Natural Hazards caused by Typhoon Morakot in Taiwan

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1. Natural Hazards in Asia
2. Typhoon Morakot
3. Disasters of Typhoon Morakot
4. Disasters Characteristics
5. Compound Disasters
6. Face the Challenge
7. Renovation strategy
8. Time scale consideration
9. Importance Evaluation of Villages
10. Simulation Model
11. Conclusions
1. Natural Hazards in Asia

- **Japan**
  - Nairiku Earthquake, 2008

- **Taiwan**
  - Chi-Chi Earthquake, 1999
  - Typhoon Morakot, 2009

- **Philippines**
  - Storm Flooding, 2009

- **Thailand**
  - South-Asia Tsunami, 2004

- **Malaysia**
  - South-Asia Tsunami, 2004
  - Storm Flooding, 2006, 2007
  - Debris Flow, 2008

- **India**
  - Debris Flow, 2007

- **Indonesia**
  - South-Asia Tsunami, 2004

Figure from “www.ooopic.com”
Storm Flooding in Philippines, 2009

Pictures from CNN.com

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Tsunami in Malaysia, 2004

Pictures from Associated Press
Tsunami in Thailand, 2004

Pictures from Associated Press
Global climate prediction by IPCC (2007)

- Catastrophic heavy rainfall > 90%
- Extreme Drought > 66%
- Extreme weather events will appear frequently and broadly in future years
  - Heat wave
  - Drought
  - Heavy storm
  - Typhoon

Hurricane Katrina (data from wiki)
Rainfall Change & Related Disasters

Rainfall
Intensity
(I, mm/hr)

Accumulative
Rainfall
(R, mm/Storm)

Type A (R < 1000, I > 100)
- Shallow Landslide
- Debris Flow
- Flooding

Type B (R ≥ 1000, I ≥ 100)
- Compound Disasters

Type C (R > 1000, I < 100)
- Deep Landslide
- Landslide Dam

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During 1991 ~ 2000
- Averagely 3.3 typhoons stroke Taiwan in one year (Tsuang et al., 1996)

After 2000
- It increased from 3.3 to 5.7 typhoons in one year (Tu et al., 2009)
Path of the center of Typhoon Morakot

- On August 2, 2009 a tropical depression formed on the sea, northwest to Philippines.
- It strengthened gradually into a tropic storm and was named Morakot.
- The storm turned into a typhoon on August 5.
- It started raining on Aug 6, 2009 in Taiwan.
- The eye of the typhoon left Taiwan from Taoyuan at 14:00 on August 8, 2009.

Typhoon Morakot made its landfall on at 23:50 on August 7, 2009.

The track data is from the UniSys Weather (2009).

At the rain gauge Yuyushan, the record shows that it rained continuously from August 6, 2009 to August 10, 2009.

The duration is 91 hours.
The comparison reveals that the rainfall intensity of Typhoon Morakot remained high for 91 hours.

The maximum intensity was 123 mm/hour at Alishan.
The accumulated rainfall depth of Typhoon Morakot is far larger than that of others. The largest accumulated rainfall depth was observed 3,079 mm at Alishan.
Rainfall data is compared with the world’s greatest observed point rainfalls (WMO, 1994).

Cumulative rainfall depths for 24-hour, 48-hour and 72-hour are close the world’s greatest observed point rainfalls.
Most of Taiwan was covered under the heavy rainfall.

Two storm centers can be found in the Isohyet.

The values of accumulated rainfall depth at these two points reached 3,000 mm.

