BASIC STUDY ON FLOOD MANAGEMENT ASSESSMENT IN METRO MANILA, PHILIPPINES

By

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DEDICATIONS

To my ever supportive better half, Arni,

To my Loving Family

And to all my friends in TMU who have made my life as a doctor student a lot more worthwhile

You've guided me through, encouraged my efforts, endured and shared my failures, applauded my successes, and patiently waited for the culmination of this work, I am forever grateful.

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PREFACE

This dissertation is accomplished as partial fulfillment of my requirements in the doctor course in engineering at the Hydrology and Water Resources Laboratory of the Department of Civil and Environmental Engineering, Graduate school of Urban Environmental Sciences, Tokyo Metropolitan University from Oct. 2010 to Sept. 2013 under the supervision of Professor Akira Kawamura.

The materials in this dissertation are focused mainly on the basic study of flood management assessment in Metro Manila, Philippines, with emphasis on perception-based gaps assessment approach for flood disaster risk reduction management systems, and environmental impact assessment of structural flood mitigation measures. This dissertation is based mainly on 6 scientific articles that have undergone reviews and assessment in suitable internationally refereed journals. In addition, some parts of this research work have been presented in a number of domestic journals and international conferences.

This study was carried out as a part of the research project, “Solutions for the water-related problems in Asian metropolitan areas” supported by the Tokyo Metropolitan Government, Japan within the program “Asian Human Resources Fund”. The field data used in this study were provided by Woodfields Consultants, Inc., the Department of Public Works and Highways (Philippines) and the Metro Manila Development Authority.

The completion of this research work was not by mere personal achievement alone. This dissertation would not have been realized without the support and inspiration of my professors, colleagues and friends during my doctoral study. Thus, I would like to take this opportunity to express my sincerest gratitude to everyone who have unconditionally offered their time and expertise for the completion of this study.

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ABSTRACT

Flooding is the most frequent and damaging natural hazard worldwide. The resulting impact of flood disasters on society depends on the economic strength of the affected country prior to the disaster. The larger the disaster and the smaller the economy, the more significant is the impact. This is very clearly seen in developing countries, like the Philippines, where weak economies become much weaker after a devastating flood event. In 2009, tropical storm Ondoy, brought heavy rainfalls that produced destructive floods in the northern islands of the Philippines, leaving inconceivable damages, especially in Metro Manila, which caused the Philippine government to re-evaluate its decades' worth of flood management strategies.

Deliberate strategies for flood damage reduction, as well as environmental protection, may aid a country (or a community) to efficiently manage scarce resources for flood mitigation. Nevertheless, many governments lack an adequate institutionalized system for applying cost effective and reliable technologies for disaster prevention, early warnings, and mitigation, mainly due to lack of systematic and reliable flood management assessment strategies. In Metro Manila, important decision elements, such as stakeholders' perception and environmental protection are often overlooked in the development of sustainable flood mitigation plans. Stakeholders can significantly contribute in achieving the desired level of prevention and protection in flood disaster-prone regions. Knowledge of the local conditions and understanding of the public's perception can significantly help address the prioritization issues involved in flood management planning. However, the integration of the stakeholders' perception in the appraisal of flood management systems has not yet been clearly established. In the case of environmental protection, environmental impact assessment (EIA) can provide a certain level of awareness on the benefits of environmentally sound and sustainable urban development. However, the common practice of EIA in the Philippines is generally qualitative and lacks clear methodology in evaluating multi-criteria systems. A study that deals with flood management assessment in Metro Manila is thus necessary to find solutions that may help cope with these inadequacies.

This study focuses on the following main objectives: 1) to develop a heuristic analytical strategy that helps identify priority concerns in the flood management systems of Metro Manila using a perception-based appraisal, and 2) to develop a systematic and rational evaluation scheme that would help incorporate environmental assessment in the appraisal of flood mitigation measures. To achieve the first objective, an analytical assessment approach was developed to identify and analyze

the flood management gaps using the questionnaire-based stakeholders' perception obtained during the aftermath of the tropical storm Ondoy. For the second objective, a quantitative analytical approach was developed for EIA to further enhance the evaluation process in the planning of flood mitigation projects.

This dissertation is composed of six chapters:

Chapter 1 is the introduction, which contains the background, motivation, and objectives of this study. A comprehensive review of literature and a description of the scopes and methods were presented in this chapter.

Chapter 2 focuses on the performance of the flood management systems in Metro Manila. A brief description of the flood management systems used in Metro Manila, before and during the aftermath of tropical storm Ondoy, was provided. The nature and characteristics of the tropical storm, as well as its effects on the flood management systems, were presented in this chapter. A multi-criteria gap analysis technique was developed to examine the flood disaster risk reduction (FDRR) management systems, which is demonstrated using a questionnaire-based database to obtain an explicit representation of the systems' strengths and weaknesses. In this study, 14 out of 17 municipalities in Metro Manila were investigated. Results revealed that small to medium scale flood management gaps exist within the 14 assessed municipalities.

Chapter 3 further explores the potential of a multi-criteria gaps assessment technique in the evaluation of FDRR management systems in Metro Manila. Perception-based assessment is inherently vague and imprecise, which often operates in a fuzzy environment. To cope with this, a fuzzy-based analytical approach was proposed to handle the uncertainties in the evaluation process of flood management gaps. The new approach is demonstrated using the same database in Chapter 2. The results reveal that the municipal-based FDRR management systems in Metro Manila are insufficient in terms of flood disaster prevention, preparedness, response and recovery. Larger gaps were found in the emergency response mechanism of the disaster preparedness management system.

Chapter 4 deals with the EIA of nine planned structural flood mitigation measures (SFMMs) in Metro Manila. A modified rapid impact assessment matrix (RIAM) technique was proposed to systematically and quantitatively evaluate the socio-economic and environmental impacts of the planned SFMMs. The distribution of impacts of each SFMM was estimated for each environmental component of the 4 environmental categories. Based on the results, most of the negative and positive impacts of SFMMs occur during their construction and operation phases, respectively.

The modified RIAM approach provided a clear panoramic view of the environmental impacts of each assessed SFMM.

Chapter 5 presents a new EIA approach that provides enhancement to the modified RIAM technique in Chapter 4. A utility-based assessment approach using the RIAM technique, coupled with a recursive evidential reasoning approach, was proposed to rationally and systematically evaluate the ecological and socio-economic impacts of 4 planned SFMMs in Metro Manila. This new approach quantitatively characterized the overall impact of each of the planned SFMMs which can provide the means for benefit maximization and optimization. Results show that the overall environmental contributions of each of the planned SFMMs is generally positive, which indicate that the utility of their positive impacts would generally outweigh their negative ones. The results also indicated that the planned river channel improvements have higher environmental benefits than the planned open channels.

Chapter 6 presents the overall conclusions and recommendations for the assessment of flood management systems in Metro Manila, including the future research works.

PUBLICATIONS

This dissertation is mainly formulated based on six scientific articles as the main milestones of the study which were reviewed and assessed by globally refereed journals. In addition, the some parts of this work have been presented in a number of domestic journals and international conferences. The following list presents the publications which are either published, accepted, or under review.

Journal Publications

1*. R.L. Gilbuena, A. Kawamura, R.R. Medina, H. Amaguchi, N. Nakagawa. 2012. Multi-Criteria gap analysis of flood disaster risk reduction management in Metro Manila, Philippines. Journal of Japan Society of Civil Engineers, Ser. B1 (Hydraulic Engineering), No. 68, pp. I_109 – I_114.

2*. R.L. Gilbuena, A. Kawamura, R.R. Medina, H. Amaguchi, N. Nakagawa. 2013.Environmental assessment of flood mitigation structures in Metro Manila, Philippines using the rapid impact assessment matrix (RIAM) technique. Journal of Japan Society of Civil Engineers, Ser. B1 (Hydraulic Engineering), No. 69(4), pp. I_109 – I_114.

3*. R.L. Gilbuena, A. Kawamura, R.R. Medina, H. Amaguchi, N. Nakagawa. 2013. Gap analysis of the flood management system in Metro Manila Philippines: A case study of the aftermath of Typhoon Ondoy. International Association of Hydrological Sciences (IAHS) Publication, No. 357, pp. 32-40.

4*. R.L. Gilbuena, A. Kawamura, R.R. Medina, N. Nakagawa, H. Amaguchi, D.D. Bui. 2013. Environmental impact assessment of structural flood mitigation measures by a rapid impact assessment matrix (RIAM) technique. Science of the Total Environment, No. 456-457, pp. 137 - 147.

5*. R.L. Gilbuena, A. Kawamura, R.R. Medina, H. Amaguchi, N. Nakagawa. 2013. Fuzzy-based gaps assessment of the flood disaster risk reduction management systems in Metro Manila, Philippines: A retrospective analysis of the impacts of tropical storm Ondoy. Natural Hazards, Submitted.

6*. R.L. Gilbuena, A. Kawamura, R.R. Medina, N. Nakagawa, H. Amaguchi. 2013. Environmental impact assessment using a utility-based recursive evidential reasoning approach for structural flood mitigation measures in Metro Manila, Philippines. Journal of Environmental Management , Submitted.

7. T.T. Nguyen, A. Kawamura, T.N. Tong, N. Nakagawa, H. Amaguchi, R.L. Gilbuena. 2013. Hydrogeochemical assessment of groundwater quality during dry and rainy season for the two main aquifers in Hanoi, Vietnam. Environmental Monitoring and Assessment, Submitted.

International Conference Publications

1*. R.L. Gilbuena, A. Kawamura, R.R. Medina, H. Amaguchi. 2011. Gap analysis of the flood management system in Metro Manila, Philippines: A case study in the aftermath of Typhoon Ondoy. Proceedings of the 5th International Conference on Flood Management (ICFM5), Tokyo, Japan, September 2011, CD-ROM.

2*. R.L. Gilbuena, A. Kawamura, R.R. Medina, N. Nakagawa, H. Amaguchi. Assessment of the flood forecasting and warning systems in Metro Manila, Philippines. Proceedings of the IHP Symposium on Extreme Events : "Meteorological, Hydrological and Tsunami Disasters: Social Adaptation and Future", Kyoto, Japan. October 2010, pp. 72 – 29.

3*. R.L. Gilbuena, A. Kawamura, R.R. Medina, N. Nakagawa, H. Amaguchi. 2012. Water quality assessment during river channel alteration for flood mitigation in Metro Manila, Philippines. Proceedings of the World Environmental & Water Resources Congress 2012, Albuquerque, U.S.A. May 2012, pp.580-591.

4*. R.L. Gilbuena, A. Kawamura, R.R. Medina, N. Nakagawa, H. Amaguchi. 2012. Assessment of management gaps in the flood mitigation and flood preparedness strategies in Metro Manila, Philippines. Proceedings of the International Conference on Water Resources, Langkawi, Malaysia., November 2012, ID: 189.

5*. R.L. Gilbuena, A. Kawamura, R.R. Medina, N. Nakagawa, H. Amaguchi. 2013. Environmental impact assessment of structural flood mitigation measures in Metro Manila, Philippines using an analytical evidential reasoning approach. Proceedings of the 6th International Conference on Water Resources and Environment Research, Koblenz, Germany, June 2013, p. 293.

6. T.T. Nguyen, A. Kawamura, T.N. Tong, N. Nakagawa, H. Amaguchi, R.L. Gilbuena, 2013. Temporal changes in the hydrochemical facies of ground water in two main aquifers in Hanoi, Vietnam. Proceedings of the 6th International Conference on Water Resources and Environment Research, Koblenz, Germany, June 2013, p. 369.

Domestic Conference Publications

1. R.R. Bituin, I.G.Q. Galang, R.L. Gilbuena, R.V. Tolentino. Comparison of bioactive contents of the different parts of selected ornamental plants. Angeles University Foundation – College of Arts and Sciences Digest, Angeles City Pampanga, Philippines, June 2004. Vol. IV, No. 3, pp. 256 – 276.

2. C.A. Arbontante, E.M. Bamba, R.D. Bundalian, C.L.B. Cunanan, M.R.Y. Espino, R.L. Gilbuena, I.P. Herrera, C.D. Liwanag, D.J.S Manlapaz, C.M. Samson, P.B. Tagarro, R.V. Tolentino, P.D. Victoria. 2004. Physico-chemical and bacteriological analysis of water samples obtained from selected sources in Angeles City. Angeles University Foundation - College of Arts and Sciences Digest, Angeles City, Pampanga, Philippines, June 2004, Vol. IV, No. 3, pp. 277 – 304.

3. R.R. Bituin, I.G.Q. Galang, R.L. Gilbuena, R.V. Tolentino, 2005. Bioautographic analysis of the different parts of selected ornamental plants. Angeles University Foundation - College of Arts and Sciences Digest, Angeles City, Pampanga, Philippines, June 2005, Vol. IV, No. 4, pp. 240 - 255.

4. M.R.Y. Espino, C.A. Arbotante, R.R. Bituin, R.L. Gilbuena, E.L. Goce, I.P. Herrera, M.C. Oronce, 2005. Phytochemical screening of selected indigenous plants in Zambales. Angeles University Foundation - College of Arts and Sciences Digest, Angeles City, Pampanga, Philippines, June 2005, Vol. IV, No. 4, pp. 97 – 111.

5*. R.L. Gilbuena, A. Kawamura, R.R. Medina, H. Amaguchi, N. Nakagawa. 2011. Urban flood in the Philippines: an overview of the flood management in Metro Manila sub-basins during and after the experience with TS Ketsana. Proceedings of the 38th Kanto Branch Annual Conference of JSCE. March 2011. CD-ROM: II-42.

6*. R.L. Gilbuena, A. Kawamura, R.R. Medina, H. Amaguchi, N. Nakagawa. 2011. Structural flood mitigation in Metro Manila : Consequences and implications on urban flood and the environment. Proceedings of the 2011 Annual Conference of Japan Society of Hydrology and Water Resources, Kyoto, Japan. August 2011, pp. 16-17.

7. T.T. Nguyen, A. Kawamura, H. Amaguchi, N. Nakagawa, R.L. Gilbuena, 2012. An overview of groundwater in Hanoi, Vietnam, Proceedings of the 39th Kanto Branch Annual Conference of JSCE, March 2012, CD-ROM : II – 16.

8*. H. Yamaji, A. Kawamura, R.L. Gilbuena, H. Amaguchi, N. Nakagawa, 2012. Multi-criteria gap analysis of flood disaster risk reduction management in Metro

Manila, Philippines. Proceedings of the 39th Kanto Branch Annual Conference of JSCE, March 2012, II-41.

9*. R.L. Gilbuena, A. Kawamura, R.R. Medina, H. Amaguchi, N. Nakagawa. 2012. Rapid impact assessment of structural flood mitigation measures in Metro Manila, Philippines. Proceedings of the 2012 Annual Conference, Japan Society of Hydrology and Water Resources, Hiroshima, Japan. September 2012, pp. 68-69.

10*. R.L. Gilbuena, A. Kawamura, R.R. Medina, H. Amaguchi, N. Nakagawa. Environmental sustainability of structural flood mitigation measures in Metro Manila, Philippines. Proceedings of the 2013 Annual Conference, Japan Society of Hydrology and Water Resources, Kobe, Japan. September 2013, Submitted.

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CHAPTER 1

INTRODUCTION

1.1. Background and motivation

1.1.1. Flood management assessment as a key process in sustainable urban development

Flooding is the most frequent and damaging natural hazard worldwide (Esteves, 2013). It is a significant environmental threat that can cause loss of human life, damage to infrastructures, disruption to economic activities, and decline in ecological resources in river basins and coastal areas (Carrasco et al., 2012). By realizing the complex nature of flood disasters and its impacts to urban development, many countries have increasingly committed themselves to develop integrated flood management approaches to address the flood risks management as well as the economic, social, and environmental effects of different flood mitigation measures (Xia and Pahl-Wostl, 2012). As a consequence, public expenditure to control floods and compensation paid for damages are also increasing, which pushes many governments to look for more efficient flood management approaches (Erdlenbruch et al., 2009).

In recent years, climate related flood disasters are becoming more and more devastating. In 2005, the catastrophic flooding in the United States after hurricane Katrina caused enormous economic damage, which was estimated at 90 billion US dollars (Jonkman et al., 2008). It is widely believed that climate change will likely increase the severity and frequency of flood events (Mazzarona et al., 2012; Kundzewicz et al., 2005), thus increasing its associated hazards. However, man made changes in river hydrology and land use, and increased development in areas at risk of flooding, can also significantly contribute to increased flood hazard (Carter et al., 2009). This may threaten existing flood mitigation measures that were mostly implemented prior to the knowledge of climate change impacts, and thus may require modification to ensure their sustainability (Scholz and Yang, 2010). For example, in the United Kingdom, a recent climate change projection indicated a 40-160 mm increase in precipitation in the east coast, and 285-1200 mm increase in the west coast of Scotland. Recognizing the adverse impacts of flooding as a policy and priority, the United Kingdom government has therefore doubled its flood defense spending since 1997 (McMinn et al., 2010).

Developing countries however have smaller, more vulnerable economies, and thus are affected in a much severe way when flood disaster strikes (Hansson et al., 2008). In the Philippines, in 2009, tropical storm Ondoy severely affected Metro Manila (the country’s economic center) which left the megacity with almost 500 casualties and an estimated damage amounting to 240 million US dollars (Gilbuena et al., 2013).

Efforts for flood mitigation in Metro Manila have been on-going since the 1950s, and several large-scale flood mitigation measures (both structural and non-structural) are being put in place since the 1970s (Fano, 2000). The flood disaster in 2009 proved that the existing flood management systems in Metro Manila are not adequate to cope with the damaging effects of extreme flood events, such as the one caused by tropical storm Ondoy. Evidently, there is a need to re-evaluate Metro Manila’s flood management systems, but would require deliberate strategies to obtain rational assessment, which could help ensure the sustainability of its urban development.

1.1.2. Problem statement and literature review

1.1.2.1. Gaps assessment of flood disaster risk reduction management systems

The flood disaster risk reduction (FDRR) management system of Metro Manila, Philippines was challenged when a rare meteorological event, locally known as typhoon Ondoy, occurred on 26 September 2009. The storm largely inundated more than one-third of Metro Manila, putting a large number of urban and flood control structures under water (Gilbuena et al., 2013).

During Ondoy's aftermath, a post-disaster needs assessment was carried-out to estimate the damages, losses and economic and social impacts of the typhoon. The post-disaster needs assessment also identified and qualitatively assessed the constraints in the FDRR management system of Metro Manila, particularly those found in land use planning, housing, water management and disaster mitigation (The World Bank, 2011). Quantitative gaps analysis can help identify priority FDRR management tasks and priority flood prone areas, which are valuable in the formulation of a strategic FDRR management improvement plan.

In a management perspective, constraints or *gaps* represent the "space between where we are and where we want to be" (Rueckert et al., 2011). Liedtka (1998) described gap analysis as a time-based intent-driven strategic planning technique that uses historical information and desired outcomes as bases for improvement. Thus, gaps analysis is both fact-based and goal-oriented, which makes it a powerful technique in the development and improvement of management systems.

The quantitative evaluation of gaps has recently been re-adopted in various areas of scientific studies. Different approaches to gaps assessment have been proposed, but most still follows the same basic principle. For instance: Oldfield et al. (2004) used gaps analysis to assess the extent at which a protected area system meets its protection goals (set by a nation or region), which typically involves a spatial comparison of biodiversity within the existing and planned protected areas; Currie et al. (2010) used gap analysis to measure the spatial distribution of public transport needs to identify the constraints in the quality of public transport provisions; Zhang et al. (2007) used the concept of gap analysis to identify the affecting factors in collaborative product development process systems by means of performance-based assessment. Despite its wide applicability, quantitative gap analysis has never been used in the evaluation of FDRR management systems. Most of the FDRR studies mainly concentrated on the effects of hydrological processes (e.g. Chen and Yu, 2007). This dissertation however focused on the implementation of the FDRR management system and the evaluation of its constraints to identify priority tasks and priority areas in aid of developing an effective FDRR management plan, using Metro Manila as a case study.

The FDRR management systems of Metro Manila consist of several FDRR measures that require simultaneous gap evaluation. To cope with this, gaps analysis, combined with a multi-criteria decision analysis (MCDA) approach, was used. MCDA is widely regarded for its robust applicability in various fields of studies. For example, Corsair et al. (2009) used MCDA to quantify non-economic objectives in the study of stream restoration; Ceccato et al. (2011), used MCDA to assess the flood risk adaptation strategies in the Upper Brahmaputra and Danube river basins in Asia and Europe; Borges and Villavicencio (2004) applied MCDA in the study of costs and impacts to abate greenhouse gases in Peru; Ambrasaite et al., (2011) used MCDA in the appraisal of transport infrastructures in the Baltic countries and Poland; Zhang et al. (2007) employed MCDA to assess the factors that affect product development in web-based collaboration; and Wu et al. (2010) used MCDA to carry out a regional vulnerability assessment of sediment disasters for the development of a disaster risk reduction plans in Central Taiwan. The use of gaps analysis combined with MCDA approach, however, is still not well explored in the literatures.

1.1.2.2. Environmental appraisal of structural flood mitigation measures

Structural flood mitigation measures (SFMMs) are regarded as major infrastructure works that have significant roles in the sustainable development of flood-prone urban centers (Kundzewicz, 1999). In view of the effects of climate change, many key cities in Southeast Asia (e.g. Jakarta in Indonesia, Bangkok in Thailand and Metro Manila in the Philippines), have been put to higher risks from more devastating floods, thus making SFMMs valuable and preferable among flood management schemes (Muto et al., 2010). SFMMs are primarily designed to significantly reduce the risks of disasters and optimize developmental benefits in flood-prone areas. However, SFMMs could still generate negative impacts that may affect the natural hydrology and ecological processes (World Meteorological Organizaton, 2010) of the receiving environment. The conduct of environmental impact assessment (EIA) during the early planning stages is thus necessary.

Faced with urgency and limited resources (Shah et al., 2010), decision-makers would need to seek the appropriate EIA techniques to formulate the necessary actions based on informed decisions. In the Philippines, EIA is being carried out mandatorily on planned SFMMs. The EIA methods commonly used are generally descriptive and qualitative in nature (Oldfield et al., 2004). These methods are similar to the EIA techniques (i.e. adhoc and simple checklist methods) described by Lohani et al. (1997). The ad hoc method is a non-structured approach that generally relies on the "experience, training and intuition" of the assessing expert. The problem with the ad hoc method is that it generally fails to provide the means to meaningfully organize considerable amounts of information about the biophysical, social and economic environment. It merely describes the pertinent information of the impacts without much regard to its importance and magnitude. This process of assessment is non-replicable, thus making the EIA conclusions difficult to review or even criticize.

The simple checklist approach, compared with the ad hoc method, is more structured, elaborative and more systematic. It typically displays a list of environmental parameters that are evaluated against a set of assessment criteria (Lohani et al., 1997). This method, however, fails to provide the necessary guidelines on how the impacts should be measured and interpreted (Lohani et al., 1997), which essentially precludes the transparency of the whole process (Pastakia and Jensen, 1998). According to Villaluz (2003), one way to advance the EIA system in the Philippines is to select methods that can provide better transparency to help “maintain the impartiality of the entire EIA process”.

An EIA that provides for the quantitative analysis of subjective judgments can help address the limitations of the two traditional EIA methods mentioned above (Ijas et al., 2010). Such concepts are fundamental in the rapid impact assessment matrix (RIAM) technique. The RIAM technique is a semi-quantitative impact assessment approach that utilizes standardized evaluation criteria and rating scales (Pastakia and Jensen, 1998). It has been favored in many case-studies by various development sectors primarily due to its simplicity and robust applications, such as in the EIA of solid waste disposal facilities in Varanasi India (Mondal et al., 2010) and Russeifa, Jordan (El-Naqa, 2005); EIA of oil spill in desalination plans in Abu Dhabi City, UAE (Al Malek and Mohamed, 2005); and environmental assessment of water resources in Ghana (Yeboah et al, 2005).

In spite of its numerous applications, there has been no reference, as far as the authors know, of its application in the EIA of SFMM in any part of the world. In the Philippines, however, it has never been used for any type of project. The Philippines can benefit from adopting this technique, thus it is imperative to provide references of its application using a local SFMM project as a case study. It is necessary however to ensure the conformity of the RIAM method with the general impact assessment approach prescribed in the Philippine EIA system.

1.2. Objectives, scope and methods

Given the above-mentioned concerns, this dissertation focuses on the following main objectives: 1) to develop an analytical strategy that can help identify priority concerns in the flood management systems of Metro Manila using a perception-based appraisal, and 2) to develop a systematic and rational evaluation scheme that would help incorporate environmental assessment in the appraisal of structural flood mitigation measures.

For the first objective, a gap analysis approach using MCDA was developed to address the needed assessment of FDRR management systems in Metro Manila. The MCDA approach was used to identify, organize and quantify the desired state of the FDRR measures. The criteria (FDRR phases) and sub-criteria (FDRR measures) of Metro Manila's flood management systems were enumerated and were given weighting factors based on priority rankings. The gaps were quantified using equivalent weight values and performance scores (translated using the questionnaire-based appraisal of selected stakeholders) of the FDRR measures. Priority tasks and priority areas in the FDRR management system have been identified, using the relationship: *bigger gaps means higher priority*. The multicriteria gap analysis method produced clear results that can be used to propose strategic improvements in the FDRR management plan of Metro Manila.

For the second main objective, this study explores the benefits of using the RIAM technique in the evaluation process of SFMM by examining the results of the EIA of selected planned SFMM in Metro Manila. Furthermore, modifications were made on the RIAM technique not only to enhance the transparency and sensitivity of the evaluation process, but also to cope with the requirements of the EIA system in the Philippines. These modifications are intended to improve the outcome of the EIA, but may also find application in other infrastructure projects. The impacts of selected planned SFMM were analyzed for possible environmental mitigation. This study also offers recommendations and conclusions with the aim of providing valuable insights for decision makers, planners and policy-makers for the improvement of the EIA system for SFMM in the Philippines.

1.3. Outline of the dissertation

This dissertation is composed of six chapters:

Chapter 1 is the introduction, which contains the background, motivation, and objectives of this study. A comprehensive review of literature and a description of the scopes and methods were presented in this chapter.

Chapter 2 focuses on the performance of the flood management systems in Metro Manila. A brief description of the flood management systems used in Metro Manila, before and during the aftermath of tropical storm Ondoy, was provided. The nature and characteristics of the tropical storm, as well as its effects on the flood management systems, were presented in this chapter. A multi-criteria gap analysis technique was developed to examine the flood disaster risk reduction (FDRR) management systems, which is demonstrated using a questionnaire-based database to obtain an explicit representation of the systems' strengths and weaknesses.

Chapter 3 further explores the potential of a multi-criteria gaps assessment technique in the evaluation of FDRR management systems in Metro Manila. A fuzzy-based analytical approach was proposed to handle the uncertainties in the evaluation process of flood management gaps. The new approach is demonstrated using the same database in Chapter 2.

Chapter 4 deals with the EIA of planned structural flood mitigation measures (SFMM) in Metro Manila. This chapter proposes the use of the RIAM technique to systematically and quantitatively evaluate the socio-economic and environmental impacts of planned SFMM in Metro Manila. The RIAM technique was slightly modified to fit the requirements of this study.

Chapter 5 presents a new EIA approach that provides enhancement to the modified RIAM technique in Chapter 4. A utility-based assessment approach using the RIAM technique, coupled with a recursive evidential reasoning approach, was proposed to rationally and systematically evaluate the ecological and socio-economic impacts of 4 planned SFMM projects in Metro Manila. This new approach is aimed to quantitatively characterize the overall impact of each planned SFMM which can provide the means for benefit maximization and optimization.

Chapter 6 presents the overall conclusions, recommendations for the flood management assessment in Metro Manila, including the future research works.

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CHAPTER 2

BASIC GAPS ASSESSMENT OF FLOOD DISASTER RISK REDUCTION MANAGEMENT SYSTEMS IN METRO MANILA

2.1. Background of the study

2.1.1. Tropical storm Ondoy

Tropical storms are intensely energetic transient weather systems that develop over regions of a very warm ocean surface, usually within 30^0S to 30^0N of the equator (Rasmusson et al, 1993). Most tropical storms, as illustrated by McDonald et al. (2005), originate from the Pacific and Indian oceans and occur during the first half of the year in the areas north of the equator (0^o to 30^oN), and second half of the year in the areas south of the equator (0^0 to 30^0S). The cost of damage caused by tropical storms both in terms of lives and economic losses can be devastatingly high, and changes to tropical storm patterns due to climate change can have overwhelming impacts to modern societies, especially in the megacities of developing countries (Braun and Aβheuer, 2011). The World Bank (2010) identified several megacities in the tropical region, including Metro Manila in the Philippines, which lies between $14^0$23'N and $14^0$44'N of the equator, as highly vulnerable to the consequences of extreme meteorological events, particularly floods. Metro Manila experiences 6 - 10 tropical cyclones every year, usually during the months of July to September.

The tropical depression Ondoy was first detected on 24 September 2009 near the east of Luzon. It intensified into a tropical storm in September 25. Fig. 2-1 shows the typhoon track of Ondoy as it traveled from east to the west of Luzon. The storm's maximum center wind was at 105 km/h, gustiness of around 135 km/h, and movement speed from 11 to 19 km/h.

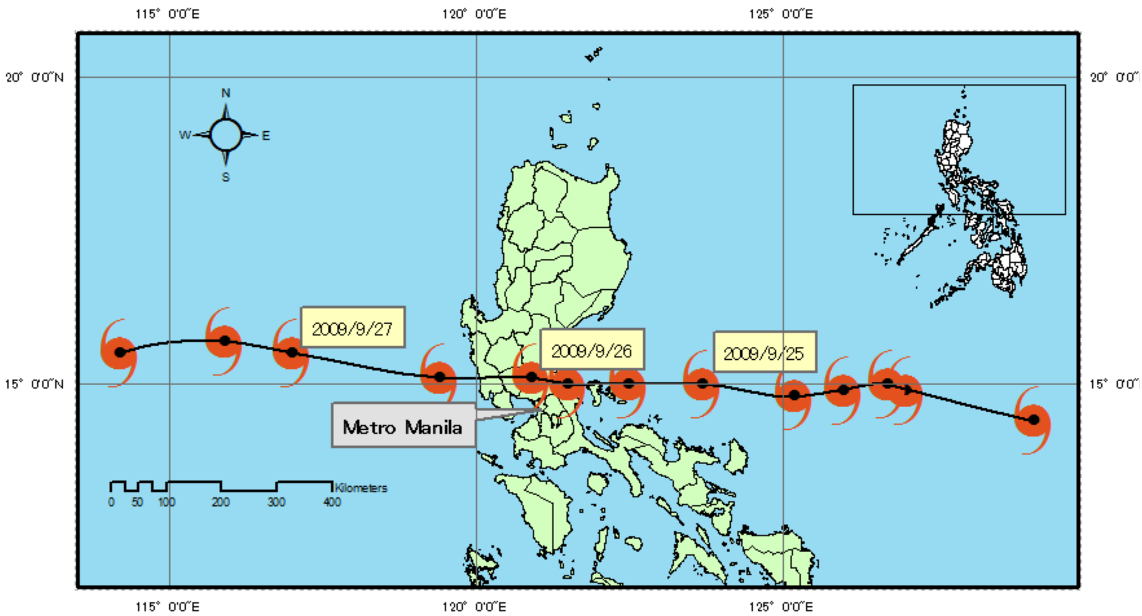

Fig. 2-1 Typhoon track of typhoon Ondoy (*data source: PAGASA*)

To further characterize tropical storm Ondoy's strength in terms of rainfall in Metro Manila, the return periods of the maximum 1-h and daily rainfall depths at the Science Garden station were estimated using Gumbel Distribution (Stedinger et al., 1993). Fig. 2-2 shows the plot of the estimated return periods for the maximum 1-h, 12-h and daily rainfall depths as recorded at the Science Garden weather station. The plots were acceptable at a significance level of 5% using the Kolmogorov-Smirnov test. Results indicate that Ondoy's rainfall return periods in 26 September 2009 for the 1-h, 12-h and daily rainfall depths were 50 years, 130 years and more than 400 years, respectively. The large disparity between the return periods implies that Ondoy's impacts were much higher, and that the possibility of devastatingly high water accumulation was much greater at longer rainfall duration.

The authors carried out field interviews and surveys on November 11 to 13, 2009 within Metro Manila to determine the extent and maximum depths of the inundation created by typhoon Ondoy. Fig.2-3 reveals that a third of the metropolis has been inundated at depths ranging from less than 1 m to more than 5 m, with

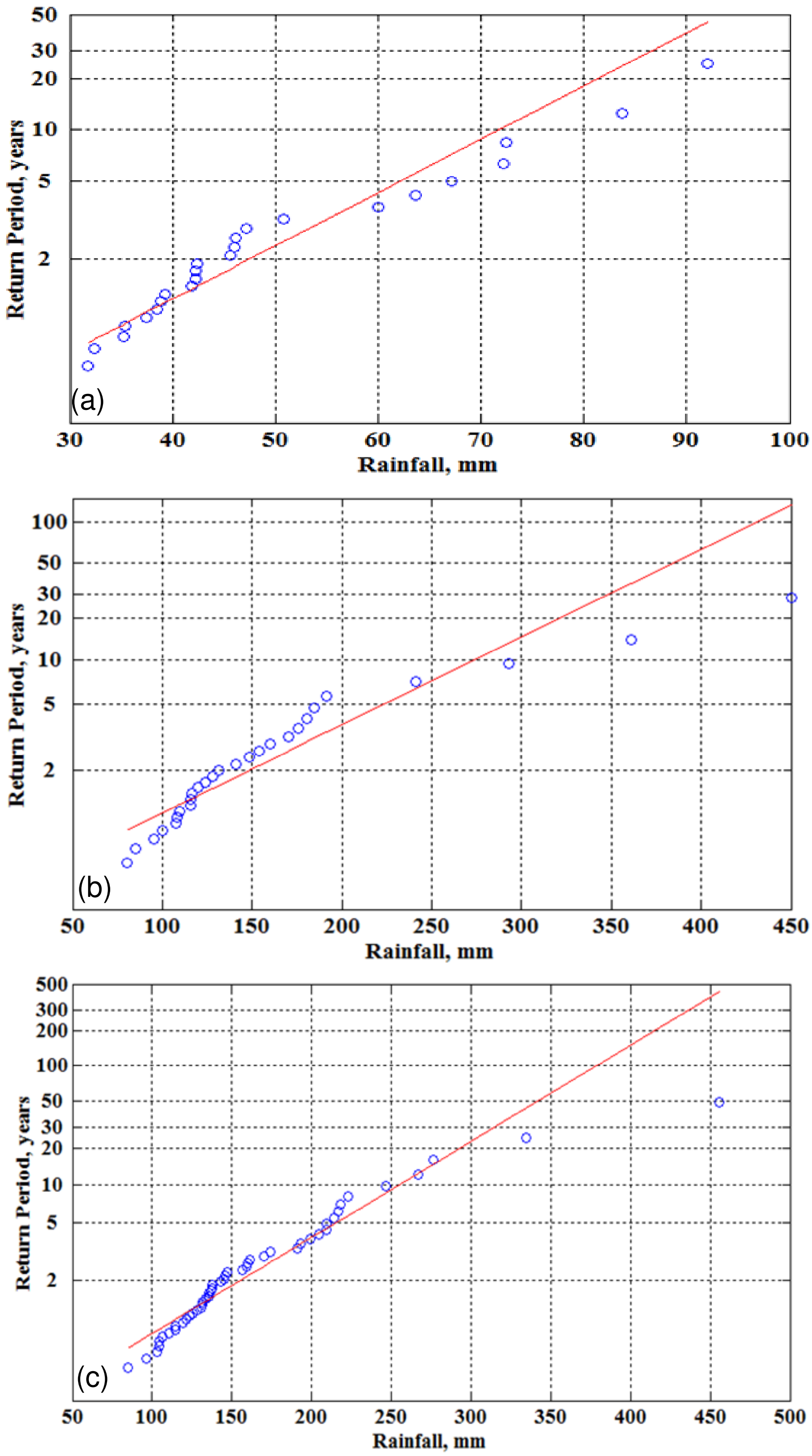

Fig. 2-2 Return period of the annual maximum (a) 1-h, (b) 12-h and (c) daily rainfall in Science Garden

duration of 3 to 8 hours in most of the affected areas. High inundation occurred

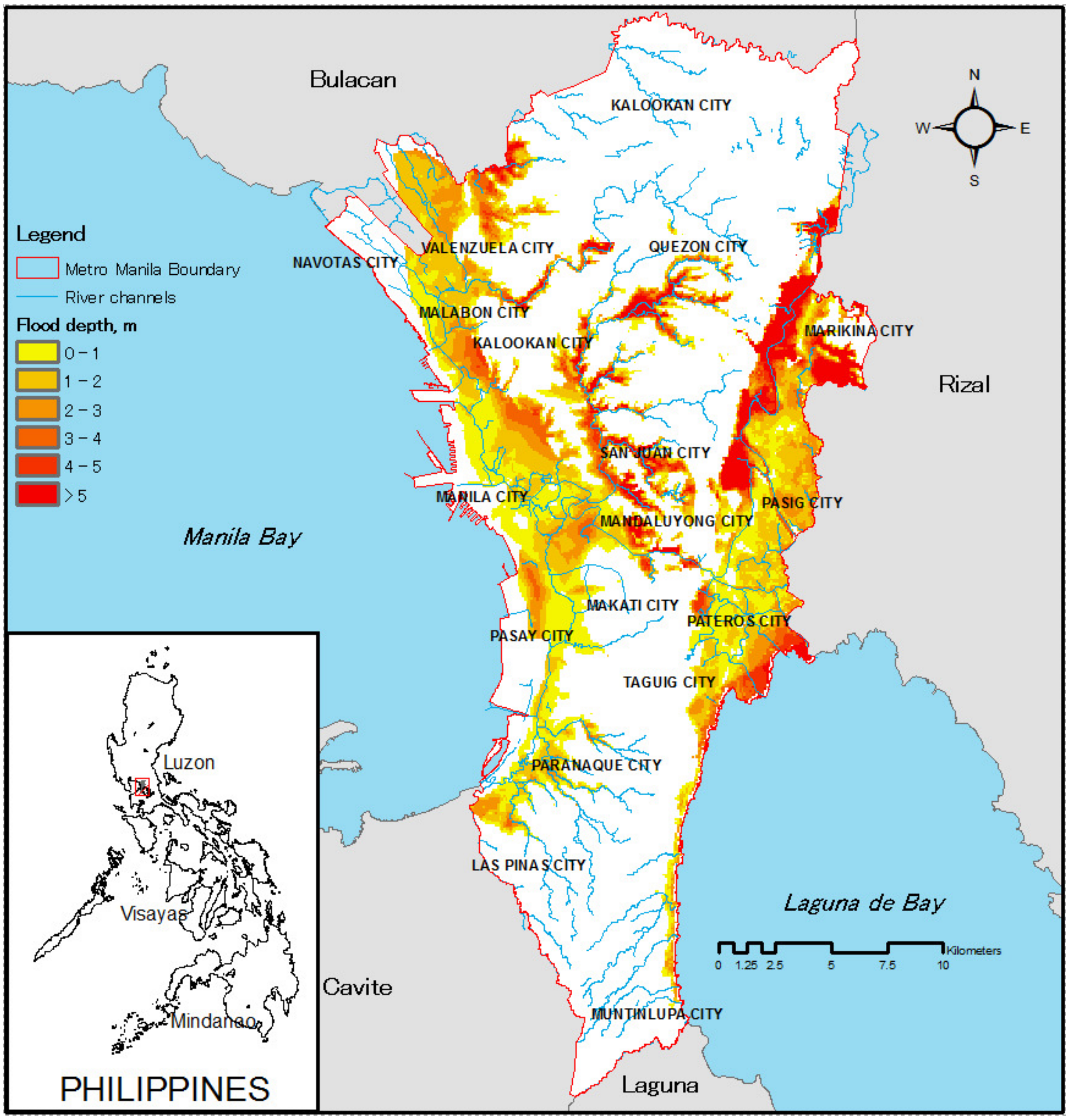

Fig. 2-3 Location of Metro Manila with maximum inundation depths during typhoon Ondoy

mostly near the banks of the Marikina and San Juan channels. The inundation in Pateros and Taguig City near the shores of Laguna de Bay Lake can be attributed to the lake's water level increase during the storm.

