博士論文（要約）

論文題目　Prediction of Future Flood Damage under Climate Change in Hat Yai Municipality, Thailand

(タイ国ハジャイにおける気候変動下の将来洪水被害予測)

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Flood is a major disaster in many parts of the world especially in urban areas owing to their relatively high potential for causing damage attributed to the areas' dense populations, concentrated infrastructure, and economic activities. Thus, numerous flood management plans have been devised and implemented in highly urbanized areas in order to cope with flooding. However, current flood management plans are unlikely to be adequate in the future because of the non-consideration of impact of climate change on extreme rainfall events, its association with increased floods and consequent flood damage. Such recognition has been recently raised by findings of the Intergovernmental Panel on Climate Change (IPCC). Nevertheless, traditional flood management often neglects impact of climate change into its consideration due to limited information on extreme rainfall events in the future for local impact study. However, very recently, such information that is sufficient for local impact study has become possible. Since the influence of climate change and flood management has scarcely been considered, study clearly demonstrating the feasibility of predicting this influence and applying the predicted findings in the real world is lacking. Moreover, integration of future projections, flood mapping and in-depth damage assessment which is essential for future mitigation plans has been also lacking. Hence, this study was conducted to demonstrate an integrated flood management concept to cope with future flood stimulated by climate change. In this study, the concept was applied to Hat Yai Municipality in Khlong U-Taphao Basin in southern Thailand which is extremely vulnerable to flooding as experienced from the great floods in the area in 2000 and 2010 causing considerable economic and social damage. The region under study has statistically experienced increased magnitude and frequency of extreme rainfall events.

The objectives of this study were: (1) to determine the changes in characteristics of extreme rainfall events caused by climate change in the future, (2) to investigate the consequent changes in flood magnitudes and to estimate spatial distribution of flood depth, (3) to develop quantitative damage functions for assessment of flood damage in the future with the current management plan, and finally, (4) to propose effective flood-alleviation measures to cope with floods in the future. Descriptions of the methods, models and major findings are summarized below.

Initially, investigation of changes in extreme rainfall events caused by climate change using statistical downscaling approach named SDSM to convert information of large-scale GCMs to station-scale was conducted. Twenty one atmospheric variables of one NCEP/NCAR reanalysis of 1981-2000 and two futuristic GCMs namely CGCM3 and HadCM3 under A2 IPCC scenario of 1981-2059 were adopted for downscaling to predict future rain at five rain gauge stations in the basin. For comparative purposes, four daily time series were delineated namely 1981-2000 as baseline period, and 2000-2019, 2020-2039 and 2040-2059 periods for future scenarios.

An algorithm for NCEP predictor selection developed for this study provided a representative set of predictors for downscaling rainfall at rain gauge stations. It was found that atmospheric moisture variables at 500 hPa and 850 hPa were essential because of their representations of water vapour in the air in the area. All of simulated return periods of 3-day rainfall fell within 95%

confidence interval of observation indicating successful regeneration although underestimation was entirely found. Results of future scenarios were contradictory between CGCM3 and HadCM3, in which the former showed significant increases in magnitude and frequency of return periods, while the latter predicted to decrease through 2040-2059. For instance, 3-day rainfall of 20-year return period in baseline period will respectively be that of 7-year and 40-year return periods in 2040-2059 under the CGCM3 and HadCM3 scenarios.

Next, the hydrologic-hydraulic InfoWorks RS 1D model with US-SCS rainfall-runoff module was adopted for investigating consequent changes in hydrological parameters including peak discharge and water level at reference hydrological stations in the basin. Such outputs were used as inputs into the InfoWorks RS 2D for generation of flood map in Hat Yai Municipality. Integration of road elevations and buildings in the municipality into the original ground elevation model was conducted to improve accuracy of depth generation prior to the future impact assessment.

InfoWorks RS 1D successfully reproduced results of discharge and water level especially in terms of peak magnitude at hydrological stations located before (X90) and inside (X44) the municipality in three historical extreme rainfall events. By integrating road elevations and buildings into 2D model, it significantly improved the accuracy of depth generation compared with 1D in which the average absolute difference was respectively 0.45 m and 0.32 m for 1D and 2D in comparison with the observed depths in the 2010 flood. Using downscaled return periods of 3-day rainfall of CGCM3 and HadCM3 scenarios, flood maps of 20-year, 50-year and 100-year return periods were generated. It was found that the current alleviation plan capable of coping with 20-year return period will be inadequate from 2020-2039 under the CGCM3 scenario. In contrast, there is no any necessity for further plan for managing 20-year return period under HadCM3. From the findings, high depth area was located in the center and upstream of the municipality respectively due to their lower elevations relative to the surrounding areas and in view of the road acting as flood barrier in the downstream part of the basin.

