Formulation of adaptation measures for flood management under the uncertainty of future projection

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***Abstract*—Climate change is anticipated to affect the conditions of precipitation, which may, in turn, increase flood and drought risks in the future. Therefore, the necessity of adaptation measures is widely recognized and advocated. However, the evaluation of climate change impacts is still in the realm of uncertainty because various future development scenarios and Global Climate Models provide different future projections. Thus, the formulation of adaptation measures requires first quantifying uncertainty in order to identify the range of probable precipitation and assessing potential disaster risk in the future with socioeconomic changes. Then, measures to reduce disaster risks should be determined by combining structural measures to mitigate the impact of hazards and non-structural measures to cope with the remaining risk that cannot be mitigated by structural measures. Essential elements of this process are past and present data of hazards, damage, and socioeconomic factors to assess current and future risks and evaluate the effectiveness of selected adaptation measures by utilizing science and technology. Close cooperation among decision makers and practitioners is crucial in this process by sharing information and resources to formulate effective measures. To facilitate dialogue and consensus among decision makers in a country for actions to achieve disaster risk reduction, the platform on water resilience and disasters has been in place in several Asian countries and is expected to be the basis for the formulation of adaptation measures. This paper explains an effective mechanism and requirements for formulating adaptation measures for mitigating the future impact of climate change.**

Keywords—climate change; adaptation measures; disaster risk reduction; platform on water resilience and disasters

I. Current and Future Water-Related Disasters and Efforts for Disaster Reduction

In the recorded numbers of natural disasters in the world, water-related disasters occupy around 80% of all natural disasters, and about 40% of the water-related disasters occur in Asia alone (Fig.1) [1]. Water-related disasters are also frequent in Japan. Flood disasters, in particular, have become more destructive as torrential rainfall has become increasingly localized and intensified. In addition, more floods of larger scales have been reported in areas that have rarely experienced such events before, causing a huge loss of human lives and property and inflicting serious damage on socio-economic activities.

The Synthesis Report of the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) warns that extreme precipitation events will become more intense and frequent in many regions and cause concerns for the possibility of further intensification of flood disasters in the future. Therefore, for the formulation of adaptation measures to respond to the impact of climate change, future changes in discharge, inundation, and other aspects of a flood hazard should be analyzed first based on the assessment of future changes in rainfall. Then, the results should be used to evaluate corresponding changes in flood disaster risk as fundamental information for designing effective adaptation measures. In the formulation of adaptation measures, it is crucial to share information among organizations concerned to create a common understanding of issues to be addressed, which is a basis to formulate a strategy with the best mix of different measures under the control of different government agencies.

There are primarily four essential issues in the process of formulating a strategy. One is the identification of uncertainty arising in the prediction of future events. Such uncertainty originates in differences among Representative Concentration Pathways (RCP) scenarios and Global Climate Models (GCMs). Another is the understanding of the background of uncertainty among all stakeholders to form a consensus. The third one is the quantification of uncertainty by predicting the range of possible values in the future, and the last one is the application of uncertainty to decision making on the best mix of adaptation measures so as to cope with possible future conditions.

In formulating a strategy with the best mix of adaptation measures, each measure should be evaluated for its effectiveness based on analysis using the latest science and technology. Unfortunately, since the development of the capacity needed to undertake this task is still underway in many developing countries, international cooperation and support are essential. The United Nations is working on this

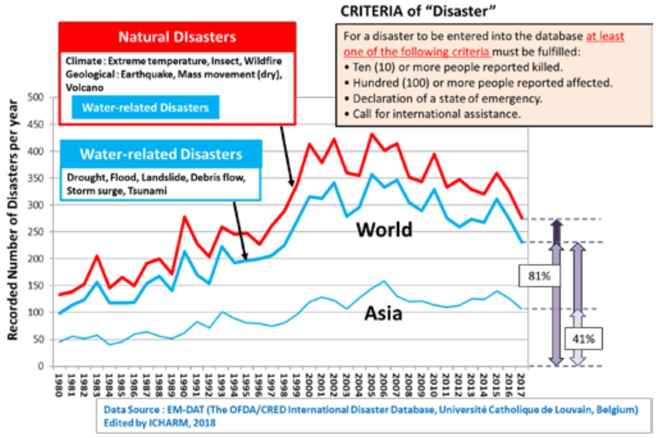

Fig. 1. Natural Disaster Trend (1980-2017)

challenge through the promotion of disaster prevention activities at international meetings and conferences, while requesting countries to make vigorous efforts to achieve the targets adopted in such conferences as an international agreement.

