Quantitative Resilience Analysis of Fiji to Cyclones

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Training for Pacific National Disaster Management Offices
12th-13th September 2012, at the Novotel in Nadi, Fiji

Outline

- National Emergency Management Agency- Technical Assistance Group
- Resilience Cost
- Application results of Resilience Cost to Fiji using historical data
- Typhoon Committee Disaster Information System (TCDIS)
- A proposal for Fiji
  - a Kind of TCDIS with resilience cost
- Conclusion
The Republic of Korea hosted the 4th Asian Ministerial Conference on Disaster Risk Reduction (AMCDRR) in 2010, with the support of GFDRR.

Incheon Declaration was adopted for “Disaster Risk Reduction (DRR) through Climate Change Adaptation (CCA).”

Incheon REMAP & Action Plan was agreed for the implementation of the declaration.

National Emergency Management Agency (NEMA) of the Republic of Korea and the World Bank/GFDRR have signed a MoU on the implementation of the Incheon Agreement and Action Plan.

NEMA-Technical Assistance Group (NEMA-TAG) is planning international projects to implement Incheon REMAP & Action Plan under a contract with NEMA/NDMI.
NEMA- TAG

- Perform “Research for Planning International Project for Implementing INCHEON REMAP and Action Plan” since March, 2011

Objectives

- The Action Plan is monitored and updated.
- The Action Plan is enforced by suggesting or implementing a few activities in the Asia and Pacific region for two years.
- As a first step of the support, NEMA and GFDRR carry out Three Sub-Regional Project to complement the ongoing projects and to bridge the gap of the ongoing projects.
- A report for the 5th AMCDDR is prepared.

- http://www.drr-tag.net/

Three Sub-Regional Project

- Three major hazard prone areas of the region.
  1. Himalayan Region for Glacier Lake Outburst Floods (GLOF)
  2. Pacific Region for Cyclone Risk Mitigation (CRM)
  3. Southeast Asian Region for Flood Risk Management and Mitigation (FMM)

Himalayan Region

- Bhutan
- India
- Nepal
- Bangladesh
- Pakistan

For GLOF

5 Countries

Pacific Region

- Fiji
- Samoa
- Vanuatu
- Marshall Island
- Papua New Guinea

For CRM

5 Countries

Southeast Asian Region

- Cambodia
- Vietnam
- Lao PDR
- Myanmar
- Philippines

For FMM

5 Countries
NEMA- TAG

Consists of 19 researchers

- **Head**
  - Chang Hwan OH (Chonbuk National University / Professor / Ph.D.)

- **Senior Researchers**
  - Kil-ha LEE (Daegu University / Professor / Ph.D.)
  - Chang Yong KIM (Korea Institute Construction Technology / Ph.D.)
  - Tae Won KIM (Websolus Co. / Director / Ph.D.)
  - Sung-Wook KIM (Gi Co. / CEO / Ph.D.)
  - Soonyoung Yu (National Institute for Mathematical Sciences / Ph.D.)

Visit to NDMO/SOPAC in Fiji (February 2-8, 2012)

A Proposal for the Pacific Region as of today

- Resilience Quantification for Decision- Making in Disaster Mitigation

- Disaster Information System for long-term forecasts of tropical cyclones and losses

Would these projects be needed/helpful?
Resilience Cost

developed by Vugrin et al. (2010)

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**Resilience**

- Definition:
  - either poorly defined or defined so broadly as to be meaningless when it comes to disasters.
  - All definitions include the concept of the system’s ability to withstand changes caused by external force.
  - Many include the system’s ability to absorb impacts and adapt for the sake of recovery, and the speed at which recovery occurs.

