6TH INTERNATIONAL CONFERENCE ON FLOOD MANAGEMENT
September 2014 - São Paulo - Brazil

STUDY ON PROBABILISTIC DISASTER RISK ASSESSMENT AND MANAGEMENT

Tsukizoe Megumi [1] and H.BABA [2]

1. *Representative, Japan International Cooperation Agency (JICA) Mozambique Office*
2. *Senior Advisor, JICA, Ph.D.*

ABSTRACT: This paper proposes a new concept of Probabilistic Approach in disaster risk assessment and management that could flexibly adapt the risk reduction plans and measures against intensifying scale of disaster. The concept, in contrast to the previous method based on a deterministic scenario of disaster, was conceived from lessons of recent disasters including extreme events that reminded us the importance of prospecting society's safety in which it can inclusively target any probable scale of natural phenomena.

The previous method of disaster risk reduction, which in this study is denoted as the deterministic scenario based approach, proved that there are remaining challenges, for example in sharing truthful information about extreme risk and its probability among local societies and communities.

The new approach with probabilistic risk assessment should then provide risk managers with reliable methodology of how to secure the local security level and how to plan the countermeasures considering the development policy of the local area, estimated future damage, cost effectiveness of disaster reduction investment, financial capacity of the society, robustness of the planned options, acceptability of the measures by community and other priority aspects such as poverty reduction and vulnerable peoples protection.

For the first step, a new concept is created to consider multiple disaster scenarios including return period and hazard scale which is necessary to set the target security level and select the appropriate options with their available financial and human resources. In the approach, we set the category of impact assessment based on wide range of hazard projection and adaptive planning with multiple scenario selections, and then prospect the total image of disaster risk reduction in every scale of impact, using the probability of each hazard. This approach enables to create strategic combination of structural and non-structural measures under redundant cooperation by various sectors including socio-economic development and infrastructures.

Key Words: disaster risk, hazard probability, probabilistic risk assessment, safety level, disaster management

1. INTRODUCTION

Intensifying scale of disaster can be described from catastrophic damages and globalizing impacts of recent disasters including the Great East Japan Earthquake and Tsunami (Fujita, 2011), Chao Phraya River Flood in Thailand (Komori et al., 2012), both in 2011, and the Typhoon Haiyan in the Philippines in 2013. It is notable that the increasing impact and risk could be caused due correspond to the background conditions such as rapid expansion of economic development, industry agglomeration in disaster risk areas, unregulated urbanization, population concentration in cities, development of watershed and land use change, all of which are causing vulnerability increase (Baba et al., 2013). The climate change is also considered as a factor intensifying hazard and increasing frequency of disaster.

Mohleji and Pielke (2014) find that global losses increased at a rate of US$3.1 billion/year from 1980 to 2008 and losses from North American, Asian, European, and Australian storms and floods account for 97% of the increase. According to the study, longer-term loss trends in these regions can be explained entirely by socioeconomic factors in each region such as increasing wealth, population growth, and increasing development in vulnerable areas.

In the contrary to the increasing needs of disaster management, the efforts of local leaders in many countries to reduce the loss and damage are still not sufficient, which give heavy impedance on the local development amongst continuous cycle of devastation and reconstruction. As Figure 1 shows, over 94% of International Disaster Financing between 1980 and 2009 was allocated to emergency response (69.6%) and reconstruction and rehabilitation (24.8%). Only 3.6% is invested to disaster prevention and preparedness (3.6%).

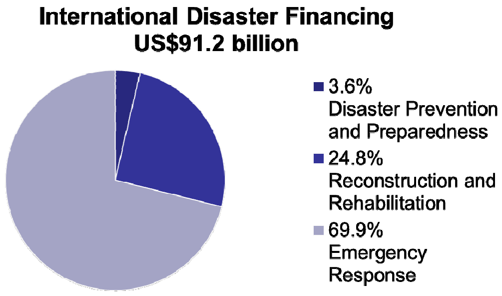

Figure 1: International Disaster Financing between 1980 and 2009. (GFDRR, 2012)

There are political advantages to hoping that a major catastrophe will not happen while a leader is in office, but then, if a catastrophe does occur, responding with full resources, irrespective of the cost. Subsidies for individual Disaster Risk Reduction (DRR) measures alongside high-profile launches for the subsidy schemes could be effective, and could be designed and implemented with explicit aspects included which gain political capital through the DRR (Kelman, 2013).

