Uncertainty Estimation and Reduction Measures in the Process of Flood Risk Assessment with Limited Information

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Executive Summary

In 2012, 328 natural disasters occurred in the world, leaving 10,783 killed and 104 million affected and causing US$142 billion damage. Of those disasters, 129 (40%) disasters claimed 6,032 fatalities (55.9%), 72 million affected people (69.2%) and caused US$32 billion (23.0%) damage in Asia alone. Although efforts are being made to reduce disaster risk, fatalities and economic damage by natural disasters are still markedly high. Obviously, it is due to rapid population growth, urbanization and globalization of economy. Especially, the impact of natural disasters causes serious damage to many aspects of societies in Asia.

Recently, hot discussions are being made on mainstreaming of disaster risk reduction in relation to post Millennium Development Goals and post Hyogo Framework for Actions in United Nations. Mainstreaming of disaster risk reduction links to pre-disaster measures. Flood risk assessment is a necessary activity to identify appropriate risk reduction measures in terms of flood disasters.

Flood-prone countries, such as Japan, have been working hard to enhance flood risk assessment by establishing legal status and developing detailed methodological guidelines. However, developing countries are still not paying close attention to this field. Comparison studies on flood risk assessment between Japan and developing countries are cited for basic understanding of the present global situation of flood risk assessment.

Even Japan has had extremely severe experiences, for example, when Rikuzentakata, along with other coastal cities, was hit by the Great East Japan Earthquake and Tsunami in 2011. Similarly, the 2011 Chao Phraya River flood in Thailand caused serious damage to industrial parks, which immediately impacted the world economy. In both cases, if appropriate risk assessment had been implemented and results had been disseminated prior to disasters, damage would have been mitigated. Field interview survey results clearly shows that such damage is attributable to lack of risk assessment.

Since developing countries are particularly vulnerable to natural disasters and will be affected seriously by climate change in the near future, the author decided that the target should be developing countries for better understanding the present status of flood risk assessment. However, uncertainty is highly problematic in the process of flood risk assessment especially in developing countries. This study estimated the degree of uncertainty contained in each step, and identified influential steps of flood risk assessment by reviewing the entire risk assessment process in a developing country and referred the results with past studies addressing the same issue in developed countries. The results show clear difference between both cases in data and information unavailability. Three major points were identified from this study: 1) Uncertainty can greatly influence the quality and availability of data and information; 2) Data unavailability in some developing countries is a serious problem. Especially, collection of damage loss data is an urgent matter; and 3) Uncertainty is also linked to model calculation. Scientists and engineers should have adequate understanding of objectives and expected results during the process of risk assessment.

The propagation of uncertainty from each independent step was also explained and the possibility of convergence of uncertainty from each step was found. Furthermore, another potential location of uncertainty was also discussed. The study conducted on uncertainty in flood risk assessment as a holistic mechanism in a poor data situation in a developing country is unique and challenging, since no similar study has conducted before.

Conventional procedures to review data and check records are the most fundamental and important actions. In addition, utilizing satellite information and additional cross-checking processes can be useful. However, it is urgent for developing countries, as well as developed countries, to start collecting disaster data extensively. Then, accuracy needed for flood risk assessment can be easily assured with assistance of technology.

At the end, the author would like to stress the necessity of enhancement of effective data collection and analysis, as well as the improvement of the entire flood risk assessment methodology. Furthermore, a lot of problems still remain unsolved for ideal water-related risk management.

Finally, the author hopes that this thesis will be utilized to encourage discussions and strengthen research towards further mainstreaming of disaster risk reduction locally and internationally, especially for developing countries to promote sustainable development.

概　要

2012年は、世界で328の自然災害が発生し、10,783人が死亡し、1億4百万人、1千4百億ドルの影響を及ぼした。その災害のうち129(40%)、6,032人(55.9%)の死者、7千2百万人(69.2%)への影響、320億ドル（23.0%）の被害がアジアだけで生じている。災害リスク低減への努力は行われてきているものの、自然災害による死者や経済影響はいまだ大きい。明らかにこれは急激な人口増加、都市化の進展、経済のグローバル化に寄るところが大きい。特に自然災害の影響はアジアの多くの側面に深刻な被害を生じることとなる。

最近、災害リスク低減の主流化という熱い議論が国連の次期ミレニアム開発目標や兵庫行動枠組に関連して行われている。災害リスク低減の主流化とは、災害前の事前対策と関係が深い。洪水リスクアセスメントというのは洪水災害に関する適切なリスク低減方策を特定する欠かせない取り組みである。

日本のような洪水頻発国では、法的な整備、詳細な手法、ガイドラインの策定などに洪水リスクアセスメントを強化する取り組みを行ってきている。しかしながら、途上国ではまだこの分野に対しては十分な取り組みが行われているとは言えない。洪水リスクアセスメントについての日本での取り組み、途上国での取り組みを、現状の世界の洪水リスクアセスメントの基本的理解のために紹介している。

日本ですら、かなりひどい経験をしてきている。例えば、陸前高田市と海岸線の市町村が2011年の東日本大震災と津波では被災している。同様に2011年のタイのチャオプラヤ川洪水では世界経済へ直ちに影響を及ぼすほど工業団地が深刻な被害を受けた。両方のケースにおいて、適切にリスクアセスメントが行われ、その結果が災害前に適切に周知されていれば、被害ももっと低減できたものと思われる。現地でのインタビュー調査結果はリスクアセスメントの欠如がこのような被害の原因であると明確にいえることがわかっている。

途上国は特に自然災害に対して脆弱で近い将来の気候変動による影響は深刻にうけるものと思われるので、著者は途上国に的を絞り、洪水リスクアセスメントの現状をよりよく理解することが必要との認識に至った。しかしながら、特に途上国においては、洪水リスクアセスメントの各段階における不確実性というのはかなり大きな問題である。この研究は不確実性の程度を各段階において

評価して、先進国で行った他の研究事例の結果を参考として、途上国での全体の洪水リスクアセスメント評価によって、最も影響が大きい段階はどこかを特定する。結果は明確にデータと各種情報の存在状況によって明確に異なっている。主に 3 点がこの研究から明らかになった。1)不確実性はデータ、情報の質と存在状況により大きく影響を受ける。2)いくつかの途上国におけるデータの不存在状況は深刻なものがある。特に被害データの収集は喫緊の課題である。3)不確実性はまた計算モデルにも関係している。科学者、技術者はリスクアセスの各段階において目的とどのような結果が求められているかを十分に理解した上で取組む必要がある。

それぞれ独立した検討段階からの不確実性の伝搬が説明でき、それぞれの段階での不確実性の縮小の可能性があることがわかった。さらに、今回の検討以外にも不確実性が生じる可能性があると言われている。途上国におけるデータ存在が厳しい中での洪水リスクアセスメントの各段階による不確実性についての研究は、他ではない非常に珍しく、困難であるが興味深い取り組みである。

データを精査して、記録をチェックするという従来型の方法は最も基礎的で重要な手法である。さらに、衛星情報や複数データの照合検査の役に立つ。しかしながら、途上国では、先進国も同じであるが、災害のデータを精力的に収集し始めることが喫緊に取組まねばならない。洪水リスクアセスメントに必要な精度は技術の支援で簡単に得られることができることになる。

最後に、著者は有効なデータの収集と解析を強化することの重要性を、洪水リスクアセスメント手法全体のさらなる改善と同じように強調したい。さらに、理想的な水災害関連リスクマネジメントに向けてはまだかなり多くの課題が残されていることを強調したい。

おわりに、この論文が、特に持続可能な開発を促進させなければならない途上国を始めとする、災害リスク低減主流化についての地域的および世界的なさらなる議論の活発化と研究の強化に活用されることを願ってやまない。

Abbreviations

ADB	- Asian Development Bank
ADRC	- Asia Disaster Reduction Center
AMCDRR	- Asian Ministerial Conference on Disaster Risk Reduction
ASEAN	- Association of South-East Asian Nations
BAS	- Bureau of Agricultural Statistics
BOI	- Board of Investment
BTOP	- Block-wise TOP model
CRED	- Centre for Research on the Epidemiology of Disasters
CV	- Coefficient of Variance
DALA	- Damage and Loss Assessment
DDPM	- Department of Disaster Prevention and Mitigation, Thailand
DEM	- Digital Elevation Model
DRR	- Disaster Risk Reduction
EGM	- Expert Group Meeting (on Improving Disaster Data to Build Resilience in Asia and the Pacific)
EM-DAT	- International Disaster Database
FID	- Flood Inundation Depth model developed by ICHARM
FMMP	- Flood Management and Mitigation Programme
FVI	- Flood Vulnerability Indices developed by ICHARM
FVI-AF	- Flood Vulnerability Indices for Average Flood
FVI-EF	- Flood Vulnerability Indices for Extreme Flood
GAR15	- Global Assessment Report 2015
GCM	- Global Circulation Model
GDP	- Gross Domestic Product
GEJET	- Great East Japan Earthquake and Tsunami
GFDRR	- Global Facility for Disaster Reduction and Recovery, World Bank
GIS	- Geographic Information System
GISTDA	- Geo-Informatics and Space Technology Development Agency
GUM	- Guide to the expression of uncertainty in measurement
HDD	- Hard Disk Drive
HFA	- Hyogo Framework for Action
HydroSHED	- Hydrological data and maps based on SHuttle Elevation Derivatives at multiple Scales
IATF	- Inter-Agency Task Force on Disaster Reduction

ICHARM	- International Centre for Water Hazard and Risk Management
IEAT	- Industrial Estate Authority of Thailand
IFAS	- Integrated Flood Analysis System
IFRC	- International Federation of Red Cross and Red Crescent Societies
IKONOS	- IKONOS comes from the Greek word for "image"
IMF	- International Monetary Fund
JAXA	- Japan Aerospace Exploration Agency
JCC	- Japanese Chamber of Commerce
JCGM	- Joint Committee for Guides in Metrology
JETRO	- Japan External Trade Organization
JICA	- Japan International Cooperation Agency
JMA	- Japan Meteorological Agency
JSCE	- Japan Society of Civil Engineers
MDGs	- Millennium Development Goals
MDRR	- Mainstreaming of Disaster Risk Reduction
METI	- Ministry of Economy, Trade and Industry, Japan
MEXT	- Ministry of Education, Culture, Sports, Science and Technology, Japan
MIKE	- hydrologic software developed by Danish Hydraulic Institute
MLIT	- Ministry of Land, Infrastructure, Transport and Tourism, Japan
MMC/NIBS	- Multi-hazard Mitigation Council of the National Institute of Building Sciences
MOC	- Ministry of Construction (former MLIT)
MODIS	- Moderate Resolution Imaging Spectrometer
MRC	- Mekong River Commission
MRCS	- Mekong River Commission Secretariat
NASA	- National Aeronautics and Space Administration
NESDB	- National Economic and Social Development Board, Thailand
NILIM	- National Institute for Land and Infrastructure Management, Japan
PAGASA	- Philippines Atmospheric, Geophysical and Astronomical Services Administration
PDNA	- Post Disaster Needs Assessment
post-MDGs	- reformation of Millennium Development Goals
post-HFA/HFA2	- reformation of Hyogo Framework for Action
PRISM	- Pico-satellite for Remote-sensing and Innovative Space Mission
PWRI	- Public Works Research Institute

REM	- Relative Elevation Model
RID	- Royal Irrigation Department of Thailand
RRI	- Rainfall-Runoff-Inundation model
SAR	- Synthetic Aperture Radar
SD	- Standard Deviation
SMART	- specific, measureable, attainable, realistic and timely
SOP	- Standard Operation Procedure for Policy Evaluation
SRTM	- Shuttle Radar Topography Mission
TA	- Technical Assistance
THB	- Thai Baht
TTJS	- The 2011 Tohoku Earthquake Tsunami Joint Survey Group
UN	- United Nations
UNESCAP	- United Nations Economic and Social Committee in Asia and Pacific
UNISDR	- United Nations International Strategy for Disaster Reduction
UNSGAB	- United Nations Secretary- Generals' Advisory Board
UN Water	- United Nations Inter-Agency Mechanism on all Freshwater
WB	- World Bank
WCDRR	- World Conference on Disaster Risk Reduction
WMCDRT	- the World Ministerial Conference on Disaster Reduction in Tohoku

Table of Contents

Table of Figures

List of Tables

Chapter 1

Introduction

1.1 Background

According to Natural Disaster Data Book 2012[1] of Asia Disaster Reduction Center (ADRC), 328 natural disasters occurred in the world in 2012, leaving 10,783 killed and 104 million affected and causing US$142 billion damage. Of them, 129 (40%) disasters claimed a total of 6,032 fatalities (55.9%), 72 million affected people (69.2%) and caused US$32 billion (23.0%) damage in Asia (**Fig. 1-1**). These figures are higher than those of any other regions in the world except for the economic damage recorded in the United States of America, which was caused mainly by hurricanes and storms. Although the number of natural disasters is declining from the 1980s, more than 300 natural disasters occur worldwide every year. The number of fatalities varies from disaster to disaster, but the 5-year average fatality has been increasing recently. Similarly, the 5-year average economic damage by natural disasters is now clearly maintaining an upward trend (**Fig. 1-2**). Fatalities and economic damage by natural disasters are obviously due to rapid population growth, urbanization and globalization of economy. Especially, the impact of natural disasters causes serious damage in several aspects of societies in Asia.

1 Asia disaster reduction center, 2012.

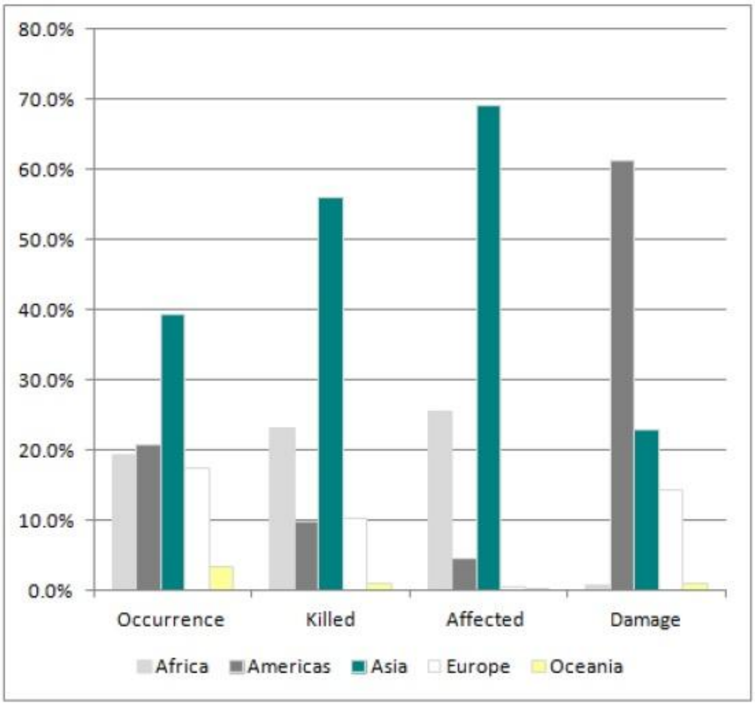

Fig. 1-1 Impacts of Natural Disasters by Regions, 2012[1]

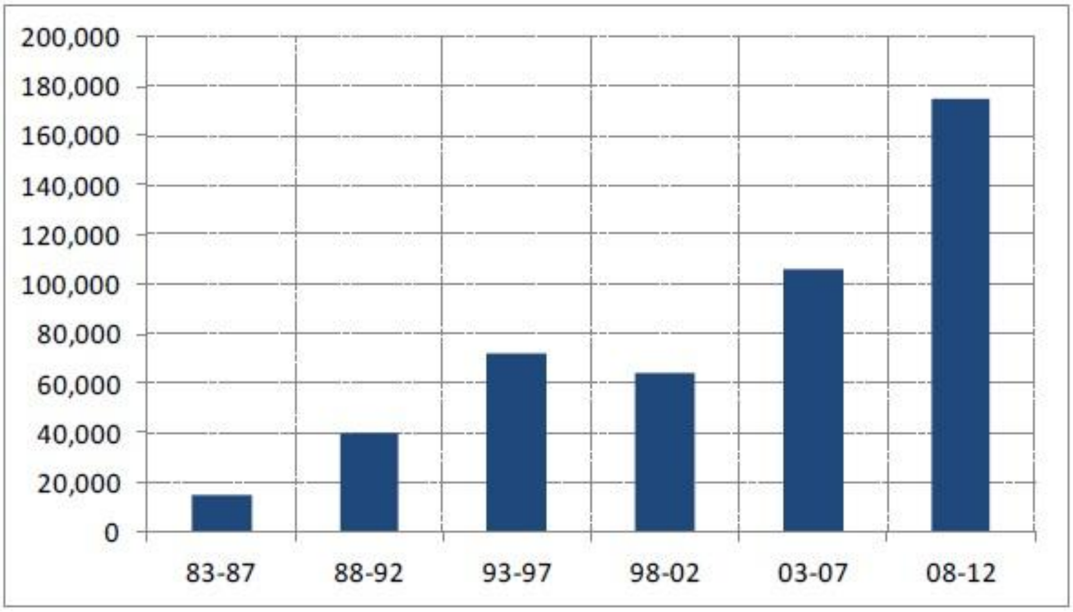

Fig. 1-2 Economic Damage (Average of 5-year period), 1983-2012[1]

In short, impacts by natural disasters have still strong influence over social development in many countries. Especially Asian countries which are experiencing rapid population and economic growth suffer serious damage when hit by large-scale disasters. It may be no exaggeration to say that disasters are the largest obstacle to sustainable development.

Disaster risk reduction is now quite a hot issue in international discussions. The year 2015 is the final year of the Millennium Development Goals (MDGs)[2] for global development projects and also of Hyogo Framework for Action (HFA) for disaster risk reduction[3]. In this regard, the inclusion of the Mainstreaming of Disaster Risk Reduction (MDRR) in all development processes to promote disaster risk reduction is now highlighted in international discussions. In addition, many have voiced the continuation of HFA into its second phase, aiming to increase investment in disaster risk reduction.

The Japanese government that has decided to accept the 3rd World Conference on Disaster Risk Reduction (WCDRR) in Sendai City in March 2015 will have huge responsibility as a major player to contribute to these discussions.

Preparation and prevention prior to disasters and investment in these actions require risk assessment. International discussions on this matter without scientific backgrounds, including well-managed risk assessment, are not valid. This is especially true in developing countries where it is often difficult to find technology and data accuracy needed to promote preparation for and prevention of possible disasters.

The author has come to understand that the promotion of these activates needs more careful research and discussions, and that they should be addressed more carefully from a scientific point of view.

To explain my intention of addressing the uncertainty of flood risk assessment, more explanation should be given about what “Mainstreaming of Disaster Risk Reduction (MDRR)” means with additional information related to this concept. The following are the history and present situation of MDRR, as well as some other background information.

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2 Uinted Nations, 2013.
3 United Nations Office for Disaster Risk Reduction, 2013.

1.2 History of "Mainstreaming of Disaster Risk Reduction"

Recently, the phrase "Mainstreaming of Disaster Risk Reduction" (MDRR) can be seen and heard in many documents and occasions in the field of disaster management. It first appeared in a document of the Inter-Agency Task Force on Disaster Reduction (IATF), which has been discussing the tasks of United Nations International Strategy for Disaster Reduction (UNISDR). The chairperson's opening remarks[4] at the first meeting of IATF in 2000 introduced the four goals of the meeting: *1) Increase public awareness of the risk of natural disasters*; *2) Obtain commitments from public authorities to reduce risks*; *3) Engage public participation to create disaster-resistant communities*; and *4) Reduce the economic and social losses of disasters*. Although the "mainstreaming" issue was not included in these four goals, the report of this meeting[5] later listed the priority future works, which included "Mainstreaming disaster reduction in sustainable development and in national planning." Then, this work also defined as one of the major tasks in UNISDR, and since then it has frequently seen in international documents.

At the same time, the project of ProVention Consortium was established in February 2000 with support from the World Bank, declaring MDRR as one of its major activities. What does MDRR mean? The publication of ProVention[6] introduced the definition of MDRR as "*there has been increasing recognition of this need to 'mainstream' disaster risk reduction into development – that is, to consider and address risks emanating from natural hazards in medium-term strategic frameworks and institutional structures, in country and sectorial strategies and policies and in the design of individual projects in hazard-prone countries. A number of development organizations have begun efforts to mainstream disaster risk reduction into their work, undertaking various related institutional, policy and procedural changes and adjusting operational practice.*"

The activities and the acronym spread around the world at once because of this project and other activities which had been advocating MDRR.

Furthermore, the World Ministerial Conference on Disaster Reduction in Tohoku (WMCDRT), 2012, which the Japanese government organized, also emphasized the importance of MDRR. At the chapter of "Towards Mainstreaming Disaster Reduction"

4 Ms. Carolyn McAskie, 2000.
5 Inter-Agency Task Force for Disaster Reduction, 2000.
6 Charlotte Benson et al., 2007.

in the declaration of WMCDRT[7], the following sentences are found; *a) The participants underscored the need to mainstream disaster reduction at every level of public policy by prioritizing it, b) allocating sufficient financial resources to it. c) the central responsibility of governments and the importance of ensuring the national ownership of disaster reduction, and d) they also affirmed important roles borne by regional and international organizations*. Furthermore, at the following paragraphs, the good preparation at the planning stage was also emphasized as follows, "*prioritization should be made in the planning of preparedness in order to effectively allocate limited human and financial resources for responding to such threats.*"

In line with discussions on MDRR, the major discussion is under way about the reformation of Millennium Development Goals (post MDGs), for the present MDGs will be due and terminated in 2015. Water-related meetings are also discussing how to prepare for this new MDGs, and a recommendation that disaster targets should be incorporated into post-MDGs has prepared by these water-related meetings, e.g., thematic session on water and disaster in New York in March 2013[8], the High Level Expert and Leaders Panel on Water and Disaster in Japan in June 2013, and Budapest conference in October 2013[9]. The UN Water, a collaborative group among water related UN organizations[10], is also preparing a recommendation to emphasize the importance of tackling issues regarding water related disasters[11].

Major activities on disaster risk reduction are also under way to prepare a post Hyogo Framework for Action (post-HFA) by 2015 based on the present HFA. The first round of international consultation was completed in May 2013, and the second round has been conducting for the key areas based on the first round consultation as follows: 1) Building community resilience – turning vulnerability into resilience; 2) Sustainable development, climate change and disaster risk reduction integration; 3) Local level action; 4) Women as a force in resilience building, gender equity in Disaster Risk Reduction (DRR); 5) Reducing exposure/underlying risk factors, 6) Strengthening risk governance and accountability; and 7) Incentivizing DRR in the private sector[12]. The players of the Asia regional consultation has been selected as coordinators in each key area, and the interested groups has been contributing to each key area in consultation

7 Chair's Summary, 2012.
8 United Nations Secretary-Generals' Advisory Board on Water and Sanitation, 2013.
9 Budapest Water Summit, 2013.
10 UN Water, 2013.
11 T. Inoue, 2013.
12 United Nations International Strategy for Disaster Risk Reduction Asia and Pacific, 2013.

with the key area coordinators. These contributions will be summarized into recommendations and submitted to the 6th Asia Ministerial Conference on Disaster Risk Reduction (AMCDRR), which will be an important milestone of the second consultation.

In parallel, UNISDR headquarters is also working on each specific topic. The Global Assessment Report 2015 (GAR15) shows important activities to collect scientific contributions and prepare the main report for describing the present situation in terms of scientific views on disaster risk reduction. The author with colleagues at the International Centre for Water Hazard and Risk Management (ICHARM) in Public Works Research Institute (PWRI) is now in preparation for both Asian consultation and GAR15 for the development of Global Flood and Drought Risk Indices, which are SMART (specific, measurable, attainable, realistic and timely) indicators with scientifically reliable background.

The decision has been made by the Japanese government to host the 3rd WCDRR in Sendai City in March 2015, following the first conference in Yokohama in 1995 and the second conference in Kobe in 2005. The Official announcement of this decision was made at the closing ceremony of the Global Platform in Geneva in June 2013 by the parliamentary secretary for disaster risk reduction. It will be delivered to the General Assembly of the United Nations soon, and should be officially approved in the meeting. The decision came from Japan's responsibility to contribute Japanese technology on disaster risk reduction to the international society as the consequence of severe experiences with several disasters, especially the Great East Japan Earthquake in 2011.

1.3 The International Recognition on the Importance of Water Related Disaster Risk Assessment

There is another important discussion on MDRR, which is the importance of preparedness prior to disasters and investment in disaster risk reduction.

At the 2nd WCDRR in Kobe and the following period after that, forecasting and warning were major issues, and investment from most donors was spent for those issues because of the 2004 Indian Ocean Tsunami disaster. Forecasting and warning are important to reduce fatalities by disasters, but cannot reduce economic damage. The international society have now come to the common understanding on disaster risk reduction that disaster prevention and investment prior to disasters should be prioritized for sustainable development of developing countries[13].

The ProVention publication introduces the following explanation:

Disaster risk reduction pays

- *A Vietnam Red Cross mangrove planting programme implemented in eight provinces in Vietnam to provide protection to coastal inhabitants from typhoons and storms cost an average US$ 0.13 million a year over the period 1994 to 2001, but reduced the annual cost of dyke maintenance by US$ 7.1m. The programme also helped save lives, protect livelihoods and generate livelihood opportunities.*[14]
- *Spending 1 per cent of a structure's value on vulnerability reduction measures can reduce probable maximum loss from hurricanes by around a third in the Caribbean, according to regional civil engineering experts.*[15]
- *One dollar spent by FEMA on hazard mitigation generates an estimated US$ 4 on average in future benefits according to a study of FEMA grants (including for retrofitting, structural mitigation projects, public awareness and education and building codes).*[16]
- *Only two schools were left standing in Grenada after the passage of Hurricane Ivan (September 2004). Both had been subject to retrofit through a World Bank initiative. One of the schools was used to house displaced persons after the event.*[17]

Although some information should be reviewed for its quantification background, disaster risk reduction prior to disasters is now recognized as an important action in international discussions with justifications of the cost required for disaster risk reduction.

Furthermore, at the 4th AMCDRR held in Incheon in October 2010[18], the emphasis of preparedness and increase of investment was discussed and added to its declaration as follows:

"*On promoting investments on DRR & CCA: to build capacities to track DRR investments, evaluate financial and economic costs and benefits of DRR to promote greater investments in reducing disasters in the region, promote comprehensive*

13 K. Takeya et al., 2013.
14 International Federation of Red Cross and Red Crescent Societies, 2002.
15 World Bank, 2000.
16 Multihazard Mitigation Council of the National Institute of Building Sciences, 2005.
17 World Bank, 2004.
18 Fourth Asia Ministerial Conference on Disaster Risk Reduction, 2010.

preparedness planning to mitigate the impacts of disasters, advocate the international donor community to increase its funding support for regional and national activities for DRR and HFA implementation, and apportion at least 10 percent of humanitarian assistance and 2 percent of development investment resources and funding for DRR by 2015".

In short, the importance of preparedness and prevention before disasters is widely recognized in line with MDRR, and risk assessment, the major process of pre-disaster measures, is also increasingly becoming mandatory. Furthermore, the technology of risk assessment needs improving, because accuracy of methodology is essential in appropriate risk assessment.

Research on technology of risk assessment, especially research on uncertainty, should be also improved and encouraged in keeping up with this political movement.

1.4 Aims and Scope

As described earlier, the international society has recognized that the importance of disaster prevention and investment prior to disasters. It must be urgently necessary to enhance disaster risk assessment as a technology to identify pre-disaster measures based on the needs of individual societies. On the other hand, there are still some problems to implement disaster risk assessment due to lack of data and information related to disasters in developing countries. In order to disseminate pre-disaster measures, problems need to be solved and risk assessment needs to be made easier to apply so that it can be used as a useful tool for disaster prevention by more decision makers.

In this thesis, the following items are described to provide better understanding of flood risk assessment and show appropriate directions to take by reviewing recent discussions in the international society on disaster risk reduction, identifying the needs of individual societies, understanding the present situation of disaster risk assessment, identifying present problems to implement disaster risk assessment, making proposals for improvement, and proposing future research topics as conclusions.

The thesis aims to identify the direction of improvement of disaster risk assessment, and it targeted at "flood" disasters, which are still the major natural hazard to the world. More specifically, it highlights uncertainties during the process of flood risk assessment and problems related to uncertainty found in the process of flood risk assessment in developing countries. It also addresses ways to reduce uncertainty contained in results. The thesis is considered as the first challenge to tackle the issue of uncertainty reduction in disaster risk assessment, although previous research has been done to identify uncertainty on flood risk assessment in developed counties. This research will help especially developing countries to enhance and accelerate flood risk reduction for building communities resilient to natural disasters.

1.5 Outline of the Thesis

This thesis is composed of six chapters, including this chapter, to help better understand the present situation of disaster risk reduction and limitation of technology and to show a further direction of research in this area. (**Fig.1-3**)

The first chapter as an introduction of the thesis introduces the general background on a recent trend of disaster risk reduction discussion in the world and the author's motivation to study flood risk assessment. Especially, the chapter highlights recent hot discussions on the mainstreaming of disaster risk reduction related to post-MDGs and post-HFA in United Nations. The mainstreaming of disaster risk reduction links to pre-disaster measures. Flood risk assessment is a necessary activity to identify appropriate risk reduction measures in terms of flood disasters.

In **Chapter 2**, flood risk assessment is introduced with descriptions of its process, technologies and methodologies. Flood risk assessment in Japan is introduced along with its legal status and detailed methodological guidelines. Using a Japanese case, examples of flood risk assessment in developing countries are also introduced. Comparison studies on flood risk assessment between Japan and developing countries are cited for basic understanding of the present situation of flood risk assessment.

In **Chapter 3**, in order to understand the importance of risk assessment, two examples in recent disasters are introduced; one is the 2011 Chao Phraya River flood in Thailand and the other is the Rikuzentakata city case hit by the Great East Japan Earthquake and Tsunami in 2011. In both cases, parts of the countries were seriously damaged by large disasters. If appropriate risk assessment is implemented and results are disseminated prior to disasters, damage should be mitigated compared with that in the last disasters. Field interview survey with affected residents and factories conducted after the disasters clearly shows that such damage is attributable to lack of risk assessment.

In **Chapter 4**, the author estimated the degree of uncertainty contained in each step of flood risk assessment by reviewing the entire process of flood risk assessment described in the second chapter. Research on uncertainty is well known with the Global Circulation Models (GCM) for climate change projection, which are available several models and shows different results for climate change projection. Ensemble experiments are implemented to identify uncertainty of climate change model projection. However, uncertainty research can hardly be seen in terms of flood risk assessment. H. Apel et al.[19] and B. Merz et al. [20] conducted research on the uncertainty of flood risk assessment in Cologne city at the Rhine River. The challenge in this chapter was to conduct an experiment on uncertainty estimation in the process of flood risk assessment in a developing country which seriously lacks data and other information on past disasters. This experiment is carried out to identify on how and where large uncertainty exists in the process of flood risk assessment in the developing country.

Chapter 5 introduces technologies to overcome problems in proper flood risk assessment described before. The establishment and installment of observation and disaster database systems and maintenance systems are essential to solve such problems, but it takes several years or more and a large budget to complete them perfectly. Therefore, utilization of satellite information should be considered as effective measures to collect useful information, although its accuracy is sometimes not enough for precise analysis. Some possible technologies to reduce uncertainty for better risk assessment results are introduced in this chapter.

Chapter 6 will wrap up all conclusions in this thesis and gives an overall conclusion. At the end of the chapter, some research topics will be proposed and introduced for improvement of flood risk reduction and related activities, some of which have already been tackled by the author and his colleagues.

Finally, the author hopes that this thesis can be utilized to encourage discussions and strengthen research towards further mainstreaming of disaster risk reduction internationally and locally, especially for developing countries for sustainable development.

19 H. Aple et al., 2006.
20 B. Merz et al., 2009.

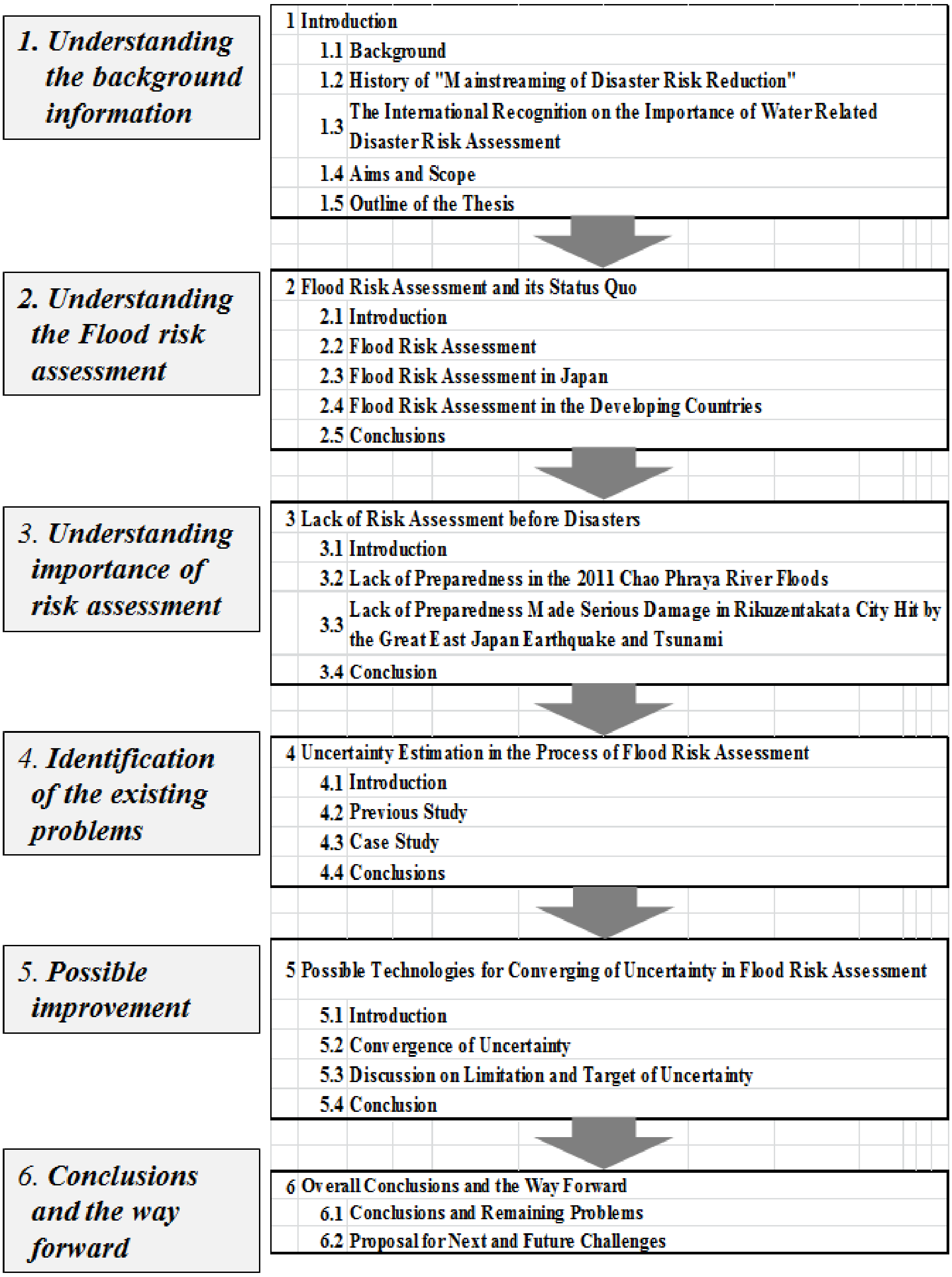

Fig. 1-3 Structure and flow chart of the thesis

References

1. Asia disaster reduction center (ADRC), Natural Disaster Data Book 2012.

2. United Nations, We can End Poverty - Millennium Development Goals and Beyond 2015-, access at 2013. http://www.un.org/millenniumgoals/

3. The United Nations Office for Disaster Risk Reduction, Hyogo Framework for Action (HFA), access at 2013. http://www.unisdr.org/we/coordinate/hfa

4. Ms. Carolyn McAskie, Introductory Statement by the Chair, Emergency Relief Coordinator, a.i., Inter-Agency task Force for Disaster Reduction, Geneva, 27-28 April 2000.

5. Inter-Agency task Force for Disaster Reduction First meeting, Summary Record and Conclusions, Geneva, 27-28 April 2000.

6. Charlotte Benson and John Twigg with Tiziana Rossetto, Tools for Mainstreaming Disaster Risk Reduction: Guidance Notes for Development Organizations, ProVention consortium, January 2007.

7. The World Ministerial Conference on Disaster Reduction in Tohoku, Chair's Summary, Tohoku, July 3rd and 4th, 2012.

8. United Nations Secretary-Generals' Advisory Board on Water and Sanitation (UNSGAB), Focus action on Water and Disasters, access at 2013. http://www.unsgab.org/index.php?menu=227

9. Budapest Water Summit – Giver the future a chance! – 8-11 October 2013, access at 2013. http://www.budapestwatersummit.hu/

10. UN Water, This is UN-Water, access at 2013. http://www.unwater.org/discover.html

11. T. Inoue, International Framework for Mainstreaming Disaster Reduction, Magazine River (Kasen), July 2013 (in Japanese).

12. UNISDR Asia and Pacific, distributed paper "Call for Expressions of Interest, Inputs for Post 2015 Framework for DRR (HFA2) from the Asia Pacific Region", September 2013. http://www.unisdr-apps.net/confluence/display/iap09/IAP+Meeting+Home

13. K. Takeya and M. Nagaishi, JICA's Approach Toward Mainstreaming Disaster Risk Management, Magazine River (Kasen), July 2013 (in Japanese).

14. International Federation of Red Cross and Red Crescent Societies (IFRC), World Disasters Report: Focus on reducing risk, Geneva: International Federation of Red Cross and Red Crescent Societies, 2002.

15. World Bank. Managing Catastrophic Risks Using Alternative Risk Financing and Insurance Pooling Mechanisms. Discussion draft. Washington, DC: World Bank, Finance, Private Sector and Infrastructure Department, Caribbean Country Management Unit, Latin America and Caribbean Region, 2000.

16. Multihazard Mitigation Council of the National Institute of Building Sciences (MMC/NIBS), Natural Hazard Mitigation Saves: An Independent Study to Assess the Future Savings from Mitigation Activities. Washington, DC: Multi-hazard Mitigation Council of the National Institute of Building Sciences, 2005.

17. World Bank. Grenada, Hurricane Ivan: Preliminary Assessment of Damages, September 17, 2004. Washington, DC: World Bank, 2004. http://siteresources.worldbank.org/INTDISMGMT/Resources/grenada_assessment.pdf

18. Fourth Asia Ministerial Conference on Disaster Risk Reduction, Incheon Declaration on Disaster Risk Reduction in Asia and the Pacific 2010, Incheon, Republic of Korea, 25-28 October 2010.

19. H. Apel, A. H. Thieken, B. Merz, and G. Blöschl, “A probabilistic modeling system for assessing flood risks”, Natural Hazards (2006) 38: 79-100; DOI: 10.1007/s1069-005-8603-7, 2006.

20. B. Merz and A. H. Thieken, “Flood risk curves and uncertainty bounds”, Natural Hazards, 51, 3, 437-458; DOI:10.1007/s11069-009-9452-6, 2009.

Chapter 2

Flood Risk Assessment and its Status Quo

2.1 Introduction

In this chapter, flood risk assessment is described with its all steps, technologies and methodologies. Flood risk assessment in Japan is introduced as an example with its legal status and detailed methodological guidelines. Using a Japanese case, examples of flood risk assessment in developing countries are also introduced. Comparison studies on flood risk assessment between Japan and developing countries are carried out for basic understanding of the present situation of flood risk assessment.

Through this chapter, discussion is made about the importance of flood risk assessment as pre-disaster activities to identify necessary actions for flood risk reduction and to clarify present problems on flood risk assessment, especially the issue of uncertainty in each risk assessment step. When flood risk assessment is conducted in developing countries, problems related to uncertainty often emerge. The chapter is devoted to explain the current situation of flood risk assessment to help understand it better.

2.2 Flood Risk Assessment

This chapter describes the definition, status and procedure of flood risk assessment in Japan. Following a Japanese case, other cases in developing countries are introduced for basic understanding of flood risk assessment.

Flood risk assessment can be improved at several levels. At the preliminary level, it is important to have good understanding of past disasters. Such understanding leads to good preparedness for future disasters. The next level is improvement of statistical technology. Better technology can produce better projection of future disasters. The next progress is based on scientific technology for reproduction by simulation and assessment of a hazard of a certain magnitude with probability analysis of past hazard records. The final level is preparation of countermeasures based on damage assessment and cost effectiveness assessment.

However, in developing countries, it is very difficult to conduct final level of flood risk assessment because of unavailability of past disaster records including meteor-hydrological data. The projection of hazards and expected damage is necessary for damage assessment; without this process, cost benefit analysis and preparing countermeasures for risk reduction, which is required to make informed decisions, cannot be made. Lack of data and information causes serious problems for future development.

After the explanation of a Japanese case, cases of developing countries are introduced. These case studies can help us better understand the present status of flood risk assessment for discussing problems.

2.2.1 Definition of Flood Risk Assessment

According to the 2009 UNISDR Terminology on Disaster Risk Reduction[1], Risk assessment is defined as "*A methodology to determine the nature and extent of risk by analysing potential hazards and evaluating existing conditions of vulnerability that together could potentially harm exposed people, property, services, livelihoods and the environment on which they depend.*" Flood risk assessment is a methodology composed of flood hazard analysis and vulnerability assessment, and the nature and extent of damage must be identified from both results. In short, identifying expected damage by a certain magnitude of a hazard (flood) should be the final result of flood risk assessment.

2.2.2 Procedure of Flood Risk Assessment

The investigation volume of the River and Sabo Technical Standard of Japan (June 2012) (hereinafter "the Standard") describes the protocol of water related disaster risk assessment (**Fig.2-1**) in Japan. As explained in Chapter 9 of the Standard, the flood risk assessment procedure consists of: 1) collecting and arranging precipitation data; 2) collecting and arranging discharge data; 3) flood discharge and inundation calculation; 4) hazard and vulnerability investigation; and 5) risk assessment analysis.

In addition to this explanation in the Standard, a hazard is defined as "*A dangerous phenomenon, substance, human activity or condition that may cause loss of life, injury or other health impacts, property damage, loss of livelihoods and services, social and economic disruption, or environmental damage*". Its magnitude is explained in the non-dimensional probability. Vulnerability is defined as "*The characteristics and*

1 UNISDR, 2009.

circumstances of a community, system or asset that make it susceptible to the damaging effects of a hazard". It means vulnerability must be explained in terms of human casualty or economic losses; in other words, the number of fatalities or monetary value. Risk is defined as "*The combination of the probability of an event and its negative consequences*". It means that risk is expressed as the product of hazard multiplied by vulnerability; furthermore, risk should be shown in probability and damage.

This relation is explained in the Pressure and Release[2] model in the following equations.

$$\begin{aligned} \mathrm{R} = \mathrm{H} \times \mathrm{V} &= f(Hazard, Vulnerability) \\ &= f(Hazard, Exposure, Basic\ Vulnerability, Capacity) \end{aligned} \quad \textbf{(2.1)}$$

The basic structure and framework of flood risk assessment should not be different. In this thesis, author conducted flood risk assessment following this protocol, estimated uncertainty in the assessment of precipitation and river discharge data collection and classification, performed flood reproduction calculation and risk assessment, and evaluated the amount of total uncertainty on final flood risk assessment results.

2.2.3 Difficulty of Flood Risk Assessment

This thesis reviews the difficulty of two major stages in the process of flood risk assessment. One is the difficulty during data collection, and the other is during data analysis. Problems typically lie in data quality and quantity as well as time and cost.

(1) Problems on data quality and quantity

In the second section in Chapter 2 of the Standard, the arrangement of ground observation stations is described. First, one station should be installed in every single area which is a part of the total catchment divided into small areas. In each area, precipitation is considered to be observed evenly. Second, if the catchment cannot be divided into small areas appropriately, it should be divided into zones of around 50 km^2 a piece. Then the station should be installed in each zone. The World Metrological Organization Guideline[3] requires the minimum standard of record is 10-20 km^2 per station in an urban area, and 2500 km^2 per station in a mountainous area. There is a great difference in distribution density of installed stations between the Tone river basin

2 B. Wisner, et al., 2004.
3 World Metrological Organization, 2008.

in Japan and other river basins in developing countries. (**Table 2-1**)

In addition, the quality of data also varies. Sometimes, it is difficult to tell which data is not appropriate, i.e., ground rainfall, satellite rainfall, low discharge, water level or calculation. It is extremely important to check data with the original record of observations, cross sections or H-Q rating curves.

Flood inundation simulation results will also be at the mercy of availability of information on micro-topography and infrastructure for flood regulation. Such information will influence selection of inundation simulation models.

(2) The status quo of disaster data availability

On the other hand, there is a major obstacle to implementation of disaster risk assessment. That is disaster data unavailability, especially in developing countries.

The existing major disaster database is International Disaster Database (EM-DAT) by Centre for Research on the Epidemiology of Disasters (CRED). It is utilized as a major data source in various reports and analyses, but it has some problems. To enter EM-DAT, at least one of the following criteria[4] must be fulfilled: a) Ten (10) or more people reported killed; b) Hundred (100) or more people reported affected; c) Declaration of a state of emergency; and d) Call for international assistance. These criteria make the database not exhaustive and reliable. To solve this problem in the future, a reliable and sustainable system of disaster database should be developed in each nation. The disaster committee and statistic committee in United Nations Economic and Social Committee in Asia and Pacific (UNESCAP) have discussed the importance of disaster database[5], and it will also be discussed in the General Assembly of UNESCAP.