In 1994, the "World Conference on Natural Disaster Reduction (WCDR)" was held in Yokohama, Japan, as the first international interdisciplinary conference to discuss natural disasters and adopted the "Yokohama Strategy and Plan of Action for a Safer World." Despite such events, the interest in natural disasters was not so high in the international society in the 1990s and 2000s since the high-risk areas of natural disasters were mainly in Asia, Africa and South America. Accordingly, when the 2nd WCDR was planned in January 2005, it did not draw much attention from many developed countries. However, it turned out to be an important event and attracted a lot of global attention because of the tsunami disaster caused by the Indian Ocean earthquake in December 2004 with more than 230,000 dead or missing including many tourists from developed countries. As a result, the 2nd WCDR was attended by participants from almost all UN member countries, and the "Hyogo Framework of Action (HFA) 2005-2015" was adopted as guidelines for the international efforts to tackle disaster reduction.

After the 2nd WCDR, though many efforts had been made for disaster risk reduction, large-scale natural disasters occurred in the world such as Hurricane Katrina of USA in 2005, Cyclone Nargis of Myanmar in 2008, a large-scale flood of Brazil in 2011, the tsunami disaster by the Tohoku Earthquake of Japan in 2011, and a large-scale flood of Thailand in 2011. In 2015, the 3rd WCDR was held in Sendai, Japan after those disasters and adopted the "Sendai Framework for Disaster Risk Reduction 2015-2030," which states four priority actions (1.Understanding disaster risk, 2.Strengthening disaster risk governance to manage disaster risk 3.Investing in disaster risk reduction for resilience, and 4. Enhancing disaster preparedness for effective response and to "Build Back Better" in recovery, rehabilitation and reconstruction) and seven global targets such as the reduction of global disaster mortality and disaster economic loss. In September 2015, the "Sustainable Development Goals (SDGs)" were adopted at the UN Sustainable Development Summit, aiming, as one of the targets, to "significantly reduce the number of deaths and the number of people affected and substantially decrease the direct economic losses caused by disasters including water-related disasters." In December 2015, the "Paris Agreement" was adopted at the UN Climate Change Conference, or COP21, in Paris, and the "enhancing adaptive capacity, strengthening resilience and reducing vulnerability to climate change" was addressed as a global goal. In December 2016, the "International Decade for Action -Water for Sustainable Development-" was adopted at the UN General Assembly, and the participants agreed with the necessity of concerted efforts to manage water-related disaster risks. Each member state is requested to make necessary efforts for the achievement of the objectives adopted at such international conferences, and the international society has reached a consensus that it will make continuous support for countries to realize the objectives.

II. Prediction of Impact of Climate Change

A. *Impact assessment of climate change using Global Climate Models (GCMs)*

For the evaluation of climate change impacts on flood disasters and the investigation of adaptation measures, changes in flood disaster risk due to climate change should be assessed as the first step. The process of flood disaster risk assessment starts from the identification of future precipitation, which is followed by the analysis of discharge and inundation caused by the precipitation in the floodplain to evaluate possible damage to be caused by the inundation as flood disaster risk. The future condition of precipitation should be estimated with an appropriate resolution for the discharge analysis of the target rivers. Such rainfall distribution can be obtained from Global Climate Models (GCMs). Although GCMs have coarse resolutions, high-resolution rainfall distribution data can be produced using a downscaling technique. However, each GCM has its own characteristics because of different structures and approximation methods used for the models to calculate the precipitation process. Simulation results differ among GCMs, which is a cause of uncertainty in the rainfall by the GCM projections. Therefore, ICHARM developed a combined method for the assessment of climate change impacts and applied it to the ADB project in Vietnam, "Climate Change and Flood Hazard Simulations Tools for ADB Spatial Application Facility (SC 109094REG)," for the assessment of flood disaster risk, which consists of: 1. Quantitative impact assessment applied to the formulation of adaptation measures and 2. Qualitative impact assessment for the evaluation and understanding of uncertainty.