To attract political will of appropriate DRR investment, by turning the leader’s attitude from reactive to preventive, it could be effective that disaster manager has better assessment tools and methodology for evidently indicating risks, impacts, and probable damage cost, then for strategically setting target level of safety considering the cost-effectiveness of expected investment including non-structural approaches and structural measures. In the concept of Probabilistic Disaster Risk Assessment and Management that we propose, probabilistic hazard projections, multiple scenario approach and strategic combination of measures could be the key elements.

2. PROBABILISTIC HAZARD PROJECTIONS

First of all, to make risk and impact assessment in an area of concern, it is needed to analyze the levels of hazard magnitude. The distribution of different magnitudes of hazard will be the basic information for setting target levels of safety of the area and for making strategy of disaster management.

Imaginary as Figure 2 while a small level hazard has high possibility and little damage, medium level has middle possibility and damage on livelihood and no casualty, for example. Large level has low possibility and heavy damage that can be controlled while extreme level has rare possibility and severe damage that needs comprehensive works to mitigate.

Small hazard can be mitigated and protected with relatively small scale of structure prevention, even which is still difficult for many developing countries. In the medium hazard, not only structure prevention but also some response measures after disaster are needed to be invested to minimize damages. In the large hazard, combination of countermeasures including early warning is definit. In extreme hazard, it is obvious that the effectiveness of structure prevention is limited, and rather warning and emergency evacuation should be emphasized.

Magnitude of hazard	Damage potential and impact
Extreme (rare prob.)	Severe damage, need comprehensive works
Large (low prob.)	Heavy damage, must be controlled
Medium (mid prob.)	Damage on livelihood, no casualty
Small (high prob.)	Little damage, avoidable

Impact assessment based on wide range of hazard projections

Coping Strategy to make Adaptive Planning	Main selection
More emphasis on response side	Warning Evacuation
Combination of designed prevention and response	Mitigation Early Warn
Preventive strategy with some response measures	Prevention Mitigation
Prevention by structure on site	Structural prevention

adaptive planning under multiple scenarios in local conditions

Figure 2: Damage potencial and impact in respective magnitude of hazard

In case of the most river basins in Japan that are in matured state of DRR investment, for example, the countermeasures against small and medium hazards have generally been completed and can prevent from most damages. The flood control plan then is normally formulated approximately in 1-2% probability, which means setting target protection levels of 100 years return period for main rivers and setting target of 50 or less years return period for minor rivers. The plan also aims to invest disaster management options on large hazard which can mitigate the damage for estimated hazard scale and partially effects even for extreme hazard.

Figure 3 illustrates an example of damage potential and target levels of impact mitigation in a matured state. In this case, the hazard probabilities are classified as of 0.1%, 1%, 10% and 100% allocated to respective magnitude of hazard to estimate damage potential.

Magnitude of hazard	Damage potential and impact	Probability per year
Extreme	Severe damage, need comprehensive works	× 0.1%
Large	Heavy damage, must be controlled	× 1%
Medium	Damage on livelihood, no casualty	× 10%
Small	Little damage, avoidable	× 100%

Impact assessment based on wide range of hazard projections

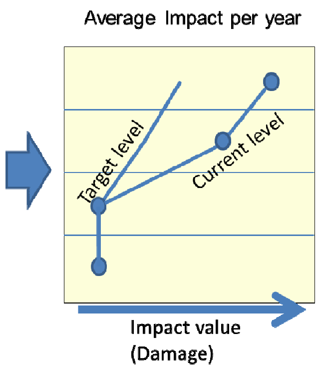

Figure 3: Damage potencial and target levels of impact mitigation (image in matured state)

In case of developing countries or premature regions for DRR, however, hazard mitigation is not enough even for small and medium level and they are continuously subjected to face damages every season. A comprehensive strategy to guarantee the sustainable improvement of security level is needed taking into consideration of these disaster intensity and frequency.