The results of disaster risk assessment are influenced not only by the methodology of assessment but also by data availability. The discussion on the emphasis of pre-disaster countermeasures should be focused on disaster risk reduction, but improvement of technology and enhancement of disaster data collection should also be tackled together.

4 CRED, access at 2013.
5 EGM on Disaster Data, 2013.

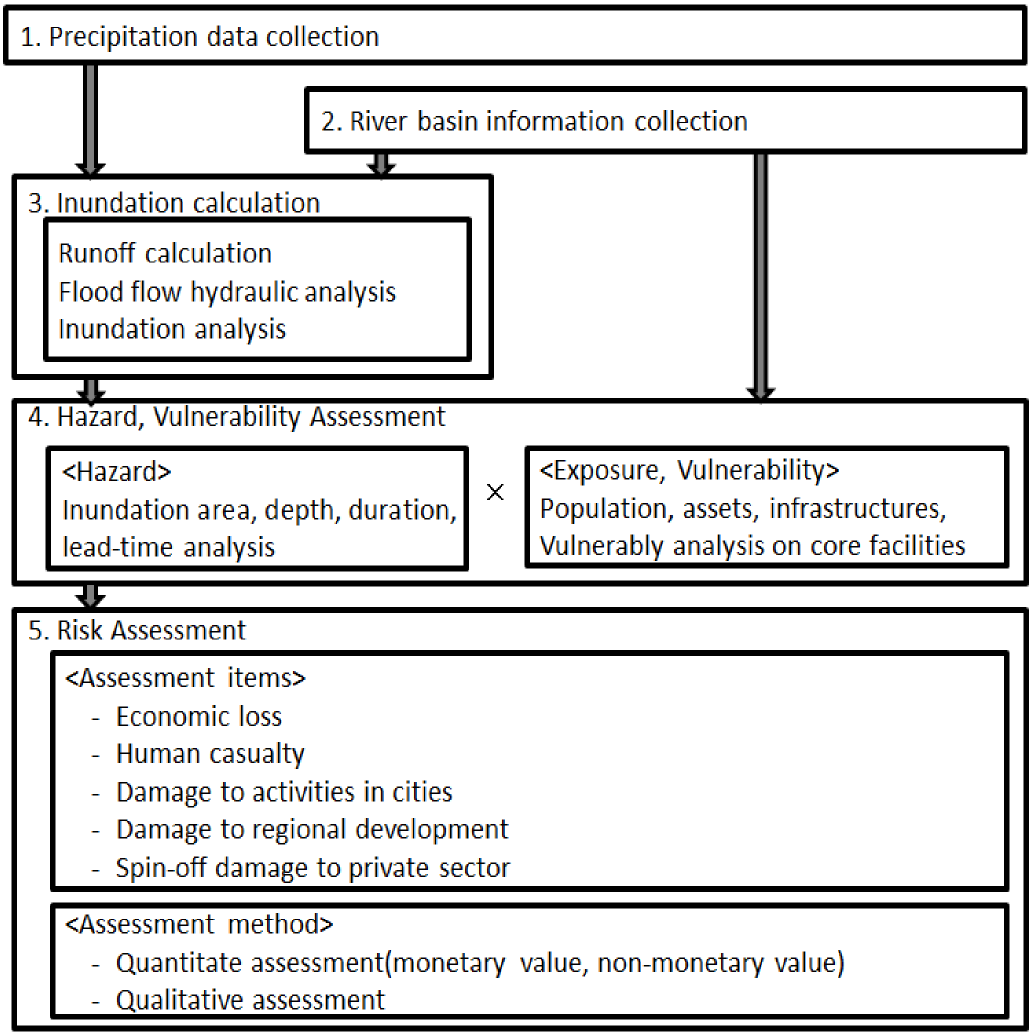

Fig. 2-1 Procedure of the flood risk assessment

Table 2-1 Comparison of the number of rainfall observation stations in four basins

River (country)	**Catchment area(km^2)**	**Rainfall stations**	**Area per station**
Tone river (Japan)	16,840	420	40.1
Solo river (Indonesia)	15,840	23	688.6
Cagayan river (the Philippines)	27,280	10	2,728.0
Pampanga river (the Philippines)	10,540	25	421.6

(3) Required time and cost

As described above, damage calculation will be necessary to identify risk. However, since damage information is likely to be unavailable, calculation of damage and risk will be the most difficult task in risk assessment.

The damage function in the Manual on Flood and Economic Investigation (draft) (hereinafter “the Manual”)[6] has been produced, based on a large-scale questionnaire survey administered to affected people about past major floods as well as thorough analysis spending a huge amount of time and cost. In this regard, the key to good risk assessment is that an effective method should be developed and applied to other areas by using statistical methods under certain conditions at some cost.

There should be always some limitations in addressing tasks. Under serious situations in developing countries with limited information for flood risk assessment, it will be very useful even to have a rough estimate of uncertainty. Challenging conditions should be a good motivation for researchers to find ways to overcome them.

(4) The definition of uncertainty

“Uncertainty” is a new criterion to show the reliability of measured data and was introduced in the “Guide to the expression of uncertainty in measurement (GUM)” by the Joint Committee for Guides in Metrology[7]. The formal definition of the term “uncertainty” is “parameter, associated with the result of a measurement, that characterizes the dispersion of the values that could reasonably be attributed to the measurand”. It is also noted that this definition of uncertainty is not inconsistent with other concepts of uncertainty, such as “an estimate characterizing the range of values within which the true value of a measurand lies”. This novel concept was rapidly accepted and utilized in the discussion of data reliability. However, few studies have addressed and discussed uncertainty of flood risk assessment. H. Apel et al. [8] and B. Merz et al. [9] studied the matter for Cologne, a city on the Rhine River, Germany, but both studies used long-term, good quality data, and did not address concerns over lack of data.

6 MLIT, 2009.
7 JCGM, 2010.
8 H. Apel, et al., 2006.
9 B. Merz, et al., 2009.

In this thesis, the author conducted flood risk assessment in a developing country with careful calibration and validation, while coping with uncertainty contained in observed data and other information. In the following chapters, the major findings are presented on: 1) the influence of the poor quality, or missing, data on the flood risk results; 2) the most influential part of the flood risk assessment process; and 3) data prioritization to decrease uncertainty when collecting field data.

The author's findings promote better flood risk assessment in developing countries by providing more efficient, effective systems and technologies, which eventually leads to further mitigation of disaster damage.

2.3 Flood Risk Assessment in Japan

2.3.1 Introduction

To understand the significance of flood risk assessment, which is the major theme of this thesis, it is important to examine how Japan addresses the matter from legal, technological and methodological aspects. Without good understanding of it, it is difficult to properly measure the status quo in developing countries. In this regard, this chapter introduces the background, legal status, technologies and methodologies of flood risk assessment in Japan.

2.3.2 History of Policy Evaluation

Discussions on policy evaluation started when the final report of the Administrative Reform Conference was published in December 1997[10].

Traditionally, the major task of public administration in Japan has been considered to create new laws and increase a budget. There have been few sections in the past governments to review and update policies based on outcomes to meet socio-economic changes of the time. The conference pointed out this as an unfavorable practice and made a new recommendation for more thorough, objective reviews on policy strategy and incorporation of review results into policy formulation.

The conference also proposed that all results and related information should be disclosed to the public in order to keep fairness and transparency of the policy-making

10 The Administrative Reform Conference, 1997.

process.

Responding to this recommendation, a new basic law for central government reformation was enacted in 1998, and the government of that time started preparation for systemizing policy evaluation for the first time.

After extensive discussions, the law on policy evaluation conducted by government agencies was finally established in June 2001[11], and each government agency made a basic plan for implementation of policy evaluation, and policy evaluation finally started at a full scale. Currently each agency has its own evaluation guidelines for different project types and conducts pre-event, post-event, and target-based evaluations for their policies.

2.3.3 Evaluation System for Public Works in Ministry of Land, Infrastructure, Transport and Tourism

The Ministry of Land, Infrastructure, Transport and Tourism (MLIT) has prepared "the MLIT Basic Plan for Policy Evaluation"[12]. This plan defines three major categories of evaluation: policy assessment, policy checkup and policy review. In addition, it also sub-categorizes types of evaluation depending on project types of public works projects, research and development projects, and regulation and tax policies.

According to the basic plan, evaluation of public works projects is further divided into three stages: evaluation of a new project at the proposal stage, reevaluation of the project at the mid-term stage, and final evaluation at the completion stage. Flood risk assessment plays an essential part in the process of this evaluation system. The most important occasion for flood risk assessment is the proposal stage, at which a new project is evaluated to determine whether it should be approved and launched as a flood risk reduction project (**Fig. 2-2**). For this purpose, MLIT has devised the standard operation procedure (SOP) for policy evaluation of new projects at the proposal stage[13]. This SOP is applied to evaluation of new projects for which a draft budget for construction or preparation of construction is proposed. In the procedure, evaluation of river and dam projects should be conducted by using the conventional evaluation system for river improvement plans defined in the River Law (**Fig. 2-3**).

11 The law on policy evaluation conducted by government agencies, 2001.
12 MLIT, 2002 (revised 2012).
13 MLIT, 2011.

This use of the existing evaluation system instead of the new one is related to the history of river improvement projects. Many years before the proposal of this policy evaluation system, several large dam and barrage construction projects, such as Hosogochi Dam and Nagaragawa Barrage, were subject to public dispute in the late 1900s.

The Ministry of Construction (MOC, now MLIT) decided to launch a new reevaluation system for large dam and barrage projects to address public controversy over, for example, large river improvement projects[14]. By the time, MOC had recognized that it was because of the lack of information disclosure in the decision-making process. It set up a new committee with an integrated evaluation method for large public works projects in 1995 in order to make the reevaluation process transparent and carry out implementation of the project smoothly after the evaluation. Although dam and barrage construction projects are generally huge, need a long time and have an extensive influence on the area, there has not any process to review them and ask for opinions from local residents while there is a review process for urban planning projects. MOC set up a dam project evaluation committee in each project area, and implemented a re-evaluation system and asked for opinions from experts and residents, especially regarding projects which had taken a long time to be completed after the actual construction started.

From these experiences, MOC recognized the necessity of an evaluation system for large river improvement projects, and decided to amend the River Law in 1997 to include the procedure of discussion on river improvement plans with information disclosure to experts and residents[15].

For these historical reasons, the River Law has already required setting up a system for project evaluation and information disclosure, which has been working equally well or better; thus, river improvement projects are actually evaluated by using the conventional system prescribed in the River Law instead of the new policy evaluation system or MLIT evaluation system.

There is another evaluation system for dam projects, which was set up in 2010 under the

14 MLIT, 2003.
15 MLIT, 1997.

initiative of the MLIT minister of that time[16]. The minister established an advisory committee for future flood control to examine individual dams, which required some kind of evaluation system. In order to avoid duplication, this evaluation by the advisory committee was included as a part of the existing policy evaluation system of MLIT. As Article 6-6 in the MLIT SOP for Project Re-evaluation states, river improvement and dam construction projects can be subject to evaluation by a special advisory committee of experts instead of the project evaluation and supervisory committee defined in the MLIT SOP for Project Re-evaluation, if such a special committee is organized for overseeing the projects.

Although the conventional system is applied to actual project evaluation, that is performed as a part of the overall evaluation framework. When a river or dam project is judged to be subject to re-evaluation and evaluation after completion by the project evaluation and supervisory committee defined in the MLIT SOP, the project has to go through the procedure required by the committee in reference to discussions of other relevant committees.

For example, the Asuwagawa dam project in the Kuzuryugawa river system, in which the author was involved and discussed at local meetings as a re-evaluated project based on the new flood control policy in 2012, and also discussed in the project evaluation committee, which delivered discussion results to the advisory committee for comments. The project was finally accepted by the Minister of Land, Infrastructure, Transport and Tourism. Furthermore, relevant documents and all detailed information including the results of cost benefit evaluation, and briefing materials for the committees, together with the project evaluation sheets, are all available on the MLIT website[17]. (**Fig. 2-4**)

16 MLIT, 2010.
17 MLIT, 2013.

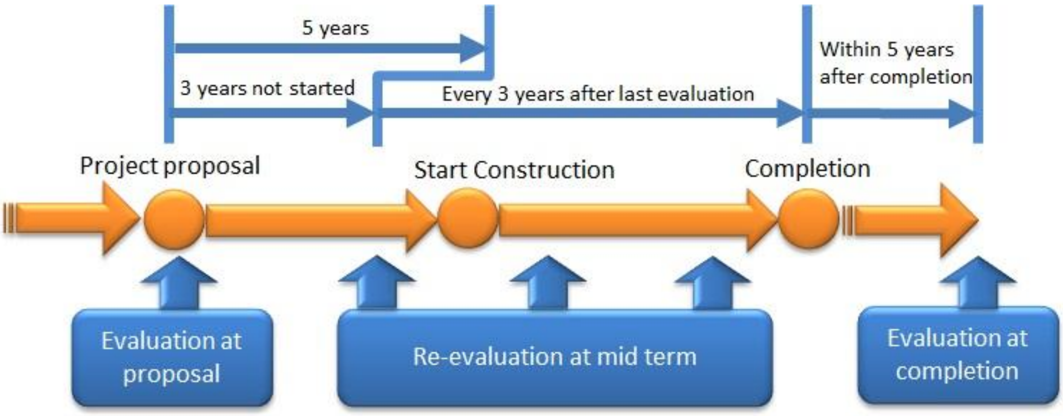

Fig. 2-2 Time frame of evaluation of public works project

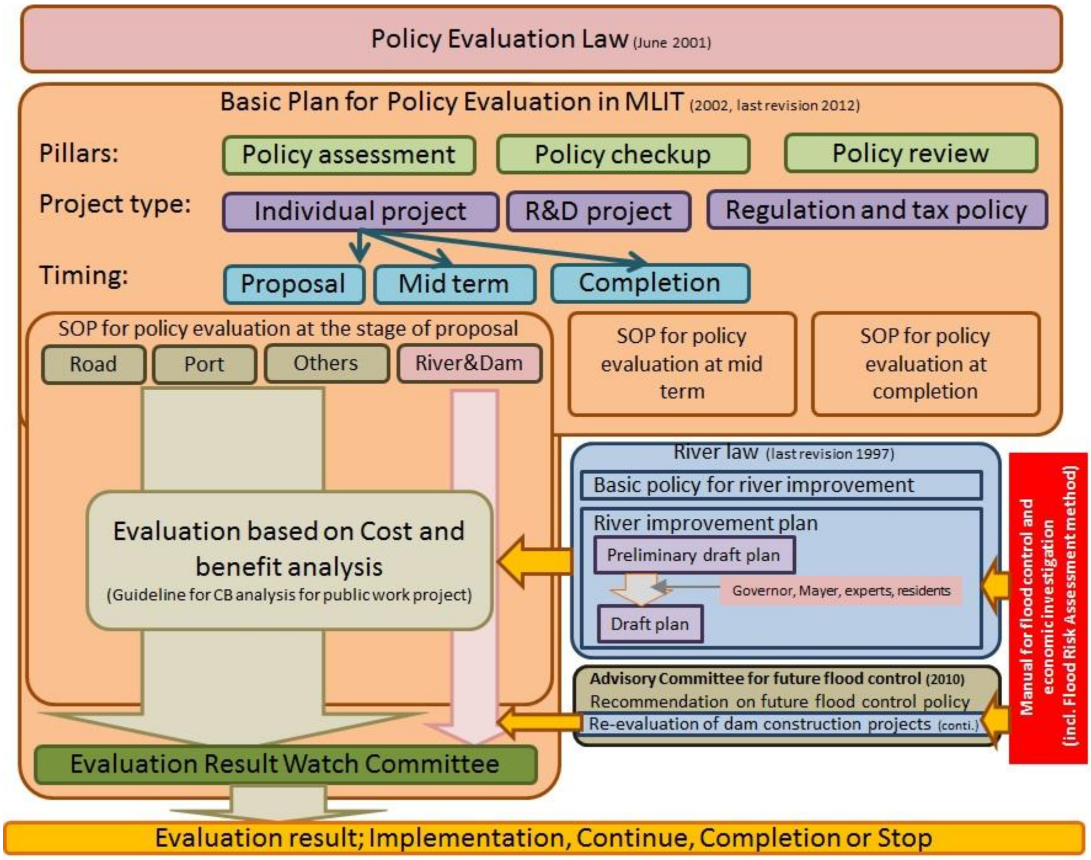

Fig. 2-3 Schematic position of flood risk assessment in policy evaluation system

2.3.4 Basic Policy for River Improvement and River Improvement Plan

The amendment of the River Law in 1997 was made to establish a new river planning system in order to reflect the recent needs of Japanese people, who hope for rich, comfortable and high-quality life and prefer the sound environment (**Fig. 2-5**).

The new river planning system is composed of a basic policy for river improvement which defines long-term plans for river improvement, and river improvement plans require practical programs on how to improve rivers over a medium term. A basic policy for river improvement requires discussions and approval by the National River Advisory Council and related Governors, and Minister's approval as long-term policy for its improvement. River improvement plans require discussions and advice from experts' group meeting and public hearings with local residents during the process of preparing the first draft plan. A river basin committee composed of experts and related municipalities needs to be set up for each river basin and.

Flood risk assessment and cost-benefit analysis are among the most important topics to be discussed. In addition, information disclosure must be obligatory concerning all materials used for these official meetings. Anyone can look at such materials at the MLIT website and public spaces in the local MLIT offices.

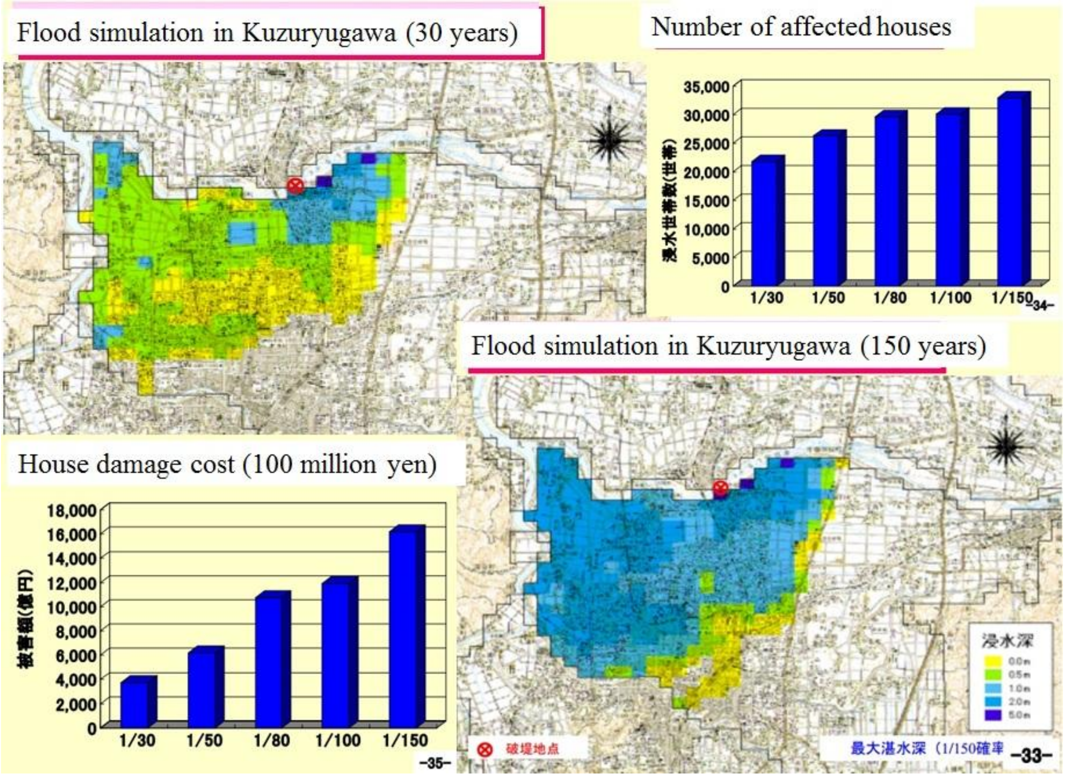

Fig. 2-4 Example of flood risk assessment calculated for Kuzuryugawa river

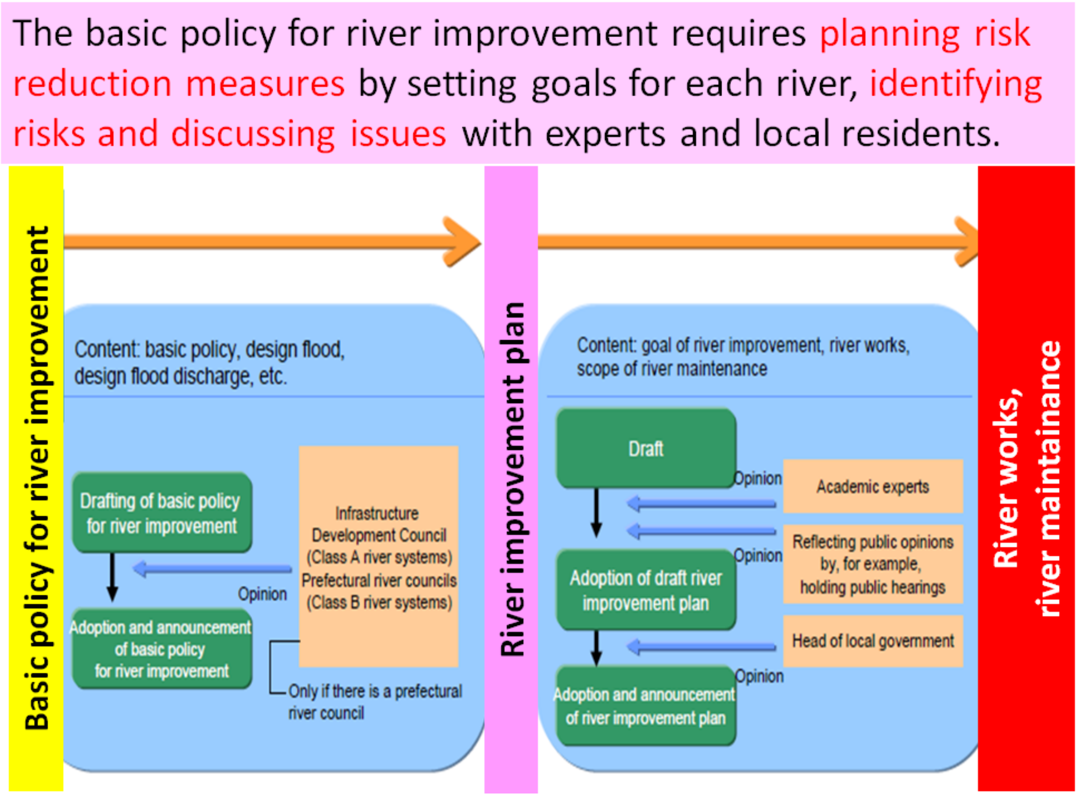

Fig. 2-5 Framework for Basic Policy for River Improvement

2.3.5 Flood Risk Assessment Methodology in the Manual for Flood Control and Economic Investigation

As described earlier, flood risk assessment is essential during the process of discussion on river improvement plans. The results of flood risk assessment are then used for cost-benefit analysis, which will be a major indicator to judge whether or not a plan is appropriate. The methodologies for cost benefit analysis and flood risk assessment are described in details in the Manual prepared by MLIT[6].

At the preamble of the Manual, the following is clearly described:
"*Although flood control infrastructure is important facilities for basic foundation to support safety on all socio economic activities, most of the benefit of their facilities cannot be measurable in economic terms. In this regard, damage reduction benefit, which can be assumed the increase in disposable income from the reduction of direct and indirect damage, should be calculated in the part of benefit on the improvement of flood control facility.*"

Practically, flood risk assessment is a method to identify and calculate a possible reduction of flood damage by countermeasures, such as simulation of flood inundation and estimation of flood damage in an inundation area during a certain magnitude of a flood[18].

The main steps of this method are as follows:

a) Identify the analysis area
b) Collect information on assets and other factors in the area
c) Study assets data（Statistics in 250m mesh）
d) Analyze characteristics in the area
e) Define conditions of flood simulation
f) Conduct flood analysis
g) Estimate flood damage
h) Estimate direct damage (house, factory, office, farming/fishery, public infrastructure）
i) Estimate indirect damage (suspension loss, emergency cost）
j) Estimate benefits （average annual estimated damage reduction）
k) Calculate project costs

18 Kinki regional development bureau of MLIT, 2002.

l) Evaluate economic efficiency

Most statistical data on house, asset and factory are available in mesh data and are a useful tool for flood risk assessment (**Fig. 2-6**).

The following are key items on flood reproduction calculation and damage conversion from water depth in the Manual.

(1) Flood reproduction calculation and cost-benefit analysis

Inundation calculation will be implemented after the process of identifying inundation blocks, breach points in the levee with the maximum discharge capacity, calculation diffusion flow, etc. The important standard is described in the Manual as follows: “Around 6 cases of flood hydrographs at various flood magnitudes should be selected and simulated at the major station points in the river basin ranging from above the maximum river capacity to less than the design magnitude of the plan. After calculation of expected damage for each of the 6 cases, the average of damage cost is accumulated, based on expected damage reduction costs multiplied by the probability of each flood level. The final result is the annual average expected damage reduction.” This result will be delivered to the total benefit of the project at the end. The total benefit and cost of the project used for formula **(2.2)** are called the cost benefit ratio. The final result of flood risk assessment should be presented as the cost benefit ratio, which is completely different from past flood records.

$$\text{Cost-Benefit ratio} = \frac{\sum_{i=1}^{N} B_t/(1+i)^{t-1}}{\sum_{i=1}^{N} C_t/(1+i)^{t-1}} \qquad \textbf{(2.2)}$$

N : evaluation duration (years), B_t: the benefit at the year t, C_t: the cost at the year t, i:Social discount rates (4%; normally in Japan)

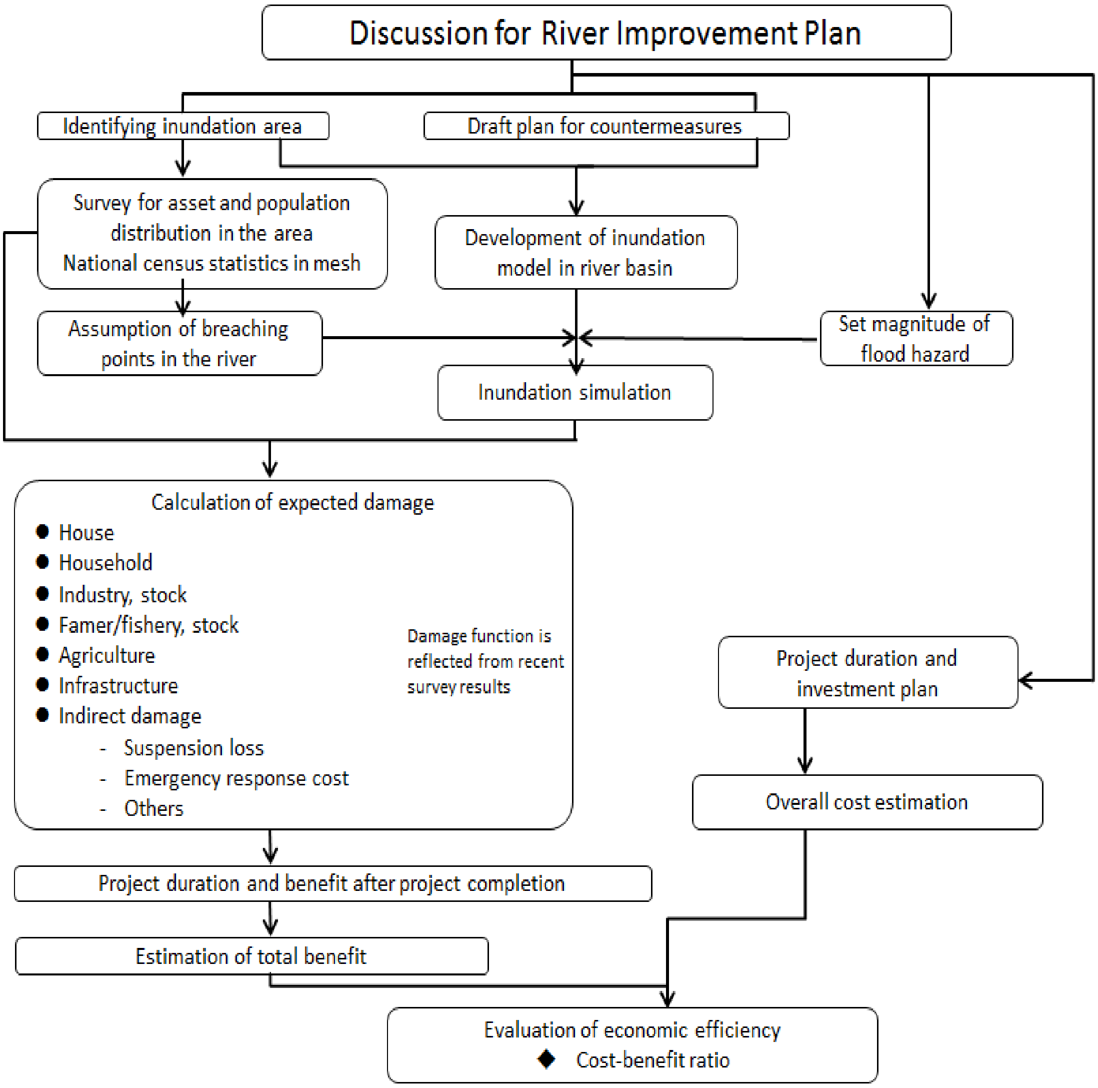

Fig. 2-6 Procedures of flood risk assessment in the Manual

(2) Damage category

Since the methodology of damage calculation in the Manual is still under discussion and updated frequently, the present method is based on the survey result from 1993 to 1996. Especially indirect damage by flood is still under review in several case studies for the discussion in the expert group committee of MLIT.

At present, the category in **Table 2-2** is defined as damage items in the Manual, and grey cells are identified by the formulas in the Manual.

MLIT is correcting field survey results on indirect damage which is presently not included in the damage estimation items by flood for the discussion in the expert group committee on the evaluation method for river improvement projects organized by MLIT.

Especially items which are not considered as damage estimation items, e.g., method for damage conversion to currency, avoidance of doubling up benefit and others, are prepared as new methods for quantification and proposed for this committee to utilize as new flood risk estimation methods.[19]

(3) Damage curve and ratio

Similarly to the damage category, the damage curves are also defined based on the actual field survey from 1993 to 1996 (**Table 2-3**). It should be also updated based on the latest results. Presently the damage information by the Great East Japan Earthquake and Tsunami are now being collected and discussed for revision of the damage curves. The revision of the damage curves for house, household, business, public services and agriculture are being discussed in the committee.

The difficulty of this revision is collection of updated damage data after large disasters due to difficulties in surveys involving victims who are not willing to talk about disaster damage they have suffered. Especially, serious damage data is hardly collected in any places in Japan. Updated damage curves and ratios in various damage ranges based on the latest disaster are always required in Japan as well as in other countries.

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19 MLIT, 2013.

Table 2-2 Category of stock damage reduction by flood in the Manual

<table>
<tr><td rowspan="24">Damage reduction benefit</td><td rowspan="9">Direct damage</td><td rowspan="8">Asset damage reduction effect</td><td rowspan="6">General asset damage</td><td>House</td></tr>
<tr><td>Household appliance</td></tr>
<tr><td>Bussiness depreciable asset</td></tr>
<tr><td>Bussiness inventory asset</td></tr>
<tr><td>Agricultural and fishery depreciable asset</td></tr>
<tr><td>Agricultural and fishery inventory asset</td></tr>
<tr><td colspan="2">Agricultural damage</td></tr>
<tr><td colspan="2">Public infrastructure damage</td></tr>
<tr><td colspan="3">Human fatality</td></tr>
<tr><td rowspan="15">Indirect damage</td><td rowspan="3">Suspention damage reduction effect</td><td rowspan="3">Bussiness suspention</td><td>Household</td></tr>
<tr><td>Office budget</td></tr>
<tr><td>Public survice</td></tr>
<tr><td rowspan="6">Post flood damage reduction effect</td><td rowspan="3">Emergency operation cost</td><td>Household</td></tr>
<tr><td>Office budget</td></tr>
<tr><td>Government/ Municipality</td></tr>
<tr><td>Spillover damage by shutdown transportations</td><td>Road, Railroad, Airport, Port</td></tr>
<tr><td>Spillover damage by shutdown lifelines</td><td>Electricity, Water supply, Gas, Telecommunication</td></tr>
<tr><td colspan="2">Other spillover damage by suspention</td></tr>
<tr><td rowspan="5">Mental damage reduction effect</td><td colspan="2">Those related to asset damage</td></tr>
<tr><td colspan="2">Those related to suspention</td></tr>
<tr><td colspan="2">Those related to casualty</td></tr>
<tr><td colspan="2">Those related to post flood damage</td></tr>
<tr><td colspan="2">Those related to spillover damage</td></tr>
<tr><td colspan="3">Risk premium</td></tr>
<tr><td colspan="5">Upgraded benefit</td></tr>
</table>

[shaded box] Items damage ratio and Damage curve available in the Manual

Table 2-3 Flood water depth and damage ratio of house in the Manual

<table>
<tr><td rowspan="2">Depth / Gradient</td><td rowspan="2">Below floor</td><td colspan="5">Above floor</td><td colspan="2">Sediment deposition</td></tr>
<tr><td>< 50</td><td>50 - 99</td><td>100 - 199</td><td>200 - 299</td><td>300 =<</td><td>< 50</td><td>50 =<</td></tr>
<tr><td><1/1000</td><td>0.032</td><td>0.092</td><td>0.119</td><td>0.266</td><td>0.580</td><td>0.834</td><td rowspan="3">0.430</td><td rowspan="3">0.785</td></tr>
<tr><td>1/1000 - 1/500</td><td>0.044</td><td>0.126</td><td>0.176</td><td>0.343</td><td>0.647</td><td>0.870</td></tr>
<tr><td>1/500 =<</td><td>0.050</td><td>0.144</td><td>0.205</td><td>0.382</td><td>0.681</td><td>0.888</td></tr>
</table>

(4) Example in Kuzuryugawa improvement plan

During the evaluation of the Asuwagawa dam project, in which the author was involved, the benefits were calculated as damage reduction related to houses and agriculture by flood control facilities. More specifically, the average annual estimated damage reduction was calculated under two different conditions: with or without Asuwagawa dams. The calculation was done at the social discount rate of 4%. The results were converted into the present value for the target evaluation duration (50 years) after starting dam operation, and added a remaining value.

Finally, the total benefits were calculated at 110.4 billion yen, and the cost-benefit ratio was 1.3 in comparison with the total project costs of 85.6 billion yen. The conclusion of the evaluation was accepted as appropriate[20].

2.3.6 Conclusion of the Current Situation of Japan

Prior to the implementation of a project, thorough evaluation is obligatory by a Japanese law concerning public works projects. Especially, for construction of large structures, such as dams, barrages, and long river dykes, cost-benefit analysis with flood risk assessment was essential.

Fortunately, most information necessary for such evaluation is available as mesh data, e.g., topography, population, and assets based on the latest census. These data make detailed flood simulation and damage estimation possible by using the latest damage conversion formula (damage curves or ratios).

As mentioned earlier, hot discussions are still continuing in Japan on how to evaluate actual flood damage, which items to be considered in evaluation of indirect damage, and how to prepare updated damage ratios. This Japanese case study deserves much attention, since the results will be useful for other countries in terms of flood risk assessement.[19]

In other words, flood risk assessment is definitely influenced by the availability of data, e.g., metrological, hydrological, topographical, societal, economic and other related information, and latest damage conversion formula.

20 Kinki regional development bureau of MLIT, 2012.

2.4 Flood Risk Assessment in the Developing Countries

2.4.1 Difficulties on Flood Risk Assessment in Developing Countries

Risk assessment in Japan can be conducted precisely because of rich data availability, and can produce accurate results compared with other countries. However, in developing countries, even simple topographical maps are hard to come by, and hydrological data, past disaster damage information and other hazard information are also hardly available.

For example, when Japan International Cooperation Agency (JICA) conducts a study related to flood risk in a developing country, the team interviews many residents and collects information as well as available statistics. Especially, a field investigation for the master plan study after the Chao Phraya flood used 885 interview results after excluding inappropriate data[21].

Disaster damage data is normally not available in developing countries. Therefore, flood damage in developing countries is often a result of rough estimation.

Although only rough data is available, damage estimation has to be conducted because the results are usually required to assess flood risk. Consultants and researchers have been challenging to prepare appropriate results as hard as possible. The cases of Thailand and Cambodia are introduced in the following sections, which involve some assumptions or other tools of satellite information. Through careful field investigation on lifestyle, micro-topography and crop cultivation characteristics, the simple method was applied or developed to these cases.[22]

2.4.2 Study on Comprehensive Flood Management Plan for the Chao Phraya River Basin Conducted by JICA

A study on flood management for the Chao Phraya basin was intensively implemented by JICA from 2011 to 2013 in corporation with MLIT, University of Tokyo, Japan Aerospace Exploration Agency (JAXA), PWRI/ICHARM and 4 hired consultant companies, just after Chao Phraya River Flood in 2011 with economic losses of around 2.6 billion yen[23].

21 JICA, 2013.
22 T. Okazumi, et al., 2013.
23 Ministry of Foreign affairs, 2013.

This is a good example to understand the difficulty of flood damage estimation in developing countries and to understand the difficulty of getting good results despite an intensive field survey. In order to get good results like those from risk assessment in Japan, a long-term database of flood disasters is essential, in addition to an intensive survey of a flood case. The Chao Phraya case is a good example to understand the difficulty concerning both aspects.

(1) Target area

The study area is the entire Chao Phraya River basin, covering 163,000 km² and composed of multiple tributaries such as the Ping, Wang, Yom, Nan, Chao Phraya, Sakae Krung, Pa Sak and Tha Chin Rivers shown in the location map (**Fig. 2-7**). Since the Bang Pakong River on the east side and the Mae Klong River in the west side have their own large river basins, they are not included in the study area.

(2) Damage (benefit) estimation

Incremental benefits are included in the evaluation by comparing with- and without-project situations. As for the direct damage caused by flood, generally, it can be calculated by the following formula:

$$\text{[Direct Damage in the Area (Baht)]} = \text{[Area Size (km}^2\text{)]} \times \text{[Damageable Value (Baht/km}^2\text{)]} \times \text{[Damage Rate by Inundation Depth]} \quad (2.3)$$

It is assumed that damage rate is the function of inundation depth (m) and the function should be estimated. Since the flood causing inundation is a probability event, the damage value to be calculated is the yearly expected value based on the probability of flood occurrence (sum of damages multiplied by each flood probability).

In this project, flood analysis with five flood scales (2-year, 10-year, 30-year, 50-year and 100-year return period) is conducted. The questionnaire survey to damaged factories and houses were conducted from August to October 2012 and analyzed in terms of i) Water depth and damage rate (all industry), ii) water depth and damage (each industry), iii) water depth and damage (all house), iv) water depth and damage (each floor area), v) water depth and damage (each floor stage). Floor height and damage were also analyzed. However, in this analysis, no significant relationship was found between

damage and water depth from the interview survey results (**Fig. 2-8**). Therefore, the study finally applied damage rates used in the Manual.
Furthermore, floor height should be considered in this area is different from that in Japan. Finally combination with Japanese damage rates and localized floor height was applied to the damage calculation.

(3) Validation

After reproduction of the 2011 Thai flood simulation and damage estimation for factory, house, agriculture and others, validation was conducted. The results found the similarity of Post Disaster Needs Assessment (PDNA) conducted by World Bank in collaboration with Ministry of Finance in Thailand, which suggests that the estimation method can be considered as appropriate for flood risk assessment of the Chao Phraya River Flood.

In Japan, the method was standardized and can be applied to any place in Japan for flood risk assessment. For this case study, due to data unavailability, data need to be collected from the target field and other sources, and need to be analyzed to create a new method combined with local characteristics, though the Japanese standardized method is used in some cases. A lot of efforts and patience are required in field survey and analysis to conduct appropriate flood risk assessment.

Fig. 2-7 Location map of Chao Phraya River Basin[21]

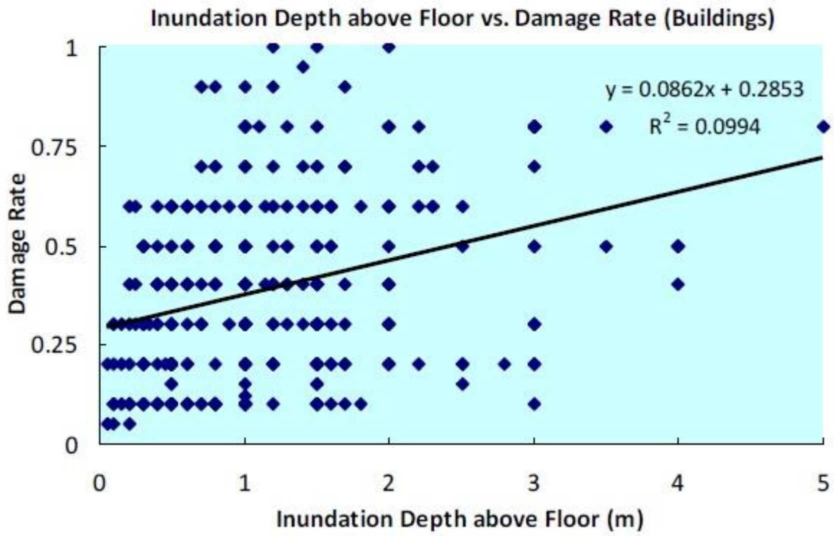


Fig. 2-8 Result from household field survey in Chao Phraya study[21]

2.4.3 Flood Risk Assessment in Cambodian Flood Plain

This study was conducted in the project of the Asian Development Bank Technical Assistance No. 7276 (ADB TA7276)[24]. The project was carried out by PWRI-ICHARM as the implement agency and ADB as the executing agency with the Mekong River Commission (MRC). It was funded by the Japan Fund for Poverty Reduction from the Japanese government. The objective was the development of a flood vulnerability assessment methodology for the Mekong flood plain.

The team collected past survey reports from the Mekong River Commission Secretariat (MRCS) and started analysis, and included some field information based on field survey, and used satellite information and Geographic Information System (GIS) to estimate damage.

The results were highly appreciated by the MRCS and ADB as a new attempt to combine local field information with satellite information and GIS.

(1) Target area

The Kompong Cham and Prey Veng flood plains in Cambodia (**Fig. 2-9**) were selected as the study area. Cambodia’s major industry is agriculture, which accounts for 30% of its Gross Domestic Product (GDP), and farmers account for 60% of its population. In particular, most of people in the study area are involved in rice cultivation, which is often damaged by extreme hydrological events. Based on this background, it was decided that agricultural damage should be calculated as vulnerability in this area.

24 ICHARM, 2013.

Fig. 2-9 Study area (Kompong Cham and Prey Veng, Cambodia)

(2) Methodology

a) Procedure

The study was designed as shown in **Fig. 2-10**. Data from various sources were used as listed in each box in the flowchart; for example, past studies by the MRC, the LandScan 2009 global population database[25], and previous research papers. GIS-based analysis is the backbone of this study, utilizing results from each research task conducted in this study (white boxes) as well as other sources (dark boxes). The benefit to use this GIS-based method is that as GIS data improves, better assessment results can be produced easily.

b) DEM analysis

The Shuttle Radar Topography Mission (SRTM) data[26] with a horizontal resolution of 3”×3” (app. 90m×90m) and a vertical resolution of 1m were used to identify micro-topographical conditions in the study area. More precise topographical data, such as IKONOS data[27], are also available in the market, but the advantages of SRTM DEM, such as worldwide availability, free of charge and easy accessibility through the HydroSHEDS[28] website, were found to be more important for this study than a higher level of accuracy that may be ensured by the use of IKONOS.

c) Hydro-metrological analysis

Plinston[29] pointed out a tendency during past floods in the Cambodian plain that the flood-plain inundation level eventually meets the river water level at a certain point (the circled area in **Fig. 2-11**). Based on this flood characteristic in this area, flood inundation areas were identified in the study area without any hydrological and hydraulic calculation in the following procedure. Firstly, water level data were collected from monitoring stations in the Mekong River and allied rivers to identify floods and natural hydro-climatic phenomenon. The hydrological characteristics of the Mekong River were found based on the analysis of the water level data from seven observation stations for a period of 17 years: (i) The yearly hydrograph shows seasonal changes and no significant difference in its water level behavior in each year; and (ii) The water level shows less variation downstream compared with upstream. Secondly, based on these characteristics, water stage data (hydrographs) at Kompong Cham and Phnom Penh

25 Budhendra B, et al., 2007.
26 Farr T, et al., 2007.
27 Toutin T, 2004.
28 Lehner B, 2006.
29 Plinston D, 2007.

were utilized. These data were used for interpolating the hydrographs between the two stations (**Fig. 2-12**) in the analysis of the study area. Thirdly, based on the characteristics in **Fig. 2-12**, inundation areas and water depths were identified by applying the water level at the nearest point in the Mekong River to the strip (or “band” as referred to in this study) of the flood plain expanding sideways. The flood plain between the two stations was divided into 31 bands, and hydrographs were plotted for each band from the interpolated water levels on the same dates. For the overlapping bands, the interpolated hydrographs at the middle of the overlapping bands were adopted (**Fig. 2-13**).

These are the steps of the procedure to estimate flood inundation areas and the water depth in each cell in the simplified methodology with the flood characteristics of the Mekong River.

