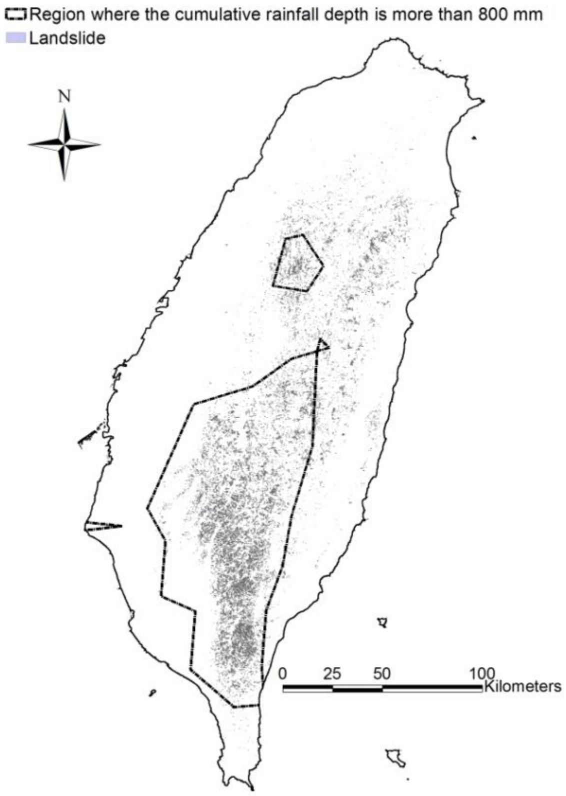

Fig. 7 Landslides within regions where the cumulative rainfall depths are more than 800 mm.

The landslide rates for regions of different cumulative rainfall depth intervals are drawn in Fig. 8. The triangles in Fig. 8 represent the landslide rates for the newly-added landslides which occurred during Typhoon Morakot. The circles represent the landslide rates for the enlarged landslides which had occurred before Typhoon Morakot and were enlarged during Typhoon Morakot. The squares are the summation of the newly-added and the enlarged landslide rates.

From Fig. 8, it can be observed that the landslide rates increase with the increasing of cumulative rainfall depth. Moreover, the newly-added landslide rates are generally larger than the enlarged landslide rates. This fact indicates that the area of the newly-added landslides during Typhoon Morakot is larger than that of the existing landslides. This phenomenon may cause more sediment yield from the slopes of landslides after Typhoon Morakot than that before Typhoon Morakot.

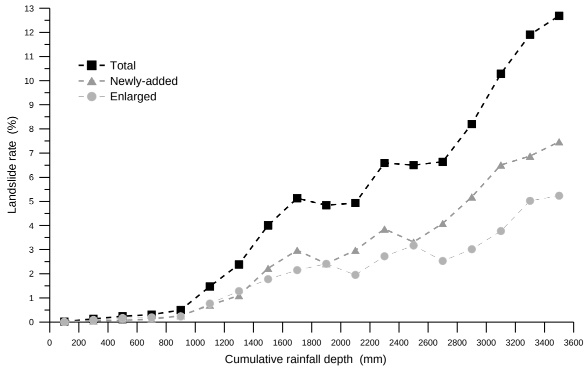

Fig. 8 Landslide rates in regions of different cumulative rainfall depth intervals

3.3 Landslide dams

Fifteen landslide dams formed during Typhoon Morakot. They were observed using the satellite imageries. The locations of the fifteen landslide dams are illustrated in Fig. 9. Most of these fifteen landslide dams spread around the storm centers. Some of them are located in the downstream areas of the storm centers. Fig. 10 is obtained by comparing the locations of the landslide dams with the isohyets. Twelve landslide dams formed in the regions within which the cumulative rainfall depths are between 1,000 mm and 2,500 mm.