1) *Quantitative impact assessment applied to the formulation of adaptation measures:* The Atmospheric Global Climate Model (AGCM), which is a type of GCM, is used for the calculation of atmospheric conditions with the sea surface temperature (SST) as premises. The model provides a good resolution since a load of calculation is relatively low compared to coupled GCMs, and its grid size of calculation is smaller than other models. ICHARM uses MRI-AGCM3.2S

[2] constructed by the Meteorological Research Institute (MRI) with 20-km mesh as boundary conditions, and downscaling is performed using the Weather Research and Forecasting (WRF) model [3] to obtain high-resolution results (much finer horizontal and temporal resolutions), which makes it possible to examine flood risk and its changes due to climate change in the target river basin [4]. In the case of the ADB Project in Vietnam, the horizontal resolution is 18-km nationwide and 6-km for the Red and Perfume River basins. SST is collected from monthly mean observations (present) or observations plus future changes derived from the Coupled Model Intercomparison Project (CMIP) [5]. Based on the results of the downscaling, a quantitative impact assessment method is developed, in which the daily rainfall intensity is calculated for the target probability of the present and future periods and the analysis of the discharge volume and inundation area is conducted using an observed rainfall pattern when a large-scale flood occurred in the past.

2) Qualitative impact assessment for the evaluation and understanding of uncertainty: To compare and comprehend the characteristics of each GCM, CMIP is being undertaken and currently CMIP5 is available. Though the uncertainty caused by model differences in predicting the impact of climate change at a global scale has been decreasing as GCMs have been improved year by year, the uncertainty generated in prediction at a regional scale is still significant. The uncertainty at a regional scale originates in the ability of each model to represent the characteristics of climate at a regional level, since each model has its compatibility; some models are suitable to represent climate conditions in some specific area while other models are suitable to do so in other areas. Therefore, understanding the difference among models in representation of climate conditions in the target area is essential to understand the uncertainty caused by the model differences.

For identifying suitable models to the target area, the scoring process is adopted in which: 1) models are selected from CMIP5 if they have enough data of basic meteorological elements (e.g., monthly precipitation, outgoing long-wave radiation, pressure at sea level, air temperature 850h Pa level, zonal wind 850h Pa level, meridional wind 850h Pa level) and 2) some of them are excluded by comparing simulated and observed data in terms of the spatial correlation coefficient (CC) and the absolute values of root mean square error (RMSE) of meteorological elements [6]. Then, statistic downscaling is undertaken to the remaining models to compare the precipitation condition in high resolution using ground observed data.

In the case of the ADB project in Vietnam, four models have been selected based on scoring system and the result of downscaling shows a similar pattern to the present (1979-2003) condition. For the future (2075-2099) period, one model (Max Planck Institutes-Earth System Model-Low Resolution (MPI-ESM-LR)) shows a different pattern from the other three models (Community Earth System Model - Community Atmospheric Model version 5 (CESM1-CAM5), National Centre for Meteorological Research - Climate Model version 5 (CNRM-CM5), NOAA Geophysical Fluid Dynamics Laboratory - Climate Model version 3 (GFDL-CM3)) (Fig.2)