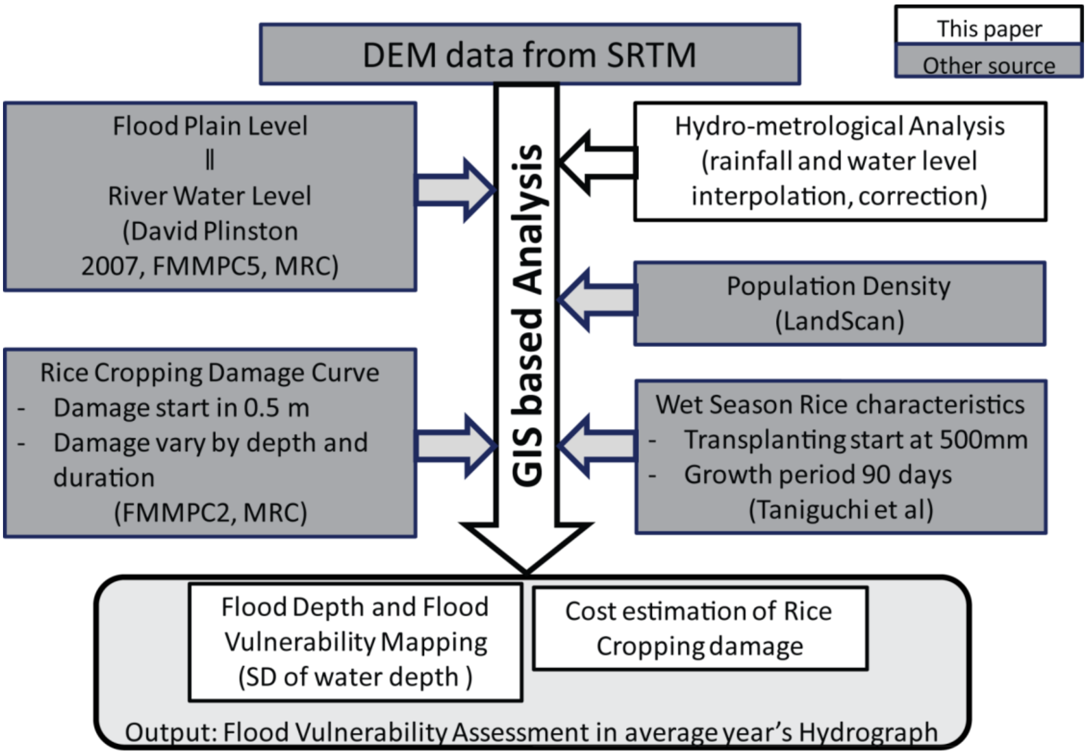


Fig. 2-10 Procedure of the study

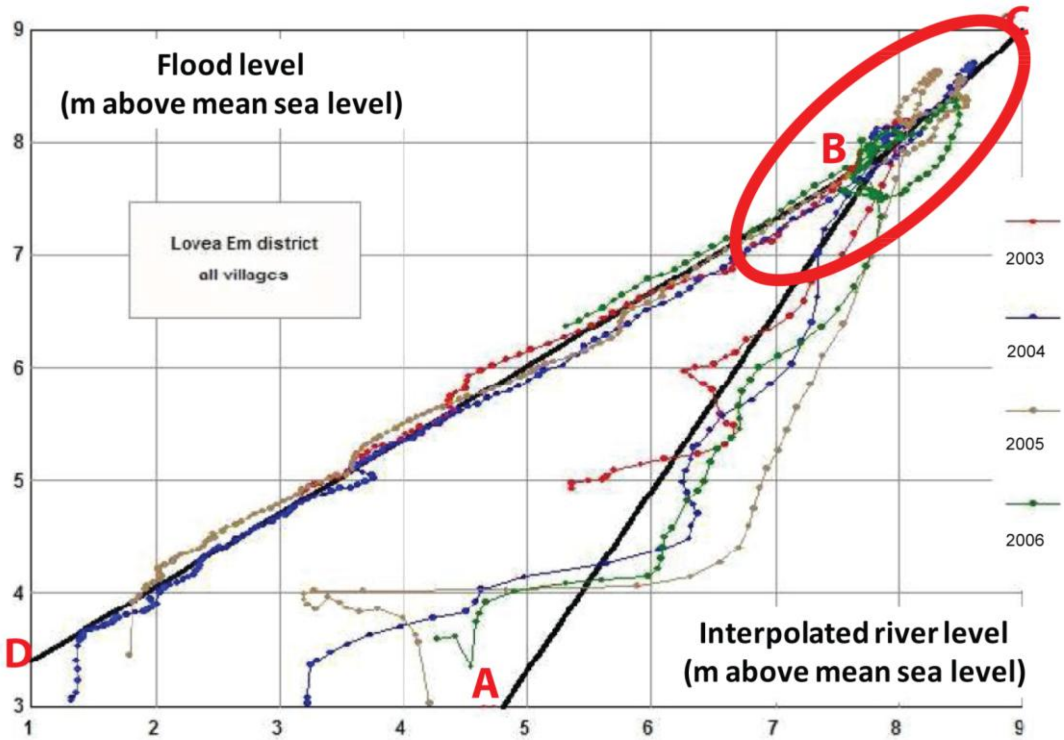


Fig. 2-11 Similarity between river water level and flood level in flood plain[28]

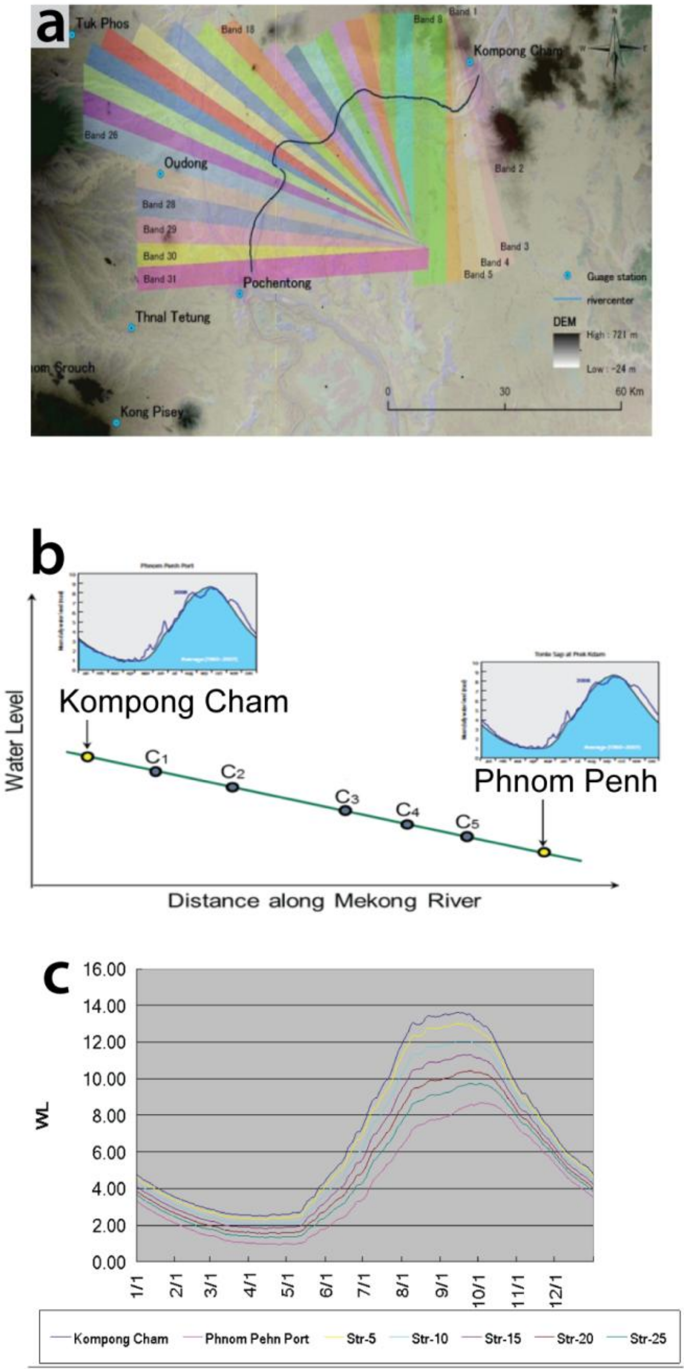


Fig. 2-12 Applying flood hydrographs to each band in the study area such as **a)** Division of floodplain by band, **b)** Interpolation of neighboring hydrographs, **c)** Hydrographs for each band

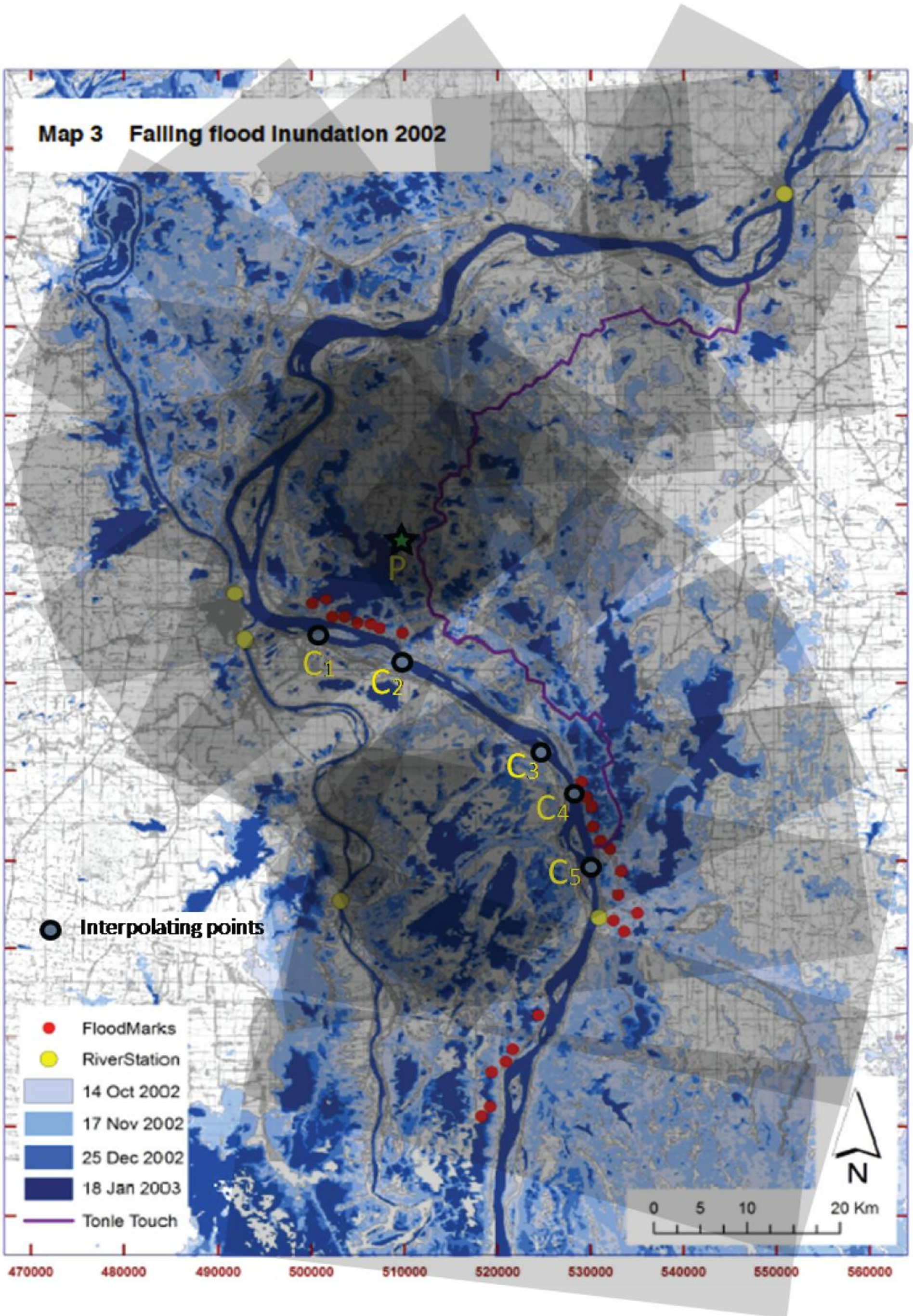


Fig. 2-13 Expanding river water level to flood plain level in each band

(3) Agriculture damage estimation

a) Rice cultivation characteristics

In the study area, the dominating rice cultivation pattern is double cropping in wet and dry seasons, producing approximately 80% and 20% of the total yield, respectively (**Fig. 2-14**). Since the purpose is to identify agricultural damage by floods, the focus was placed on wet-season rice farming. Wet-season rice farming starts annual transplanting at the onset of the rainy season, and floods sometimes occur before rice has grown enough to survive flood damage. Considering its much larger production, flood damage to wet-season rice farming is likely to be a devastating impact to Cambodia.

b) Characteristics and damage of wet season rice

The following two factors are characteristic of wet-season rice cultivation: (a) Farmers will start rice transplantation when rainfall accumulates to 500mm[30], which makes soil moisture high enough for transplanting; and (b) the growing period normally lasts for 90 days before rice harvesting[31]. In addition, according to the MRC Flood Management and Mitigation Programme (FMMP) Component 2 report[32], the harvest damage to rice yield starts when the water depth in rice paddies reaches over 50cm. From these characteristics, damage to wet-season rice can be identified on the condition that the water depth in paddy fields is over 50cm during the rice growing period.

This definition can also be translated into hydro-metrological phenomena. When the water depth in a certain area is over 50cm during the growing period, i.e., about 90 days after the total rainfall reaches 500mm, calculation of rice damage can be started (**Fig. 2-15**).

30 Taniguchi T, et al., 2009.
31 Ros B, 2011.
32 MRCS, 2010.

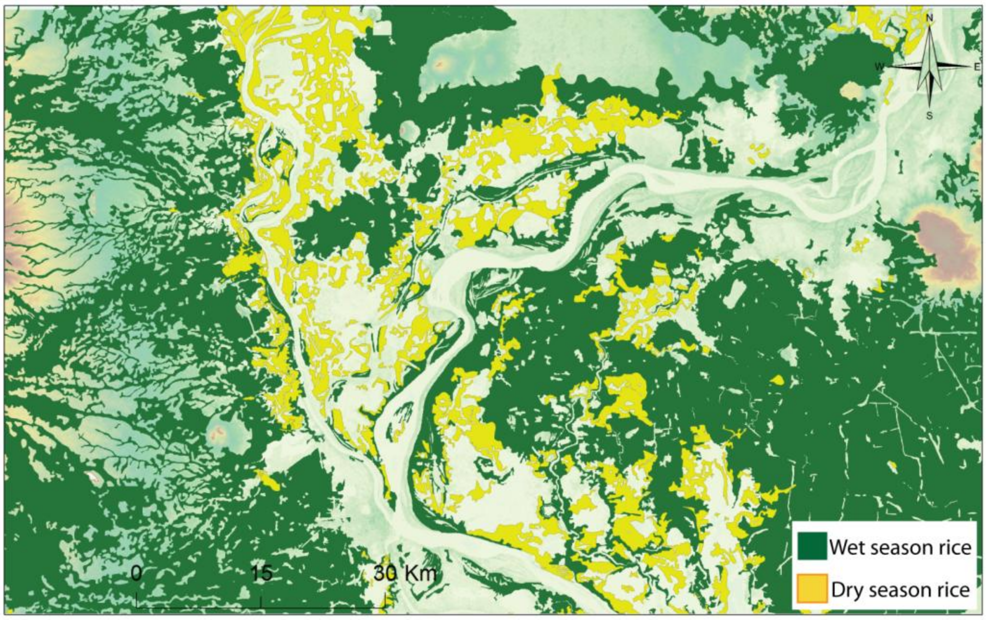


Fig. 2-14 Rice cropping distribution[31]

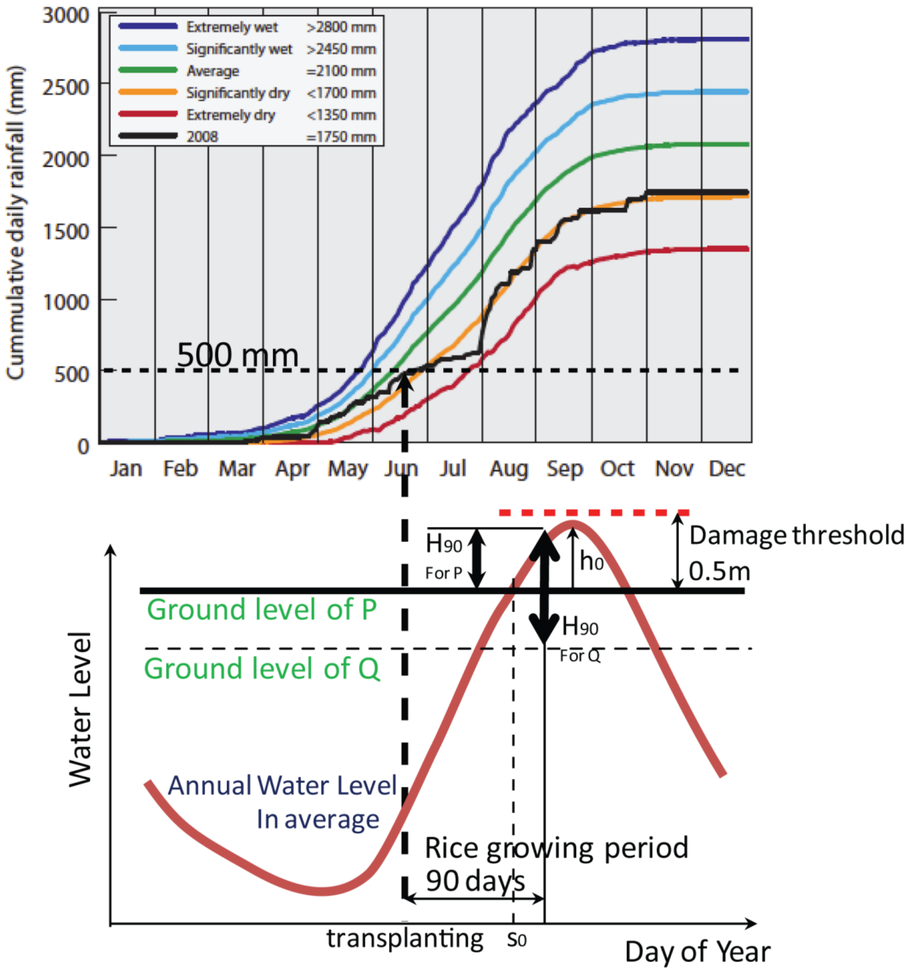


Fig. 2-15 Standard cropping pattern of wet season rice

The calculation was conducted in the following procedure:

i) The rainfall data from 1991-2007 in the study area were collected, and the accumulated rainfall in each cell was calculated by using the Thiessen polygon method.

ii) Inundation water depths were calculated by using the hydrological method described in 4.3 and topographical data.

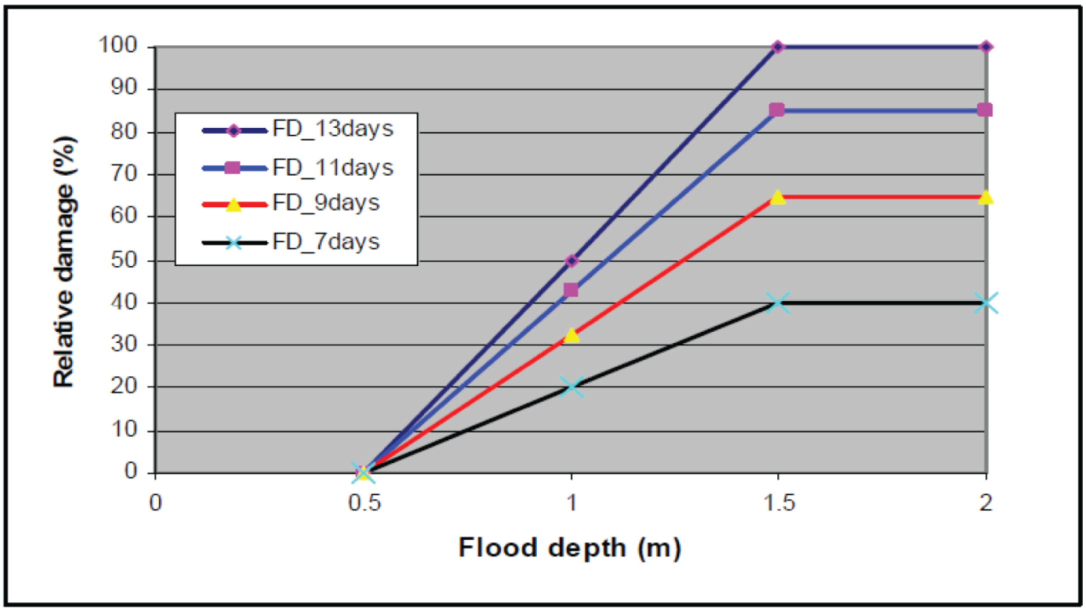
iii) Based on the results from i) and ii), the maximum water depth and its duration during the growing period were calculated.

iv) MRC's FMMP Component 2 showed damage curves which show damage increases in proportion to depth and duration (**Fig. 2-16**). These results were used to calculate flood damage to rice yield in each cell and total damage in this area.

c) Results

(i) Maximum inundation depth and inundation duration

Fig. 2-17 overlays the maximum inundation depths on their durations described in "(2)-c) Hydro-metrological analysis" and "(3)-b) Characteristics and damage of wet season rice", respectively. In this figure, the white colored areas show the areas not flooded over 0.5m, while the darkest areas show the areas flooded over 0.5m for more than 15days or permanent water bodies. **Fig. 2-18** represents a maximum inundation depth map for the average flood year. The average flood year was determined from the analysis of the water level data from seven observation stations for a period of 17 years. Since the rice damage curves (**Fig. 2-16**) link the damage ratio to inundation depth and inundation duration, it was possible to calculate flood damage to rice for the average year flood in the study area.



damage = (h-0.5)(-86.875 + 22.5d -0.625d2)
h=flood depth, d=day, This equation is defined for 0.5≦h ≦1.5m,
And if d>13, then d=13. If h>1.5, then h=1.5

Fig. 2-16 Relative damage curves for paddies

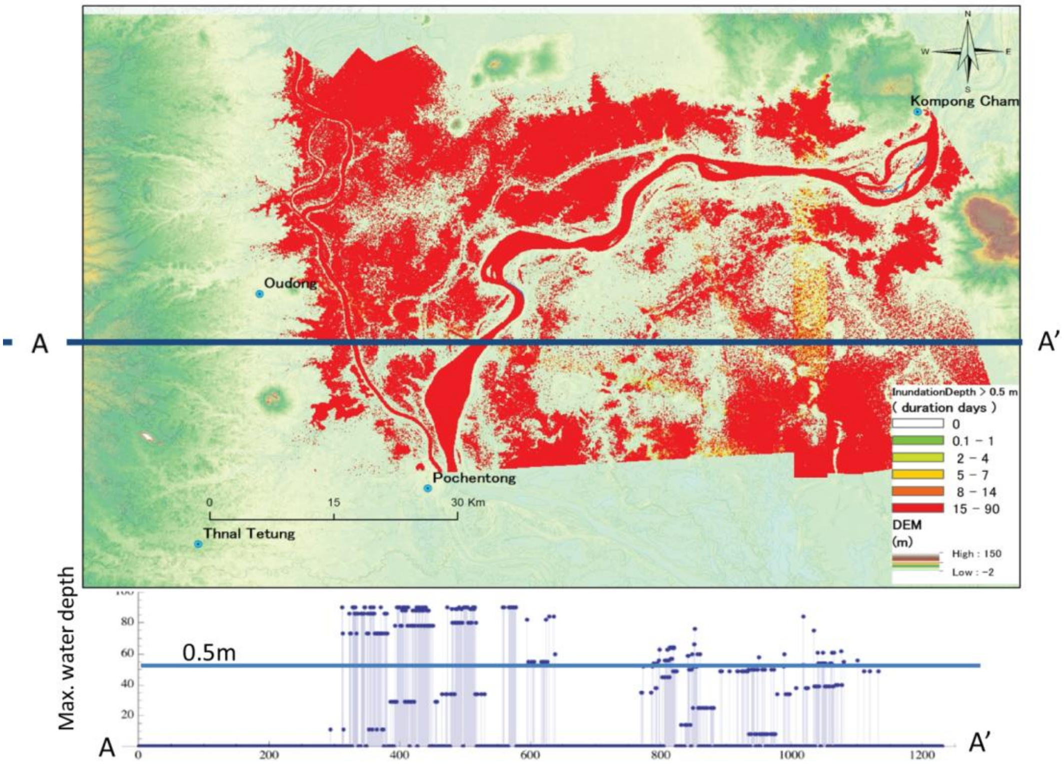


Fig. 2-17 Number of days of inundation depth over 0.5m during rice growth period (from rice transplanting to 90days after that)

(ii) Damage to rice harvest

Agricultural damage in each grid was calculated according to the damage curves in **Fig. 2-16**. Then the amount of agricultural damage for each grid was calculated by multiplying a damage ratio with the average yield of US$392 per hectare based on the data of the Cambodian Ministry of Planning (2009). The cultivation area of wet-season rice was derived from the 2003 agricultural land use data provided by the Cambodian Ministry of Public Works and Transport. The resulting agricultural damage map in the average year is shown in **Fig. 2-19**. Since the total area of paddy field in the study area is 714, 687 ha, the total yield in the study area was calculated to be US$280.15 million. While the amount of wet season rice damage in the average year was US$24.79 million from **Fig. 2-19**, the proportion of the amount of wet-season rice damage to the total yield in the area was 8.85 %.

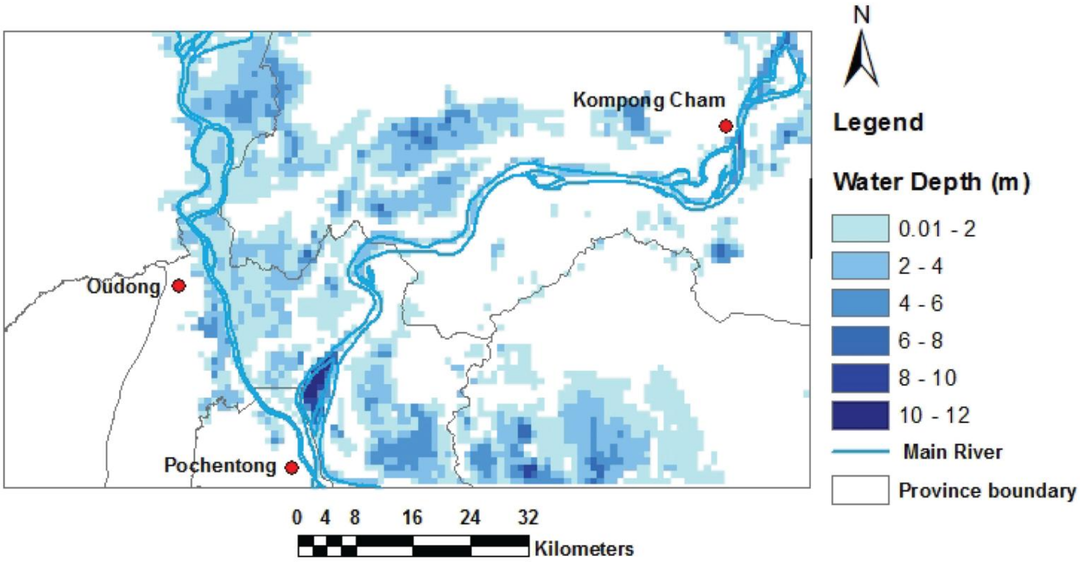


Fig. 2-18 Maximum inundation depth map in 2006 (Average year) in study area

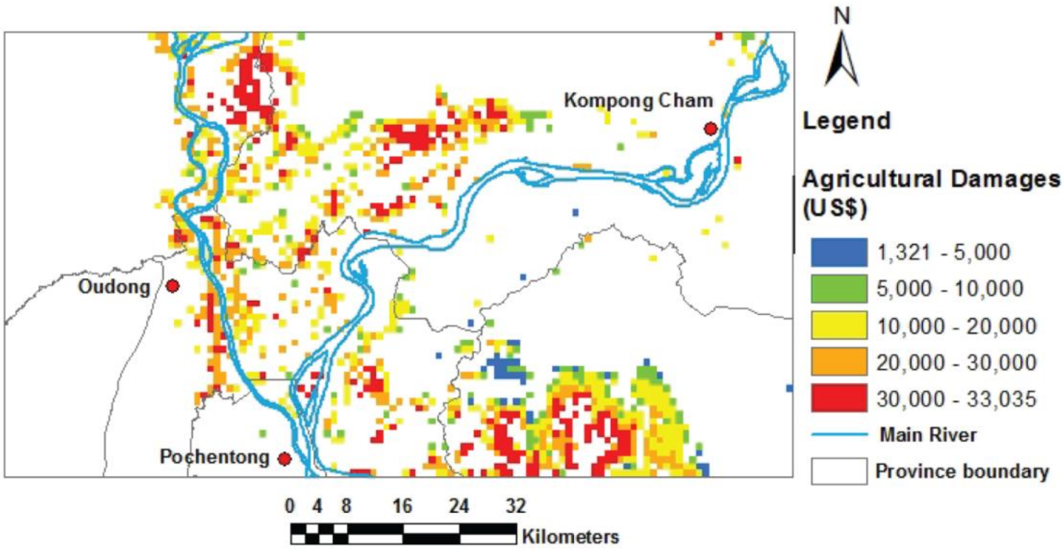


Fig. 2-19 Agricultural damage map in 2006 (Average year) in study area

(4) Validation of the results

a) Identifying flood vulnerable areas

In the previous process, inundation areas and water depth in each area were identified, and damage was estimated. Flood vulnerability assessment, though roughly estimated, was also conducted. However, the validation of this method was difficult due to lack of official data. Instead, the method was validated from a different perspective by comparing with other livelihood data such as settlement area and population density.

b) Hypothesis on flood characteristics in relation to undulation

To discuss flood vulnerability, how residents in the area are coping with topography needs to be taken into consideration, because their livelihoods are seriously affected by floods, which are directly linked to topography. People who live in areas with low undulations are assumed to be seriously affected by flood events. On the other hand, people who live in areas with undulations are assumed not to.

c) Standard deviation for representing the undulation in each grid

Based on this hypothesis, undulation was mapped based on information expressed by the standard deviation (*SD*) of maximum water depth during the rice growing period from transplanting to harvesting calculated by means of the method in "(3)-b) Characteristics and damage of wet season rice" (**Fig. 2-15**). Each cell (90m×90m, 8100m^2) has its own attribute (maximum water depth), and *SD* is calculated as representation of the grid (consisting of 121 cells, i.e., the target cell at the center and five neighboring cells each in four directions, total ≈1 km^2) (**Fig. 2-20**). *SD* calculations were repeated with equation (2.4) and plotted onto the resulting map in **Fig. 2-21**.

$$SD^2 = \frac{1}{N-1}\sum_{i=1}^{N}(d_i - \bar{d})^2 \qquad (2.4)$$

d = water depth in a cell, *SD*= standard deviation as representative in a grid, *N*= total number of cell in a grid

Figure 2-22 shows the field observation results. Points (c) and (d) show low *SDs*, suggesting a flat topography (low undulations), while points (a) and (b) show higher *SDs*, suggesting a contrasted topography (high undulations).

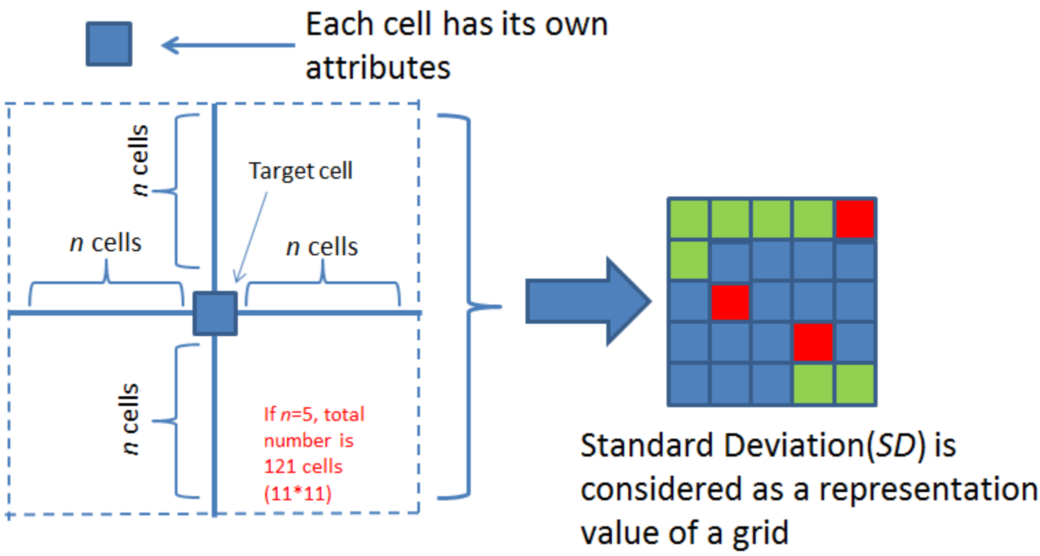


Fig. 2-20 Representation value of a grid

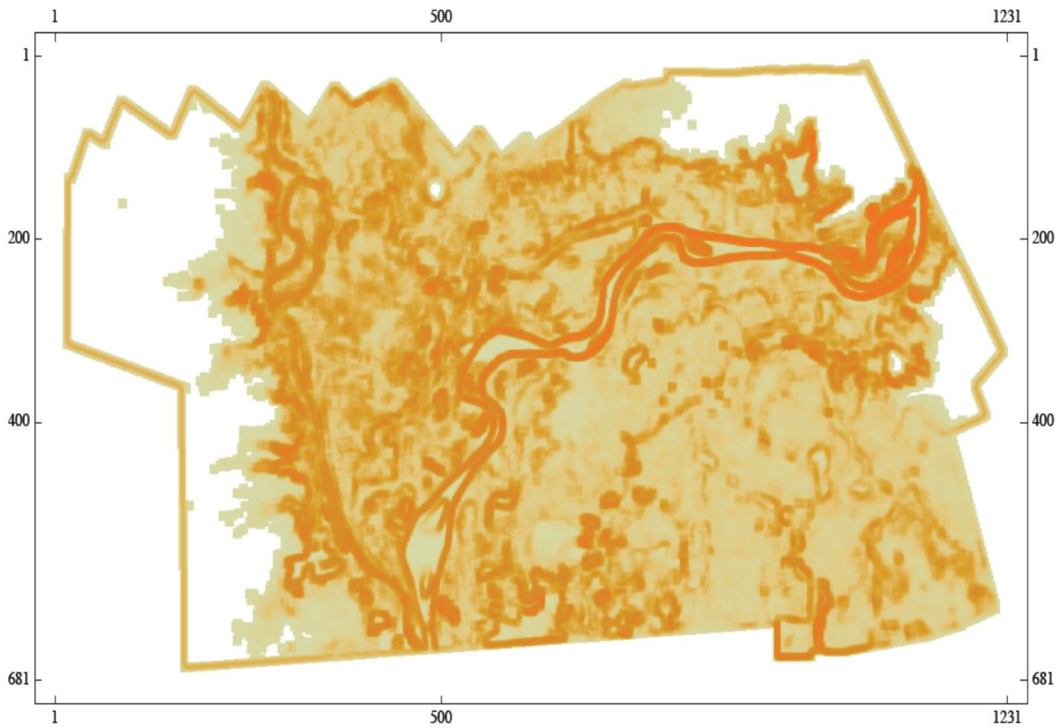


Fig. 2-21 *SD* of the maximum inundation depth during rice growing period

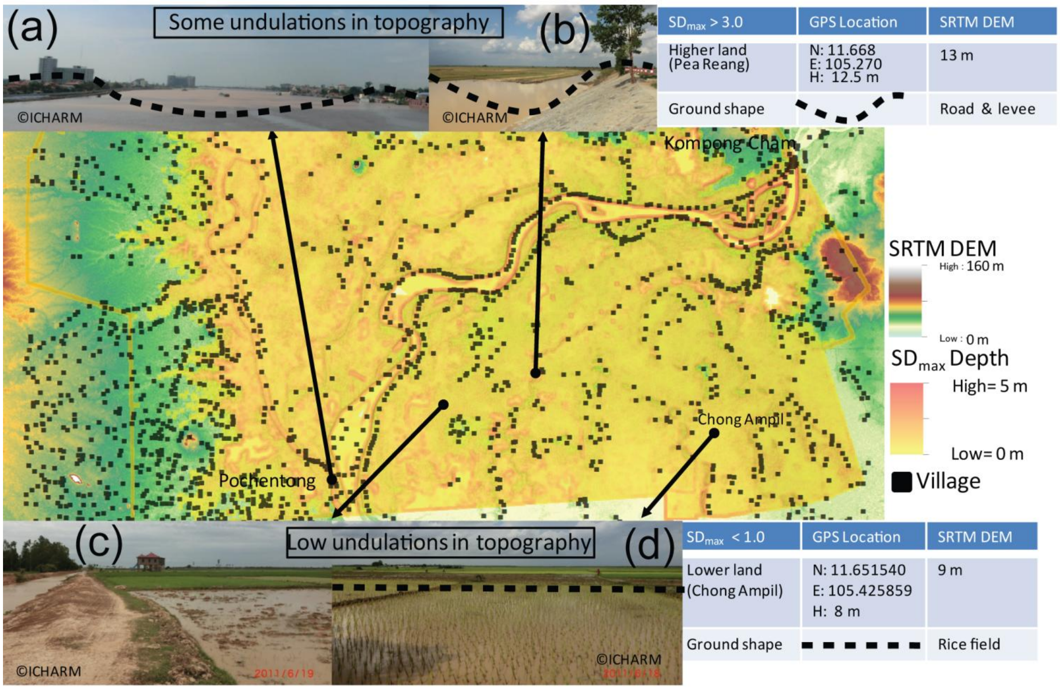


Fig. 2-22 Field survey points and their photos

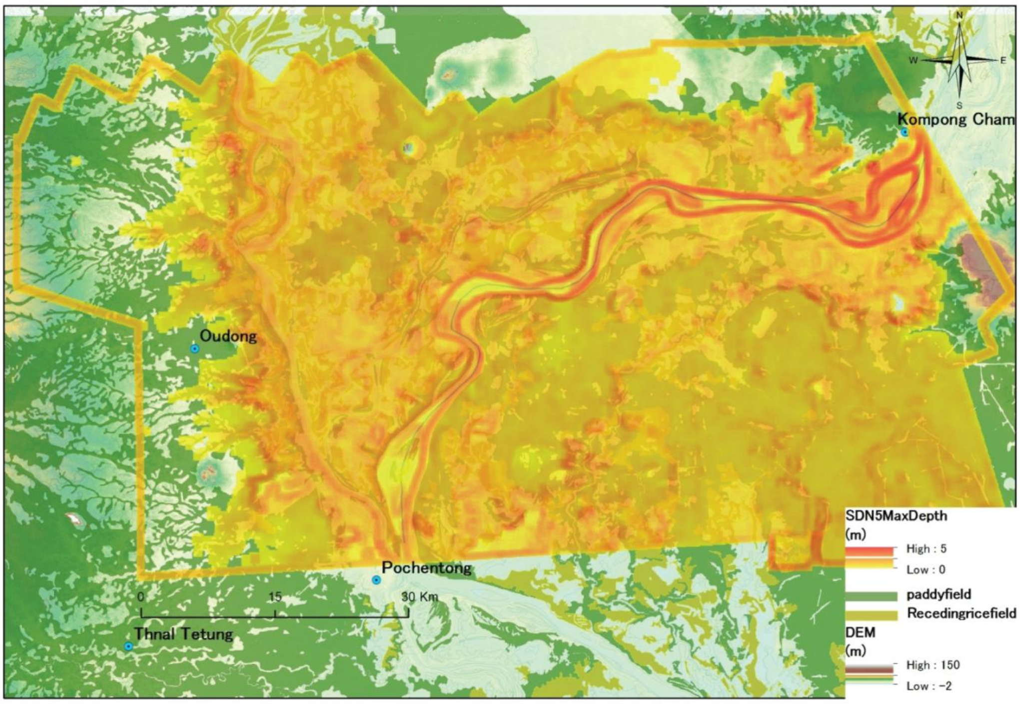


Fig. 2-23 *SD* of the maximum inundation depth during rice growing period overlaid on agricultural land use map

d) Water-depth undulation and land use

Figure 2-23 is an overlay map of water-depth *SD* distribution and agricultural land use. This figure shows that the high *SD* areas (shown in dark color) roughly match the borders between wet- and dry-season rice fields. It also shows some agreement between the high *SD* areas and the areas where people have adopted the dual cropping pattern. It suggests that people in the high undulation areas practice a more resilient cropping style.

Figure 2-24 shows the distribution of population density, which was plotted from the globally available LandScan data for each 1km cell, overlaid on the *SD* distribution map in **Fig. 2-23** and a major road map. Each square dot indicates the population density of over 1000 persons/km^2. There is a good agreement between the highly populated areas and the high *SD* areas. In short, these areas are characterized by high undulations and differences in inundation depth among neighboring paddy fields. Furthermore, the analysis found that the areas along the roads show relatively higher undulations (high *SD*) and are highly populated (in the case of (a) in **Fig. 2-24**). However, some areas are also highly populated even though not located along the roads (in the case of (b)). In addition, there are other areas that are rather unpopulated with low *SDs* even though along the roads (in the case of (c)). Therefore, it was concluded that there may be a correlation between high population density and high *SD* whether a road exist or not.

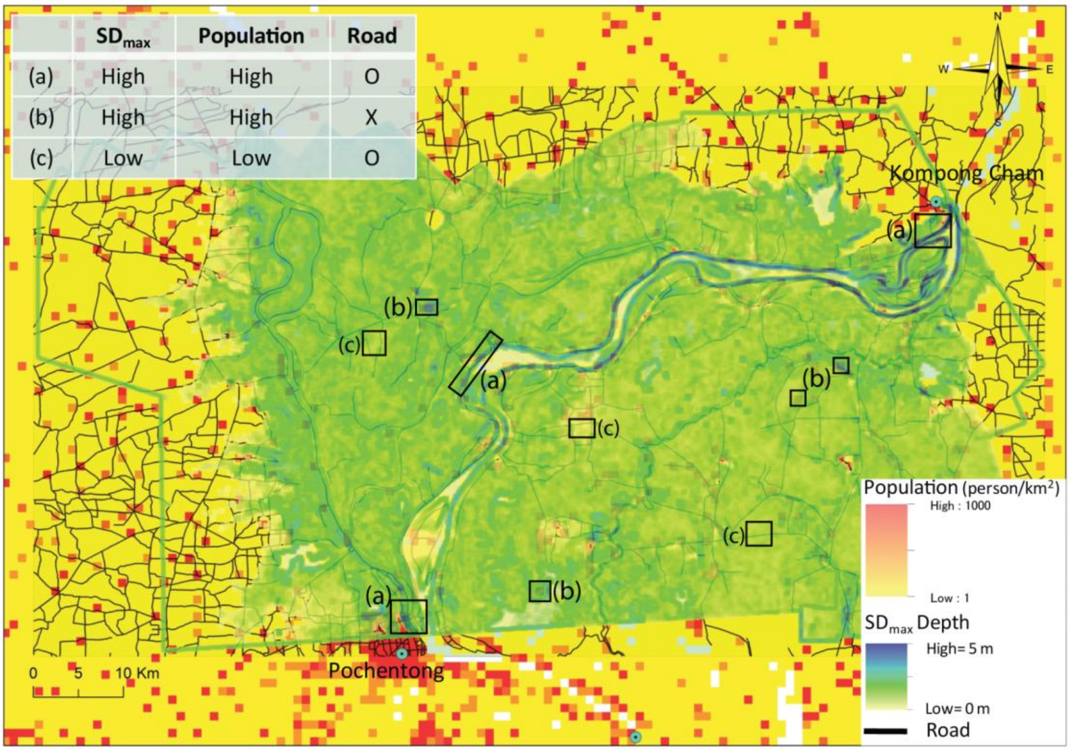


Fig. 2-24 *SD* of the maximum inundation depth during rice growing period overlaid on population density distribution and major roads

2.4.4 Comparison between Flood Risk Assessment in Developing Countries and Japan

In this section, practical problems regarding flood risk assessment in developing countries are identified and reviewed from case studies. The case studies introduce data and information collection requiring effort and cost, a developed method combining the Japanese standards and local experiences, a new method using satellite information, and damage estimation over a large flood area.

The comparison between Japan and other cases are summarized in **Table 2-4**. The difficulty exists not only in the accuracy of data but also in difference in resolution of each dataset, as well as in different information from different sources. The reliability of data is also a serious issue affecting data accuracy. Historical data and accumulation of data are also influential factors over reliability. An accurate dataset makes accurate simulation and accurate damage calculation. Finally accurate results lead to more reliable explanations to decision makers.

It means when more reliable explanations to decision makers are necessary, more detailed data and information should be collected and prepared for flood risk assessment by spending cost and time. It is hard to obtain reliable results from consultation alone when field information is unavailable.

Table 2-4 Comparison between Japan and other cases in typical items of flood risk assessment

Major items	Japanese Standard(the Manual on FCEI)	Chao Phraya flood mater plan study	Agriculture damge estimation in Cambodia	Comments
Topographic, Socio-economic information	Standard: 1/2,500 National basic map SocioEconomic data in National land numerical information (50m)	Desital Elevation Model(60"; 1800m grid) 2km grid household data, damage in each small village(Tambon)	DEM from SRTM (90m grid) Population from LandScan(1km grid) Landuse from MRCS survey	Basic information directly links to accuarcy of result. Coordination with inundation model is necessary
Flood inundation simulation model	Standard:250m grid, 2D unsteady flow 6 cases of flood magnitude	Rainfall Runoff Inundation model developed by ICHARM Hydrological data from National Climate Data Center of US	ICHARM Hydro-Geo Method (assumption from river water level based on Cambodian Irrigation system)	Depending on availability of topographical and hydrological info. Inundation info is necessary for calibration. Coordination with asset info is important.
Damage ratio	Direct damage rate is defined by water depth, slope gradient and duration. For house, household, bussiness, agriculture/fishery	Damage ratio was applied Japanese one. Damage was adjusted by floor height surveyed in the field.	Wet Season Rice damage ratio depend on water depth and duration from past study by MRCS.	Past study will be useful for applied local characteristics. Data collection from field is depending on cost and time.
Result of comparison	Direct damage can be estimate in better accuarcy. Indiret damage is under consideration	Result of industrial damage calculation could be adjusted in cariblation.	Validation of damage result is difficult. But, result can be acceptable by other validation method.	If higher accuary of estimation is required, data collection should be stengthened. It means depending on the requrement.