2.1.2. Descriptive assessment of flood disaster risk reduction management systems in Metro Manila

2.1.2.1. Flooding and flood control structures in Metro Manila

Flood has been observed in Metro Manila, particularly in Manila City, in as early as the eighteenth century. However, flood mitigation was initiated only during the early part of the 20th century, where storm drains were incorporated in the design of main roads (Liongson, 2000). In 1952, a comprehensive study of the drainage system of Manila City and its suburban areas was completed (Fano, 2000). The improvement of the drainage systems (i.e. channel dredging, river widening, river training works, etc.) since then became the main measure for flood mitigation. Construction of large scale flood control structures (i.e. large-scale weirs, large-scale flood gates and high capacity pumping stations) was started only in the early part of the 1980s. Further developments for flood mitigation are still being continued under the construction projects of the Department of Public Works and Highways (1998) and flood risk reduction programs of the Metro Manila Development Authority (n.d.). According to the MMDA, the flood prone areas of Metro Manila have been reduced from 20% of Metro Manila's total land area in 2002 to about 4% in 2008. However, the flood created by tropical storm Ondoy in 2009 covered at least 34% of the metropolis. The sudden increase in the flooded areas in 2009 indicates that the flood control structures collectively performed poorly during this event. These structures were overwhelmed by the onrushing floods, mainly because most of the structures were designed using 10 and 30 years discharge return periods for the drainage works and flood protection works (i.e. protection from river overflow) respectively (Gatan, 2009). It is surmised that Metro Manila did not have the capability to prevent flooding due to tropical storm Ondoy, but the risks to the population could have been reduced by proper implementation of non-structural flood mitigation measures, such as accurate flood forecasting and flood warning combined with an effective emergency response.

2.1.2.2. Flood forecasting

The Philippine Atmospheric, Geophysical and Astronomical Services Administration (PAGASA) is the primary source of information for storm intensity and possibility of floods in Metro Manila. However PAGASA's forecasting capability in 2009 was limited only to the following: prediction of the storm's intensity (i.e. wind speed, gustiness, etc.); prediction of floods in certain river basins using rainfall depths and water levels; and giving real-time updates on the status of major dams for possible water release and flash floods. It also does not have the technology to estimate the amount of rainfall before intense precipitation. Specifically, PAGASA's flood forecasting system includes: a) basin flood forecasting, and b) flood forecasting and flood warning system for dam operation (FFWSDO). For the basin flood forecasting, only four river basins in Luzon were being monitored, which unfortunately does not include Metro Manila. On the other hand, the FFWSDO covers four major dams in Luzon, but again, does not include the major flood prone areas of Metro Manila. As a matter of fact, the dams that are being monitored by PAGASA had no significant contribution to the flooding in September 2009.

The other flood forecasting system in Metro Manila is the Effective Flood Control Operation and Warning System (EFCOS) whose components are installed in the Marikina, Pasig and San Juan river basins, as shown in Fig. 2-4. The EFCOS was originally installed in 1978, improved in 1993 and rehabilitated in 2001. The main purpose of EFCOS is to reduce the occurrence of floods in the cities of Marikina, Pasig, San Juan and Manila (Fig. 2-1) through the operation of its weirs (at the Rosario station) and hydraulic control structure (at the Napindan station) that are aided by a water level forecasting system. Fig. 2-4 shows the location of 9 rain gauge stations and 11 water level gauging stations within the Pasig basin, San Juan basin and Marikina basin. All rain gauge stations are monitored and maintained by the PAGASA. The water level gauging stations are monitored and maintained by the

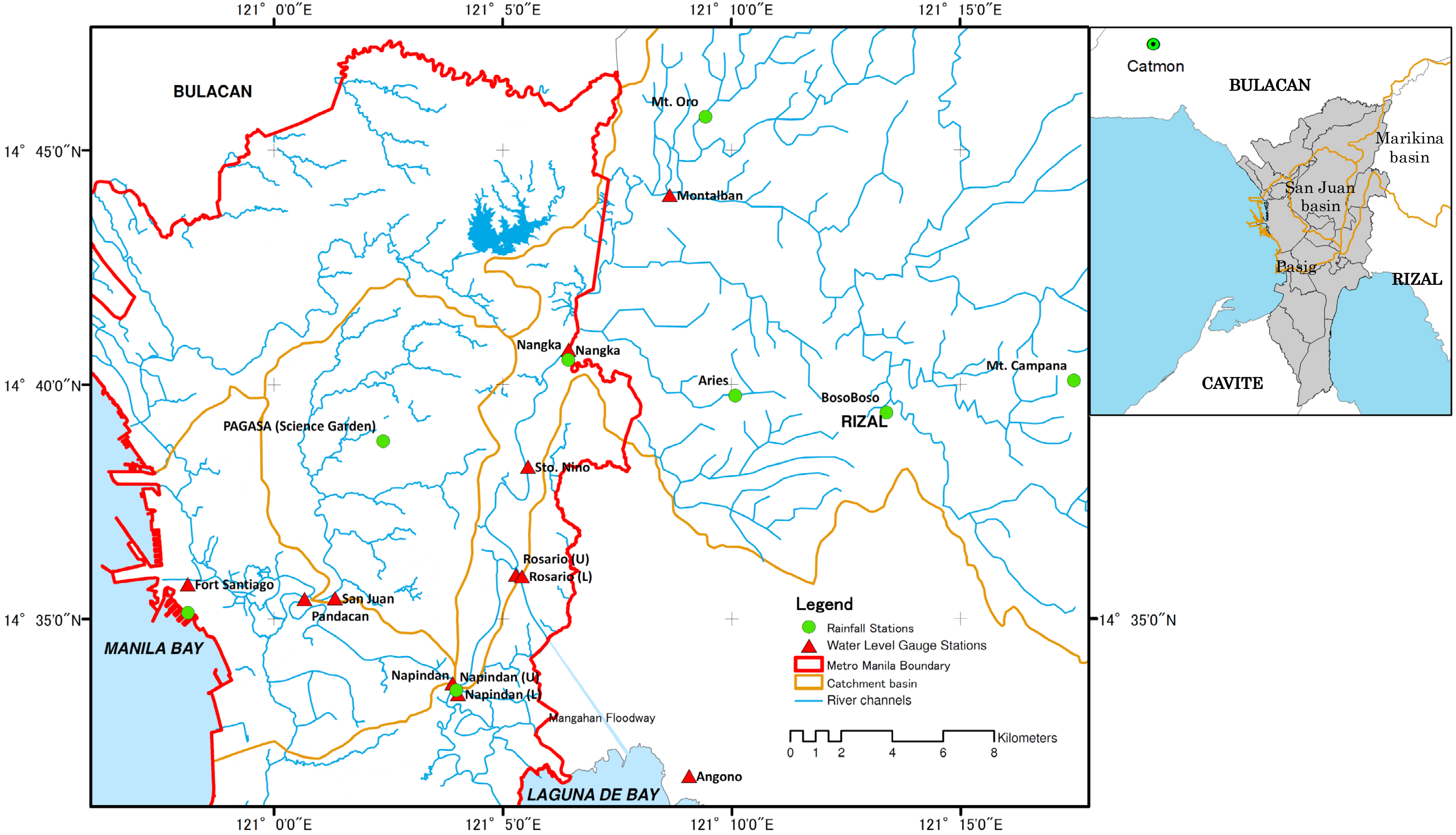

Fig. 2-4 Location map of rainfall and water level gauging stations (*information source: PAGASA and EFCOS*)

MMDA. EFCOS is also designed to prevent channel overflow in the east and west banks of the Manggahan floodway (DPWH, 2009).

The forecasting capability of EFCOS is embedded in its data processing system located at the control station near the Rosario rainfall gauge station. Real-time rainfall depths and water level data are used for flood simulation (updating every 10 mins) through a telemetry system that connects the rain gauges in Mt. Campana, Mt. Oro, Boso-boso, Aries, Nangka, Science Garden and Napindan; and the water level gauges in Montalban, Nangka, Sto. Niño, Rosario, Napindan, Angono, Pandacan, and Fort Santiago (Fig. 2-4). The operation of the Rosario weir, which opens to the Manggahan floodway, is based on the predicted water level at the Sto. Niño water level gauging station. Fig. 2-5 shows the hyetographs and water level graphs of selected rainfall and water level gauging stations located at the upper stream, middle stream and lower streams of EFCOS. When the water level at the Sto. Niño station is predicted to reach 15.2 m, with corresponding tidal level of 11.4 m in Manila Bay (Badilla, 2008), the gates at the Manggahan floodway should be opened to redirect some of the water towards the Laguna de Bay Lake. Unfortunately, the operation of the flood forecasting system has been stopped in 2006 due to "budget constraints". Since then, only the water levels and rainfall depths are being monitored, but are not used to predict floods. Thus, Metro Manila essentially had no operational flood forecasting system when tropical storm Ondoy came. On 25 September 2009, rain started to occur at around 6PM to 12AM; and on 26 September 2009 at around 3 A.M., the water level at the Sto. Niño station reached a level of 15.27 m (Fig. 2-5) with a level of 11.83 m in Fort Santiago (the water level gauging station close to the river mouth near Manila bay), but the gates at the Manggahan floodway was not immediately opened. The rains continued at around 7AM of September 26, and further intensified until 12PM. Consequently, the water rose to at least a height of 21.6 m at the Sto. Niño station, and the water level at the Rosario weir exceeded the

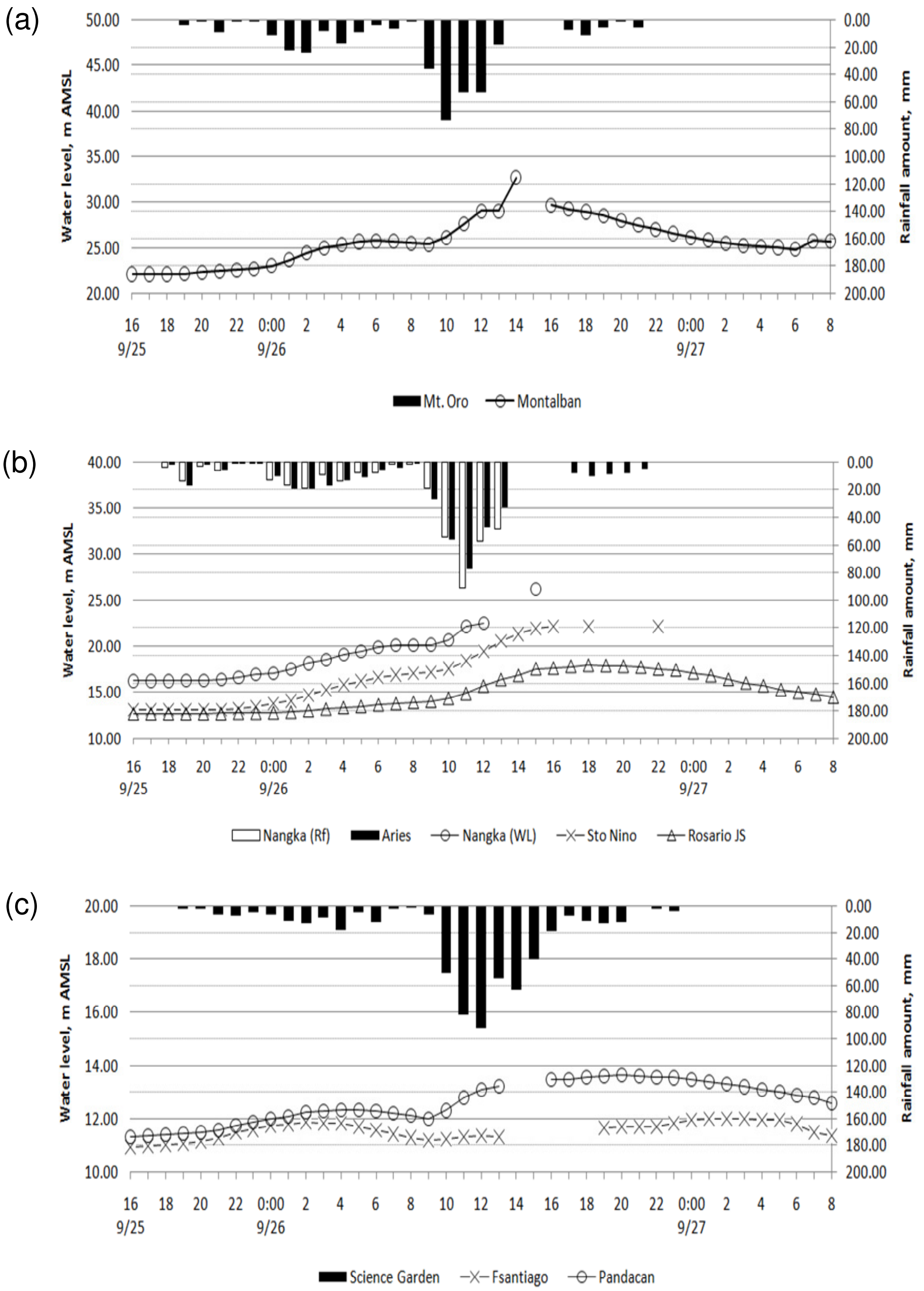

Fig. 2-5 Hyetographs and water level graphs representing the a) upper stream, b) middle stream, and c) lower stream of the EFCOS (*Data Source: PAGASA, EFCOS*)

normal level by at least 5m which may have caused the very high inundation at the upper stream of EFCOS, within Marikina City.

The main gap in this situation is the absence of an effective flood forecasting system, which was due to lack of an operational data processing system. In addition, the “breaks” or missing data in the water level graphs of Montalban, Nangka, Sto. Niño, Pandacan and Fort Santiago stations indicate that there were interruptions in the operation of the water level sensors. Based on a key informant interview at EFCOS, these interruptions were caused by the submergence of the water level sensors during the typhoon, which indicates a gap in the planned monitoring operation of the water level since the sensors were not designed to be high enough to measure all of the water level increase caused by tropical storm Ondoy.

The rainfall stations of EFCOS, though continuously operational, have stopped sending real-time information to PAGASA since 2006 due to a damaged link between them. This link has not been re-established up to the time when typhoon Ondoy came. Thus, a flood warning based on these data was not released by PAGASA during the storm.

2.1.2.3. Flood warning systems

Flood warning systems usually go hand-in-hand with forecasting systems. In the case of Metro Manila, PAGASA issues warning information about possible flooding via the local media (i.e. radio, television and internet). The warning released by PAGASA is usually not based on hydrological simulation. On 25 September 2009, PAGASA issued a flood bulletin for the whole of Metro Manila during typhoon Ondoy on the basis of storm warning signals (i.e. wind speed of the storm). Accurate prediction of the location and extent of flooding was not available. Since the issuance of flood bulletins relies heavily on PAGASA, one of the gaps that need to be filled in is the data processing and flood simulation capability. Although EFCOS has a built-in warning system, these are installed only along the east and west banks of the Manggahan Floodway. The warning system of EFCOS consists of speakers (megaphones) and radios. These are activated when the Rosario weir is about to be opened. A message announcing the release of water is sent to all the nine warning stations along the Manggahan floodway. However, since the EFCOS is no longer operational, the warning system was also not used during typhoon Ondoy. Clearly, the gap that exists here is the absence of an effective warning system. Advanced warning systems do not exist in other flood-prone areas; however, community-based early warning systems are adopted by some small communities as a means to cope with frequent flooding. Here, water levels of rivers are directly observed by locally-based volunteers. When the water level of a river reaches a critical height, warning is sent throughout the community by means of megaphones, sirens and/or church bells. This practice has been proven useful by several small communities during typhoon Ondoy.

2.2. Semi-quantitative multi-attribute gaps assessment

People are often faced with problems having multiple objectives and conflicting requirements. To simplify decision-making, critical aspects is usually used as basis for prioritization. Thus, in order to identify the critical aspects and to compare and assess which decision is most appropriate a multicriteria gap analysis method was used.

The conduct of multicriteria gap analysis method in this study follows three stages, the first stage consists of enumerating the criteria or *FDRR activities*, and sub-criteria or *FDRR measures* (Fig. 2-6). In this paper, the FDRR activities include: Prevention, Preparedness, Response and Recovery. The enumerated FDRR activities and FDRR measures are shown in Table 2-1. Weighted scores are assigned to each FDRR activity and FDRR measure. In this paper, the authors proposed a weighted score assignment method based on priority ranks. Priority ranking is done by

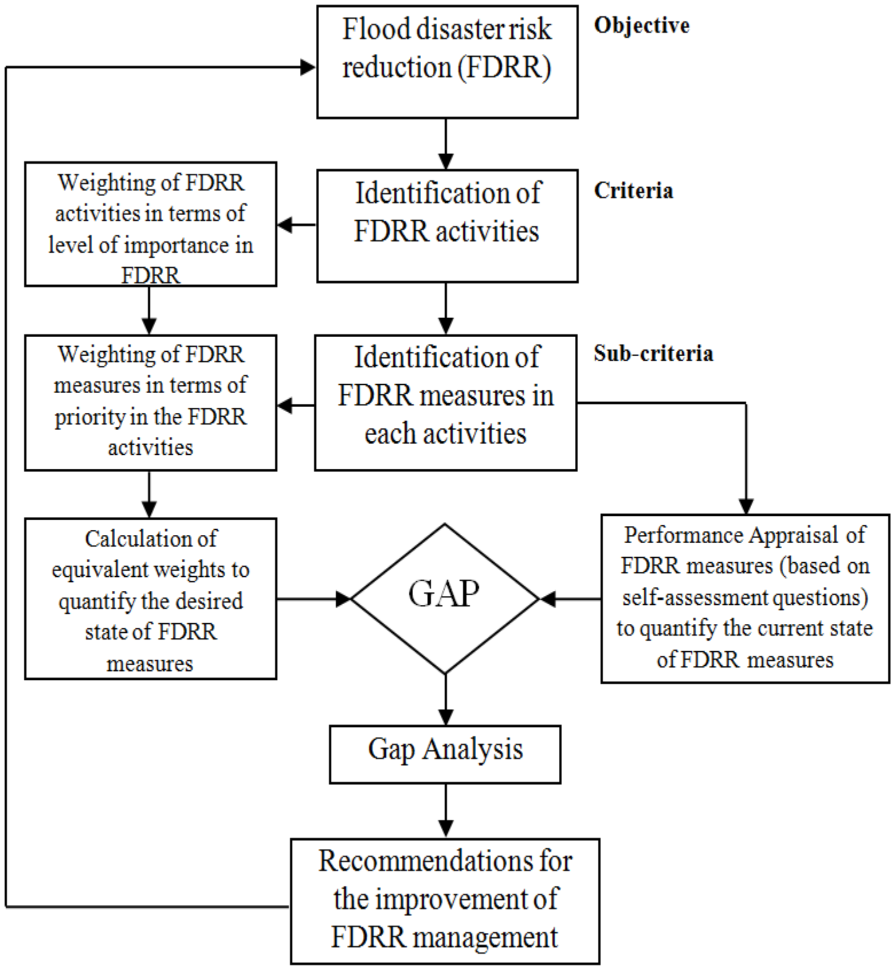

Fig. 2-6 Conceptual framework of multi-criteria gap analysis

arranging the criteria on the basis of relative importance. The ranks are given as positive integer values from 1 to *p*, where *p*, is the number of criteria (or sub-criteria) within the same group. The criterion that has a rank of 1 has the highest importance within that group. The relative importance of each criterion was subjectively determined based on 1) order of need prior to the occurrence of disaster, i.e. Prevention criterion is expected to have the highest risk reduction compared to Recovery criterion, where the disaster has already occurred; and 2) when the criterion is most likely a prerequisite of the succeeding criterion. For example, in the Preparedness criterion, Institutional Framework (Serial Code D) ranks higher than Vulnerability Assessment (Serial Code E), since organizational structure for disaster

Table 2-1 Weighted scores of Metro Manila FDRR management components.

FDRR Activities (i)	Priority Rank (R_i)	Weight Level 1 (W_i)	Serial Code	FDRR Measures (j)	Priority Rank ($R_{i,j}$)	Weight Level 2 ($W_{i,j}$)	Equiv. Weight ($W_{eq,i,j}$)
Prevention	1	0.4	A	Avoidance of settlement in flood hazard zones	1	0.500	0.200
			B	Flood mitigation measures (structural and/or non-structural)	2	0.333	0.133
			C	Early flood warning	3	0.167	0.067
Preparedness	2	0.3	D	Institutional framework	1	0.286	0.086
			E	Vulnerability assessment (hazard mapping)	2	0.238	0.071
			F	Response mechanisms (evacuation and rescue procedures)	3	0.190	0.057
			G	Information systems	4	0.143	0.043
			H	Public education and flood hazard awareness	5	0.095	0.029
			I	Emergency response capability (e.g. rescue and communcation equipment, training, etc.)	6	0.048	0.014
Response	3	0.2	J	Warning Dissemination	1	0.500	0.100
			K	Evacuation response	2	0.333	0.067
			L	Emergency response (e.g. rescue operations)	3	0.167	0.033
Recovery	4	0.1	M	Rehabilitation	1	1.000	0.100

Table 2-2 Performance appraisal of FDRR management systems of 14 out of 17 municipalities in Metro Manila.

Serial Code	Performance Appraisal ($P_{i,j,k}$)													
	M1 Malabon City	**M2** Caloocan City (M2)	**M3** Navotas City (M3)	**M4** Valenzuela City	**M5** Makati City	**M6** Pateros	**M7** Pasig City	**M8** Taguig City	**M9** Marikina City	**M10** Quezon City	**M11** Manila City	**M12** Las Pinas City	**M13** Paranaque City	**M14** Muntinlupa City
A	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
B	0.5	0.5	1.0	0.5	1.0	0.5	0.5	1.0	1.0	0.5	0.5	0.0	0.5	0.5
C	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
D	1.0	1.0	1.0	1.0	1.0	0.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
E	1.0	0.5	0.5	0.5	1.0	0.5	0.5	0.5	1.0	1.0	1.0	1.0	0.0	0.5
F	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	0.5	1.0
G	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
H	0.5	1.0	1.0	1.0	0.5	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
I	0.5	0.5	1.0	1.0	0.5	0.0	0.5	1.0	0.5	0.5	0.0	0.5	0.5	0.5
J	0.5	1.0	1.0	1.0	0.5	0.0	0.0	1.0	0.5	1.0	1.0	1.0	1.0	0.5
K	0.5	1.0	1.0	1.0	0.5	0.0	0.0	0.5	0.5	1.0	0.5	0.5	1.0	1.0
L	0.0	0.0	1.0	0.5	0.5	0.0	0.5	1.0	0.5	0.5	0.0	0.0	0.0	0.5
M	0.5	0.5	1.0	1.0	0.5	0.5	0.5	1.0	0.5	0.5	0.5	1.0	0.5	0.5

Table 2-3 Gaps assessment indices of FDRR management systems of 14 out of 17 municipalities in Metro Manila.

Serial Code	Gap index ($\Delta_{i,j,k}$)													
	M1 Malabon City	**M2** Caloocan City (M2)	**M3** Navotas City (M3)	**M4** Valenzuela City	**M5** Makati City	**M6** Pateros	**M7** Pasig City	**M8** Taguig City	**M9** Marikina City	**M10** Quezon City	**M11** Manila City	**M12** Las Pinas City	**M13** Paranaque City	**M14** Muntinlupa City
A	0.1000	0.1000	0.1000	0.1000	0.1000	0.1000	0.1000	0.1000	0.1000	0.1000	0.1000	0.1000	0.1000	0.1000
B	0.0667	0.0667	0.0000	0.0667	0.0000	0.0667	0.0667	0.0000	0.0000	0.0667	0.0667	0.1333	0.0667	0.0667
C	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
D	0.0000	0.0000	0.0000	0.0000	0.0000	0.0857	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
E	0.0000	0.0357	0.0357	0.0357	0.0000	0.0357	0.0357	0.0357	0.0000	0.0000	0.0000	0.0000	0.0714	0.0357
F	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0286	0.0000
G	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
H	0.0143	0.0000	0.0000	0.0000	0.0143	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
I	0.0071	0.0071	0.0000	0.0000	0.0071	0.0143	0.0071	0.0000	0.0071	0.0071	0.0143	0.0071	0.0071	0.0071
J	0.0500	0.0000	0.0000	0.0000	0.0500	0.1000	0.1000	0.0000	0.0500	0.0000	0.0000	0.0000	0.0000	0.0500
K	0.0333	0.0000	0.0000	0.0000	0.0333	0.0667	0.0667	0.0333	0.0333	0.0000	0.0333	0.0333	0.0000	0.0000
L	0.0333	0.0333	0.0000	0.0167	0.0167	0.0333	0.0167	0.0000	0.0167	0.0167	0.0333	0.0333	0.0333	0.0167
M	0.0500	0.0500	0.0000	0.0000	0.0500	0.0500	0.0500	0.0000	0.0500	0.0500	0.0500	0.0000	0.0500	0.0500

management and appropriate policies must be established prior to conducting any vulnerability assessment to provide a guiding committee for the assessors. The weighted scores are then determined based on the rank, at which the sum of the weighted scores in a group of criteria is equal to 1.0. The weighted scores, W_i and $W_{i,j}$, of the i^{th} FDRR activities and j^{th} FDRR measures, respectively, were determined using the following expressions:

$$W_i = \frac{(n - R_i + 1)}{\sum_{i=1}^{n} R_i} \qquad (2-1)$$

$$W_{i,j} = \frac{(n_i - R_{i,j} + 1)}{\sum_{j=1}^{n_i} R_{i,j}} \qquad (2-2)$$

where, n is the total number of FDRR activities and n_i is the total number of FDRR measures. R_i and $R_{i,j}$ are priority ranks of the i^{th} FDRR activity and j^{th} FDRR measure. In this study, $n = 4$, $n_1 = 3$, $n_2 = 6$, $n_3 = 3$ and $n_4 = 1$. The equivalent weight, $W_{eq,i,j}$, was calculated for each FDRR measure based on the product of the weighted scores of the FDRR activities and FDRR measures, as shown in Eq. 2-3:

$$W_{eq,i,j} = W_i \times W_{i,j} \qquad (2-3)$$

Table 2-1 shows the priority ranks and weighted scores of each FDRR activity and FDRR measure, with computed equivalent weights corresponding to each FDRR measure.

The second stage consists of performance appraisal of each FDRR measure based on the FDRR management system assessment done by the LGUs. Prior to appraisal, the evaluation measure was first defined (Zhang et al, 2007), in this study, 3 categories were used:

$$E = (1.0 \quad 0.5 \quad 0.0) \qquad (2-4)$$

A value of 1.0 or *achieved goal* means that the desired state of FDRR measure is in place and there is no known constraint that will contribute in the poor performance of the FDRR management. A value of 0.5 or *inadequately achieved goal* means that the desired state of FDRR measure is in place, but there is at least one observed constraint that may contribute to the poor performance of the FDRR management system. Lastly, a value score of 0.0 or *no achievement* means that the desired FDRR measure is not yet in place thus, may result in unmitigated disaster when flood occurs. During the FDRR management survey in Metro Manila, 14 (including the lone municipality of Pateros) out of the 17 municipalities were assessed, and the assessment results were translated to performance scores. Table 2-2 shows assessment of 14 municipalities with scores based on the self-assessment done by the municipal local government representatives.

To further explain this, in Malabon City, the emergency response was performed when floods occurred during typhoon Ondoy. However, several constraints were observed such as lack of rescue vehicles and lack of rescuers' training that resulted in the poor performance of the overall emergency response mechanism. The performance score (Table 2-2) of the Emergency Response Capability measure (Serial Code I) of Malabon City is 0.5.

The third stage is the calculation of gap indices. The product of the equivalent weight, $W_{eq,i,j}$, of each FDRR measure, and the performance appraisal, $P_{i,j,k}$, of the k^{th} municipality, represents the estimated actual performance of the FDRR measures. The gap index, $\Delta_{i,j,k}$, is computed by taking the difference of the equivalent weight, $W_{eq,i,j}$, and the estimated actual performance of a FDRR measure ($W_{eq,i,j} \times P_{i,j,k}$). This is expressed by the formula:

$$\Delta_{i,j,k} = W_{eq,i,j} - W_{eq,i,j} \times P_{i,j,k} \qquad (2-5)$$

Table 2-3 shows the gap indices, $\Delta_{i,j,k}$, of 3 of the 14 LGUs, as examples, computed using Eqn. 2-5.

The FDRR management gap index, Δ_k of the k^{th} LGU, is determined using the following expression:

$$\Delta_k = \sum_{i=1}^{n} \sum_{j=1}^{n_i} \Delta_{i,j,k} \qquad (2-6)$$

The FDRR management gap indices of Metro Manila by FDRR measure, $\Delta_{MM,i,j}$ are calculated using the following formula:

$$\Delta_{MM,i,j} = \sum_{k=1}^{N} \Delta_{i,j,k} /N \qquad (2-7)$$

where N is the total number of assessed municipal FDRR management systems, in this case $N = 14$.

2.3. Results and discussion

Graphs are very useful in evaluating quantified constraints. These provide simple and convenient means to visually compare the gap indices of the FDRR measures, and gap indices of the flood prone municipal LGUs. Fig. 2-7 shows the gap index values, Δ_k, computed using Eq. 2-6, of all FDRR-assessed municipal LGUs in Metro Manila. Pateros and Pasig City have gap index values higher than 0.40, while Navotas City and Taguig City have gap index values lower than 0.20. The relatively large difference between the gap index values of these municipalities roughly indicates the inconsistencies in the implementation of the FDRR systems within the administrative region. Pateros, the smallest municipality in Metro Manila (2.1 km^2), has the highest gap index value (Δ_k = 0.55). This municipality has a population of more than 62,000 people, making it the second most densely populated municipality (next to Manila City) in the Philippines. Around 60% of Pateros is prone to 10 years return flood, however during typhoon Ondoy, almost 100% of its area was inundated (1 to 2m). Based on the assessment of the FDRR management assessment system of Pateros, it has many settlement areas vulnerable to flood (Serial Code A),

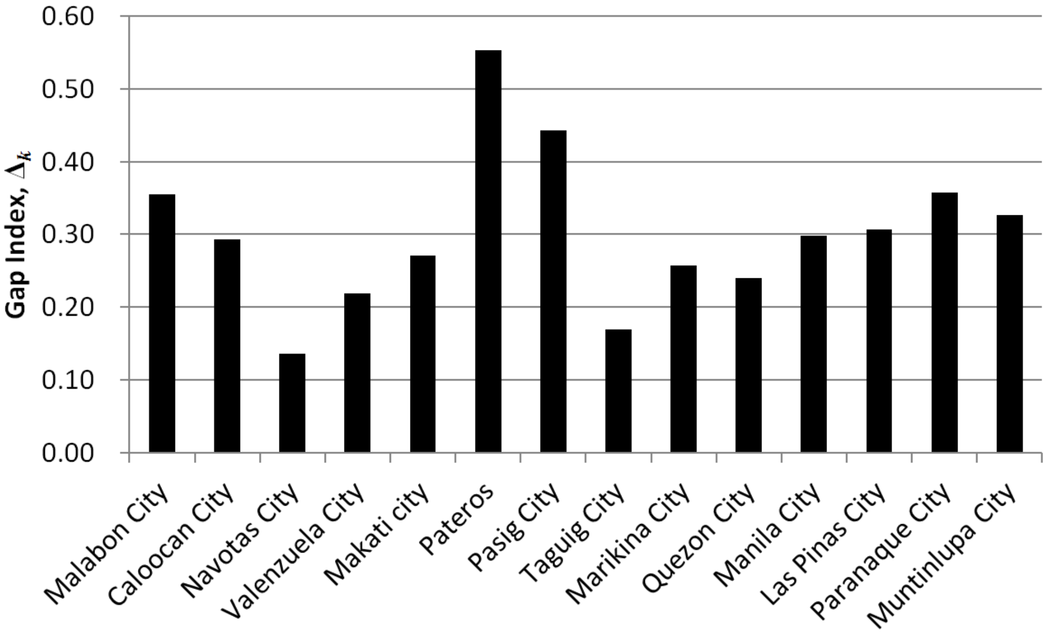

Fig. 2-7 Gap value chart of 14 assessed municipalities in Metro Manila.

has no clear FDRR management institutional framework (Serial Code D), has no systematic procedures for flood warning dissemination (Serial Code J), not efficient in the conduct of evacuation procedures (Serial Code K), and it is not capable of performing effective rescue and emergency operations (Serial Code L). Thus, Pateros requires serious and immediate attention to improve its FDRR management system.

On the other hand, the relatively smaller gaps (Fig. 2-7) of Navotas City (Δ_k = 0.14) and Taguig City (Δ_k = 0.17) indicates that these LGUs have more established FDRR management systems compared to the other municipalities. The FDRR constraints in Navotas City and Taguig City are mainly due to the presence of settlements in flood hazard areas (Serial Code A in Table 2-3). This land use-related problem is a common situation in Metro Manila. To address this issue, it will basically require land use conversion in the flood hazard areas, which may result in the resettlement of affected population. The local policy requires the government to compensate (i.e. in terms of housing, utilities, livelihood, etc.) any of those who will be displaced by a government initiated programs. Such activities will require space and entail

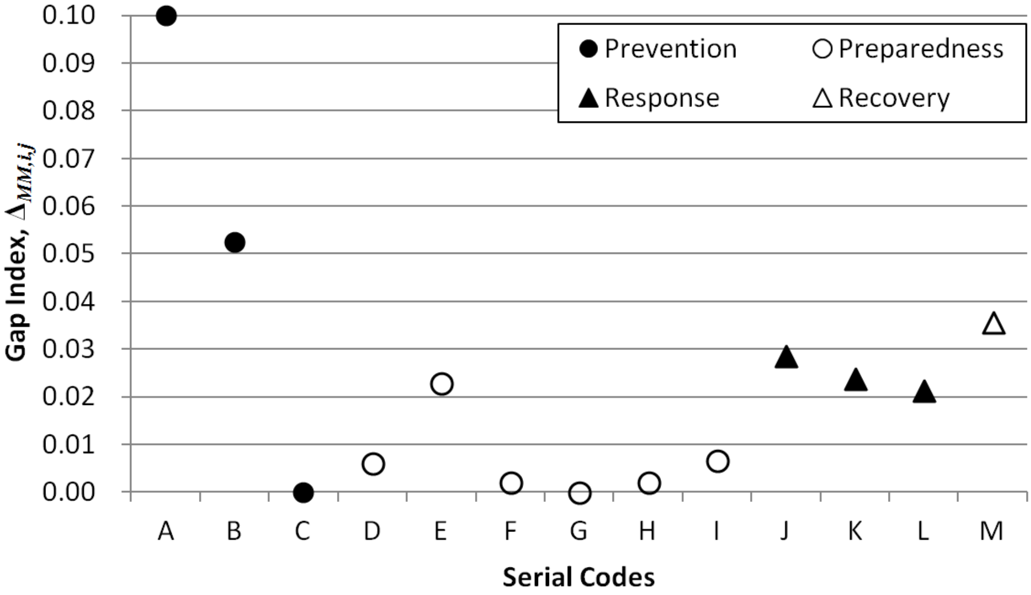

Fig. 2-8 Gap value chart of the sub-criteria based on the assessment of 14 Metro Manila municipalities.

substantial resettlement budget allocation. Relocation of the affected population may also have impact in the local political situations. The absence of comprehensive flood hazard maps (Serial Code E in Table 2-3) is also a common issue, which is primarily due to the unavailability of information necessary in the preparation of a flood hazard map (e.g. topographic map, geologic map, hydrological data, etc.). From a general perspective, the gaps in the FDRR management system of each LGU, as shown in Fig. 2-7, are fairly small (except Pateros), which indicates that most LGUs are still pro-active in reducing the effects of flood disasters despite the existence of various constraints.

Looking at the overall FDRR management system of Metro Manila, to identify the priority FDRR measures on the basis of constraints, the gap indices of each measure, $\Delta_{MM,i,j}$, were evaluated. Fig. 2-8 shows the gap index values of each FDRR measure as computed using Eq. 2-7. The shapes (●,○, ▲, and △) represent the FDRR activities (or first level criteria) of the FDRR management system. The meaning of the alphabets (Serial Codes) A to M, are shown in Table 2-3. In Fig. 2-8, Serial Code A ($\Delta_{MM,i,j}$ = 0.100) has the largest gap in the FDRR management system. As explained above, land use and resettlement issues are common in Metro Manila due to the lack of space and insufficiency of budget for relocation. The constraints in Serial Code B ($\Delta_{MM,i,j}$ = 0.052) is perhaps due to the lack of effective flood mitigation measures (structural on non-structural measures) in several flood prone areas (e.g. Las Piňas City). With regards to Serial Code C ($\Delta_{MM,i,j}$ = 0), there was no constraint identified since all the assessed municipalities claimed that they have community-based early flood warning systems, which is perhaps due to their experiences with recurring floods. The gap index value concerning the effectiveness of the early flood warning systems (Fig. 2-8, Serial Code J), however, was high ($\Delta_{MM,i,j}$ = 0.029). In terms of Preparedness (○), Metro Manila clearly has gaps in the preparation of flood hazard maps (Serial Code E, $\Delta_{MM,i,j}$ = 0.023). This is attributed to the lack of updated physical maps (topographical maps, geologic maps, etc.) and meteorological and hydrological data (rainfall, river discharge, etc.). All LGUs have information systems (Serial Code G) and most have response mechanisms (Serial Code F) for flood emergencies, however, execution of these measures were found ineffective in several municipalities. In general, Metro Manila, is weak in the Response (▲) criterion, (Serial Codes J, K and L), as evidenced by the unreliable flood forecasting and warning systems, lack of rescue teams and lack of evacuation vehicles during typhoon Ondoy. The gaps in the Recovery (△) criterion (Serial Code M) are mostly attributed to the lack of funds of most LGUs to engage in immediate flood disaster rehabilitation.

2.4. Conclusion

The magnitude of the rainfall spilled by typhoon Ondoy in Metro Manila was unprecedented resulting in overwhelming floods and tremendous amount of damages. The flood control structures of Metro Manila were rendered ineffective in preventing the devastating effects of the tropical cyclone. Further investigation on the hydraulic designs of the flood control structures that failed during typhoon Ondoy will be very useful in improving the safety levels of the drainages and channels in the critical sub-basins of Metro Manila.

