論文の内容の要旨

(Thesis Summary)

Study on economic damage due to pluvial flood in Japan and the world and the impact of climate change

(日本と世界における内水氾濫による経済的被害と気候変動による影響に関する研究)

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(本文 Body)

The assessment of flood risk and its future prediction under the anthropogenic climate change are important to policy makers for future preparedness and adaptation planning. Almost all countries in the world including major cities suffer from flood damage every year due to large exposed population and property. Flood losses are increasing more rapidly during the late 20th century and are expected to increase in future too. The intensity of damage varies as per the level of their vulnerability; as a result economic loss intensity due to floods is much higher in developing countries than in developed countries. Even though huge investments for the improvement of flood control infrastructures were made, flooding remains a serious problem throughout the world. Some large scale and record breaking flooding events in recent years in terms of physical losses provided serious attention to world leaders and policy makers towards proper planning and management of flood control infrastructures and formulating future adaptation strategies. It is presumed that future increase in hazards extremes resulting from climate variability and socio-economic development will increase economic losses. Various studies projected a large increment of flood losses in the world by late 21st century, and even worse there will be large spatial and inter-annual variability.

Flooding related to rainfall usually divided into large-scale fluvial floods, and pluvial floods that occur due to excessive rainfall and overwhelms local drainage systems. The share of pluvial flooding to total physical losses cannot be underestimated. The pluvial flood damage, particularly in densely populated urban areas and areas with poor drainage facilities were recorded very high not only during heavy rainfall events, but also at moderate to low rainfall events. Rapid urbanization with poor infrastructures often promotes increasing flood damage not only to economy but also to human lives. Due to the highest concentration of capital in urban regions, a small changes in rainfall intensity can led to large increase in pluvial flood damage and hence pluvial flood damage could be a large component of physical losses in future climate change condition.

In this regards, a proper way of estimating pluvial flood damage amount and thereby assessing its risk in local to global scale in present and future is a demanding task for not only scientific communities, but also indispensable for decision makers.

To this end, various flood damage assessment models have been developed and used. Most studies regarding flood damage assessment have been done for large scale fluvial flooding. Many conceptual models which provide the different vulnerability or risk indices for spatial comparison were used by various organizations. These index-based approaches might be suitable for assessing relative risk distribution; however a decision maker requires proper estimate of economic damage in absolute monetary terms so that economic viability of proposed infrastructure development plan could be justified.

The direct flood damage estimating models so far developed basically utilizes integration of two different sub-models. A hydrological model is used to estimate hydrological parameters and a loss model is used to relate these hydrological parameters to damage amount. However, a hydrological model usually needs large resources and still there is a need of better understanding of flooding characteristics in inner urban areas. Calibration and validation of these models are often difficult due to limited data availability. On the other hand various loss models, so far developed in some local scale using past flooding damage data have serious uncertainties while using for different temporal and spatial regions. Uncertainty related to types of property and its values are also critical in loss models while expanding the model to different regions. Moreover, an extreme event corresponding to large return period is usually taken for damage assessments providing largest possible damage, however total annual damage is usually associated with many high frequency events and reported as equal as extreme events. There is a need of a model which can incorporate all potential events for damage so that proper estimate of annual damage could be made.

To address the aforementioned issues, in this research, we present a novel and robust statistical model for pluvial flood damage assessment particularly for general property. We used recorded historical daily damage data in Japan that are archived in Ministry of Land, Infrastructure, Transport and Tourism (MLIT) of Government of Japan to produce functions namely damage occurrence probability function and damage cost function. The former function represent the relationship of exceedance probability of rainfall to its corresponding damage probability, and latter represent the relationship of exceedance probability of rainfall to relative damage amount for a particular location. Our statistical approach gives the probability of damage following every daily rainfall event and thereby estimates annual damage as a function of rainfall, population density, topographical slope, and gross domestic product. The newly developed model largely reduces use of sophisticated hydrological models on one hand and current micro-scale loss models in the other hand. The model could be a very light and robust tool for decision makers to estimate annual damage for short term planning and to estimate expected annual damage for long term planning with reasonable level of confidence.