2.5 Conclusions

In this chapter, flood risk assessment was introduced with its all steps, technologies and methodologies. Flood risk assessment in Japan was explained with its legal status and detailed methodological guidelines.

The legal status of flood risk assessment is specified in the Policy Evaluation Law, and it is currently mandatory to conduct SOP for policy evaluation at proposal, midterm and completion of the project, following the Basic Plan for Policy Evaluation of MLIT. Evaluation of river and dam projects at the proposal stage of SOP is linked to the river improvement planning prescribed in the River Law. For the discussion on each draft river improvement plan, flood risk assessment and cost benefit analysis have to be done based on the Manual prepared by MLIT. Because river and dam improvement projects have a long history of discussion on environment conservation and development, strict requirements of public information disclosure, evaluation and disclosure of pre-project activities have been established.

Following the Japanese case, examples of flood risk assessment in developing countries were also introduced. If flood risk assessment is required for decision making under poor data and information circumstances, a simplified method based on careful field survey should be implemented to overcome lack of data for preparing some results although these results may include some uncertainty.

Based on studies in both cases, comparison in flood risk assessment between Japan and developing countries was conducted for the basic understanding of the present situation of flood risk assessment. This comparison study showed availability of dataset and information is the most influential factor on the accuracy of results, but the coordination of resolution of data, simulation models and damage calculation is also found as important considerations. Even a high resolution simulation model cannot function well if the resolution of data is not good enough to match that of the model. Holistic coordination and management in flood risk assessment as a system will be the key for effective implementation.

Through this chapter, discussion was made about the importance of flood risk assessment as pre-disaster activities to identify necessary action for flood risk reduction and present problems on flood risk assessment, which mainly concerns uncertainty during each assessment step. It is very common to face problems related to uncertainty when risk assessment is conducted in developing countries.

Accurate datasets are needed to carry out accurate simulation and accurate damage calculation, and accurate results lead to more reliable explanations to decision makers. It means that when more reliable explanations to decision makers are necessary, more detailed data and information should be collected and prepared for flood risk assessment by spending cost and time. However, when time and cost are limited, satellites and other methods should be opted as alternative ways to collect necessary data and information with careful consideration on uncertainty.

Important steps and recommendations of flood risk assessment in developing countries were identified as follows:

1) Review available related data and information and collect them as much as possible.
2) Conduct observations and hearings in the field for more data and information, if they are not enough.
3) Use data and information from satellites as supplementary information.
4) Select runoff and inundation models based on collected data and information. Sometimes models define what data is necessary. Keep the same level of accuracy between data and a model for the operability of the model. (A model with a high resolution is not always necessary.)
5) Conduct careful calibration and validation of reproduction models with good understanding of the target of flood risk assessment. Satellite information can be good supplementary information.
6) Prepare damage function based on past disaster investigation. If data is not available, conduct additional interviews and surveys in the field, or consider combination with another available standard.
7) Validate damage calculation without appropriate information.

Reference

1. United Nations International Strategy for Disaster Reduction (UNISDR), 2009 UNISDR Terminology on Disaster Risk Reduction, Switzerland, May 2009

2. B. Wisner, P. Blaikie, T. Cannon, and I. Davis, At Risk second edition, Natural hazards, people's vulnerability and disasters, Routledge, Taylor and Francis Group, London and New York, 2004

3. World Metrological Organization, Guide to Hydrological Practices (WMO No.168) 6th Edition, I.2-24, 2008.

4. Centre for Research on the Epidemiology of Disasters – CRED, Criteria and Definition, Explanatory Notes, EM-DAT, International Disaster Database, access in 2013, http://www.emdat.be/criteria-and-definition

5. Expert Group Meeting (EGM) on Improving Disaster Data to Build Resilience in Asia and the Pacific, Summary and the Way Forward, 1 October 2013, http://northeast-sro.unescap.org/meeting/2013/EGM.html

6. MLIT, the manuals for flood control and economic investigation (draft), 2009, (in Japanese). http://www.mlit.go.jp/river/basic_info/seisaku_hyouka/gaiyou/hyouka/h1704/chisui.pdf

7. Joint Committee for Guides in Metrology, "Evaluation of measurement data – guide to the expression of uncertainty in measurement", JCGM 100:2008, GUM 1995 with minor corrections, corrected version 2010

8. H. Apel, A. H. Thieken, B. Merz, and G. Blöschl, "A probabilistic modeling system for assessing flood risks", Natural Hazards (2006) 38: 79-100; DOI: 10.1007/s1069-005-8603-7, 2006.

9. B. Merz and A. H. Thieken, "Flood risk curves and uncertainty bounds", Natural Hazards, 51, 3, 437-458; DOI:10.1007/s11069-009-9452-6, 2009.

10. The Administrative Reform Conference, The final report of Administrative Reform Conference, December 1997, (in Japanese). http://www.soumu.go.jp/main_sosiki/hyouka/kaigi.htm

11. The law on policy evaluation conducted by government agencies, June 2001, (in Japanese). http://www.soumu.go.jp/main_sosiki/hyouka/houritu.htm

12. MLIT, The Basic Plan for Policy Evaluation in MLIT, 2002 (revised in 2012), (in Japanese). https://www.mlit.go.jp/common/000223038.pdf

13. MLIT, The standard operation procedure for the policy evaluation at the stage for new project proposal in MLIT, 2011, (in Japanese). http://www.mlit.go.jp/common/000111427.pdf

14. MLIT, Dam project - Evaluation on various effect and impact to the area - , prepared for program evaluation, March 2003, (in Japanese). https://www.mlit.go.jp/common/000043135.pdf

15. MLIT, The amendment of river law, May 1997, (in Japanese). http://www.mlit.go.jp/river/hourei_tsutatsu/kasen/gaiyou/houritu/9705.html

16. MLIT, The Advisory Committee for future flood control, December 2010, (in Japanese). http://www.mlit.go.jp/river/shinngikai_blog/tisuinoarikata/

17. MLIT, Carte on project evaluation, 2013, (in Japanese). http://www.mlit.go.jp/tec/hyouka/public/jghks/chart.htm

18. Kinki regional development bureau of MLIT, Material 2 Flood control in Kuzuryugawa at 5th Kuzuryuugawa river basin committee, September 2002, (in Japanese). http://www.kkr.mlit.go.jp/fukui/ryuiki/shiryou.html

19. Water and Disaster Management Bureau, MLIT, 5th Study Group on Evaluation Methodology of River Improvement, March 2013, (in Japanese). https://www.mlit.go.jp/river/basic_info/seisaku_hyouka/gaiyou/seisaku/kenkyukai_hyouka/index.html

20. Kinki regional development bureau of MLIT, Material3 Asuwagawa dam project, 7th Project watch and evaluation committee, March 2012, (in Japanese). http://www.kkr.mlit.go.jp/plan/zigyohyoka/index-2011-07.html

21. Japan International Cooperation Agency (JICA), Project for the comprehensive flood management plan for the Chao Phraya river basin, September 2013.

22. T. Okazumi, S. Tanaka, Y. Kwak, B. B. Shrestha, and A. Sugiura A., Flood vulnerability assessment in the light of rice cultivation characteristics in Mekong River flood plain in Cambodia, Paddy and Water Environment, ISSN 1611-2490, Paddy Water Environ DOI 10.1007/s10333-013-0403-1, 2013.

23. Ministry of Foreign Affairs, Aid policy for Thailand, April 2013. http://www.mofa.go.jp/mofaj/gaiko/oda/seisaku/houshin/pdfs/thailand-2.pdf

24. International Centre for Water Hazard and Risk Management, Public Works Research Institute, “Supporting Investment for Water Related Disaster Management”, Asia Development Bank Technical Assistance no. 7276, March 2013. http://www.adb.org/projects/documents/supporting-investments-water-related-disaster-management-tacr

25. Budhendra B, Bright E, Coleman P, Urban M., LandScan USA: a high-resolution geospatial and temporal modeling approach for population distribution and dynamics. GeoJournal 69: 103-117. doi:10.1007/s10708-007-9105-9, 2007.

26. Farr T, Rosen P, Caro E, Crippen R, Duren R, Hensley S, Kobrick M, Paller M, Rodriguez E, Roth L, Seal D, Shaffer S, Shimada J, Umland J, Werner M, Oskin M, Burbank D, Alsdorf D, The Shuttle Radar Topography Mission, Rev. Geophys45, 2007.

27. Toutin T., DTM Generation from Ikonos In-Track Stereo Images Using a 3D Physical Model, Photogrammetric Engineering & Remote Sensing, 70（6）, 695–702, 2004.

28. Lehner B, Verdin K, Jarvis A., HydroSHEDS Technical Documentation. Version 1.0, World Wildlife Fund US, Washington, DC: 1-27, 2004. http://hydrosheds.cr.usgs.gov

29. Plinston D., Mapping Flood Statistics in Selected Districts on the Cambodian Flood Plain: Consultancy Report, Mekong River Commission, The Flood Management and Mitigation Programme, Land Management Component, 2007.

30. Taniguchi T, Matsumoto T, Shimizu K, Horikawa N, Yoshida T., Development of a Distributed Water Circulation Model Incorporating Various Paddy Water Uses Part 1, A Model for Estimating Cropping Pattern and Area, Journal of Japan Society of Hydrology and Water Resources　22 (2), 101-113, 2009.

31. Ros B, Nang P, Chhim C., Agricultural Development and Climate Change, The case of Cambodia, Cambodia's leading independent development policy research institute Working Paper Series No. 65, 2011.

32. Mekong River Commission Secretariat, Flood Damages, Benefits and Flood Risk in Focal Areas: The Flood Management and Mitigation Programme, Component 2: Structural Measures & Flood Proofing in the Lower Mekong Basin, Draft Final Report, Volume 2C, 2010.

Chapter 3

Lack of Risk Assessment before Disasters

3.1 Introduction

In order to understand the importance of flood risk assessment, the result of survey on bad practices is introduced. These bad practices are characterized by lack of appropriate risk assessment, inadequate dissemination of risk information, failure of incorporating risk information into policy for pre-disaster preparation.

The first case is the Chao Phraya river flood, and the second one is the Great East Japan Earthquake and Tsunami (GEJET). Both occurred in 2011 and caused serious damage to the areas[1].

Interviews and questionnaire surveys to affected Japanese factories were conducted in 2012 and 2013 funded by the Public Works Research Institute (PWRI). This project was named “The investigation on real picture of supply chain economic damage during the Chao Phraya river flood 2011”. The objectives were to find out concatenation damage in the Chao Phraya river basin and the reason why these factories were built in this flood prone area.

The interview survey in Rikuzentakata city was conducted together with United Nations Economic and Social Commission for Asia and Pacific (UNESCAP) in July 2011, and analyzed afterwards. The main objective was to find out reasons why the past development expanded to the coastal area which was seriously affected by tsunamis during the great earthquake.

These two examples can clearly explain the effectiveness of appropriate risk assessment in advance and the importance of sharing the information with residents and preparing prevention measures based on risk assessment.

1 T. Okazumi, et al., 2013.

3.2 Lack of Preparedness in the 2011 Chao Phraya River Floods

3.2.1 Hydrological Situation[2]

Around late July 2011, a tropical storm, Nock-Ten, and heavy monsoon caused severe rainfall and thus flooding from the upper northeastern part down to the central part of Thailand. Subsequently, the Chao Phraya River flooded and inundated 15 provinces of the country (**Fig. 3-1**)[3].

According to the Royal Irrigation Department (RID) of Thailand, the accumulated rainfall from January 1, 2011, to November 27, 2011, reached 1,888.3 mm, which was 365.9 mm (24%) larger than the accumulated monthly average of 1,522.4 mm. **Fig. 3-2** shows comparison between average monthly rainfalls during the 24 years from 1982 to 2002 and those of 2011. The 2011 averages exceeded the 1982-2002 averages consecutively from May to October. These heavy rainfalls resulted in a large flood and extensive inundation.

Figure 3-3 shows hydrographs of the past major floods at the Nakhon Sawan station. The highest discharge is 5,451 m^3/s in 2006, followed by 4,820 m^3/s in 1995 and 4,686 m^3/s in 2011. The 2011 flood hydrograph forms a very gentle peak with the discharge increasing gradually. It took about 1.5 months for the discharge to exceed the river flow capacity of 3,500 m^3/s. This long, high floodwater slowly weakened the river dikes, and finally breached them at several locations between Nakhon Sawan and Ayutthaya in particular.

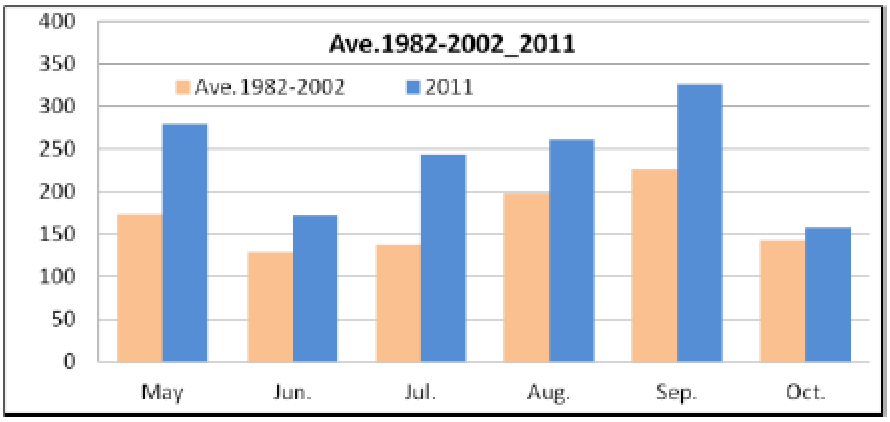
Due to the low flow capacity of the Chao Phraya River, an overwhelming amount of water spilled from the breached sections or overflowed the river dikes and banks to flood plains. **Fig. 3-4** shows the transition of the flood inundation areas.

Flood inundation occurred in the Nan and Yom River Basins as early as late July. The inundated water reached Nakhon Sawan in September. In the middle of September, dike breaches and overflows began to take place in the delta area downstream of Nakhon Sawan. The floodwater flowed down in both the eastern and western sides of the Chao Phraya River. In the middle of October, it swallowed 7 industrial estates in Ayutthaya and Pathum Thani provinces one after another. Finally it entered into a part of Bangkok

2 JICA, 2013.
3 ADRC, 2012.

by the beginning of November. In the lower areas, the inundation continued until the floodwater drained naturally or was pumped out of the areas in December or later.

Fig. 3-1 Location map of Chao Phraya River Basin[2]



Source: "Reservoir Operation for Future Flood" by Oki Taikan, Institute of Industrial Science, The University of Tokyo, Presentation Material for 1st Joint Seminar of Irrigation Water Resources Management on January 14, 2012.

Fig. 3-2 Basin mean monthly rainfall of Chao Phraya River Basin

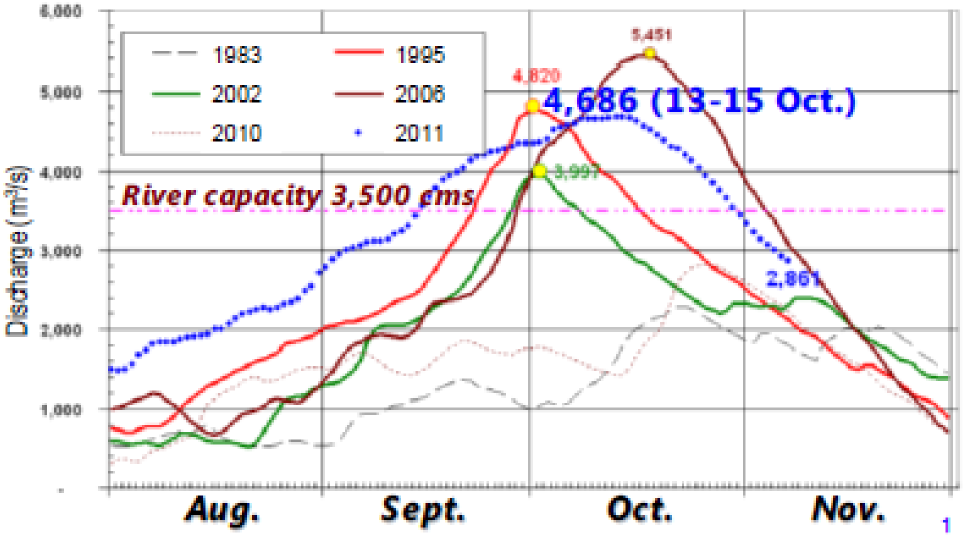


Fig. 3-3 Hydrographs at Nakhon Sawan

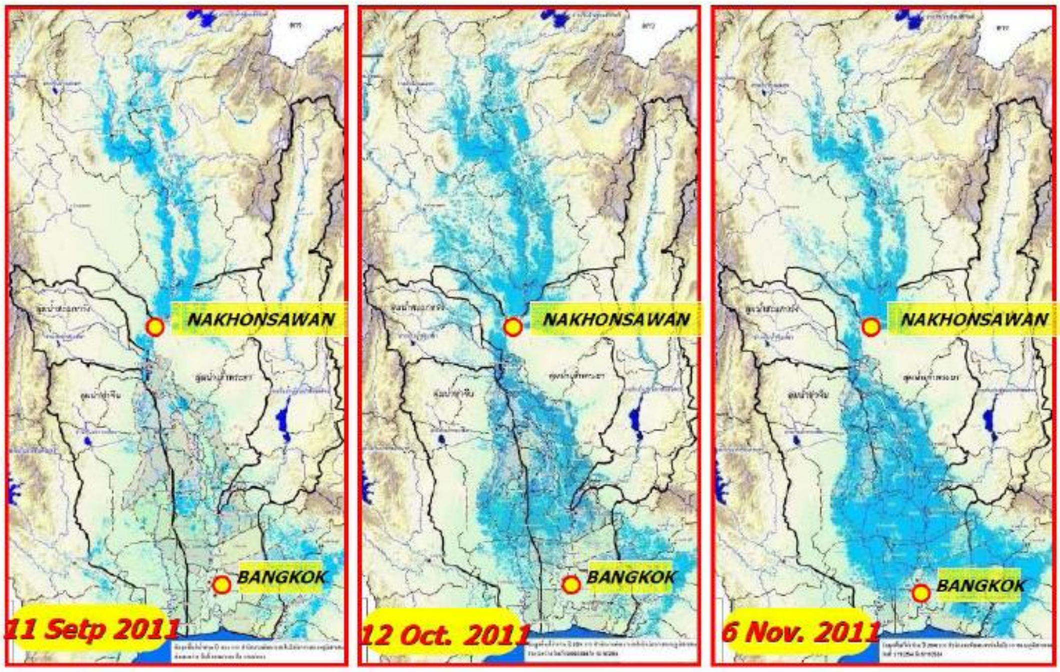


Fig. 3-4 Temporal changes of flood inundation areas during the 2011 Flood (Data source: GISTDA)

3.2.2 Reported Flood Damage

The total inundation area is estimated at approximately 28,000km^2. **Table 3-1** compares the inundation areas of past major floods, which clearly shows how extensive the flood inundation of 2011 was. Accordingly the extensive inundation caused enormous flood damage as summarized in **Table 3-2**. Approximately 13 million people, i.e., 1 out of 5 Thai people, were affected, and 657 people were killed in the flood (as of December 1, 2011). Houses and infrastructures as well as agriculture areas were heavily damaged. In particular, manufactures suffer huge damage and losses as described in the following subsections.

After the flood disaster, damage and losses were assessed by various agencies. The World Bank conducted Post Disaster Needs Assessment (PDNA) during November 7-25, 2011, to estimate damage and losses incurred by the flood in 2011 in collaboration with the Ministry of Finance and both national and international agencies. The full assessment report was finalized on January 27, 2012. There are also other damage assessments and preliminary cost estimations for rehabilitation projects compiled by the government of Thailand and Asian Development Bank (ADB) as well as Japan External Trade Organization (JETRO).

(1) Post disaster needs assessment (PDNA)

Based on the DALA (Damage and Losses Assessment) methodology[4], the total damage and losses incurred by the flood in 2011 is estimated at 1.43 trillion THB, out of which the damage of the physical assets amounts to 630.3 billion THB and associated losses are 799 billion THB, respectively (**Table 3-3**). According to the DALA methodology, damage refers to direct impacts on physical assets, products, raw materials machinery and properties. Losses include reduced or lost production opportunities such as loss of income, reduced production efficiency, increasing expenditures over a period of time. Reduction in income due to interruption of service delivery and increase in transport costs are also considered to be losses.

The manufacturing sector accounted for two-thirds of the disaster damage. Industrial estates in Ayutthaya and Pathum Thani provinces were severely impacted. The water resources management sector counted only damage referring to the physical damage made to dykes, levees and canals, while the finance and banking sector counted only

4 Global Facility for Disaster Reduction and Recovery, access in 2013.

losses without serious physical damages. The tourism sector also suffered heavy losses from losing tourists visits and canceling of attractions and events rather than damage caused to physical assets.

(2) Rapid flood management assessment by ADB

ADB conducted rapid flood management assessment after the flood in 2011 and released a report in January 2012. The analysis in the report summarized the impact of the flood, flooding mechanism, including rainfall records, reservoir operation and flood water diversion. The financial impact estimate was cited as 1.4 trillion THB from the assessment of the World Bank (WB) (**Table 3-4**).

The ADB report analysis suggests that change of land use pattern, namely, reclamation of wetlands and lack of town planning, increased the surface runoff and retarded flood water flow. Inappropriate planning and/or engineering designs of infrastructure without considering water flow patterns also contributed to complicate flood management.

⑶ Industrial parks and estate survey by JETRO

JETRO conducted questionnaire surveys for Japanese companies at the occasions of business seminars. The focus of the survey by JETRO was to update the damage and impact situations of the Japanese companies and to offer information as to the current situation and the policies and measures taken by the Thai government in relation to the trade and investment so that the Japanese companies could make timely business decisions. This helped the government of Japan to extend policy assistance to both relevant Thai and Japanese parties to facilitate quick recovery of the manufacturing sector. In terms of impacts of the manufacturing and retail sectors for Ayutthaya and Pathum Thani provinces, JETRO and PDNA estimated at 208,611 million THB and 196,436 million THB, respectively. The estimates were similar although the surveys were based on different samples. At the time of the questionnaire survey in November 2012, the Japanese companies were hoping to resume manufacturing at the same factory sites in Thailand. No companies wanted to move out of Thailand at that point; however, they may have to make different business decisions if the situation does not improve in the future.

(3) Others

Even though the industrial areas with major damage are located in the past flood plains and thus are very vulnerable to floods, the tenant companies had not been informed of the fact at all. As a result, their awareness of the risk was low and flood preparedness was insufficient as a whole. Generally speaking, in a sound market mechanism like the one in the United States, the premiums of flood insurance change in accordance with inundation depth so that users of the service can recognize the risk to which they are exposed. In Thailand, however, the premiums do not vary depending on the potential of risk at each location.

As a whole, the companies that suffered serious damage during the 2011 flood seems to have low flood-risk awareness.

Table 3-1 Inundation areas of past floods

Year	Inundation Area (km^2)
1983	11,900*
1995	6,140*
1996	7,120*
2002	5,080*
2006	19,000*
2011	28,000

*Data Source of inundation area: " Integrated Flood Mitigation Management in the Lower Chao Phraya River Basin" Dr. Somkiat P. & Dr. Pomsak S., 2007

Table 3-2 Flood damage

Items	Contents
Affected Areas	43,600 villages, 4,917 sub-districts, 684 districts of 65 provinces.
Affected Population	In total 13,425,869 people of 4,039,459 families are affected.
Damaged Houses	2,329 houses: wholly damaged. 96,833 houses: partly damaged.
Agriculture damage	1.8 million hectare cultivated area,
Damages of Infrastructures	13,961 roads, 982 weirs, 142 embankments, 724 bridges,
Damage of livestock	13.41 million livestock
Damages of fish/shrimp/shell ponds	over 37,107 ha
Death toll	657 deaths(in 44 provinces)

Flood damages as of December 1, 2011

Data Source: Department of Disaster Prevention and Mitigation, Thailand (DDPM)

Table 3-3 Summary of damage and losses by sector (in million THB)

Subsector	Disaster Effect			Ownership	
	Damage	Losses	Total	Public	Private
Infrastructure					
Water Resources Management	8,715	-	8,715	8,715	-
Transport	23,538	6,938	30,476	30,326	150
Telecommunication	1,290	2,558	3,848	1,597	2,251
Electricity	3,186	5,716	8,901	5,385	3,517
Water Supply and Sanitation	3,497	1,984	5,481	5,481	-
Productive					
Agriculture, Livestock and Fishery	5,666	34,715	40,381	-	40,381
Manufacturing	513,881	493,258	1,007,139	-	1,007,139
Tourism	5,134	89,673	94,808	403	94,405
Finance & Banking		115,276	115,276	74,076	41,200
Social					
Health	1,684	2,133	3,817	1,627	2,190
Social	-	-	-	-	-
Education	13,051	1,798	14,849	10,614	4,235
Housing	45,908	37,889	83,797	12,500	71,297
Cultural Heritage	4,429	3,076	7,505	3,041	4,463
Cross Cutting					
Environment	375	176	551	212	339
Total	630,354	795,191	1,425,544	141,477	1,284,066

Source: DALA estimates, National Economic and Social Development Board (NESDB) and Ministry for Industry damages and losses in Thailand floods 2554 Rapid Assessment for RRR. 01-18-2012

Note: Losses for each sector include higher expenditures due to floods

Table 3-4 Assessment by ADB of the flood impact by sector

Sector	Impact
Agriculture	12.61 million ha farmland
Industry	9,859 manufacturing plants in 8 province 838 factories in 7 industrial parks
Historical Site	313 sites damaged (Ayutthaya counts for 130)
Education	3,088 schools
Waste Management in BMA	12,963 tons/day (146.62% of average trash: 8,500tons)

3.2.3 Overview of Economic Damage

In overall, damage in agriculture, manufacturing and service industries decreased the country's GDP (market value) by about 33 billion baht and its economic growth by 3.7%. Consequently, the annual GDP growth resulted in a 0.1% increase in 2011, a huge drop from the estimated growth of 3.8%[5,6](**Table 3-5**). Besides these economic drops, the Chao Phraya floods drew global attention for one specific reason: the impact of the floods did not remain within Thailand but spread all over the world mainly through foreign companies and industrial complexes located at the center of the country. This section is devoted to outline economic damage, especially the chain-reaction damage, which is considered as the unique characteristic of this disaster event, including the description of damage types and responses to them based on interviews conducted in Thailand[7].

This flood impacted not only Thailand but also other adjacent countries in Asia. **Table 3-6** shows changes in automobile production for four months after the flood[8]. Thailand shows a huge decline after the flood compared to the same months in the previous year, and so do other countries. It shows an 85% drop in November 2011, the Philippines 22.1%, Viet Nam 11.3%, and Malaysia 2.5%. Indonesia was able to keep a high level of automobile production in October 2011 but could not avoid the flood impact, recoding only a 0.7% increase in November 2011 (**Fig. 3-5**).

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5 H. E. V., Futrakul, 2012.
6 A. Termpittayapaisith, 2012.
7 METI, 2012.
8 METI, 2012.

Table 3-5 Thai GDP growth ratio (compared to the previous year's same quarters) [6]

	2010	2011	2011			
			1st Quarter	2nd Quarter	3rd Quarter	4th Quarter
GDP Growth Ratio %	7.8	0.1	3.2	2.7	3.7	-9.0
Agriculture Sector %	-2.3	3.8	7.6	6.7	0.5	0.7
Non-Agriculture Sector %	8.8	-0.3	2.8	2.4	3.9	-10.1

(A. Termpittayapaisith, 2012)

Table 3-6 Impact on automobile production in adjacent countries [8]

Comparison in previous year(%)		Indonesia	Philippines	Viet Nam	Malaysia	Thailand
2011	*Oct*	22.6	-11.7	2.7	-5.2	-67.6
	Nov	0.7	-22.1	-11.3	-2.5	-85.0
	Dec	28.6	2.4	-15.6	-22.8	-27.6
2012	*Jan*	8.5	-11.9	-29.7	-14.7	-4.0

Source : Trade white paper, Japan, 2012

The Japanese automobile makers have large proportions in auto manufacturing in the Association of South-East Asian Nations (ASEAN) area. Especially their shares account for more than 90% of automobile production in Thailand, Indonesia and the Philippines. In addition, Thailand plays a hub role for supplying automobile parts to surrounding countries and regions. In order to survey the impact of the supply-chain interruption by the Thai flood, the movement of products was reviewed. The product movement in Thailand and Guangdong in China showed a large impact by the Chao Phraya flood, which further worsened by the Great East Japan Earthquake in March 2011(**Fig. 3-6**).

In order to figure out the impact of the flood on the global supply chain in relation to Hard Disk Drive (HDD), the export of HDD to China before and after the flood was compared (**Fig. 3-7**). The HDD export to China decreased by 21.0 % from the figure in the previous month in 2011, although it was an increase of 6.8%, compared with that in the same month in 2010. Furthermore, the export to China continued decreasing dramatically, while China rapidly increased the import of HDD from the Republic of Korea, the Philippines, Malaysia and increased Chinese products. Finally the total import of HDD by China stopped decreasing (In November 2011, it was minus 2.1% compared to the previous month, and plus 9.4% compared to the same month in the previous year). Still, the import from Thailand was kept at a lower level, while the import from other countries remained at a higher level, although the import from Thailand gradually recovered. The total import of HDD to China actually grew larger than that before the Chao Phraya flood (**Fig. 3-7**). All this proves that HDD makers and other supply makers outside Thailand increased its productivity and provided alternate products after the flood. The HDD industry was different from the automobile industry in that the flood actually encouraged the production of alternative products to cover the decrease of the supply from Thailand.

There was another interesting story. Many Japanese companies dispatched Thai workers from Thailand to factories in Japan in order to keep their supply chains and production during the Chao Phraya flooding.

Evidence can be seen in **Fig. 3-8,** which describes the number of Thai workers in Japan and the world. Damaged Japanese factories dispatched many Thai workers to Japan temporarily. The statistics in the Central Bank of Thailand indicated that the recent number of Thai workers in the world is around 1 to 1.5 million and those in Japan count 500. However, just after the Chao Phraya flood, Thai workers in Japan increased up to

3,500 in December 2011 due to a large number of those workers sent to Japan, and it rapidly decreased down to 400 in March 2012 because most of them went back to Thailand.

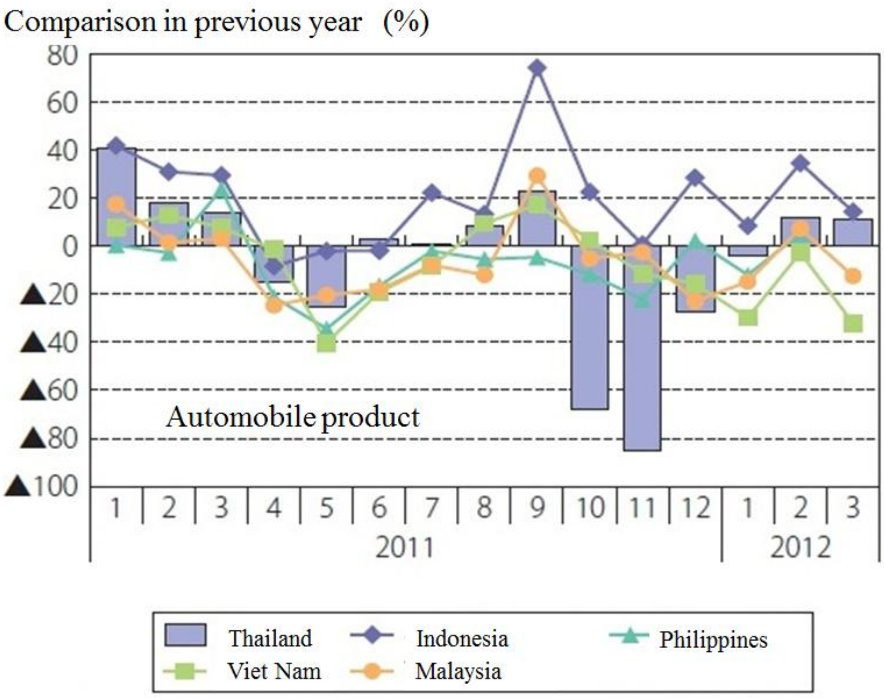

Fig. 3-5 Impact to adjacent countries in Automobile product

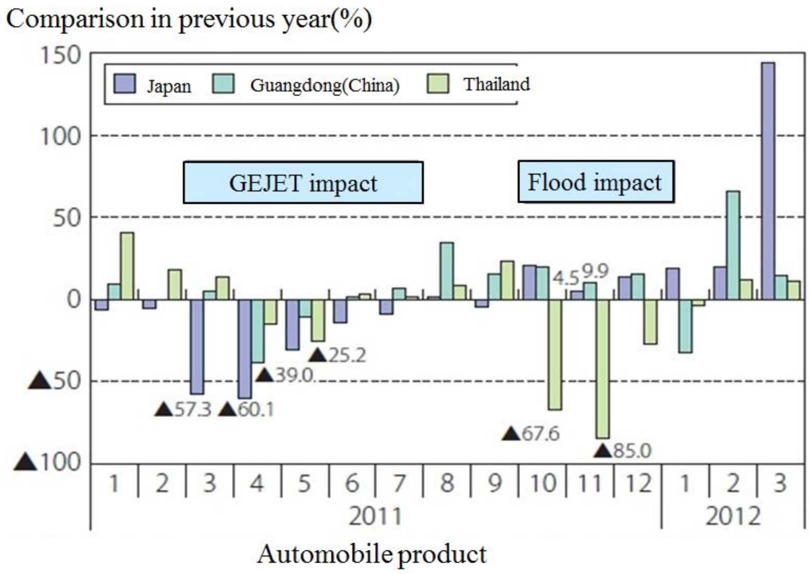

Fig 3-6 Economic impact by two large disasters

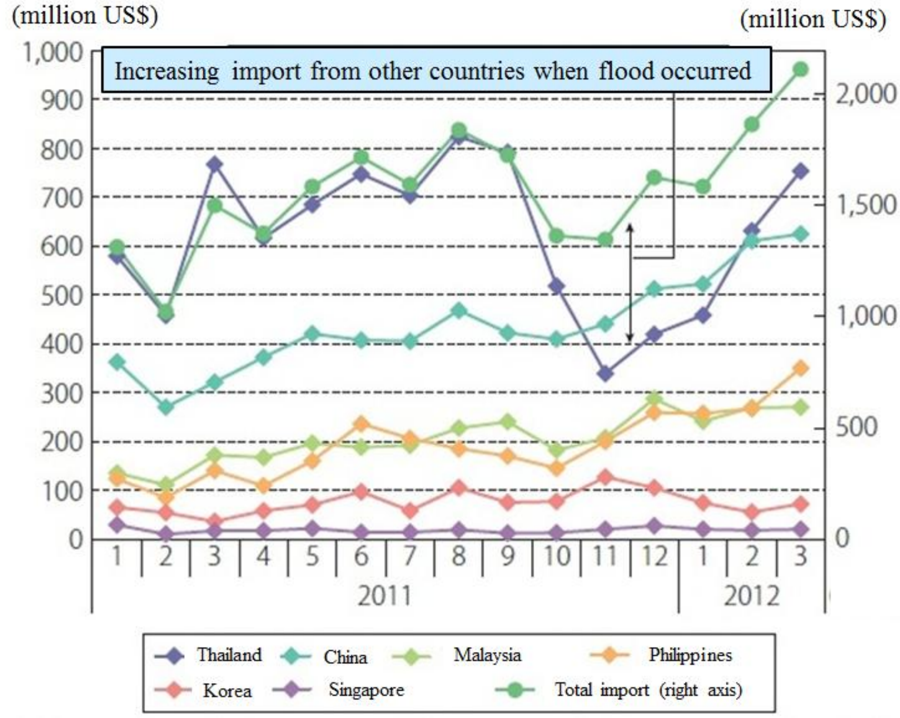

Fig. 3-7 Impact to other adjacent countries in HDD import

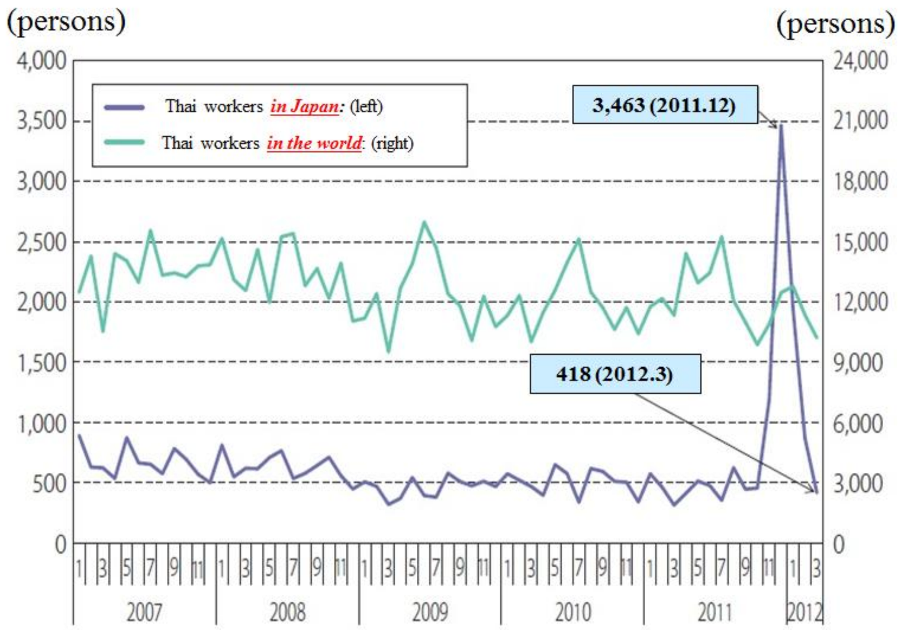

Fig. 3-8 Impact to workforce movement

3.2.4 Outline of Field Survey

With respect to the Chao Phraya River flood case, two sets of investigation were conducted on the 2011 flood damage in Thailand, especially on its chain-reaction impact on economic activity. First, literature review and interview survey were undertaken in Japan for companies with factories affected by the floods, which was followed by interview survey in Thailand in May 2012. In Thailand, interviews were conducted with Japanese factories in four industrial complexes, nine Japanese companies with flood-affected factories, the Japanese Chamber of Commerce, Bangkok (JCC), and the Bangkok branch of JETRO. Some companies were introduced to the investigation team through the Japan International Cooperation Agency (JICA), with which ICHARM is jointly involved in a Chao Phraya flood management project. Others were contacted thorough snowball sampling and the network of executives of Japanese companies in Thailand.

Before interviews with individual companies, the team visited JCC and JETRO to collect general information on expansion of Japanese companies in Thailand and their responses to the disaster. Then, individual factories in the industrial complexes, such as the Rojana Industrial Park, Hi-Tech Industrial Estate, Bang Pa-in Industrial Estate, and Factory Land (Wangnoi) of Ayutthaya Province and the Nava Nakorn Industrial Estate of Pathum Thani Province, were visited for interviews with representatives of each factory. Interviews were also carried out at their headquarters in Bangkok. In August 2012, further investigation was conducted for 1,370 Japanese companies in Thailand through the Internet with help from JCC. As of late-August, 38 of them responded and their answers are currently being analyzed in detail.

3.2.5 Economic Damage Identified in this Survey

The impact of floods was particularly serious on local Japanese companies in economic terms. More specifically, Japanese companies that based their businesses in the country earlier than others had greater damage, reportedly because many of those companies have their factories in the industrial complexes in central Thailand (Ayutthaya and Pathum Thani Provinces) that are relatively old, mostly established in the 1980s[9]. From October to December of 2011, well over 1,000 factories of 804 companies were inundated including 43 factories in the Saha Rattana Nakorn Industrial Estate, 198 in the Rojana Industrial Park, 143 in the Hi-Tech Industrial Estate, 89 in the Bangpa-In

9 The Japanese Society of Thai Studies, 2009.

Industrial Estate, 572 in the Factory Land Wangnoi, 227 in the Nava Nakorn Industrial Estate, and 44 in the Bangkadi Industrial Park (**Fig. 3-9**). Remarkably, 449 out of 804 were Japanese companies[10]. Japan experienced the first annual trade deficit in 2011 since 1980, supposedly in large part due to the Chao Phraya floods in addition to other economic factors.

The expansion of economic losses caused by the 2011 Thai floods is attributed to vertical specialization and a supply-chain structure on which Japanese companies have commonly relied[11]. According to the interviews with JETRO and JCC, in most cases, Japanese manufacturers in Thailand import parts from Japan or procure them from local manufacturers, put them together and export products to the global market. During the disaster last year, this vertical specialization and parts procurement system worked against them and became the principal factor for the damage to expand overseas. Thailand has been a successful case in many industries, especially cars and electronics, and thus supporting industries are also prosperous[12]. This unfortunately has caused the rapid and broad expansion of flood damage both domestically and internationally.

The production of HDD and automobile is a typical example. Thailand accounts for 43% of the world's HDD production[13]. The 2011 floods inundated HDD suppliers and factories, causing price increases and product shortages. The impacts were far-reaching throughout the world; the global production of end products requiring HDD installation, such as computers and video recorders, also decreased. In the car industry, due to its pyramid structure of supporting industries, in which the primary suppliers have over ten times more secondary and tertiary suppliers underneath, the impact of flood damage was even greater.

10 JETRO, 2012.
11 Tokyo Marine &Nichido Fire Insurance Co. Ltd., 2011.
12 Japanese Chamber of Commerce Bangkok, 2011/2012.
13 Development Bank of Japan, 2012.

Fig. 3-9 Affected industrial estates and parks (within a dotted line)
(Modified JETRO's figure with their permission)

3.2.6 Historical Background of Settlement of Japanese Companies

To identify reasons that Japanese companies had chosen to be in industrial complexes affected by the 2011 Thai floods, various factors were sorted out into external and internal ones. External factors include investment policies in favor of foreign companies by the Board of Investment (BOI) and the Industrial Estate Authority of Thailand (IEAT), deregulation regarding taxation and foreign workers, efforts by the Thai government to attract specific industries such as cars, and Thailand's high-quality and inexpensive labor. In addition, socio-economic conditions in Japan including Japanese youth avoiding the manufacturing industry and the strong yen are also considered as external factors. Internal (corporate) factors include the facts that the country is relatively safe and at a good location geopolitically and that people are friendly to Japanese, as well as good social and living conditions[14].

Historically, industrial complexes along the Chao Phraya River were developed earlier than others in the areas that used to be rice fields. Until the 1970s, industrial areas around Bangkok were confined within an approximately 50 km from the capital, and farmland lay farther outside. In the 1980s, more industrial areas were developed in five provinces around Bangkok. That was the results from efforts by the public and private sectors to attract foreign companies to Thailand by developing rice fields specifically for industrial use and by building necessary infrastructures. Consequently, industrial complexes are located in areas that used to be rice fields[15]. Additional incentives were also provided by BOI and IEAT for foreign companies to make investment to start their businesses in Thailand[16].

A drastic turn took place in 1997at the Asia currency and economic crises. The Thai government started economic structural adjustment under the supervision of the International Monetary Fund (IMF), and had to address new foreign currency policy. The government deregulated the limitation of investment ratio by foreign capital and eliminated regulations on import tariff exemptions for raw and other materials. In 2001, BOI selected five target industries of agriculture and fisheries, automobile, clothing, information and communications and high-value added services and lifted investment zone regulations for certain types of business. Subsequently, BOI also designated 2008 and 2009 as the Thailand Investment Year and encouraged more investment in existing

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14 Organization for Small & Medium Enterprises and Regional Innovation, 2006.
15 J. Kitahara, 1995.
16 A. Suehiro, 1993.

businesses related to, for example, cars and electronics to strengthen competitive edges in the industrial sector.

Secondary and tertiary suppliers have also come over to Thailand and started business. Behind this corporate decision are not only the economic incentives explained so far but also the recent trend of rising yen and a business judgment in which they think that it is better for them to move to the same location with their main business partners to continue securing strong business ties[17,18,19].

In May 2012, interviews were conducted to factory representatives of the Rojana Industrial Park, the Hi-Tech Industrial Estate, the Bangpa-In Industrial Estate, the Factory Land Wangnoi, and the Nava Nakorn Industrial Estate. Many of them commonly responded that though they were aware of some flood risk, they thought that no serious flooding would ever occur in their complexes because they are located in areas previously used as rice fields.

3.2.7 Types of Chain-Reaction Economic Damage and Countermeasures

In general, companies in a supply chain have a very strong business tie between each other based on mutual trust. In some cases, because of that, partner companies helped flood-affected companies to restore their factories and resume manufacturing as soon as possible. In particular, home appliance manufactures were under tremendous pressure, because delay in supplying end products to the market eventually means smaller shelf shares in retail stores, resulting in serious disadvantages in the market. Knowing that, in the worst case, such conditions could last for a long time, manufacturers made desperate efforts to restore their offices and factories sometimes even with help from their partners.

Based on the interviews with factory representatives as mentioned before, the analyses found that the chain-reaction economic damage can be categorized into three types as tabulated in **Fig. 3-10**.