Damage functions representing relationship of damage in monetary value (Baht) per building and depths were established by conducting a survey on the 2010 flood to collect necessary information mainly including building information, damage, and awareness time. Face-to-face questionnaire interview methodology was applied in this survey. Buildings in Hat Yai Municipality were categorized into detached house (DH), town house (TH), row house (RH), service industry plus health care (SI+HC) and offices including government, state enterprises and public utilities (OF+GO), to reflect difference in socioeconomic classes and activities, and the corresponding sample sizes were respectively 50, 50, 50, 103 and 84 respondents. Owing to difficulties in obtaining actual damage of particular types of structure and contents, multiplication of replacement cost by deterioration value was applied instead as damage cost. Other types of damage such as vehicle damage, associated clean-up costs and loss of income were determined in all building categories. In addition, stock damage was solely considered in SI+HC because of its nature of building activity while business rehabilitation costs were included only for SI+HC and OF+GO. Total tangible damage was determined by the summation of damage calculated from valid damage function of each building based on type of consideration.

It was found that more than 35% of total respondents were unaware of the flood, and major source of information leading to awareness came from neighbour communications, radio broadcasts and government's flags installed in particular areas. Most of the respondents experienced flood depth of 151-200 cm with duration of 1-3 days. In this study, valid damage function for calculation of total tangible damage included structural damage, damage to contents and stock damage of SI+HC. Remaining invalid functions referred to complexity from people's damage prevention strategies and method for restoring damaged components to be solely explained by flood depths. Damage results referring to the 2010 flood based on the simulated 2010 flood map by the developed InfoWorks RS 2D indicated that DH, RH and SI+HC were in similar magnitude of total tangible damage, and structural damage was responsible for the highest portion. However, considering in term of average damage, SI+HC was the highest. It is noteworthy that SI+HC is densely located in the center of the municipality where flood depth is relatively higher than other areas. Climate change under A2 IPCC scenario will cause significant increase in damage in which by 50-year return period in 1981-2000, 2000-2019, 2020-2039 and 2040-2059 to be respectively 670, 614, 1,070 and 1,700 million Baht under CGCM3, while it will be respectively 670, 472, 270 and 31 million Baht under HadCM3 in case of the current alleviation plan. Additional finding in this part referred to investigation of influence of awareness time availability on damage to contents. By comparing damage to contents of all building types categorized by availability of awareness time before the flood reached the building with no awareness time, significant reduction of damage to contents varying with time availability was discovered in case of 1-hour, 2-hour, 4-hour and 8-hour advanced awareness times. For instance, with 8-hour awareness time at 300 cm depth it can save 50.7% of total damage to contents. This indicated that flood warning systems can be considered as one of the alleviation plan options as demonstrated in the later part of the study.

Furthermore, investigation of outbreak of Diarrhea and Leptospirosis in the future was conducted. By referring to records of Songkhla Public Health on patients and definition of epidemic period of flood-related disease from the past study, linear relationship of number of infected people divided by flood depth area and flood depths in the range of 50 cm until 300 cm was developed. Clear relationship was found in case of Leptospirosis while it was weaker in Diarrhea case. The latter was due to combination of people infected by the flood and those infected not by the flood which was not possible to be distinctly separated, thus solely using flood depths cannot clearly capture the trend. Moreover, sensitivity of depth area in 1-50 cm range to the patient density was another cause of this weak correlation. Corresponding to previous findings, by magnitude of 100-year return period in 2040-2059, risk of Leptospirosis will be 2.13 times higher than that in 1981-2000 under CGCM3 whereas it will be about 1.66 times risk reduction in HadCM3. In the Diarrhea case, more than two times increase in risk was found in 50-year and 100-year return periods in 2040-2059 compared with 1981-2000 under CGCM3. In HadCM3, 50-year return period will not cause serious risk of both diseases in 2040-2059.

In the last part of this study, seven alleviation plans were designed and assessed in their damage reduction potentials in the future. Plans considered in this study included: Plan (1) 100% conversion of rubber plantation which has hitherto occupied 66.2% of the total basin area to agroforestry; Plan (2) warning systems of 1-hour, 2-hour, 4-hour and 8-hour advanced awareness; Plan (3) enlargement of Khlong Ror 1 cross-sections; Plan (4) combination of (1) and (2); Plan (5) combination of (2) and (3); Plan (6) combination of (1) and (3); and Plan (7) combination of (1), (2) and (3).

Apart from Plan (2), all are capable of coping with 20-year return period of CGCM3 until 2020-2039 which is not manageable by the current plan. Moreover, from 2020-2039, 50-year return period of HadCM3 will not cause any damage. In addition, Plan (1) and Plan (2) are capable of coping with 50-year return period of CGCM3 until 2000-2019 and the whole considered periods in HadCM3 are preventable. Furthermore, 20-year return period of CGCM3 in 2040-2059 is effectively coped with. Moreover, 100-year return period of HadCM3 will be almost manageable by the plans in 2000-2019 and completely manageable from 2020-2039.