The point to be emphasized, which is different from matured countries, is that even if investment for large hazard is conducted, the damage in small and medium hazard cannot be dramatically decreased due mainly to the vulnerability of people living in high risk area. In case of flood protection, for example, large structure is not always effective against inland flood and small side stream that require rather meticulous measures than hard structure. In addition, it is necessary to consider respective condition of each countries and regions such as financial size, capacity of technology and organizations.

Finally, the strategy for improving security level should be customized in each area's damage potential and impacts that can be analyzed by probability of the occurrence of multiple hazard levels (Figure 4).

Magnitude of hazard	Damage potential and impact	Probability per year
Extreme	Severe damage, need comprehensive works	× 0.1%
Large	Heavy damage, must be controlled	× 1%
Medium	Damage on livelihood, no casualty	× 10%
Small	Little damage, avoidable	× 100%

Impact assessment based on wide range of hazard projections

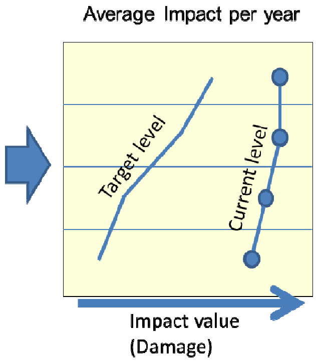

Figure 4: Damage potencial and target levels of impact mitigation (image in developing state)

3. DRR STRATEGY BY MULTIPLE SCENARIO APPROACH

To comprehensively tackle with the occurrence of different levels of hazards, together with the changing conditions of vulnerable areas by the socioeconomic factors such as increasing wealth, population growth, urbanization, and industry agglomeration, as well as the uncertainty such as climate change, we need to have a methodology to formulate DRR strategy which takes a consistent approach.

Most of the countries have been adapting such approaches as setting target protection level based on a preset particular hazard in fixed scenario, which is "Deterministic Approach" as Approach A or Approach B mentioned below.

Approach A: Supplemental measures for extremes over the planned security level. Supplemental measures will be provided for the extreme flood or extreme drought which exceeds the originally planned rainfall or discharge based on the past hydro-meteorological data. Water system shall basically be managed without changing the original plans but with consideration of future security level change due to climate change impacts or any uncertain events. Japan is the typical example that selected this approach.
Approach B: Improving measures based on periodical revision of planned security level. The planned rainfall and discharge will be periodically revised by reviewing the previous ones taking into account the observed and projected variation due to climate change impacts or any uncertainty. Nederland is the typical example that selected this approach.

However, the capacity of those approaches for adaptation against the uncertainty is not sufficient. Further flexibility of disaster management plans and resiliency of countermeasures are also needed even for the wide range of the risks projected. Here a new concept of multiple scenario approach is created to minimize damages and losses under the multiple scenarios by comprehensive combination of structural and non-structural measures. In this approach, it considers multiple disaster scenarios from multiple hazard scales to set the target security levels differently by various options and coordinate the appropriate options with their available financial and human resources, as showed in Figure 5.