Given that the structural measures have its limitations, the damages and casualties may have been reduced if there were timely and sufficient flood warnings. The primary reason for this is that there was no reliable flood forecasting and warning system installed in all of the flood prone areas of Metro Manila, and there is no reliable real-time data links for rainfall monitoring between concerned government offices. Funds must be allocated for the research and development of effective flood forecasting and early warning systems, as well as for its operation and maintenance. Aside from improving the infrastructures for better communication and data transfer, it is further recommended that a system be put in place that can estimate and predict the amount of rainfall within and around Metro Manila, at which the data is collected and processed by flood forecasting offices using flood simulation models. The existing flood warning system should be enhanced to provide effective dissemination of flood bulletins, especially in frequently flooded areas. Community-based flood warning systems should be strengthened and must be encouraged in all flood-prone communities. Training on emergency response should also be provided to all constituents who were affected by tropical storm Ondoy.

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CHAPTER 3

FUZZY-BASED GAPS ASSESSMENT OF FLOOD DISASTER RISK REDUCTION MANAGEMENT SYSTEM IN METRO MANILA

3.1. Introduction

On 26 September 2009, Metro Manila has been under critical condition when a rare meteorological event, tropical storm *Ondoy*, occurred. Ondoy poured the highest rainfall ever recorded in Metro Manila (Gilbuena et al. 2013) that resulted in the inundation of a third of the Metropolis, submergence of important urban infrastructures, and deposition of tons of sediments on roads, drainages and residential areas. This event affected more than 4.5 million people, caused the death of almost 500 residents, and incurred an accumulated loss amounting to more than PhP 11 Billion (Rabonza 2009) (PhP 1.00: USD 0.0216 in 2009).

According to Wang (2012), this picture of disaster is becoming more and more frequent and intense in many cities around the world (e.g. Hurricane Katrina in 2005, Cyclone Nargis in 2008 and Typhoon Morakot in 2009), which makes the sustainable management of urban flood risks an increasingly challenging task for urban developers and policy-makers alike. The World Meteorological Organization (2008) identified work items that can be carried out to address the problems of urban flood risks. Among which, involves the participation of stakeholders in flood risk assessment, especially those from the community level. It emphasizes that meeting the needs for effective flood risk management is more achievable if the stakeholders themselves are involved in the decision-making. By arming the decision-makers with information that distinctly identify the leading constraints in each community (or municipality), measures that are aimed to reduce the flood disaster risks can then be effectively and efficiently carried out.

In Metro Manila, the aftermath of the tropical storm Ondoy prompted the Philippine government to carry out a post-disaster needs assessment (The World

Bank 2009) in all the 17 municipalities of the metropolis to estimate the damages, losses, and other economic and social impacts caused by the tropical storm. The post-disaster needs assessment was partly aimed to identify key management issues, which, if properly addressed can help improve Metro Manila's flood risk resilience. One such recommendation is a community-based participatory approach that encourages local communities to engage in the decision-making. A questionnaire-based assessment was then launched in each participating municipality to identify the weaknesses and deficiencies in the flood disaster risk reduction (FDRR) management systems that were observed *before*, *during* and *after* the tropical storm. The result of the assessment describes a panoramic view of the constraints in the FDRR management of each municipality. There is however a need to aggregate the results to identify which municipality is most critical, and which key FDRR management components need to be immediately improved. An approach that can quantify and aggregate the views of the local communities should be made available.

In a management perspective, constraints or *gaps*, according to Rueckert et al. (2011), represent the concept of the "space between where we are and where we want to be". Liedtka (1998) describe gaps assessment as a time-based intent-driven strategic planning technique that uses historical information and desired outcomes as bases for improvement. Gaps assessment is thus both fact-based and goal-oriented, which makes it a powerful technique in the development and improvement of management systems. The quantitative assessment of gaps in the FDRR management, thus, can be useful in the identification of high risk flood-prone areas as well as identify constraints existing within each municipal-based FDRR management systems.

The quantitative evaluation of gaps has recently been re-adopted in various areas of scientific studies. Different approaches to gaps assessment have been proposed, but most still follows the same basic principle. For instance: Oldfield et al. (2004) used gaps analysis to assess the extent at which a protected area system meets its protection goals (set by a nation or region), which typically involves a spatial comparison of biodiversity within the existing and planned protected areas; Currie et al. (2010) used gap analysis to measure the spatial distribution of public transport needs to identify the constraints in the quality of public transport provisions; Zhang et al. (2007) used the concept of gap analysis to identify the affecting factors in collaborative product development process systems by means of performance-based assessment.

Despite its usefulness and wide applicability, the quantitative assessment of gaps has not yet been fully explored in the evaluation of FDRR management systems. In Metro Manila, the framework of FDRR management system is typically composed of various measures encapsulated in four phases: prevention, preparedness, response and recovery (Department of Defense, 2011). The evaluation of the FDRR management system entails the evaluation of each measure (as performance indicators) in each phase, thus, taking the form of a multi-attribute decision-making problem. Multi-attribute decision making is widely regarded for its robust application in various fields (Calizaya et al. 2009; Corsair et al. 2009; Rebai et al. 2006; Wu et al. 2010; Yoe 2007), particularly those that require comparison of benefits and importance. Each multi-attribute decision making problem is associated with multiple attributes that are often referred to as "goals" or "decisions" (Triantaphyllou et al. 1998). To determine the "gaps" in the attributes, the technique for order performance by similarity to ideal solutions (TOPSIS) can be used. TOPSIS is a common technique used to deal with multi-attribute decision making problems (Behzadian et al. 2012; Jiang et al. 2011; Uyun and Riadi 2011). It bases upon the concept -- the best value is the one with the shortest distance from the positive ideal state, and the farthest from the negative ideal state (Wang and Elhag 2006) -- which fits well with the requirements for gap analysis. One powerful feature of gap analysis is its capability to assimilate qualitative judgment into quantitative-based assessment. Qualitative judgments, however, often operate within a fuzzy environment due to its imprecision and vagueness (Mechefske and Wang 2001). Bellman and Zadeh (1970) first introduced the theory of fuzzy sets in multi-criteria decision making problems as an effective way to treat vagueness. Jin et al. (2012) pointed out that fuzzy numbers are convenient in expressing fuzzy or inexact data. Thus, to cope with the qualitative judgments, a fuzzy approach to TOPSIS using fuzzy sets is necessary (e.g. Chen 2000; Chen and Tsao 2008; Krohling and Campanharo 2011; Momeni et al. 2011;

Wang and Elhag 2006; Zhang et al. 2013).

In this study, a municipal-based gaps assessment of the FDRR management systems in Metro Manila is proposed using a fuzzy-TOPSIS technique. This approach is meant to provide a rapid comparative assessment method (in the form of gap analysis), using the perception of municipal-based stakeholders, in the identification of priority areas needed in the strategic planning and improvement of FDRR management in Metro Manila. The FDRR phases are treated as FDRR sub-systems. The FDRR sub-systems and the FDRR indicators were given fuzzy weights based on priority ranking. The fuzzy gap indices were calculated using equivalent fuzzy weights, fuzzy ideal scores (translated from the questionnaire-based assessments) and fuzzy performance ratings. Crisp gap indices were computed to determine the priority areas (municipalities) and to identify the specific FDRR indicators that require improvement as well. The decision is made based on the relationship: *bigger gaps means higher priority*.

3.2. Study area

Metro Manila, Philippines is a megacity (population of more than 10 million) clustered by 17 highly urbanized municipalities. It is situated in a semi-alluvial fan that opens to Manila Bay on the west and Laguna de Bay Lake on the southeast (Pineda 2000). Fig. 3-1 shows the administrative boundary of Metro Manila including its 17 municipal local government units. It is the country's political and economic capital with annual contribution of around 33% of the country's gross domestic product (National Statistics Coordination Board 2011). Despite its progress, floods have persistently slowed down the region's economic growth. The floods in Metro Manila regularly caused heavy inundation and traffic, which often result in the suspension of office and school works (Page 2000). Floods in Metro Manila can also be devastating, often causing the loss of lives and damages to properties and public infrastructures. In 1952, the national government completed its first comprehensive drainage improvement plan covering most of the present day Metro Manila (Bureau

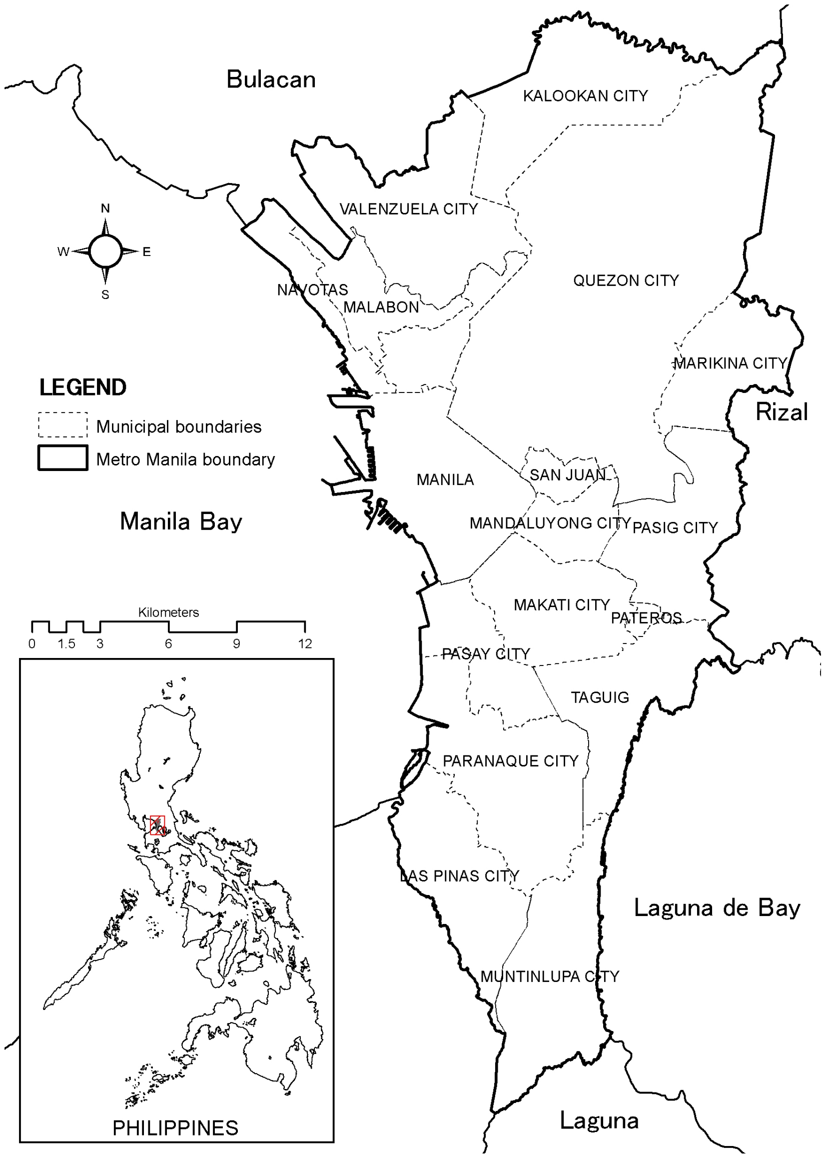

Fig. 3-1 Geographical location of Metro Manila and its 17 Municipalities

of Public Works 1952). Floods however persisted as Metro Manila expanded and further developed into a highly urbanized megacity.

The municipal local government units are often tasked to co-manage the FDRR management system along with several of the national government offices. The tasks typically include the operation of structural measures; implementation of non-structural measures; preparedness operations; response operations; and rehabilitation/recovery operations.

3.3. Tropical storm Ondoy

On 26 September 2009, the tropical depression Ondoy developed into a tropical storm, and raged across Metro Manila with a rainfall far exceeding all the precipitation levels recorded in this area since 1961. The highest 12-hr rainfall was measured around 450 mm, an amount almost twice the average monthly rainfall in the area for the same historical period (The World Bank, 2009). This resulted in the swift build-up of immense floods along the low-lying areas and violent flash floods near large river systems, causing devastation for millions of lives and tremendous losses in agriculture, infrastructures and properties (The World Bank, 2009).

Table 3-1 shows a summary of the inundated areas and the number of people (by municipality) affected by the onslaught of the tropical storm Ondoy. During the first few weeks after the storm, the authors conducted a comprehensive field survey, as part of the post-disaster needs assessment study of the national government, to investigate the extent of the tropical storm's impacts in Metro Manila and its suburbs. A questionnaire-based survey instrument was developed to aid in the assessment of the municipal-based FDRR management systems. The management systems were evaluated based on different time frames: before Ondoy, during Ondoy and after Ondoy (aftermath of the storm). The inquiries were made based on the general components of the framework of the FDRR management of Metro Manila, which is composed of the disaster prevention/mitigation system, disaster preparedness system, disaster and emergency response system and disaster recovery/rehabilitation system (Department of Defense, 2011). The results of these inquiries are used to quantitatively assess the gaps in the FDRR management systems in each of the municipalities in Metro Manila.

Table 3-1 Damage profile of the 14 assessed municipalities in Metro Manila during the tropical storm Ondoy.

Code	Municipalities	Area, km^2	Flooded Area (%)	Estimated Population (x 10^3)	Affected Population (%)	Direct Damage (x10^6 pesos)
M1	Malabon City	15.76	87.44	364	88.51	2,857
M2	Caloocan City	53.33	21.28	1,379	29.98	4,543
M3	Navotas City	10.77	47.63	245	69.90	658
M4	Valenzuela City	44.58	48.70	569	41.47	2,129
M5	Makati City	27.36	54.57	510	72.59	3,480
M6	Pateros	2.10	92.86	62	99.91	808
M7	Pasig City	31.00	79.29	617	81.86	4,344
M8	Taguig City	47.88	35.92	613	47.22	2,527
M9	Marikina City	21.50	77.67	425	65.45	3,699
M10	Quezon City	161.12	21.11	2,679	25.66	7,320
M11	Manila City	38.55	76.84	1,661	73.18	7,337
M12	Las Pinas City	41.54	25.93	532	35.84	1,347
M13	Paranaque City	47.69	35.58	553	48.95	2,085
M14	Muntinlupa City	46.70	5.37	453	12.79	579

3.4. Gaps assessment

In the event of calamities, decision-makers and planners are often left to deal with tasks that attempt to resolve management issues as swiftly and as efficiently as possible. These issues however, often carry multiple objectives and conflicting requirements. To simplify the process of decision-making, the evaluation process should be concentrated in the immediate identification of critical aspects. This promotes efficiency and focused goal-setting for prioritization. Critical to the identification of FDRR management gaps are the FDRR indicators and the actual performance of FDRR management. Fig. 3-2 shows the conceptual framework used in the assessment of gaps in the FDRR management system in Metro Manila.

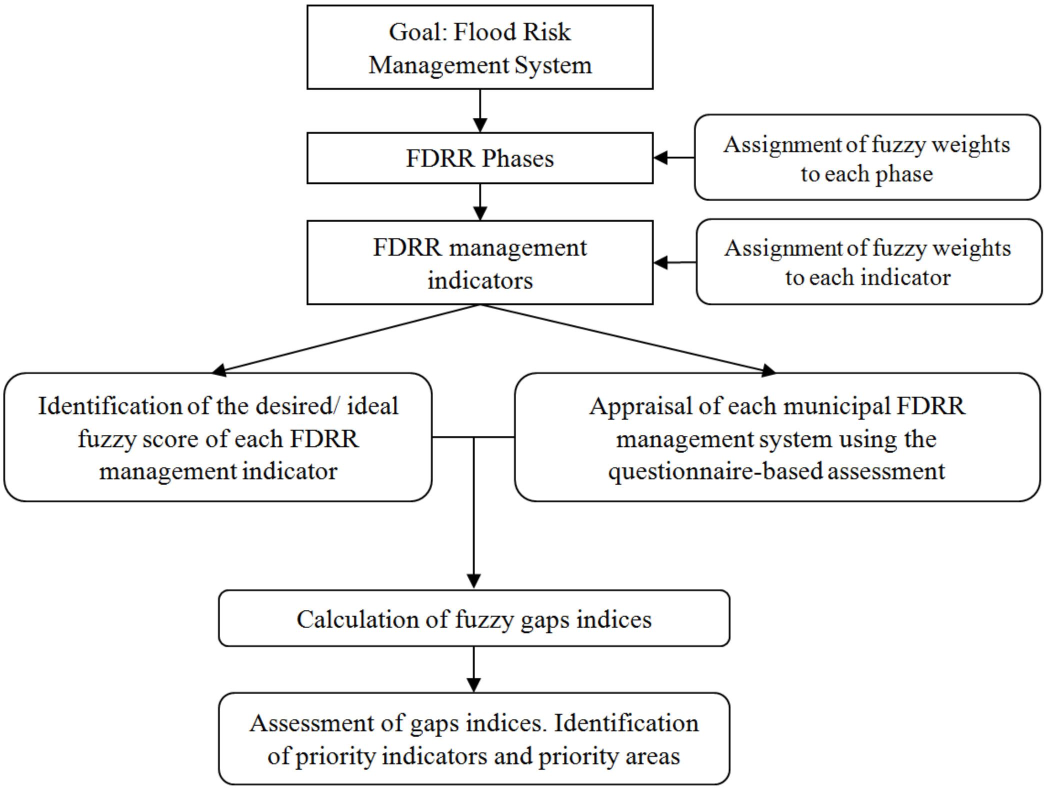

Fig. 3-2 Gaps assessment framework of the FDRR management systems in Metro Manila

Fig. 3-3 shows the hierarchical structure for the evaluation of the performance of the FDRR management systems in Metro Manila. Based on this figure, the FDRR management system of Metro Manila is composed of 4 sub-systems (i.e. Prevention (S1), Preparedness (S2), Response (S3) and Recovery/Rehabilitation (S4)). Each subsystem is composed of at least one FDRR indicator. These indicators were identified by the authors and are based on the flood management scheme currently in place in Metro Manila. The subsystems S1, S2, S3 and S4 have 3, 6, 3 and 1 FDRR performance indicators, respectively. The overall FDRR performance of each of the municipality in Metro Manila is determined by the aggregated ratings of each FDRR indicator. In this study, 14 out of the 17 municipalities of Metro Manila were assessed for FDRR management gaps. Table 3-2 shows the description of each FDRR performance indicators in each FDRR subsystem. As shown in this table, each of the

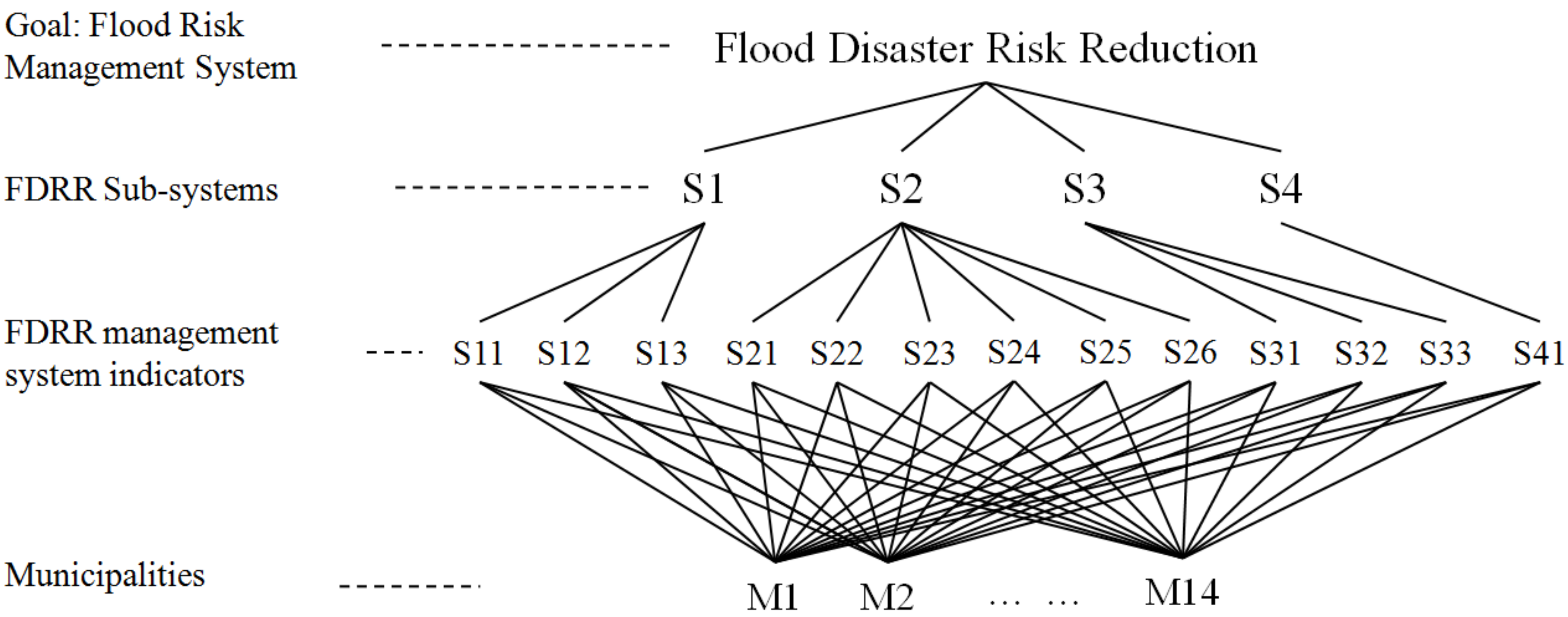

Fig. 3-3 The decision hierarchy for the performance appraisal of FDRR management systems in Metro Manila.

Table 3-2 The fuzzy weights of the FDRR sub-systems and FDRR indicators and the equivalent fuzzy weights

Flood disaster risk reduction Sub-systems	Rank	FDRR Subsystem fuzzy weight W_i	Flood disaster risk reduction indicators	Rank	FDRR Indicator fuzzy weight W_{ij}	Fuzzy Equivalent $W_{eq,ij}$
Prevention (S1)	1	(0.600,0.800,1.000)	Flood zoning (S11)	1	(0.500,0.750,1.000)	(0.300,0.600,1.000)
			Structural flood mitigation measures (S12)	2	(0.250,0.500,0.750)	(0.150,0.400,0.750)
			Municipal-based Early Flood Warning (S13)	3	(0.000,0.250,0.500)	(0.000,0.200,0.500)
Preparedness (S2)	2	(0.400,0.600,0.800)	Institutional framework (S21)	1	(0.714,0.857,1.000)	(0.286,0.514,0.800)
			Vulnerability assessment (S22)	2	(0.571,0.714,0.857)	(0.229,0.429,0.686)
			Emergency response mechanisms (S23)	3	(0.429,0.571,0.714)	(0.171,0.343,0.571)
			Communication systems (S24)	4	(0.286,0.429,0.571)	(0.114,0.257,0.457)
			Public education and awareness (S25)	5	(0.143,0.286,0.429)	(0.057,0.171,0.343)
			Availability of rescue equipment (S26)	6	(0.000,0.143,0.286)	(0.000,0.086,0.229)
Response (S3)	3	(0.200,0.400,0.600)	Warning dissemination (S31)	1	(0.500,0.750,1.000)	(0.100,0.300,0.600)
			Evacuation response (S32)	2	(0.250,0.500,0.750)	(0.050,0.200,0.450)
			Timely response and rescue operations (S33)	3	(0.000,0.250,0.500)	(0.000,0.100,0.300)
Rehabilitation/ Recovery (S4)	4	(0.000,0.200,0.400)	Recovery/Rehabilitation (S41)	1	(0.000,0.500,1.000)	(0.000,0.100,0.400)

subsystems and FDRR indicators is ranked by the authors according to 'relative importance', with the rank of 1 indicating the highest priority. The relative importance of a FDRR subsystem/FDRR indicator is subjectively determined based on 1) order of need prior to the occurrence of disaster (i.e. Prevention subsystem is expected to provide higher risk reduction compared to the Recovery subsystem) and 2) when the subsystem/indicator is most likely a prerequisite of another subsystem/indicator. The ranking of FDRR indicators is carried out in each FDRR sub-systems, such that, the FDRR indicator that has the highest relative importance in a subsystem is given the rank of 1, while the rest of the FDRR indicators are ranked accordingly.

3.4.1. Fuzzy TOPSIS

TOPSIS is a numerical approach developed by Hwang and Yoon (1981) that bases upon the concept: the best performing option is the one with the shortest distance from the ideal desirable solution and the farthest distance from the ideal undesirable solution. In TOPSIS, the performance ratings and the weights of the attributes are given as crisp values. The use of numerical values in the appraisal of FDRR performance indicators may have limitations in dealing with uncertainties. Extending the concept of TOPSIS to the fuzzy environment is thus necessary to solve the problems of multi-attribute decision making with uncertain data, resulting in a fuzzy TOPSIS (Chen 2000; Krohling and Campanharo 2011; Triantaphyllou and Lin 1996).

In this study, the assessment of FDRR management gaps in each of the 14 assessed municipalities in Metro Manila was carried out using the fuzzy TOPSIS approach. This study is a first attempt, not only to combine the concept of gaps analysis and fuzzy TOPSIS, but also to provide a first view on the application of fuzzy TOPSIS in the evaluation of FDRR managements systems. Using the concept of gaps analysis and fuzzy TOPSIS, the gaps in the FDRR management system of each municipality is determined by taking the difference (or "distance") between the actual performance and the desired performance of each municipality on each FDRR indicator using fuzzy numbers. The distances acquired are then expressed in terms of separation measures, which in turn are used to calculate the overall gaps in each municipality and in each FDRR management system. A separation measure is a distance norm denoting the distance of the combined fuzzy gaps from a positive ideal (most desirable) or negative ideal (most undesirable) solutions (Chen 2000). In this study, the separation measure is calculated using Euclidean distance, which has been effectively used in many fuzzy TOPSIS-related studies (e.g. Chen 2000; Krohling and Campanharo 2011; Triantaphyllou and Lin 1996). Further details of this combined approach are explained within the rest of this section.

In practical applications, the triangular-shaped membership function is often used to represent fuzzy numbers. Fuzzy solutions using fuzzy numbers proved to be very effective for solving decision-making problems where the available information is imprecise (Krohling and Campanharo 2011). The following are some important basic definitions of fuzzy sets and fuzzy numbers based on recent works by Krohling and Campanharo (2011) and Roghanian and Ansari (2010):

Definition 1: A fuzzy set A in a universe of discourse X is characterized by a membership function $\mu_A(x)$ that assigns each element in x in X a real number in the interval [0, 1]. The numeric value $\mu_A(x)$ stands for the grade of membership of x in A.

Definition 2: The fuzzy elements of A are defined by a triplet (a_1, a_2, a_3). The membership function is thus defined by:

$$\mu_A(x) = \begin{cases} \frac{(x-a_1)}{(a_2-a_1)}, & a_1 \le x \le a_2 \\ \frac{(a_3-x)}{(a_3-a_2)}, & a_2 \le x \le a_3 \\ 0, & \text{otherwise} \end{cases} \qquad (3-1)$$

Definition 3: Given two triangular fuzzy numbers $A = (a_1, a_2, a_3)$ and $B = (b_1, b_2, b_3)$, the arithmetic operations are defined as follows:

$$\text{Addition: } A\{+\}B = (a_1, a_2, a_3)\{+\}(b_1, b_2, b_3) \qquad (3-2)$$

$$= (a_1 + b_1, a_2 + b_2, a_3 + b_3)$$

$$\text{Subtraction: } A\{-\}B = (a_1, a_2, a_3)\{-\}(b_1, b_2, b_3) \qquad (3-3)$$

$$= (a_1 - b_1, a_2 - b_2, a_3 - b_3)$$

$$\text{Multiplication: } A\{\times\}B = (a_1, a_2, a_3)\{\times\}(b_1, b_2, b_3) \qquad (3-4)$$

$$= (a_1 \cdot b_1, a_2 \cdot b_2, a_3 \cdot b_3)$$

$$\text{Division: } A\{/\}B = (a_1, a_2, a_3)\{/\}(b_1, b_2, b_3) \qquad (3-5)$$

$$= \left(\frac{a_1}{b_1}, \frac{a_2}{b_2}, \frac{a_3}{b_3}\right)$$

$$\text{Exponent: } A^{\{n\}} = ({a_1}^n, {a_2}^n, {a_3}^n);\ B^{\{n\}} = ({b_1}^n, {b_2}^n, {b_3}^n) \qquad (3-6)$$

The operators in "{ }" denotes fuzzy operation. Each of the FDRR sub-systems was assigned intuitively with fuzzy weights (e.g. Fernandez and Lutz 2010; Zhang et al. 2007), W_i of the i^{th} subsystem (i = 1, 2, 3 and 4), according to the designated rank in Table 2. The fuzzy weights of the subsystems are based on the membership functions in Fig. 3-4(a). The FDRR performance indicators were assigned with fuzzy weights, W_{ij} of the j^{th} FDRR indicator (j = 1,2,3 if i= 1,3; j = 1,2,…6, if i = 2; and j = 1,2,…, 4, if i = 4), according to the designated rank in Table 2, such that, the fuzzy weights of the FDRR indicators of S1 and S3 subsystems are based on the membership functions in Fig. 3-4(b). Similarly, the fuzzy weights of the FDRR indicators of S2 and S4

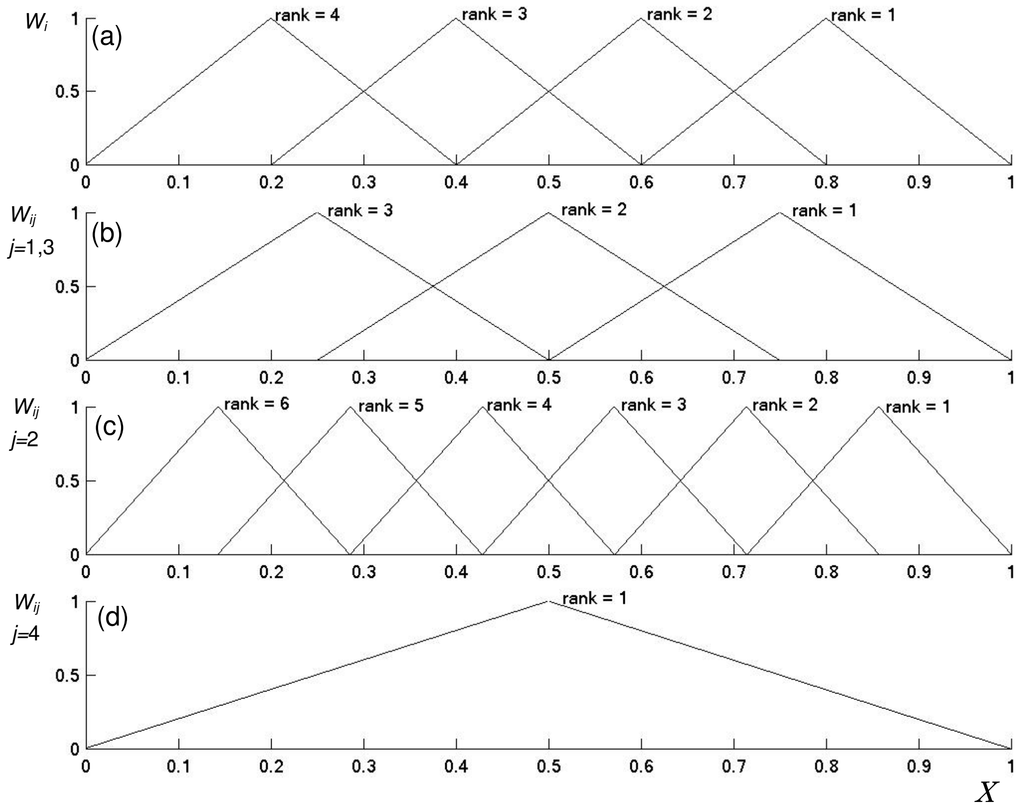

Fig. 3-4 Membership functions used in the assignment of fuzzy weights for the sub-systems (*i*) and FDRR indicators (*ij*). The numbers at the top of the plots represent the corresponding priority of each fuzzy weight. (a) 4 attributes, (b) 3 attributes, (c) 6 attributes, (d) 1 attribute.

subsystems are based on the membership functions in Fig. 3-4(c) and 3-4(d), respectively. The equivalent fuzzy weight of each FDRR indicator, $W_{eq,i,j}$, is calculated as shown in Table 2 using the following formula:

$$W_{eq,ij} = W_i\{\times\}W_{ij} \qquad (3-7)$$

The performance of each FDRR indicator is then rated using the appraisal done by municipal government representatives in Metro Manila in October 2009. The appraisal was carried out in the form of a questionnaire-based interview. The results of the interview are then simplified into the following linguistic definition: *Poor*, *Fair* and *Good*. The *Poor* rating indicates that the desired FDRR management system is

Table 3-3 Performance appraisal of the flood disaster risk reduction management systems of 14 municipalities in Metro Manila

Flood disaster risk reduction sub-systems	indicators	Performance Appraisal													
		M1	M2	M3	M4	M5	M6	M7	M8	M9	M10	M11	M12	M13	M14
Prevention (S1)	S11	Fair	Fair	Fair	Fair	Fair	Fair	Fair	Fair	Fair	Fair	Fair	Fair	Fair	Fair
	S12	Fair	Fair	Good	Fair	Good	Fair	Fair	Good	Good	Fair	Fair	Poor	Fair	Fair
	S13	Good	Good	Good	Good	Good	Good	Good	Good	Good	Good	Good	Good	Good	Good
Preparedness (S2)	S21	Good	Good	Good	Good	Good	Poor	Good	Good	Good	Good	Good	Good	Good	Good
	S22	Good	Fair	Fair	Fair	Good	Fair	Fair	Fair	Good	Good	Good	Good	Poor	Fair
	S23	Good	Good	Good	Good	Good	Good	Good	Good	Good	Good	Good	Good	Fair	Good
	S24	Good	Good	Good	Good	Good	Good	Good	Good	Good	Good	Good	Good	Good	Good
	S25	Fair	Good	Good	Good	Fair	Good	Good	Good	Good	Good	Good	Good	Good	Good
	S26	Fair	Fair	Good	Good	Fair	Poor	Fair	Good	Fair	Fair	Poor	Fair	Fair	Fair
Response (S3)	S31	Fair	Good	Good	Good	Fair	Poor	Poor	Good	Fair	Good	Good	Good	Good	Fair
	S32	Fair	Good	Good	Good	Fair	Poor	Poor	Fair	Fair	Good	Fair	Fair	Good	Good
	S33	Poor	Poor	Good	Fair	Fair	Poor	Fair	Good	Fair	Fair	Poor	Poor	Poor	Fair
Recovery/ Rehabilitation (S4)	S41	Fair	Fair	Good	Good	Fair	Fair	Fair	Good	Fair	Fair	Fair	Good	Fair	Fair

not in place, thus may result to unmitigated disasters. The *Fair* rating indicates that the FDRR management system is in place, but it is inadequate or can be improved to achieve the desired level of confidence. The *Good* rating indicates that the desired level of confidence or satisfaction was achieved. The corresponding linguistic ratings of each performance indicator for each municipality are shown in Table 3-3. Each of the linguistic rating is then given a corresponding fuzzy performance appraisal, $P_{m,ij}$ of the m^{th} municipality (m = 1,2,..., 14), based on the membership functions in Fig. 3-5,which is expressed by:

$$P_{m,ij} = \begin{cases} Poor = [0.00 \quad 0.25 \quad 0.50] \\ Fair = [0.25 \quad 0.50 \quad 0.75] \\ Good = [0.5 \quad 0.75 \quad 1.00] \end{cases} \qquad (3-8)$$

The weighted fuzzy performance appraisal, $F_{m,ij}$, for 14 municipalities is then calculated using the following formula:

$$F_{m,ij} = W_{eq,ij}\{\times\}P_{m,ij} \qquad (3-9)$$

The fuzzy TOPSIS henceforth is described as follows:

Step 1: Identify the positive ideal rating and negative ideal rating. In this study, the positive ideal rating, P^+, is defined as the *desirable performance*, which corresponds to the fuzzy numbers of the performance appraisal "Good". On the other hand, the negative ideal rating, P^-, is defined as the *worst performance*, which corresponds to the fuzzy performance appraisal "Poor".

Step 2: Calculate the positive ideal ($F^+_{m,ij}$) and negative ideal ($F^-_{m,ij}$) solutions of each FDRR indicator and each municipality using the following equations:

$$F^+_{m,ij} = W_{eq,ij}\{\times\}P^+ \qquad (3-10)$$

$$F^-_{m,ij} = W_{eq,ij}\{\times\}P^- \qquad (3-11)$$

Step 3: Calculate the positive and negative distances (or fuzzy positive and fuzzy negative gaps), $D^+_{m,ij}$ and $D^-_{m,ij}$, between each of the weighted fuzzy performance

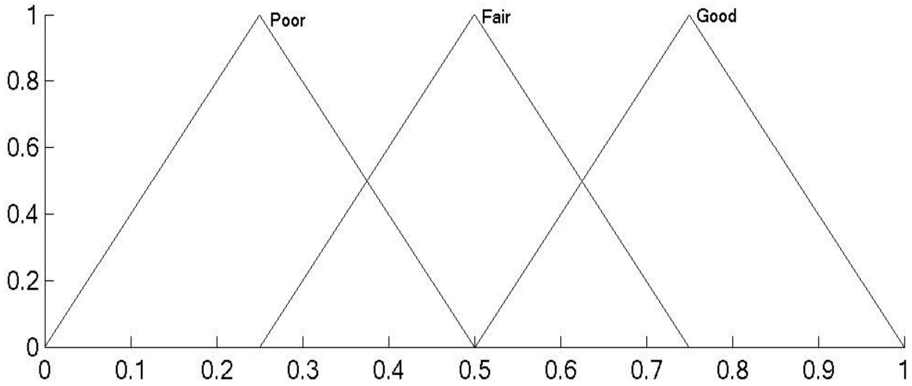

Fig. 3-5 Membership functions of the performance ratings for the evaluation of FDRR management systems in Metro Manila.

appraisal ($F_{m,ij}$), and the positive and negative ideal solutions ($F^+_{m,ij}$ and $F^-_{m,ij}$, respectively) using the following equations:

$$D^+_{m,ij} = F^+_{m,ij}\{-\}F_{m,ij} \qquad (3-12)$$

$$D^-_{m,ij} = F_{m,ij}\{-\}F^-_{m,ij} \qquad (3-13)$$

Step 4: Calculate the fuzzy positive aggregated distance, D^+_m, and fuzzy aggregated negative distance, D^-_m, using the Euclidean distance according to the method proposed by Triantaphyllou and Lin (1996), as expressed in these equations:

$$D^+_m = \left(\sum_{ij}\left(D^+_{m,ij}\right)^{\{2\}}\right)^{\left\{\frac{1}{2}\right\}} \qquad (3-14)$$

$$D^-_m = \left(\sum_{ij}\left(D^-_{m,ij}\right)^{\{2\}}\right)^{\left\{\frac{1}{2}\right\}} \qquad (3-15)$$

where D^+_m and D^-_m have the fuzzy elements $(d^+_{m1}, d^+_{m2}, d^+_{m3})$ and $(d^-_{m1}, d^-_{m2}, d^-_{m3})$, respectively.

