Optimization Analysis of Flood Adaptation under Pseudo Global Warming Scenario

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Abstract

Based on the researches of climate change, the extreme typhoon events are expected to become more frequent in the future. For coping with such disasters, this study investigated adaptation projects that could mitigate the impact of extreme disasters. It used Typhoon Morakot as an example, which caused the worst flooding in the history of Taiwan, and applied the Pseudo Global Warming method to analyze the impact of global warming on precipitation, particularly the losses caused by flooding; then suitable countermeasures were proposed. The Zengwun River in southwestern Taiwan, whose watershed was among the most ravaged by Typhoon Morakot, was chosen for a demonstration area, to determine the optimal adaptation project. The results indicated that in the global warming scenario, a Morakot-level disaster would cause flood-induced economic losses 14% greater than those inflicted by the original Typhoon Morakot. Subsequently, this study evaluated the costs and benefits of four adaptation plans and their various combinations. These four were (1) large-scale detention basins, (2) flood detention parks, (3) riverbed dredging, and (4) improved evacuation and sheltering plans. A composite adaptation project combining riverbed dredging and improved plans for evacuation and sheltering was eventually determined to be the optimal option, as it could create a maximum net benefit.

Key words: PGW, Flood, CBA, Adaptation

1. Introduction

In recent years, various catastrophes caused by global warming have caught the world's attention, especially the losses caused by extreme floods (EEA, 2010; Kundzewicz et al., 2013). When decision-makers face the growingly severe impact of climate change, they regard climate impact information as paramount, because a complete climate change impact assessment can achieve the following two imperatives: first, use scientific methods to evaluate both the impact of climate change and plans for adaptation; second, use information obtained from the assessment to help policy makers and decision-makers choose suitable adaptation options, and develop strategies that can combine adaptation measures with mitigation measures (IPCC, 1994). Therefore, in early 2015, the Third World Conference on Disaster Reduction (held in Sendai City, Japan) emphasized that the reduction of losses of human life and property caused by disasters should be regarded as a crucial goal from 2015 to 2030. Then, at the end of 2015, the 21st yearly session of the Conference of the Parties (COP21) proposed the Warsaw Loss and Damage Mechanism (WIM) for dealing with climate-related effects, including residual impacts after adaptation. Due to the work of COP21, quantitative research on the effectiveness of adaptation will become a new pillar of the international climate change regime.

To alleviate these impacts, it is important to drastically reduce anthropogenic greenhouse gas emissions (i.e., to mitigate greenhouse gas emissions) at a global scale. However, high-impact-low-probability extreme events have been occurring more often than expected over the past decades; for such events, efforts that prevent, avoid, and reduce disaster risks (i.e., efforts for adaptation) are crucial and even more urgent at a local scale from a realistic and pragmatic perspective (Klein and Maciver, 1999).

The Taiwan Scientific Assessment Report on Climate Change (Hsu et al., 2011) stated that up to 2000, the frequency of heavy rainfall in typhoons was approximately one heavy rain every 2 years; the frequency of occurrence after 2000 increased at least once in more than 1 year, based on the statistical precipitation data in Taiwan from 1970 to 2009. The report also shows that the average temperature in Taiwan increased by 1.4 degrees over the past 100 years (1911–2009), that is, it has risen 0.14 degrees per decade on average, 1.89 times the global average. Thus Taiwan faces an unusually high potential flood impact by the end of the century. How can we accelerate public adaptation to flood disasters will be a critical challenge. This study's purpose is to analyze the strengths and weaknesses of each adaptation option; the results can help decision makers choose the most suitable adaptation plan by a CBA method. Finally, the evaluation results can also provide feedback for adjusting impact assessments, so as to understand the net impact or remaining impact.

2. Methodology

Recently, extensive research has proven that risk-based analysis is the most efficient method for adaptation assessment (European Commission, 2007; Dawson et al., 2008). Therefore, in first step of our study is the climate scenario setting. This study applied pseudo global warming (PGW) to simulate some possible impacts under certain warming scenarios based on real data from Typhoon Morakot. In the second step, the flood impacts and economic losses are calculated using the corresponding meteorological data. In the third step, the adaptation policies are discussed based on government planning projects. Finally, the optimal project is subjected to CBA. The data and methods used in these steps are further described in the following sections.

2.1 Pseudo Global Warming Scenario

The observed rainfall of Typhoon Morakot was used for the simulation of precipitation patterns, and the simulated results exhibited a high degree of consistency with what actually happened. Then, the PGW method was applied to simulate the possible impact of Typhoon Morakot on Taiwan in 2075. The phenomenon was predicted to be particularly pronounced in the Yunlin, Chiayi, and Tainan regions, where the increases would be as high as 60% in the plains. Moreover, the heavy rainfalls in the mountains of these three regions would be increased by more than 20% (Cheng Chao-Tzuen, et al. 2016).