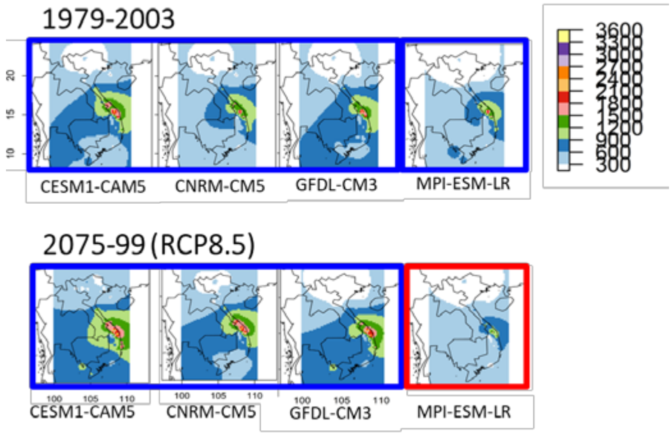

Fig. 2. Average Rainfall in October-November-December

[7]. This is because the simulation results of the three models show that the north wind is dominant while the one model shows that the south wind is dominant as a result of the simulation of north-east monsoon formulated in the seasonal climate changes. As this case demonstrates, the simulation of climate change impact may differ according to model differences, and thus it is considered as one of the reasons causing uncertainty in the prediction.

B. Uncertainty caused by future climate scenarios

The fifth assessment report of IPCC sets four scenarios such as RCP2.6, RCP4.5, RCP6.0 and RCP8.5 in assessing the impact of future climate change. The results of future prediction for each scenario vary depending on models, and therefore the report shows a certain range of future prediction value for each scenario. As is described in II A 2), the uncertainty caused by model differences should be well recognized, but it is not realistic to calculate all the prediction values of each model to be reflected in planning. The most practical and valid way is to use a high-resolution model of AGCM for dynamic downscaling. Even in such analysis, the uncertainty caused by the four scenarios should be noted and counted in the formulation of adaptation measures.

III. Disaster Risk Assessment

After the identification of the target precipitation, discharge and inundation analysis is conducted to simulate flood hazard conditions and then assess flood disaster damage. The damage caused by a flood is categorized into direct and indirect damage; direct damage refers to mortality, damage to agriculture, damage to houses and buildings, interruption of lifeline utilities such as water supply, gas and electricity. Indirect damage includes stagnation of socio-economic activities caused by the interruption of lifeline utilities and transportation.

For the quantification of direct damage according to the scale of a flood (area, depth and period of inundation), the correlation between damage and flood scale is indicated in the form of a damage curve. Fig.3 is an example of a damage curve [8], which shows the percentage of rice yield loss

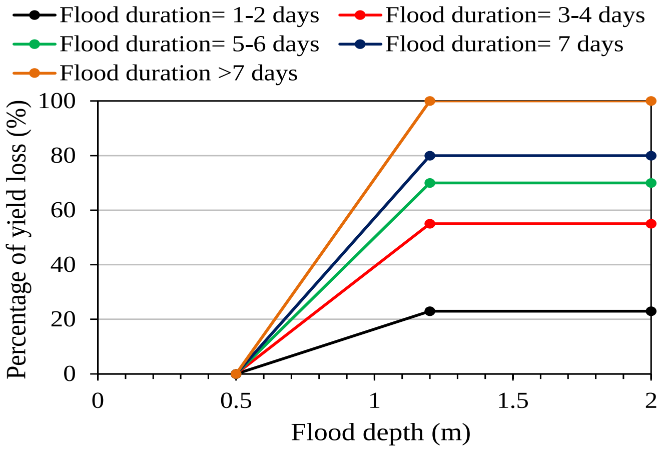

Fig. 3. Damage Curves for Maturity Stage of Rice Crops

caused by the depth and duration of inundation in the rice field. By using a damage curve, the monetary value of damages can be evaluated by simulating a flood hazard. Fig.4 compares the damage to rice crop between the present and future climates for the same flood probability (return period) [9]. Since a damage curve can be established from the actual data of past floods and damage in the field, the accumulation of data is essential.