The first category includes the most serious cases. In these cases, there will be no demand and no supply. What is possible is only to restore facilities as soon as possible.

17 K. Oizumi, 2012.
18 M. Mori, 2010.
19 T. Nakasu, et. al., 2011.

Those in this situation are required to secure sales channels for business survival, while at the same time suppliers continue working to resume manufacturing, checking progress in restoration and seeking for alternatives to supply as many parts as possible. The A corporation in the Factory Land Wangnoi, for example, took an emergency measure to continue manufacturing parts in partner factories. They took another measure to secure their business by coordinating between parts suppliers and retail stores not affected by the floods.

Companies in the second category responded differently. A precision instruments maker is a case in point. This company usually imports parts from Japan, assembles products in Thailand, and ships them back to Japan. Since this regular production process was no longer possible as a result of the floods, they sent Thai workers to Japan to have them continue doing the same work there, which then helped the corporation keep their business. The company made such a decision because their production takes special manufacturing techniques and their Thai workers are trained to be specialized in them.

In the third category, suppliers had a hard time because of huge drops in demand for their parts and thus serious sales decreases. Some companies in this situation made various efforts to minimize the impact of the floods. While waiting for regular partners to resume operation, they tried to find new partners who can use their parts and also control the production.

3.2.8 Conclusion for Chao Phraya Flood and Damage

As mentioned above, based on the Thai government policy, the reclamation was conducted in the retarding and inundated area previously utilized as paddy field, and development of industrial clusters has expanded this area to build more industrial parks. Furthermore, several economic incentives made by the Thai government helped attract more foreign factories.

While the rapid development in this area, sufficient risk assessment was not conducted and information related to flood risk was not provided for residents. Then finally foreign factories installed in these areas were seriously damaged by the 2011 flood.

This is a typical case of poor practice resulting from lack of risk assessment and not sharing risk information before a disaster.

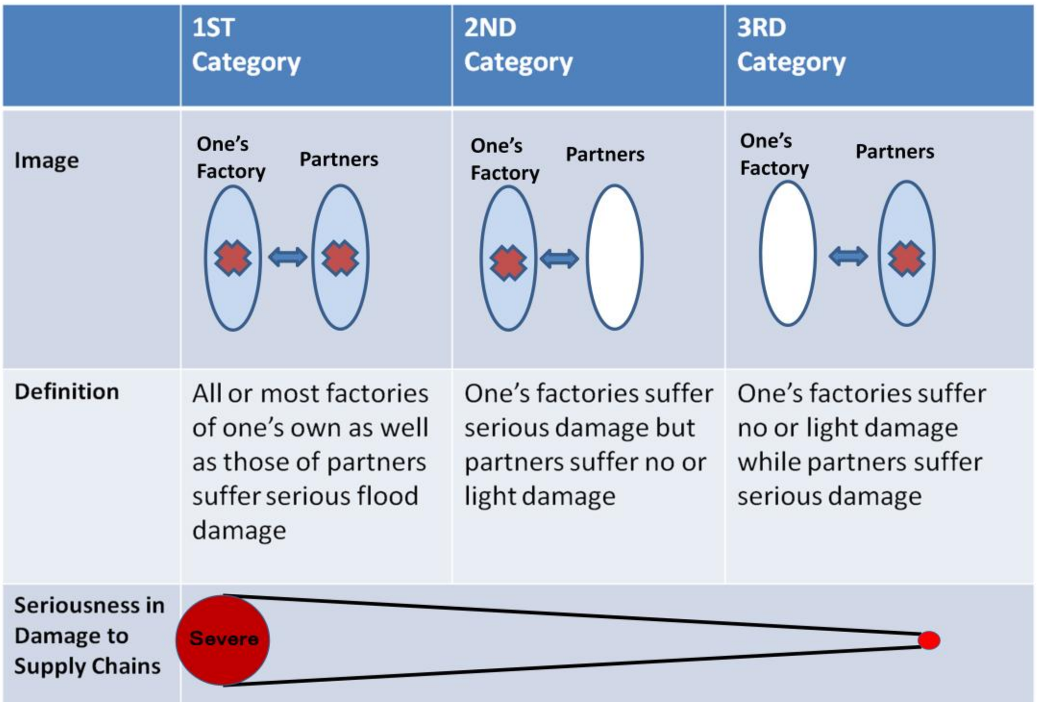


Fig. 3-10 Categories of chain-reaction economic damage.

Note; Results from analysis of all companies with economic damage. Among them, those with the "x" mark suffered direct impact from the 2011 floods.

3.3 Lack of Preparedness Made Serious Damage in Rikuzentakata City Hit by the GEJET

3.3.1 Outline of Damage by GEJET

The magnitude (M) 9.0 earthquake produced huge tsunamis that killed nearly 20,000 people and wreaked destruction along the Tohoku coast of Japan in 2011. The tsunami traveled across the Pacific basin, triggering evacuations and causing severe damages in many countries; one person was killed in California, U.S., and another in Papua Indonesia province in Indonesia. Located on the subduction zone interface off the coast of the Tohoku Region, the quake ruptured a 300 km-long fault extending from near the southern end of Ibaraki Prefecture to central Iwate Prefecture[20]. It was the largest magnitude earthquake recorded in Japan in historic times, and the combined impacts of the earthquake and tsunamis left 15,858 dead and 3,021 missing[21]. Associated economic losses were reportedly estimated at US$ 300 billion, making it the most costly natural disaster of all time. There was thought to be fairly good knowledge on the expected sizes and locations of prospective large-scale events based on about 400 years of historical records that included M7 to 8 earthquakes in Tohoku, Japan. Because of that, the seismological community was shocked by this M9 event. The highest water level (40.1 m) at Ryouri Bay in Iwate Prefecture was the greatest tsunami height ever measured in the country[22]. Water heights were close to or exceeded 20 m in most populated coastal communities in Iwate and northern Miyagi prefectures. Huge tsunamis caused by the unexpectedly strong earthquake inundated coastal regions, which were probably among the best tsunami-prepared regions in the world. Tsunami inundation hazard maps and evacuation places calculated by numerical models based on a M8.2 earthquake were unfortunately not very helpful to escape from the mega tsunamis of the time (**Fig. 3-11**).

3.3.2 Survey Method

With reference to GEJET case, comprehensive research was conducted to understand the disaster damage in Rikuzentakata by employing literature review, statistical data analyses and interviews with disaster victims of Rikuzentakata (**Fig. 3-12**). Documents for the literature review and statistical data analyses were collected from a wide range of information sources from publication by the central government, Iwate Prefecture,

20 L. Dengler, et. al., 2011.
21 Japanese metropolitan police department, 2012.
22 The 2011 Tohoku Earthquake Tsunami joint survey group, 2012.

Rikuzentakata city and newspaper publishers, to online articles and statistics, to historical documents available at the Special Library for Disaster Management, Municipal Reference Library, and Iwate Prefectural Library. General information on the disaster was obtained from the Cabinet Office, the Ministry of Internal Affairs and Communications, and the Fire and Disaster Management Agency, and information on disaster victims was acquired from documents made available by the National Police Agency. Geographical information was mainly from the Geospatial Information Authority of Japan, local information from Iwate Prefecture and the Iwate Restoration Network, and local statistical and historical information mainly from the document[23] listed in References at the end of this paper.

23 K. Yamaguchi, et al., 2011.

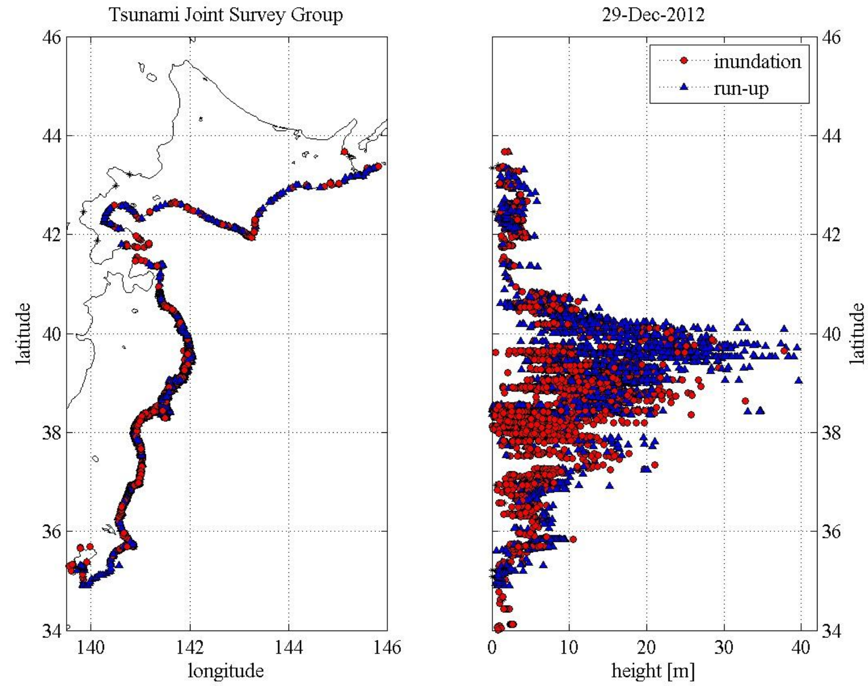


Fig 3-11 The 2011 Tohoku Earthquake Tsunami Joint Survey (TTJS) Group (http://www.coastal.jp/ttjt/ access as of 19 December 2013)[32]

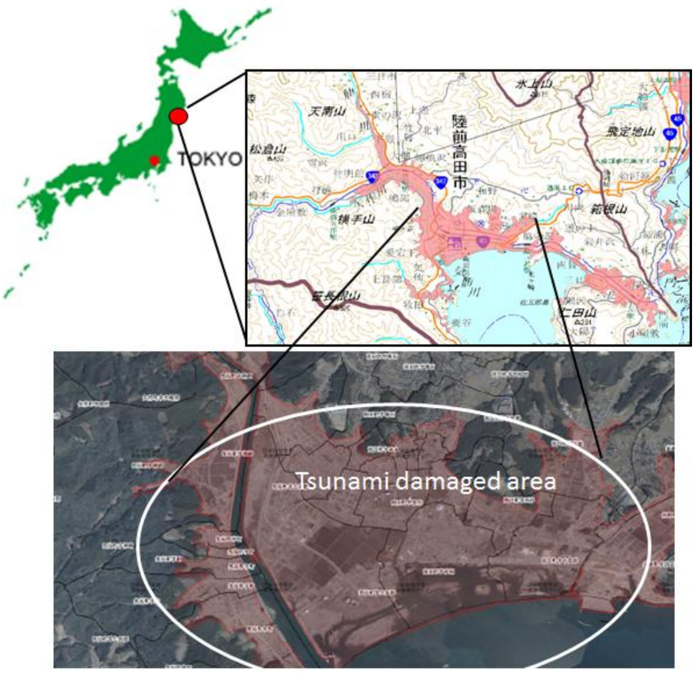


Fig. 3-12 Location of Rikuzentakata city

3.3.3 Methodology of Interview Survey in Rikuzentakata City

Interview survey was conducted during 18-28 July 2011. A pair or trio of interviewers visited disaster victims in person at shelters, makeshift houses, remains of private houses or other places to which they moved after the disaster.

During an interview, interviewees were asked a series of questions according to the prepared questionnaire sheet. However, the survey was carried out flexibly, not rigidly following the plan, carefully considering the rights and conditions of interviewees.

A total of 37 victims participated in this interview survey, which helped understand the evacuation behavior and its background information of 207 people including 55 who were killed during the disaster.

The joint investigation team on evacuation during the March 11 tsunami disaster carefully coordinated all interviews of different researchers in this area. The investigation team including the author was assigned to Rikuzentakata and conducted the survey with the prepared questionnaire at several places such as shelters and makeshift houses after getting permission from Rikuzentakata city and its city mayor.

The interviews were conducted very carefully, providing extra care for the feelings of victims. Although the procedure was all arranged beforehand, the interviewers did not mind the victims sidetracking, as they had agreed among them before the survey to go along with the interviewees and listen to whatever they would want to talk about. They were even prepared to discontinue the interview anytime if necessary. A total of 32 interviews both for individuals and families were carried out during the 2-week survey, and about 2 to 3 hours was spent per interview.

The survey was originally planned as a quantitative investigation using questionnaires but turned out to be more like a qualitative investigation when actually conducted. The interviewees were 37 disaster victims, consisting of 21 females and 16 males aged 40 or older, though attributes and ages were not determined in some cases. The interview questions were asked mainly based on the prepared questionnaire, including the life or death of family members and their detailed evacuation behavior, the relevancy of the recent evacuation behavior to past tsunami experience, the awareness about hazard maps, the experience of family talk about tsunamis, the participation in municipal evacuation drills, and any requests to city and state governments. Besides their answers to the questions, whatever they were willing to talk about was all documented. This report is written based on part of such recorded interview results.

3.3.4 Urban Development in Rikuzentakata City

On-site interviews were conducted with residents of Rikuzentakata city, which suffered tremendous tsunami damage, in addition to intensive literature review.

Fig. 3-13 shows the demographic changes in Rikuzentakata after 1960, when the Chili Tsunami hit the city along with other coastal areas. Comparison of the areas in the black circles reveals a rapid development of the Takata downtown area after 1960. According to demographic statistics provided by Iwate Prefecture, Rikuzentakata's population showed a 21% decrease between 1980 and 2010. On the other hand, the population of the Takata area increased from 6,461 in 1950 to 7,711 in 2005[24]. This population increase, and hence the expansion of the Takata downtown area, reflected social conditions of the time. After the 1960 Chili tsunami disaster, tsunami protection projects were launched along with other national-land enhancement projects, thanks to rapid economic progress after the strong Isewan Typhoon Disaster in 1959. During those projects, over 5-meter-high seawalls were constructed to protect the Takata area, which accelerated the area's development.

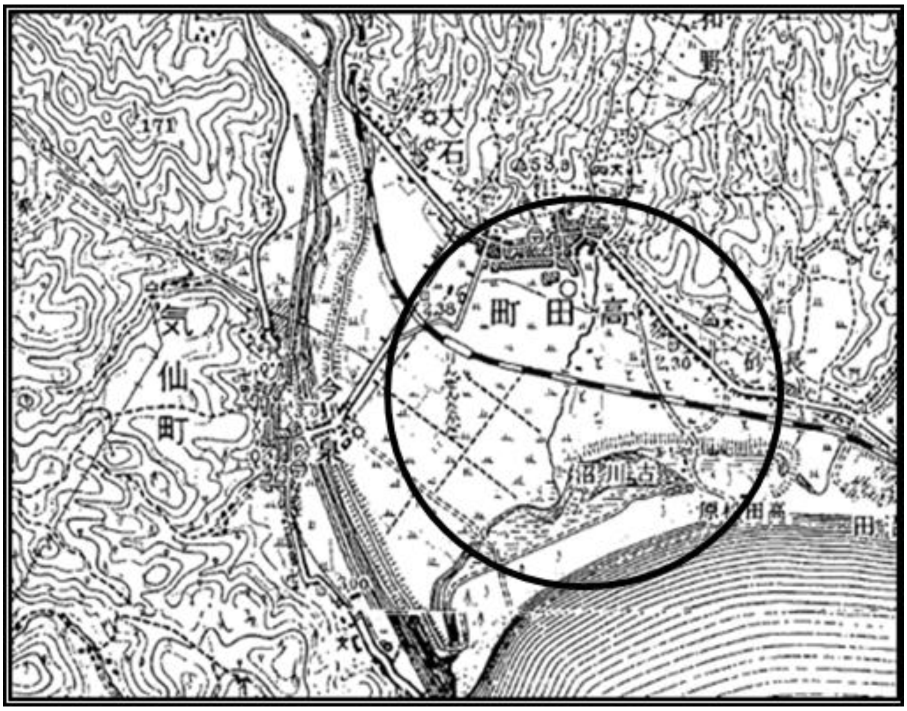
Based on information provided by Rikuzentakata city during the on-site investigation, the casualty rate of the downtown Takata area is 12%, which is twice as high as the second highest rate of 6% in Kesen Town. The interview comments of Takata residents coincide with these statistics and other information. The evidence from the interviews shows that the residents did not start evacuating right away, that they did not expect the tsunami to arrive so soon, and that they did not imagine the tsunami coming.

The interviews with affected local residents also revealed that the association of the initial warning on the tsunami height with their past experience delayed their evacuation. Rikuzentakata had been hit twice by tsunamis from the earthquakes in Chile; the tsunami heights were 4-5 meters high in 1960 and 1.9 meters in 2010 and did not cause serious harm to the area. Because the first warning by Japan Meteorological Agency (JMA) announced that the expected tsunami height would be about 3 meters, many local people did not start evacuation soon enough, taking it for granted that the coming

24 Iwate Survey of Statistics Section, 2012.

tsunami may also cause little harm to the area. The interview results clearly indicated that many people thought the tsunami would never come over the railway until they confirmed its scale with the naked eye. Most tsunami survivors are those living on higher ground who would have a plenty of time to evacuate even if they start escaping after seeing the arrival of tsunami.

(A)



(B)

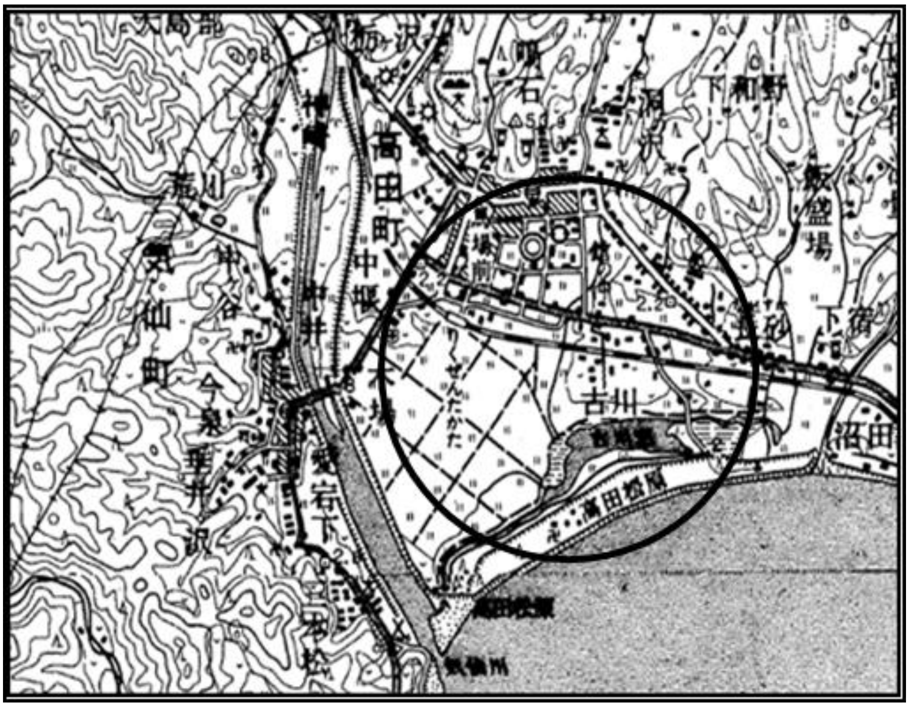


Fig. 3-13 Change of Takata area in Rikuzentakata city **(A)** 1952, **(B)** 1968

3.3.5 Conclusion for the Rikuzentakata City Damage

The Rikuzentakata case shows that they expanded urban development up to the coastal area although the area had a history of being affected by tsunami before. After 1960 because of the Chili tsunami, higher seawalls were implemented. This may be one of the reasons to expand the development up to the coast.

The improvement of seawalls ironically led to the low preparedness of the residents. They may have thought that the seawalls were now high enough to protect them from previous tsunamis, paying little attention to inadequate warning systems. Further investigation is necessary to confirm the effect of the construction of the seawalls on local residents.

3.4 Conclusion

In this chapter, two cases were introduced as poor practices. The first case is the Chao Phraya river flood, and the second one is GEJET. Both occurred in 2011 and caused serious damage to the areas.

These two examples can clearly explain the effectiveness of appropriate risk assessment in advance and the importance of sharing information with residents and preparing prevention measures based on risk assessment.

In the Chao Phraya river flood case, the reclamation was conducted in the retarding and inundated areas that were utilized as paddy fields previously, and the development of industrial clusters has expanded in these areas to build more industrial parks with several economic incentives made by the Thai government. Despite this rapid land development, sufficient risk assessment was not conducted and information on flood risk was not provided. Then finally factories in the developed areas were seriously damaged during the 2011 flood. This is a typical case of poor practice resulting from lack of risk assessment and risk information sharing before a disaster.

The Rikuzentakata case shows that they expanded urban development up to the coastal area although the area had a history of being affected by tsunami before. After 1960, higher seawalls were constructed because of the Chili tsunami. The improvement of seawalls ironically led to the low preparedness of the residents. They may have thought that the seawalls were now high enough to protect them from previous levels of tsunamis, paying little attention to inadequate warning systems. In addition, experience of no significant damage in Chili earthquake tsunami also resulted in low preparedness among local residents. More investigation is necessary to confirm the psychological effect of the construction of the seawalls on local residents.

Although each case addresses an issue of accepting development in high risk areas, the cases clearly represent poor practices in terms of preparedness before disasters on implementation of risk assessment beforehand and sharing information to all level in this area. However, careful attention should also be paid to such development in promoting the mainstreaming of disaster risk reduction in developing policy as explained in chapter 1.

Poor practices can ironically provide insightful lessons for better understanding disaster risk management. Based on this understanding, the author will present a practical case study on uncertainty estimation of flood risk assessment in a developing country in the following chapter.

Reference

1. T. Okazumi, T. Nakasu, M. Sugimoto, and Y. Adikari: Lessons Learnt From Two Unprecedented Disasters in 2011 -Great East Japan Earthquake and Tsunami in Japan and Chao Phraya River flood in Thailand-, Background Paper prepared for the Global Assessment Report on Disaster Risk Reduction 2013. access in 2013: http://www.preventionweb.net/english/hyogo/gar/2013/en/home/documents.html

2. Japan International Cooperation Agency (JICA), Project for the Comprehensive Flood Management Plan for the Chao Phraya River Basin, March 2013.

3. Asian Disaster Reduction Center, Thailand: Tropical Strom, Flood: 2011/08/03, 2012 http://www.adrc.asia/view_disaster_en.php?NationCode=764&lang=en&KEY=1544

4. Global Facility for Disaster Reduction and Recovery (GFDRR), Damage, Loss and Needs Assessment – Tools and Methodology, access at 2014 https://www.gfdrr.org/Track-III-TA-Tools

5. H. E. V., Futrakul, Thailand's economy after the great flood, BLL seminar handout March 23, 2012, Tokyo, 2012. http://www.rieti.go.jp/en/events/bbl/12032301.pdf

6. A. Termpittayapaisith, NESDE Secretary General, Thailand's Future Development and Water Management Plans, 2012; http://blogs.yahoo.co.jp/festiva1202/65551342.html

7. Ministry of Economy, Trade and Industry (METI), Disaster Response for Thai Flood, Tokyo, 2012 (in Japanese). http://www.meti.go.jp/topic/data/111028aj.html

8. METI, Trade White Paper 2012 (in Japanese). http://www.meti.go.jp/report/tsuhaku2012/2012honbun_p/index.html

9. The Japanese Society of Thai Studies ed., Thai Dictionary, Mekong, Japan, 2009 (in Japanese).

10. JETRO, Special Topics: Information on Thai Flood Disaster Recovery, Tokyo, 2012 (in Japanese). http://www.jetro.go.jp/world/asia/th/flood/

11. Tokyo Marine &Nichido Fire Insurance Co. Ltd., Lesson Learned from 2011 Thai Flood: Water related disaster risk countermeasures points for overseas offices, Tokyo Marine &Nichido Fire

Insurance Co. Ltd., Tokyo, 2011 (in Japanese).

12. Japanese Chamber of Commerce Bangkok, Economic Overviews in Thailand, Bangkok, 2011/2012 (in Japanese).

13. Development Bank of Japan, Impact for HDD Supply Chains caused by Thai Flood, Japan, 2012 (in Japanese). http://www.dbj.jp/ja/topics/report/2011/files/0000008482_file2.pdf

14. Organization for Small & Medium Enterprises and Regional Innovation, Japan, Factual Investigation on Business Challenge for SME in Thailand, 2006

15. J. Kitahara, Natural and Geographical Features, T. Ayabe, and Y. Ishii, ed., To know more about Thailand, Kobundo, 1995(in Japanese).

16. A. Suehiro, Thailand: Development and Democracy, Iwanamishoten, 1993(in Japanese).

17. K. Oizumi, How to Think about Thai Flood: Reducing Natural Disaster Risk on Supply Chains, RIM Transpacific Business Information : 12-44, 2012(in Japanese).

18. M. Mori, Special Issue on Response to A Strong Yen: Starting up Activities Overseas by Japanese Manufacturing Industries for Survival, Factory Management : 56-12, Nikkankogyoshinbun, 2010(in Japanese).

19. T. Nakasu, and J. Sato, Thai Environmental Chronology Edit Committee ed. An Environmental Chronology, Japan and the World, Suirensya, 2011(in Japanese).

20. L. Dengler and M. Sugimoto, Learning from Earthquakes the Japan Tohoku Tsunami of March 11, 2011, EERI/ERI/ITSTs special earthquake report, November, California, 2011. http://www.eqclearinghouse.org/2011-03-11-sendai/files/2011/11/Japan-eq-report-tsunami2.pdf

21. Japanese metropolitan police department, The Causalities number of the Great East Japan Earthquake, Tokyo, 2012(in Japanese).

22. The 2011 Tohoku Earthquake Tsunami joint survey group, Field survey results 14 Jan 2012, Japan, 2012. http://www.coastal.jp/tsunami2011/

23. K. Yamaguchi, Y. Shimizu, et al., Japan Descriptive Geographical Memorandum: Hokkaido and Tohoku II, Asakurashoten, 2011(in Japanese).

24. Iwate Survey of Statistics Section, Iwate Statistics Information, 2012(in Japanese). http://www3.pref.iwate.jp/webdb/view/outside/s14Tokei/top.html

Chapter 4

Uncertainty Estimation in the Process of Flood Risk Assessment

4.1 Introduction

4.1.1 Necessity of study on uncertainty

The importance of flood risk assessment has been reaffirmed recently due to the recent trend of mainstreaming of disaster risk reduction as described in Chapter 1. The evidence on lack of risk assessment was also confirmed in Chapter 2. In Japan, flood risk assessment has already established its legal status officially, and has been implemented in various projects for flood risk reduction as a standardized procedure. In short, flood risk assessment is mandatory prior to all activities related to flood risk reduction. In addition, the challenge to obtain more accurate results is continuing, and progress in this area is constantly being made.

On the other hand, flood damage is still increasing, and enormous economic and human impacts occur in the world, especially in Asia, which is a region with rapid population and economic growth. However, the condition of implementation of flood risk assessment was not so improved in collection and archives of disaster data. It is still a lot of problems to implement flood risk assessment in the region as described in Chapter 2.

Uncertainty is one of the major issues in flood risk assessment. It is composed of several steps and each step contains uncertainty. To improve its accuracy effectively, it is necessary to identify which part of flood risk assessment is the source of uncertainty. Unfortunately, few studies have been done on uncertainty in terms of the entire process of flood risk assessment. Research on uncertainty in flood runoff and flood inundation models can be easily found in the field of hydrology and hydraulics, but discussions on uncertainty in relation to flood risk assessment as a holistic system are hardly found.

In this chapter, the study on identification of flood risk assessment in a developing country is introduced to explain which step has a higher degree of uncertainty and how influential uncertainty from each step may be over the final result. Furthermore, assuming the entire procedure of flood risk assessment as a system, this study shows how results can be better when each step is improved[1]. It is hard to find this type of research involving a developing country, although some studies are found in the case of developed countries.

4.1.2 Uncertainty Estimation

While Guide to the expression of uncertainty in measurement (GUM) describes uncertainty in terms of the measurement process[2], Takemura et al.[3] applied the concept to the precaution approach of disaster countermeasures to categorize risk assessment objectively. For their decision-making process, they classified cases of risk assessment into three stages: certainty, risk, and uncertainty, and the latter stage was further separated into ambiguous and blind decision making. Takemura et al., concluded that the state of blindness in decision-making should be avoided as much as possible, and that decisions should be made in the state of ambiguity or, more preferably, in the risk stage when decisions can be made based on likelihood.

B. Merz et al.[4] attempted to categorize uncertainty into epistemic and aleatory uncertainty. They explained aleatory uncertainty is unavoidable and occurs regardless of efforts to prevent it. Epistemic uncertainty can be reduced by technical improvement. In this thesis, the author highlights epistemic uncertainty and explains how to reduce it in flood risk assessment.

4.1.3 The Process of Uncertainty Estimation

According to GUM, the process of uncertainty estimation starts with identifying uncertainty causes, then estimation of individual uncertainty for each cause, and then combines all individual uncertainties to evaluate total uncertainty.

In this thesis, based on the standard flood risk assessment process, the author identified and evaluated potential uncertainty in each assessment module and evaluated the most critical module for the total of uncertainty by comparing uncertainties in modules with the coefficient of variation as the standard uncertainty. Following the research of B. Merz et al., and similar studies, the author identified and evaluated the major causes of uncertainty listed in their paper, reviewing uncertainty causes and other related items

1 T. Okazumi et al., 2013.
2 JCGM, 2010.
3 K. Takemura, et al., 2004.
4 B. Merz, et al., 2009.

during the process of flood risk assessment. The author paid particular attention to observation data inaccuracy, lack of validation information for the runoff and inundation calculation, and lack of risk model validation data, which are major problems in developing countries.

4.2 Previous Study

Few studies have addressed uncertainty in each step of flood risk assessment except B. Merz and his colleagues, Helmholtz-Centre Potsdam, GFZ German Research Centre for Geoscience, who have produced some papers. In this section, "Flood risk curves and uncertainty bounds, 2009"[4] which discusses uncertainty by utilizing several runoff models and risk models at each step of flood risk assessment in River Rhine, will be introduced as a good reference before tackling the targets.

4.2.1 Purposes

B. Merz and his fellow researchers attempt the separation between aleatory and epistemic uncertainty in flood risk analysis conducted in the City of Cologne, Germany. This flood risk assessment consists of three modules; i) flood frequency analysis, ii) inundation estimation, and iii) damage estimation. In their study, the epistemic uncertainty of each module is quantified. The epistemic uncertainty associated with the risk estimation is reduced by introducing additional information into the risk analysis. Finally, the contribution of the other modules to the total uncertainty is quantified. Then, they explain the separation of the uncertainty (epistemic) that can be reduced by more knowledge and the uncertainty (aleatory) that is not reducible.

4.2.2 Study area

The city of Cologne is located at the Lower Rhine (**Fig. 4-1**). At the Cologne station, the Rhine has a drainage area of 144,232 km^2. Floods in Cologne are caused by rainfall events with long duration, typically in the range of 10 to 20 days. Most of the floods are winter floods, caused by rather moderate rainfall.

4.2.3 Data and information

Cologne has a long experience with floods. **Fig. 4-2** shows the systematic flood observations at the Cologne station as well as historic flood records. Recent floods occurred in December 1993 and in January 1995. Both floods had a similar genesis. The Christmas flood of December 1993 was caused by high antecedent soil moisture due to a first sequence of rainfall events, followed by abundant rainfall in a second sequence and snow melt. In January 1995, a similar effect was produced by snow melt and frozen soil in the uplands. Thus, heavy precipitation in the uplands of the Middle and Lower Rhine resulted in catastrophic 5 flooding events[5,6]. The damages reported to be inflicted on Cologne amounted to €76.7 million and €33.2 million in 1993 and 1995, respectively[7,8].

5 Disse et al., 2001.
6 Pfister et al., 2004.
7 Vogt, 1995.
8 Fink et al., 1996.

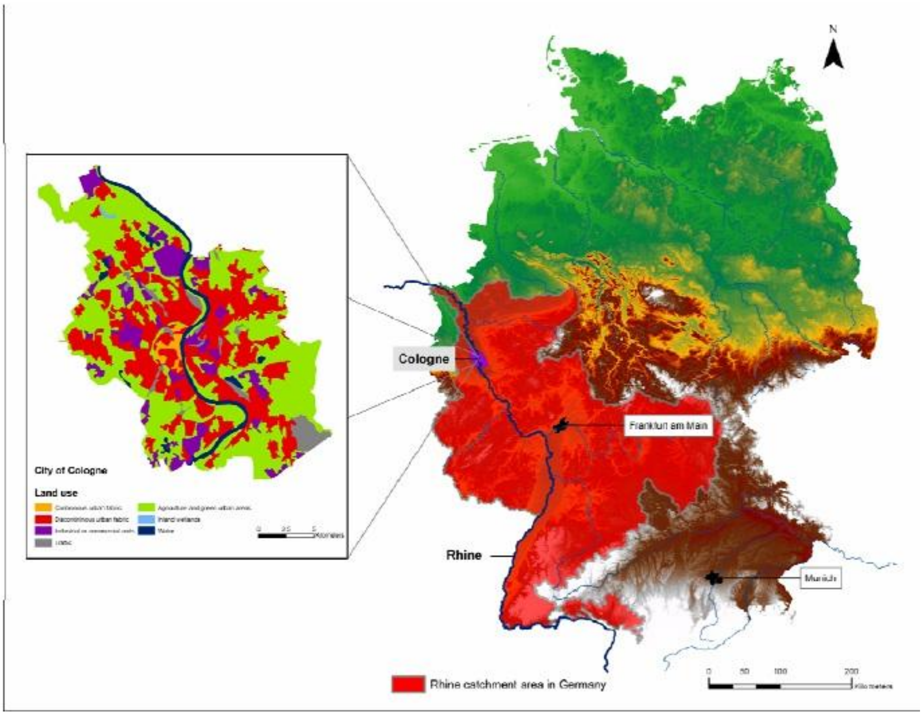
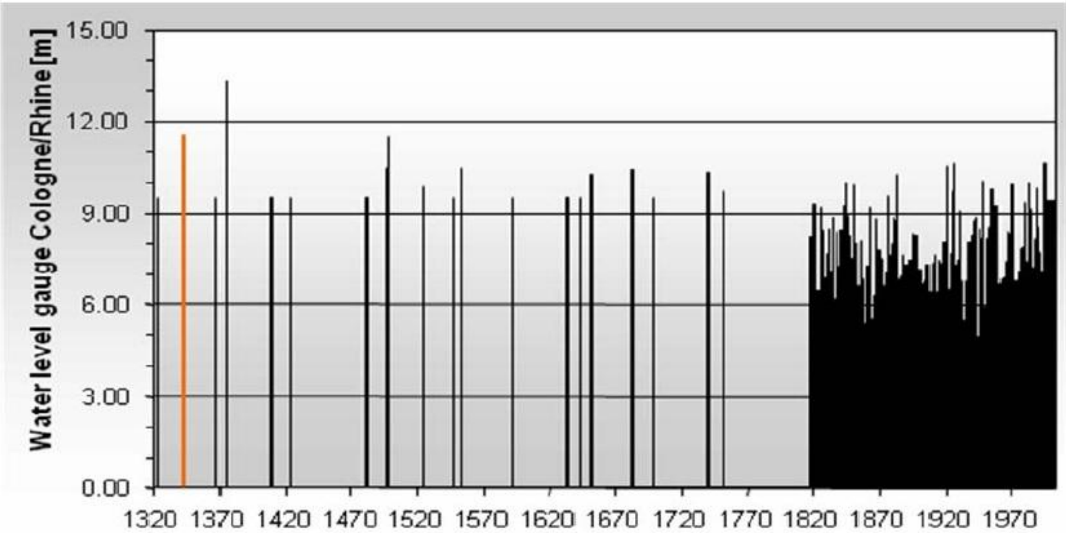


Fig. 4-1 Map of the River Rhine, its catchment and location of study area Cologne



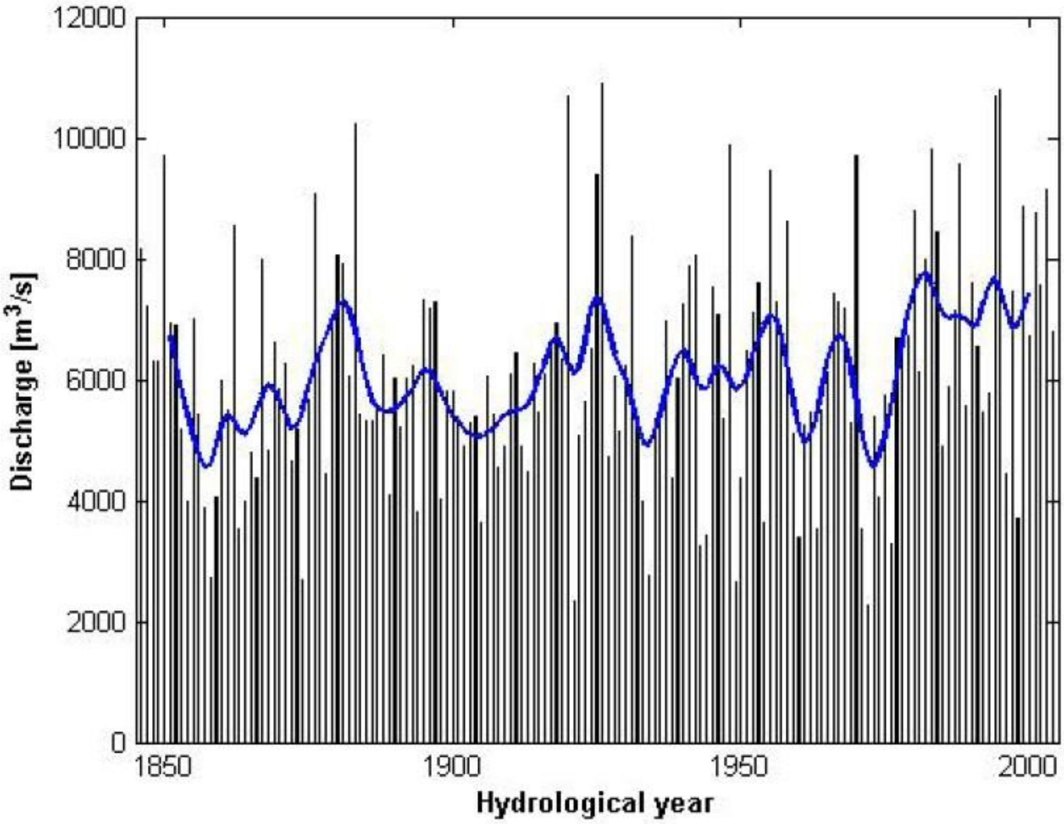


Fig. 4-2 Flood time series at gauge Cologne/Rhine: Historical and systematic water level observations; Systematic discharge observations, annual maximum flood AMS 1846-2004.

4.2.4 Result of analysis

(1) Inundation estimation

Figure 4-3 shows the relationship between two hydraulic models in the flooded areas in Cologne. The dotted lines represent the uncertainty band attached to the best estimate. There are two models. One is DFNK which was developed by the author of this previous study. The other is HWSZ which was provided by the Flood Defense Centre of the City of Cologne. DFNK showed its result as water levels below 12 m, and HWSZ showed water levels above 12 m.

(2) Risk curve and uncertainty bounds

All parallel models of the three modules, which were considered to be plausible, were combined. In total, 36 models resulted from this combination (9 flood frequency curves × 2 inundation extent models × 2 damage models). Each model provides flood damage of return periods from T=10 to T=1000 years. The results of the 36 models are plotted in **Fig. 4-4**[9]. The risk curve (blue solid) for the City of Cologne and the associated uncertainty (black dotted) are plotted based on the results from 36 models (**Fig. 4-4** left). The same are plotted based on 156 models including non-plausible models (right). The blue dots show approximate damage estimates of the floods in 1993 (€76.7 million) and 1995 (€33.2 million).

9 Visser et. Al., 2000

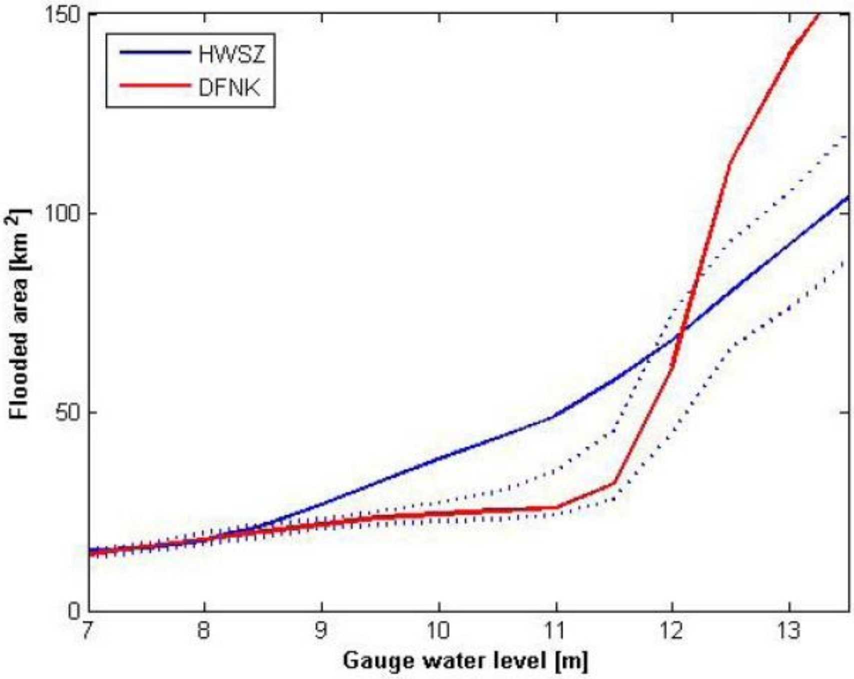


Fig. 4-3 Results of Inundation estimation by two models

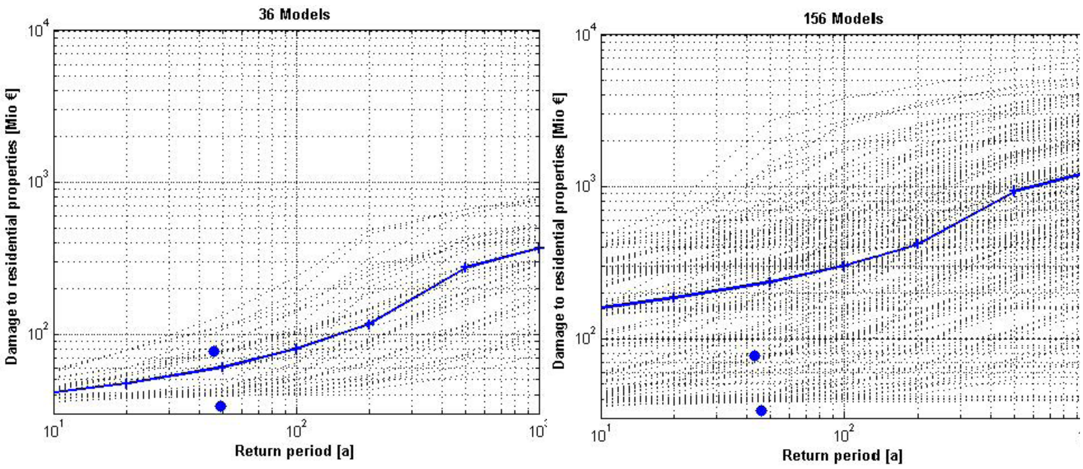


Fig. 4-4 Risk curve and uncertainty bounds

(3) Relative contribution of the three modules to the total maximum uncertainty range as function of return period

When different modules are combined to obtain an overall result, it is desirable to have information on the relative roles of different uncertainty sources. The concept of parallel models provides a simple way to quantify the relative roles. The risk estimated in the study was composed of three modules. The combination of a module *i* with the maximum uncertainty range $MUR_{c,T}$ of the complete chain of modules as function of return period *T* was calculated as follows:

1. $MUR_{c,T}$ was calculated, in which all modules take into account where all models are considered as plausible. For a specific return period T the maximum uncertainty range is given by subtracting the minimum value from the maximum value.
2. The reduced uncertainty range $UR_{i,T}$ was calculated by using for module *i* the best estimate model, while all other modules are in full operation. The different between $MUR_{c,T}$ and $UR_{i,T}$ may be seen as the level of uncertainty, caused by the module that was set to $R_{i,T} = \frac{MUR_{c,T} - UR_{i,T}}{MUR_{c,T}} 100\%$
3. Step 2 was repeated for all modules.

Figure 4-5 shows the result of this procedure applied to the three modules of the flood risk analysis of the City of Cologne. It is obvious that the damage module contributes a small share to the total uncertainty. In addition, this share is almost constant throughout the considered range of return periods. Of more importance for the total epistemic uncertainty are the two modules of flood frequency estimation and inundation estimation. Their shares change across the return period range. For return periods below of 80 years, the uncertainty of inundation estimation contributes a largest share to the total uncertainty, whereas above 80 years, the total uncertainty is dominated by the uncertainty of flood frequency analysis.

In reference to this result, the author implemented the following case study applying a possible method to review all modules of flood risk assessment in a developing country. The chapter also presents findings from this study.