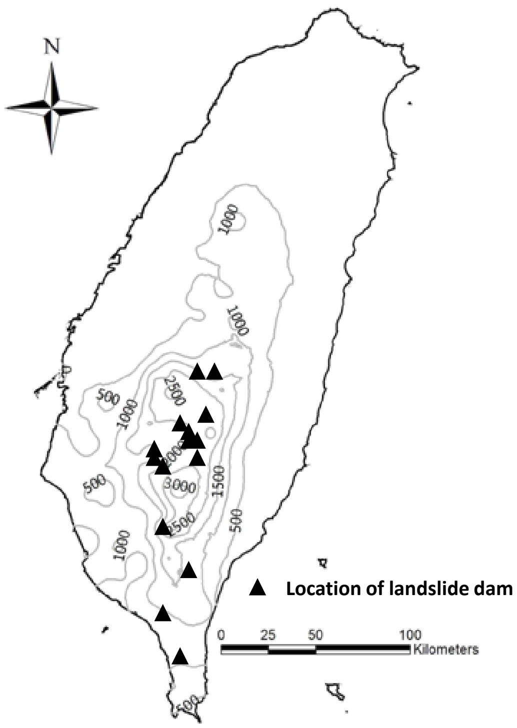

Fig. 9 Locations of landslide dams formed during Typhoon Morakot.

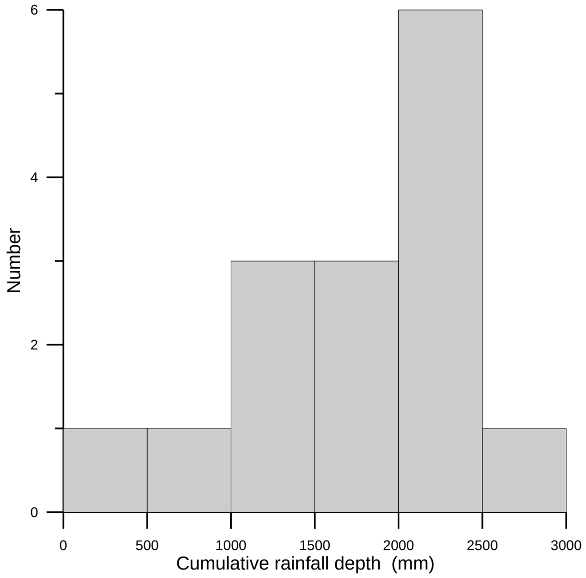

Fig. 10 Number of landslide dams occurred in regions where the cumulative rainfall is different.

3.4 Turbid water

During Typhoon Morakot, the turbid water was observed in reservoirs. The water treatment plant of the Nanhua reservoir is capable of handling the water whose turbidity measured in nephelometric turbidity units (NTU) is no more than 100 NTU. The turbidity of water in the Nanhua reservoir measured in NTU is given in Fig. 11. It can be seen that the turbidity of water was not less than 100 NTU until August 14, 2009. Therefore, the water supply of the Nanhua reservoir ceased for almost one week.

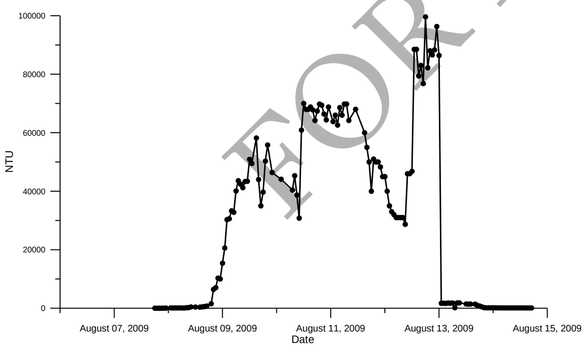

Fig. 11 Time series of the turbidity measured in nephelometric turbidity units (NTU) in the Nanhua reservoir during Typhoon Morakot

3.5 Driftwoods

Driftwoods are one source of damages to various facilities, such as bridges, levees, and dams. Driftwoods may collide with these facilities, and may cause disablement of them. Driftwoods in river channels may obstruct the water flow and may raise the water level of flood. The increased water level enlarges the damage of flood.

After Typhoon Morakot, many bare lands and landslides can be observed from the satellite imageries. This implies that the vegetation at these places was destroyed during Typhoon Morakot. The resulted driftwoods rolled down river channels or were probably moved to river channels by the strong surface runoff. Then the driftwoods in the river channels were flushed downstream to the sea or stopped by dams, bridges and other facilities.

From our field investigation, the driftwoods were observed in the downstream areas of the storm centers. For example, Fig. 12 shows the driftwoods observed in the Tsengwen reservoir.