One-fifth of Taiwan was covered.
Summary of Rainfall Characteristics

- Long duration (91 hours)
- High intensity (123 mm/hour)
- Large accumulated rainfall depth (3,000 mm-72 hour)
- Broad extent (1/5 of Taiwan was covered)
3.1 Spatial Distribution of Hazard locations

1. Geo-hazards in the mountains located within the range of precipitation > 1,000mm

2. Precipitation > 2,000mm: the most serious area

3. Most floods located at the downstream of rainfall center (Chiayi, Tainan, Kaoshiung & Pingdong Counties)
3.2 Disasters in Mountainous Area

1. Landslide
   ① Rapidly, Directly strike the villages
   ② Breakage of the lifeline
   ③ Provide the sediments for triggering subsequent movement
   ④ Natural Dam

2. Debris Flow
   ① Strike the villages
   ② Breakage of the lifeline

3. Natural Dam (& Breach)
   ① High-concentration flow (debris flow)
   ② Flood in the downstream
3.2 Disasters in Mountainous Area

Example for Shinkai (新開) Village

32 killed at this area

Rainfall (mm/hr)

Landslide period

I = 98 mm/hr
R = 2342 mm

新發雨量站

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### 3.2 Disasters in Mountainous Area (Landslide Area)

<table>
<thead>
<tr>
<th>Basin</th>
<th>Before Morakot</th>
<th>After Morakot</th>
<th>New Counts</th>
<th>Enlarged Area</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Count</td>
<td>Area (ha)</td>
<td>Count</td>
<td>Area (ha)</td>
</tr>
<tr>
<td>曾文溪</td>
<td>607</td>
<td>820</td>
<td>2,576</td>
<td>3,868</td>
</tr>
<tr>
<td>八掌溪</td>
<td>26</td>
<td>65</td>
<td>71</td>
<td>123</td>
</tr>
<tr>
<td>高屏溪</td>
<td>3,335</td>
<td>3,993</td>
<td>14,765</td>
<td>22,667</td>
</tr>
<tr>
<td>銀濃溪</td>
<td>1,853</td>
<td>2,464</td>
<td>7,864</td>
<td>11,075</td>
</tr>
<tr>
<td>旗山溪</td>
<td>641</td>
<td>638</td>
<td>3,406</td>
<td>6,021</td>
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<td>隘寮溪</td>
<td>841</td>
<td>891</td>
<td>3,495</td>
<td>5,571</td>
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<td>台東沿海</td>
<td>853</td>
<td>1,064</td>
<td>5,480</td>
<td>9,136</td>
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<td>林邊溪</td>
<td>167</td>
<td>218</td>
<td>415</td>
<td>1,853</td>
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<tr>
<td>濁水溪</td>
<td>3,717</td>
<td>5,652</td>
<td>10,579</td>
<td>13,657</td>
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<tr>
<td><strong>Total</strong></td>
<td>8705</td>
<td>11812.18</td>
<td>33886</td>
<td>51304</td>
</tr>
</tbody>
</table>

1*. Data collect from Forestry Bureau, Central Geological Survey & DPRC

2*. The results were just for urgent relieving disaster & needed advanced check
3.2 Disasters in Mountainous Area (Debris Flow)

Example for Nagisalu (南沙魯) Village

26 killed by the debris flow

I = 88 mm/hr
R = 2074 mm

甲仙雨量站

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3.2 Disasters in Mountainous Area (Debris Flow)
3.2 Disasters in Mountainous Area (Debris Flow)
3.2 Disasters in Mountainous Area (Landslide Dam)
3.2 Disasters in Mountainous Area (Landslide Dam)
3.3 Disasters in Plain Area

1. **Insufficient Drainage System**
   - Appearance at most locations due to heavy rainfall
   - Local area with small scale

2. **Levee Brake**
   - Rapidly over bigger living area
   - Fine deposits

3. **Levee Overflow**
   - Nearby river area
   - Fine deposits

4. **Drift Woods**
3.3 Disasters in Plain Area (Bridge Break)

- 雙園大橋 (Swan-Uen Bridge)
- 高屏溪 (Kaoping River)
- Break Length 459m
- 6 persons missing (at least)
3.3 Disasters in Plain Area (Levee Breach)
3.3 Disasters in Plain Area (Inundation)
# 3.4 Damages