The contents and scales of indirect damage are deduced from the condition of socio-economic activities in the area. So-called "chain-reaction damage" should be also considered, since flood damage sometimes expands to areas outside the directly affected area especially when they are connected through socio-economic activities. For example, a massive flood occurred in 2011 in the Chao Phraya River basin, Thailand, submerged a myriad of companies in its industrial estates that were producing mechanical parts for manufactures in Japan. These companies were compelled to stop operation, which affected manufactures in Japan considerably, and caused international chain-reaction damage. This incident typically teaches us that it is desirable to evaluate not only direct damage but also indirect damage in the assessment of disasters, and the differences between the two types of damage

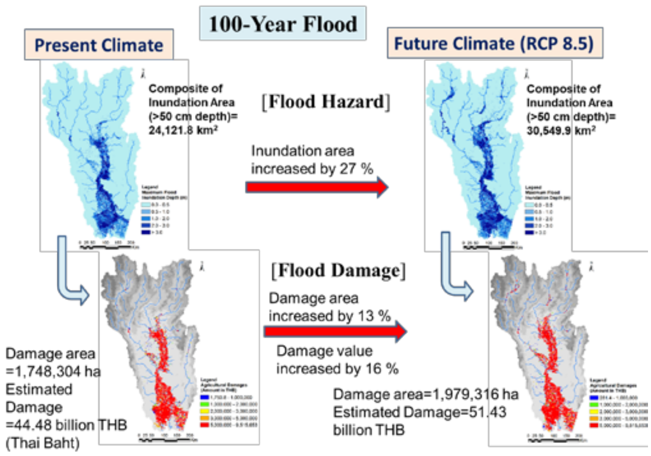

Fig. 4. Flood Damage Assessment (Rice Crops) in Chao Phraya River Basin

should be always kept in mind. While direct damage has a clear correlation with the scale of a flood, an indirect damage is not defined by the scale of a flood alone. Furthermore, damage evaluation requires expertise on target objects and activities for collecting information and conducting analyses. Investigation and research should be performed by employing interdisciplinary approaches under the cooperation of various fields of science and technology related to flood disasters.

IV. Formulation of Adaptation Measures

The basic process to formulate a strategy for flood disaster risk reduction is comprised of: 1) Identification of a target flood, 2) Assessment of flood disaster risk caused by the target flood, 3) Evaluation of the effectiveness of countermeasures to reduce disaster risk, and 4) Adoption of a strategy consisting of different measures. The formulation of adaptation measures for climate change also follows the same sequence. The elements of flood disaster risk are the scale of a hazard, the vulnerability of the target objectives and actions, and the exposure of the target objectives and actions to the flood hazard (Fig.5), and flood disaster risk is defined by these three overlapping elements [10]. A risk reduction strategy is developed by considering how each of the elements can be reduced. Hazard can be reduced by structural measures such as dams and diversion channels, vulnerability by flood-proofing buildings and basic infrastructure and installing early warning systems, and exposure by river improvement, land use changes and evacuation. A practical strategy can be formulated by creating the best mix of these measures. For structural measures, cost effectiveness can be assessed by comparing the construction cost with the economic benefit that is estimated based on the difference in economic damage before and after the completion of structural measures.

As mentioned before, in the formulation of adaptation measures for climate change, the uncertainty derived from the difference among models and scenarios should be considered in the determination of a target flood. Another important point is that the consideration of the remaining risk, which refers to the possibility of a flood occurrence exceeding the probability (return period) of a target flood set to design structural measures. A contingency plan should be prepared to save lives