(After Rose, 2009)
Quantitative Resilience Studies

<table>
<thead>
<tr>
<th>Researcher(s)</th>
<th>Quantification</th>
<th>Variables</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bruneau et al. (2003)</td>
<td>$RL = \int_{t_0}^{t_f} [100 - Q(t)]dt$</td>
<td>$RL$: Resilience Loss, $Q(t)$: degradation in the quality of community infrastructure, $t_0$: time of occurrence of an incident, $t_f$: time to full recovery</td>
</tr>
<tr>
<td>Chang and Shinozuka (2004)</td>
<td>$R = P(A</td>
<td>\bar{I}) = P(r_0 &lt; r^<em>, t_f &lt; t^</em>)$</td>
</tr>
<tr>
<td>Rose (2007)</td>
<td><strong>Dynamic resilience</strong> $= \sum_{i=0}^{\infty} Y_{on}(t_i) - \sum_{i=0}^{\infty} Y_{on}(t_i)$</td>
<td>$\Delta DY^{%}$: the maximum percent change in output, $DY$: the actual percent change in output</td>
</tr>
<tr>
<td>Rose (2007)</td>
<td>$RDR = \frac{\int TSP(t) - SP(0) \alpha dt + \int \alpha RE(t) \alpha dt}{\int TSP(t) \alpha dt}$</td>
<td>$n$, $m$: number of time steps considered, $t_i$: the $i^{th}$ time step, $Y_{on}$: system output under hastened recovery efforts, $Y_{ou}$: system output without hastened recovery efforts, $RDR$: Recovery Dependent</td>
</tr>
<tr>
<td>Vugrin et al. (2010)</td>
<td><strong>Static resilience</strong> $= \frac{\Delta DY^{%}}{\Delta Y^{%}}$</td>
<td></td>
</tr>
</tbody>
</table>

US Critical Infrastructure Resilience

Given the occurrence of a particular, disruptive incident (or set of incidents), the resilience of a system to that/those incident(s) is the system’s ability to efficiently reduce both the magnitude and duration of the deviation from target system performance levels.

**Resilience**

- **Component**
  - Systemic Impact
  - Total Recovery Effort

- **Determining Features**
  - Absorptive Capacity
  - Adaptive Capacity
  - Restorative Capacity

- **Distinguishing Characteristics of Capacity**
  - Considers aspects that automatically manifest after the disruption
  - Considers internal aspects that manifest over time after the disruption
  - Considers ability to affect and repair internal system features

- **Effort Required**
  - Automatic/ Little Effort
  - Internal Effort Required
  - External Effort Often Required

- **Measurement of Component**
  - Internal Measurement
  - Exogenous Measurement

(Vugrin et al., 2010)
Resilience Cost (RC)

- Resilience Cost = System Impact + Total Recovery Effort
  - Developed for Critical Infrastructure Protection in US (Vugrin et al., 2010)
  - The higher resilience cost indicates the less resilient system

System Impact (SI)

- Target System Performance (TSP)
- System Performance (SP)
- Duration (t_f - t_0)
- Time (t)

Total Recovery Effort (TRE)

- System 1
- System 2
- Recovery Effort
- Time (t)

Resilience Cost (RC) Indices

- Recovery Dependent Resilience (RDR) Cost Index
  \[ RDR(RE) = \frac{\int_{t_0}^{t_f} [(TSP(t) - SP(t)] dt + \alpha \times \int_{t_0}^{t_f} |RE(t)| dt}{\int_{t_0}^{t_f} |TSP(t)| dt} \]

- Optimal Resilience (OR) Cost Index
  \[ OR = \min_{RE} \frac{\int_{t_0}^{t_f} [(TSP(t) - SP(t)] dt + \alpha \times \int_{t_0}^{t_f} |RE(t)| dt}{\int_{t_0}^{t_f} |TSP(t)| dt} \]

where TSP = Target System Performance; SP = System Performance.

R = Recovery Effort.
\( \alpha \) is a term that weighs system impact vs. recovery effort.

Denominator is a normalizing term that allows for comparison of systems that are of differing magnitudes.
An example

- using Natural Hazard Statistics (2009) in Korea
- Korea reports losses and recovery costs every year
- not used for resilience analysis yet.