<table>
<thead>
<tr>
<th>County</th>
<th>Death Confirmed</th>
<th>Not Confirmed</th>
<th>Missing</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Major Hazard Area</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>屏東縣</td>
<td>28</td>
<td>6</td>
<td>14</td>
<td>48</td>
</tr>
<tr>
<td>高雄縣</td>
<td>491</td>
<td>66</td>
<td>38</td>
<td>595</td>
</tr>
<tr>
<td>臺南縣</td>
<td>25</td>
<td></td>
<td></td>
<td>25</td>
</tr>
<tr>
<td>嘉義縣</td>
<td>17</td>
<td>1</td>
<td>2</td>
<td>20</td>
</tr>
<tr>
<td>臺東縣</td>
<td></td>
<td></td>
<td>7</td>
<td>7</td>
</tr>
<tr>
<td>南投縣</td>
<td>11</td>
<td></td>
<td>5</td>
<td>16</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>572</td>
<td>73</td>
<td>66</td>
<td>711</td>
</tr>
<tr>
<td><strong>The Other Area</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>高雄市</td>
<td>10</td>
<td></td>
<td>2</td>
<td>12</td>
</tr>
<tr>
<td>臺北縣</td>
<td>9</td>
<td>1</td>
<td>1</td>
<td>11</td>
</tr>
<tr>
<td>基隆市</td>
<td></td>
<td></td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>臺中市</td>
<td>2</td>
<td></td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>臺南市</td>
<td>6</td>
<td></td>
<td>4</td>
<td>10</td>
</tr>
<tr>
<td>苗栗縣</td>
<td>1</td>
<td></td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>臺中縣</td>
<td>7</td>
<td></td>
<td></td>
<td>7</td>
</tr>
<tr>
<td>彰化縣</td>
<td>6</td>
<td></td>
<td></td>
<td>6</td>
</tr>
<tr>
<td>雲林縣</td>
<td>3</td>
<td></td>
<td></td>
<td>3</td>
</tr>
<tr>
<td>連江縣</td>
<td>1</td>
<td></td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>新竹縣</td>
<td>1</td>
<td></td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>臺北市</td>
<td>1</td>
<td></td>
<td></td>
<td>1</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>47</td>
<td>1</td>
<td>10</td>
<td>58</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>619</td>
<td>74</td>
<td>76</td>
<td>769</td>
</tr>
</tbody>
</table>
4. Disaster Characteristics

- Disasters spread over a very large region (Over 5,000 km²)
- Large amount of sediment yield and movement (1.2 billion m³)
- Disasters were compounded
- Secondary disasters will easily and continuously occur in the future (10 to 20 years)
- Such kind of disasters need a new Methodology to Make Renovation Strategy
5. Compound Disaster (Xiaolin Village)

Before Typhoon Morakot (2008/11)
5. Compound Disaster (Xiaolin Village)

After Typhoon Morakot (2009/08)
More than 400 people in Xiaolin village were killed.

The only remaining building in Siaolin village after the landslide.
5. Compound Disaster (Xiaolin Village)

3D Satellite Image
Before Typhoon Morakot
5. Compound Disaster (Xiaolin Village)

3D Satellite Image After Typhoon Morakot
5. Compound Disaster  (Landslide Simulation)
5. Compound Disaster (Dam Breach)

2. Levee Breach

3. Bridge Breach

1. Dam broke at 7:00

4. Peak wave passed at 08:30

Riverbed gradient = 0.9%
Average Speed of Flood Wave
27.5 km / 1.5 hr = 5 m/s
5. Compound Disaster (Flooding)
5. Compound Disaster  (Xiaolin Village)

3D Satellite Image
Before Typhoon Morakot

Nanfong  No.9  No.8
## 5. Compound Disaster (Process)