Step 5: Determine the fuzzy gap index, Δ_m of the m^{th} municipality, using the method adapted from Triantaphyllou and Lin (1996), as expressed by the following equation:

$$\Delta_m = D_m^+ \{/\} (D_m^+ \{+\} D_m^-) \quad (3-16)$$

Step 6: Calculate the crisp gap index, δ_m of the m^{th} municipality from the fuzzy elements of $D_{m,ij}^+$ and $D_{m,ij}^-$ using the following equations (Chen 2000; Chen and Tsao 2008; Szmidt and Kacprzyk 2000):

$$d_m^+ = \sqrt{\frac{1}{3}[(d_{m1}^+)^2 + (d_{m2}^+)^2 + (d_{m3}^+)^2]} \quad (3-17)$$

$$d_m^- = \sqrt{\frac{1}{3}[(d_{m1}^-)^2 + (d_{m2}^-)^2 + (d_{m3}^-)^2]} \quad (3-18)$$

$$\delta_m = \frac{d_m^+}{d_m^+ + d_m^-} \quad (3-19)$$

Step 7: Calculate the gaps in the FDRR indicators. The fuzzy aggregated distance of the FDRR indicators, D_{ij}^+ and D_{ij}^-, which have the fuzzy elements $(d_{ij1}^+, d_{ij2}^+, d_{ij3}^+)$ and $(d_{ij1}^-, d_{ij2}^-, d_{ij3}^-)$, respectively, can be calculated using the following equations:

$$D_{ij}^+ = \left(\sum_m \left(D_{m,ij}^+\right)^{\{2\}}\right)^{\{\frac{1}{2}\}} \quad (3-20)$$

$$D_{ij}^- = \left(\sum_m \left(D_{m,ij}^-\right)^{\{2\}}\right)^{\{\frac{1}{2}\}} \quad (3-21)$$

The crisp gap index of the FDRR indicators,δ_{ij}, can then be calculated using the formulas similar to Eqs. 3-17 to 3-19:

$$d_{ij}^+ = \sqrt{\frac{1}{3}\left[\left(d_{ij1}^+\right)^2 + \left(d_{ij2}^+\right)^2 + \left(d_{ij3}^+\right)^2\right]} \quad (3-22)$$

$$d_{ij}^{-} = \sqrt{\frac{1}{3}\left[\left(d_{ij1}^{-}\right)^2 + \left(d_{ij2}^{-}\right)^2 + \left(d_{ij3}^{-}\right)^2\right]} \qquad (3-23)$$

$$\delta_{ij} = \frac{d_{ij}^{+}}{d_{ij}^{+} + d_{ij}^{-}} \qquad (3-24)$$

3.5. Results of fuzzy-based gaps assessment

The fuzzy and crisp gap indices of the FDRR management system of each municipality were calculated by using the combined concept of gap analysis and fuzzy TOPSIS. To illustrate the method, take for example the fuzzy performance appraisal carried out for the municipality of Pateros (M6) in Table 3-3. Using the definition of the fuzzy performance appraisal ($P_{m,ij}$) in Eq. 3-8, the fuzzy equivalent performance appraisal($F_{m,ij}$) was calculated using Eqs. 3-7 and 3-9. By following the procedures Steps 1 to 3 in Section 4.2, the fuzzy positive and negative gaps ($D_{m,ij}^{+}$, $D_{m,ij}^{-}$) were calculated. The results were plotted as shown Figs. 3-6 and 3-7, for $D_{m,ij}^{+}$ and $D_{m,ij}^{-}$, respectively. Based on the fuzzy positive gaps in Fig. 3-6, the largest gap is found in FDRR indicator S21 while no gap was observed in S13, S23, S24, and S25 (since $P_{m,ij}$ = *Good*). Similarly, the fuzzy negative gaps in Fig. 3-7 show that the FDRR indicators S21, S26, S31, S32 and S33 have no gap, since the corresponding $P_{m,ij}$ is *Poor* as seen in Table 3-3. To calculate the fuzzy gap index of Pateros (Δ_6), the procedure from steps 4 to 10 was used. The rest of the fuzzy gap indices of all assessed municipalities (Δ_m) were calculated using the same procedure, and were plotted as shown in Fig. 3-8. Using the order of rank method proposed by Triantaphyllou and Lin (1996), it shows that Pateros has the highest fuzzy gap index, while Navotas City (M3) has the lowest gap compared to all the other assessed municipalities. To calculate the crisp gap indices of each municipality (δ_m), the procedure in Step 6 was carried out. The results are shown in a histogram in Fig. 3-9.

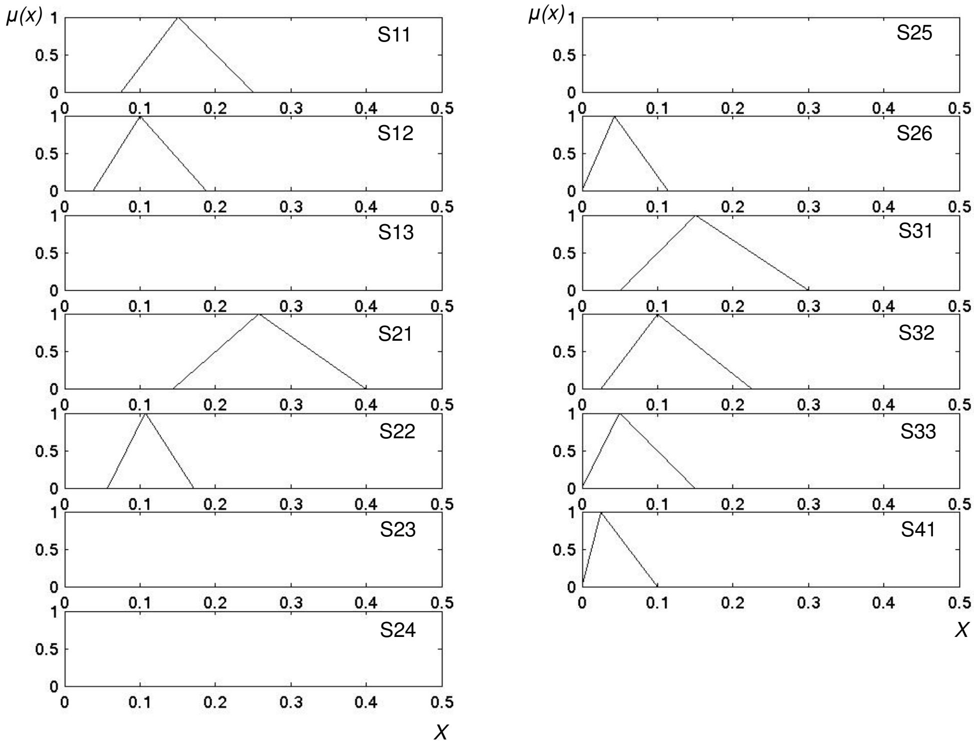

Fig. 3-6 Fuzzy positive gaps in the FDRR management of Pateros based on the FDRR indicators in Table 3-2.

It is worth to note that the priority ranks derived using fuzzy gap indices are consistent with the ranks determined using crisp gap indices.

The calculation of the overall gap index of each FDRR indicator (δ_{ij}) (from 14 assessed municipalities) was carried out according to Step 7 in Section 4.2. The results are summarized in a histogram as shown in Fig. 3-10. The highest gap index ($\delta_{ij} = 0.594$) is seen in S33 (i.e. timely response and rescue operations), while the gap index for S13 (municipal-based early warning system) and S24 (communication systems) is zero.

3.6. Analyses and discussion

In this study, the gap indices represent the weaknesses in the FDRR management systems in Metro Manila. Using these values, we can rank the

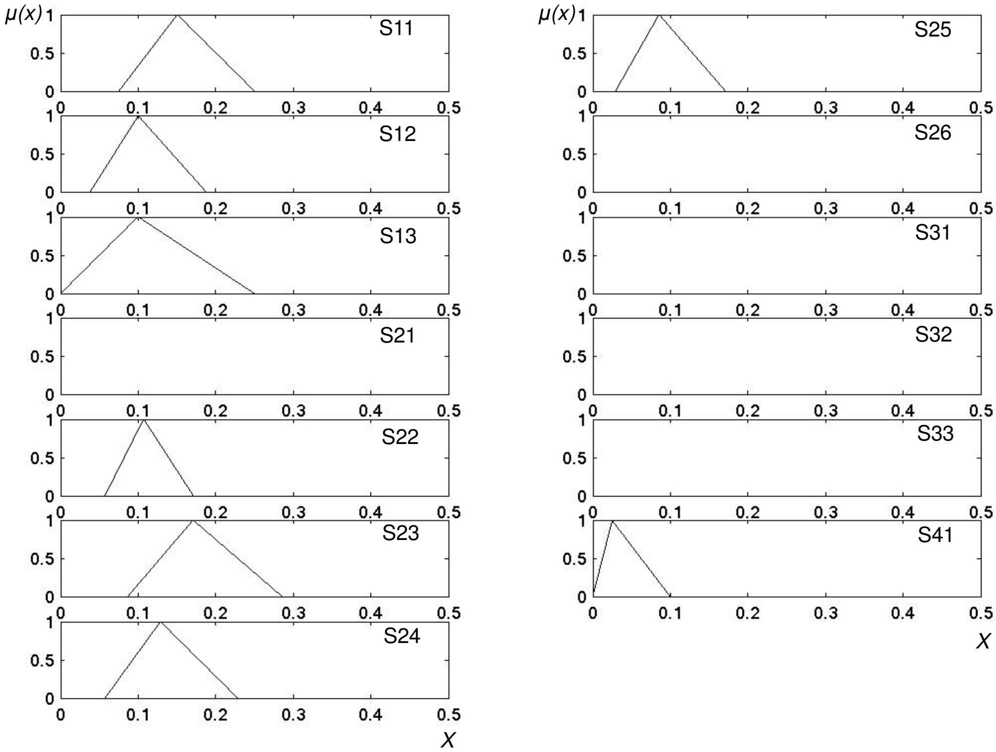

Fig. 3-7 Fuzzy negative gaps in the FDRR management of Pateros based on the FDRR indicators in Table 3-2.

municipalities and FDRR management indicators in order of priority. The crisp gap indices of the municipalities are consistent with the fuzzy gap indices, thus, for simplicity, only the crisp gap indices obtained from the same fuzzy gap values are analyzed and discussed. For the purpose of brevity, 4 municipalities with the highest gaps and 4 municipalities with the lowest gaps are analyzed and discussed.

Based on Fig. 3-9, the 4 municipalities with the highest gap indices (in descending order) are Pateros (M6) ($\delta_m = 0.536$), Pasig City (M7) ($\delta_m = 0.415$), Parañaque City (M13) ($\delta_m = 0.411$) and Las Piñas City (M12) ($\delta_m = 0.363$). The gaps in the FDRR management of Pateros is attributed to the poor performance of the municipality in its emergency response (Response sub-system, S3) during the tropical storm Ondoy, which indicates that Pateros requires immediate support from governing authorities to improve their FDRR management system. From Table 3-3,

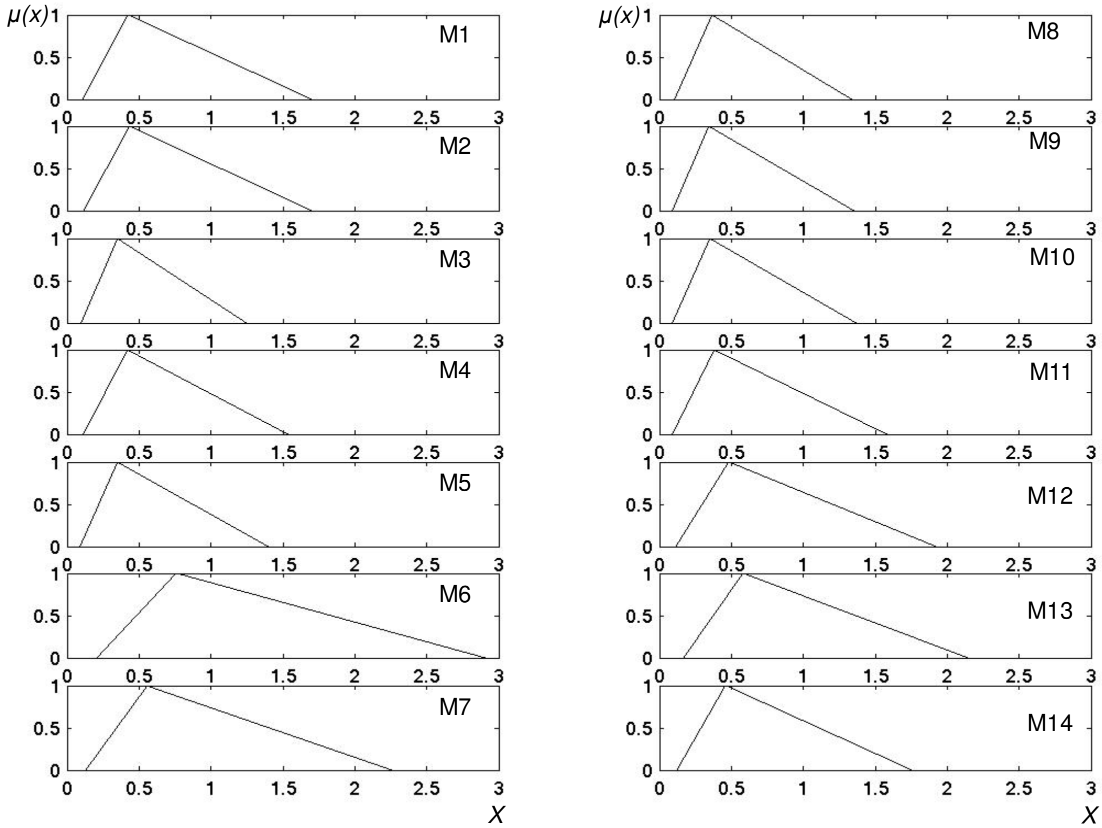

Fig. 3-8 Fuzzy gap indices of the 14 assessed municipalities.

the flood disaster prevention mechanism was given a relatively low evaluation, which suggests that there is a need to establish a municipal-based institutional FDRR management framework in Pateros. The poor performance in the flood management system of Pateros is evident in its experience during the tropical storm Ondoy, where 92.86% of its total land area was inundated and nearly 100% of its population was affected as shown in Table 3-1.

Pasig City, on the other hand, is poor in terms of their disaster response (S3) during the tropical storm Ondoy. As seen in Table 3-3, the residents experienced poor performance in terms of flood warning dissemination (S31) and evacuation (S32). Pasig City has the 3rd highest number of population that was affected during the storm (about 505,000 persons), and 4th in term of the highest amount of damage incurred

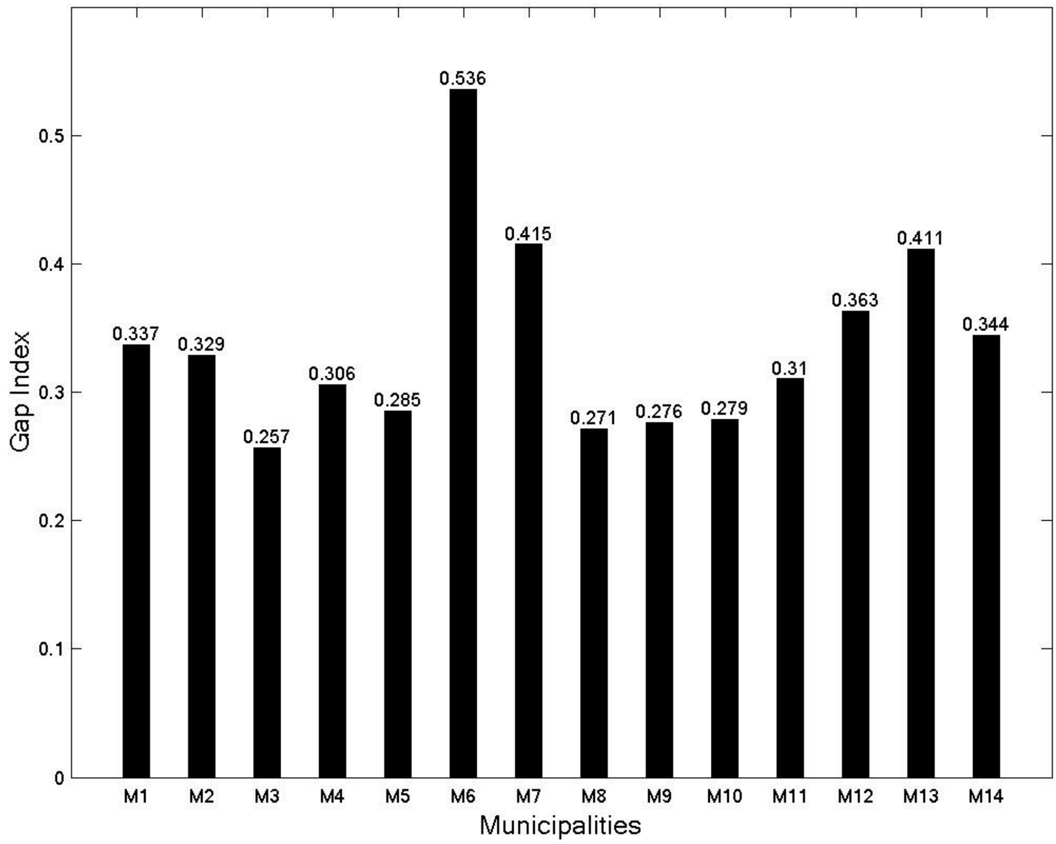

Fig. 3-9 Histogram of crisp gap indices representing the overall gaps in the FDRR management systems of the 14 assessed municipalities in Metro Manila.

within Metro Manila. Review of the flood warning dissemination and evacuation response systems, including the identification of evacuation areas is necessary, since flood vulnerability (S22) has not yet been sufficiently established in Pasig City. In general, based on the results of the study, Pasig City requires serious improvement in its disaster Response (S3) as well as enhancement in its Prevention (S1) and Recovery (S4) measures.

Based on the performance appraisal in Table 3-3, Parañaque City was insufficient in terms of flood vulnerability assessment (S22) and timely emergency response and rescue (S33). Establishing its flood vulnerability may provide the necessary information that can help address the weaknesses in S33. Hence, improvement in the flood preparedness and emergency response of Parañaque City is

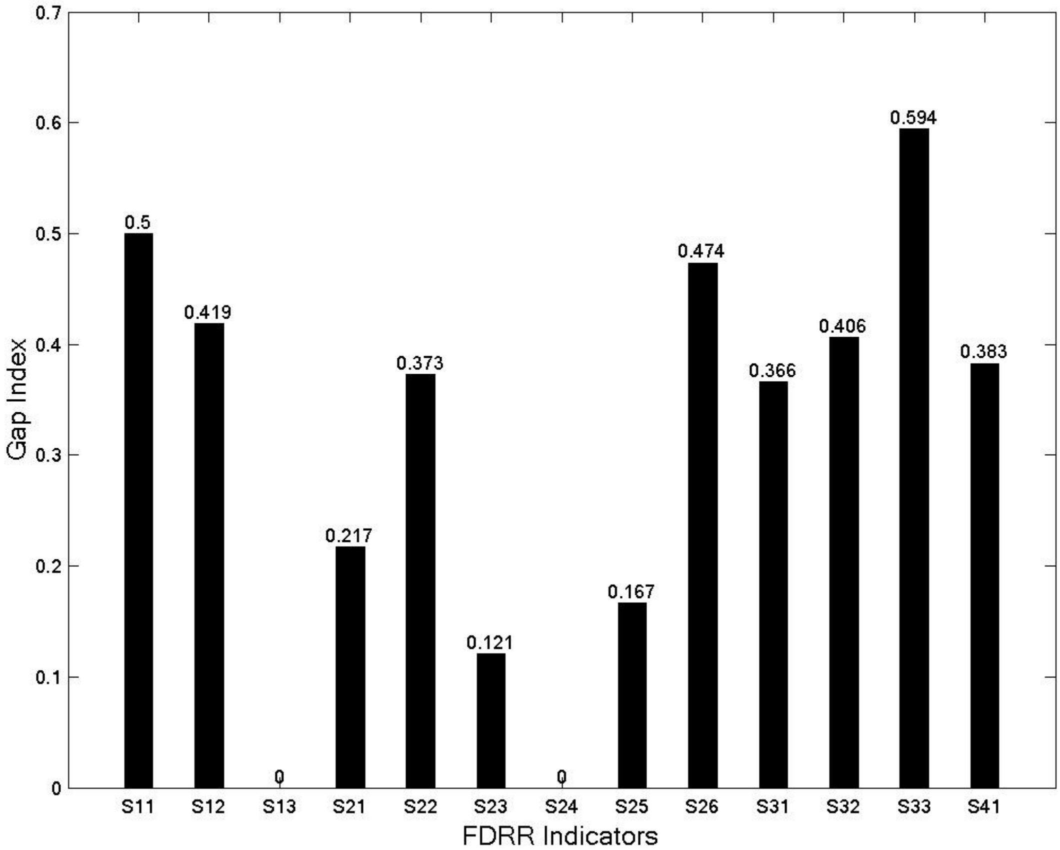

Fig. 3-10 Histogram of crisp gap indices representing the overall gaps in each of the FDRR indicators of the 14 assessed municipalities in Metro Manila.

critical for the success of its FDRR management system.

The FDRR management system of Las Piñas City is particularly weak in terms of flood prevention (S1) and flood disaster response (S3). The structural flood mitigation measures (S12) are particularly pointed out as insufficient to prevent large floods from occurring within the city. The city also requires improvement in its emergency response and rescuing operations (S33). On the other hand, its flood disaster preparedness (S2) system and disaster recovery system (S4) are already quite satisfactory (based on the appraisal), which perhaps can be further strengthened.

The four municipalities with the lowest gap indices are (in ascending order) Navotas City (M3) ($\delta_m = 0.257$), Taguig City (M8) ($\delta_m = 0.271$), Marikina City (M9) ($\delta_m = 0.276$) and Quezon City (M10) ($\delta_m = 0.279$) (Fig. 3-9). The relatively small differences in their gap indices indicate that the overall level of satisfaction in their FDRR management system is almost the same. Closer inspection of the ratings in Table 3-3 reveals that Navotas City is much more similar with Taguig City than with Marikina City and Quezon City. All 4 municipalities have the same performance ratings for the FDRR indicators under Prevention (S1) while the ratings vary for Preparedness (S2), Response (S3) and Recovery (S4). This suggests that the FDRR indicators in S1 significantly affect the results of the gaps assessment.

With regard to Navotas City and Taguig City, both municipalities have shown satisfactory performance in terms of Prevention (S1) and Preparedness (S2). Both also performed quite fairly in terms of disaster response and disaster recovery. Marikina City on the other hand performed quite well in terms of disaster recovery, which may be due in part to its high economic status compared to some of the clustered cities in Metro Manila. It is however particularly weak in terms of flood zoning (S11) and vulnerability assessment (S22), which is perhaps due to its rapidly increasing urbanization.

Quezon City is the largest and most populated municipality in Metro Manila (as shown in Table 3-1). Its road network serves as a major artery to most municipalities in Metro Manila, thus making it the busiest in terms of economic activities. The FDRR management in Quezon City is generally good in terms of flood preparedness (S2) and emergency response (S3). Its weak points, however, exist in disaster prevention (S1), which is primarily due to the weak implementation of flood zoning (S11) in highly-densed communities, and poor maintenance of structural flood mitigation measures (S12) (such as drainage systems).

In terms of the FDRR management components, S33 (timely response and rescue operations) has the highest gap index, indicating that most of the municipalities are particularly weak in the implementation of this measure. Most of the surveyed municipalities gave a rating of either fair or poor. Only 2 municipalities (Navotas City and Taguig City) indicated that the speed of their response and rescue operations during the flooding of the tropical storm Ondoy was satisfactory. Next to S33 is S11 (Flood Zoning), which many of the assessed municipalities believe could still be improved. The FDRR indicators that have the lowest gap index ($\delta_m = 0$) are S13 (municipal-based early flood warning) and S24 (communication systems). The absence of gaps in S13 (Fig. 3-10) indicates that, as a preventive measure, all the assessed municipalities already have early flood warning systems in place, however, the gaps in S31 (warning dissemination, $\delta_m = 0.366$) suggests that some municipalities do not have an effective means to communicate the potential flood disasters within their area. Although S24 shows no gap (indicating the availability of communication systems in all assessed municipalities), the effective use of communication equipment should include fast dissemination. Many flood hazard zones in Metro Manila is densely populated with hard-to-reach areas, thus making it difficult for many flood managers to instantly communicate flood warnings to all their constituents. In view of this, some of the gaps in S32 (Evacuation response) and S33 (Timely response and rescue operations) can be due to the insufficiencies in S31.

In general, the proposed FDRR management gaps assessment provides a systematic, transparent and more objective approach in obtaining the bases for FDRR improvement/enhancement prioritization. The approach however is highly dependent on the knowledge of the respondents in their FDRR management system. The analysis of gaps must also provide reasonable findings to reduce the possibility of misprioritization of resources. Additonal factors (i.e. affected population and flood damages) can be considered in the analysis to determine an overall and more reasonable priority index.

3.7. Conclusion

This study is a first attempt to describe a method for gaps assessment of FDRR management using a fuzzy multi-attribute decision making approach. A formulation was derived, based on fuzzy TOPSIS, to systematically and quantitatively determine the gaps in municipal-based FDRR management systems using the appraisal provided by municipal-based stakeholders. The conclusions are drawn as follows:

(1) The gaps existing in the municipal-based FDRR management systems in Metro Manila can be quantified and evaluated using fuzzy multi-attribute gaps assessment method;

(2) The use of priority ranking in the multi-attribute decision making provided a systematic solution in the assignment of fuzzy weights on each of the FDRR phases (subsystems) and FDRR measures (indicator);

(3) The overall gaps in the FDRR management systems in each of the 14 assessed municipalities in Metro Manila are relatively low; however, serious attention is needed to improve the disaster preparedness and disaster response mechanisms. A system for flood disaster recovery is needed in most municipalities to avoid compounding issues from higher frequency of flood events. Relocation of human settlement and proper land use planning will significantly reduce the risks and potential damages in flood prone areas;

Finally, the proposed gaps assessment approach provides a simple but reasonable means to carry out a rapid comparative assessment of the different municipal-based FDRR management systems in Metro Manila. By focusing only on the need to immediately identify the priority areas (i.e. municipalities) for FDRR management improvement, the priority indices were reasonably obtained using the qualitative judgment of the assessors. This approach is simple and can be useful in providing insights to researchers and decision-makers. To accommodate more complex decision-making, this approach can still be improved by: expanding the performance rating scale (e.g. very poor, poor, fair, good, very good); enhancement of the fuzzy weighting scheme; and combination with other decision support systems (e.g. evidential reasoning approach).

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CHAPTER 4

BASIC ENVIRONMENTAL IMPACT STUDY OF STRUCTURAL FLOOD MITIGATION MEASURES USING THE RAPID IMPACT ASSESSMENT MATRIX (RIAM) TECHNIQUE

4.1. Introduction

Environmental impact assessment (EIA), in principle, is the systematic approach used in the identification and evaluation of beneficial and harmful impacts on the physical, biological and socio-economic components of the environment, which may arise from the implementation of projects, plans, programs or policies (Petts 1999; Wang et al. 2006). At present, EIA is a common feature in the appraisal of planned infrastructure projects (Tamura et al., 1994) such as roads (Zhou and Sheate 2011), flood protection systems (Ludwig et al., 1995) and water supply systems (Al-agha and Mortaja, 2005). Flood protection systems, particularly structural flood mitigation measures (SFMM), are being undertaken throughout the centuries to reduce flood damages and losses (Poulard et al., 2010). In Southeast Asia, most of its key cities, including Jakarta (Indonesia), Bangkok (Thailand) and Metro Manila (Philippines), to name but a few, are highly vulnerable to immense inundations and violent floods. Recent studies on climate change (The World Bank, 2010; Yusuf and Francisco, 2009) indicated that this region will experience higher frequency of extreme flood events, creating greater demands for SFMM. The use of SFMM has perhaps become very valuable in many urbanized areas; however, poor management decisions in the implementation of these infrastructures may lead to geomorphological, ecological and/or social ramifications (Everard, 2004). For instance, in the past, several channelization works in Europe (for the purpose of flood control) brought adverse ecological consequences in many European river systems

(Brookes and Gregory, 1983). EIA thus is a necessary step during the early planning stages of SFMM in order to gain clear insights of the structures' probable impacts with respect to the different components of the total environment. Likewise, the use of appropriate EIA techniques can aid the decision-makers to formulate appropriate actions based on informed decisions in light of project urgency and limited resources, which are common constraints in the developing countries (Shah et al. 2010).

In the Philippines, through Presidential Decree No. 1586 (1978) – a law that requires the assessment of a proposed project to determine its effects on the "quality of the environment"– EIA is mandatorily being carried out on planned SFMM. The EIA methods commonly used are generally descriptive and qualitative in nature (e.g. Department of Public Works and Highways, 1998; City Office of Navotas, 2009), which are similar to the EIA methods (i.e. ad hoc and simple checklist methods) described by Lohani et al. (1997). The ad hoc method is a non-structured approach that generally relies on the "experience, training and intuition" of the assessing expert. The problem with the ad hoc method is that it generally lacks the means to meaningfully organize considerable amounts of information about the biophysical, social and economic environment. It merely describes the pertinent information concerning the impacts without much emphasis on importance and magnitude. This process of assessment is non-replicable, which makes the EIA conclusions at times difficult to review or even criticize (Lohani et al., 1997). The simple checklist method, on the other hand, is structured, elaborative and more systematic compared to the ad hoc method. It typically displays a list of environmental parameters (or potential impacts) that are evaluated against a set of assessment criteria (Barthwal, 2002; Lohani, et al. 1997). One disadvantage of this method is that it often fails to account for the spatial and cumulative effects of the identified impacts (Munier, 2004). The simple checklist method is also deficient when it comes to providing the necessary guidelines for estimating and interpreting the degrees of impacts (Lohani et al., 1997), which essentially precludes the transparency of the EIA process. According to Villaluz (2003), one way to advance the EIA system in the Philippines is to select methods that will provide better transparency to help “maintain the impartiality of the entire process”.

An EIA approach that provides for the quantitative analysis of subjective judgments may help address the limitations of the two traditional EIA methods mentioned above (Ijas et al., 2010). Such concepts, including the assessment of cumulative effects, are fundamental in the rapid impact assessment matrix (RIAM) technique (Pastakia and Jensen, 1998). The RIAM technique is a semi-quantitative impact assessment approach that utilizes standardized evaluation criteria and rating scales. It has been favored in many case-studies from various sectors (Mondal et al., 2010; El-Naqa, 2005; Al Malek and Mohamed, 2005; Yeboah, et al. 2005) primarily due to its simplicity and robust application. In spite of its wide reception, there has been no reference, as far as the authors know, of its use in the EIA of SFMM in any part of the world. The applicability of the RIAM in the Philippine EIA system is also yet to be established. The Philippines can benefit from adopting this EIA method, thus it is important to provide references of its application. It is necessary however to ensure the conformity of the RIAM technique with the general impact assessment approach prescribed in the Philippine EIA system. In this EIA system, the evaluation and prediction of the likely impacts must be made in terms of project phase timelines (i.e. pre-construction, construction, operation and abandonment phases), which have not been given emphasis in the past RIAM studies that the authors are aware of.

This chapter mainly explores the benefits of using the RIAM technique in the evaluation of SFMM by examining the results of the EIA of selected planned SFMM projects in Metro Manila. The primary aim is to improve the transparency and minimize subjectivity in the EIA process specific to the SFMM projects in Metro Manila. Furthermore, a slight modification of the RIAM method is proposed not only to enhance the transparency and sensitivity of the evaluation process, but also to cope with the requirements of the EIA system in the Philippines. These modifications are intended to improve the outcome of the EIA, but may also find application in other infrastructure projects. The following sections introduce the basic profile and environmental conditions of the study area; elaborate and demonstrate the application of the RIAM method; analyze and discuss the results of the impact assessment; and offer some recommendations and conclusions with the aim of providing valuable insights for decision makers, planners and policy makers for the improvement of the EIA practice in the Philippines.

4.2. Environmental setting

Metro Manila is an administrative region in the Philippines that serves as a focal point for major political and economic activities in the country. The geographic location of Metro Manila is shown in Fig.4-1. Based on this map, Metro Manila is situated in a semi-alluvial fan that opens to Manila Bay on the west and Laguna de Bay Lake on the southeast. At present, the metropolis is comprised of 17 highly urbanized municipalities that are sharing a relatively small area of 638 km^2. The population in Metro Manila is about 11,758,000 persons (National Statistics Office, 2007), making it the most densely populated administrative region in the country. According to the study of the National Statistical Coordination Board (2009), about 30% of the country’s gross domestic product comes from Metro Manila. Despite the high economic activities in this region, the economic growth and urban development in many of its municipalities is persistently slow, which according to Page (2000), is partly due to the frequently occurring disasters caused by immense and violent floods that takes place during the monsoon and storm periods (from May to October). The costs of flooding in Metro Manila (based on 2008 values) can range from PhP 15 billion ($337 million) to PhP 111 billion ($2.5 billion), which is 3% to 24% of the region’s gross domestic product (The World Bank, 2010). Recent flood events

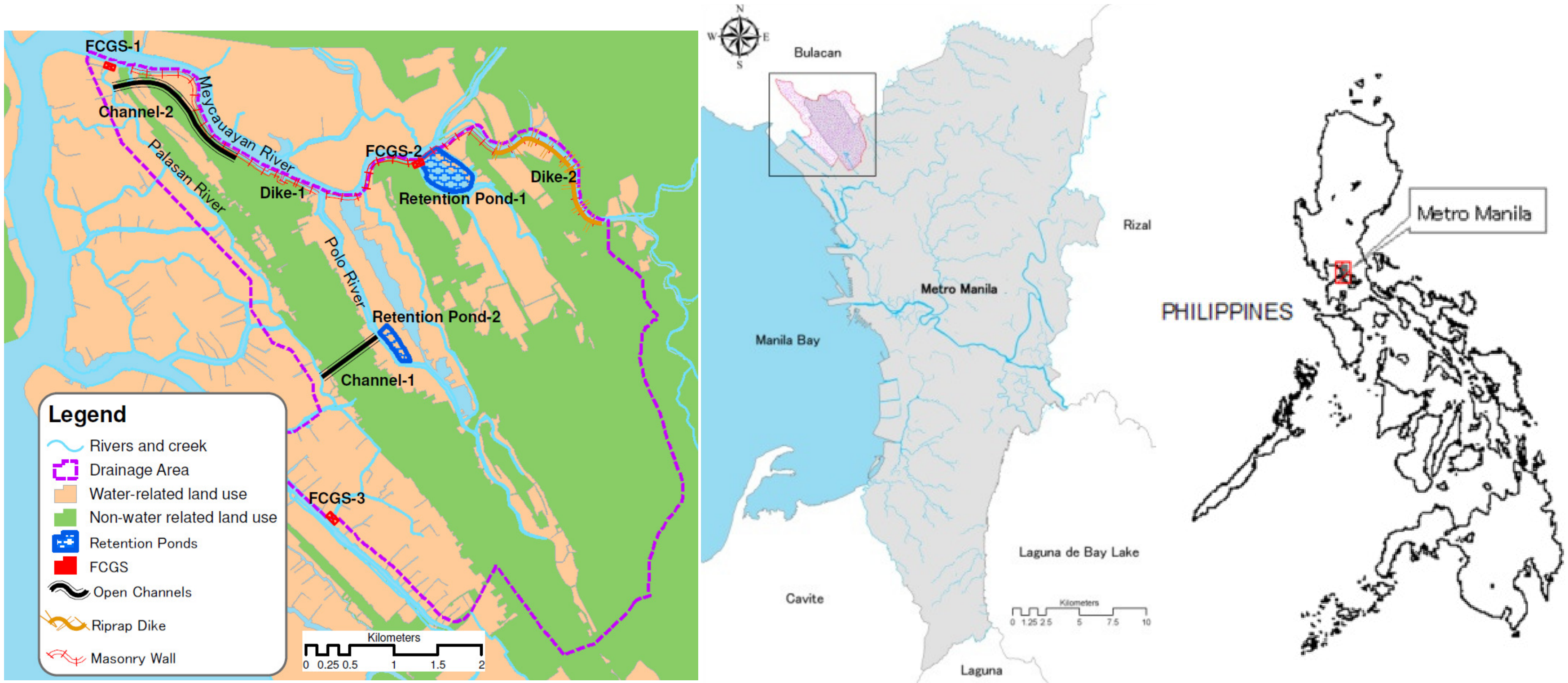

Fig. 4-1 Geographical locations of Metro Manila and the study area (right), and locations of the planned structural flood mitigation measures (left). The structural flood mitigation measures are labeled as follows: Dike-1 and Dike-2 for the lower stream and upper stream dikes, respectively; Channel-1 and Channel-2 for the diversion channel and small open channel, respectively; Flood control gate structures (FCGS) -1, -2 and -3; and Retention Ponds-1 and -2.

(Rabonza, 2009) are increasingly devastating, resulting in the loss of many lives and causing immense damages to properties. According to Fano (2000), the occurrences of floods in Metro Manila have been documented as early as 1898. However, there seems to be no record of the actions taken to mitigate the occurrences of floods until 1943. The major flood event that took place in 1943 compelled the Philippine government, shortly after the incident, to initiate its first comprehensive flood study and flood control plan, which were completed in 1952 (Bureau of Public Works 1952). The flood control plan consisted mainly of drainage improvements covering most parts of the present day Metro Manila.

This chapter focuses on the flood-prone sub-drainage area (approximately 20 km^2) that is located at the north-northwest part of Metro Manila, as indicated in Fig. 4-1. This sub-drainage area is home to approximately 160,000 residents. Its topography is generally characterized by flat and low-lying coastal plains with ground elevation ranging from 0 to 1.5 m above mean sea level. It has a mixed land-use comprised of commercial districts, industrial districts, residential areas and fishponds. As shown in Fig. 4-1, the study area is bordered by two rivers and three creeks with 3 minor river systems traversing the drainage area from southeast to northwest. The average annual rainfall is less than 3,000 mm. The river system has limited aquatic biota due to the poor water quality conditions. Garbage, especially commercial plastics, was observed deposited along the riverbanks and floating along the river mid-streams. Migratory birds that feed on insects, fishes and invertebrates were observed wandering and nesting close to the Meycauayan River, while few patches of mangroves exist at the lower section of the Meycauayan River. Most mangrove areas have been converted to fishponds and settlement areas. Water hyacinths were observed at the approaching upstream of the Meycauayan River. High volume of settlers is found at and near the left bank of the upper section of the Meycauayan River and along narrow natural waterways. Due to the very poor discharge capacity in this drainage area, floods can easily manifest during the rainy seasons, contributing to the slow economic growth rate of the affected municipalities.

To improve the drainage conditions, 2 river improvement works, 2 open channels, 2 retention ponds and 3 flood control gate structures were proposed by the Department of Public Works and Highways (2001), under the Metro Manila flagship program on flood management. Table 4-1 shows salient information of the 9 planned SFMM investigated in this study. The locations of these structures are shown in Fig. 4-1. The river improvement works as described in Table 4-1 involves the construction of masonry walls (Dike-1) and riprap dikes (Dike-2) at the left bank of the lower and upper sections of the Meycauayan River, respectively. These structures will serve as preventive measures from bank overflow, and protection from the scouring effects of turbulent flow against the river's critical bends and bridge abutments. The open channels consist of a diversion canal (Channel-1) that will discharge excess water from the Polo River to the Palasan River; and a small drainage channel (Channel-2) that will aid in the draining of surface water near the lower section of the Meycauayan River (Fig. 4-1). Settlements can be found along the alignment of the planned open channels and retention ponds. The authors evaluated the environmental impacts of these 9 planned SFMMs using the modified RIAM technique.