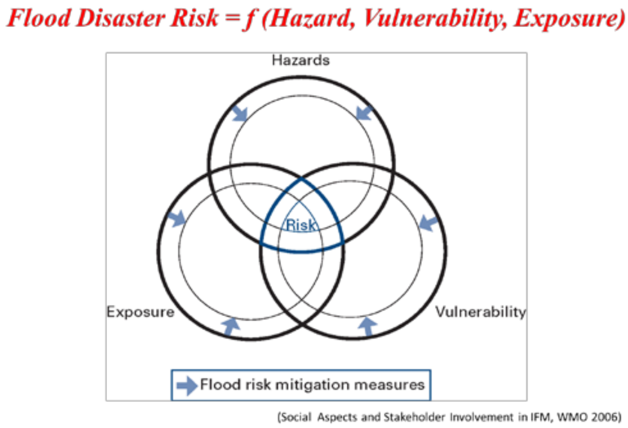

Fig. 5. The Elements of Flood Disaster Risk

and certain types of property by, for example, early warning and evacuation in case of a flood that exceeds the design flood defined for the structure. Flood hazard maps are a useful and effective tool for developing a contingency plan providing information on possible inundation area and depth in case of a flood exceeding the design flood scale of the structure or when structural measures are destroyed.

In an actual process of formulating a strategy for climate change, the first step is to decide the target scenario from four RCP climate change scenarios for designing structural measures. The second step is to adopt a model with a resolution high enough for the planning, which is followed by the third and fourth steps to set the design scale of a flood in terms of probability (return period) and analyze the discharge volume needed to design structural measures. The probability of occurrence of discharge exceeding the design flood volume for the structural measures that is caused by the uncertainty should also be considered as the remaining risk and incorporated in a contingency plan. In this process, although the uncertainty caused by different scenarios can be quantified, the uncertainty originating in different models can be hardly quantified since it takes a huge volume of calculation to estimate all the model-derived uncertainty, as described above. At present, therefore, it is practical and preferable to select one high-resolution model using the latest science and technology and assess uncertainty by calculating the discharge based on the four scenarios and identifying the range of future risk. It should be noted, however, that the evaluation method of uncertainty will be reexamined according to the future revisions of the scenarios or the improvement of modeling methods. In such occasions, hazard maps and contingency plans also need to be reviewed.

V. Conclusion and Recommendations

For the formulation of adaptation measures to prepare for the impact of climate change, it is practical and rational to introduce structural measures to ensure a certain safety level and to use contingency planning to manage the remaining risk, which arises corresponding to uncertainty derived from different future scenarios or climate models or from the possibility of occurrence of a flood that exceeds the design scale of the structure measures. A contingency plan should contain: 1) Provision and supply to the public of disaster risk information produced by the government based on science and technology; 2) Support and assistance provided by the government for the public to take emergency actions (securing evacuation sites and routes, preparing communication systems, etc.); and 3) Appropriate preparedness and smooth emergency response by the public based on the information provided from the government. These actions can be effective only when the government and the public work together under a cooperative scheme. Therefore, a trans-disciplinary relationship between “science and technology” and “society” should be promoted.

Based on science and technology, the government should create and deliver disaster risk information and risk reduction measures. To facilitate such efforts, the International Flood Initiative (IFI), for which ICHARM has been the secretariat, assists the government and academia entities in formulating a “Platform on Water Resilience and Disasters (Platform)” of each country. In addition, the High-Level Panel on Water, consisting of the heads of 11 countries, submitted a report entitled “Making Every Drop Count – An Agenda for Water Action – ” to the UN Secretary-General and the World Bank President on March 14, 2018, which underlines the importance of building preparedness to reduce water-related disasters and the necessity to formulate a Platform involving all stakeholders to facilitate dialogue and scale up community-based risk reduction practice. In the Global Earth Observation System of Systems (GEOSS) Asia Pacific (AP) Symposium 2018, the Platform project was highlighted in the session of the GEOSS Asian Water Cycle Initiative (AWCI) with reports from several countries where the project is already in progress. The symposium was wrapped up, adopting the Kyoto Statement 2018, which stresses that the Platform project deserves the full-scale efforts of AWCI [11]. Since further implementation of a Platform in each country needs advice and assistance based on science and technology from the international society, IFI has been vigorously working to strengthen communication among countries and between countries and international organizations. For science and technology to contribute to socio-economic development, the global community needs to continue making concerted efforts to facilitate global dialogue, share practical knowledge and experience, and enhance international cooperation.

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