<table>
<thead>
<tr>
<th>Date</th>
<th>Time</th>
<th>Event</th>
<th>Event number</th>
</tr>
</thead>
<tbody>
<tr>
<td>2009/8/6</td>
<td>08:30</td>
<td>Typhoon warning was issued.</td>
<td>1</td>
</tr>
<tr>
<td>2009/8/7</td>
<td>17:00</td>
<td>Yellow debris flow warning was issued.</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>23:00</td>
<td>Red debris flow warning was issued</td>
<td>3</td>
</tr>
<tr>
<td>2009/8/8</td>
<td>19:00</td>
<td><strong>Bridge #10</strong> was flooded. <strong>Northward road was interrupted.</strong></td>
<td>4</td>
</tr>
<tr>
<td></td>
<td></td>
<td><strong>Bridge #8</strong> collapsed. <strong>Southward road was interrupted.</strong></td>
<td></td>
</tr>
<tr>
<td></td>
<td>23:00</td>
<td><strong>Bridge #9</strong> was flooded. The inundated depth was about 60cm.</td>
<td>5</td>
</tr>
<tr>
<td>2009/8/9</td>
<td>05:20</td>
<td><strong>Bridge #9</strong> was flooded. The inundated depth was raised from 60cm to 200 cm.</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td>05:30</td>
<td>43 inhabitants moved to a hut.</td>
<td>7</td>
</tr>
<tr>
<td></td>
<td>06:20</td>
<td>The <strong>landslide</strong> occurred. <strong>Northern part of the village was destroyed</strong> <strong>The landslide dam formed.</strong></td>
<td>8</td>
</tr>
<tr>
<td></td>
<td>07:00</td>
<td><strong>Landslide dam broke. Southern part of the village was flush out.</strong></td>
<td>9</td>
</tr>
<tr>
<td>2009/8/10</td>
<td>05:30</td>
<td>The warning for typhoon was lifted.</td>
<td>10</td>
</tr>
<tr>
<td>2009/8/11</td>
<td>-</td>
<td>43 survivors were evacuated by helicopters.</td>
<td>11</td>
</tr>
</tbody>
</table>
1. Shallow landslide occurred
2. Bridge #8 broke (debris flow)
3. Bridge #10 broke
4. Bridge #9 inundated
5. Large scale landslide occurred, Bridge Nanfong broke
6. Natural dam breach
7. Bridge Jaishan broke
8. Wave passed Bridge Shanlin
Landslide occurred and deposited on the streambed. Natural dam broke and stopped the runoff in the upstream area.
6. Face the Challenge of Compound Disasters

- If we don’t know the sequence of compound disasters than how to do the warning system.

- If we don’t know categories of compound disasters than how to mitigate the hazards.
7. Renovation strategy (Flowchart)

Start

Disaster Investigation

Damage Evaluation of Villages

Importance Evaluation of Villages

Time Scale Choice of Renovation

Compound Disasters Simulation

Planning of Renovation Strategy

Decision Making

End
For the village Renovation, different time scale can be considered

- Short-term
  - Only watershed C is considered.

- Long-term
  - Watersheds A, B and C are all considered.

On long-term consideration, the village renovation will be expanded to a watershed management
9. Importance Evaluation of Villages

- Evaluating factors
  - Population
  - Damage cost
  - Industry Structure

- Time Scale Consideration

![Map showing importance levels for villages]
10. Simulation Model

- Rainfall input
  - Surface Runoff Simulation
  - Infiltration and Groundwater Simulation
    - Shallow landslide simulation
    - Deep landslide simulation
  - Main Stream Simulation
  - Debris Flow
  - Landslide Dam formation/break
Sediment Runoff Process at Kaoping Watershed

After 3 Years

After 6 Years

After 10 Years

Deposition

Erosion
荖濃溪 編號 17 斷面

左斷133  H=659.025
右斷133A  H=658.603

1:800

雨季前斷面
雨季後斷面

17

Front of sediment deposition

1st測量成果
2nd測量成果
Conclusion

Rainfall characteristics of Typhoon Morakot
- Long duration (91 hours)
- High intensity (123 mm/hour)
- Large accumulated rainfall depth (3,000 mm-72 hour)
- Broad extent (one-fifth of Taiwan was covered by strong rainfall)