4.3. RIAM methodology

Evaluation and review of the EIA was carried out using the RIAM technique to determine the degree of impacts of the planned flood mitigation structures along the immediate and surrounding environment of the study area. Table 4-2 shows the scope of the EIA indicated by the list of 32 environmental components. Impacts that will arise from the implementation of the planned structures (i.e. Dike-1, Dike-2, Channel-1 and Channel-2) on each environmental component are denoted by the symbol (●). The symbol (X), on the other hand, indicates that the implementation of

Table 4-1 Salient features of the selected planned structural flood mitigation measures in Metro Manila.

Planned structural flood mitigation measures	Description of activities	Length (m)	Width (m)	Average Depth (m)	Area (ha)	Size (m^2)
Dike-1	Raising of masonry wall, installation of ripraps and alteration of river bank configuration at the lower section of the Meycauayan River)	4,900	4.0	-	-	-
Dike-2	Raising of riprap dike, installation of new ripraps, and alteration of river bank configuration at the upper section of the Meycauayan River	2,340	4.0	-	-	-
Channel-1	Construction of diversion canal between the Polo River and the Palasan River by excavation	850	9.6	3	-	-
Channel-2	Construction of drainage channel in the lower reaches of the Meycauayan River by excavation	1,650	5.6	2.1	-	-
Retention Pond -1	Increase existing capacity by excavating to an average of 1.5 m depth	-	-	1.5	22	-
Retention Pond-2	Construct a pond by excavation to an average depth of 2.0 m and install embankment	-	-	2.0	5	-
FCGS-1	Installation of steel roller gate with pump station	-	-	-	-	20
FCGS-2	Installation of steel roller gate with pump station	-	-	-	-	20
FCGS-3	Installation of steel roller gate with pump station	-	-	-	-	20

Table 4-2 Sample summary checklist of potential impacts for Dike-1, Dike-2, Channel-1 and Channel-2.

Environmental Categories	Item no.	Environmental Components	Code	Structural Flood Mitigation Measures			
				Dike-1	Dike-2	Channel-1	Channel-2
Physical/ Chemical	1	Land/soil disturbance due to site clearing	PC-P-1	●[a]	●	●	●
	2	Change in landuse	PC-C-1	X[b]	X	●	X
	3	Local geology and soil erosion	PC-C-2	●	●	●	●
	4	Drinking water	PC-C-3	●	●	●	●
	5	Erosion and riverbank scouring	PC-C-4	●	●	X	X
	6	Surface and groundwater hydrology	PC-O-1	●	●	X	X
	7	Hydraulic conditions	PC-O-2	●	●	●	●
Biological/ Ecological	8	Aquatic habitat	BE-C-1	●	●	X	●
	9	Wildilfe and terrestrial impacts	BE-C-2	●	●	X	●
	10	Riparian and wetlands	BE-C-3	●	●	X	X
	11	Waste generation from construction and excavation	BE-C-4	●	●	●	●
	12	Aquatic/freshwater biology	BE-C-5	X	X	●	●
	13	Surface water quality	BE-C-6	●	●	●	●
	14	Aquatic habitat	BE-O-1	●	●	●	●
	15	Water quality	BE-O-2	●	●	●	●
Social/ Cultural	16	Involuntary Resettlement	SC-P-1	●	●	●	●
	17	Public acceptance	SC-P-2	X	X	●	●
	18	Air quality	SC-C-1	●	●	●	●
	19	Noise levels	SC-C-2	●	●	●	●
	20	Population dynamics	SC-C-3	●	●	●	●
	21	Dependency burden	SC-C-4	●	●	●	●
	22	Housing characteristics and utilities	SC-C-5	●	●	●	●
	23	Health and safety of construction workers	SC-C-6	●	●	●	●
	24	Health and safety of general public	SC-C-7	●	●	●	●
	25	Aesthetic and cultural scenic sites	SC-C-8	●	●	●	●
	26	Local planning, coordination and economic growth	SC-C-9	●	●	●	●
	27	Public utilities and infrastructure	SC-C-10	●	●	●	●
	28	Natural environmental and health hazards	SC-O-1	●	●	●	●
	29	Urban living conditions	SC-O-2	●	●	●	●
Economics/ Operational	30	Property and infrastructure	EO-O-1	●	●	●	●
	31	Development potential	EO-O-2	●	●	●	●
	32	Local revenue and economy	EO-O-3	●	●	●	●

[a] "●" − Potential source of impact; [b] "X "−No perceived impact

the planned SFMMs have no perceived impact on the environmental components. Each of the environmental component falls under one of the 4 environmental categories defined by Pastakia and Jensen (1998): Physical/Chemical (PC), Biological/Ecological (BE), Social/Cultural (SC) and Economics/Operational (EO). Typically, the grouping of environmental components stops here, but for the purpose of this study, the RIAM method is slightly modified to further sub-group the environmental components in terms of project phases. As earlier discussed, project phasing improves the outcome of the EIA, since this allows the review of a wider scope of impacts that benefits the formulation of environmental management plans. In the Philippines, based on the national environmental impact statement system (Department of Environment and Natural Resources, 2003), the typical project phases to be considered for infrastructure projects are pre-construction phase, construction phase, operation phase and abandonment phase. The term *abandonment phase* refers to a project phase wherein a project is decommissioned (or abandoned) upon reaching the end of its productive life (e.g. Kaiser, 2005; Rapantova et al., 2012), or when it simply ceases its operation for whatever reason. In this study however, open channels and river improvements are considered as *permanent* structures that are only subject to either maintenance or further enhancement due to their long term (or perpetual) necessity in Metro Manila, thus the abandonment phase was not included in this study. The abbreviations used for the project phases in this study are as follows: Construction Phase (C), Pre-construction Phase (P) and Operation Phase (O). Giving emphasis to project phases, each of the environmental components is labeled using the following syntax: environmental category – project phase – sequence number (e.g. Item #2 in Table 4-2 is labeled as PC-C-1, which stands for Physical/Chemical category, construction phase and first in the sequence of the group PC-C, respectively). In this study, there are 7, 8 and 14 environmental components in the Physical/Chemical, Biological/Ecological and Social/Cultural categories, respectively.

The Economics/ Operational category has 3 components that focus only on major economic considerations during the operation phase. Similar to most infrastructure projects in the Philippines, the comprehensive study of the economic aspect was separately carried out by the Department of Public Works and Highways (2001), which ensured that the projects, when implemented, can provide the desired economic benefits within the covered areas. In addition, the projects in this study are in part funded through overseas development assistance, which reduces the burden of project cost.

The RIAM method has provisions for the semi-quantitative evaluation of environmental components using a set of standardized assessment criteria. Unlike the simple checklist approach described in Section 1, the evaluation of the assessment criteria in RIAM is clearly explained by a standard scaling procedure (Pastakia and Jensen, 1998).The assessment criteria are categorized into 2 groups, namely group *A* and group *B*. The *A* group consists of the Importance Criterion (*A1*) and Magnitude Criterion (*A2*), while the *B* group consists of the Permanence Criterion (*B1*), Reversibility Criterion (*B2*) and Cumulative Criterion (*B3*). The scale values of *A1* and *A2* and the impact description of each scale are shown in Table 4-3. The range of scales of *A1* is from 0 to 4 while the range of scales of *A2* is from -3 to 3. In the *B* group, as shown in column I of Table 4-4, the range of scales of each criterion is from 1 to 3, where the scale value of 1 denotes *no change/not applicable*. The impact descriptions of the scale values 2 and 3, however, vary between *B1*, *B2* and *B3* (Pastakia and Jensen 1998).

The values of the assessment criteria of groups *A* and *B* are determined either by using the experience and intuition of the assessing team, or by referring to empirical evidences (if available), such as those acquired from experiments or from generally

Table 4-3 Assessment criteria of Group _A_ (Pastakia and Jensen 1998).

Assessment criteria	Scale	Description
A1 (Importance of Conditions)	4	Important to national/international interests
	3	Important to regional/national interests
	2	Important to areas immediately outside the local condition
	1	Important only to the local condition
	0	No Importance
A2 (Magnitude of change)	3	Major positive benefit
	2	Significant improvement in status quo
	1	Improvement in status quo
	0	No change/status quo
	-1	Negative change to status quo
	-2	Significant negative disbenefit or change
	-3	Major disbenefit or change

known past experiences. The descriptions of the scales as shown in Tables 4-3 and 4-4 serve as guidelines for the appraisal of each assessment criterion. These descriptions however, are vague and may have various interpretations depending on the assessing individual. The worth of the environmental scores can be compromised if the bases or references used in the appraisal are not consistently applied in the assessment of the projects. These bases (or references) were decided upon by the assessing team prior to the appraisal of each criterion of groups _A_ and _B._ In this study, the assessment criteria in Tables 4-3 and 4-4 are further explained using the following descriptions:

a. Assessment criterion _A1_ (Importance of conditions): Pastakia (1998) defined _A1_ as the measure of importance of a project within a specified spatial boundary. In this study, prior to the appraisal of _A1_, the spatial boundaries were decided upon by the assessing team using the study area and the administrative boundaries as reference. For instance, the term "local condition" (when _A1_ = 1) refers to the

Table 4-4 Assessment criteria of Group _B_ showing the original (Pastakia and Jensen 1998) and slightly modified scales of each criteria.

Assessment criteria	I Original		II Slightly modified	
	Scale	Description	Scale	Description
B1 (Permanence)			0	No change/ not applicable
	1	No change/ not applicable	1	Negligible change
	2	Temporary	2	Temporary
	3	Permanent	3	Permanent
B2 (Reversibility)			0	No change/ not applicable
	1	No change/ not applicable	1	Negligible change
	2	Reversible	2	Reversible
	3	Irreversible	3	Irreversible
B3 (Cumulative)			0	No change/ not applicable
	1	No change/ not applicable	1	Negligible change
	2	Non-cumulative/ single	2	Non-cumulative/ single
	3	Cumulative/ synergistic	3	Cumulative/ synergistic

environmental condition confined within the boundary of the drainage area (as shown in Fig. 4-1). This drainage area encompasses 3 municipalities (i.e. Valenzuela City, Obando and Meycauayan City). The area that is "immediately outside the local condition" (when _A1_ = 2 in Table 4-3) refer to the parts outside the drainage area, but within the boundaries of the 3 municipalities. The term "regional" (when _A1_ = 3 in Table 4-3) refers to the administrative regions that cover the 3 municipalities hosting the proposed projects (i.e. Metro Manila and Region III). The term "national" (when _A1_ = 4 in Table 4-3) extends to the boundaries of the Philippine territory.

b. Assessment criterion _A2_ (Magnitude): Pastakia (1998) defined _A2_ as a "measure of scale of benefit/dis-benefit of an impact or a condition". The "measure of scale" (or *significance*) typically depends on the expert judgment of the assessing team, which could be based on calculable environmental thresholds or perceived magnitude of impact. Take for example the assessment of river water quality in terms of dissolved oxygen. If a project is predicted (or perceived) to cause a slight (or temporary) depletion of dissolved oxygen, the corresponding magnitude is *negative change* (or *A2* = -1). If the project however, is predicted to substantially cause the depletion of dissolved oxygen (but still within the permissible limit), the corresponding magnitude is *significant negative change* (or *A2* = -2). If the project will cause the depletion of the dissolved oxygen below the permissible limit, then the corresponding magnitude is *major negative change* (*A2* = -3). Each environmental component may have several indicators for the identification of magnitude. The indicator with the worst/best magnitude is taken as the basis for the environmental component being assessed. For example, the construction of Dike-1 will not affect the concentration of heavy metals on the river, but will temporarily affect turbidity due to soil disturbance. Turbidity is thus favored as the magnitude indicator for water quality instead of heavy metals. The same principle is applied on the positive scales with focus instead on environmental improvement.

c. Assessment criterion *B1* (Permanence): Pastakia (1998) defined *B1* as the "measure of the temporal status of the condition". This determines whether the impact of a project is temporary or permanent. For example, the construction of dike rip raps in Dike-1 is considered permanent, while the noise that will be generated during its construction is a temporary condition.

d. Assessment criterion *B2* (Reversibility): Pastakia (1998) defined *B2* as the "measure of control over the effect of a condition". It was pointed out that *B2* should not be confused or equated with *B1*. For example, the removal of soil during open channelization is permanent but its effect on the nearby aquatic habitat is reversible.

e. Assessment criterion *B3* (Cumulative): Pastakia (1998) described *B3* as the "measure of whether the effect will have a single direct impact or whether it will be a cumulative effect over time, or a synergistic effect with other conditions". This criterion is used to judge the compounding effects of a condition. For instance, the open channels, over long periods of non-flow, will stagnate resulting in poor water quality, which can also be a source of disease causing vectors. The effect is said to be "cumulative", thus the assessment criterion *B3* should carry a scale value of 3 according to Table 4-4.

To clearly represent the image of "no change" or "not applicable" in the evaluation of the *B* criteria, the impact descriptor *no change/not applicable* is re-assigned to the scale value 0, while the scale value of 1 takes a new impact descriptor *negligible change*, as shown in column II of Table 4-4. The impact descriptor *negligible change* is proposed in this study to make a distinction between non-significant impacts and significant impacts, which is not clearly delineated in the original procedure. As pointed out by Kuitunen et al. (2008), the evaluation of the *B* criteria becomes difficult when the significance of impacts "seems to vary and whose characteristics also vary", necessitating the need for disambiguation. In this study, to address the ambiguity of varying impact significance (particularly in the assessment of the *B* criteria) the impact descriptor *negligible change* (which represents non-significance) is included in the evaluation options. The modifications mentioned above are intended to enhance the transparency of the RIAM method.

Using the scales determined in each of the assessment criteria, the environmental score (*ES*) is calculated using the simple formula (Pastakia and Jensen 1998):

$$ES = [A1 \text{ x } A2] \text{ x } [B1 + B2 + B3] \quad (4\text{-}1)$$

Table 4-5 Conversion table of environmental scores to range bands (Pastakia and Jensen 1998) with slight modification.

Range Bands	Environmental Scores	Description
+E	+72 to +108	There will be a major positive change or impact
+D	+36 to +71	There will be a significant positive change or impact
+C	+19 to +35	There will be a moderate positive change or impact
+B	+10 to +18	There will be positive change or impact
+A	+1 to +9	There will be a slight positive change or impact
NI	0	No identified impact (A1, A2, B1, B2 and B3 have zero scores)
NC	0	Negligible change (At least one assessment criterion is non-zero)
-A	-1 to -9	There will be a slightly negative change or impact
-B	-10 to -18	There will be a negative change or impact
-C	-19 to -35	There will be a moderate negative change or impact
-D	-36 to -71	There will be significant negative change or impact
-E	-72 to -108	There will be a major negative change or impact

The environmental score is used to classify the impact in terms of the degree of change represented by range bands as defined by Pastakia and Jensen (1998). Table 4-5 shows the range bands with the corresponding range of environmental scores and impact descriptions. For example, an environmental component with a computed environmental score of 38 would fall within the range band [+D]. However, in response to the slight modification made in the original assessment criteria in Table 4-4, the range bands were slightly revised to replace [N] with [NI] and [NC], where [NI] stands for no identified impact and [NC] for negligible change. Both [NI] and [NC] have an environmental score of 0. The difference between [NI] and [NC] is that the range band [NI] is given when all the scale values of the assessment criteria are zero, while the range band [NC] is applied when there is at least one non-zero scale value in any of the assessment criteria. Consequently, this enhances the efficiency of the evaluation process by allowing the identification of the range band [NI] for an environmental component with *no perceived impacts* (symbol “X”) in Table 4-2 prior to the actual implementation of the RIAM technique. To illustrate, with reference to Table 4-2, Dike-1 has no impact on Item #2 (PC-C-1), hence, the scale values of all the assessment criteria automatically take the value of zero, and equivalently, a range band of [NI].

4.4. EIA using the RIAM technique

Prior to the appraisal, the planned SFMMs were divided into two groups according to environmental components. Dikes-1 and -2 and Channels-1 and -2 were appraised using 7 PC components, 8 BE components, 14 SC components and 3 EO components. Retention Ponds-1 and -2 and FCGS-1,-2 and -3 were evaluated using 5 PC components, 8 BE components, 12 SC components and 2 EO components. Table 4-6a shows the summary of the RIAM analysis of Dike-1, Dike-2, Channel-1 and Channel-2, while Table 4-6b shows the RIAM analysis of Retention Pond-1, Retention Pond-2, FCGS-1 and FCGS-2. Tables-4a and -4b show the appraisal of the assessment criteria, the calculated environmental scores and the corresponding range bands. To illustrate how the range bands were determined using the slightly modified RIAM, consider the impact assessment of Dike-1 at Item #3 (PC-C-2) in Table 4-6a, which represents the impacts on local geology and potential soil erosion in Table 4-2. Dike-1 was evaluated to determine the impacts of its activities on the environmental component PC-C-2 (which stands for physical/chemical environmental component; construction phase; and specifically, geological and soil aspects in Table 4-2) during the construction phase. The activities involved in Dike-1 are: construction of masonry wall, installation of ripraps, and improvement of river bank configuration to enhance the river capacity. Its specific activities, particularly site clearing, riverbed excavation and river bank incision, based on the feasibility study may temporarily cause soil erosion along the Meycauayan River. The activities in Dike-1 will cover a length of

Table 4-6a RIAM analysis of planned river improvement works (Dikes -1 and -2) and open channels (Channels -1 and -2).

Code	Structural flood mitigation measures																											
	Dike-1							Dike-2							Channel-1							Channel-2						
	RIAM analysis							RIAM analysis							RIAM analysis							RIAM analysis						
	A1	A2	B1	B2	B3	ES	RB	A1	A2	B1	B2	B3	ES	RB	A1	A2	B1	B2	B3	ES	RB	A1	A2	B1	B2	B3	ES	RB
PC-P-1	0	-1	2	2	1	0	NC	0	-1	2	2	1	0	NC	0	-1	2	2	1	0	NC	0	-1	2	2	1	0	NC
PC-C-1	0	0	0	0	0	0	NI	0	0	0	0	0	0	NI	1	-2	3	3	1	-14	-B	0	0	0	0	0	0	NI
PC-C-2	1	-2	2	2	3	-14	-B	1	-2	2	2	3	-14	-B	1	-2	2	2	1	-10	-B	1	-2	2	2	1	-10	-B
PC-C-3	4	0	2	2	1	0	NC	4	0	2	2	1	0	NC	4	0	2	2	1	0	NC	4	0	2	2	1	0	NC
PC-C-4	1	2	3	2	1	12	+B	1	2	3	2	1	12	+B	0	0	0	0	0	0	NI	0	0	0	0	0	0	NI
PC-O-1	1	-1	2	2	1	-5	-A	1	-1	2	2	1	-5	-A	0	0	0	0	0	0	NI	0	0	0	0	0	0	NI
PC-O-2	2	3	3	2	1	36	+D	2	3	3	2	1	36	+D	1	3	3	2	1	18	+B	1	3	3	2	1	18	+B
BE-C-1	1	-2	2	2	1	-10	-B	1	-2	2	2	1	-10	-B	0	0	0	0	0	0	NI	1	-2	2	2	1	-10	-B
BE-C-2	1	-1	3	3	1	-7	-A	1	-1	3	3	1	-7	-A	0	0	0	0	0	0	NI	1	-1	3	3	1	-7	-A
BE-C-3	1	-2	3	2	0	-10	-B	1	0	2	2	3	0	NC	0	0	0	0	0	0	NI	0	0	0	0	0	0	NI
BE-C-4	1	-1	2	2	3	-7	-A	1	-1	2	2	3	-7	-A	1	-1	2	2	3	-7	-A	1	-1	2	2	3	-7	-A
BE-C-5	0	0	0	0	0	0	NI	0	0	0	0	0	0	NI	1	-1	2	3	1	-6	-A	1	-1	2	3	1	-6	-A
BE-C-6	1	-1	2	1	3	-6	-A	1	-1	2	1	3	-6	-A	1	-1	2	1	3	-6	-A	1	-1	2	1	3	-6	-A
BE-O-1	1	1	3	2	1	6	+A	1	1	3	2	1	6	+A	1	0	3	2	1	0	NC	1	0	3	2	1	0	NC
BE-O-2	1	1	3	2	1	6	+A	1	1	3	2	1	6	+A	1	0	3	2	1	0	NC	1	-1	3	2	1	-6	-A
SC-P-1	2	-2	3	3	1	-28	-C	2	-3	3	3	1	-42	-D	2	-3	3	3	1	-42	-D	2	-2	3	3	1	-28	-C
SC-P-2	0	0	0	0	0	0	NI	0	0	0	0	0	0	NI	1	-1	3	3	0	-6	-A	1	-3	3	3	0	-18	-B
SC-C-1	1	-1	2	1	2	-5	-A	1	-1	2	1	2	-5	-A	1	-1	2	1	2	-5	-A	1	-1	2	1	2	-5	-A
SC-C-2	1	-1	2	1	1	-4	-A	1	-1	2	1	1	-4	-A	1	-1	2	1	1	-4	-A	1	-1	2	1	1	-4	-A
SC-C-3	1	-1	2	1	1	-4	-A	1	-1	2	1	1	-4	-A	1	-1	2	1	1	-4	-A	1	-1	2	1	1	-4	-A
SC-C-4	2	1	2	1	1	8	+A	2	1	2	1	1	8	+A	2	1	2	1	1	8	+A	2	1	2	1	1	8	+A
SC-C-5	2	0	2	1	1	0	NC	2	0	2	1	1	0	NC	2	0	2	1	1	0	NC	2	0	2	1	1	0	NC
SC-C-6	1	-1	2	1	1	-4	-A	1	-1	2	1	1	-4	-A	1	-1	2	1	1	-4	-A	1	-1	2	1	1	-4	-A
SC-C-7	1	-1	2	1	1	-4	-A	1	-1	2	1	1	-4	-A	1	-1	2	1	1	-4	-A	1	-1	2	1	1	-4	-A
SC-C-8	0	-1	2	1	1	0	NC	0	-1	2	1	1	0	NC	0	-1	2	1	1	0	NC	0	-1	2	1	1	0	NC
SC-C-9	1	1	2	1	1	4	+A	1	1	2	1	1	4	+A	1	1	2	1	1	4	+A	1	1	2	1	1	4	+A
SC-C-10	1	-1	2	1	1	-4	-A	1	-1	2	1	1	-4	-A	1	-1	2	1	1	-4	-A	1	-1	2	1	1	-4	-A
SC-O-1	2	3	3	1	1	30	+C	2	3	3	1	1	30	+C	1	-2	2	2	0	-8	-A	1	-2	2	2	0	-8	-A
SC-O-2	2	3	3	1	1	30	+B	2	3	3	1	1	30	+B	1	3	3	1	1	15	+B	1	3	3	1	1	15	+B
EO-O-1	1	1	3	1	1	5	+A	1	1	3	1	1	5	+A	1	1	3	1	1	5	+A	1	1	3	1	1	5	+A
EO-O-2	1	3	3	1	1	15	+B	1	3	3	1	1	15	+B	1	3	3	1	1	15	+B	1	3	3	1	1	15	+B
EO-O-3	2	3	3	1	1	30	+C	2	3	3	1	1	30	+C	2	3	3	1	1	30	+C	2	3	3	1	1	30	+C

Table 4-6b RIAM analysis of planned retention ponds (Retention Ponds-1 and -2) and flood control gate structures (FCGS-1 and -2).

Structural flood mitigation measures

Code	Retention Pond-1							Retention Pond-2							FCGS-1							FCGS-2/ FCGS-3						
	RIAM analysis							RIAM analysis							RIAM analysis							RIAM analysis						
	A1	A2	B1	B2	B3	ES	RB	A1	A2	B1	B2	B3	ES	RB	A1	A2	B1	B2	B3	ES	RB	A1	A2	B1	B2	B3	ES	RB
PC-P-1	0	-1	1	1	1	0	NC	1	-1	3	2	2	-7	-A	1	-1	1	1	0	-2	-A	1	-1	1	1	0	-2	-A
PC-C-1	0	0	0	0	0	0	NI	1	-1	3	2	2	-7	-A	0	0	0	0	0	0	NI	0	0	0	0	0	0	NI
PC-C-2	1	-1	1	1	1	-3	-A	2	-1	1	1	1	-6	-A	0	0	0	0	0	0	NI	0	0	0	0	0	0	NI
PC-C-3	0	0	0	0	0	0	NI	0	0	0	0	0	0	NI	1	-1	1	1	0	-2	-A	1	-1	1	1	0	-2	-A
PC-O-2	2	1	2	1	1	8	+A	2	1	2	1	1	8	+A	1	1	2	2	0	4	+A	1	1	2	2	0	4	+A
BE-C-1	1	-1	2	1	1	-4	-A	0	0	0	0	0	0	NI	1	-1	1	1	0	-2	-A	1	-1	1	1	0	-2	-A
BE-C-2	0	0	0	0	0	0	NI	1	-1	1	1	1	-3	-A	0	0	0	0	0	0	NI	0	0	0	0	0	0	NI
BE-C-3	0	0	0	0	0	0	NI	1	-1	0	1	1	-2	-A	1	-1	1	1	0	-2	-A	1	0	0	0	0	0	NC
BE-C-4	2	-1	2	1	2	-10	-B	2	-1	2	1	2	-10	-B	1	-1	1	2	0	-3	-A	1	-1	1	2	0	-3	-A
BE-C-5	1	-1	2	1	1	-4	-A	0	0	0	0	0	0	NI	1	-1	1	1	0	-2	-A	1	-1	1	1	0	-2	-A
BE-C-6	1	-1	1	1	1	-3	-A	1	-1	1	1	1	-3	-A	0	0	1	1	0	0	NC	0	0	1	1	0	0	NC
BE-O-1	0	0	0	0	0	0	NI	1	1	3	2	2	7	+A	1	0	1	1	0	0	NC	1	0	1	1	0	0	NC
BE-O-2	1	-1	1	1	1	-3	-A	1	-1	1	1	1	-3	-A	0	0	1	1	0	0	NC	0	0	1	1	0	0	NC
SC-P-1	1	0	0	0	0	0	NC	1	-2	3	3	2	-16	-B	0	0	0	0	0	0	NI	0	0	0	0	0	0	NI
SC-C-1	1	-1	1	1	1	-3	-A	1	-1	1	1	1	-3	-A	1	-1	1	2	0	-3	-A	1	-1	1	2	0	-3	-A
SC-C-2	1	-1	1	1	1	-3	-A	1	-1	1	1	1	-3	-A	1	-1	1	2	0	-3	-A	1	-1	1	2	0	-3	-A
SC-C-3	1	0	0	0	0	0	NC	1	-1	1	1	1	-3	-A	1	0	0	1	0	0	NC	1	0	0	1	0	0	NC
SC-C-4	1	0	0	0	0	0	NC	1	1	1	1	1	3	+A	1	1	1	1	0	2	+A	1	1	1	1	0	2	+A
SC-C-5	0	0	0	0	0	0	NI	1	1	1	1	1	3	+A	1	1	1	1	0	2	+A	1	1	1	1	0	2	+A
SC-C-6	1	-1	1	1	1	-3	-A	1	-1	1	1	1	-3	-A	1	-1	0	1	0	-1	-A	1	-1	0	1	0	-1	-A
SC-C-7	1	-1	1	1	1	-3	-A	1	-1	1	1	1	-3	-A	1	-1	0	1	0	-1	-A	1	-1	0	1	0	-1	-A
SC-O-1	0	0	0	0	0	0	NI	1	-2	2	2	2	-12	-B	2	0	0	0	0	0	NC	2	0	0	0	0	0	NC
SC-O-2	2	1	1	1	1	6	+A	2	2	2	1	1	16	+B	2	2	2	1	0	12	+B	2	2	2	1	0	12	+B
SC-O-3	0	0	0	0	0	0	NI	0	0	0	0	0	0	NI	1	-1	2	0	1	-3	-A	1	-1	2	0	1	-3	-A
SC-O-4	0	0	0	0	0	0	NI	0	0	0	0	0	0	NI	1	-1	2	0	1	-3	-A	1	-1	2	0	1	-3	-A
EO-O-1	2	1	2	1	1	8	+A	2	1	2	1	1	8	+A	1	2	2	1	1	8	+A	1	2	2	1	1	8	+A
EO-O-2	2	1	2	1	1	8	+A	2	1	2	1	1	8	+A	1	2	2	1	1	8	+A	1	2	2	1	1	8	+A

4.9 km along the lower section of Meycauayan River, encompassing several municipalities and sub-drainage areas. These activities, however, are confined only along the main river channel, thus *A1* = 1, indicating PC-C-2's extent of importance; *A2* = -2, since the perceived magnitude of change will generate significant primary (increase of total suspended solids in the river stream) and secondary negative impacts (deposition of eroded soil along the river downstream, which may also affect the mangrove areas); Then *B1* = 2, since the condition that will be caused by Dike-1's activities is only temporary; *B2* = 2, since the negative impacts of Dike-1 activities can be considered reversible; and *B3* = 3, since silts from eroded river banks may accumulate downstream. Hence, using Eqn. 4-1, *ES* = -14. Using Table 4-5, the environmental score falls within the range band [–B], which means that Dike-1 will probably cause negative impacts on PC-C-2 during the construction phase.

Another example is the assessment of Channel-2 against the environmental component BE-C-1 (Aquatic habitat). Emergent aquatic vegetation contributes to water quality and nutrient cycling that is vital to any estuary. The removal of riparian vegetation in some portions of the Meycauayan River and along the alignment of the new open channel in Barangay Tawiran and Barangay Paco could result in reduced inputs of leaves and twigs, which are important as a food base for some aquatic organisms, and may contribute to the increased in-channel photosynthesis. These changes can shift the aquatic ecosystem from a heterotrophic to an autotrophic state, at least for the adjacent streams and spawning grounds in Meycauayan and Obando. Such impacts would have a localized (*A1* = 1), medium intensity (*A2* = -2), medium term/temporary (*B1* = 2) impacts. To mitigate these impacts, several bank protection methods that incorporate vegetation can be carried out. Essentially, these designs have the same environmental benefits as vegetative designs. Four of the most widely used and successful of these techniques are erosion control matting, cellular concrete blocks, seeded soil-covered riprap, and stem-sprouting woody plants in combination with engineering materials; 2) another option is through replanting of mangroves and nipas along the riverbanks. For inland vegetation, buffer zones should be established along the naked open channel where the use of native or endemic trees is highly recommended, thus the impact is reversible ($\underline{B2}$ =2) and negligibly cumulative ($\underline{B3}$ = 1). Using Eqn. 4-1, $\underline{ES}$ = -10, which is equivalent to range band [-B] according to Table 4-5.

The study was carefully carried out by a team of EIA practitioners and researchers that have a combined experience of more than 10 years in the preparation of feasibility studies and environmental impact assessment of SFMM in the Philippines. The main assessing team is composed of the authors and experienced EIA consultants. The authors are academics and experts in the field of hydrology and water resources management. The EIA consultants include a civil/environmental engineer, hydrogeologist, aquatic/marine and terrestrial biologist, air and water quality specialist, and social development specialist (urban planner). Using the modified procedures of the RIAM method described in Section 3, Table 4-6a was created using collected information from actual field investigation and secondary data. The actual field investigation included environmental surveys (i.e. water quality, sediment quality, air quality and terrestrial surveys) and social (stakeholder perception) surveys. Other socially relevant concerns were acquired through focus group discussions participated by key stakeholders (composed of community leaders, government representatives, academics and residents within the study area). Other information were acquired from the unpublished studies of SFMM under the flood control projects of the Department of Public Works and Highways; reports from internationally funded studies along the study area; and socio-economic profiles of local government units, as well as from the interviews of relevant government agencies and municipal offices.

4.5. Analysis and discussion

Negative impacts often require serious attention from planners and decision-makers, since these eventually become the backbone of environmental management and monitoring plans, and sometimes the basis for the acceptance or rejection of a proposed project (Lohani et al. 1997). In this section, more attention is given on the examination of negative impacts, with focus on the environmental categories (i.e. Physical/ Chemical, Biological/Ecological, Social/Cultural and Economics/Operational categories) and project phases. Basic suggestions for the reduction of negative impacts are offered whenever deemed necessary and applicable.

4.5.1. River improvement works and open channels

According to Table 4-6a, the assessment criteria (*A1*, *A2*, *B1*, *B2* and *B3*) were evaluated and the environmental scores were calculated to determine the range band of each environmental component affected by the 4 planned structures (i.e. Dike-1, Dike-2, Channel-1 and Channel-2). The item numbers in Table 4-6a correspond to the description of environmental components in Table 4-2. For example, Item #1 (PC-P-1) in Table 4-6a corresponds to description "Land/soil disturbance due to site clearing" in Table 4-2.

In Table 4-6a, under the Physical/Chemical category, the lowest scores and corresponding range bands of Dike-1, Dike-2, Channel-1 and Channel-2 are (-14,[-B]), (-14,[-B]), (-14,[-B]) and (-10,[-B]), respectively, which mainly occur in Item #4 (PC-C-2), except for Channel-1, which occurs in Item #2 (PC-C-1). This indicates that all of the seriously adverse impacts on the Physical/Chemical category, particularly with regard to the local geology and soil erosion Item #3 (PC-C-2), will occur during the construction phase. The range band of Channel-1with regards to the change in land use during the construction phase (Item #2, PC-C-1) is [-B], which indicates that substantial change will occur, and that there may be secondary consequences on the Biological/Ecological and Social/Cultural categories.

The range band of the dike structures concerning the surface and groundwater hydrology (Item #6, PC-O-1) is [-A], while the open channel structures have the range band [NI]. The main reason for this difference is that the interlocking revetments, which will be constructed in the dike structures, will partly interrupt the exchange between the surface water and groundwater. However, the impact is considered to be of low intensity since the exchange will continue through the river bed.

With regard to other impacts on land/soil disturbance (Item #1, PC-P-1) and water quality (Item #4, PC-C-3), the effects are surmised to be negligible (range band [NC]), indicating that any of these structures will not pose any severe impacts on those environmental components within the study area. Significantly high positive range band [+D] occurs in Item #7 (PC-O-2) for Dike-1 and Dike-2, which indicates that the hydraulic conditions of the Meycauayan River will substantially be improved when the dike structures are completed.

Under the Biological/Ecological category in Table 4-6a, the lowest scores and corresponding range bands of Dike-1, Dike-2, Channel-1 and Channel-2 are (-10, [-B]) on Item #8 (BE-C-1) and Item #10 (BE-C-3); (-10, [-B]) on Item #8 (BE-C-1); (-7, [-A]) on Item #11 (BE-C-4) and (-10, [-B]) on Item #8 (BE-C-1), respectively. These results indicate that the most adverse impacts in the Biological/ Ecological category, particularly on the aquatic habitat (Item #8, BE-C-1), will occur during the construction phase. Presence of riparian species (Item #10, BE-C-3) were observed along the proposed location of Dike-1 in the Meycauayan River, thus would result to a negative impact. If the removal of mangroves cannot be prevented, the negative impact of Dike-1 can be reduced by replanting equivalent riparian species in other viable sections of the river (for example, at the right bank).

The range band [+A] occur only for Dike-1 and Dike-2 on Item #14 (BE-O-1, aquatic habitat) and Item #15 (BE-O-2, surface water quality), which indicates that the operation of the dike structures will slightly bring benefits to the river environment in the ecological sense. On the other hand, the operation of the open channels will not experience substantial change, as indicated by the range band [NC]. However, slight negative impact [-A] in Channel-2 may occur due to the decay of inundated vegetation and water stagnation (non-flow of water) during the dry seasons that would further diminish the quality of the surface water due to eutrophication (Huang et al 2003; Kneis et al. 2009).

Under the Social/ Cultural category, the lowest scores and range bands of Dike-1, Dike-2, Channel-1 and Channel-2 are (-28, [-C]), (-42, [-D]), (-42, [-D]) and (-28, [-C]), respectively. These results show that among the 4 environmental categories, the planned structures will generate the most severe impacts [-D] in the Social/Cultural category, which will occur particularly in Item #16 (SC-P-1, involuntary resettlement). This indicates that the displacement of settlers along the affected areas is a highly sensitive issue that requires serious attention to address just compensation, and allocate ample resources (Lohani et al. 1997) for resettlement. Tamura et al. (1994) emphasized that consensus with the regional inhabitants must be obtained before any project is realized to avoid serious problems afterwards.

With regard to significant negative impacts, the range bands in Item #16 (SC-P-1) show that Dike-2 and Channel-1 have more severe impacts than Dike-1 and Channel-2, which is primarily due to the higher density of settlers residing directly along Dike-2 and Channel-1, as confirmed during the site survey. Other negative impacts (i.e. [-A] and [-B]) during the pre-construction phase may occur on Item #17 (SC-P-2, public acceptance), but only for the planned open channels as a result of the general public's fears due to the lack of understanding on the project's benefits and negative impacts. The negative impacts however, may be resolved through proper information and education campaign.

During the construction phase, several slightly negative impacts (range band [-A]) will occur, particularly in Item #18 (SC-C-1, air quality), Item #19 (SC-C-2, noise level), Item #20 (SC-C-3, population dynamics), Item #23 (SC-C-6, health and safety of workers), Item #24 (SC-C-7, health and safety of public) and Item #27 (SC-C-10, public utilities and infrastructures). The negative impacts in Item #18 (SC-C1) and Item #19 (SC-C-2) are manageable as long as the contractors operate their equipment in compliance with the local environmental standards. With regard to Item #20 (SC-C-3), the expected impacts are only temporary, which may improve after the SFMM are completed. The negative impacts that will occur on Item #23 (SC-C-6), Item #24 (SC-C-7) and Item #27 (SC-C-10) can be addressed by requiring the contractors to prepare and strictly adhere to their construction safety procedures.

During the operation phase, positive impacts ([+B] and [+C]) are generally anticipated, however, slightly negative impact may occur on Item #28 (SC-O-1, natural environmental and health hazards) during the operation of open channel structures. As mentioned above, water stagnation may occur in the open channel structures, which in turn may become the breeding ground for disease-carrying vectors (such as dengue-carrying mosquitoes) since the incidence of dengue has been reportedly quite prevalent around the study area (Department of Health, 2008). These hazards, imposed by the open channel structures, may be reduced by ensuring the constant flow of surface water either by engineering design or by operational means.

Under the Environmental/ Operational category in Table 4-6a, no negative impact was identified, since it is believed that the SFMM will contribute significantly in the regional economy influenced by the study area. The highest score ($\underline{ES}$ = 30) with range band [+C] occurs in Item #32 (EO-O-3, local revenue and economy), which strongly supports the presumption of the positive contributions of the planned structures. The cost of implementation was not included in the assessment since, as mentioned in Section 3, the planned structures are the alternatives found economically feasible for flood mitigation in the study area. This creates the presumption that the cost of implementation (without the mitigation measures to reduce the negative impacts) can be shouldered by the budget provided by the national government.