2.2 Flood simulation

This study applied a three-dimensional unstructured grid Finite-Volume Coastal Ocean Model (FVCOM), which was developed by Chen et al. (2006), to simulate the flooding of Tainan induced by rainfall and by the overtopping of flood control structures (including internal and external water). After verifying the precision of the FVCOM through the aforementioned test, the researchers conducted a flood simulation of Tainan in an RCP8.5 scenario with the PGW method, and then compared the results with the real-world flooding caused by Typhoon Morakot in 2009. According to the results, as opposed to the 957.74 km^2 flooded by Typhoon Morakot, the inundation area predicted with PGW would be as high as 1057.24 km^2. In other words, under the RCP8.5 scenario, the inundation area in Tainan would see a 10.4% increase (99.54 km^2) beyond the flooding caused by Typhoon Morakot.

2.3 Flood Loss assessment

According to flood simulations, the Typhoon Loss Assessment System (TLAS) can be adapted to evaluate flood losses. The TLAS was built based on articles (Hsin-chi Li et al., 2014; 2017) and survey reports regarding Typhoon Morakot (W.S. Li, 2009). Losses were primarily divided into population casualties and property losses. The code for calculating property losses includes 27 land use modules that consider special categories such as agricultural, industrial, commercial, public facilities, traffic, and hydraulic facilities losses. Losses are estimated using calculation formulas for various loss types under various flood depths of the selected flood range.

According to the TLAS results, the total loss inflicted by PGW Morakot in whole Taiwan would amount to 1.09 billion US dollars, 14% higher than the actual Typhoon Morakot. The greatest loss would be household loss, primarily because Tainan is a highly urbanized and densely populated area. Overall, the results suggested that for Taiwan, the impact of global warming would only intensify in the future. For this reason, the establishment of proper adaptation measures to mitigate natural disasters should be given a high priority.

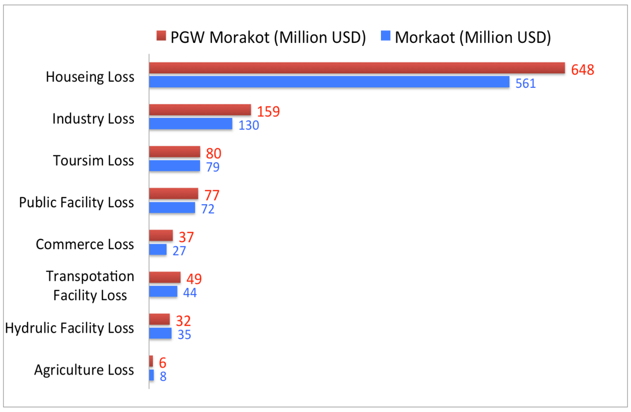

Figure 1. Loss Assessment of Typhoon Morakot and PGW Morkaot

3. Adaptation plans

Generally, a flood can be the result of two factors. The first is external water; the storm water of a heavy rainfall in the upstream catchment area can rush downstream along a river course, and in the event that the river cannot hold so much water, it will spill over the embankment and cause a flood. The other factor is internal water; this type of flood occurs when the drainage system of an urban area fails to accommodate storm water or divert it into a river, hence causing the runoff to flood the area. From the perspective of risk mitigation, reducing the exposure to it, or the vulnerability of the environment can only mitigate the impact of natural disasters that can barely be influenced by human intervention. Hence, the present study consulted the literature and the authorities' plans for the Zengwun River, for the development of numerous adaptation plans showed as Table 1.

Table 1 Adaptation plans

Plan	Purpose	Contents
P1	Reducing environmental vulnerability	Detention space
P2	Reducing environmental vulnerability	Flood detention parks
P3	Reducing environmental vulnerability	Dredging of riverbed
P4	Reducing exposure	Improving evacuation and sheltering plans

Based on the literature and Table 1, the adaptation measures devised by the project primarily aimed to reduce the vulnerability of the environment and the exposure to natural disasters. In terms of reducing the vulnerability of the environment, this study proposed to increase flood detention space (Plan 1 and Plan 2) and the cross section of the river channel (Plan 3). Plan 1 has been the major post-Morakot adaptation measure of the Water Resources Agency for the Zengwun River; the Agency plans to build embankments 3 m in height around the inundation areas to improve the water-holding capacity of these areas. The plan is expected to create a total of 1500 ha of additional flood detention space. Plan 2 is a measure that has been adopted by numerous counties and cities. The concept is to break up the volume of stormwater and detain it in small and dispersed spaces, so as to alleviate the potential of flooding. Existing examples indicate that the volume and water depth each park is able to accommodate can vary by the park's location and function. For research purposes, the present study adopted a minimum depth of 30 cm. The river dredging in Plan 3 is a routine operation of the Water Resources Agency, which is aimed to increase the cross section of a river channel to reduce the risk of overtopping. The present study adopted 1 m as the depth for annual dredging.