Fig. 12 Driftwoods in the Tsengwen reservoir

4. The compound hazard

As aforementioned, a landslide occurred in Siaolin village caused casualties of over four hundred people. In fact, various disasters occurred almost simultaneously in Siaolin village. This is an example of the compound hazard.

Disasters occurred in Siaolin village included a debris flow, a landslide, a landslide dam, and the break of the landslide dam. The break of the landslide dam induced a flash flood as well. A simplified map of Siaolin village is drawn in Fig. 13 for readers to understand the compound hazard.

The incremental and accumulated hyetographs observed at the rain gauge Yuyushan near Siaolin village is drawn in Fig. 14. Important events and the corresponding cumulative rainfall depths are also listed in Fig. 14.

The first event is the shallow landslide followed by a debris flow. The bridge #8 (see Fig. 13) was destroyed by the debris flow. At about 6:00 on August 9, 2009, the landslide occurred when the cumulative rainfall depth was 2,023 mm. The landslide then caused a landslide dam and the landslide dam broke soon. A flash flood which was accompanied with the break of the landslide dam occurred immediately.

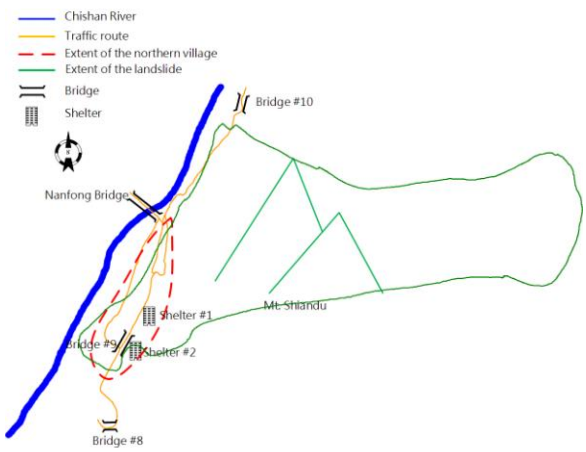

Fig. 13 A simplified map of Siaolin village

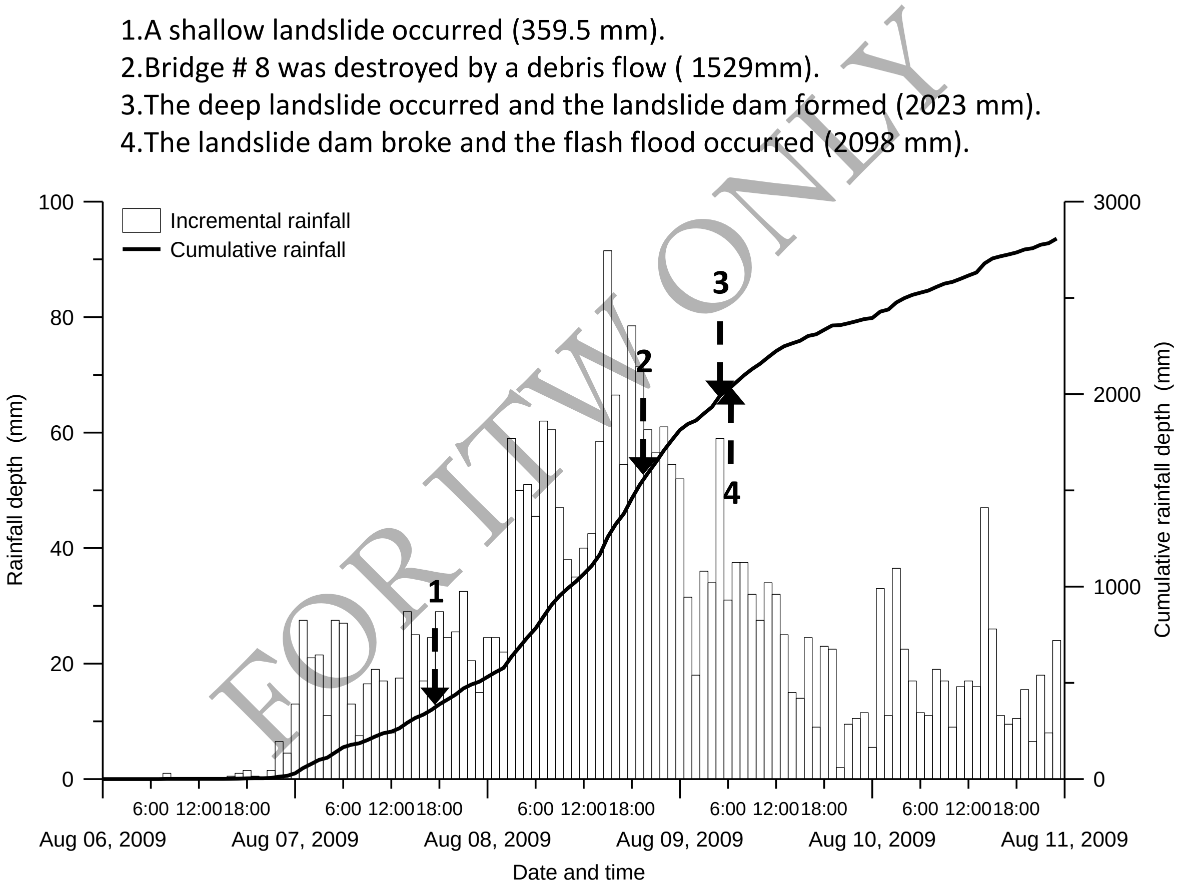

Fig. 14 Incremental and accumulated rainfall hyetograph of the rain gauge Yuyushan

5. Planning of countermeasures

Disasters caused by Typhoon Morakot have four features. The first is that disasters spread over a very large region. The second is that, as aforementioned, types of disasters were numerous. Therefore, the methods for managing these disasters are diverse. The third is that magnitudes of the disasters were large. Difficulties for managing these disasters are then raised. The fourth is that the aftermath of these disasters will last for a long time as that of the earthquake 921 in Taiwan. As a result, secondary disasters will easily occur in the future.

In the past of Taiwan, the countermeasures against a disaster are often planned by considering the disaster itself only. That is the interaction between the countermeasures and the environment is usually not considered. However, due to the four features of the disasters caused by Typhoon Morakot, the past thought is not applicable to the disasters. A more complete thought to effectively to manage the disasters caused by Typhoon Morakot is hence needed. The available resources for managing disasters are limited as well. An efficient allocation of the resources is also necessary for renovating the disasters.