4.5.2. Retention ponds and flood control gate structures

Based on the RIAM analysis in Table 4-6b, majority of the potential negative impacts in Retention Pond-1 occurs in the BE category, while Retention Pond-2 affects mostly the SC category. This is perhaps due to the fact that Retention Pond-1 already exists and will only be slightly modified to improve its capacity (as indicated by the higher counts of [NI] and [NC]), while Retention Pond-2 is yet to be excavated, thus will affect heavily its closest vicinity. It is also worth to note that Retention Pond-2 does not have impacts that may lead to negligible change [NC]. Even though Retention Pond-2 has a high number of negative impacts, it is still expected to generate substantial benefits during the operation phase. The negative impacts of Retention Pond-2 can still be curbed by allocating sufficient resources in the project budget to properly compensate those who will be displaced during the project implementation. Other negative impacts in Retention Pond-1 and Retention Pond-2 are mostly temporary and reversible. For the FCGS, most of the negative impacts are temporary and reversible and will not result to significant negative change. A number of positive impacts with high magnitude (i.e. $A2 > 1$) will occur during the operation of the FCGS facilities. The RIAM method however cannot provide a measure on the effects of the combined impacts of the 3 FCGS. The results can only imply that simultaneous operation of these facilities during a flood event will substantially benefit its immediate locality.

General analysis

As a whole, the total of the negative and positive range bands of Dike-1, Dike-2, Channel-1 and Channel-2 are (15,9), (14,9), (15,7) and (16,7), respectively (shown in

Table 4-6a). The relatively close values of these sums indicate that there is not much difference in the number of positive and negative impacts in these planned SFMMs. However, to further examine the positive and negative impacts of the planned structures, the sum of environmental scores for Dike-1, Dike-2, Channel-1 and Channel-2 were calculated for the Physical/Chemical, Biological/Ecological, Social/Cultural and Economics/Operational as shown in Table 4-7. As seen in this table, there exists a clear gap between the positive impacts of the dike structures (Dike-1 and Dike-2) and the open channel structures (Channel-1 and Channel-2). The dike structures are generally more desirable compared to the open channel in terms of the Physical/Chemical, Biological/Ecological and Social/Cultural categories, while the Economics/Operational category generates the same cumulative scores. On the other hand, the cumulative scores of the negative impacts do not show any clear conclusion as to which structure will generate more severe impacts. The results in the Social/Cultural category, however, indicate that open channel structures are less socially desirable compared to the dike structures.

To compare further the impacts of the 4 planned structures in terms of the environmental categories and project phases, histograms were created to represent the impact profiles as shown in Figs. 4-2 and 4-3. In Fig. 4-2, it can be observed that [-A] is the most numerous range band in the 4 planned SFMMs (dominated by the Social/Cultural category), while [-E] and [+E] are not present in any of the proposed projects. Negative impacts are much more numerous than the positive impacts, however, most of the negative impacts are within the range band [-A]. The positive impacts on the other hand are fairly distributed in the scale of positive range bands. Generally, the impact profiles of Dike-1 and Dike-2 are very similar to each other. Likewise, the impact profiles of Channel-1 and Channel-2 are also very similar, which implies that similar types of structural flood mitigation projects will likely generate the same impacts provided that the environmental conditions are also similar

Table 4-7 Summary of the summed environmental scores of the structural flood mitigation measures.

Structural flood mitigation measures	Cumulative Positive Environmental Scores				Cumulative Negative Environmental Scores			
	PC	BE	SC	EO	PC	BE	SC	EO
Dike-1	48	12	72	50	-19	-40	-53	0
Dike-2	48	12	72	50	-19	-30	-67	0
Channel-1	18	0	27	50	-24	-19	-81	0
Channel-2	18	0	27	50	-10	-42	-79	0

*PC, Physical/Chemical; BE, Biological/Ecological; SC, Social/Cultural; EO, Economy/Operational

(such as in the case of co-located projects). In terms of project phases, the most number of negative impacts occur during the construction phase, while the least number of negative impacts take place during the pre-construction phase. The most severe impacts however, are generated during the pre-construction. Most of the positive impacts occur during the operation phase, and some even occur during the construction phase, which indicates that upon completion, the planned structures will generally benefit the environment, which indicates that implementation of the 4 planned structures will in the long run provide benefits to both the human and ecological environments.

In Fig. 4-3, the range of impacts is from [-B] to [+B]. Retention Pond-1 and Retention Pond-2 exhibit similar characteristics and functions as indicated by the results in Table 4-6b; however they differ significantly in the RIAM profile of their potential impacts (Figs. 4-6b(a) and 4-6b(b)). Retention Pond-2, thus is expected to generate higher negative impacts both in the range bands of [-B] and [-A].

In terms of project phases in Fig. 4-3, most of the potential negative impacts would occur during the construction phase, while most of the positive impacts would be during the operation phase. For Retention Pond-2, majority of the negative

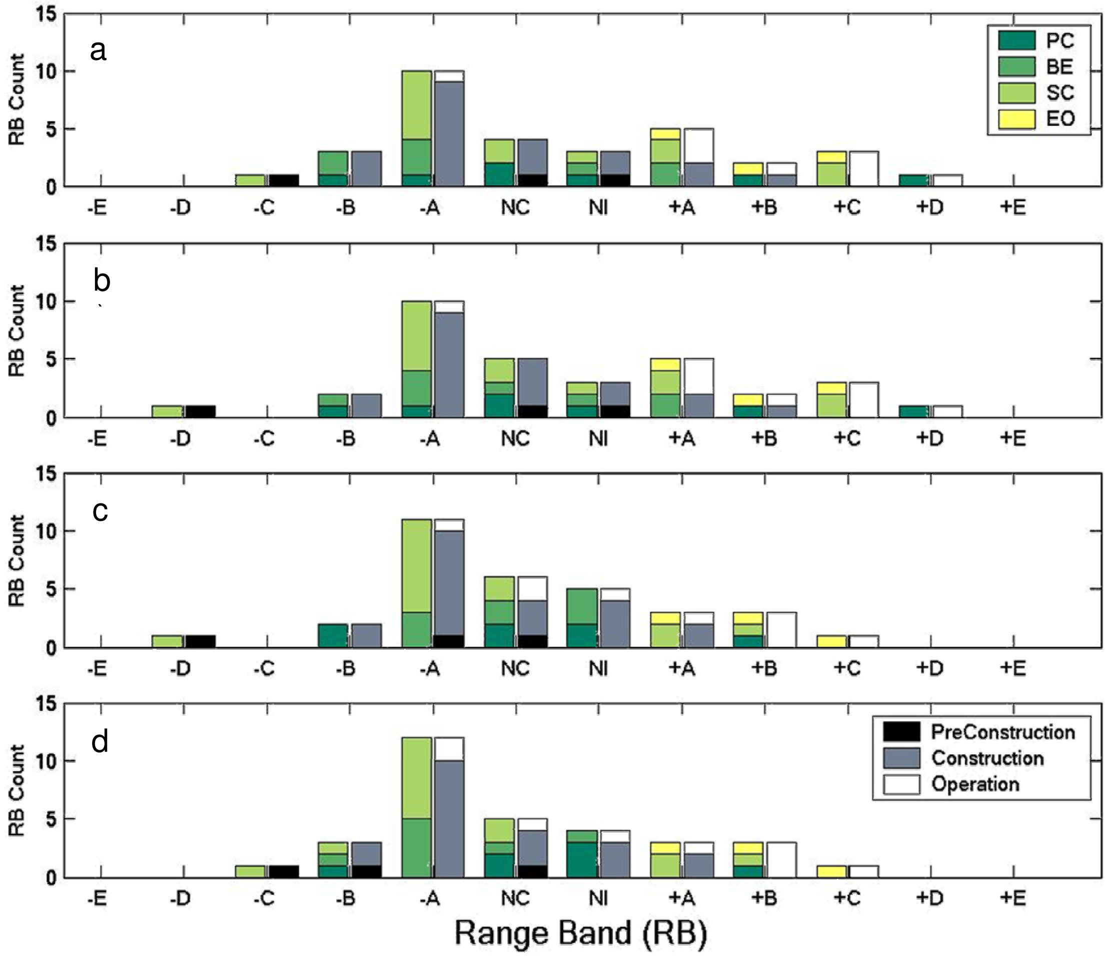

Fig. 4-2 RIAM histograms of a) Dike-1, b) Dike-2, c) Channel-1 and d) Channel-2 that corresponds to Table 4-6a.

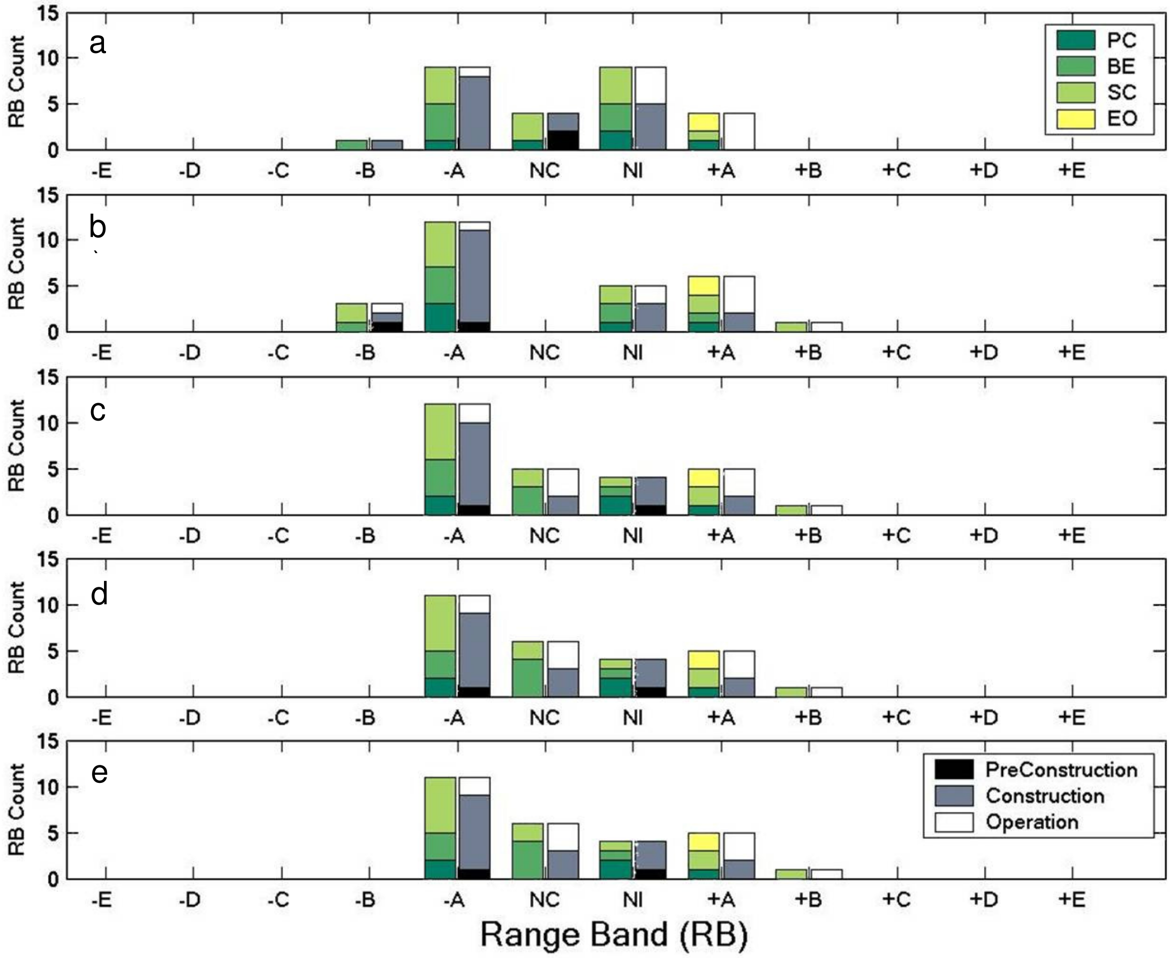

Fig. 4-3 RIAM histograms of a) Retention Pond-1, b) Retention Pond-2, c) FCGS-1, d) FCGS-2 and e) FCGS-3 that corresponds to Table 4-6b.

impacts were observed in the SC category, which is perhaps due to the highly urbanized characteristic of the study area. Most of the open spaces are already converted for residential/industrial use and water-related land use (i.e. fish ponds). The results of this study can be re-evaluated and/or verified during the project implementation stage as part of the environmental management and monitoring activities.

The entirety of the EIA examination in this study shows that the evaluation process using the RIAM technique has gone much farther than the simple EIA techniques being used in the Philippines in the past. This method of assessment has improved the impartiality of the EIA process, particularly in the use of subjective judgments, to achieve more meaningful results. The bases of the assessment were made clearer and more transparent during the examination of the EIA conclusions. There is however a limitation when examining the cumulative effects of co-located (with the same study area) projects, since the procedure for this has not yet been developed in the RIAM. Subjectivity of judgment, however, may still persist when the availability of empirical evidence is not sufficient, thus relying on the experience and intuition of the assessor.

The assessment criteria in group *A* heavily affect the outcome of the Environmental Score. Take for example the scale values for the assessment criterion *A1* (Table 4-3). A value of zero may immediately mean that the project has no impact. Further, the descriptions referring to the spatial boundaries are quite vague (e.g. local condition, regional, etc.). It is thus necessary for the assessing team to define the spatial boundaries as a preliminary step prior to appraisal. It is also important to take caution when assigning a value of zero for both *A1* and *A2*.

For future studies, the application of the RIAM technique could be extended to soft-structural (e.g. mangrove re-forestation) and non-structural (e.g. early flood warning system) flood mitigation measures to achieve a more complete insight concerning the environmental impacts associated with flood mitigation. The soft structural and non-structural measures often serve as complement to the structural measures that reduce not only the consequences of flood risks, but also adverse impacts on the surrounding environment.

4.6. Conclusion

The case of the EIA of SFMM in Metro Manila has demonstrated the applicability of the RIAM technique as an alternative EIA method in the Philippines. The study also demonstrated the flexibility of the RIAM technique to cope with the modifications made to enhance the efficiency and transparency of the evaluation process, with particular reference to the slight modification of the assessment criteria in the *B* group and the integration of the project phases in the EIA examination process. The inclusion of the impact descriptor *negligible impact* provided the means to distinguish the results that show "negligible impacts" with the results that indicated "no change". Essentially, the RIAM technique complements very well with the general EIA approach in the Philippines, making it highly viable for application in other project types. Subjective judgment however is still evident in the assessment process, but the combination of appraisal by quantitative scaling and estimation of the degree of impacts by means of the range bands presents an improvement compared with the traditional methods with regards to the impartiality of the entire EIA process. Another limitation of the RIAM technique is that it currently does not provide for the evaluation of aggregated impacts of co-located SFMM projects, which could perhaps be addressed by assigning weights on the importance and magnitude of each of the planned structure. In general, the EIA of SFMM by the RIAM technique provides a simple but very effective means to identify the significance of potential impacts in a very transparent manner, leading to clearer and more meaningful EIA conclusions. The results of this study may be useful in the improvement of the EIA practice in the

Philippines.

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CHAPTER 5

EVALUATION OF STRUCTURAL FLOOD MITIGATION MEASURES BY UTILITY-BASED ENVIRONMENTAL ASSESSMENT

5.1. Introduction

For centuries, people have been undertaking hydraulic works in different parts of the world to alleviate flood damages (Poulard et al., 2010). In Southeast Asia, most of the key cities, including Jakarta (Indonesia), Bangkok (Thailand) and Metro Manila (Philippines), to name but a few, are highly vulnerable to destructive flash floods and inundations. Results of recent studies on climate change (The World Bank, 2010; Yusuf and Francisco, 2009) indicated that the Southeast Asian region will likely experience higher frequency of extreme flood events in the coming years, thus creating higher demand for flood mitigation projects, which often includes structural measures. Structural flood mitigation measures (SFMMs) are technological features that are often used, and considered valuable, in many highly urbanized flood prone areas. Poor implementation and management of these infrastructures, however, may lead to geomorphological, ecological and social ramifications (Everard, 2004). For instance in the past, several channelization works in Europe (for flood protection) have resulted in various adverse environmental consequences in several river ecosystems (Brookes and Gregory, 1983). The process of environmental impact assessment (EIA) must then be taken as a necessary step during the early planning stages of SFMM projects to obtain a clear view of the costs and benefits, not only for social and economic development, but also to minimize the projects' consequences on the ecological environment.

In principle, EIA is a process undertaken to identify the beneficial and harmful effects of projects, plans, programs or policies on the physical, biological and socio-economic components of the environment (Petts 1999; Wang et al. 2006). The use of appropriate EIA techniques can aid planners and decision-makers in formulating appropriate actions based on informed decisions in light of project urgency and limited resources, which are common constraints in many developing countries (Shah et al. 2010).

In the Philippines, particularly in Metro Manila, the EIA methods used for SFMMs are generally descriptive and qualitative (e.g. Department of Public Works and Highways, 1998; City Office of Navotas, 2009), which are basically similar to the ad hoc and checklist methods described by Lohani et al. (1997). Numerous innovations already exist that can help address some of the weaknesses of these methods, among which are the multicriteria/ multiattribute decision analysis approach (McDaniels, 1996; Hokkanen and Salminen, 1997; Kim et al., 1998), weighting-scaling checklists (Canter and Sadler, 1997), input-output analysis method (Lenzen et al., 2003), life cycle assessment (Tukker, 2000; Brentrup et al., 2004), analytic hierarchical process (Ramanathan, 2001; Goyal and Deshpande, 2001), fuzzy sets approaches (Munda et al., 1994; Parashar et al., 1997), and the Rapid Impact Assessment Matrix (RIAM) technique (Pastakia, 1998; Mondal et al., 2010; El-Naqa, 2005; Al Malek and Mohamed, 2005).

For SFMM projects, the authors proposed the use of a modified RIAM technique (Gilbuena et al., 2013a) that reduces the subjectivity, as well as improve the transparency, of the EIA process in the Philippines. This method, however, does not provide the means to measure the overall impacts of each project alternative (Gilbuena et al., 2013a). If the overall impact of a SFMM project can be quantitatively estimated, planners and decision-makers may be able to maximize the potential benefits of each project alternative.

Yang and Sen (1994) developed a recursive evidential reasoning approach, which uses a belief structure to model qualitative assessments that have uncertainties on the basis of decision theory and the Dempster-Shafer theory of evidence. Luo and Caselton (1997) pointed out that the Dempster-Shafer theory provides a natural and readily grasped basis for the expression of uncertainties, which offers more flexibility than the traditional statistical methods and Bayesian approach (Beynon, 2000) when quantifying weak or subjective information (Luo and Caselton, 1997). The evidential reasoning approach in general addresses the uncertainties and lack of knowledge in subjective decisions that are inherent in qualitative assessment processes (Yang, 2001). This approach has been used to deal with multiattribute decision analysis problems in engineering and management, for example, in vehicle assessment (Yang and Sen, 1994), cargo ship design (Sen and Yang, 1995), system safety analysis and synthesis (Wang et al., 1995), car performance assessment (Yang, 2001) and environmental impact assessment (Wang et al., 2006). Further, a utility-based information transformation technique has been developed in the evidential reasoning approach to provide a systematic procedure to transform various types of information into a unified format, so that both quantitative and qualitative information with uncertainties can be handled in a consistent manner (Yang, 2001). This approach has been coupled with the RIAM technique to obtain a unified EIA result in the form of utility values (Wang et al., 2006), which opens a systematic and effective way to compare and rank project alternatives. The potential of this approach however, has not been fully explored, especially the benefits of its utility-based assessment and its application in the EIA of planned SFMM projects.

This chapter explores the application of a utility-based recursive evidential reasoning approach (as an extension in the RIAM technique) in the EIA of planned SFMM projects. A utility function based on "gains" and "losses" (Kahneman and Tversky, 1979), is proposed to cope with the modified RIAM technique (Gilbuena, et al. 2013a) and to estimate the utility values in terms of the negative and positive utility range to create a distinction between the effects of the aggregated positive and negative impacts. In addition, the algorithm of the utility-based assessment is presented in a simple “step-by-step” approach to provide a clear and comprehensive procedure for the EIA of SFMM projects.

The proposed modifications in the utility-based evidential reasoning approach are intended to advance the EIA process for SFMM projects in the Philippines, but may also find application in other forms of EIA studies. The succeeding sections describes the EIA of the 4 SFMMs using the modified RIAM technique; elaborate on the recursive evidential reasoning approach and development of a new utility function compatible with the modified RIAM technique; analyze and discuss the results of the impact assessment; and offer some recommendations and conclusions with the aim of improving the practice of EIA for SFMMs in the Philippines.

5.2. EIA by the modified RIAM technique

The EIA of the 4 SFMM projects (Dike-1, Dike-2, Channel-1 and Channel-2 in Chapter 4) was carried out by the authors using a modified RIAM technique (Gilbuena et al., 2013a). This EIA technique provides the means for a semi-quantitative evaluation of the environmental factors using a set of standardized assessment criteria. Unlike the simple checklist approach mentioned in Section 5.1, the evaluation of the assessment criteria in RIAM is clearly explained in Chapter 4.

Despite the clarity of the assessment of each environmental component provided by the RIAM technique, it is still unable to estimate the overall impacts of the SFMM projects in terms of the environmental categories and the total environment, which, if reasonably obtained, can be highly valuable for decision-making and/ or for the optimization of environmental benefits.

5.3. EIA of SFMM using the evidential reasoning approach

The recursive evidential reasoning approach provides an effective way to synthesize the information of assessed environmental factors. The process is based on the belief decision matrix and the combination rule of the Dempster-Shafer theory (Yang, 2001). The Dempster-Shafer Theory is a mathematical theory of evidence that was first developed by Dempster (1967), and later extended by Shafer (1976), that deals with the weights of evidence and numerical degrees of support based upon the available evidences (Barnett, 1981). This theory also allows the aggregation of the measures of evidence (known as probability mass) from different sources using the Dempster's rule of combination (Beynon et al., 2000; Wang et al., 2006), resulting in a new measure of evidence that represents how strongly the evidence supports the hypothesis (Wang et al., 2006). In this study, the evidence is represented by the assessment results of the RIAM analysis that was carried out by the authors based on the EIA of planned SFMM projects in Metro Manila (Gilbuena et al., 2013a).

A recursive evidential reasoning algorithm has been developed (Yang and Singh, 1994; Yang and Sen, 1994; Yang, 2001), which can be used to aggregate the assessment results of the basic environmental components in the EIA of planned SFMM project p. The assessment follows a hierarchical process as shown in Fig. 5-1. Based on this figure, the environmental components are first aggregated in each environmental category using the evidential reasoning approach. The assessment results of the environmental categories are then further aggregated to establish an overall assessment of each SFMM project. The recursive evidential reasoning algorithm used in this study is described in detail in the following steps:

Step 1: Construct the decision matrix $D_{p,q}(i,n)$ for each q^{th} environmental category of each p^{th} SFMM project according to the results of the RIAM analysis, where row i is the item number of each environmental component of q^{th} environmental category,

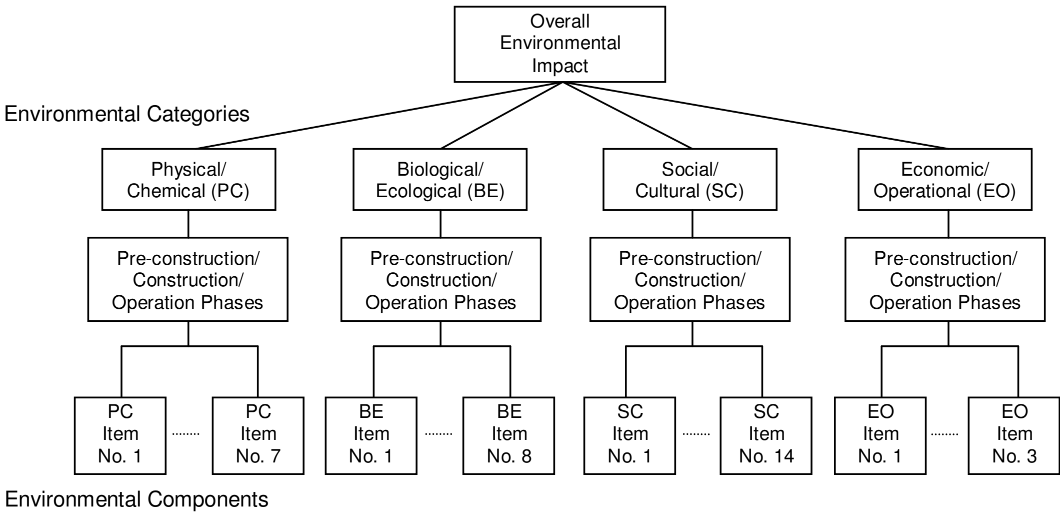

Fig. 5-1 The hierarchical diagram for the environmental impact assessment of the structural flood mitigation measures in Metro Manila.

and column n is the identifier of the range band variable H_n, where $p =$ 1 to 4, $i = 1$ to $I_{p,q}$ (where $I_{p,q} =$ 7, 8, 14 and 3 for $q =$ 1, 2, 3 and 4, respectively), and $H_n =$ {[-E], [-D], [-C], [-B], [-A], [-NC], [-NI], [+A], [+B], [+C], [+D], [+E]} that sequentially corresponds to $n = 1,2,3,\ldots,N$ (where $N = 12$). In this study, the decision matrix $D_{p,q}(i,n)$, consisting of decision elements (or degree of belief) $\beta_{p,q,i,n}$, was constructed based on the RIAM analysis in Table 5-1. The decision elements $\beta_{p,q,i,n}$ were determined using the following conditions:

$$\beta_{p,q,i,n} = 1 \text{ if } H_n = H^*_{n(p,q,i)} \tag{5-2}$$

$$\beta_{p,q,i,n} = 0 \text{ if } H_n \neq H^*_{n(p,q,i)} \tag{5-3}$$

Where $H^*_{n(p,q,i)}$ represents the decision range band by the RIAM analysis of planned SFMM projects.

Step 2: Relative weights $w_{p,q}$ and $w_{p,q,i}$ are assigned to the q^{th} environmental category and i^{th} environmental component, respectively (as shown independent of project p in Table 5-1), with conditions $\sum_{q=1}^{4} w_{p,q} = 1$ and $\sum_{i=1}^{I_q} w_{p,q,i} = 1$ (Wang et al., 2006). In this study, each environmental category is assumed to be of equal

Table 5-1 Results of the RIAM analysis of the selected planned structural flood mitigation measures in Metro Manila (Gilbuena et al, 2013), and relative weights of the Environmental Category and Environmental Components.

Environmental Category, Relative Weight ($W_{p,q}$) **-Environmental Components**	**Code**	**Item No.**	**Relative Weight ($W_{p,q,i}$)**	**Summary of the RIAM analysis**							
				Dike-1		**Dike-2**		**Channel-1**		**Channel-2**	
				ES	Range Band	ES	Range Band	ES	Range Band	ES	Range Band
Physical/ Chemical (PC), 0.25											
-Land/soil disturbance due to site clearing	PC-P-1	1	0.1429	0	NC	0	NC	0	NC	0	NC
-Change in landuse	PC-C-1	2	0.1429	0	NI	0	NI	-14	-B	0	NI
-Local geology and soil erosion	PC-C-2	3	0.1429	-14	-B	-14	-B	-10	-B	-10	-B
-Drinking water	PC-C-3	4	0.1429	0	NC	0	NC	0	NC	0	NC
-Erosion and riverbank scouring	PC-C-4	5	0.1429	12	+B	12	+B	0	NI	0	NI
-Surface and groundwater hydrology	PC-O-1	6	0.1429	-5	-A	-5	-A	0	NI	0	NI
-Hydraulic conditions	PC-O-2	7	0.1429	36	+D	36	+D	18	+B	18	+B
Biological/ Ecological (BE), 0.25											
-Aquatic habitat	BE-C-1	1	0.125	-10	-B	-10	-B	0	NI	-10	-B
-Wildilfe and terrestrial impacts	BE-C-2	2	0.125	-7	-A	-7	-A	0	NI	-7	-A
-Riparian and wetlands	BE-C-3	3	0.125	-10	-B	0	NC	0	NI	0	NI
-Waste generation from construction and excavation	BE-C-4	4	0.125	-7	-A	-7	-A	-7	-A	-7	-A
-Aquatic/freshwater biology	BE-C-5	5	0.125	0	NI	0	NI	-6	-A	-6	-A
-Surface water quality	BE-C-6	6	0.125	-6	-A	-6	-A	-6	-A	-6	-A
-Aquatic habitat	BE-O-1	7	0.125	6	+A	6	+A	0	NC	0	NC
-Water quality	BE-O-2	8	0.125	6	+A	6	+A	0	NC	-6	-A
Social/ Cultural (SC),0.25											
-Involuntary Resettlement	SC-P-1	1	0.0714	-28	-C	-42	-D	-42	-D	-28	-C
-Public acceptance	SC-P-2	2	0.0714	0	NI	0	NI	-6	-A	-18	-B
-Air quality	SC-C-1	3	0.0714	-5	-A	-5	-A	-5	-A	-5	-A
-Noise levels	SC-C-2	4	0.0714	-4	-A	-4	-A	-4	-A	-4	-A
-Population dynamics	SC-C-3	5	0.0714	-4	-A	-4	-A	-4	-A	-4	-A
-Dependency burden	SC-C-4	6	0.0714	8	+A	8	+A	8	+A	8	+A
-Housing characteristics and utilities	SC-C-5	7	0.0714	0	NC	0	NC	0	NC	0	NC
-Health and safety of construction workers	SC-C-6	8	0.0714	-4	-A	-4	-A	-4	-A	-4	-A
-Health and safety of general public	SC-C-7	9	0.0714	-4	-A	-4	-A	-4	-A	-4	-A
-Aesthetic and cultural scenic sites	SC-C-8	10	0.0714	0	NC	0	NC	0	NC	0	NC
-Local planning, coordination and economic growth	SC-C-9	11	0.0714	4	+A	4	+A	4	+A	4	+A
-Public utilities and infrastructure	SC-C-10	12	0.0714	-4	-A	-4	-A	-4	-A	-4	-A
-Natural environmental and health hazards	SC-O-1	13	0.0714	30	+C	30	+C	-8	-A	-8	-A
-Urban living conditions	SC-O-2	14	0.0714	30	+C	30	+C	15	+B	15	+B
Economic/ Operational (EO), 0.25											
-Property and infrastructure	EO-O-1	1	0.3333	5	+A	5	+A	5	+A	5	+A
-Development potential	EO-O-2	2	0.3333	15	+B	15	+B	15	+B	15	+B
-Local revenue and economy	EO-O-3	3	0.3333	30	+C	30	+C	30	+C	30	+C

relative importance, thus $w_{p,1} = w_{p,2} = w_{p,3} = w_{p,4} = 1/4$. Similar to Wang et al. (2006), the environmental components of the q^{th} environmental category are assumed to have the same relative weights, thus $w_{p,1,i} = 1/7$, $w_{p,2,i} = 1/8$, $w_{p,3,i} = 1/14$ and $w_{p,4,i} = 1/3$.

Step 3: Transform the degrees of belief $\beta_{p,q,i,n}$ into basic probability mass $m_{p,q,i,n}$ and calculate the "unassigned" probability mass $\hat{m}_{p,q,i}$ (Wang et al., 2006). The probability mass $\hat{m}_{p,q,i}$ is split into two parts: $\overline{m}_{p,q,i}$ and $\tilde{m}_{p,q,i}$. The probability mass $\overline{m}_{p,q,i}$ is caused by the relative importance of the environmental components, which is the proportion of beliefs that remains to be assigned depending upon how many other environmental components are assessed, while $\tilde{m}_{p,q,i}$ represents the "incompleteness" (or ignorance) in the assessment (Wang et al., 2006). The probability masses are calculated using the following equations.

$$m_{p,q,i,n} = w_{p,q,i}\beta_{p,q,i,n} \qquad (5-4)$$

$$\tilde{m}_{p,q,i} = w_{p,q,i}\left(1 - \sum_{n=1}^{N} \beta_{p,q,i,n}\right) \qquad (5-5)$$

$$\overline{m}_{p,q,i} = 1 - w_{p,q,i} \qquad (5-6)$$

$$\hat{m}_{p,q,i} = \tilde{m}_{p,q,i} + \overline{m}_{p,q,i} \qquad (5-7)$$

In the case where the RIAM analysis of a SFMM project p is complete (i.e. all environmental components are individually assessed), then the value for $\tilde{m}_{p,q,i}$ is zero, which makes $\hat{m}_{p,q,i} = \overline{m}_{p,q,i}$.

Step 4: Construct the decision matrix $D_p^i(q,n)$, whose elements consist of $\beta_{p,q,n}^i$ (aggregated in terms of environmental components i). The aggregated decision elements $\beta_{p,q,n}^i$ of each SFMM project p and environmental category q are calculated using the following evidential reasoning algorithm (Wang et al., 2006):

Step 4.1: Initial aggregation. Aggregate the first and second probability masses of each environmental category (i.e. $m_{p,q,1,n_1}$ and $m_{p,q,2,n_2}$), where n_1 and n_2 are the range band identifiers for the first and second environmental components (i.e. i = 1 and 2), respectively, by first calculating the normalization factor $K_{p,q,j}$ of the j^{th} aggregation of the environmental components i using Eqn. 5-8:

$$K_{p,q,j} = \left[1 - \sum_{n_1=1}^{N} \sum_{\substack{n_2=1 \\ n_2 \neq n_1}}^{N} m_{p,q,1,n_1} m_{p,q,2,n_2}\right]^{-1} \qquad (5-8)$$

And then calculate the aggregated probability masses $\mu_{p,q,j,n}$, $\tilde{\mu}_{p,q,j}$, $\overline{\mu}_{p,q,j}$, $\hat{\mu}_{p,q,j}$, at $j = 1$ using Eqns. 5-9 to 5-12.

$$\mu_{p,q,1,n} = K_{p,q,1}\left[m_{p,q,1,n} m_{p,q,2,n} + m_{p,q,1,n} \widehat{m}_{p,q,2} + \widehat{m}_{p,q,1} m_{p,q,2,n}\right] \qquad (5-9)$$

$$\tilde{\mu}_{p,q,1} = K_{p,q,1}\left[\widetilde{m}_{p,q,1} \widetilde{m}_{p,q,2} + \widetilde{m}_{p,q,1} \overline{m}_{p,q,2} + \overline{m}_{p,q,1} \widetilde{m}_{p,q,2}\right] \qquad (5-10)$$

$$\overline{\mu}_{p,q,1} = K_{p,q,1}\left[\overline{m}_{p,q,1} \overline{m}_{p,q,2}\right] \qquad (5-11)$$

$$\hat{\mu}_{p,q,1} = \tilde{\mu}_{p,q,1} + \overline{\mu}_{p,q,1} \qquad (5-12)$$

Step 4.2: Recursive algorithm for the j^{th} aggregation of the environmental component i . Calculate the normalization factor $K_{p,q,j}$ and the aggregated probability masses $\mu_{p,q,j,n}$, $\tilde{\mu}_{p,q,j}$, $\overline{\mu}_{p,q,j}$, $\hat{\mu}_{p,q,j}$, where $j = 2$ to J and $J = I_q - 1$ using the following algorithm.

$$K_{p,q,j} = \left[1 - \sum_{n_{j-1}=1}^{N} \sum_{\substack{n_{j+1}=1 \\ n_{j+1} \neq n_{j-1}}}^{N} \mu_{p,q,j-1,n_{j-1}} m_{p,q,j+1,n_{j+1}}\right]^{-1} \qquad (5-13)$$

$$\mu_{p,q,j,n} = K_{p,q,j}\left[\mu_{p,q,j-1,n} m_{p,q,j+1,n} + \mu_{p,q,j-1,n} \widehat{m}_{p,q,j+1} + \hat{\mu}_{p,q,j-1} m_{p,q,j+1,n}\right]$$

$$(5-14)$$

$$\tilde{\mu}_{p,q,j} = K_{p,q,j}\left[\tilde{\mu}_{p,q,j-1}\widetilde{m}_{p,q,j+1} + \tilde{\mu}_{p,q,j-1}\overline{m}_{p,q,j+1} + \overline{\mu}_{p,q,j-1}\widetilde{m}_{p,q,j+1}\right]$$

$$(5-15)$$

$$\overline{\mu}_{p,q,j} = K_{p,q,j}\left[\overline{\mu}_{p,q,j-1}\overline{m}_{p,q,j+1}\right] \qquad (5-16)$$

$$\hat{\mu}_{p,q,j} = \tilde{\mu}_{p,q,j} + \overline{\mu}_{p,q,j} \qquad (5-17)$$

Then, calculate the aggregated degree of belief $\beta^{i}_{p,q,n}$ of each environmental category from the final aggregated probability masses (i.e. when $j = J$) using the following equation.

$$\beta^{i}_{p,q,n} = \frac{\mu_{p,q,J,n}}{1-\overline{\mu}_{p,q,J}} \qquad (5-18)$$

Step 5: Finally, construct the decision vector $D^{q,i}_{p}(n)$, which consists of the overall decision elements, i.e. the overall degrees of belief $\beta^{q,i}_{p,n}$, by aggregating the q environmental categories of the p^{th} SFMM project. The decision elements $\beta^{q,i}_{p,n}$ are calculated using a similar procedure from Steps 1 to 4 by calculating the j^{th} aggregation of the probability masses $\mu^{q}_{p,j,n}$ (aggregated q environmental categories), where $j = 1$ to J aggregations (where $J = 3$), using the formula:

$$\beta^{q,i}_{p,n} = \frac{\mu^{q}_{p,J,n}}{1-\overline{\mu}^{q}_{p,J}} \qquad (5-19)$$

5.4. Utility-based environmental assessment

In the utility-based recursive evidential reasoning approach (Yang, 2001; Wang et al., 2006), the overall utility of project p assessed on the q^{th} environmental category and i^{th} environmental component is given by the expected utility U_p that is further known in this study as the environmental utility index. If the utility value of the range band variable H_n is given by the utility function $u(H_n)$, U_p can then be estimated using the following equation:

$$U_p = \sum_{n=1}^{N} \beta_{p,n}^{q,i} u(H_n) \qquad (5-20)$$

In the estimation of the environmental utility index U_p, it is more desirable if the utility values can be explicitly estimated, thus it is important to establish a clear basis for the values of $u(H_n)$ to further reduce subjectivity in the outcome of the EIA for decision analysis.