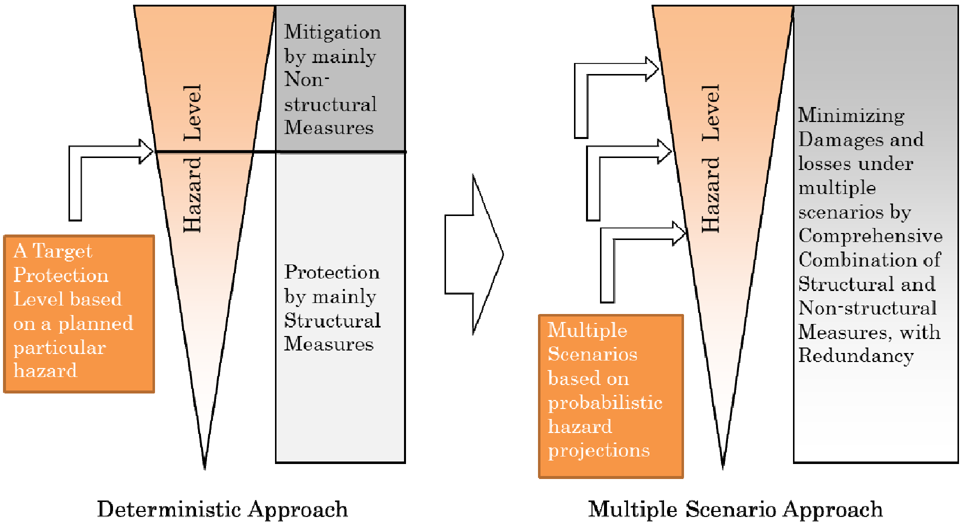

Figure 5: Concept and structure of “Deterministic Approach” and “Multiple scenario Approach”

After the Great East Japan Earthquake and Tsunami, the disaster management authority of Japan has improved the tsunami prevention plan that consists of two target hazard levels. It was developed based on the reflection of lessons from the single scenario plan that couldn’t function effectively for the events beyond the estimated target protection level. In contrast, it is expected that most of the countermeasures planned by different target protection levels can contribute to damage mitigation through synergetic effect and redundancy for the combination of measures. This can be defined as “Multiple scenario Approach” as Approach C mentioned below. Especially for the developing countries which have room and flexibility to introduce new approach for planning methodology, this option has much possibility to be introduced.

Approach C: Combination of measures for multiple security levels based on variation or uncertainty in climate change or any socioeconomic factors. Multiple safety levels of flood or drought, considering variation and uncertainty analysis, will be set up for potential options of scenarios for measures to be selected. The required measures are composed by a combination of various structural and non-structural measures. Optimization of those measures will be made taking into consideration of damage reduction benefit, investment cost, social and environmental impacts, etc.

4. STRATEGIC COMBINATION OF COUNTERMEASURES

With regard to a methodology for a comprehensive strategy to support the sustainable improvement of security level, Countermeasures are categorized into several options such as prevention of hazard by structure like dikes and dams, mitigation by watershed measures, hazard proofing and Business Continuity Management (BCM), Non-structural measures like early warning and flood fighting, land use planning, insurance and relocation, according to the order of preventive extent (Figure 6). Generally, preventive measures cost much. In the other hand, each countermeasure can be categorized into the respective hazard scenario from small to extreme. For example, while a dike against large hazard is preventive measure, a low cost dike against small hazard is relatively reactive measure.

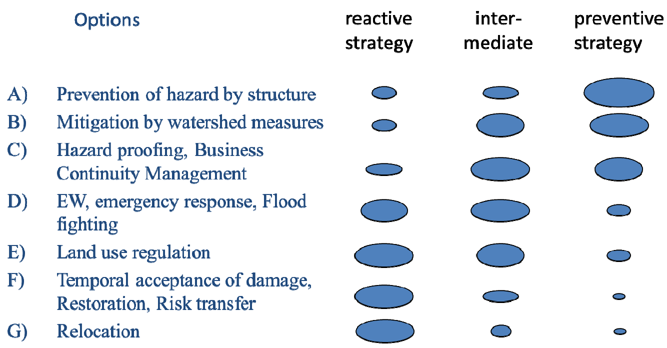

Figure 6: Strategic combination of preventive and reactive measures

In the practical situation of developing disaster management plan, a list of all the possible countermeasures in the region according to the order of category and strategic security level can be prepared, and then each option is evaluated through with some criteria such as cost/benefit, effectiveness of mitigating damage, acceptability and robustness. In addition, it is required to consider the number of the candidate plans multiplying possible countermeasures by target scenarios, to clarify the appropriate plans for multiple scenarios.

The robustness is one of another key criterion evaluating the flexibility and effectiveness to various scenarios. For example, some structural plan which completely cannot work for the planned emergency level must be low robustness. The chart (Figure 7) shows the example of flood management options. Even if some options have the same costs and benefits, the dependence on low robustness countermeasure should be avoided or combined with other backup measures. The important point is to choose a better combination to increase robustness.