**Heavy Rain in July 11-16, 2009**

<table>
<thead>
<tr>
<th>Province</th>
<th>Loss (KWON)</th>
<th>Recovery (KWMON)</th>
<th>Loss + Recovery as of 2008</th>
<th>GDP (KWON)</th>
<th>RDR Index</th>
</tr>
</thead>
<tbody>
<tr>
<td>Seoul</td>
<td>23,890</td>
<td>32,083</td>
<td>55,973</td>
<td>488,742,730,000</td>
<td>0.00000</td>
</tr>
<tr>
<td>Pusan</td>
<td>29,874,682</td>
<td>75,083,180</td>
<td>105,011,993</td>
<td>16,947,606,300</td>
<td>0.00741</td>
</tr>
<tr>
<td>Incheon</td>
<td>199,145</td>
<td>1,106,235</td>
<td>1,305,380</td>
<td>15,934,214,000</td>
<td>0.00000</td>
</tr>
<tr>
<td>Gwangju</td>
<td>801,991</td>
<td>1,005,698</td>
<td>1,808,699</td>
<td>14,815,973,400</td>
<td>0.000011</td>
</tr>
<tr>
<td>Daegu</td>
<td>1,187,765</td>
<td>1,513,675</td>
<td>2,701,440</td>
<td>8,181,284,100</td>
<td>0.00030</td>
</tr>
<tr>
<td>Gyeonggi</td>
<td>37,688,787</td>
<td>121,466,231</td>
<td>159,155,018</td>
<td>207,337,710,800</td>
<td>0.00077</td>
</tr>
<tr>
<td>Gwangju</td>
<td>30,647,107</td>
<td>72,245,480</td>
<td>102,892,587</td>
<td>12,087,428,200</td>
<td>0.00856</td>
</tr>
<tr>
<td>Chungcheongbuk</td>
<td>93,224,362</td>
<td>61,230,637</td>
<td>154,455,000</td>
<td>18,027,234,400</td>
<td>0.00318</td>
</tr>
<tr>
<td>Chungcheongnam</td>
<td>9,305,663</td>
<td>34,618,071</td>
<td>43,923,734</td>
<td>47,574,627,300</td>
<td>0.00104</td>
</tr>
<tr>
<td>Jeolla</td>
<td>13,152,941</td>
<td>822,707,136</td>
<td>85,400,476</td>
<td>18,005,527,800</td>
<td>0.00586</td>
</tr>
<tr>
<td>Jeollanam</td>
<td>26,944,245</td>
<td>633,682,960</td>
<td>89,236,246</td>
<td>29,630,816,500</td>
<td>0.00311</td>
</tr>
<tr>
<td>Gyeongnambuk</td>
<td>2,946,696</td>
<td>20,674,703</td>
<td>23,621,399</td>
<td>38,209,455,700</td>
<td>0.00014</td>
</tr>
<tr>
<td>Gyeongnamnam</td>
<td>67,731,722</td>
<td>178,000,148</td>
<td>245,732,070</td>
<td>43,782,170,500</td>
<td>0.00517</td>
</tr>
</tbody>
</table>

![Graph showing RDR Index versus GDP and Loss](image)

Application results of Resilience Cost to Fiji using historical data

Using 6 historical events,
referring to NATIONAL DISASTER MANAGEMENT OFFICE (NDMO) reports
### Four findings

- Community resilience in 2007
- Comparison of TC- MICK (Category 1) and TC- TOMAS (Category 4)
- Comparison of TC- Ami (Category 3) and TC- Gene (Category 3)
- Recovery Dependent Resilience Cost

### Resilience of Fiji to Natural Disasters

Comparison of community resilience in 2007

<table>
<thead>
<tr>
<th>Division</th>
<th>Western</th>
<th>Northern</th>
<th>Eastern</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hazard</td>
<td>Flood</td>
<td>Flood</td>
<td>TC-Cliff</td>
</tr>
<tr>
<td>Period</td>
<td>Feb. 9-12</td>
<td>March 24-25</td>
<td>April 4-6</td>
</tr>
<tr>
<td>System Impact</td>
<td>2,985,989</td>
<td>631,827</td>
<td>63,500</td>
</tr>
<tr>
<td>Recovery Effort</td>
<td>2,626,234</td>
<td>1,524,174</td>
<td>534,867</td>
</tr>
<tr>
<td>Resilience Cost</td>
<td>6,244,050</td>
<td>8,815,683</td>
<td>158,583</td>
</tr>
</tbody>
</table>