Wang et al. (2006) adopted a set of linear utility functions, which is similar to the curves shown in Fig. 5-2, to carry out a utility-based information transformation on the distributed degrees of belief (based on the EIA of alternative methods to conserve Rupa Tal Lake), and to help illustrate how the project options can be

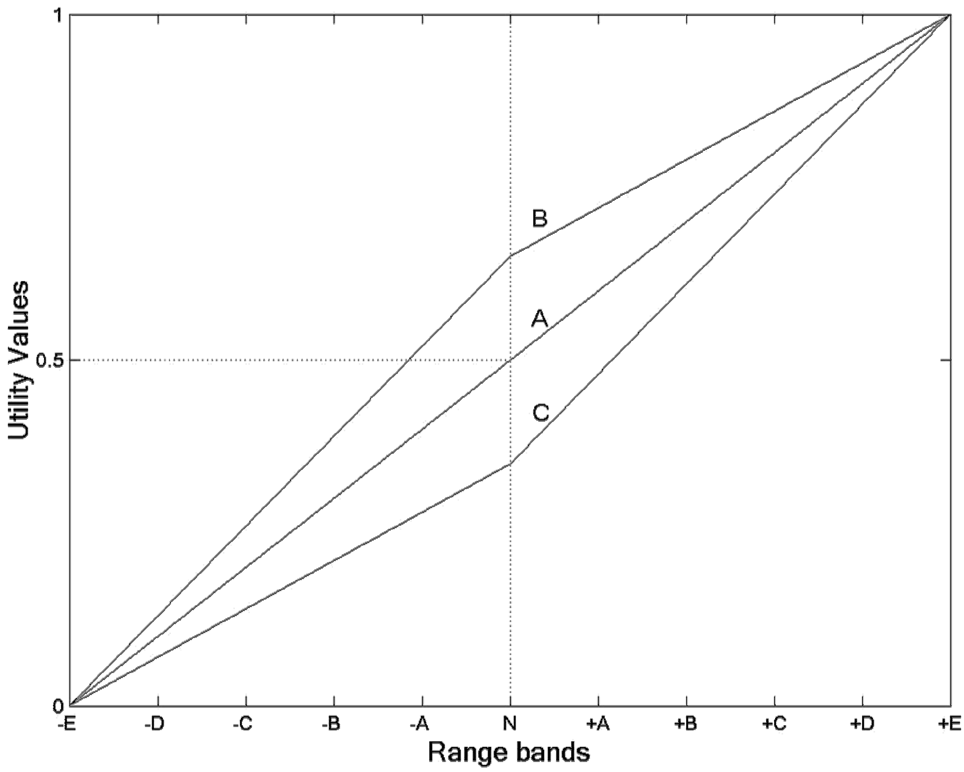

Fig. 5-2 Utility functions showing 3 types of decision preferences according to Wang et al. (2006): *neutral* (curve A), *risk-aversed* (curve B) and *risk-seeking* (curve C).

compared and ranked according to the results of the environmental assessment. From this figure, the range of the utility values is from 0 to 1, which implies that the expected utility will always be greater than or equal to zero. The preferences of the decision-makers (i.e. *risk neutral*, *risk-aversive* and *risk-seeking*) have also been taken into consideration. The risk neutral decision-maker is represented by curve A (Fig. 5-2), which assumes that the utility values are equidistantly distributed in the normalized utility range. The other two curves B and C (Fig. 5-2) represent the decision preferences *risk-aversive* and *risk-seeking* behaviors, respectively. Based on Fig. 5-2, a risk-aversive decision-maker's marginal utility (curve B) drastically increases as the level of impact (denoted by the range bands) improves up to range band [N], and then gradually increase (reduced slope) as the level of impact improves further towards the range band [+E]. Inversely, the marginal utility of a risk-seeking decision-maker (curve C in Fig. 5-2) gradually increase from [-E] to [N], then drastically increase (increase in slope) from [N] to [+E].

5.4 Development of utility functions for RIAM-based evaluation of planned SFMMs

In EIA, decisions must be made based on rational judgment, which is particularly enhanced in the RIAM technique (Pastakia and Jensen, 1998; Gilbuena et al., 2013a). In a RIAM-based assessment, the impacts are classified using the range band variable H_n based on the ranges of the environmental scores as shown in Table 5-2. The environmental scores range from -108 to 108. Each range band has a corresponding range of environmental scores denoted by the minimum and maximum values, as shown in Table 3. As described by Pastakia and Jensen (1998), the environmental scores are heavily influenced by the Importance (*A1*) and Magnitude (*A2*) assessment criteria, which provide the clues regarding the basic preferences a decision-maker might take. The use of the environmental scores as basis to estimate the basic utility functions thus, is a good option to approximate the basic preferences of a

Table 5-2 Equivalent range bands based on the environmental scores according to Gilbuena et al (2013).

Environmental Scores Min	Environmental Scores Max	Range Bands	Description
-108	-72	-E	There will be a major negative change or impact
-71	-36	-D	There will be significant negative change or impact
-35	-19	-C	There will be a moderate negative change or impact
-18	-10	-B	There will be a negative change or impact
-9	-1	-A	There will be a slightly negative change or impact
0	0	NC	Negligible change (At least one assessment criterion is non-zero)
0	0	NI	No identified impact (A1, A2, B1, B2 and B3 have zero scores)
+1	+9	+A	There will be a slight positive change or impact
+10	+18	+B	There will be positive change or impact
+19	+35	+C	There will be a moderate positive change or impact
+36	+71	+D	There will be a significant positive change or impact
+72	+108	+E	There will be a major positive change or impact

decision-maker.

In this study, the range of environmental scores is taken as the range of the utility values that is normalized within the range -1 to 1. Fig. 5-3 shows the proposed utility function in the EIA of SFMM using the RIAM technique. Since each range band is represented by a minimum and a maximum value (Table 3), the basic utility functions can be expressed by $u_{min}(H_n)$ and $u_{max}(H_n)$, for the lower and upper bounds of a range band, respectively. The average utility function $u_{ave}(H_n)$ can then be estimated as the average of $u_{min}(H_n)$ and $u_{max}(H_n)$ as follows:

$$u_{ave}(H_n) = \frac{u_{min}(H_n) + u_{max}(H_n)}{2} \qquad (5-21)$$

The utility functions $u_{min}(H_n)$, $u_{max}(H_n)$ and $u_{ave}(H_n)$ are defined here as

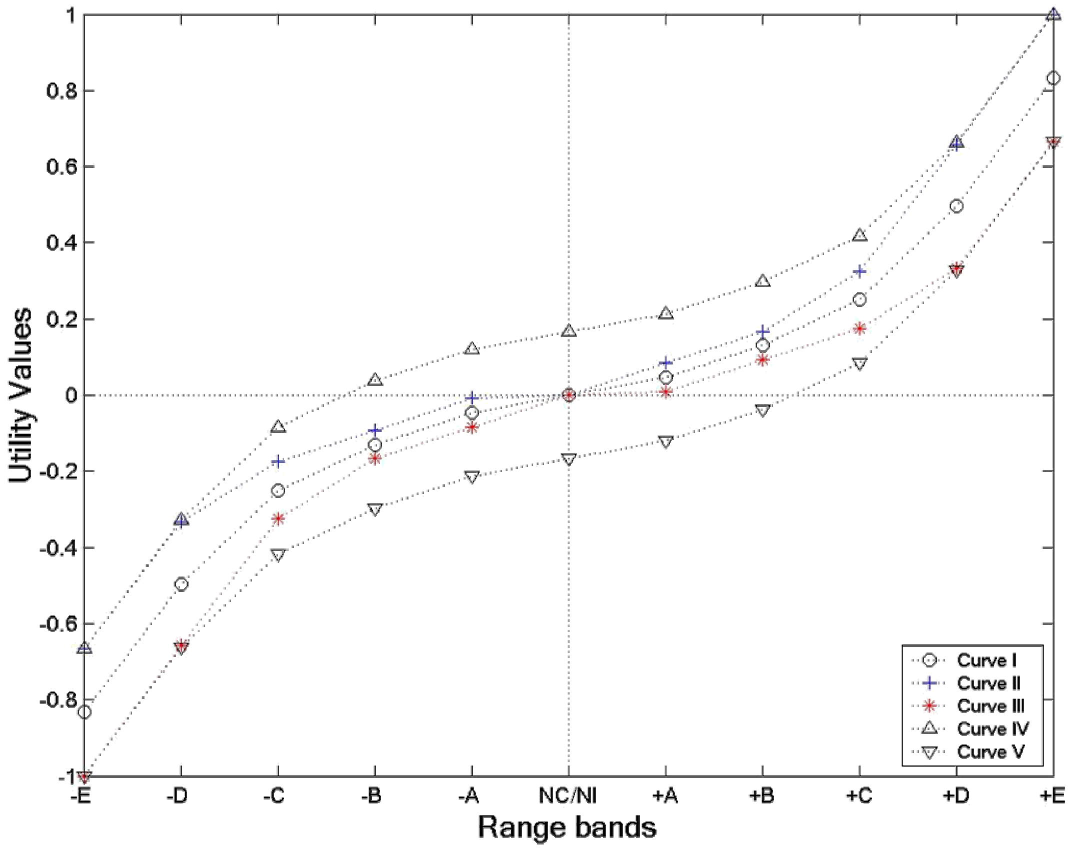

Fig. 5-3 Expected utility functions indicating the preferences and attitudes of the decision decision-makers. Attitudes: Neutral/average (Curve I), Basic optimistic/basic maximum (Curve II), Basic pessimistic/basic minimum (Curve III), relative optimistic (Curve IV) and relative pessimistic (Curve V).

the basic utility functions for the utility-based information transformation of the outcome of the EIA using the RIAM technique. The basic utility curves are plotted as shown in Fig. 5-3. Curves I, II and III correspond to $u_{ave}(H_n)$, $u_{max}(H_n)$ and $u_{min}(H_n)$, respectively. Based on these curves, the basic utility functions are convex as the positive impacts increase (from [+A] to [+E]), and concave as the negative impacts worsen (from [-A] to [-E]). Table 5-3 shows the utility values used for Fig. 5-3.

The convex curves in the domain of the positive range bands indicate that the marginal utility drastically increases as the level of positive impacts increase (i.e. approaching [+E]), which is characteristically *risk-seeking* (Kahneman and Tversky,

Table 5-3 Utility values of the utility functions in Fig. 5-3.

Range Bands	Neutral/ Average	Basic optimistic/ maximum	Minimum	Optimistic	Pessimistic
-E	-0.833	-0.667	-1.000	-0.667	-1.000
-D	-0.495	-0.333	-0.657	-0.329	-0.662
-C	-0.250	-0.176	-0.324	-0.083	-0.417
-B	-0.130	-0.093	-0.167	0.037	-0.296
-A	-0.046	-0.009	-0.083	0.120	-0.213
NC	0.000	0.000	0.000	0.167	-0.167
NI	0.000	0.000	0.000	0.167	-0.167
A	0.046	0.083	0.009	0.213	-0.120
B	0.130	0.167	0.093	0.296	-0.037
C	0.250	0.324	0.176	0.417	0.083
D	0.495	0.657	0.333	0.662	0.329
E	0.833	1.000	0.667	1.000	0.667

1979) towards obtaining significant environmental benefits. On the other hand, the concave curves in the domain of the negative range bands indicate that the marginal utility drastically decreases as the level of impacts worsens (i.e. approaching [-E]), which is characteristically *risk-aversive* (Kahneman and Tversky, 1979) towards incurring negative environmental effects. One advantage of using positive and negative utility values is that people normally perceive outcomes as "gains and losses" (relative to some neutral point) rather than as final states of welfare (Kahneman and Tversky, 1979), thus providing a simpler and more rational representation of the environmental assessment.

Curve I represents the average basic attitude of a decision maker towards a planned SFMM project. In some instances however, an *optimistic* (or a *pessimistic*) decision-maker may opt for higher (or lower) utility values. In this case, Curve II represents the basic optimistic attitude, while Curve III may represent the basic pessimistic attitude of a decision-maker for the estimation of the environmental utility index. Note that Curves I, II and III converge at $u(NC) = u(NI) = 0$. In reality, some decision-makers would perceive negligible change [NC] and no impacts [NI] as advantageous (for an optimist) or disadvantageous (for a pessimist), which would merit higher (or lower) utility values for [NC] and [NI]. Such adjustments can be termed as relative viewpoints (i.e. relative optimistic or relative pessimistic views). To cope with varying viewpoints, concerning particularly [NC] and [NI], the average basic utility function (Curve I) may be shifted upwards to represent a relative optimistic viewpoint, and downward for a relatively pessimistic viewpoint. For illustration purposes, the utility functions Curves IV and V (Fig. 5-3) are plotted to represent the relative optimistic and pessimistic viewpoints, respectively. In this example, the uniform "distance" of Curve IV (or Curve V) from Curve I is assumed to be equivalent to the maximum distance between $u_{ave}(H_n)$ and $u_{max}(H_n)$ (or $u_{min}(H_n)$). In theory, if a SFMM project has a negative environmental utility index ($U_p < 0$), the project would most likely yield more negative environmental impacts that should be avoided or reduced through project modification. A positive environmental utility index ($U_p > 0$) on the other hand, would mean that the SFMM will yield more favorable outcomes, which could be pursued and even maximized.

5.5. Results and discussion

Table 5-4 shows the distribution of the degree of belief of the aggregated environmental components $\beta_{p,q,n}^{i}$ and aggregated environmental categories $\beta_{p,n}^{q,i}$ of Dike-1, Dike-2, Channel-1 and Channel-2. Fig. 5-4 shows the graphical comparison of the distribution of degree of belief of $\beta_{p,q,n}^{i}$ with the range band counts in Chapter 4-2. The distribution profiles of $\beta_{p,q,n}^{i}$ and $\beta_{p,n}^{q,i}$ in Table 5-4 shares some similarities with the distribution profile of the range band counts in Fig. 4-2. For example, the degree of belief $\beta_{p,n}^{q,i}$ in each SFMM is found highest in range band [-A], and that [-D] has relatively low values for Dike-2 and Channel-1, which are all consistent with the characteristic of the distribution profile in Fig. 4-2. However, Table 5-4 shows a more explicit view of the probable impacts of each SFMM, which is vaguely captured by the range band counts in Fig. 4-2. For instance, Fig. 4-2 suggests that Dike-2 and Channel-1 will incur the same "amount" of [-D] impact during the pre-construction phase. In Table 5-4 however, at range band [-D], Dike-2 has a higher degree of belief than Channel-1, indicating that Dike-2 will have a higher chance of incurring a level of impact equivalent to [-D] than Channel-1. This further implies that Channel-1 is more desirable (in terms of incurring [-D]) than Dike-2. The difference in the distribution profiles between Table 5-4 and Fig.4-2 is due to the effect of the weighting factors $w_{p,q}$ and $w_{p,q,i}$ during the calculation of the probability masses, which adds more flexibility to the RIAM technique since the relative importance between each environmental component can now be clearly taken into consideration. The visual comparison of the EIA of the planned SFMMs in Fig. 5-4 further shows the discrepancy between the distribution profile of the degrees of belief in Fig. 5-4a and the range band counts in Fig. 5-4b in terms of the environmental categories.

With regards to the distribution of $\beta_{p,n}^{q,i}$, it is clear that range band [-A] dominates all other range bands (shown in Table 5-4), but more importantly, [-A] dominates the domain of the negative range bands, which indicates that most of the negative impacts will likely be equivalent to [-A]. In the domain of the positive range bands, [+A] dominates in Dike-1 and Dike-2, while [+B] dominates in Channel-1 and Channel-2. The desirability of the projects however, cannot be based entirely on the dominant range bands, since these range bands represent only small portions of the overall distribution (for each SFMM) of the degrees of belief. To estimate the overall utility (or environmental utility index) U_p based on the distribution of $\beta_{p,n}^{q,i}$, Eqn. 5-20 was used.

Table 5-4 Distributed assessment of the aggregated degrees of belief for the 4 planned structural flood mitigation measures in Metro Manila.

SFMM	Environmental Categories	Degree of belief, β											
		-E	**-D**	**-C**	**-B**	**-A**	**NC**	**NI**	**A**	**B**	**C**	**D**	**E**
Dike-1	Physical/Chemical, $\left(\beta_{1,1,n}^{i}\right)$	0	0	0	0.1395	0.1395	0.3023	0.1395	0	0.1395	0	0.1395	0
	Biological/Ecological $\left(\beta_{1,2,n}^{i}\right)$	0	0	0	0.2453	0.3949	0	0.1145	0.2453	0	0	0	0
	Social/Cultural $\left(\beta_{1,3,n}^{i}\right)$	0	0	0.0645	0	0.4693	0.1339	0.0645	0.1339	0	0.1339	0	0
	Economic/Operational $\left(\beta_{1,4,n}^{i}\right)$	0	0	0	0	0	0	0	0.3333	0.3333	0.3333	0	0
	Environment $\left(\beta_{1,n}^{q,i}\right)$	0	0	0.0153	0.0938	0.2624	0.1064	0.0780	0.1815	0.1156	0.1141	0.0330	0
Dike-2	Physical/Chemical $\left(\beta_{2,1,n}^{i}\right)$	0	0	0	0.1400	0.1400	0.3020	0.1400	0	0.1400	0	0.1400	0
	Biological/Ecological $\left(\beta_{2,2,n}^{i}\right)$	0	0	0	0.1160	0.4010	0.1160	0.1160	0.2490	0	0	0	0
	Social/Cultural $\left(\beta_{2,3,n}^{i}\right)$	0	0.0645	0	0	0.4690	0.1340	0.0645	0.1340	0	0.1340	0	0
	Economic/Operational $\left(\beta_{2,4,n}^{i}\right)$	0	0	0	0	0	0	0	0.3330	0.3330	0.3330	0	0
	Environment $\left(\beta_{2,n}^{q,i}\right)$	0	0.0152	0	0.0617	0.2634	0.1377	0.0782	0.1820	0.1152	0.1137	0.0329	0
Channel-1	Physical/Chemical $\left(\beta_{3,1,n}^{i}\right)$	0	0	0	0.2890	0	0.2890	0.2890	0	0.1330	0	0	0
	Biological/Ecological $\left(\beta_{3,2,n}^{i}\right)$	0	0	0	0	0.3810	0.2370	0.3810	0	0	0	0	0
	Social/Cultural $\left(\beta_{3,3,n}^{i}\right)$	0	0.0600	0	0	0.6310	0.1250	0	0.1250	0.0600	0	0	0
	Economic/Operational $\left(\beta_{3,4,n}^{i}\right)$	0	0	0	0	0	0	0	0.3330	0.3330	0.3330	0	0
	Environment $\left(\beta_{3,n}^{q,i}\right)$	0	0.0143	0	0.0688	0.2601	0.1657	0.1683	0.1123	0.1312	0.0793	0	0
Channel-2	Physical/Chemical $\left(\beta_{4,1,n}^{i}\right)$	0	0	0	0.1300	0	0.2820	0.4580	0	0.1300	0	0	0
	Biological/Ecological $\left(\beta_{4,2,n}^{i}\right)$	0	0	0	0.1040	0.6890	0.1040	0.1040	0	0	0	0	0
	Social/Cultural $\left(\beta_{4,3,n}^{i}\right)$	0	0	0.0625	0.0625	0.5530	0.1300	0	0.1300	0.0625	0	0	0
	Economic/Operational $\left(\beta_{4,4,n}^{i}\right)$	0	0	0	0	0	0	0	0.3330	0.3330	0.3330	0	0
	Environment $\left(\beta_{4,n}^{q,i}\right)$	0	0	0.0148	0.0725	0.3245	0.1285	0.1370	0.1132	0.1304	0.0790	0	0

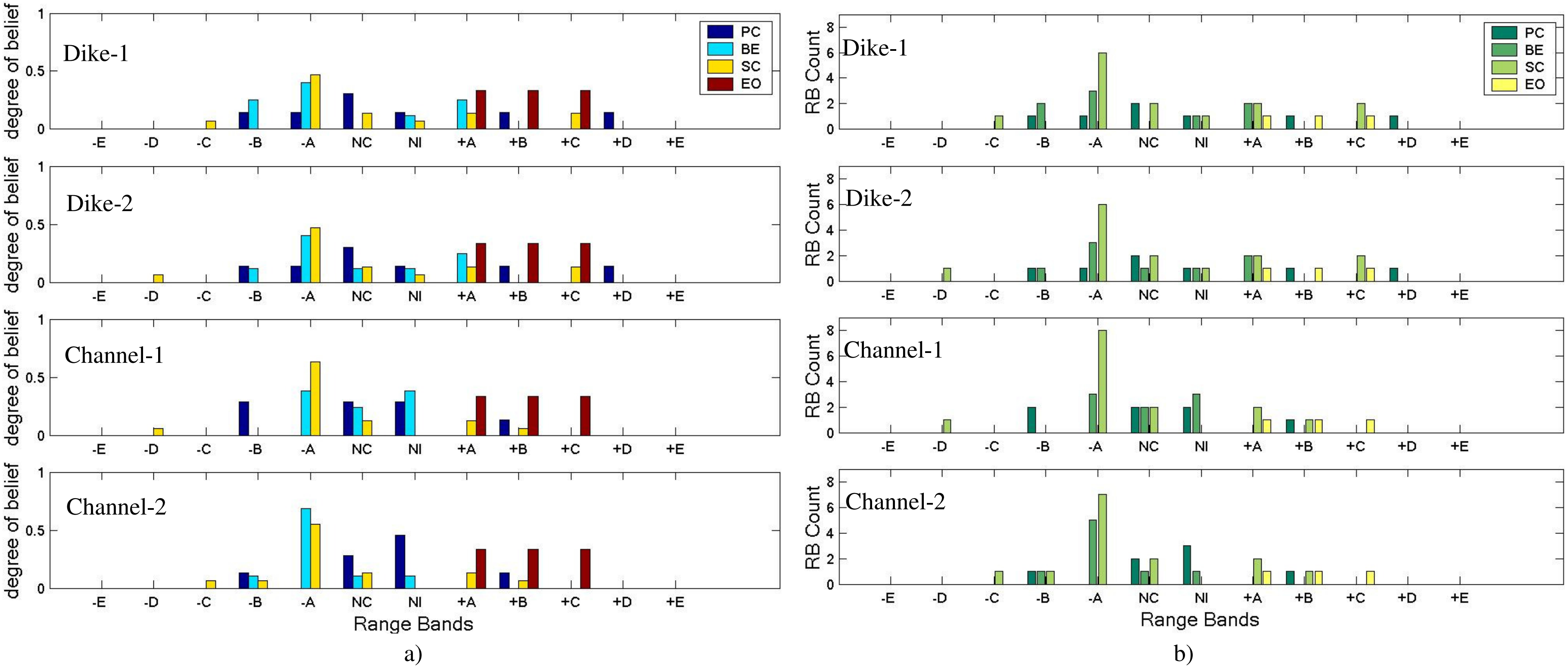

Fig. 5-4 Comparison of histograms of a) the utility-based RIAM analysis based on $\beta^{i}_{p,q,n}$ in Table 5-4 and b) the basic RIAM analysis based on the results in Chapter 4.

Table 5-5 Environmental utility indices of the 4 planned SFMM projects in Metro Manila, Philippines.

Utility Curve	Attitude	Utility Values, U_p			
		Dike-1	**Dike-2**	**Channel-1**	**Channel-2**
Curve I	Neutral (average basic utility)	0.0402	0.0404	0.0140	0.0138
Curve II	Basic optimistic (maximum basic utility)	0.0793	0.0797	0.0434	0.0445
Curve III	Basic pessimistic (minimum basic utility)	0.0010	0.0011	-0.0154	-0.0169
Curve IV	Relative optimistic	0.2068	0.2070	0.1807	0.1805
Curve V	Relative pessimistic	-0.1265	-0.1263	-0.1527	-0.1529

Table 5-5 summarizes the environmental utility indices of the planned SFMM projects according to the different attitudes (or viewpoints) of a decision-maker based on the proposed basic utility curves (Curves I, II and III) and relative optimistic and pessimistic utility curves (i.e. Curves IV and V, respectively). For a neutral decision maker (Curve I), the order of rank of the SFMMs, from highest to lowest net benefits, is Dike-2, Dike-1, Channel-1 and Channel-2. For a basic optimistic decision-maker (Curve II), the order of rank is Dike-2, Dike-1, Channel-2 and Channel-1, and for a basic pessimistic decision-maker (Curve III), the order is Dike-2, Dike-1, Channel-1 and Channel-2.

Based on the results, Dike-1 and Dike-2 are both consistently in the same order of rank in Curves I, II and III, but Channel-1 and Channel-2 switched positions in the order of rank in Curve II. More interestingly, in Curve III, both Channel-1 and Channel-2 have negative U_p, while Dike-1 and Dike-2 both remained positive. In the first case, the change in the order of rank of Channel-1 in Curve II suggests that the negative impacts of Channel-1 would be more severe than Channel-2. This can be inferred based on the preferences in Curve II, which has lower risk-aversiveness (towards the negative impacts) compared with the risk-aversion in Curves I and III. In the second case, Channel-1 and Channel-2 both have negative U_p in Curve III, which implies that the planned channelization projects (i.e. Channel-1 and Channel-2) will most likely incur higher negative impacts than the planned river improvement projects (i.e. Dike-1 and Dike2). A pessimistic decision-maker may recommend the re-evaluation (or re-design) of Channel-1 and Channel-2 to improve the environmental impacts of the two projects. In general, Dike-1, Dike-2, Channel-1 and Channel-2 all indicate slight environmental utility.

For a relatively optimistic decision-maker (Curve IV), the environmental utility indices are significantly higher than those in Curve II, which is due to the heavy influence of the positive utility values assigned to [NC] and [NI]. In contrast, the use of Curve V resulted in negative environmental utility indices, which are significantly lower than those in Curve III. Here, it is obvious that shifting Curve I either upwards or downwards would result in significant change in the environmental utility indices. Such viewpoints must be carefully taken in to consideration when estimating the environmental utility indices since these may result in the “over-bias” the decision-maker towards the positive or negative impacts.

The result of the EIA of the planned SFMM projects using the evidential reasoning approach thus, provides valuable insights as to how the projects can be further optimized to maximize the environmental benefits and to minimize the effects of the negative impacts. The preferences and attitudes of a decision-maker must also be given serious consideration, since this could significantly affect the final decision for the SFMM project. The characteristics of the distribution of impacts of the 4 SFMMs have been accurately captured by the environmental utility indices. Validation of the results of the EIA can be carried out as part of the environmental monitoring activities during the 3 phases of project implementation by using the same utility-based environmental impact assessment approach.

5.6. Conclusion

This study explores the application of a utility-based recursive evidential reasoning approach as an extension to the RIAM technique for SFMM projects in Metro Manila. The utility-based recursive evidential reasoning approach was used to determine the distributed assessment of the environmental categories in terms of the degrees of belief on each range band variable H_n, and calculated the environmental utility index U_p of each SFMM. Using the outcome of the recursive evidential reasoning approach, the SFMMs were assessed based on benefits maximization (risk-seeking positive gains) and benefits loss aversion. The evidential reasoning approach shows flexibility by allowing the assignment of relative weights on the environmental components and environmental categories, and by means of the utility functions that can be adjusted according to the decision-maker's preference and attitude (or viewpoint). The basic utility functions, $u_{min}(H_n)$, $u_{max}(H_n)$ and $u_{ave}(H_n)$ provide the basis for decision preferences, which on their own, can generate reasonable results that can be used to analyze the characteristics of the distributed impacts for benefit maximization and/or impact optimization. Based on the results, Dike-2 was found to have the highest environmental utility index (regardless of decision-maker attitude), while Channel-2 generally has the lowest, except when the basic maximum utility function is used $u_{max}(H_n)$, which suggests that Channel-1 has more severe negative impacts than Channel-2. In addition, the planned river improvement works (i.e. Dike-1 and Dike-2) have been shown to have higher positive net environmental impacts compared with the planned channelization projects (i.e. Channel-1 and Channel-2), which indicate high desirability for dike projects in Metro Manila. The modification made on the utility functions has allowed for a more meaningful interpretation of the environmental utility indices in terms of gains and losses, which was used to compare the relative expected utilities of the planned SFMMs. The proposed utility functions provide a more convenient way to interpret the final utility outcome, which can be very useful in the decision-making processes using the results of EIA. This new approach thus, opens more windows for the improvement of the EIA process used in the Philippines, particularly for planned SFMMs in Metro Manila, but may also find use in other types of EIA studies.

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CHAPTER 6

CONCLUSIONS AND RECOMMENDATIONS

6.1. General conclusions

Flood management systems are essential to ensure sustainable urban development in Metro Manila. The effectiveness of these systems depends on how their components or measures are efficiently and rationally being carried out. By establishing procedures for the evaluation of flood management systems, strategies for future flood mitigation can be clearly formulated, which may also help address the need for sustainable flood management systems. For that reason, this study presented an assessment of the flood management systems in Metro Manila. This study also explored several new strategies that may aid in effective flood management assessment. These new strategies are focused on the following main objectives: 1) to develop a heuristic analytical strategy that helps identify priority concerns in the flood management systems of Metro Manila using a perception-based appraisal, and 2) to develop a systematic and rational evaluation scheme that would help incorporate environmental assessment in the appraisal of flood mitigation measures. To achieve the first objective, an analytical assessment approach was developed to identify and analyze the flood management gaps using the questionnaire-based stakeholders' perception obtained during the aftermath of the tropical storm Ondoy. For the second objective, a quantitative analytical approach was developed for EIA to further enhance the evaluation process in the planning of flood mitigation projects.

Based on the general assessment of the flood management system in Metro Manila, The magnitude of the rainfall spilled by typhoon Ondoy was unprecedented, which resulted in overwhelming floods that rendered ineffective the flood control structures, and eventually caused tremendous amount of damages and losses. The FDRR management systems in Metro Manila were then evaluated using a quantitative multi-criteria gap analysis approach. Based on the results, the overall gaps in the FDRR management systems were found to be relatively low, except for the gaps present in the Prevention criterion of the FDRR management systems of most assessed municipalities. The municipality of Pateros however, lacks several important FDRR measures, which resulted in relatively high FDRR management gaps. This new multi-criteria gap analysis approach provides an estimate that would enable decision-makers and planners to establish priority ranks in terms of the stakeholders' perception on the FDRR measures and municipal FDRR management systems. The results however present an explicit representation of the stakeholders' appraisal, which may have a different outcome if the fuzziness of the judgments is taken into consideration. To address this, a fuzzy-based multi-criteria gap analysis approach was developed to test the effects of fuzzy decisions. The results generally show that the calculated gap indices using the fuzzy-based approach are different from the ones obtained using the non-fuzzy approach. Certain similarities however, can be observed. For example, both methods indicate that the municipality of Pateros and the City of Navotas have the highest and lowest gap indices, respectively. The main advantage of the fuzzy-based analytical approach is that it takes into consideration a wider range of probable decisions for the appraisal of each FDRR measure, as well as the uncertainty in the assignment of priority ranks, which gives a more realistic outcome as a result.

In the assessment of specific flood management measures, planned SFMMs in Metro Manila were evaluated based on their environmental impacts. The assessment involved the use of a modified RIAM technique, which provided a panoramic view of the distribution of the level of impacts in terms not just of environmental categories (i.e. Physical/Chemical, Biological/Ecological, Social/Cultural and Economics/ Operational) but also of project phases. Based on the results, severe (or significant) impacts on the social/cultural environment are expected during the pre-construction phase of one dike and one open channel projects. This is mainly due to the issue of displacing many informal settlers prior to the start of project construction. Most of the negative impacts will occur during the construction phase, while most of the positive ones will be obtained during the construction phase. Essentially, the modified RIAM technique complements very well with the general EIA approach used in the Philippines, making it highly viable for application in other project types. One limitation of the modified RIAM technique however, is that it does not provide for the aggregation of impacts, thus comparison of overall environmental benefits between the SFMMs are vague and inconclusive. To address this inadequacy, the evidential reasoning approach was used to supplement the modified RIAM technique to rationally and systematically aggregate the environmental impacts, thus obtaining an overall representation of the assessment of each SFMM. This additional modification not only provided the means to estimate the overall environmental impact of each SFMM (based on utility values), but also provided the means to investigate the aggregated impacts of each the environmental categories. This new utility-based EIA approach enhanced the way structural flood mitigation measures can be appraised, wherein environmental impacts can be used to rank each planned SFMM in terms of environmental utility. Based on the results, Dike-2 was found to have the highest environmental utility index (regardless of decision-maker attitude), while

Channel-2 generally has the lowest, except when the basic maximum utility function is used $u_{max}(H_n)$, which suggests that Channel-1 has more severe negative impacts than Channel-2. In addition, the planned river improvement works (i.e. Dike-1 and Dike-2) have been shown to have higher positive net environmental impacts compared with the planned channelization projects (i.e. Channel-1 and Channel-2), which indicate high desirability for dike projects in Metro Manila. The modification made on the utility functions has allowed for a more meaningful interpretation of the environmental utility indices in terms of gains and losses, which was used to compare the relative expected utilities of the planned SFMMs. This new approach thus, opens more windows for the improvement of the EIA process used in the Philippines, particularly for planned SFMMs in Metro Manila, but may also find use in other types of EIA studies.

6.2. Recommendations

6.2.1. Recommendations based on the general assessment of the overall flood management system in Metro Manila

Regarding the general assessment of the flood management systems in Metro Manila during the aftermath of tropical storm Ondoy, it was clear that structural measures have their limitations, the damages and casualties however, may have been reduced if there were timely and sufficient flood warning systems. The primary reason for this is that there were no reliable flood forecasting and warning systems designated to each flood risk areas. There is also no reliable real-time data links for rainfall monitoring between the monitoring government offices. Sufficient funds must be allocated for the research and development of effective flood forecasting and early warning systems, as well as for its operation and maintenance. Aside from improving the infrastructures for better communication and data transfer, it is further recommended that a system be put in place that can estimate and predict the amount of rainfall within and around Metro Manila, at which the data is collected and processed by flood forecasting offices using flood simulation models. The existing flood warning system should be enhanced to provide effective dissemination of flood bulletins, especially in frequently flooded areas. Community-based flood warning systems should be strengthened and must be encouraged in all flood-prone communities. Training on emergency response should also be provided to all constituents who were affected by typhoon Ondoy.

6.2.2. Recommendations based on the quantitative gap analysis of the FDRR management systems

The overall gaps in the FDRR management systems in each of the 14 assessed municipalities in Metro Manila are relatively low. However, serious attention is needed to improve the disaster preparedness and emergency response mechanisms of the disaster preparedness system. A system for flood disaster recovery is needed in most municipalities to avoid compounding issues from higher frequency of flood events. Relocation of human settlement and proper land use planning may significantly reduce the risks and potential flood damages.

6.2.3. Recommendations based on the appraisal of SFMMs using EIA techniques

The modified RIAM technique provides clear assessment of impacts of each planned SFMMs. Dike projects were found to have higher environmental utility than the open channels, which suggest that dike projects are more desirable on an environmental perspective. The environmental utility of each planned SFMM however may still be improved by addressing some of the specific negative impacts during the pre-construction and construction phases of the dike and open channel SFMMs. It was shown that the dike and open channel SFMMs have considerable potential negative impacts, however few, during the pre-construction phase, which significantly reduces the environmental utility values of the social/cultural category. Slightly negative impacts are numerous, but mostly occur during the construction phase. By putting in place the necessary environmental mitigation measures, the overall environmental utility may be further improved.

6.3. Future Works

Future research works may involve further study on the integration of quantitative gaps assessment of FDRR management systems and environmental assessment of structural flood mitigation measures as component of an integrated sustainable flood management planning process. Research on the gaps assessment of specific FDRR management components using the combination of stakeholders' perception and results of technical investigations may further enhance the outcome of FDRR management assessment. Development of decision support tools for FDRR management assessment using fuzzy-based algorithms would also be a significant step for efficient and systematic approach to FDRR management assessment.

For the appraisal of flood mitigation measures, a study on the application of the modified RIAM technique on non-structural measures is needed to obtain holistic perspectives on the environmental impacts of flood management alternatives. The applicability of the modified RIAM technique to estimate the environmental sustainability of both structural and non-structural flood mitigation measures can also be investigated using geocybernetics techniques (e.g. Phillips, 2010; 2011).

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APPENDIX A. SURVEY QUESTIONNAIRE FOR FDRR ASSESSMENT

Province:/City_________________________

Name of Respondent: ______________________________ Sex: _________________

Agency/Office: ________________________________

Position:____

Tel No.: _______________________ Fax No.: ____________________ E-mail:_______________

1. Severe Damages caused by the Typhoon No.16 (Ondoy) and No.17 (Pepeng) in September 26 and October 3, 2009

1-1 Disasters caused by the typhoons

We would like to ask you filling out the following tables with information concerning the disaster that occurred in the province/municipality on 26 of September and 3 of October 2009. And also we would like to ask you attaching detailed damage descriptions and maps of damaged areas (if any) at the end of this questionnaire?

a) Ondoy and/or Pepeng	b) Name of River Basin/River:
c) Disaster area	Are maps of disaster areas available ☐ Yes ☐ No
d) Type of disaster (Please check)	☐Flood ☐Flash flood ☐Debris / Mud flow ☐Storm surge ☐Landslide ☐Coastal erosion ☐Others (Pls. Specify): ____________________________
e) Causes of the disaster	☐ Typhoon ☐ Heavy rain ☐ Others (Pls. specify): _____________________________
f) Major damages (Check those applicable)	☐ Casualties ☐ House and assets ☐ Public facilities ☐ Road & Transportation facilities ☐ Water supply system ☐ Power supply system ☐ Communications infrastructure ☐ Agricultural products ☐ Fisheries including fishpond ☐ Industrial products ☐ Disease: _______________________________________ ☐ Others (Pls. specify): _____________________________

g) Required mitigation and rehabilitation for disaster risk reduction (Check all possible)	☐ Increase discharge capacity of river channels ☐ Flood control facilities ☐ Structural measures against landslide and mudflows ☐ Proper river management ☐ Proper watersheds management ☐ Dredging heavy sedimentation in river bed ☐ Reforestation in the watersheds ☐ Removal of existing informal structures/people in the river channel ☐ ☐ Others (Pls. specify): ______________________________
h) Required Mitigation and Preparedness against the disaster (Check all possible)	☐ Emergency responses including evacuation ☐ Establishment of community based disaster management organization ☐ Preparation of community based hazard maps ☐ Establishment of community based early warning and forecasting system ☐ Community based information system ☐ Evacuation route ☐ Shelters ☐ Information and public awareness ☐ Others (Pls. specify): ______________________________
1) Required emergency response for the disaster	☐ Early warning ☐ Information ☐ Evacuation order ☐ Safe evacuation ☐ Rescue ☐ Shelter ☐ Food and water supply for refugees ☐ Others (Pls. specify): ______________________________

2. Pre-Event: Preparedness for Disaster Risks Reduction against Typhoon Ondoy and/or Pepeng

Looking back to the time when the last severely damaging disaster occurred, please answer the following questions about your experiences regarding the response measures that you adopted and preparedness required.

2.1 Preparedness

2.1.1 Information and Awareness

a) For those who experienced a severe damages from flood, debris flow/mud flow and landslide:
Are you aware of the fact that the Province/Municipality is:

- flood-prone area: ☐ No ☐ Yes

- Sediment-prone area: ☐ No ☐ Yes
- Typhoon-prone area: ☐ No ☐ Yes

Do you think that people in the Province/Municipality are aware of the disaster prone areas?

- flood-prone area: ☐ No ☐ Yes ☐ Very much
- sediment-prone area: ☐ No ☐ Yes ☐ Very much
- typhoon-prone areas? ☐ No ☐ Yes ☐ Very much

2.1.2 Preparedness (related to questions 2.1.1:

a) Are there any preparedness measures you are undertaking? ☐ Yes ☐ No

b) If Yes, what are these? Please mention 5 major preparedness you have been adopting in the province/municipality. Please explain briefly each of the measures.

1. ______________________________
2. ______________________________
3. ______________________________
4. ______________________________
5. ______________________________

c) What other preparedness measures do you think are necessary in addition to the ones you mentioned in item b)? Please mention the first five most important ones.

1. ______________________________
2. ______________________________
3. ______________________________
4. ______________________________
5. ______________________________

d) Do you think that there are constraints to the successful adaptation of the existing preparedness measures you mentioned above (item b)? ☐ Yes ☐ No

If Yes, what are these?

____

____

____

____

e) Do you think that there will be constraints to the successful implementation of the additional mitigation measures that you have mentioned in item d)? ☐ Yes ☐ No

If Yes, what are these?

____

____

____

____

2.2 Structural and Non-structural Mitigation Measures to Reduce Risk

a) Are there any existing structural and nonstructural disaster risk mitigation measures in the province/city ?