5.1 Involved factors

Since the characteristics of disasters within different watersheds are different, an appropriate classification for the watersheds is necessary for planning the strategies. One class responds to one strategy. Three factors that are the damage cost ratio of protected objects, the landslide rate, and the variation of riverbed serve as the basis for the ensuing classification.

5.2 Classification

Watersheds are classified using the three factors. Each factor is then divided into three grades as shown in Table 2. It should be noted that in general the damage cost ratio is considered based on the casualties and the loss of property. One grade represents a severity degree of the corresponding factor. For convenience, each grade of a factor is denoted by a specific symbol as given Table 2.

Table 2 Grades of the three factors used to classify watersheds

Factor	Severity		
	Low	Medium	High
Damage cost ratio of village	III	II	I
Landslide rate	c	b	a
Variation of riverbed	C	B	A

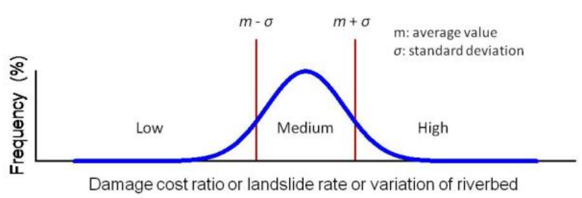

Fig. 15 Definition of the severity of the three factors

The severity of the three factors is determined using the concept given in Fig. 1. As shown in Fig. 1, the occurrence frequency versus the corresponding quantity of one of the three factors is plotted. The average value and the standard deviation can then be calculated. The first grade of severity is within the interval where the quantity is less than the average value minus a standard deviation. The second grade is within the interval where the quantity is between the value of the average value minus a standard deviation and the average value plus a standard deviation.

A watershed can be symbolized by a token that consecutively combines the symbols of the three factors. For example, a watershed, whose damage cost ratio of village is high, landslide rate is medium, and variation of riverbed is medium, is symbolized as IbB; a watershed, whose damage of protected object is low, landslide rate is high, and variation of riverbed is high, is symbolized as IIIaA, and so on. In summary, there are 27 combinations of the symbols.