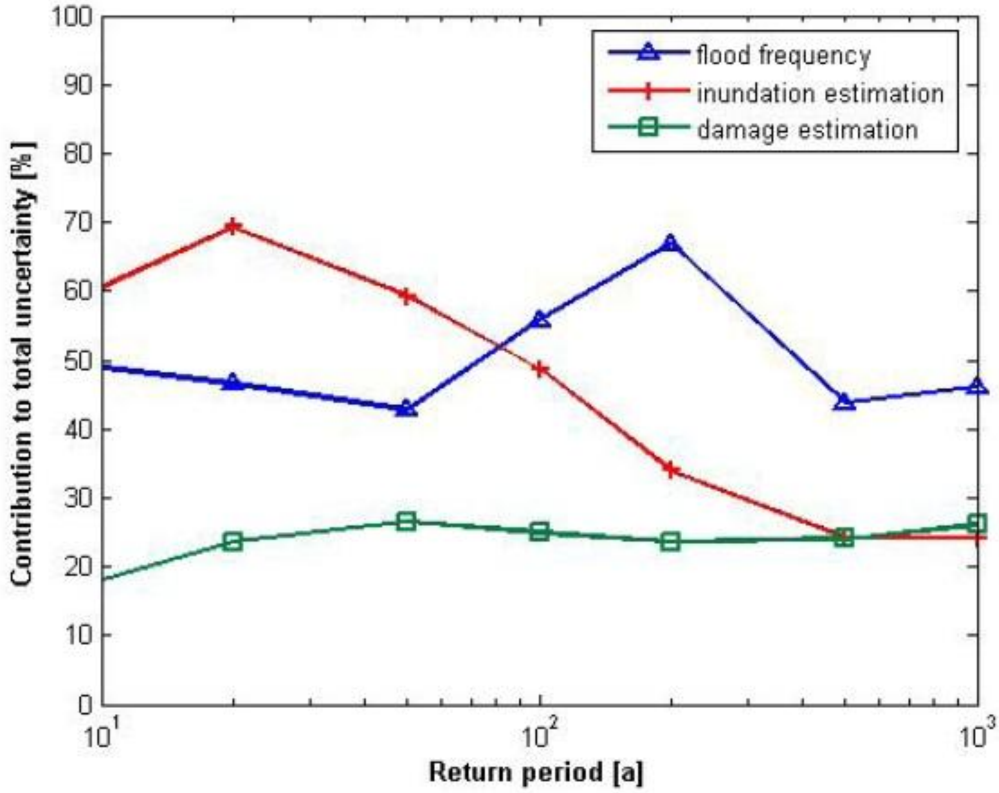


Fig. 4-5 Relative contribution of the three modules to the total maximum uncertainty range

4.3 Case Study

4.3.1 Study Area

In this section, the Pampanga River Basin, one of the largest river basins located at Luzon Island in the Philippines, was selected as the case study area for flood risk assessment (**Fig. 4-6**). The Philippines is a typhoon-prone country, and the Pampanga River has a typhoon frequency of about five in every three years. Major floods occurred when typhoons and monsoon rainfall hit in 2012, affecting about 9,000 people in the Central Luzon (Region III), most of whom lived in the Pampanga River Basin[10].

The Pampanga River Basin has a catchment area of 10,434km^2 in close proximity of the Metro Manila. This area was recently developed, and is a major rice cultivation area in the Philippines, with a sophisticated irrigation system. The Pantabangan Dam, with a 3 billion cubic meter capacity, is located in the Pampanga River headwaters, providing water to the downstream irrigation area. The middle and lower basins lie in flat, wide areas that slow water during flooding (e.g. Candaba swamps). Observation stations, presently 17 rainfall and 11 water level stations, were installed since the 1970s with official development assistance from the Japanese Government (**Fig. 4-7**). This observing system is relatively sophisticated compared to other developing countries, but the instrument maintenance and data processing are not as well managed as those in Japan.

Through the work with the Asian Development Bank(ADB) and the Ministry of Education, Culture, Sports, Science and Technology-Japan (MEXT)-funded Sousei Program for Risk Information on Climate Change, it was found that many developing countries do not have even basic topographical information, and that damage data necessary for flood risk assessment are often unavailable. Though these problems were also found in the Philippines, they were successfully addressed to resolve the uncertainty issue.

10 National Disaster Risk Reduction and Management Council (NDRRMC), 2012.

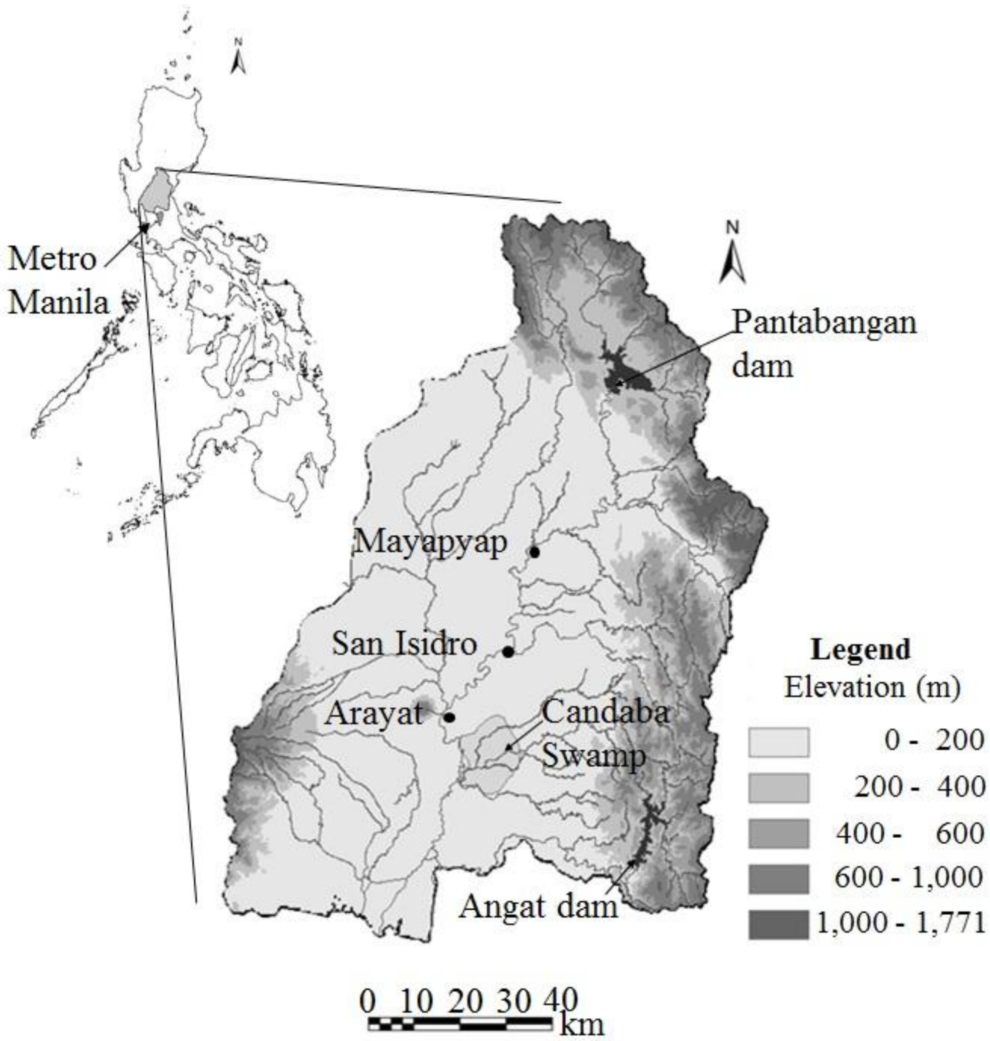


Fig. 4-6 Case study area of the Pampanga River Basin with water level observation stations, dams and flood retention basin (Candaba swamp).

Fig. 4-7 Present seventeen observation stations in Pampanga River Basin

4.3.2 Problems in Observation Data and Validation

(1) Importance of observation data validation

The major difficulty in conducting flood risk assessment in developing countries lies in observational data uncertainty. The limited number of observation stations and the lack of maintenance can sometimes make observations impossible. In addition, lack of data processing knowledge prevents detection of abnormal values, leaving a great deal of uncertainty in data.

To plan appropriate countermeasures, problems establishing a reliable mechanism for flood risk assessment in developing countries should be solved in light of increased climate change impacts.

(2) Disaster damage record and data availability

In the following sub sections, data review will be discussed. In this process, data unavailability brings serious problems in various steps. Especially, in probability analysis, the most crucial point is whether the largest hazard or ones close to that scale had occurred during the periods with missing data. Data on large-scale hazards can directly influence a probability curve in probability analysis. Disaster damage record can be a good reference to determine whether or not major hazards occurred during a period with poor data availability. If no significant damage was recorded during the period, it can be evidence of no occurrence of a major hazard. **Table 4-1** shows: a) the total number of affected people by disasters in each year; b) the number of affected people by flood in Region III, in which the Pampanga River Basin is located; c) supplementary information by International Disaster Database (EM-DAT); and d) available data of rainfall and discharge. Data review was conducted to see whether distractive damage occurred during the periods in which data is unavailable. Category a) in **Table 4-1** includes not only floods but also storms and other disasters, and b) is available only for recent years after 1998. Review of all available information confirmed that destructive damage occurred by floods in the Pampanga River in 2004, 2007, 2009 and 2011. In 1990 and 1995, serious damage was found in some areas including Region III in the Philippines, but it was estimated that Pampanga did not suffer such serious damage, and floods were not the main hazard in those years, according to EM-DAT information. The analysis suggests that hazards that occurred during the years of data unavailability were ones of low magnitude and that their impacts are uninfluential in probability analysis. For this reason, probable hydrological values were identified from the equinoctial line of the larger dataset.

(3) Reviewing precipitation data

Ideally, as many precipitation data as possible should to be collected in an appropriate manner for as long a period as possible for accurate flood reproduction. However, rainfall observation in the Pampanga River Basin was not necessarily an ideal situation. In 1980, there were merely 7 rainfall observation stations in the basin. In addition, only 5 of them were functioning appropriately and were able to continue recording reliable data. Then, 7 additional gauging stations were installed after 1992, 5 more stations were added after 2009, and today 17 stations are in operation (**Fig. 4-8** and **Fig. 4-9**). Such changes in the amount of observational data are not rare in developing countries, depending on progress in the installment of stations, technical malfunctions and other reasons.

Fig. 4-8 shows changes in rainfall data availability and the number of observation stations in the Pampanga River Basin between 1980 and 2012. In an actual situation, it is sometimes difficult to decide whether to use data recorded only by a small number of stations for a long period of time or data recorded by a large number of stations for a short period of time, because data selection such as this can directly affect the level of uncertainty. In principle, a probability curve changes as more data accumulates. In this sense, it is more reasonable to use a larger set of data observed for a longer duration even with some data missing periods, instead of data observed for a shorter duration without cease. a In short, duration should include as long a time period as possible. In this review, the effect of change in the number of stations should be examined in comparison between the case in which only 5 stations were kept as data source and the case in which more and more stations were included as data source during those 33 years.

Fig. 4-10 compares the following two datasets: 1) the longest observational duration regardless of the number of stations (disk in **Fig. 4-10** and beige square in **Fig. 4-8**); 2) the longest observational duration with the smaller number of stations (square in **Fig. 4-10** and dotted square in **Fig. 4-8**). The basin-average precipitation was calculated by the Thiessen method for each datasets. The calculation results were then plotted on a Gumbel probability paper and compared by applying the Gumbel distribution curve as shown in **Eq.4-1**. As explained in (2), the total observation duration should be kept as 33 years, and probability analysis was conducted based on assumption of no serious hazards for 11 years. The comparison found that the two datasets show no significant difference in this figure in terms of the 10-year return period.

$$f_x(x) = \frac{1}{\alpha} exp\left[-\frac{x-\xi}{\alpha} - exp\left(-\frac{x-\xi}{\alpha}\right)\right] \quad \text{(4-1 a)}$$

$$F_x(x) = exp\left[-exp\left(-\frac{x-\xi}{\alpha}\right)\right] \quad \text{(4-1 b)}$$

; where at $-\infty < x < \infty$

As a result, considering that there is always a possibility that some gap exists among individual rainfall events of the two datasets, the rainfall data with a longer observational duration regardless of the number of stations should be regarded as the best dataset in this case in order to show the distribution of rainfall.

Table 4-1 Disaster damage and data availability

year	Disaster Damage Including	Date	TC name	Flood damage Only Region III	Date	TC name	Comments: EM-DAT	Rainfall	Discharge	
									Arayat	San Isidro
1974	55,575	25-29 Oct	WENING						○	○
1975	0								○	○
1976	2,719,415	19-28 May	DIDANG				Storm; Luzon, Manila			
1977	789,846	10-15 Nov	UNDING							
1978	849,430	24-27 Aug	MIDING							
1979	201,942	9-14 Aug	MAMENG							
1980	264,116	18-22 July	NITANG					○		
1981	932,994	22-27 Nov	ANDING					○		
1982	568,875	7-11 Dec	BIDANG					○		
1983	628,985	12-16 July	BEBENG						○	○
1984	470,962	27-30 Aug	MARING							
1985	1,054,063	15-20 Sep	SALING							
1986	730,357	6-10 July	GADING						○	○
1987	55,567	12-20 Aug	ISING						○	○
1988	2,742,666	21-26 Oct	UNSANG							
1989	682,699	9-11 Oct	SALING						○	
1990	5,498,290	10-14 Nov	RUPING				Storm; Samar, Masbate province		○	
1991	505,756	8-11 July	ETANG						○	
1992	725,956	16-18 Aug	GLORING					○	○	○
1993	2,060,677	30-7 Oct	KADIANG					○	○	○
1994	616,860	18-20 July	NORMING					○		
1995	4,583,618	30-4 Nov	ROSING				Storm; Luzon, Visaya, Calauag	○		
1996	686,250	21-26 July	GLORING					○	○	○
1997	1,521,125	15-17 Aug	IBIANG						○	
1998	3,901,673	15-25 Oct	LOLENG	742,716	Sep	GADING		○	○	
1999	1,245,917	28-1 Aug	ISING					○	○	
2000	2,455,942	25-1 Nov	REMING	795,593	Oct	REMING		○	○	
2001	1,902,413	2-5 July	FERIA					○		
2002	3,278,341	28-3 July	FLORITA					○		
2003	1,795,601	19-21 July	HARUROT	367,842	July	HARUROT		○		
2004	2,150,363	20-24 Aug	MARCE	1,186,165	Aug	MARCE		○	○	○
2005	598,853	16-20 Dec	QUEDAN	45,183	Sep	LABUYO		○	○	○
2006	4,139,195	25-29 Sep	MILENYO	663,800	Aug	HENRY		○	○	○
2007	1,198,398	5-10 Aug	DODONG	1,214,761	Aug	DODONG		○	○	
2008	4,776,778	18-22 June	FRANK	244,186	June	FRANK				
2009	4,901,234	24-27 Sep	ONDOY	1,109,981	Oct	PEPENG	Sep, ONDOY 828,157	○	○	○
2010	2,008,984	16-21 Oct	JUAN	240,511	Oct	JUAN		○	○	
2011	3,105,355	24-28 Sep	PEDRING	2,272,218	Sep	PEDRING		○	○	○
※ ***Source:*** *Destructive Typhoons 1970-2011, National Disaster Risk Reduction and Management Council*				※ ***Source:*** *Flood damage data, Effects of Weather Disturbances in Region III, Regional Disaster Risk Reduction and Management Council*				33(11) years (miss)	38(16) years (miss)	38(25) years (miss)

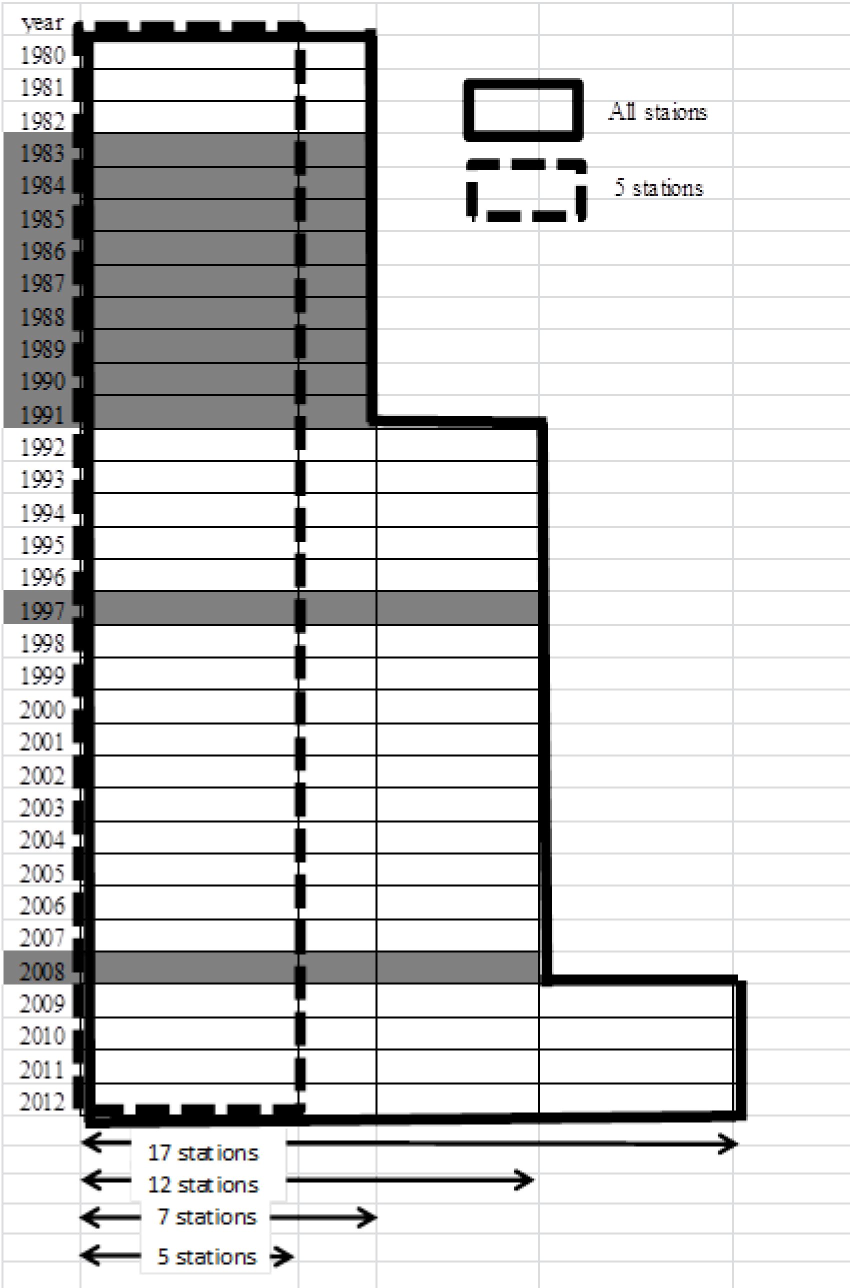


Fig. 4-8 Rainfall stations' data availability in Pampanga River Basin

(A)

(B)

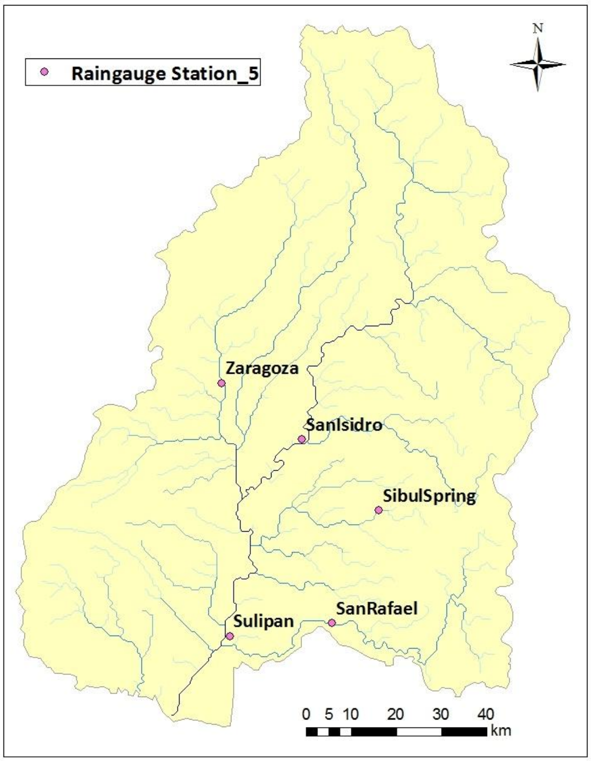


Fig. 4-9 Observation stations in Pampanga River Basin

(A) 12 stations, **(B)** 5 stations

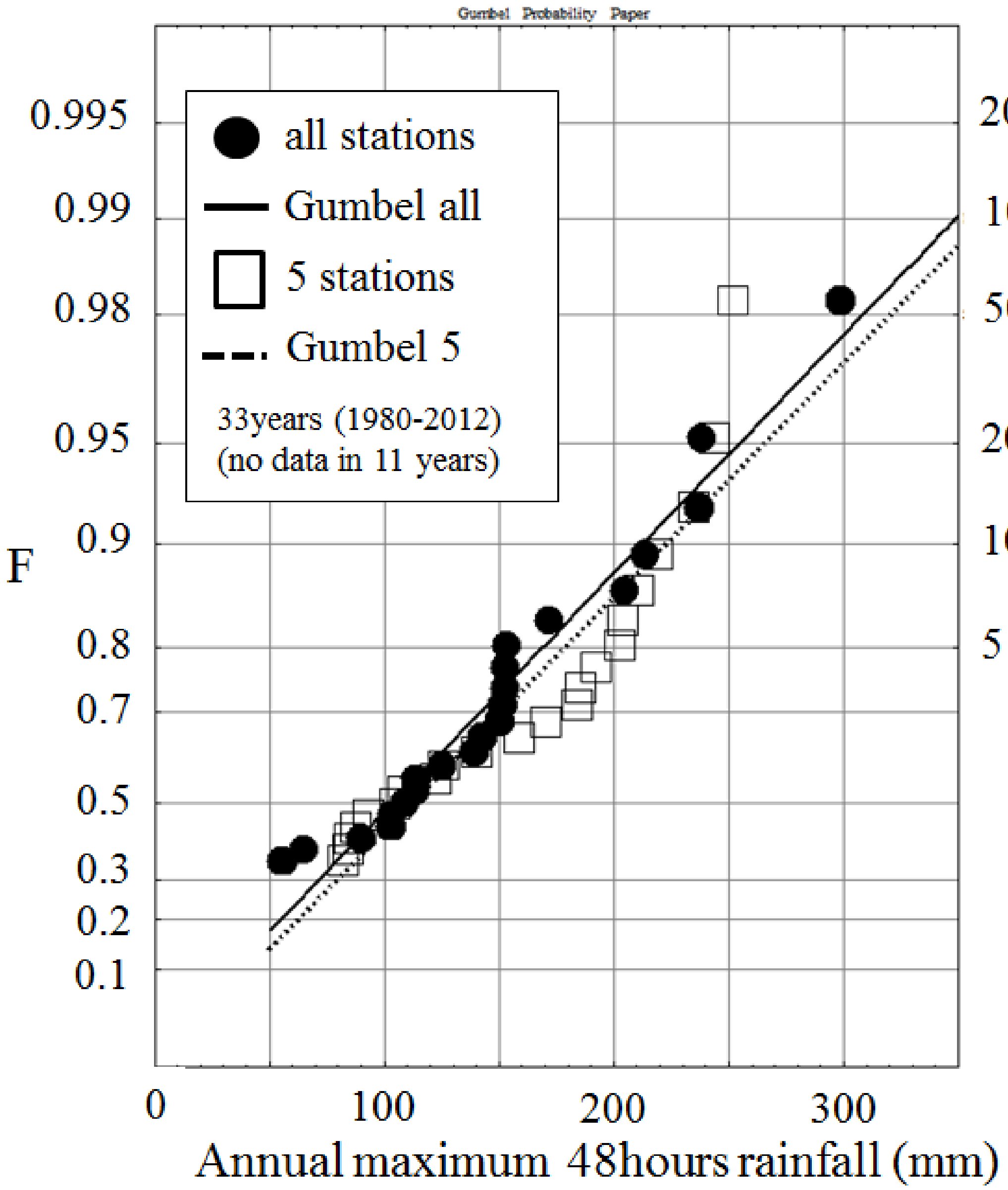


Fig. 4-10 Comparison among four different rainfall datasets

(4) Reviewing river discharge data

The checking list for flood forecasting systems, prepared by the National Institute for Land and Infrastructure Management (NILIM) (the check list)[11], explained items for system improvement. Holistic reviews for hydrological data are described as follows: a) comparing total precipitation and total runoff, b) checking water balance in river profile, c) checking H-Q rating curves, d) checking the resistance equation in river bed. Checking these items is important, especially for observation data.

Review of discharge data is normally conducted by the Ministry of Land, Infrastructure, Transport and Tourism (MLIT) office in Japan, but is not regularly reviewed in developing countries. Because of this comparing the original observation data with the original measurement record is essential, and an important step to reduce uncertainty in recorded data.

Water level data, measured at gauging stations in the Pampanga River Basin, were reviewed to detect missing values and outliers. Missing data often occurred because the water level gauge was not working properly. The longest time series data were recorded at Arayat and San Isidro stations. For Arayat station, annual maximum daily discharge data for 24 years were estimated using the existing H-Q rating curve fitted to the Gumbel distribution, plotted in **Fig. 4-11** (circles and dotted line). After the field survey investigation, the existing H-Q rating curve was revised based on cross-section profile, velocity record, and continuity of discharge in upper and lower gauging points. The revised H-Q correlation was used to estimate river discharge, plotted as disks in **Fig. 4-11**. The revised flood discharge values were smaller than the original values, reducing the magnitude of peak flood discharge. The comparison between original and revised discharges is shown in **Fig. 4-12**. It shows revised is smaller than original discharge.

Practically, the original data provided by the Pampanga sub center of the Philippine Atmospheric Geophysical Services Administration (PAGASA) were found not reliable based on the field survey in the Arayat station, especially at H-Q rating curves at the following points.

a) Cross-sections of the river

The cross-sections provided by PAGASA was analyzed and found to have some

11 Flood disaster prevention division, NILIM, 2010.

problems. The deposit from Mt. Pinatubo eruption in 1991 made significant change in cross section at the Arayat station. Gradual aggradation had occurred before Mt. Pinatubo, but a huge amount of deposit made significant aggradation in 1991, then degradation was occurring after the eruption. It means that significant change in cross section has occurred in recent years. And, this means H-Q rating curves should be carefully analyzed.（**Fig. 4-13**）

b) Continuity of the river flow

In addition to cross section, the continuity of the river flow was also considered. Based on the field survey in several stations in Pampanga, the maximum flow capacities were estimated as in **Fig. 4-14**. The maximum flow capacity at the Arayat station was estimated at 2,000m^3/s from the river flow continuity.

The original discharge data included records of more than 2,000m^3/s at the Arayat station. However, from the abovementioned two points, such a large discharge cannot flow at the Arayat point based on the recent cross section profile and river flow continuity. The recorded discharges of more than 2,000m^3/s were eliminated, and H-Q curves were re-estimated (**Fig. 4-15**).

The new H-Q rating curves provided new discharge data, and the data were analyzed by using the Gumbel distribution. The result is a solid line in **Fig. 4-11**.

The difference between the original and revised data, both from Gumbel calculation, was evaluated by using a statistical method. The revised data represent variation of data revealed by reviewing a data. In order to evaluate a characteristic of variance, average (μ), variance (σ^2), standard deviation(σ) and coefficient of variation(CV) of population are used in the following calculation.

$$CV = \sigma / \mu \qquad \textbf{(4.2)}$$

CV is usually considered as relative standard deviation and standard uncertainty of samples and expressed in percentage. CV also represents an uncertainty of samples.

$$CV = u(x)/\bar{x} \qquad \textbf{(4.3)}$$

where $u(x)$ is standard uncertainty of samples, and $\bar{x}$ is average of samples.

In **Fig. 4-11**, flood discharges for a 10-year return period event was selected as a representative case. The original and revised flood discharge values for the 10-year return period were identified as 2,600m^3/s and 2,100m^3/s, respectively. Finally, at the discharge reviewing module, average ($\overline{x_o}$), standard deviation (s_o), and the coefficient of variance (CV_o) as standard variance was calculated, 2,350 m^3/s, 354 m^3/s, and 15% respectively.

As found in the previous description, reviewing original data was not often sufficient in developing countries, as similar difficulties are sometimes experienced even in developed countries. Especially, in developing countries, all data and information should be subject to constant examination and cross-checked from several perspectives. Reviewing actual field situations and circumstances and judging data based on good understanding of actual phenomena is the most important procedure when conducting studies in developing countries.

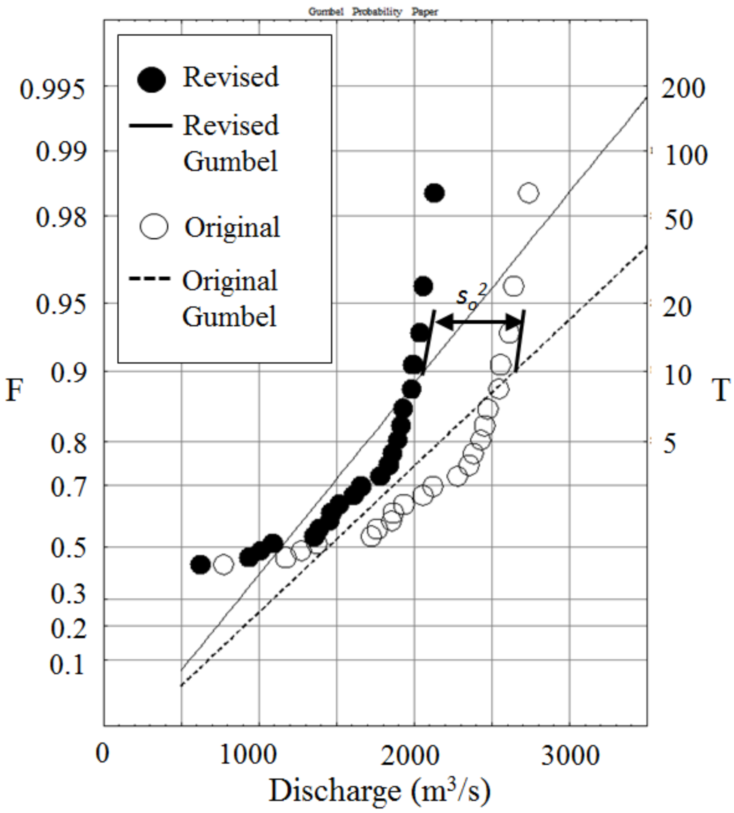


Fig. 4-11 River discharge estimated with the original (circles) and revised (disks) H-Q curve at the Arayat station.

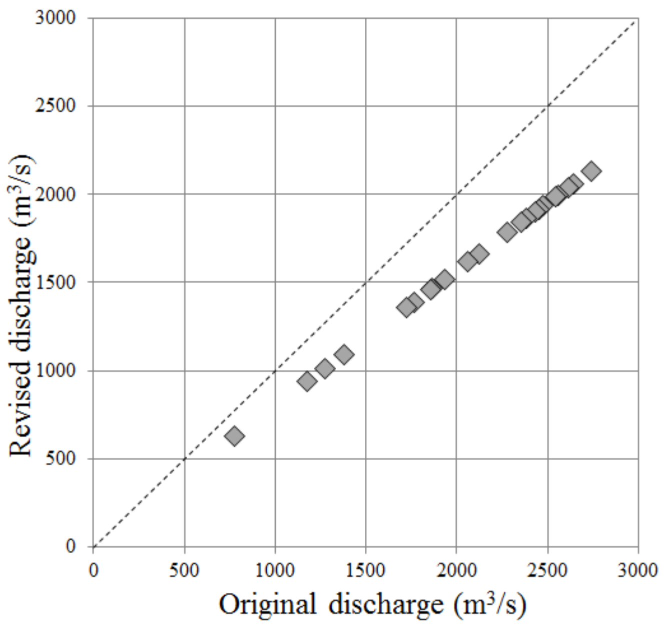
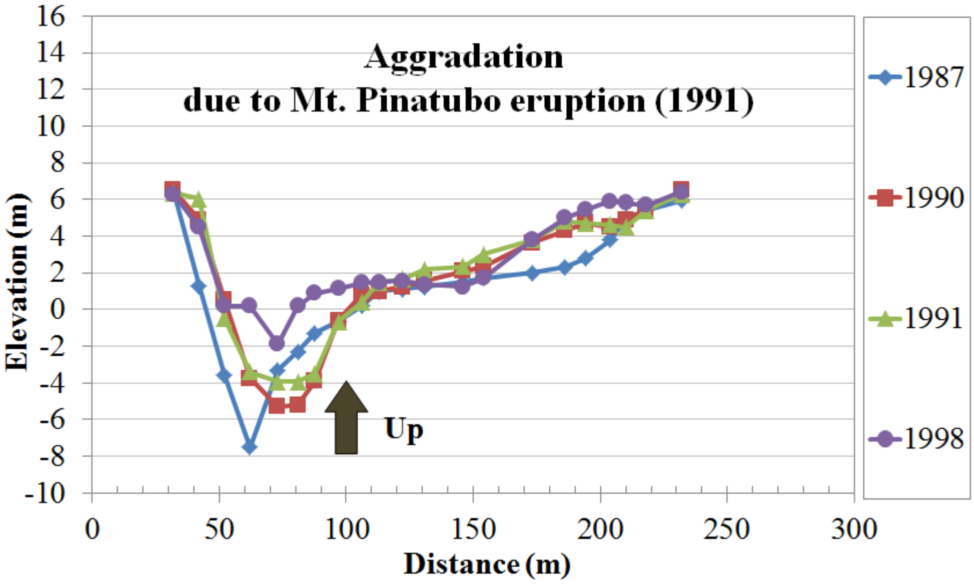


Fig. 4-12 Comparison between original and revised discharge

(A)



(B)

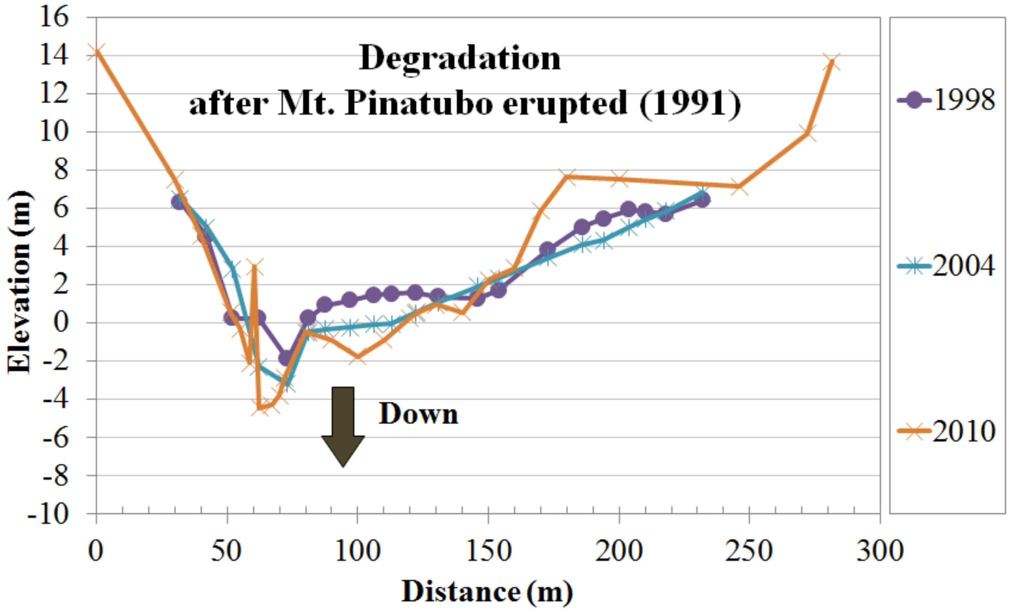


Fig. 4-13 Change of cross section at Arayat station

Note: **(A)** Gradual aggradations had occurred before Mt. Pinatubo erupted, but a huge amount of deposit made significant aggradations in 1991, then **(B)** degradation was occurring after the eruption.

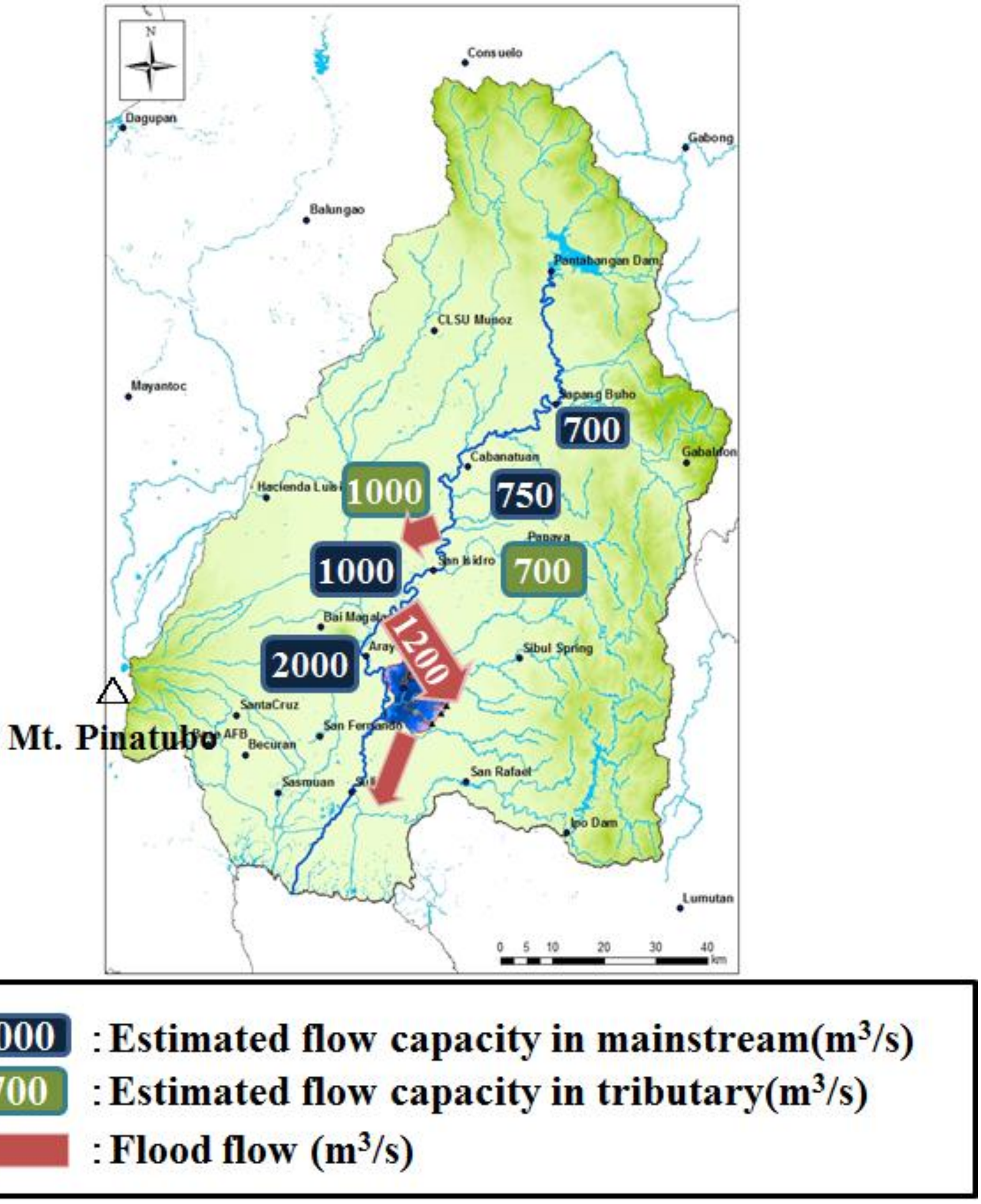


Fig. 4-14 Continuity of river discharge in Pampanga River

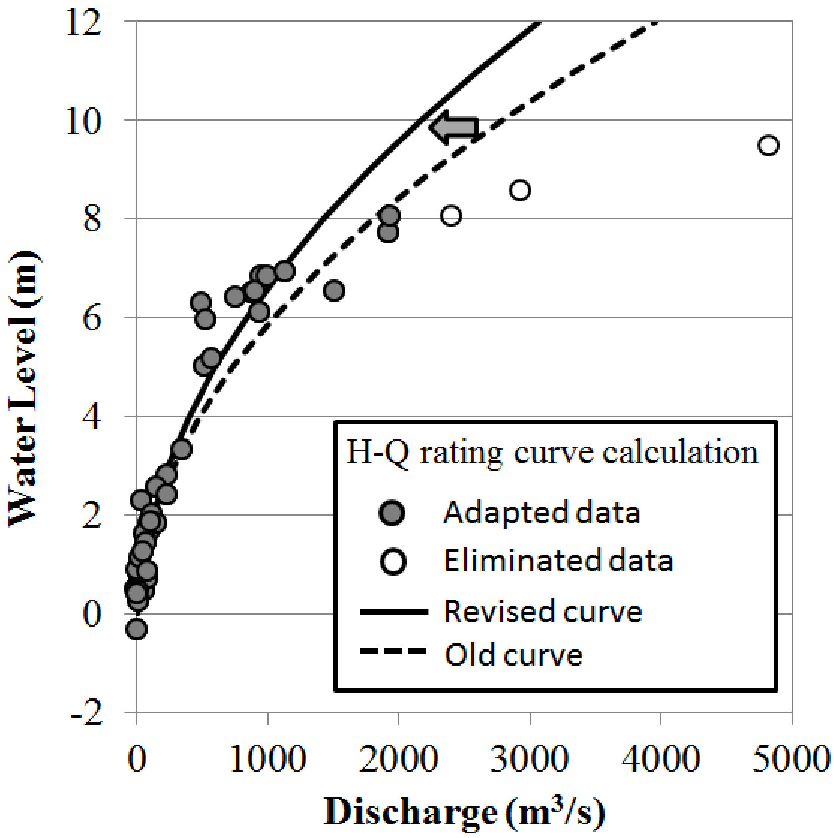


Fig. 4-15 Change of H-Q curve based on field observation

4.3.3 Problems in Flood Reproduction Calculation

(1) Selection of runoff model

The Integrated Flood Analysis System (IFAS) with a distributed model, developed by the Public Works Research Institute (PWRI)[12,13], and the Block-wise TOP (BTOP) model[14] were selected for runoff analysis of Pampanga River floods (**Fig. 4-16, Fig. 4-17**). It is common to have some difficulty in collecting topographical, geological, and precipitation data in developing countries, which can cause uncertainty in runoff process simulations. Both IFAS and BTOP models are commonly applied to river basins of developing countries, utilizing satellite-based information, which reduces data collection difficulty. For the Pampanga River Basin, The IFAS and BTOP models were constructed to meet local conditions by using available global Digital Elevation Model (DEM) and Geographical Information System (GIS) data with a cell size of 1 km and 0.5 km, respectively. The IFAS and BTOP models had the same input from hourly measured precipitation data and simulated hourly river discharge for selected flood events.

(2) Uncertainty in flood runoff model

Five major floods with available hourly discharge data were used to calibrate parameters. Data supplied by the San Isidro station data were used to avoid problems from a widely inundated area near the Arayat station. Revised hourly river discharge of the 2009 flood were used as calibration data for flood runoff models, and flood data from 1992, 1993, 2004, and 2005 were used for model validation. **Fig. 4-18** shows that both BTOP (diamonds) and IFAS (squares) models resulted in different discharge values from those based on observed data (triangles) due to phenomena that can influence calculation results such as major inundations in several locations upstream and in tributaries and fluctuation of peak discharges in flood events. Calibration of parameters can also be a source of uncertainty, depending on which flood was selected for calibration and to which part of the flooding process parameters were calibrated, i.e., to the flood peak or the rising limb. Furthermore, because the discharge comparison was made for daily, peak discharge, not hourly, the simulation had a large gap with an average difference.

Observed discharge data, calculation results of IFAS and BTOP, and calculated variance

12 T. Sugiura, et al., 2009.
13 M. Miyamoto, et al., 2012.
14 K. Takeuchi, et al., 2008.

factors were compared in **Table 4-2**. Especially, the coefficients of variance at runoff model (CV_m) were compared to identify variance characteristics of samples. The results shows CV_m were completely different among the flood events, due to difference in magnitude of flood and difference in flood peak and rising limb. In the comparison of each module, the 2009 flood representing of 10 year return period events was evaluated at 42% of CV_m. Since other CV_m in different flood events showed completely different results, identification of CV_m in a runoff model should be discussed carefully.