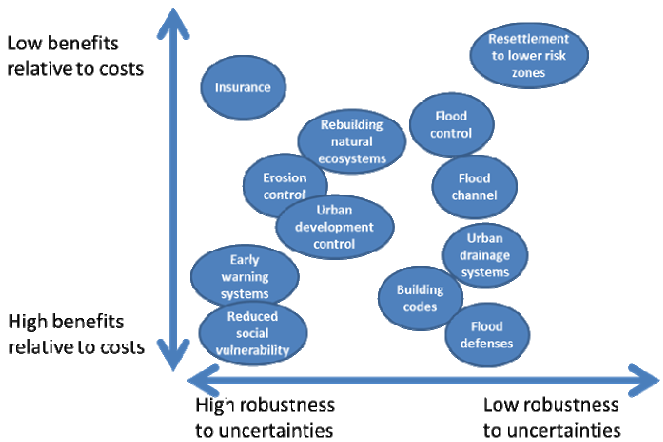

Figure 7: Relative costs and benefits of flood management options
(Modified from source: Adapted from Ranger and Garbett-Shields, 2011)

5. BENEFIT / COST PERFORMANCE

To consider Benefit by Cost performance, a method to calculate the effectiveness of damage mitigation using Stage-Damage Curve is useful. As Figure 8, Stage-Damage Curve shows the relativity between damage and Probability in a condition. If the damage can be calculated with the category of magnitude of hazard or the probability, average damage cost per year can be calculated. To conduct countermeasures for disaster management, the Stage-Damage Curve should be sifted to left side in respective probability.

The value for damage mitigation is the difference between a curve before conducted countermeasures and a curve after the countermeasures.

In case of flood management, the effectiveness of structural measure can be estimated with the difference of expected inundation. The effectiveness of non-structural measures can be estimated to convert the number of dead and affected people to economic loss.

Therefore, Benefit / Cost performance comparing with costs for countermeasures and values for disaster mitigation can be estimated using the Stage-Damage Curve through calculation of effectiveness of the damage mitigation of respective countermeasures. In the process, the different security level in respective magnitude of hazard should be considered for all countermeasures.

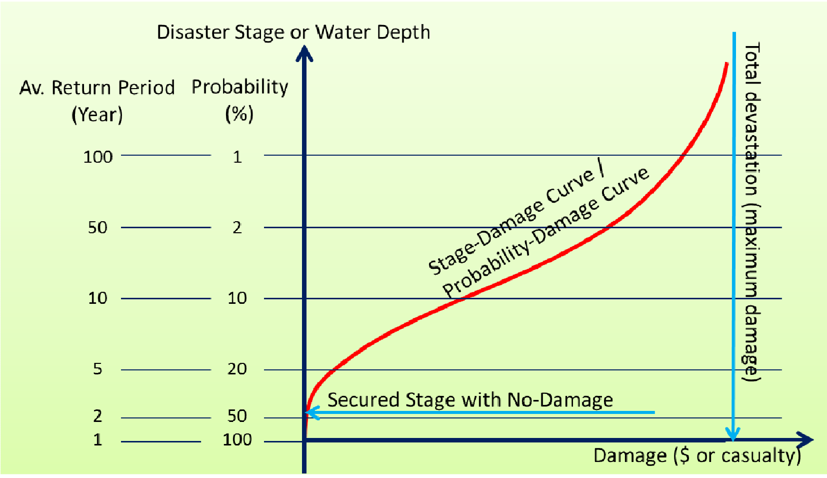

Figure 8: Stage-Damage Curve with probability

6. TOTAL COST

In the course of the above mentioned processes, it is possible to assess respective countermeasures in terms of strategic policy, cost for investment, and effectiveness of damage mitigation. Therefore, selection of countermeasures with these criteria can lead much effective investment for reducing total cost of disaster management which consists of probable damage and protection cost.

According to the assessment tool for strategic target setting ranging through reactive to preventive, several countermeasures should be conducted year by year and the position in the Figure 9 is expected to be approaching to the Point Cost Optimum. It can be verified that total cost can be reduced with "Multiple Scenario Approach" based on probabilistic hazard projections.