The model was first developed using the damage data for the period of 1993-2002 and validated through 2003-2009, calculating area average total national pluvial flood damage in Japan. The results for Japan showed reasonable agreement with annual damage for the period 1993–2002 in calibration and 2003-2009 in validation. The annual damage variation is well matched with the recorded annual damage in most of the years. The expected annual damage estimated during 1993-2009 by the model (90 billion yen) is also well comparable with recorded average annual damage for the same period (97 billion yen). The average monthly variation of damage is also well matched with the recorded average monthly damage variation, expanding the applicability of the model for seasonal damage estimation. Furthermore, we evaluated uncertainty of our model, basically due to damage data preparation and methodology applied. The regional distribution of expected pluvial flood damage over Japan was also estimated, which reveals that bigger cities had higher absolute damage than smaller cities had. On the other hand, vulnerability of smaller cities seems to be higher than bigger cities. This might be due to lower preparedness for pluvial flooding.

The sensitivity test for different resolution precipitation data shows that the calculated total annual damage is almost insensitive to the horizontal resolution. Flexibility of the model leads us for future projection of pluvial flood damage in Japan and also extending the methodology to entire globe.

Daily precipitation results of multiple climate models were used for Japan to predict future pluvial flood damage under different climate scenarios. The daily precipitation results from MRI-AGCM with 13 different scheme candidates based on their output resolution, convective schemes, and future SSTs (ensemble of three different clusters of CMIP models SST outputs) were used for A1B scenario in far-future [2083-2095]. Five different GCM candidates were used for RCP2.6 and RCP8.5 scenario. The results for ensemble mean of expected annual pluvial flood damage in Japan shows an increment of 105% during far-future [2083-2095] from the base period [1993-2005] in A1B scenario. For this scenario, the pluvial flood damage will be more than double and expected to reach up to 177 (±44) billion yen per year. On the other hand, two RCP scenarios show the ensembles mean increment of about 47% and 247% in RCP2.6 and RCP8.5 respectively during the far-future [2083-2095] from present [1993-2005]. The average annual damage for RCP2.6 scenario will rise up to 116 (±17) billion yen and that for RCP8.5 is 274 (±92) billion yen at 2005 price during the late 21st century. Also inter-annual variations of damage for RCP8.5 scenarios are significantly higher in far-future than that in the present period. The results of average monthly variation show the damage associated with East-Asian monsoon (June-July) and typhoons (Sep-Oct) both are significantly increases in future climate, however there is a large uncertainty among the ensemble members. Long term future run using four different GCMs for RCP2.6 and RCP8.5 scenarios reveals that there is a continuous rising trend of pluvial flood damage amount for RCP8.5 scenario, however the increment rate will be dramatically rise after 2060s, if present socio-economic development level persists in future too.

The model was further applied to estimate pluvial flood damage in the world. The global daily precipitation data (CPC unified gauge based dataset) along with population density, gross domestic product, and topographical slope were utilized with 0.5° spatial resolution. The vulnerability of each country was assumed as an inverse function of human development index (HDI). The vulnerability parameters, optimized for Japan, were converted with inverse relationship of HDI of Japan and other countries. The results of global expected damage distribution from the period (1990-2005) shows that the absolute pluvial flood damage was higher in developed regions for example in Eastern USA, Western Europe and Japan. Eastern China, Northern India, including Bangladesh, Pakistan and some South-east Asian nations also had higher absolute damage value. But, relative damage amount with respect to the corresponding gross domestic product shows Central African nations and South Asian nations had higher vulnerability.

Since the absence of global database for pluvial flood damage, it was hard to validate the results of global estimation of pluvial flood damage directly. The capability of the new model was tested with the expected annual national damage estimated by the model for different countries. The correlation of average annual national damage due to general flood damage recorded in EM-DAT was highly correlated with expected pluvial flood damage estimated by this model, showing its capability to produce the average annual damage in each nation. The expected annual global pluvial flood damage for the period 1990-2005 is estimated to be 6.3 billion USD (2000 price), which is about 25% of total approximate flood damage (25 billion USD) during this period.

The entire work is described in the present dissertation through chapter 1 to Chapter 6. Chapter 1 is an introductory one. Chapter 2 reviews the risk assessment and damage modeling techniques for different flood types, damage types for present and future climate along with their limitations. Chapter 3 describes the formulation of the pluvial flood assessment model with detail description of data and methodology and its evaluation in present. Chapter 4 describes the application of the model for future assessment of pluvial flood in Japan in different climate scenarios. Chapter 5 deals a way to widen the model for global assessment and evaluate the results based on current global database. The final section concludes the study with recommendations.