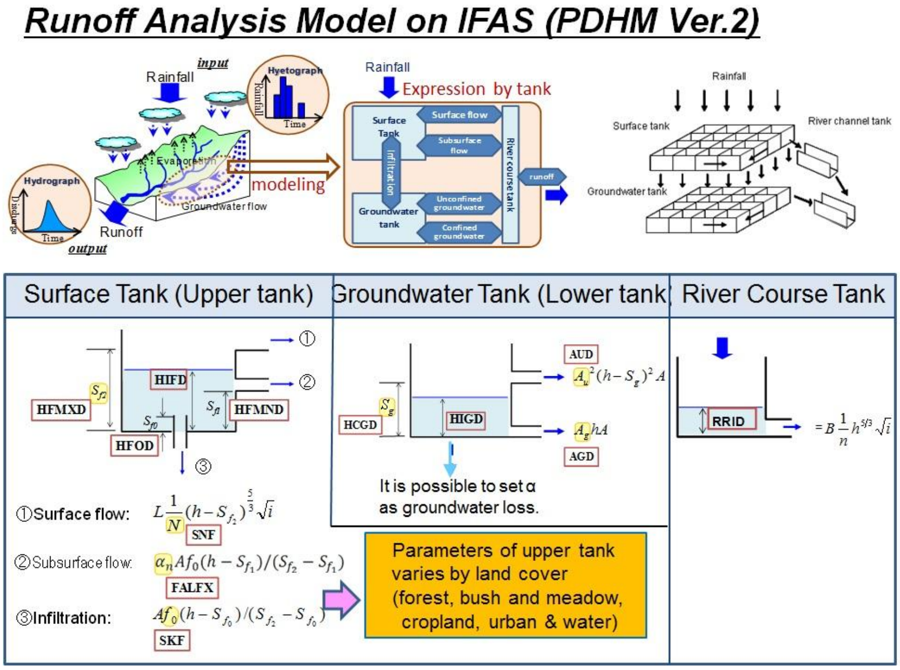


Fig 4-16 Schematic mechanism of IFAS flood runoff model

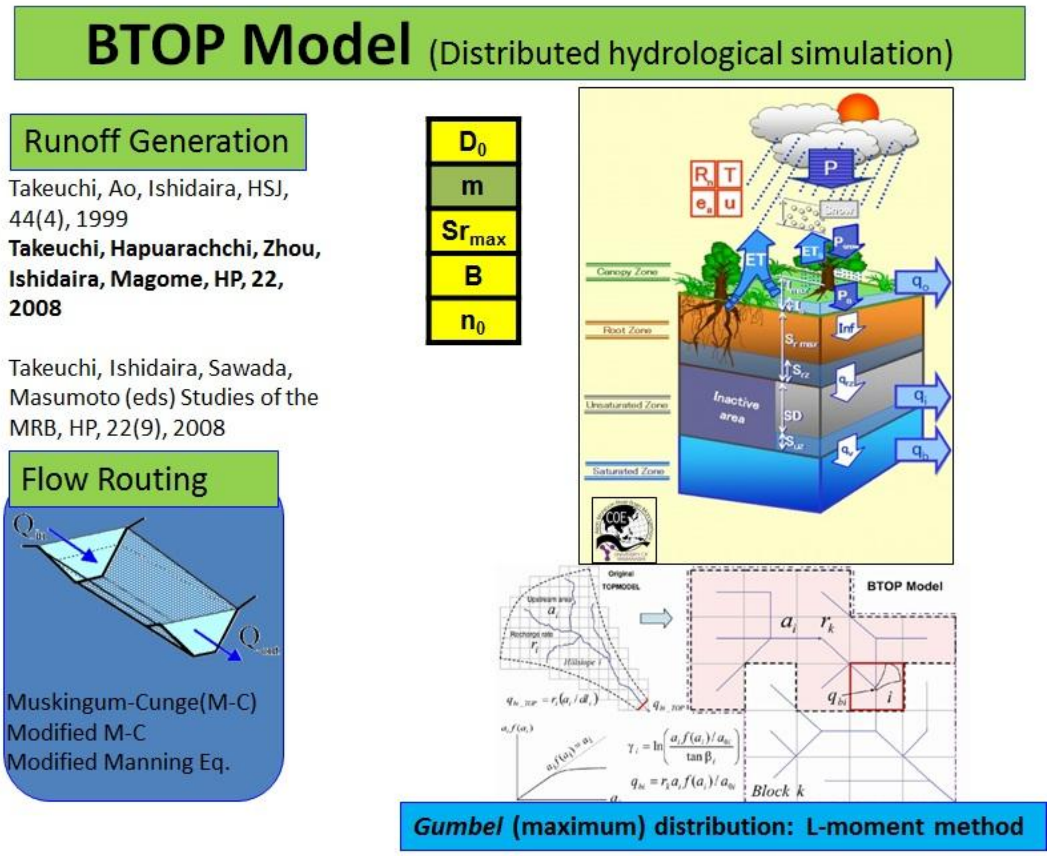


Fig 4-17 Schematic mechanism of BTOP runoff model

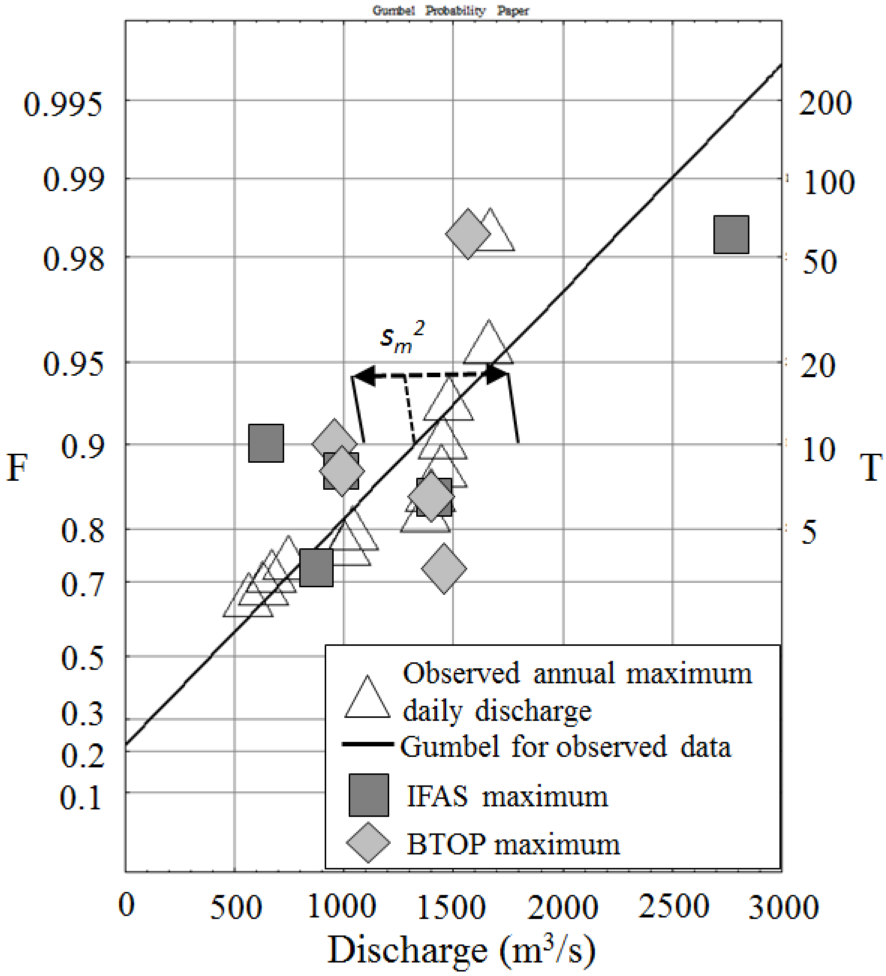


Fig. 4-18 The calculated by IFAS and BTOP models and observed flood river discharge at San Isidro station.

Table 4-2 Result of variance runoff calculation

No.	Flood year	Observed daily discharge	IFAS result	BTOP result	Average	Standard Deviation	Coefficient of Variation
1	2004	748.23	850.30	1,444.41	1,014.31	375.95	0.37
2	1992	1,398.99	1,398.84	1,386.39	1,394.74	7.23	0.01
3	2005	1,449.23	988.97	989.00	1,142.40	265.72	0.23
4	2009	1,452.26	615.88	955.49	1,007.88	420.64	0.42
5	1993	1,667.80	2,548.00	1,506.96	1,907.59	560.42	0.29

4.3.4 Problems in Risk Estimation

(1) Problems in damage estimation

To estimate risk at the final step of flood risk assessment, the results of a hydrological model in certain magnitude (e.g., inundation area, inundation depth and inundation duration) are overlaid on population and assets to estimate damage. The flood control and economic investigation manual[15] divided damage into several categories: house damage, household damage, business damage (amortization or stock), agricultural and fishery business damage (amortization or stock), agricultural damage, and infrastructure damage.

In developing countries, damage information itself is inadequately collected and analyzed. Damage curves used to convert hazard to damage should be created based on various information. Practically speaking, the agricultural, household, and industrial damage should be top priority data collected in developing countries.

(2) Damage calculation in developing countries

A general method for agricultural damage calculation is based on inundation depth and duration. Rice crop damage calculation requires different damage curves for different growth phases. Crop cultivation information and a crop calendar are used for damage calculation in an inundation area[16,17]. House damage is calculated according to a house damage function curve, which is the correlation between slope and water depth in Japan. The Innovation program of climate change projection for the 21st century (Kakushin program) and Sugiura et al.[18,19] developed different damage curves for simple houses in Nepal, and stilt houses in Cambodia, respectively.

Finally, each industrial classification and factory will have different damage pattern, so industrial damage should be based on investigation.

(3) Damage calculation in the Pampanga River Basin

Crop cultivation is a major industry in the Philippines and specifically in the Pampanga River Basin. Crop damage by inundation, as defined by the formula of Bureau of

15 MLIT, 2005.
16 B. B. Shrestha, et al., 2013.
17 T. Okazumi, et al., 2013.
18 MEXT, 2012.
19 A. Sugiura et al., 2013.

Agricultural Statistics (BAS), the Philippines[20], can represent flood damage in this river basin. (**Table 4-3**)

Local Ministry of Agriculture staff estimate the damage in post-flood investigations (**Fig. 4-19**). Actual damage depends on judgment of investigative staff, but the yield loss formula has a range and can be a source of uncertainty.

Rainfall Runoff Inundation (RRI) model using satellite data was selected to calculate inundation area, inundation duration, and inundation depth (**Fig. 4-20**)[21,22]. The RRI created inundation hydrographs for each 0.5×0.5 km grid, and implemented crop damage calculations by: a) identifying crop area using an overlaid land use map, b) identifying crop growth stage from a crop calendar and flood timing, and c) estimating damage based on flood days and water depth to calculate the total damage.

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20 Bureau of Agriculture Statistics, 2013
21 T. Sayama, et al., 2013.
22 T. Sayama, et al., 2011.

Table 4-3 Crop damage calculation manual, Bureau of Agriculture Statistics

Growth Stage of Rice	Calculation Method
Seedbed / Seedling **20 days from palay germination**	***Value of production losses*** = Area affected x Cost of input / hectare x yield loss
Newly Planted Stage **1-20 days after sowing**	
Vegetative Stage **21-45 days**	
Reproductive Stage **46-75 days**	***Value of Production Losses*** = Volume of losses x most recent farm gate price ***Volume of losses*** = Most recent yield/hectare x area damaged x Yield loss
Maturing Stage **76-115 days**	

- Totally Damaged Area: refers to an area where the expected production is completely lost or damaged. The crop has no more chance of recovery.
- Partially Damaged Area: refers to affected area of standing crop with chances of recovery during the cropping season.

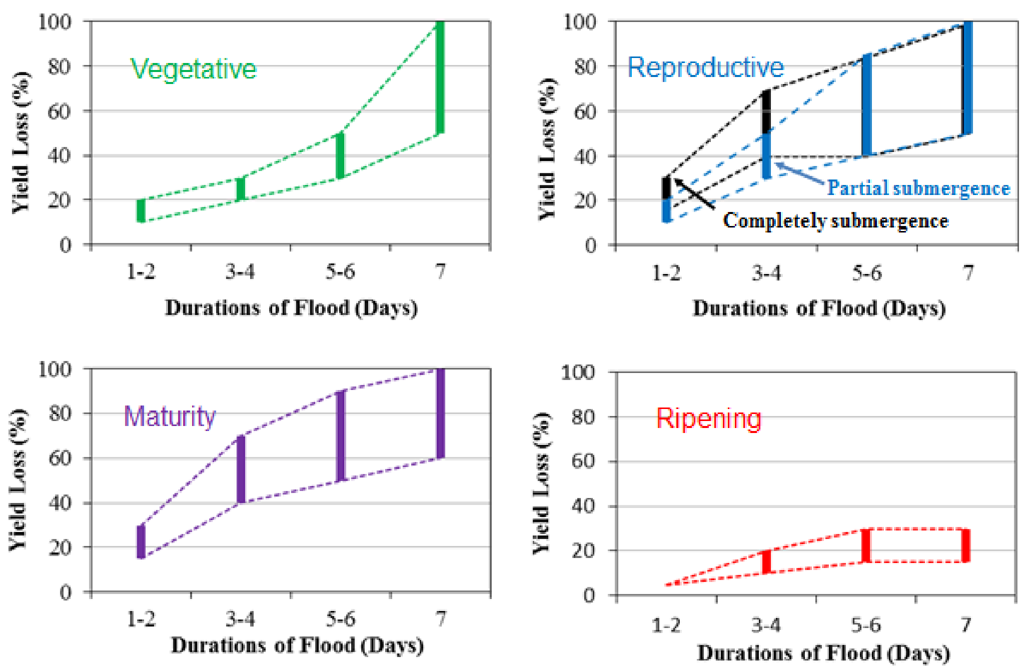


Fig. 4-19 Crop damage curves at vegetative, reproductive, maturity and ripening stages of palay (rice)

(4) Damage calculation in 2011 flood in Pampanga river basin

For validation of flood damage calculations, the 2011 flood was selected as 10-year return period event because of similarity to uncertainty estimation observations and model results, and because calibration of the RRI model referenced ～10-year discharges. Agricultural damage was selected to be representative of this area, following the method described above.

Figures 4-21 A and B show the calculated results from the maximum and minimum agricultural damage function of Bureau of Agricultural Statistics (BAS). The difference between the maximum and minimum values in the same damage function caused a major difference in results. The statistic of past flood damage is not categorized in the river basin. **Table 4-4** compares actual results for Pampanga province and Calumpit municipality[23]. The actual damage value for Calumpit municipality fell between the maximum and minimum calculation, while the actual damage of Pampanga province exceeded the maximum calculated value. This result arose from the actual damage (including wind damage) and the uncertainty of the damage calculation when applied over a wide area. In addition, large uncertainty in the damage calculation step and accumulation from the previous steps made such a large difference. However, more careful analysis and actual data is necessary in order to solve this hypothesis.

(5) Damage calculation in the similar size of flood

The magnitude of rainfall in the 2011 flood was adjusted for comparison among similar rainfall, discharge, and damage. The result for 10-year return period rainfall in **Fig. 4-10** was around 78% of the 2011 flood rainfall, so a compressed rainfall dataset was created by multiplying the 2011 flood rainfall by 0.78 and inundation and damage calculations were made by using the RRI model with the method described in (4) as follows. The total damage was estimated at 443,708 thousand pesos as maximum and 229, 505 thousand pesos as minimum. The average of damage was 336, 606 thousand pesos, while the standard deviation (s_r) was 151, 464 thousands pesos, and finally Coefficient of Variance at risk estimation module (CV_r) was calculated at 45% (**Fig. 4-22**).

23 Bulacan Provincial Agricultural Office, 2011.

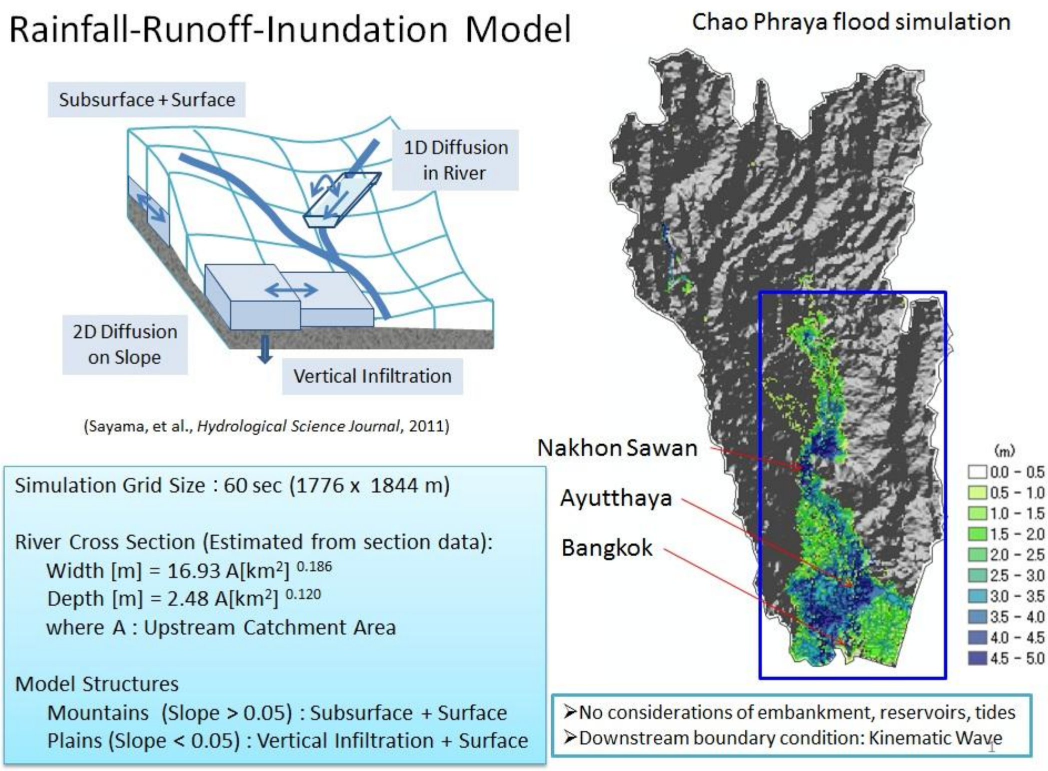


Fig. 4-20 RRI model explanation

Table 4-4 Agricultural damage calculated and reported for 2011 flood

					milions pesos
Volume of damage functions	**Pampanga River Basin**	**Pampanga province（total affected area 15,900ha）**		**Calumpit municipality（total affected area 1,250ha)**	
	Calculated	*Caluculated*	*Reported*	*Caluculated*	*Reported*
Maxium	1,754	777	1,376	54	37
Minimum	966	443		30	

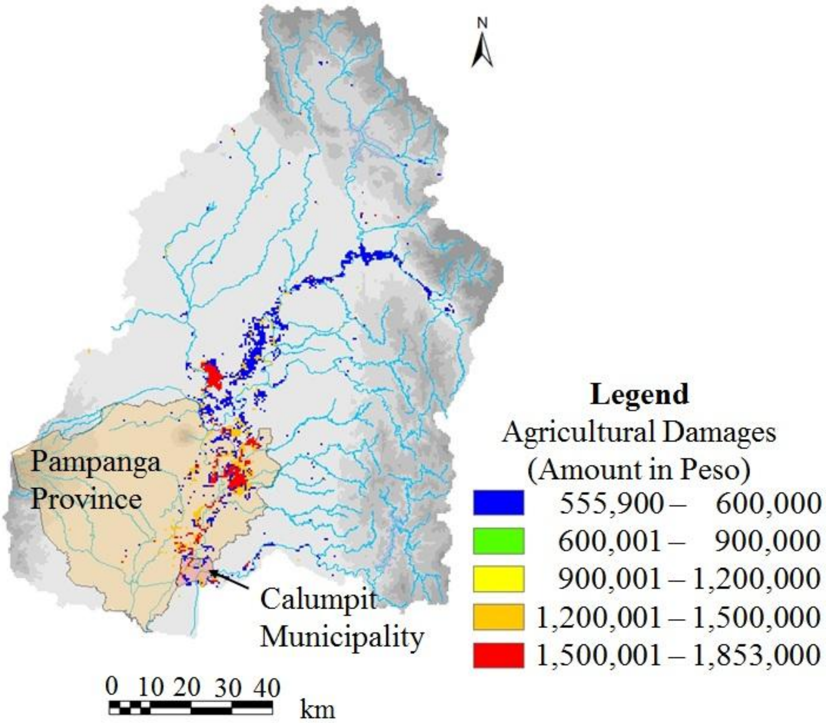
※ Caluculation condition : Rice yield 4,360 kg/ha [25]

Farm gate price =17 peso/kg [22]

Loss volume＝rice yield × damaged area × yield damage ratio

Loss value＝loss volume × farm gate price

(A)



(B)

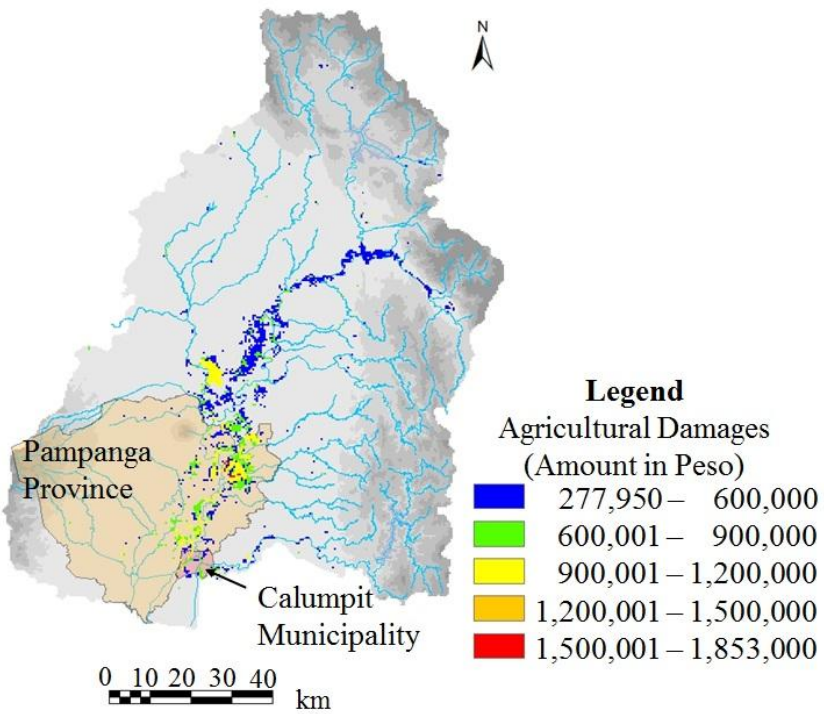
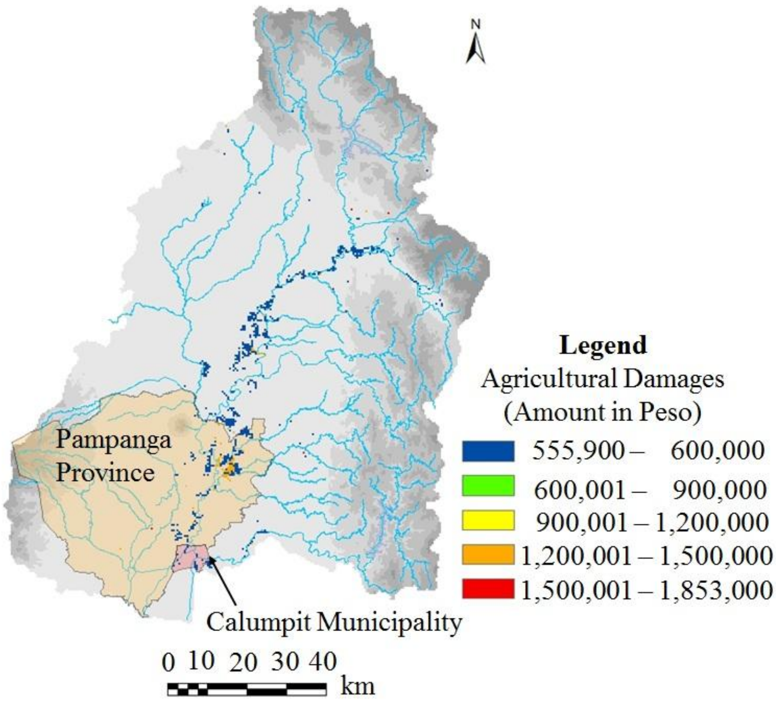


Fig. 4-21 Maximum **(A)** and minimum **(B)** estimated agricultural damages for 2011 flood.

(A)



(B)

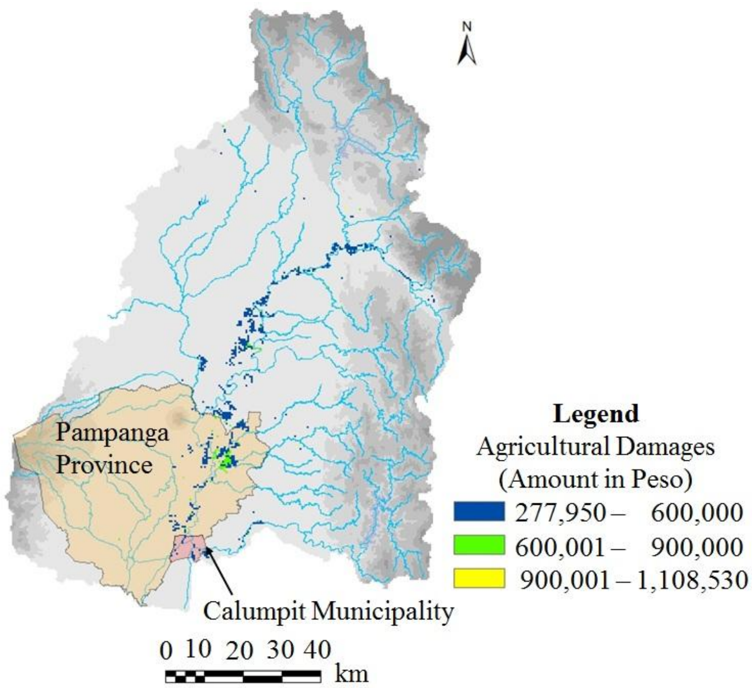


Fig. 4-22 Maximum **(A)** and minimum **(B)** estimated agricultural damages for similar magnitude of flood.

4.3.5 Influence Items in Uncertainty Estimation

(1) Limitation of uncertainty estimation in case study

It is important to understand difference in method between the previous study and this case study.

- The previous study was implemented for integrated uncertainty estimation in combination of different models of three modules. Relative contribution in each module uncertainty was evaluated in comparison with total maximum uncertainty range.
- In the case study of this thesis, uncertainty estimation was implemented only for each module and the results were compared among the modules. The integrated uncertainty could not be estimated due to lack of dataset in the case study.
- Coefficient of Variance at each module can be a good reference for comparison due to normalization of resulted variance among the modules.

Both case studies are similar, but the results show completely different characteristics.

(2) Impact of uncertainty

Location of potential uncertainty and its causes are summarized in **Table 4-5**. A series of uncertainties occurred in modules of reviewing observation data, reproduction runoff model and risk estimation during the process of flood risk assessment. From comparison of Coefficient of Variance (CV) among modules, CV at risk estimation (CV_r) was relatively high, and CV at runoff reproduction model (CV_m) followed. In short, this suggests that the final result of flood risk assessment may be influenced by the risk estimation.

This result is very interesting because the previous study pointed out that large uncertainty contribution are from inundation estimation and flood frequency, and that uncertainty at damage estimation was relatively small in 10-year return period events. The different tendency between the two results might come from difference between developed and developing countries. The tendency might also be from examination of discharge data and fluctuation of damage formula which are not included in the previous study implemented in Germany.

Table 4-5 Major location of potential uncertainties

Existing uncertainty	Major location of potential uncertainties
(1) Observed data collection	
Hydrological observation	Water level gauge (automatic, manual), Flow velocity (rotameter)
Cross section	Change of river bed (aggradation, degradation, mainstream)
Routing curve	Change of routing curve by flood and time
Roughness coefficient	Change of river bed morphology
Overall discharge	Calibration of rainfall and runoff, continuity, inundation phenomena
(2) Flood frequency analysis	
Extreme value statistics	Stationarity, Homogeneity, Independence
Choice of samples	Selection of time period, Annual maximum series, Peak-over-threshold, Unavailable number of samples
Choice of distribution function	GEV, Gumbel distribution, Lognormal
Choice of parameter estimation method	Method of moments, L-moments, Maximum Likelihood
Statistics inference uncertainty	Uncertainty associated with fitting and extrapolating based on the given data
(3) Flood reproduction calculation	
Topographical model	Resolution of horizontal and vertical, Rpresentation of linear elements (e.g. road, embankments) with inundation constraining effects
Runoff model	Negligence of propagation of flow in inundation areas, Parameter setting (target, accuracy)
Inundation model	Breaching and failure, Parameter setting (target, accuracy)
Calibration data related to (1)	Unavailability of data, Uncertainty of observed data, Inundation record
(4) Risk estimation	
Assets estimation in flooded areas	Bias in spatial disaggregation; uncertainty of asset estimates derived from regional statistics
Stage-damage functions	Uncertainty of agriculture damage function (big range of damage, defferent damage function in growth stage), unavailability of damage function
Calibration data	Unavailability of damage data (household, industry; direct damage, indirect damage), Uncertainty of damage data

※ Reproduction in reference to B. Merz et. al [4], Manuals of NILIM[11] and others

4.3.6 Propagation of Uncertainty

When reviewing total uncertainty during flood risk assessment, propagation of uncertainty might be considered because the result of a previous assessment step influences the result of the next assessment step. Yet each next step of flood risk assessment creates an independent result, because the result of the next step does not influence the previous step. The general relationship explained in GUM[2] is when all input quantities can be considered independent, the combined uncertainty $u_c(y)$ of the estimate y is the square root of the combined variance $u_c^2(y)$, see **Eq.(4.4)**.

$$u_c^2(y) = \sum_{i=1}^{N} \left(\frac{\partial f}{\partial x_i}\right)^2 u^2(x_i) \tag{4.4}$$

where y is the estimate of the measured Y; and Y is a function of $f(x_i)$, which is the result of the measurement and obtained by appropriately combining the standard uncertainties of the input estimates $x_1, x_2, \ldots, x_N$.

Figure 4-23 shows the schematic relationship of uncertainty propagation. In **Fig 4-23**, the first step dealing with observed data can makes the s_o standard deviation, and the second step with runoff and inundation simulation makes the s_m standard deviation, and finally the third step with damage and risk assessment makes s_r standard deviation. Since the result of each step occurs independently, the variance at the second step will be s_m^2 plus some amount of s_o^2, and the final variance at the third step will be s_r^2 plus some amount of s_m^2.

When the combined uncertainty S was considered, the total uncertainty from the three steps **Eq.(4.5)** explains the propagation of uncertainty as follows:

$$S^2 = \alpha \times s_o^2 + \beta \times s_m^2 + \gamma \times s_r^2 \tag{4.5}$$

When this propagation occurs, parameters α, β and γ vary depending on situation. Unfortunately, identification of these parameters was not made in this thesis due to lack of dataset. In addition to conduct careful reviewing each module for identification of each parameters, combination of module models to identify the total uncertainty is necessary to find a clear relation of uncertainty among the modules.

4.4 Conclusions

This study estimated uncertainty of flood risk assessment in the case of the Pampanga River Basin, although it did not use the same method employed in the Rhine study. The results demonstrated the importance of uncertainty estimation in the process of flood risk assessment, which consists of field data reviewing, runoff discharge simulation, inundation simulation and damage calculation module.

Through the uncertainty estimation in the risk assessment of a 10-year return period flood, the calculated uncertainty was large in every flood risk assessment module, and the uncertainty at the damage calculation module can be considered as the major influential factor over the final result of the risk assessment. Runoff simulation module was identified as the biggest uncertainty next to damage calculation module, although it depends on the flood event characteristic.

This result of the case study is also interesting as difference from the previous study. In addition, the convergence of uncertainty from each independent module in the risk assessment was explained in this study.

The study strongly suggests that the influential damage estimation module is mainly due to lack of damage information. The condition of data availability in the Philippines is relatively better than in other developing countries. However, collecting disaster loss data should be more emphasized.

In conclusion, the following points were found from this case study of uncertainty estimation in the Pampanga River Basin including the author's experiences from conducting studies in other developing countries.

1) Uncertainty can greatly be influenced the quality and availability of data and information. Keeping good data quality is directly linked to the capacity of officers in charges of data acquisition and archiving offices. This can be supported by capacity building from international organizations.
2) However, data unavailability in some developing countries is a serious problem. Especially, collection of damage loss data is an urgent matter, which needs an institutional mechanism for improvement. The necessity of risk assessment is increasing for developing countries where flood risk is rapidly rising. Support for this area should be emphasized for international donors.

3) Uncertainty is also linked to model calculation. Scientists and engineers in the field of risk assessment should have adequate understanding of objectives and expected results during the process of risk assessment, because calculation results will be affected seriously by calibration of reproduction models. Understanding these critical points regarding modeling is essential for appropriate performance of calculation.

In this study, investigation was conducted regarding which part of flood risk assessment contains uncertainty and how influential each part of uncertainty is. Furthermore, another potential location of uncertainty was also discussed. The study conducted on uncertainty in flood risk assessment as a holistic mechanism in a poor data situation in a developing country is unique and challenging since no similar study was conducted in the past.

However, for clear understandings and precise identification of uncertainty, the analysis based on rich data is necessary. Additional case study in another river basin will be also necessary for better comparison in different condition.

Based on the understanding of uncertainty during the process of risk assessment, the next chapter will address how to reduce uncertainty by using recent advanced technology to overcome data unavailability and quality in developing countries.

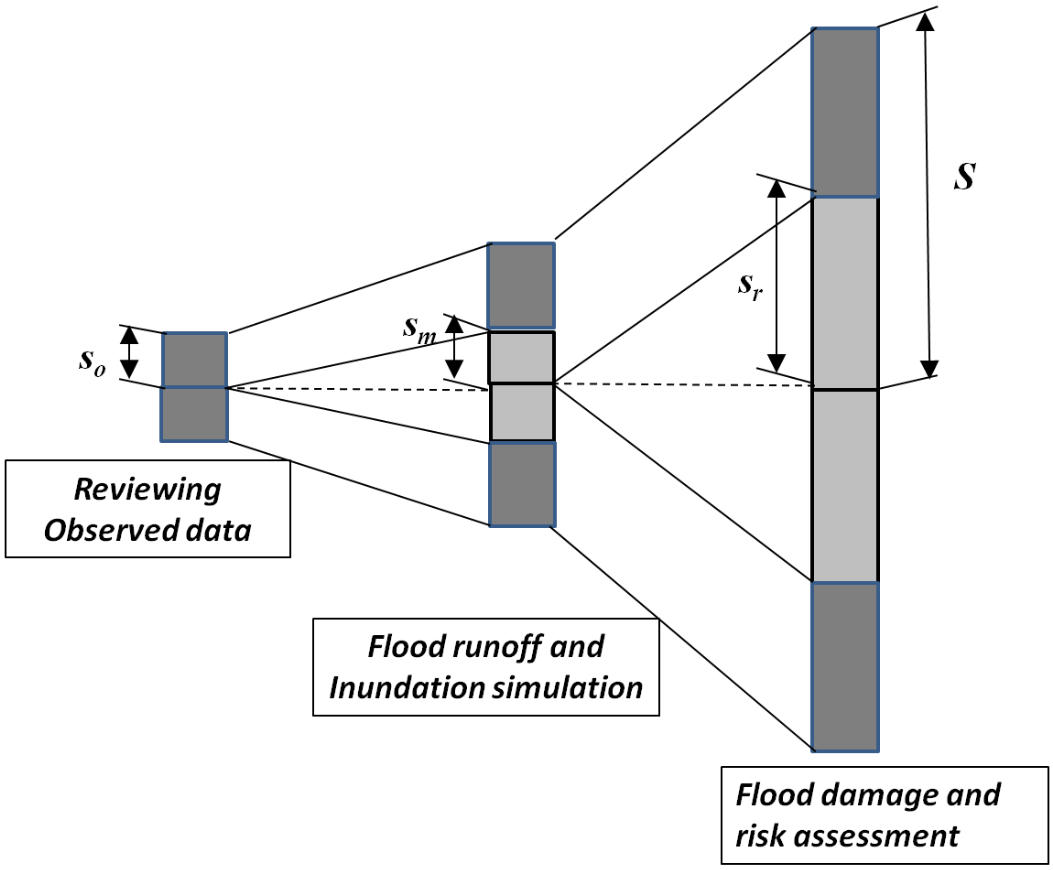


Fig. 4-23 Schematic relation of uncertainty propagation

References

1. T. Okazumi, M. Miyamoto, B. B. Shrestha, and M. Gusyev, Uncertainty Estimation during the Process of Flood Risk Assessment in Developing Countries - Case Study in the Pampanga River basin -, Journal of Disaster Research vol. 9 no.1 : 69-77, 2014.

2. Joint Committee for Guides in Metrology, "Evaluation of measurement data – guide to the expression of uncertainty in measurement", JCGM 100:2008, GUM 1995 with minor corrections, corrected version 2010.

3. K. Takemura, K. Yoshikawa, and S. Fujii, "Taxonomy of uncertainties and risk evaluation", A proposal of the theoretical framework, Journal of Socio-technological Research, vol.2, 12-20, Oct. 2004 (in Japanese).

4. B. Merz and A. H. Thieken, "Flood risk curves and uncertainty bounds", Natural Hazards, 51, 3, 437-458; DOI:10.1007/s11069-009-9452-6, 2009.

5. M. Disse, H. Engel, Flood events in the Rhine basins: genesis, influences and mitigation, Natural Hazards 23: 271-290, 2001.

6. L. Pfister, J. Kwadijk, A. Musy, A. Bronstert, and L. Hoffmann, Climate change, land use change and runoff prediction in the Rhine-Meuse Basin, River Research and Applications 20: 229-241. DOI: 10.1002/rra.775, 2004.

7. R. Vogt, Hochwasser in Koln: Dokumentation der Fachtagung "Mit dem Hochwasser leben", Baden-Baden : 48-55, 1995.

8. A. Fink, U. Ulbrich, and H. Engel, Aspects of the January 1995 flood in Germany. Weather 51: 34-39, 1996.

9. Visser H, Folkert RJM, Hoekstra J, de Wolff JJ, Identifying key sources of uncertainty in climate change projections. Climatic Change 45(3-4): 421-457, 2000.

10. National Disaster Risk Reduction and Management Council, "Sitrep no.11 re Effects of Tropical Storm "HELEN" and enhanced southwest monsoon", NDRRMC UPDATA, 19 August, 2012

11. National Disaster Risk Reduction and Management Council, “Destructive Typhoon 1970-2011”, 2012.

12. Regional Disaster Risk Reduction and Management Council, “Flood Damage Data, Effect of Weather Disturbance in Region III”, 2012.

13. J.R. Stedinger, and R.M. Vogel, E.Foufoula-georgiou, Frequency Analysis of Extreme Events, Chapter 18, Handbook of Hydrology, McGRAW-HILL, INC., 1993.

14. Flood disaster prevention division, Research Center for Disaster Management, National Institute for Land and Infrastructure Management, Ministry of Land, Infrastructure, Transport and Tourism, Japan, “Checklist of flood forecasting system, ver. 2009, details and supplemental explanation”, June 2010.

15. T. Sugiura, K. Fukami, N. Fujiwara, K. Hamaguchi, S. Nakamura, S. Hironaka, K. Nakamura, T. Wada, M. Ishikawa, T. Shimizu, H. Inomata, and K. Ito; “Development of integrated flood analysis system (IFAS) and its applications”, Proceeding of the 8th International Conference on Hydro-informatics (HIC2009), CD-ROM, 2009.

16. M. Miyamoto, A. Sugiura, T. Okazumi, S. Tanaka, S. Nabesaka, and K. Fukami, “Suggestion for an advanced early warning system based on flood forecasting in Bengawan Solo river basin, Indonesia”, Proceedings of the 10th International Conference on Hydro-informatics, Hamburg, Germany, 2012.

17. K. Takeuchi, P. Hapuarachchi, M. Zhou, H. Ishidaira, and J. Magome, “A BTOP model to extend TOPMODEL for distributed hydrological simulation of large basins”, Hydrological Processes, 22: 3236-3251, 2008.

18. Ministry of Land, Infrastructure, Transport and Tourism, “Manual on flood control and economic investigation (draft)”, April 2005 (in Japanese).

19. B. B. Shrestha, T. Okazumi, S. Tanaka, A. Sugiura, Y. Kwak, and S. Hibino, “Development of flood vulnerability indices for lower Mekong basin in Cambodian floodplain”, Annual Journal of Hydraulic Engineering, JSCE, Vol.57, February, 2013.

20. T. Okazumi, S. Tanaka, Y. Kwak, B. B. Shrestha, and A. Sugiura, “Flood vulnerability assessment in the light of rice cultivation characteristics in Mekong river flood plain in Cambodia”, Paddy and Water Environment, DOI 10.1007/s10333-013-043-1, 2013.

21. Ministry of Education, Culture, Sports, Science and Technology-Japan, “Report in 2011, projection of the change in future weather extremes using super-high-resolution atmospheric models, innovative program of climate change projection for the 21st century”: 207-218, March 2012 (in Japanese).

22. A. Sugiura, S. Tanaka, T. Okazumi, Y. Kwak, S. Hibino, and B. B. Shrestha, “Calculation of flood house damages in the Mekong river basin in Cambodia”, 6th International Perspective on Water resources and the Environment, Turkey, January 2013.

23. Bureau of Agricultural Statistics, “Manual on damage assessment and reporting system”, Department of Agriculture, Philippines, February 2013.

24. T. Sayama, Y. Tatebe, M. Fujioka, T. Ushiyama, A. Yorozuya, and S. Tanaka, “Rainfall - runoff inundation forecasting in 2011 Thailand flood”, Journal of Japan Society of Civil Engineering, 2013 (in Japanese).

25. T. Sayama, G. Ozawa, T. Kawakami, S. Nabesaka, and K. Fukami, “Rainfall-runoff-inundation analysis of Pakistan flood 2010 at the Kabul river basin”, Hydrological Science Journal, IAHS, 2011.

26. Bulacan Provincial Agricultural Office, “Final validation report for cereals”, 2011.

Chapter 5

Possible Technologies for Convergence of Uncertainty in Flood Risk Assessment

5.1 Introduction

In the previous chapter, the results of the case study clearly showed uncertainty exists in each step of flood risk assessment, and the greatest uncertainty exists in damage calculation. Furthermore, uncertainty in each step is carried over to the next step in flood risk assessment, and the final uncertainty becomes large as a result of accumulation of uncertainty at each step. Uncertainty contained in the results reflects the unavailability and quality of data and information, and it is also linked to difficulty in collecting information in developing countries. Especially, it is the evidence that information on direct damage, for example, to human, house, agriculture and industry is sometimes difficult to collect, and that some countries do not have any systems for damage data collection or damage calculation. Unfortunately, this kind of difficulty exists not only in the process using damage data, but also in other steps of flood risk assessment. In conclusion, it is clear that overcoming this difficulty is an important challenge for uncertain studies.

This means that flood risk assessment can be seen as one holistic system consisting of multiple steps. Identifying uncertainty in each step, finding out the most problematic step, clarifying an uncertainty accumulation mechanism to the final result, and specifying causes of uncertainty are similar to system maintenance.

The interesting mechanism is that each step receives uncertainty from the previous step, adds more uncertainty unique in each step, and carries it over to the next step. An actual flood is assessed in each step based on a wide range of data such as precipitation, water level, inundation area, water depth, and damage. Uncertainty adds up through the process of risk assessment because each set of data contains uncertainty, which is carries over to the next step at which uncertainty from the previous step is combined with uncertainty at the current step.

In this aspect, this chapter recommends necessary actions to reduce uncertainty, and introduces useful technology for that purpose. Combination of conventional measures and new technology can help for cross-checking data and information, and contributes to reduction of uncertainty in the final results.

Other issues discussed in this section are what is the main target in uncertainty reduction, what level of uncertainty can be considered acceptable, and how much uncertainty can be reduced by the technology proposed in this study.

5.2 Convergence of Uncertainty

Efforts to reduce uncertainty in each step of flood risk assessment are important to obtain reasonable results because of the stepwise-linkages. Accumulation of each effort brings a better result. In this aspect, conventional and basic procedures should be the foundation of all technology; however, new technology is also available in the world. Combination of conventional and new technology and use of multiple sets of information to cross-check data at each step are useful during flood risk assessment. As for new technology, the development of satellite data and the improvement of its availability are effective to cross-check information and thus to reduce uncertainty especially in developing countries. Uncertainty can be further reduced by the combining observation information (e.g., cross section, flow velocity, historical flood record, maximum flood marks in past floods to identify the maximum inundation area and depth) with satellite information (Moderate Resolution Imaging Spectrometer (MODIS), Synthetic Aperture Radar (SAR) and Pico-satellite for Remote-sensing and Innovative Space Mission (PRISM)) to identify inundation areas and depths, and vegetation growth measurement. Uncertainty reduction in each step, represented by white arrows in **Fig. 5-1,** reduced uncertainty in the entire process and produced better assessment results[1,2].

Before introduction of new technology, the following are recommendations will reduce uncertainty in flood risk assessment:

a) *Data collection*: Field data play an important, fundamental role in statistical analysis, model simulation, and damage estimation. Preparation of reliable, accurate hydrological and damage data is a costly and time-consuming process, but of paramount importance for risk assessment of past and future flood events.

b) *Data cross-validation*: Through international cooperation, a reliable and automated data collection mechanism needs to be established a major activity for

1 A. Yorozuya et al., 2013.
2 T. Okazumi et al., 2013.

mainstreaming disaster risk reduction. Satellite information was useful for data collection in remote areas without observing stations, and to cross-validate field data. The data cross-validation reduced uncertainty and such research should be encouraged on this topic.

c) *Data prioritization*: From a flood risk reduction perspective, further research is needed in the field of flood risk uncertainty estimation to identify cost-effective, relevant flood damage mitigation actions. Accurately estimating flood risk uncertainty requires the stepwise approach of data prioritization to cover critical data gaps. In addition, satellite information should be used as supplementary measures to reduce uncertainty during the flood risk assessment process.

Based on these recommendations, potential technology will be discussed in the following subsections in terms of hazard observation, reproduction model, and damage estimation.