Disaster characteristics of Typhoon Morakot
- Disasters spread over a very large region (over 5,000 km²)
- Disasters were compounded
- Large amount of sediment yield and movement (1.2 billion m³)
- Secondary disasters will easily and continuously occur in the future
Conclusion

- Understanding and proper prediction of disaster process can provide effective and efficient renovation strategy.
- The powerful simulation model is necessary in the renovation.
Conclusion

- Different time scales should be taken into account when one determines the renovation strategy.
- On long-term consideration, the village renovation will be expanded to a watershed management.
Thank you for your attention
8. Sediment Budget Model

- **Subbasin systems**
  - Watershed divide into several subbasins with joint relationships
  - Sediment yield is estimated in each subbasin
  - Sediments transport downstream, and total at each junction
  - Remnant sediments are computed between 2 junctions
Simulation of Sediment Runoff Process

- Surface runoff
  \[
  \frac{\partial A}{\partial t} + \frac{\partial (Q)}{\partial x} = 0
  \]
  \[
  \frac{\partial Q}{\partial t} + \frac{\partial}{\partial x} \left( \frac{Q^2}{A} \right) + g \frac{\partial h}{\partial x} = gA(s_0 - s_f)
  \]

- Sediment yield and transportation

  Surface Erosion: USLE
  \[
  V = R_m \times K_m \times S \times L \times C \times P
  \]

  Landslide: ranged by Satellite Image

- Sediment particle size variation

- (Engineering) constructions
Sediment Yield & Transportation Simulation

**Input**
- Rainfall
- Topography
- Geo-parameters
- Landslide

**Output**
- Hydrograph of water
- Hydrograph of sediment
- Deposition/Erosion of sediments

**Graph:**
- *Impulse*
  - Threshold of Cum. Precipitation
  - Landslide
  - Erosion

- *Response*
  - i
  - Q
  - Vs
  - Qs

*FOR ITW ONLY*
7. Renovation strategy

- The resources must be allocated reasonably so that the renovation can be managed effectively and efficiently.
Traditional Methodology of Making Renovation Strategy in Sediment-Related Disasters is

\[ Y - O = \Delta V \]

- \( Y = \text{Sediment Yield after extreme event (varied with time)} \)
- \( O = \text{Designed Sediment Runoff (constant)} \)
- \( \Delta V = \text{Amount of Sediment Control} \)

**How to control the sediment?**

Under Design \[ \Delta V \]
Over Design \[ \Delta V \]
Example 1 ~ the Shoufeng Watershed

Large Scale Landslide occurred in 1984

Sabo Dam built in 1994

Natural Neck

Village

Before Landslide

After Landslide
Example 1 ~ the Shoufeng Watershed

The channel is departed into 7 sections

1. Landslide Tribury
2. Neck Section
3. Upstream of the Sabo Dam
4. Downstream of the Bridge
Example 1 ~ How to determine $Y$ and $\Delta V$?

Large Scale Landslide occurred in 1984.

$V = 15$ million m$^3$
Example 2 ~ the Blackstone Watershed

Before the Chi-Chi earthquake

\[
\frac{\text{Landslide area}}{\text{Catchment area}} = 1.4\% 
\]

After the Chi-Chi earthquake

\[
\frac{\text{Landslide area}}{\text{Catchment area}} = 18.2\% 
\]
Example 2 ~ the Blackstone Watershed

- Deposits on Riverbed \((10^4 \times \text{m}^3)\)
- Enlarged Landslide-Area Ratio (%)
Example 2 ~ How to make the criteria of debris flow warning?

```
Debris-Flow Event in 2000
Debris-Flow Event in 2001
Debris-Flow Event in 2004
Debris-Flow Event in 2005
Non-occurring Event
```

- **Effective Intensity (mm/hr)**
- **Culmulative Rainfall (mm)**
  - 1959~1999
  - 2000
  - 2001~03
  - 2004
  - 2005~07
  - 2008~2009

Decrease
Recover