The Point Cost Optimum could be located at the intersection point between possible damage and the protection cost. Total cost must be boosted up by the cost for emergency response and reconstruction and rehabilitation. As the chart shows, most of the countries suffering from natural disasters might be in the left side position and repeating damages. Such situation of countries vulnerable to natural disasters, however, should be shifted to the right side position by investing protection cost, reducing damage cost and then reducing the total. The final goal is supposed to stay in the Point Cost Optimum which is the best condition for disaster management execution sustainably. This methodology can create incentives for decision makers to invest more protection cost with limited financial source. In this process the assessment of probability of disaster risks is the key elements.

We are conducting case study of this approach in Mozambique to verify the applicability of it. The result will be reported on following papers or occasions later.

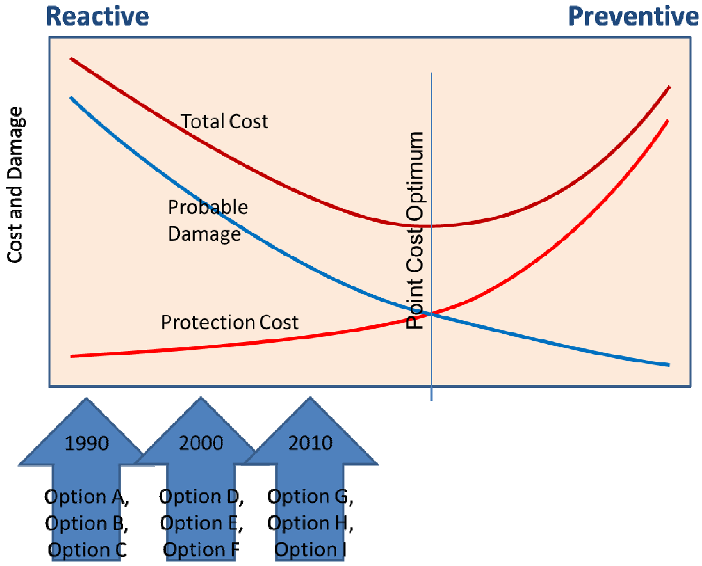

Figure 9: Assessment tool for strategic target setting ranging during the selection of options

7. REFERENCES

Baba, H., I. Adachi, H. Takabayashi, N. Nagatomo, S. Nakasone, H. Matsumoto, and T. Shimano, 2013: "Introductory study on Disaster Risk Assessment and Area Business Continuity Planning in industry agglomerated areas in the ASEAN" *Journal of Integrated Disaster Management (IDRiM Journal)*, Vol.3 No.2, Dec. 2013, 184-195.

Fujita, Takehiko, 2011: "Tsunami Impacting Eastern Japan and Preparedness for Extraordinary Natural Disaster", Presentation of Mr.Takehiko FUJITA , Acting President of PARI, IAPH Busan 2011 <http://www.pari.go.jp/en/files/items/3733/File/2011052327IAPH.pdf>

GFDRR, World Bank, 2012: "Managing diaster risks for a resilient future". Brochure in Sendai Report by Japan, GFDRR, World Bank. Ppage 4. <http://www.gfdrr.org/sites/gfdrr.org/files/Sendai_Brochure_English.pdf>

Kelman, Ilan. 2013: "Disaster Mitigation is Cost Effective". World Bank, Washington, DC. <https://openknowledge.worldbank.org/handle/10986/16341> License: CC BY 3.0 Unported.

Komori, D., S. Nakamura, M. Kiguchi, A. Nishijima, D. Yamazaki, S. Suzuki, and T. Oki, 2012: "Characteristics of the 2011 Chao Phraya River flood in Central Thailand." *Hydrological Research Letters*, 6(0), 41-46.

Mohleji, S. and Pielke, R., Jr., 2014: "Reconciliation of Trends in Global and Regional Economic Losses from Weather Events: 1980–2008." *Nat. Hazards Rev.*, 10.1061/(ASCE)NH.1527-6996.0000141 (Feb. 22, 2014).

Ranger, Nicola and Su-Lin Garbett-Shiels: "How can decision-makers in developing countries incorporate uncertainty about future climate risks into existing planning and policymaking processes?" Policy paper, March 2011, Centre for Climate Change Economics and Policy, Grantham Research Institute on Climate Change and the Environment in collaboration with the World Resources Report