- The northern division was the most vulnerable to Natural disasters in 2007.
- This result is in good agreement with the facts:
  - The dominant north-west to south-east TC tracks gives some increased risk of damage in the outlying north-west island groups.
  - Sugarcane industry in the northern division is vulnerable to tropical cyclones.
- The northern division caused the more losses; while the western division required the more recovery efforts
  - Urbanization
Resilience of Fiji to Tropical Cyclones

TC-MICK vs. TC-TOMAS

<table>
<thead>
<tr>
<th></th>
<th>TC-MICK</th>
<th>TC-TOMAS</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Period</strong></td>
<td>Dec. 13-16, 2009</td>
<td>March 12-16, 2010</td>
</tr>
<tr>
<td><strong>System Impact</strong></td>
<td>59,412,170.18</td>
<td>84,732,380.49</td>
</tr>
<tr>
<td>Direct damage</td>
<td>59,356,480.18</td>
<td>84,326,800.49</td>
</tr>
<tr>
<td>Indirect damage</td>
<td>55,690.00</td>
<td>405,580.00</td>
</tr>
<tr>
<td><strong>Total Recovery Effort</strong></td>
<td>11,607,567.85</td>
<td>12,250,928.24</td>
</tr>
<tr>
<td>Recovery</td>
<td>11,505,167.84</td>
<td>11,505,167.84</td>
</tr>
<tr>
<td>Relief rations</td>
<td>102,400.01</td>
<td>745,760.40</td>
</tr>
<tr>
<td><strong>Resilience Cost</strong></td>
<td>71,019,738.03</td>
<td>96,983,308.73</td>
</tr>
</tbody>
</table>

- Fiji was more vulnerable to TC-TOMAS (Category 4) than TC-MICK (Category 1)
- The result can be changed if the number of casualties (3 in TC-MICK vs. 1 in TC-TOMAS) are considered when evaluating the system impact (or the resilience cost)

Resilience of Fiji to Tropical Cyclones

Indirect Damage

- The number of evacuees can address the indirect damage.
  - assuming 8-hour work per day and the minimum wage per hour of F$ 1.25
Resilience of Fiji to Tropical Cyclones

TC- Ami vs. TC- Gene (Category 3) (unit: Fiji Dollars)

<table>
<thead>
<tr>
<th>Impact Period</th>
<th>TC- Ami</th>
<th>TC- Gene</th>
</tr>
</thead>
<tbody>
<tr>
<td>Casualties</td>
<td>104,387,789</td>
<td>51,405,947.18</td>
</tr>
<tr>
<td>Total Recovery Effort</td>
<td>24,492,142</td>
<td>51,405,947.18</td>
</tr>
<tr>
<td>Resilience Cost</td>
<td>128,879,931</td>
<td>102,811,894.36</td>
</tr>
</tbody>
</table>

- Fiji was more vulnerable to TC-Ami than TC-Gene despite the same category
- This result is probably due to the fact that Fiji has become resilient to TCs
  - with the early warning system since 2002-03 cyclone season.
  - with learning through experience
- The recovery efforts increased despite the decrease in losses
  - need to find the causes of the high ratio of recovery efforts/losses if the data is reliable.