In terms of reducing the exposure, the adaptation measure devised by the project (Plan 4) aimed to improve the plans for evacuation and sheltering. According to the statistics of the Ministry of Health and Welfare (Department of Social Assistance and Social Work), the Greater Tainan Area can accommodate up to 92,990 households of refugees. The calculation of the present study was therefore based on this figure. However, readers should be aware that for ordinary hazardous events, only partial evacuation will be practiced; full evacuation will only be executed in the face of extreme disasters.

4. Benefit analysis of adaptation plans

After providing the adaptation projects, the next step was the cost-benefit analysis by the economic indices of NPV and BCR. This present study devised numerous combinations of the adaptation plans in Table 2.

Table 2 Combinations of adaptation plans

Project No.	Content	Project No.	Content
No. 1	P1	No. 9	P2+P4
No. 2	P2	No. 10	P3+P4
No. 3	P3	No. 11	P1+P2+P3
No. 4	P4	No. 12	P1+P2+P4
No. 5	P1+P2	No. 13	P1+P3+P4
No. 6	P1+P3	No. 14	P2+P3+P4

No. 7	P1+P4	No. 15	P1+P2+P3+P4
No. 8	P2+P3		

In Table 2, No. 1 to No. 4 are the results for individual plans; No. 1 to No. 3 are for detention basins, flood detention parks, and riverbed dredging, respectively, whereas No. 4 is for the improvement of evacuation and sheltering plans. The difference between No. 4 and the other three is that it is only designed to reduce casualties, not property loss. No. 5 to No. 15 are different combinations of the first four, and all of them can reduce the affected households and property loss to some extent.

Finally, when costs were added into the analysis, net benefit of numerous adaptation projects were showed as figure 2. Consider Project No. 5, which had the greatest negative value, for example; it had an expected annual benefit of 16 million US dollars, and an expected annual cost as high as 34 million US dollars, hence its negative net benefit of −18 million US dollars. Moreover, judging from its BCR, Project No. 5 only had a BCR of 0.47, suggesting that its cost was so high that it was more than twice as high as its benefit. Both these results ruled out Project No. 5 as a viable option. Project No. 14, which had the greatest expected annual benefit (36 million US dollars), has a positive net benefit; the addition of cost cut down its net benefit to 9 million US dollars. Although it still had a high BCR of 1.34, its high cost could become a liability in its execution.

According to the economic index of net benefit, the top three adaptation projects for Tainan would be Projects No. 10, No. 3, and No. 13, which exhibited net benefits of 27 million US dollars, 20 million US dollars, and 18 million US dollars, respectively. However, their BCRs (22.44, 40.36, and 2.84, respectively) indicated that although Project No. 10 had the highest net benefit, Project No. 3 was the one with the greatest BCR. Nevertheless, because Project No. 10 and Project No. 3 came out in front for net benefit and BCR respectively, either could be an ideal option.

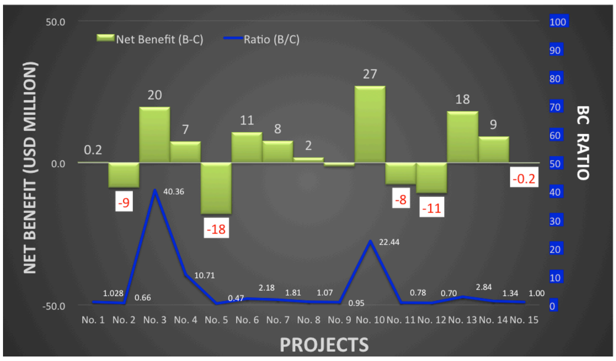

Figure 2. Benefit analysis of adaptation projects

4. Summary and conclusions

Under the assumption that typhoon events with extreme rainfall will become increasingly frequent in the future, this study adopted Typhoon Morakot as the basis for a regional dynamical downscaling PGW analysis that investigated the effects of global warming-induced precipitation on Taiwan at the end of the 21st century (2075). The results suggested that precipitation in the plains of southwestern Taiwan could increase by 60%, and heavy rainfall areas in the mountains of the same region would also increase by more than 20%. Based on this information, this study further chose the Zengwun River, which is a major river in that region and whose watershed was among those most ravaged by Typhoon Morakot, for an analysis to identify the optimal adaptation project for climate change.

According to the simulated rainfall of PGW Morakot, the loss caused by flooding of Tainan in that scenario would be 14% greater than the historical loss of Typhoon Morakot. This suggested that at the latter part of this century, the damage inflicted by Morakot-level disasters would be even worse than what the actual Typhoon Morakot had done. To alleviate the enormous loss in the foreseeable future, this study conducted a CBA on adaptation plans the authorities were planning or were about to implement.

Finally, based on the cost analysis results of different combination of adaptation plans, the optimal adaptation project for Tainan, in terms of net benefit, was found to be Project No. 10, which was a combination of riverbed dredging and improved evacuation and sheltering plans. It could be expected to create a net benefit of 27 million US dollars, the highest among the fifteen adaptation projects.

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