The classification of watersheds is performed based on the damage cost ratio. In this paper, it is considered that the priority of the damage cost ratio is the first, because it concerns the safety of inhabitants. The watersheds are classified into three classes as given in Table 3. Members of each class are also given in Table 3. However, some of the members are invalid and are removed. For example, IIIaA is an impossible entity. The entity IIIaA's damage cost ratio is low, implying that the watershed was slightly damaged and no people was killed, but the landslide rate is high and the variation of riverbed is high. Such an entity does not exist.

Table 3 Classification of watersheds

Class	Symbol	Number of valid members
1	IaA, IaB, IaC, IbA, IbB, ~~IbC~~, IcA, ~~IcB~~, ~~IcC~~	6
2	~~IIaA~~, IIaB, IIaC, IIbA, IIbB, IIbC, IIcA, IIcB, ~~IIcC~~	7
3	~~IIIaA~~, IIIaB, IIIaC, IIIbA, IIIbB, IIIbC, IIIcA, IIIcB, IIIcC	8

5.3 Strategy

A watershed of class 1 is considered the serveliest damaged, because there were many casualties. Obviously, the most important point for a watershed of class 1 is the safety of the inhabitants. It is decided in this paper that a watershed of class 1 is impossible to be recovered using construction. Further development of the land should be prohibited until the land gets stable. Therefore, the strategy for renovating these watersheds is to move the inhabitants to safe places and to monitor the subsequent changes as given in Table 3.

Watersheds of classes 2 and 3 are considered possibly to be recovered respectively using concrete construction and ecological engineering methods. All renovation principals for different targets are listed in Table 4. For a watershed of class 1, the inhabitants must be moved to a safe place. The landslide and river are renovated using the natural regeneration. Because the damage is too large to be recovered, no construction is suggested. For a watershed of class 2, reconstruction is suggested for villages; landslide engineering is suggested for landslides and river engineering is suggested for rivers. For a watershed of class 3, grant is given to villagers to repair the village; for landslides and rivers, the artificial regeneration, such as vegetation planting and migration of species, is suggested.

Table 4 Renovation principals for watersheds of each class

Class	Village	Landslide area	River
1	Migration	Natural regeneration	Natural regeneration
2	Reconstruction	Landslide engineering	River engineering
3	Repaired with grant-in-aid	Artificial regeneration	Artificial regeneration

6. Conclusions

The torrential rainfall played an important role during Typhoon Morakot. As aforementioned, disasters of different types occurred around the storm centers or in the downstream areas of the storm centers. In addition, compound hazards occurred in Taiwan during Typhoon Morakot. The disasters occurred in Siaolin village is one example of the compound hazard.

Compound hazards, such as the ones occurred during Typhoon Morakot, are often inevitable. One possible way to alleviate the loss of the compound hazard is to use the early warning system. However, at present the warning system is often specialized for single hazards and is not sufficient to deal with the compound hazard. It is suggested that we have to develop an early warning system for the compound hazard.

Typhoon Morakot significantly affected Taiwan. Various disasters occurred over a very large area. It is expected that the aftermath of theses disasters will last for a long time. Therefore a systematically way to plan the strategies to renovate the damaged watersheds is of great demand. The strategies provide guidelines to effectively and efficiently allocate limited resources for the renovation. In this paper, a methodology to plan the strategies is proposed. The regular inspection of the implementation of the strategies is considered the key of the proposed methodology. It is hoped that the damaged environment can be recovered by the proposed methodology.

References

Unisys Weather (2009), http://weather.unisys.com/hurricane/w_pacific/2009/MORAKOT/track.dat.

Shieh C.L., Wang C.M., Lai W.C., Tsang Y.C., Lee S.P. (2009): The composite hazard resulted from Typhoon Morakot in Taiwan, Journal of the Japan Society of Erosion Control Engineering, Vol. 62, No.4, pp. 61-65.

Shieh C.L., Wang C.M., Chen Y.S., Tsai Y.J., Zeng W.S. An overview of disasters resulted from Typhoon Morakot in Taiwan, Journal of disaster research (accepted)

Water resource agency, Ministry of economic affairs, Taiwan, (2009): Dreading and restoration after Typhoon Morakot, Water resource agency, Ministry of economic affairs, Taiwan (in Chinese).