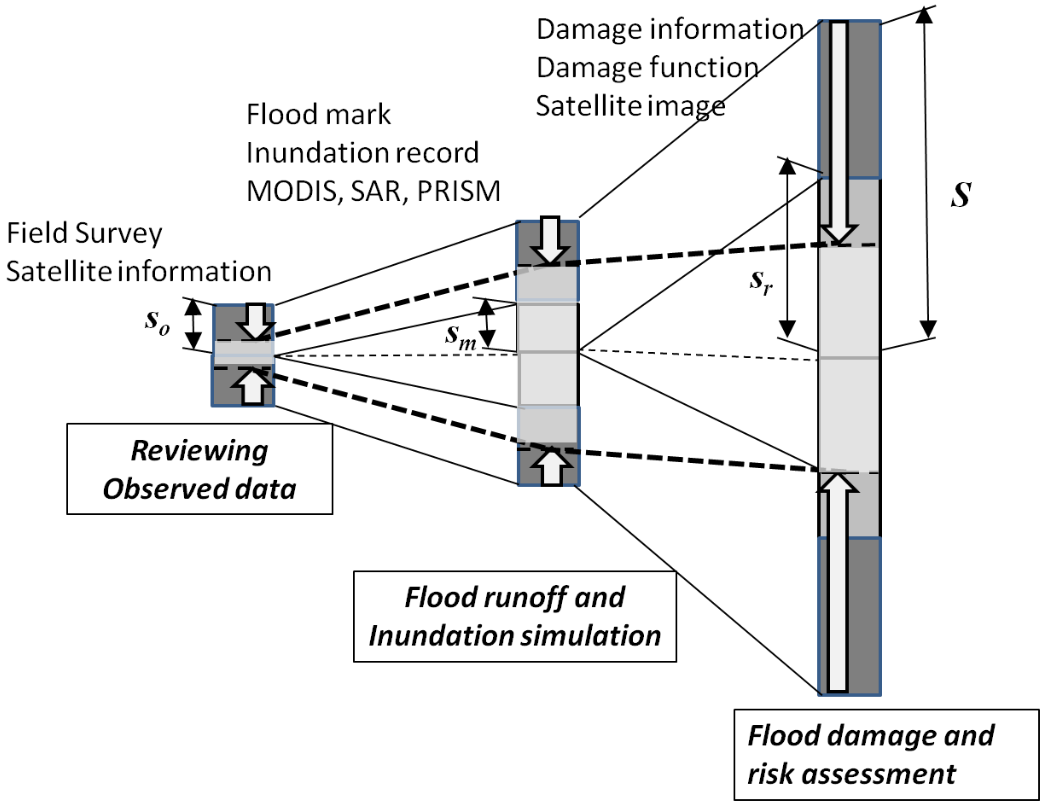


Fig. 5-1 Convergence of uncertainty

5.2.1 Hazard Observation Method

Information of maximum inundation depth and area is important for inundation model calibration. This information can be obtained by interviewing residents and measuring flood marks as precise as possible during post-flood investigation. In developing countries, this information is normally quite inadequate or sometimes unavailable.

To collect this information, International Centre for Water Hazard and Risk Management (ICHARM) has been using satellite information to identify inundation area and depth. Yorozuya et al[3],[4]. applied 8-day composite information obtained by MODIS[5], which can estimate water bodies. Overlaying another topographic data such as Shuttle Radar Topography Mission (90mx90m grid)[6] made identification of inundation area and water depth possible. **Fig. 5-2** shows one such example using the Mekong River flood plain in Cambodia. The blue line in the graph is the elevation of the dotted line in the map.

The advantages of MODIS and Shuttle Radar Topography Mission (SRTM) information are free of charge and easy to handle. However, MODIS information can be influenced by cloud, and it is not applicable to short-term runoff. Further development of composition of other sensors or other information is expected.

3 A. Yorozuya et al., 2013.
4 A. Yorozuya et al., 2013.
5 Y. Kwak et al., 2012.
6 SRTM.

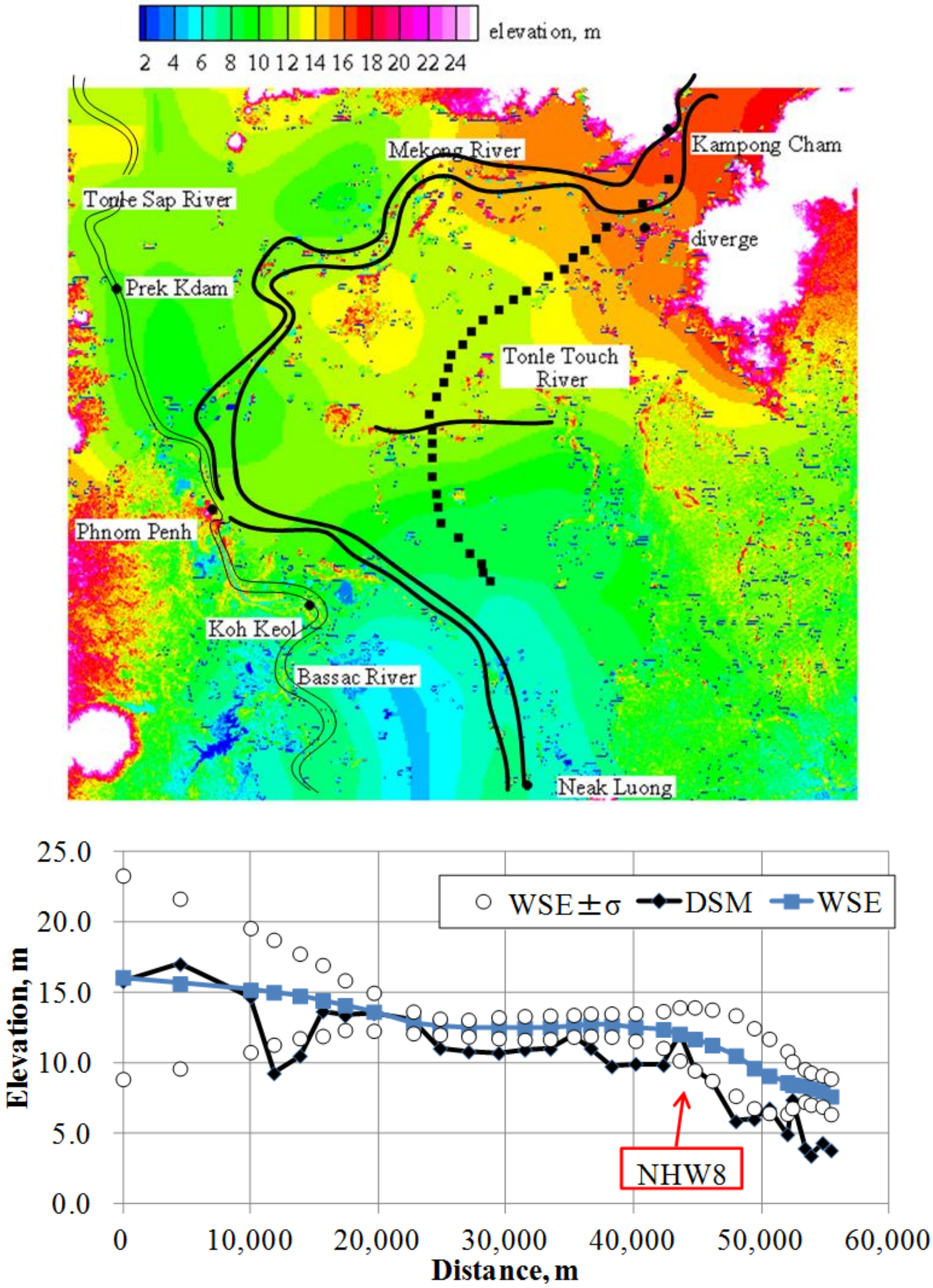


Fig. 5-2 Identification of inundation area and depth in the Cambodia plain from satellite information

5.2.2 Hazard Simulation Method

When selecting a runoff and inundation simulation model, one can easily select a popular model. However, it does not work sometimes in developing countries because it usually needs detailed topography as input data. In such a case, one has to decide to use the model even though it requires a huge amount of time and cost to measure the target area or to simply give it up. To avoid this situation, a simulation model applicable to developing counties is introduced in this subsection.

(1) Runoff-Rainfall Inundation (RRI) model[7,8]

ICHARM developed the RRI model, which can overcome difficulties in implementing flood inundation simulation in wide flat plains where existing models have problems in simulation.

The RRI model can simulate rainfall running down the slope, gathering into the river, flowing in the river, and flooding at the same time. This model can use satellite rainfall and satellite topography.

A Japan International Cooperation Agency (JICA) report presented comparison between the RRI model and the MIKE model as a popular model. Major results are shown in **Fig. 5-2** and **Table 5-1**[9].

While the MIKE model is a simplified model, the RRI model is a unique model which can simulate both runoff and inundation. However, compared with other types of software, RRI is still simple, being provided free of charge as an open program using m code, though it needs more improvement in applicability to a wider range of conditions.

(2) ICHARM Hydro-Geo method[10,11]

The ICHARM Hydro-Geo Method was developed to identify inundation area and depth in a Cambodian flood plain using a Cambodian irrigation system with colematage which naturally intakes water to paddy fields. The method was introduced in detail in section 2.4.3 with utilized hydro-meteorological analysis, Geographic Information

7 T. Sayama et al., 2013.
8 T. Sayama et al., 2011.
9 JICA, 2013.
10 T. Okazumi et al., 2013.
11 ICHARM, 2013.

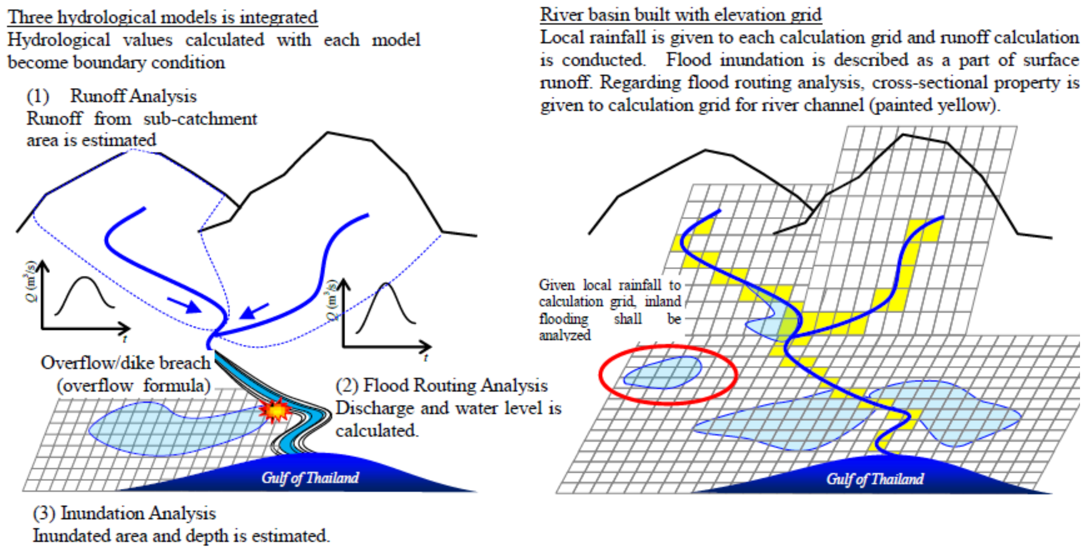
System (GIS), and the Cambodian irrigation system in relation to water level in the Mekong River and micro topography.

This method can be applied to flood plains similar to the Cambodian plain with no significant dykes and similar river water level and flood inundation level.

(3) Flood Inundation Depth (FID) method[12]

In FID method (**Fig. 5-4**), relative elevation and flow data which was provided by HydroSHEDS, National Aeronautics and Space Administration (NASA), are utilized to identify inundation area without any other hydrological and hydraulic calculation. This was developed for identification of large river basin inundation area in global estimation in future climate change situations during the Innovation Program of Climate Change Projection for the 21st Century (Kakushin program)[13]. This model can benefit developing countries because a complex model is not included in this model. However, since accuracy is not very high, it can be effective to identify inundation in global analysis, not in river-basin or more detailed analysis.

12 Y. Kwak et al., 2012.
13 MEXT, 2012.



【MIKE Series】 【RRI Model】

Fig. 5-3 Schematic difference between MIKE series and RRI model

Table 5-1 Some differences between MIKE series and RRI model (1)

Items	RRI model	MIKE series
1. Runoff Analysis		
Model type	Distributed hydrological model (grid-type model), River basin is modeled with elevation grid., Runoff in each grid would be calculated., Calculated runoff flows to the river as surface runoff, intermediate runoff and groundwater etc. according to the water level gradient.	Lamped hydrological model Sub-catchment area is determined at arbitrary point. Runoff from sub-catchment area is given to the flood routing model as boundary condition.
Others	Runoff and inundation phenomenon is analyzed at the same model., It is not necessary to set up sub-catchment border.	NAM module is suitable for not only short term also mid-long term runoff analysis. In addition, NAM is able to deal snow flood., Local rainfall can be given to flood analysis model (MIKE-21) directly in order to evaluate inland flooding. However, it is necessary to identify inland flooding area in advance.
2. Flood Routing Analysis (one dimentional model)		
Hydraulic model	One dimensional unsteady model Diffusion wave model (Kinematic wave is selectable)	One dimensional unsteady model Full-dynamic model (Diffusive model and kinematic model are selectable)
3. Flood Inundation Analysis (Two dimentinoal model)		
Hydraulic model	Diffusion wave model (Kinematic wave model is also selectable)	Full-dynamic model

Table 5-1 Some differences between MIKE series and RRI model (2)

Items	RRI model	MIKE series
4. Others		
Program code	Fortran 90/95 Publication of the program code to research and development institute in developing countries is under consideration (as of September 2013) If the program code is disclosed, users can modify for their flood control planning etc.	Unknown Program code is unpublished.
Distributer	ICHARM http://www.icharm.pwri.go.jp/index_j.html	DHI Water & Environment http://www.dhigroup.com/
Price	Under consideration	Depend on the number of modules. If MIKE-11, MIKE-21, MIKE FLOOD and necessary modules for flood analysis are procured, the cost can be approx. 1 million baht
Remarks		MIKE Series has high affinity with the ArcGIS (ESRI,US). DHI has local agency in Thailand (DHI Thailand, http://mikebydhi.com/Contact/AsiaPacific/T hailand.aspx)
Others	Input data such as elevation data, roughness coefficient etc. are basically two-dimensional array except for tidal data and hydrograph. GIS software is very useful for editing work and user can set-up parameters easily.	MIKE Series has many parameters and model building requires some getting used to it. MIKE has powerful analysis engines. If wrong parameters are set-up in the model, MIKE can calculate with warning and the result may include errors. Careful evaluation of result is necessary and modelers are required a certain level of hydraulic/hydrological knowledge.

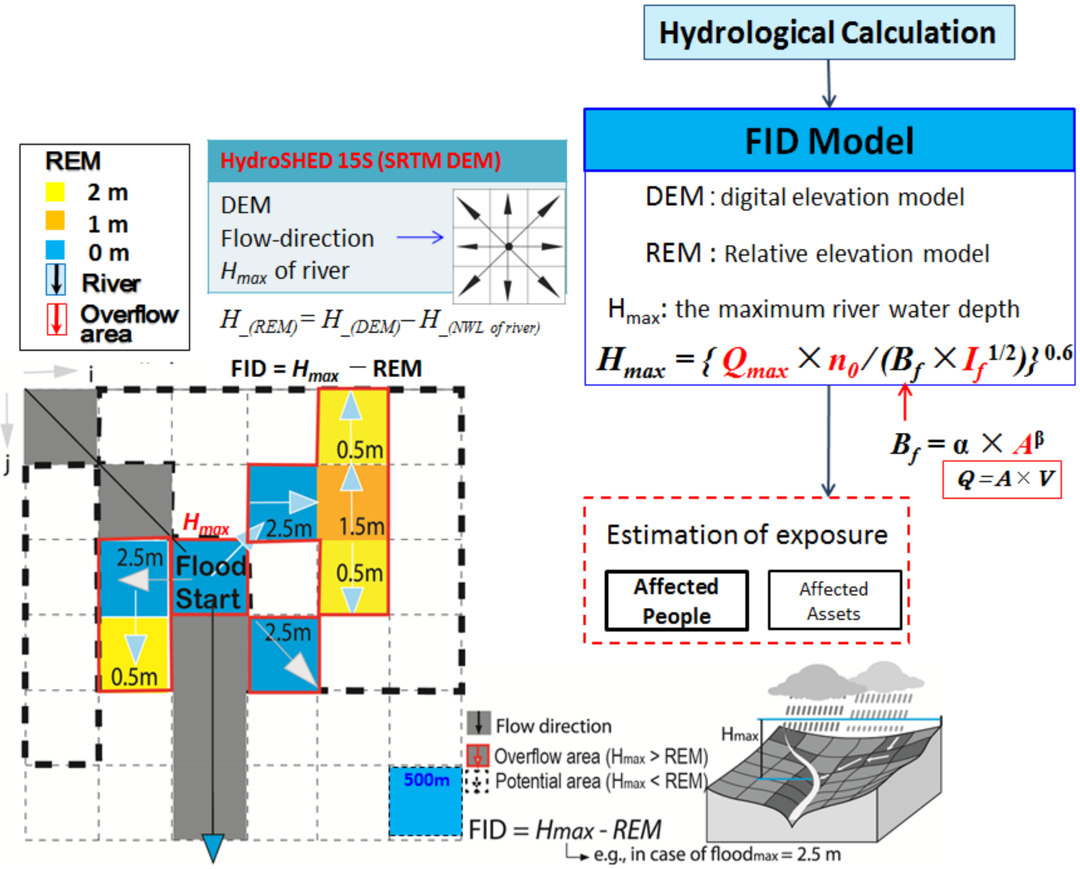


Fig. 5-4 Flood Inundation Depth model

5.2.3 Damage Estimation Depth Method

As explained in chapter 4, the most difficult step is damage assessment during flood risk assessment. In Japan, the Manual on Flood Control and Economic Investigation (draft) defines the damage formula for houses[14]. However, normally such damage formulas are not defined in developing countries. If such damage formulas can be defined in developing countries, it will be great contribution to flood risk assessment in those countries.

ICHARM developed such a damage formula in 2013 based on the result of the Mekong River Commission survey in 2008, which investigated the 2006 flood. Furthermore, statistical analysis was applied to this formula, and estimated household value rates were confirmed whether they would agree with the Gumma distribution. This basic relationship was found and used to estimate house damage in the Cambodia flood plain (**Fig. 5-5**)[15]. Furthermore, ICHARM is working on further development of damage curves including the factors of floor height, house site, and so on.

Previously, ICHARM tackled to find out the relationship between roof structures and house values in the West Rapti River in Nepal. Roof type was designated by satellite image, and this damage formula is used to estimate damage in this study.

As explained in section 2.4.3, rice crop damage depends on water depth and duration of inundation, and calculated total damage using rainfall analysis and inundation analysis.

In Sousei program[16], ICHARM is now trying to find out damage curves of houses and agriculture in the Pampanga River basin area by reviewing past studies.

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14 MLIT, 2005.
15 A. Sugiura et al., 2013.
16 MEXT, 2013.

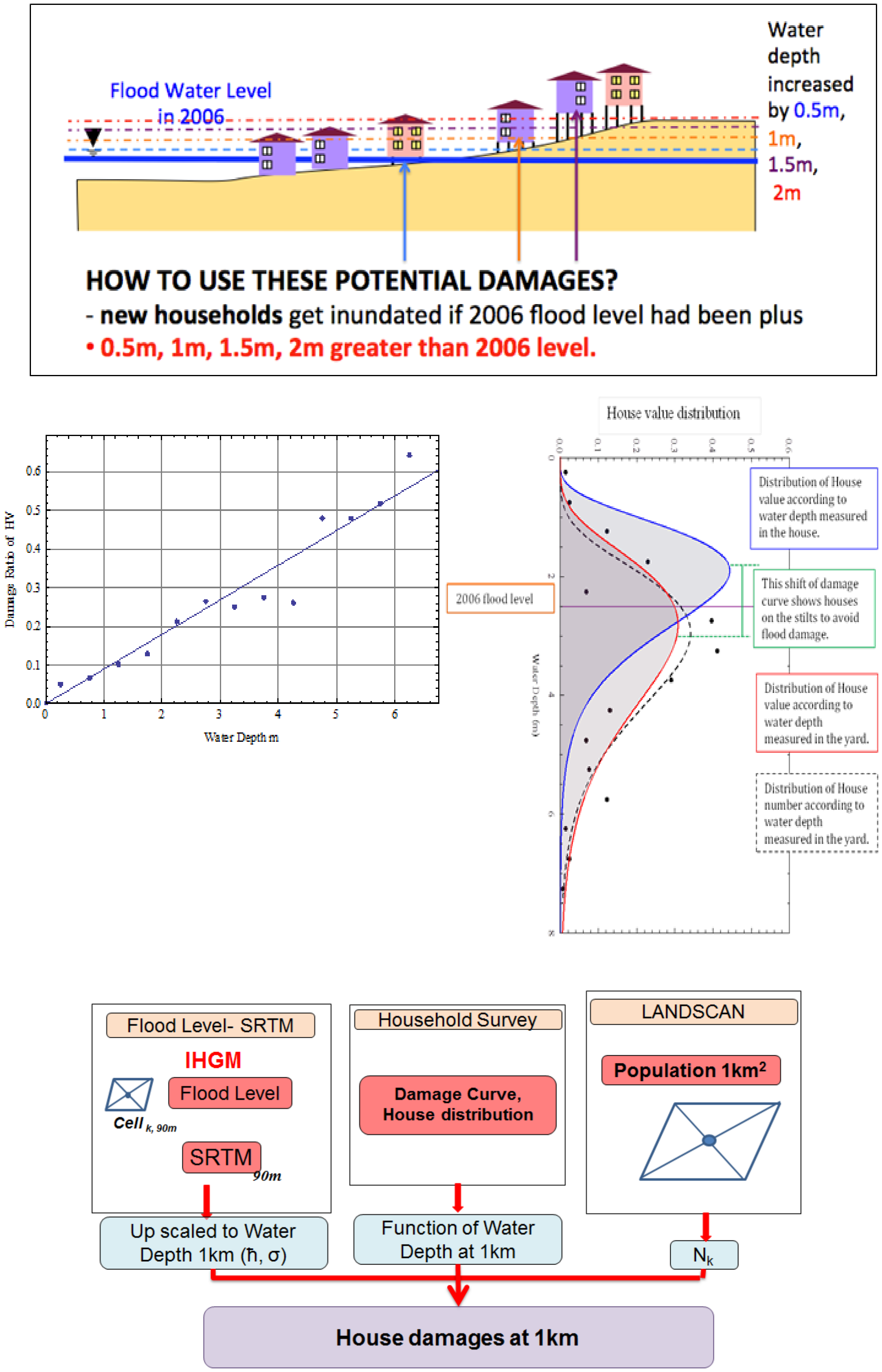


Fig. 5-5 House damage calculation in Cambodian flood plain study

5.3 Discussion on Limitation and Target of Uncertainty

As explained in the previous chapters, uncertainty always occurs during flood risk assessment; even greater uncertainty is often expected during flood risk assessment in developing countries. Furthermore, data unavailability makes validation of the results difficult. As a consequence, the results of calculation are often not reliable, which makes the implementation of flood risk assessment seemingly meaningless.

This subsection discusses the limitation of uncertainty and the limitation of implementation of flood risk assessment.

5.3.1 Limitation of Uncertainty

In the discussion of the limitation of uncertainty during flood risk assessment, it is important to start it with how to use the results of such assessment. The original objective defines what extent of accuracy is necessary.

5.3.2 User’s Perspectives

First, it is critical to review the purposes of flood risk assessment and consider how to use the results of the assessment.

Flood risk assessment is usually implemented on a river-basin scale. And its purpose is the identification of countermeasures after flood damage has occurred in consideration of the weakest point in the river, types of frequent damage, and expected locations prone to future floods among other issues.

If there are some areas with the same probability of flood damage, the following are considered: Which area is the most vulnerable or may suffer the most serious damage, what kind of countermeasures should be selected, what other measures, such as avoidance, transfer, removal, shift and reduction, should be considered, what kind of or how large measures are appropriate, how much it will cost to implement such measures , what are the results of cost-benefit analysis, and whether such measures are feasible or not.

In short, the following are identified as important points:

1) Identification of high risk areas and their boundary

2) Ranking of high risk areas
3) Identification of countermeasures and their cost
4) Identification of the effectiveness of the measures
5) Cost benefit analysis

The results of flood risk assessment will influence the quality of countermeasures. Accurate results lead to detailed and accurate analysis, selection of appropriate countermeasures, and good justification to explain to decision-makers for budget and institution.

The framework of risk management to tackle disasters is composed of four methods: 1) Reduction, 2) Avoidance, 3) Transfer, and 4) Acceptance.[17]

"Acceptance" is accepting a certain size of disaster and damage, and "Transfer" is accepting disaster and damage and compensating damage by insurance for recovery. In both cases, damage will be accepted. Only in the case of avoidance or reduction, countermeasure should be considered.

"Reduction" refers to mitigation of damage, especially prevention of damage by structural measures. So-called structural measures should be validated in magnitude of investment and size of structure, location of measures, and quality of structure. The feasibility should be justified before starting the project of structures by cost-benefit analysis. This is pre evaluation of individual public works projects described in section 2.3.3.

Individual public works projects include cost for necessary investigation and data collection. However, avoidance countermeasures should not be justified to invest in implementation. Cost for avoidance such as land use regulation, flood forecasting and warning system should be allocated to societal cost.

In this regard, because measures to be implemented should be different as a society to protect grows, more accurate and detailed information and data should be collected depending on developmental level of the society.

In the preliminary level, reviewing past hazards with inundated records can bring

17 N. Maki, 2006.

minimum information to avoidance. If there are residents in past inundated areas, warning should be the minimum requirement for evacuation.

For the next step, if the city's population grew in these hazardous areas, forecasting and warning systems are necessary. However, some information on damage is needed to justify the cost of this system installment.

For the next step, if the city grew larger and several places are located in hazardous areas, land use regulation should be placed. Introduction of regulation is necessary for negotiation with residents, and justification based on technical analysis with data is needed.

Finally, protection for some zones should be implemented after examining the cost, benefit and effectiveness based on detailed information and data.

It can be said that a larger society requires more data for analysis.

5.3.3 Possible Proposal to Reduce Problems

Flood vulnerability indices (FVI) developed for a province in the Cambodian flood plain in the Mekong River will be introduced in this subsection. This study was conducted in spite of quite low data availability, and calculated absolute damage cannot be validated due to lack of damage information. At last, the indicators were developed for residents to use them for evacuation, land use and cultivation. The final results were presented at training for Cambodian engineers supported by the Mekong River Commission.

(1) Development of FVI[18]

Based on the flood observation data from 1991-2007, the average water depth of the 2000 flood was the highest in this duration. Thus, the flood was referred to as an extreme flood.

The average water depth of the flood in 2006 was almost equal to the average water depth of the years 1991-2007.

18 B. B. Shrestha et al., 2013.

Two kinds of FVI were developed. The first one is FVI for average flood, and the second one is FVI for extreme flood. Thus, FVI for the 2006 flood was evaluated as average flood. The Flood Vulnerability Indices for Average Flood (FVI-AF) are identified by normalizing the calculated value of damage in each grid. To normalize the value, the calculated value in each grid is divided by the maximum value of calculated damage as follows:

$$FVI - AF = \frac{Value\ of\ damage\ in\ a\ grid}{Maximum\ value\ of\ damage} \tag{5.1}$$

Flood Vulnerability Indices for Extreme Flood (FVI-EF) are defined to identify the damage gap area between average flood and extreme flood. Average flood brings some damage but extreme flood brings serious damage. It means that adequate preparedness is needed for extreme flood in such areas. The variations of gap area of flood vulnerability to extreme flood are identified by difference rate with average flood damage as follows:

$$FVI\text{-}EF = \frac{Damage\ (2000\ Flood) - Damage\ (2006\ Flood)}{Damage\ (2006\ Flood)} \tag{5.2}$$

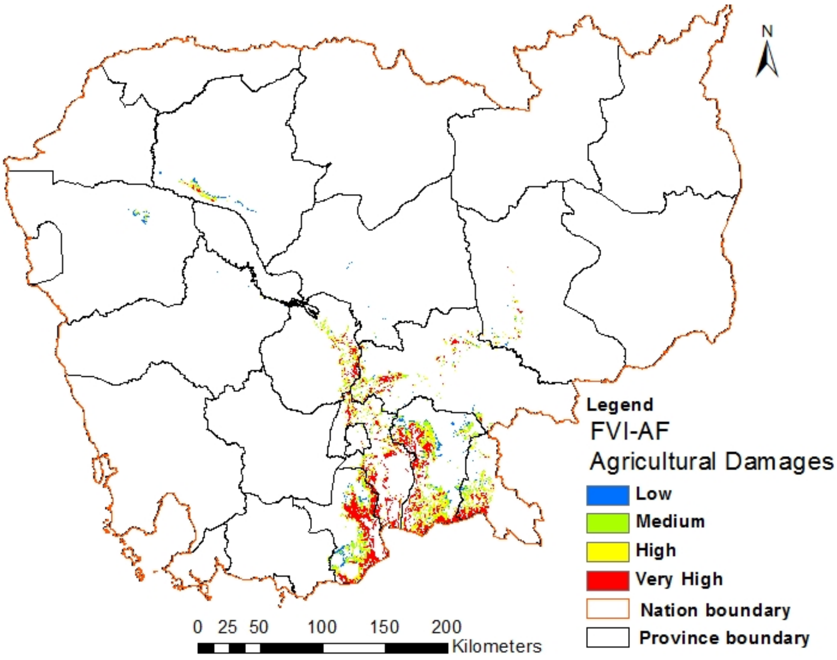
Figure 5-6A shows FVIs of potential agricultural damage for average flood. The FVI-AF is defined for areas with low to very high vulnerability based on normalized values ranging from 0 to 1. The normalized value are 0 - 0.25, 0.25 - 0.5, 0.5 - 0.75 and 0.75 - 1, respectively, defined as low, medium, high and very high vulnerability. In average flood, people living in the area often face agricultural damage. Based on the FVI-AF map, they can identify which area is highly vulnerable to floods and which area is low at flood vulnerability.

Figure 5-6B shows FVIs of agricultural damage for extreme flood. The figure shows identification of agricultural damage gap areas between average flood (2006 Flood) and extreme flood (2000 Flood). In the red areas of the figure, agricultural damage is very serious in extreme flood than in average flood. In the blue areas, agricultural damage is serious in average flood than in extreme flood. During the growing period, floodwater depth in the blue areas is higher in average flood than in extreme flood. In average years, agricultural damage can be more serious in average flood than in extreme flood, because the agricultural damage is caused by significant inundation during the growing period which is determined by accumulated rainfall of that area.

By utilizing FVI-AF, information on vulnerable areas can be easily found, and areas where preparedness is needed can be easily identified. In average flood, some damage is experienced in the Cambodian flood plain, but when extreme flood occurs, serious damage is inflicted to the area. That means that adequate preparedness for extreme flood is needed in such areas. By utilizing FVI-EF to identify gap area between average flood damage and extreme flood damage, areas where serious preparedness for extreme flood is needed can be identified.

FVIs are designed also to estimate agricultural damage. They can identify areas which are easily affected by floods. The results of FVIs can be used to effectively increase preparedness for floods in the areas of agriculture, houses and other assets. The developed FVIs can be useful for local communities, decision makers and developers when translation tools are well prepared.

(A)



(B)

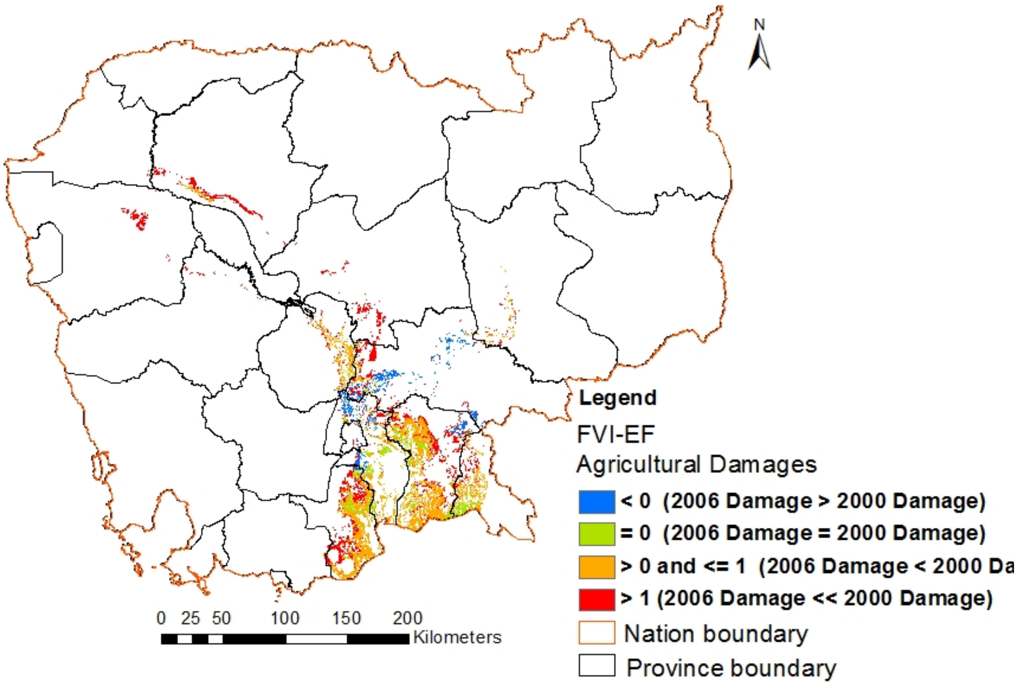


Fig.5-6 Flood vulnerability indices of agricultural damages **(A)** for average flood, FVI-AF, **(B)** for extreme flood, FVI-EF.

5.4 Conclusion

Uncertainty in flood risk assessment shows interesting behaviors. It affects individual results, is carried over to the next step, and influences the final results. It is also found that additional information, such as field survey results and satellite information can reduce uncertainty at each step.

Conventional procedures to review data and check records are the most fundamental and important actions. In addition, utilizing satellite information and an additional cross-checking process can be very useful.

The analysis of flood risk assessment showed a holistic mechanism and locations of potential uncertainty in the process, as well as the possibility of convergence of uncertainty. It should be good guidance to engineers working on models and technology to collect better information.

The limitation of uncertainty cannot be defined because it depends on social progress and the necessity level of flood risk assessment. However, accumulation and archives of data and information cannot improve immediately. It is urgent for developing countries, as well as developed countries, to start collecting disaster data. Once data availability improves, accuracy needed for flood risk assessment can be easily assured with assistance of technology.

For supporting developing countries, it is important first of all to identify necessary information for flood risk assessment and to enhance data availability for cross-checking. Although data and information are often limited in developing countries, relative risk indicators such as FVI can help overcome poor data and technology to offer useful advice about land use and evacuation by using average flood damage and extreme flood damage, and its combination.

References

1. A. Yorozuya, H. Kamimera, T. Okazumi, Y. Kwak, "Study about estimation of water surface elevation on inundated area applying satellite based information", Journal of River Engineering, Japan Society of Civil Engineering, vol. 19 : 341-344, June 2013 (in Japanese).

2. T. Okazumi, S. Tanaka, "Applicable methodologies for flood risk assessment in the river basin in developing countries", Journal of River Engineering, Japan Society of Civil Engineering, vol. 19 : 17-20, June 2013 (in Japanese).

3. Kwak, Y. et al., Estimation of flood volume in Chao Phraya river basin, Thailand from MODIS images coupled with flood Inundation level, IEEE-IGARSS2012 : 887-890, 2012.

4. Shuttle Radar Topography Mission http://www2.jpl.nasa.gov/srtm/

5. A. Yorozuya, et al., Study on PRISM DSM Application to Inundation Analysis and its Modification Method, Journal of Japan Society of Civil Engineers Ser. B1(Hydraulic Engineering), Vol.69, No.4, I_1549-I_1554, 2013 (in Japanese).

6. A. Yorozuya, H. Kamimera, T. Okazumi, Y. Iwami, and Y. Kwak, Estimation of water surface elevation on inundated area using satellite based information. In Piantadosi, J., Anderssen, R.S. and Boland J. (eds) MODSIM, 20th International Congress on Modelling and Simulation. Modelling and Simulation Society of Australia and New Zealand, December 2013 : 2353-2359. ISBN: 978-0-9872143-3-1, 2013.

7. T. Sayama, Y. Tatebe, M. Fujioka, T. Ushiyama, A. Yorozuya, and S. Tanaka, "Rainfall - runoff inundation forecasting in 2011 Thailand flood", Journal of Japan Society of Civil Engineering, 2013 (in Japanese).

8. Takahiro Sayama, Go Ozawa, Takahiro Kawakami, Seishi Nabesaka and Kazuhiko Fukami: Rainfall-Runoff-Inundation Analysis of Pakistan Flood 2010 at the Kabul River Basin, Hydrological Science Journal, IAHS, 2011.

9. Japan International Cooperation Agency (JICA), Project for the comprehensive flood management plan for the Chao Phraya river basin, September 2013.

10. T. Okazumi, S. Tanaka, Y. Kwak, B. B. Shrestha, and A. Sugiura A., Flood vulnerability assessment in the light of rice cultivation characteristics in Mekong River flood plain in Cambodia, Paddy and Water Environment, ISSN 1611-2490, Paddy Water Environ DOI 10.1007/s10333-013-0403-1, 2013.

11. International Centre for Water Hazard and Risk Management, Public Works Research Institute, "Supporting Investment for Water Related Disaster Management", Asia Development Bank Technical Assistance no. 7276, March 2013.
http://www.adb.org/projects/documents/supporting-investments-water-related-disaster-management-tacr

12. Kwak. Y., K. Takeuchi, J. Magome and K. Fukami: A new approach to flood risk assessment in Asia-Pacific region based on MRI-AGCM outputs, Hydrological Research Letters, 2012.

13. Ministry of Education, Culture, Sports, Science and Technology-Japan, "Report in 2011, projection of the change in future weather extremes using super-high-resolution atmospheric models, innovative program of climate change projection for the 21st century" : 207-218, March 2012 (in Japanese).

14. Ministry of Land, Infrastructure, Transport and Tourism, "Manual on flood control and economic investigation (draft)", April 2005 (in Japanese).

15. Sugiura A., Tanaka S., Okazumi T., Kwak Y., Hibino S., Shrestha B.B., Calculation of Flood House Damages in the Mekong River Basin in Cambodia, Proceedings of "International Perspective on Water Resources and the Environment", Turkey, 2013.

16. MEXT, "Report in 2013, Precise impact assessments on climate change in the Program for Risk Information on Climate Change" : 69-71, 2013 (in Japanese).

17. N. Maki, Special topics; "Disaster Countermeasures Using Land Use Regulation – Towards Safety and Security National Land-", Journal of Natural Disaster Science, J. JSNDS 25-2 135-154, 2006 (in Japanese).

18. B. B. Shrestha, T. Okazumi, S. Tanaka, A. Sugiura, Y. Kwak, S. Hibino, Development of flood vulnerability indices for lower Mekong basin in Cambodian floodplain, Journal of Japan Society of Civil Engineers, Ser. B1 (Hydraulic Engineering), Vol.69, No.4, I_1-I_6, 2013

Chapter 6

Overall Conclusions and the Way Forward

6.1 Conclusions and Remaining Problems

The objective of this thesis is to give guidance for good understanding of present problems and necessary actions to be taken in the future in order to encourage and improve technology of flood risk assessment towards disaster risk reduction in the world. For this purpose, the author decided that the target should be developing countries for better understanding the present situations in the world, because identification of problems in developing countries will provide useful information that will contribute to this objective.

The framework of this thesis was introduced in chapter 1 as follows:

- Chapter 1 introduced the definition and background of mainstreaming of disaster risk reduction.
- Chapter 2 introduced the present status of flood risk assessment in Japan and developing countries.
- Chapter 3 showed poor practices in which pre-disaster assessment was not well implemented due to the lack of understanding of its importance.
- Chapter 4 introduced the results of a case study in a developing county for identification of problems and influential factors in flood risk assessment.
- Chapter 5 introduced possible new technologies to reduce uncertainty and proposed approaches to tackle flood risk uncertainty.

The details of the findings in each chapter are described in the following:

In **Chapter 2**, flood risk assessment was introduced with its all steps, technologies and methodologies. Flood risk assessments in Japan and developing countries were introduced. If flood risk assessment is required for decision making under poor data and information circumstances, a simplified method based on careful field survey should be implemented to overcome lack of data. Comparison studies on flood risk assessment between cases in Japan and developing countries were conducted for the basic understanding of the present situation of flood risk assessment. Through this chapter, discussion was made about the importance of flood risk assessment as pre-disaster activities to identify necessary action for flood risk reduction and present problems on flood risk assessment, which mainly concerns uncertainty.

In **Chapter 3**, two cases were introduced as poor practices. The first case is the Chao Phraya river flood, and the second one is the Great East Japan Earthquake and Tsunami. Both occurred in 2011 and caused serious damage to the areas. These two examples can clearly explain the effectiveness of appropriate risk assessment in advance and the importance of sharing information with residents and preparing prevention measures based on risk assessment. In the two cases, the main problem is poor coordination with development and risk assessment. In the Chao Phraya river flood case, land development was conducted and expanded to build more industrial parks with several economic incentives without sufficient risk assessment and information on flood risk. Then finally factories in these areas were seriously damaged by the 2011 flood. The Rikuzentakata city case showed that urban development was expanded up to the coastal area which experienced tsunami before without paying little attention to inadequate warning systems.

In **Chapter 4**, a study was implemented for estimation of uncertainty during flood risk assessment in the case of the Pampanga River basin. Through the uncertainty estimation in the risk assessment of a 10-year return period flood, the calculated uncertainty was large in every flood risk assessment step, and the uncertainty at the damage calculation step can be considered as the major influential factor over the final result of the risk assessment. The study strongly suggests that this is mainly due to lack of damage information. In addition, this is probably characteristics of developing countries because a past study in Germany showed damage estimation was not the most influential factor to the total uncertainty. The following three points were found from this case study of uncertainty estimation: 1) Uncertainty can greatly influence the quality and availability of data and information; 2) Data unavailability in some developing countries is a serious problem. Especially, collection of damage loss data is an urgent matter; and 3) Uncertainty is also linked to model calculation. Scientists and engineers should have adequate understanding of objectives and expected results during the process of risk assessment. At the end, investigation was conducted where uncertainty is and how much influence they are. And discussion on another potential location of uncertainty also introduced. Such study on uncertainty of flood risk assessment procedure as holistic mechanism in poor data situation in developing country must be unique and challenging. No similar study was conducted in the past.

In **Chapter 5**, uncertainty in flood risk assessment shows quite interesting behaviors. It affects individual results at each step is carried over to the next step, and influences the final results. Analysis of flood risk assessment showed holistic mechanism and locations of potential uncertainties in each process, and possibility of convergence. It gave good guidance to developer who works for technology to observe better information and useful model. Conventional procedures to review data and check records are most fundamental and important actions. In addition, utilizing satellite information and an additional cross-checking process can be useful. At present, however, limitation of uncertainty cannot be defined, and the accumulation and archives of data and information cannot improve immediately. It is urgent for developing countries, as well as developed countries, to start collecting disaster data. Then, accuracy needed for flood risk assessment can be easily assured with assistance of technology.

This study provides interesting results for understanding uncertainty in flood risk assessment. Especially, the study results are different compared with past study results. However, the following items still remain for further research.

1) Identification on detailed causes of uncertainty at each step of flood risk assessment, and its range /band of uncertainty.
2) Effectiveness of uncertainty reduction by advanced technology and development of further technology.
3) Development of method on effective data collection and damage formula

The abovementioned development can enhance effective data collection and analysis, and improve the entire flood risk assessment methodology. Furthermore, a lot of problems still remain unsolved for ideal water-related risk management, which will be presented in the following subsection.

6.2 Proposal for Next and Future Challenges

In this thesis, uncertainty was highlighted as one of the problems during flood risk assessment. However, there are many remaining problems aside from flood risk. Studies which should be implemented in the near future are introduced in the following. They should be rigorously promoted for future progress in this field.

(1) Further implementation of research on uncertainty during flood risk assessment is important for enhancing pre-disaster measures. Especially, uncertainty estimation of flood risk assessment under poor data and information circumstances in developing countries should be an urgent research topic. It is important to add more case studies in this field.

(2) Drought is sometimes a more serious problem than flood in the world. Under climate change conditions, high drought risk areas will spread in the world. There are a lot of past studies on hydrological drought in future climate change conditions, but not many on socio-economic drought risk. International Centre for Water Hazard and Risk Management (ICHARM) has been tackling this problem recently, and more research should be encouraged to develop a socio-economic drought risk assessment methodology.[1]

(3) The development of global flood and drought risk indices is another research area that should be promoted. If simple flood and drought risk indices are successfully developed, investment in this filed will be encouraged. Combination of these indices and a basin level methodology such as (1) and (2) can expand regional activities.[2]。

(4) The major purpose of flood risk assessment is to apply its results to cost-benefit analysis as explained in chapter 2. Quantifying structural measures can be possible, but quantifying non-structural measures is difficult. That is why it is difficult to explain what non-structural measures should be implemented to what extent. For encouraging non-structural measures, quantifying them is important for justification. Recently, social capital is recognized as a key indicator for preparedness of non-structural measures. ICHARM is now tackling measuring this societal capital by conducting questionnaire surveys for community leaders to develop Flood Disaster Preparedness Indices[3], which should be formulated for practical use. Especially, there is some limitation to tackle structural measures alone in developing countries. Such activities to encourage non-structural measures should also be implemented.

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1 MEXT, April 2013.
2 ICHARM, 2013.
3 T. Nakasu, et al., 2012.

(5) It is important to expand research to cover a wide range of water-related disasters besides floods including droughts, storm surges, and tsunamis. The development of risk assessment for these hazards should also be discussed.

The author hopes that this study can encourage further research on uncertainty in flood risk assessment, development of effective technology and countermeasures, enhancement of pre-disaster measures, and finally reduction of damage of natural hazards.

References

1. MEXT, “Report in 2013, Precise impact assessments on climate change in the Program for Risk Information on Climate Change” : 69-71, 2013 (in Japanese).

2. International Centre for Water Hazard and Risk Management, Public Works Research Institute, “Supporting Investment for Water Related Disaster Management”, Asia Development Bank Technical Assistance no. 7276, March 2013.
   http://www.adb.org/projects/documents/supporting-investments-water-related-disaster-management-tacr

3. T. Nakasu, T. Okazumi, and Y. Shimizu, Development of local disaster preparedness indices for flood in Thailand – Case study in Ubon Ratchathani and Hat Yai, Journal of Thai Studies, The Japanese Society for Thai Studies, No. 12 : 65-81, 2012 (in Japanese).