Recovery Dependent Resilience Cost

TC- DAMAM (Category 4, Dec. 2007) (unit: Fiji Dollars)

<table>
<thead>
<tr>
<th>Recovery Scenario</th>
<th>System Impact</th>
<th>Recovery</th>
<th>Relief rations</th>
<th>Resilience Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Provision of new house</td>
<td>500,251.95</td>
<td>534,867.02</td>
<td>0</td>
<td>1,036,118.97</td>
</tr>
<tr>
<td>Provision of financial grant for building material</td>
<td>500,251.95</td>
<td>446,717.42</td>
<td>91,884.24</td>
<td>1,038,853.61</td>
</tr>
<tr>
<td>Provision of financial grant purely for the purpose of rehabilitation</td>
<td>500,251.95</td>
<td>352,687.22</td>
<td>183,768.48</td>
<td>1,036,707.65</td>
</tr>
</tbody>
</table>

- The first option seems optimal given the least resilience cost despite the most recovery cost
  - Relief rations assumed
- System impacts can be affected depending on recovery strategies
  - The best strategy should be determined with considering recovery costs as well as system impacts
Summary

Resilience Cost is applied to quantitatively assess the resilience of Fiji to disasters, based on historical damage data.

The resilience cost, which was developed by the US DHS to protect critical infrastructures, is the sum of the system impact and the total recovery effort after an incident.

The higher resilience cost indicates that a system is less resilient to the incident.

Study results show that the resilience of Fiji to TCs depends on the strength and the path of a TC as well as inventory in affected areas.

In particular, the northern division whose economy is based on commercial agriculture of sugar cane is vulnerable to TCs due to the frequency of TCs as well as the vulnerability of agriculture to TCs.

Resilience of a region or a nation to disasters can be quantified using the concept of “resilience cost”

The resilience costs of regions can be compared each other given that the resilience cost index is the sum of the system impact and the recovery effort divided by the size of the region.

This study result demonstrates that the resilience cost is a good indicator to determine a location to give priority to for resilience enhancement or recovery resources and can be used to assess causes of vulnerability.

In addition, the resilience cost may be used to determine optimal recovery strategies if integrated with a modeling, simulation, and analysis program given scenario analysis capabilities.
Typhoon Committee Disaster Information System (TCDIS)

WEB GIS Based
Typhoon Disaster Information Analysis System
developed by the Republic of Korea

TCDIS

Typhoon Committee

- an inter-governmental body organized under the joint auspices of the Economic and Social Commission for Asia and the Pacific (ESCAP) and the World Meteorological Organization (WMO) in 1968 to promote and coordinate the planning and implementation of measures required for minimizing the loss of life and material damage caused by typhoons in Asia and the Pacific.

- The founding members of the committee were China; Hong Kong, China; Japan; Republic of Korea; Lao People’s Democratic Republic; Philippines; and Thailand. More recent members include, Cambodia since 1972, Malaysia since 1976, Viet Nam since 1979, Macao, China since 1993, People’s Democratic Republic of Korea since 1993, Singapore since 1997, and the USA since 1998 raising TC membership to fourteen.

TC Disaster Information System

- During the 38th session of the TC held in 2005, the members of the Working Group on Disaster Prevention and Preparedness (WGDP) agreed to establish an efficient data sharing tool of various tropical cyclone related disasters for TC members.
Following WMO (World Meteorological Organization) Web Style Guide
Search for a Similar Typhoon

Disaster Information
Regional Risk Analysis

A proposal for Fiji

a Kind of TDIS with resilience cost
A proposal for Fiji

- Development of a Tropical Cyclone Disaster Information System similar to TCDIS for Fiji
  - to estimate a Tropical Cyclone trajectory and its damages using historical data.

Tropical cyclone information

- GIS
- TCDIS
- Resilience Analysis

Disaster information

e.g., permanent Committee on GIS Infrastructure for Asia and the Pacific (PCGIASP)

Conclusion

- We would like to develop a Tropical Cyclone Disaster Information System (similar to TCDIS) for Fiji to estimate a Tropical Cyclone trajectory and its damages using historical data.
- The resilience cost will be used for data analysis in the system, given that the resilience cost compares vulnerability to a hazard across a nation more accurately than conventional methods (e.g., reporting damage and recovery cost separately, or one of them only), if used for data analysis in Disaster Information System.
- The system can be provided by the Republic of Korea in a cheap and easy way given the advanced technology and expertise in Korea if Fiji needs the system.
Thank you