☐ Yes ☐ No

b) If Yes, what are these existing disaster risk mitigation measures?

1. ____
2. ____
3. ____
4. ____
5. ____

Example of disaster risk mitigation measures:

Structural: *Flood control facilities*
Sediment and landslide control facilities.
Strengthening of infrastructure facilities against floods and landslides

Non-structural: *Real-time observation stations for rainfall and water level*
Hazard mapping
Forecasting and warning system

c) Do you think that there are any constraints in the successful disaster mitigation you mentioned above (item a)? ☐ Yes ☐ No

If Yes, what are these?

____

____

____

____

d) In your idea, what are the necessary actions to improve the existing disaster mitigation in the province? Please mention the first five major ones.

1. ____
2. ____
3. ____

4. ______________________________
5. ______________________________

2.3 Early Warning and Evacuation

2.3.1 When did you evacuate people from disaster areas?

☐ Early evacuation (before disaster) ☐ Just before the disaster occurs

☐ During the occurrence of disaster ☐ No evacuation

2.3.2 Which office or group determines the evacuation timing? ______________________________

2.3.3 Are there any information system from the province/municipality to the people?

☐ Yes ☐ No

2.3.4 Which office or group disseminates the warning to the people? ______________________________

Early Evacuation Before Disaster Happens

a) Is there any evacuation system? ☐ Yes ☐ No

b) Is the early evacuation being conducted effective? ☐ Yes ☐ No

c) If No, what are the reasons why early evacuation could not be conducted effectively? Please mention the 5 most major ones.

1. ______________________________
2. ______________________________
3. ______________________________
4. ______________________________
5. ______________________________

d) What are the measures necessary in order to improve the conduct of early evacuation? Please mention the 5 most major ones.

1. ______________________________
2. ______________________________
3. ______________________________
4. ______________________________
5. ______________________________

d) Generally, are there good communication lines between and among the PDCC, MDCC and BDCC during early evacuation? ☐ Yes ☐ No

e) If No, what are the main reasons for the poor communication lines between and among PDCC, MDCC and BDCC during early evacuation? Please mention the 5 most major reasons.

1. ______________________________
2. ______________________________
3. ______________________________
4. ______________________________
5. ______________________________

2-4 Emergency Responses During Disaster Stage (i.e., rescuing victims etc.)

a) Were there any constraints to conduct the emergency responses during the occurrence of the disaster?

☐ Yes ☐ No

If Yes, what are these constraints? Please mention the 5 most major ones.

1. ______________________________
2. ______________________________
3. ______________________________
4. ______________________________
5. ______________________________

b) What are the actions necessary to improve the emergency response measures during disasters?

Please mention the 5 most major ones.

1. ______________________________
2. ______________________________
3. ______________________________
4. ______________________________
5. ______________________________

c) Generally, are there good communication systems between and among the PDCC, MDCC and BDCC during the response stage? ☐ Yes ☐ No

e) If No, what are the main reasons for the poor communication systems between and among PDCC, MDCC and BDCC during the response stage? Please mention the 5 most major reasons.

1. ______________________________
2. ______________________________
3. ______________________________
4. ______________________________
5. ______________________________

2. 5 Post-Event Stage (Rehabilitation such as reconstruction of facilities and responses)

a) Are there constraints to the effective implementation of rehabilitation of disaster mitigation facilities during the post-disaster stage? ☐ Yes ☐ No

If Yes, what are these constraints? Please mention the 5 most major ones.

1. ______________________________
2. ______________________________
3. ______________________________
4. ______________________________
5. ______________________________

b) What are the measures necessary in order to improve the implementation of rehabilitation measures? Please mention the 5 most major ones.

1. ______________________________
2. ______________________________
3. ______________________________
4. ______________________________
5. ______________________________

3. Data and Hazard Map Requirements for Disaster Management

In order to facilitate the improvement of disaster risk reduction management, data requirement and hazard map requirements are likewise given focus in this study. Please answer the following questions based on your knowledge about the present status of disaster risk reduction management in the province.

3.1 Data Requirements

3.1.1 Availability of Baseline Information

☐ Topographic maps: Scale:____________ , Year ____________

Scale:____________ , Year ____________

Scale:____________ , Year ____________

☐ Aerial photographs: Scale:____________ , Year ____________

☐ Geological maps: Scale:____________ , Year ____________

☐ Land Use Map: Scale:____________ , Year ____________

☐ Meteorological data: Number of existing stations under operation ____________

☐ Hydrological data: Number of existing stations under operation ____________

☐ Socio-Economic Data/Profile: Year ____________ (most recent)

☐ Other data (Please specify): ____________________________ Year: _________

3.1.2 Which types of data do you think need to be strengthened/enhanced in order to improve disaster risk management in the province?

1. ____
2. ____
3. ____
4. ____
5. ____

3.1.3 Do you see any problems or constraints to such data strengthening/enhancement?

☐ Yes ☐ No

If Yes, what are these problems or constraints. Please describe.

____

____

____

____

3.2 Hazard Map Requirements

1) Have any hazard maps been developed before? ☐ Yes ☐ No

If No, what are the reasons why the hazard maps have not been created?

____

____

____

2) Is there any evacuation place identified in the province? ☐Yes ☐No

4) Is there any evacuation route identified in the province? ☐Yes ☐No

5) Are there any maps indicating the evacuation places and routes? ☐Yes ☐No

If Yes, please attach the maps at the end of this questionnaire.

6a) Have the <u>evacuation places</u> functioned effectively during the last occurrence of the most severely damaging disaster? ☐Yes ☐No

If No, what do you think are the reasons why they have not functioned effectively?

____

____

____

6b) Have the <u>evacuation routes</u> functioned effectively during the last occurrence of the most severely damaging disaster? ☐Yes ☐No

If No, what do you think are the reasons why they have not functioned effectively?

____

7a) Do people know the location of evacuation places? ☐Yes ☐No

7b) Do people know the location of evacuation routes? ☐Yes ☐No

8) In what ways can people be informed about the location of evacuation places and routes?

____

9) Are the risks of natural disasters such as floods, mudflows and landslides or hazardmaps considered in the land use plan and urban development plan? ☐Yes ☐No

If Yes, what type of disaster are considered in the urban land use plan?

____

4. Burden of Disaster Rehabilitation

We would like to know the burden of disaster rehabilitation on the provincial budget and expenditure during the last 5 years since the start of disaster risk management in the province.

Item	**Year**				
1) Total Provincial Budget (In Million Pesos)					
a) Budget for construction and investment					
b) Budget for operation and maintenance					
c) Budget for rehabilitation of the damage					
d) Budget for disaster management					

2) Total Provincial Expenditure (Actual) (In Million Pesos)					
a) Expenditure for construction and investment					
b) Expenditure for operations and maintenance					
c) Expenditure for rehabilitation of the damage					
d) Expenditure for others					

5. Opinions and Suggestions for Adaptation Initiatives for Disaster Risk Reduction Management in climate change

Please describe the problems of the province regarding Disaster Risk Reduction Management, if you know of any. Also, give your suggestions on how it can be improved, if you have any.

____

____

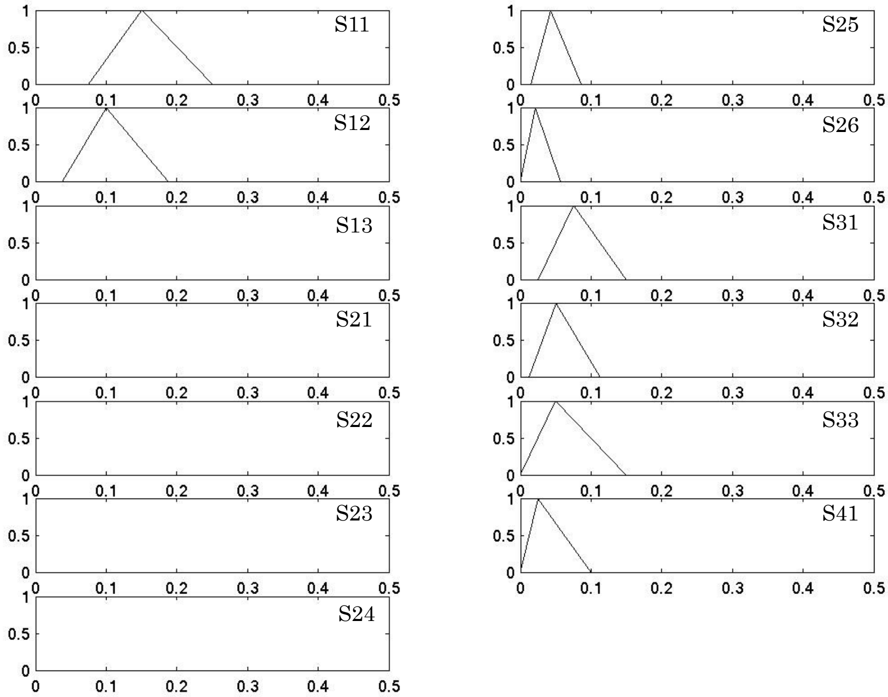
____

____

Thank you for your cooperation!

APPENDIX B. FUZZY FDRR GAP INDICES OF 14 ASSESSED MUNICIPALITIES IN METRO MANILA

a) Fuzzy positive gaps



b) Fuzzy negative gaps

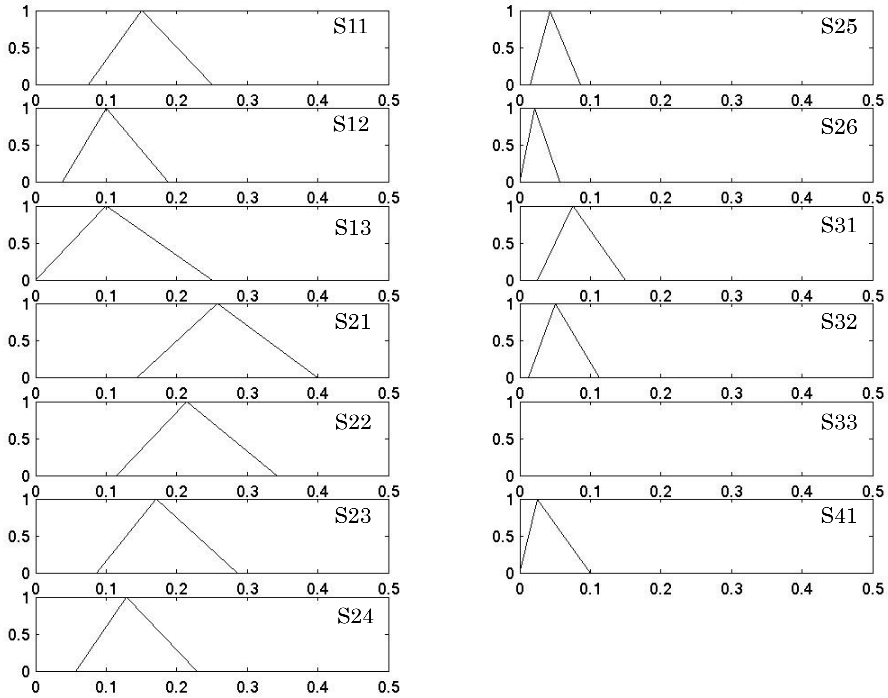
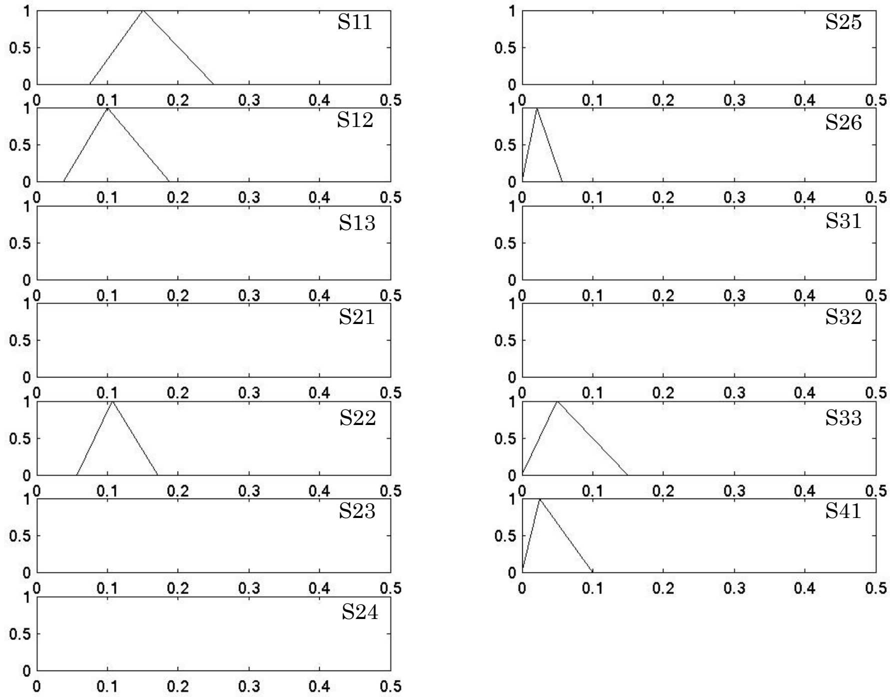


Fig. B-1 Fuzzy FDRR gap indices for Malabon City

a) Fuzzy positive gaps



b) Fuzzy negative gaps

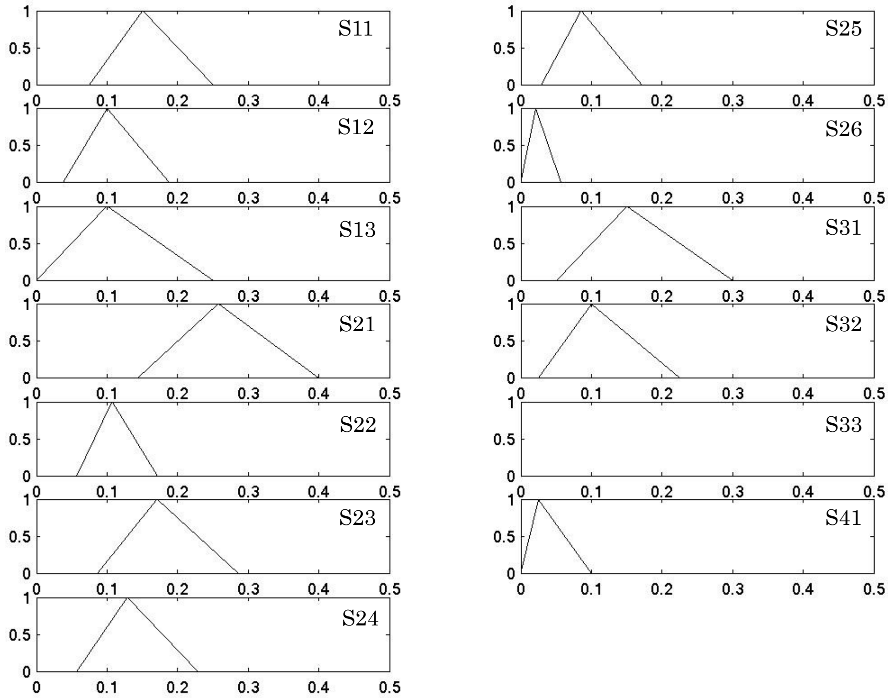
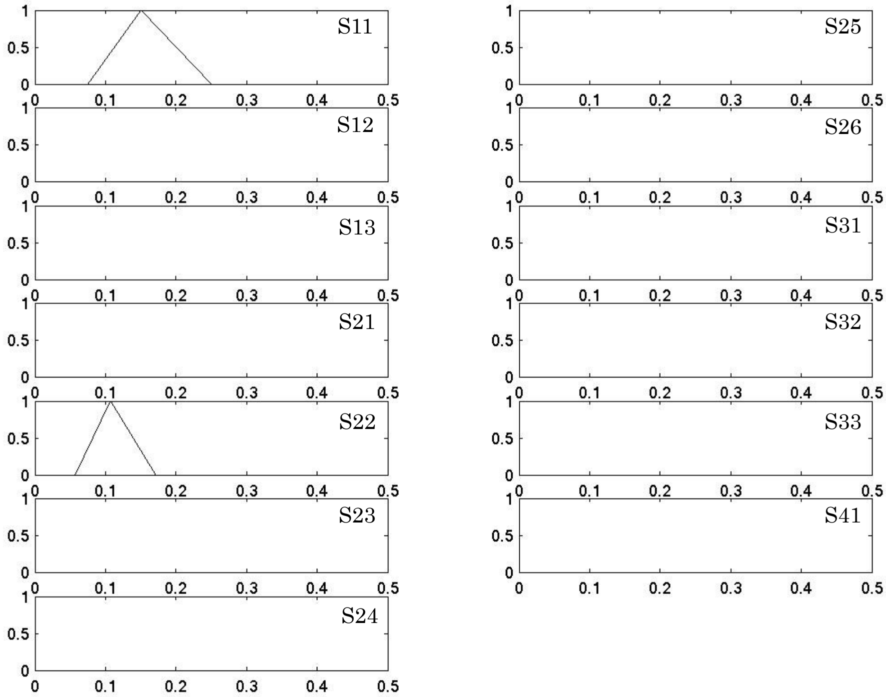


Fig. B-2 Fuzzy FDRR gap indices for Caloocan City

a) Fuzzy positive gaps



b) Fuzzy negative gaps

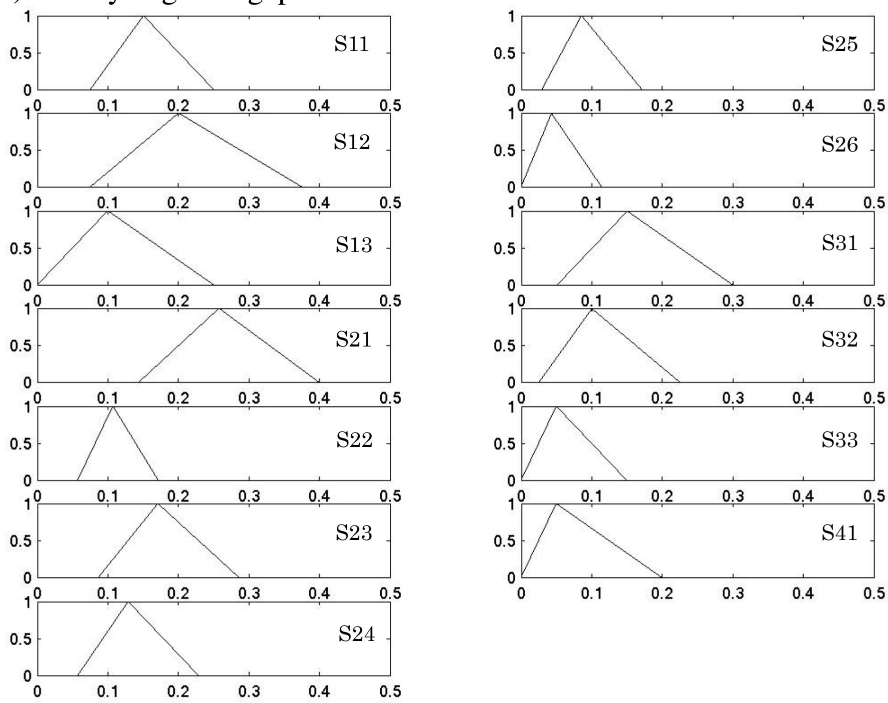
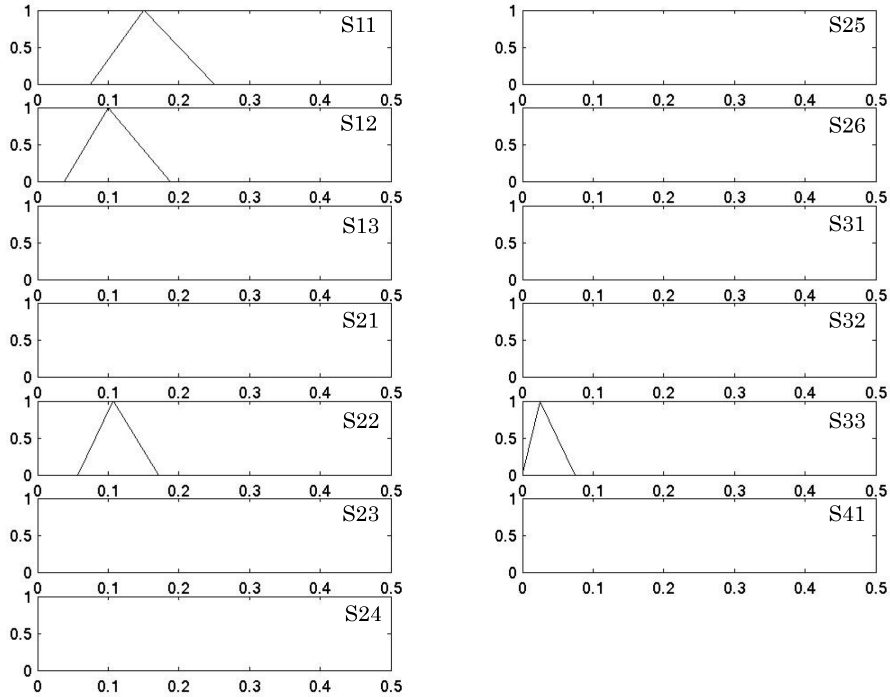


Fig. B-3 Fuzzy FDRR gap indices for Navotas City

a) Fuzzy positive gaps



b) Fuzzy negative gaps

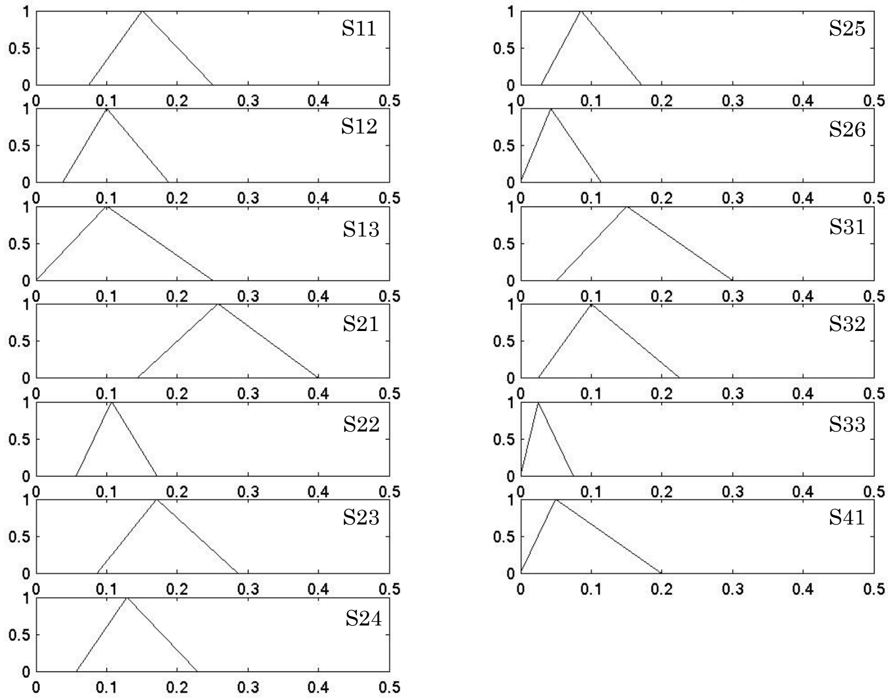
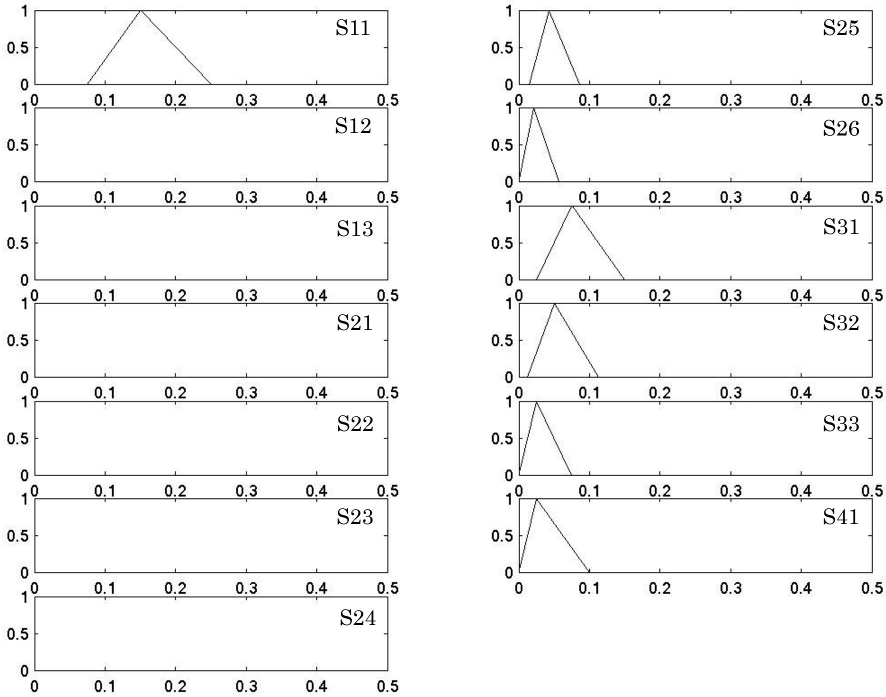


Fig. B-4 Fuzzy FDRR gap indices for Valenzuela City

a) Fuzzy positive gaps



b) Fuzzy negative gaps

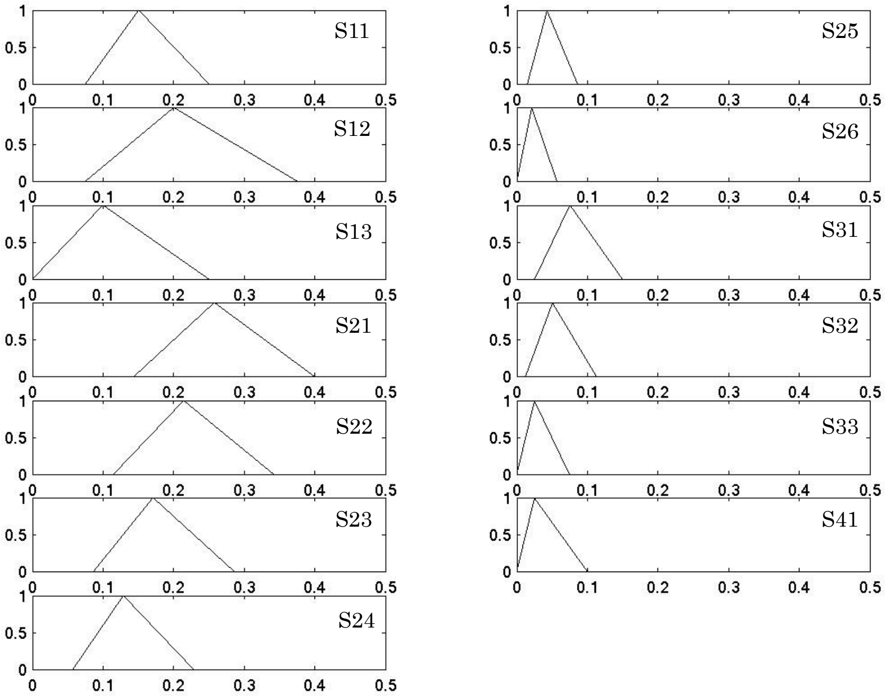
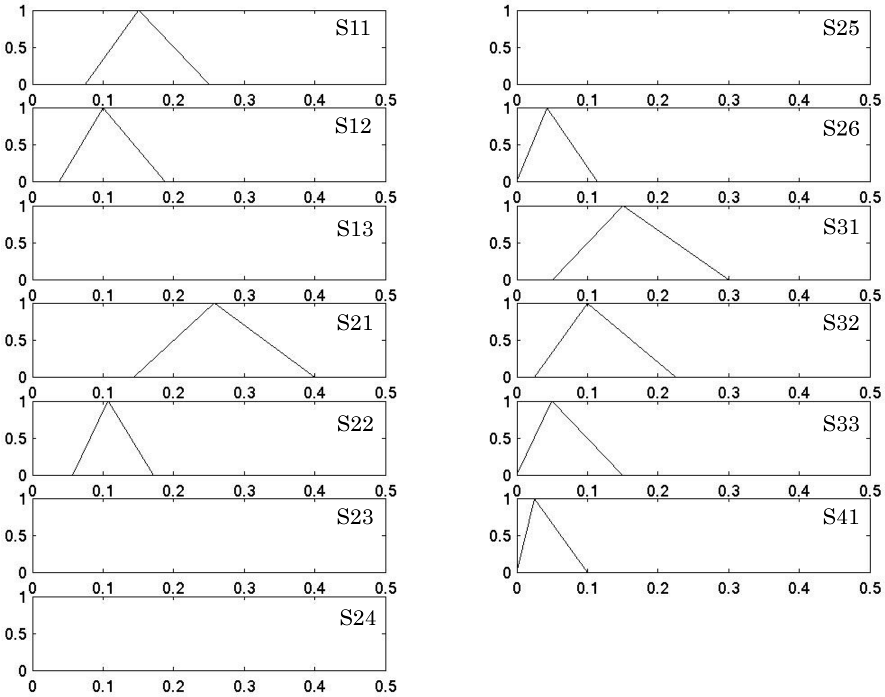


Fig. B-5 Fuzzy FDRR gap indices for Makati City

a) Fuzzy positive gaps



b) Fuzzy negative gaps

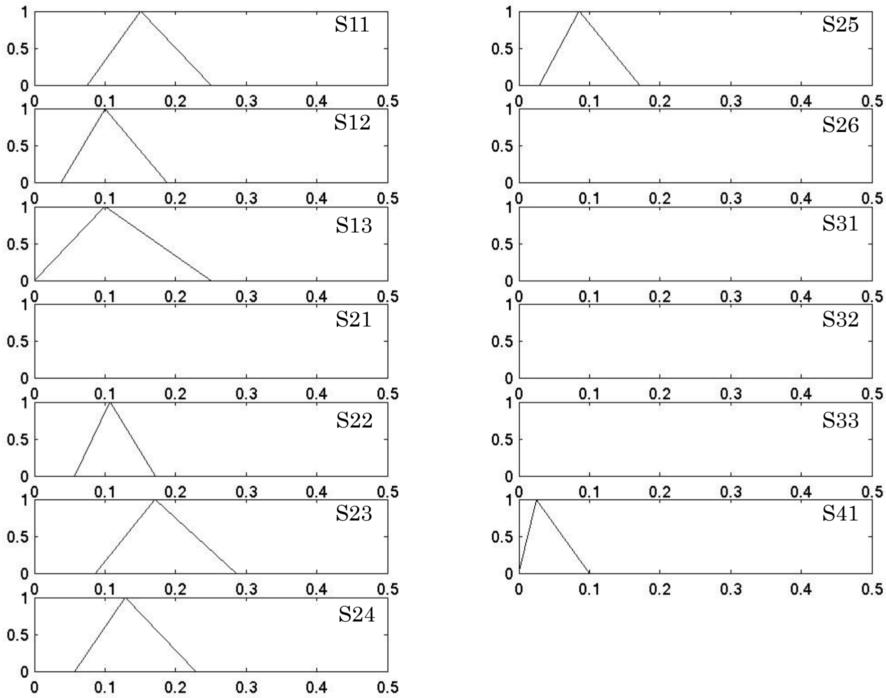
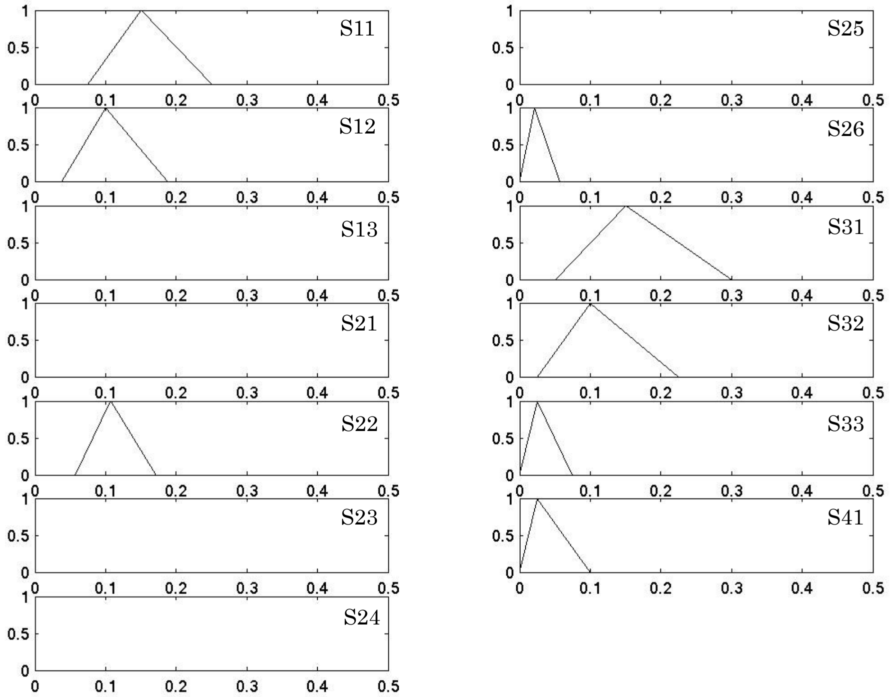


Fig. B-6 Fuzzy FDRR gap indices for Pateros

a) Fuzzy positive gaps



b) Fuzzy negative gaps

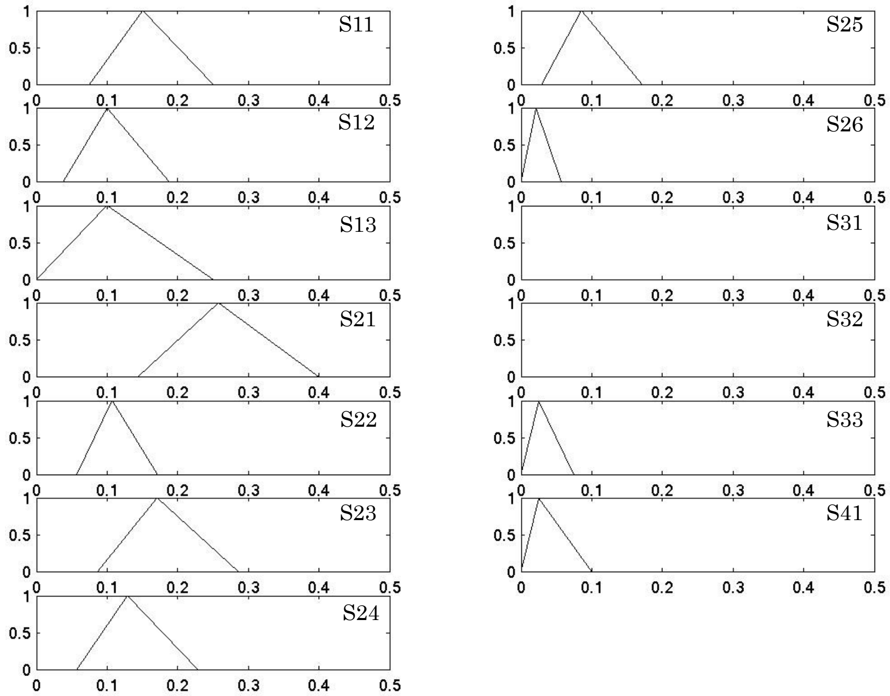
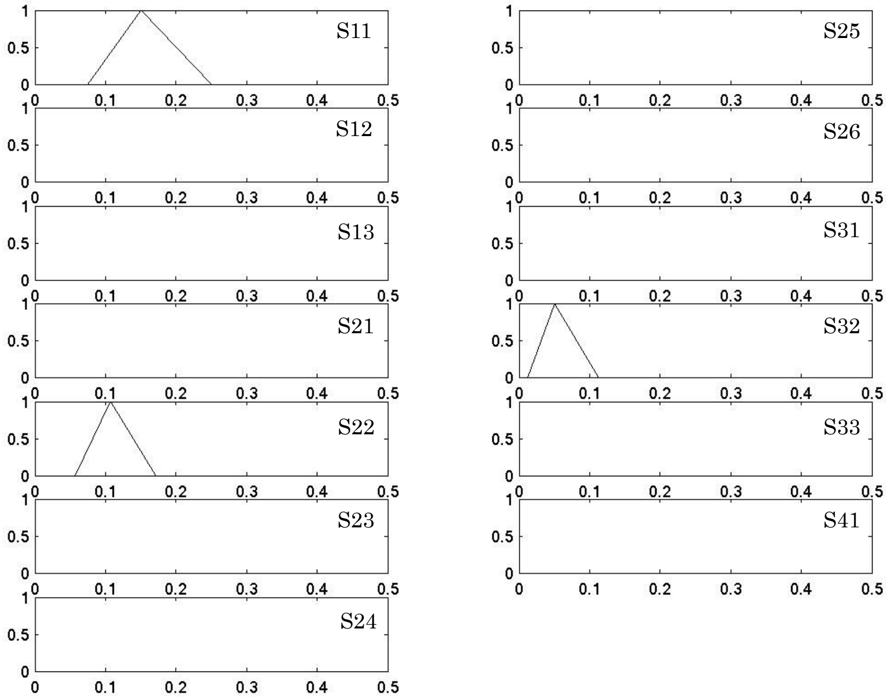


Fig. B-7 Fuzzy FDRR gap indices for Pasig City

a) Fuzzy positive gaps



b) Fuzzy negative gaps

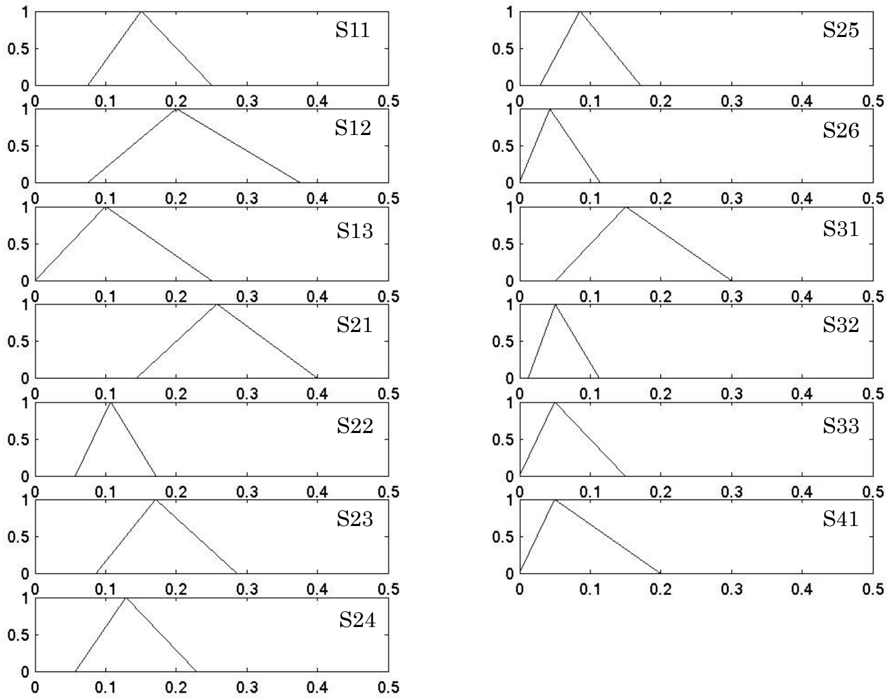


Fig. B-8 Fuzzy FDRR gap indices for Taguig City

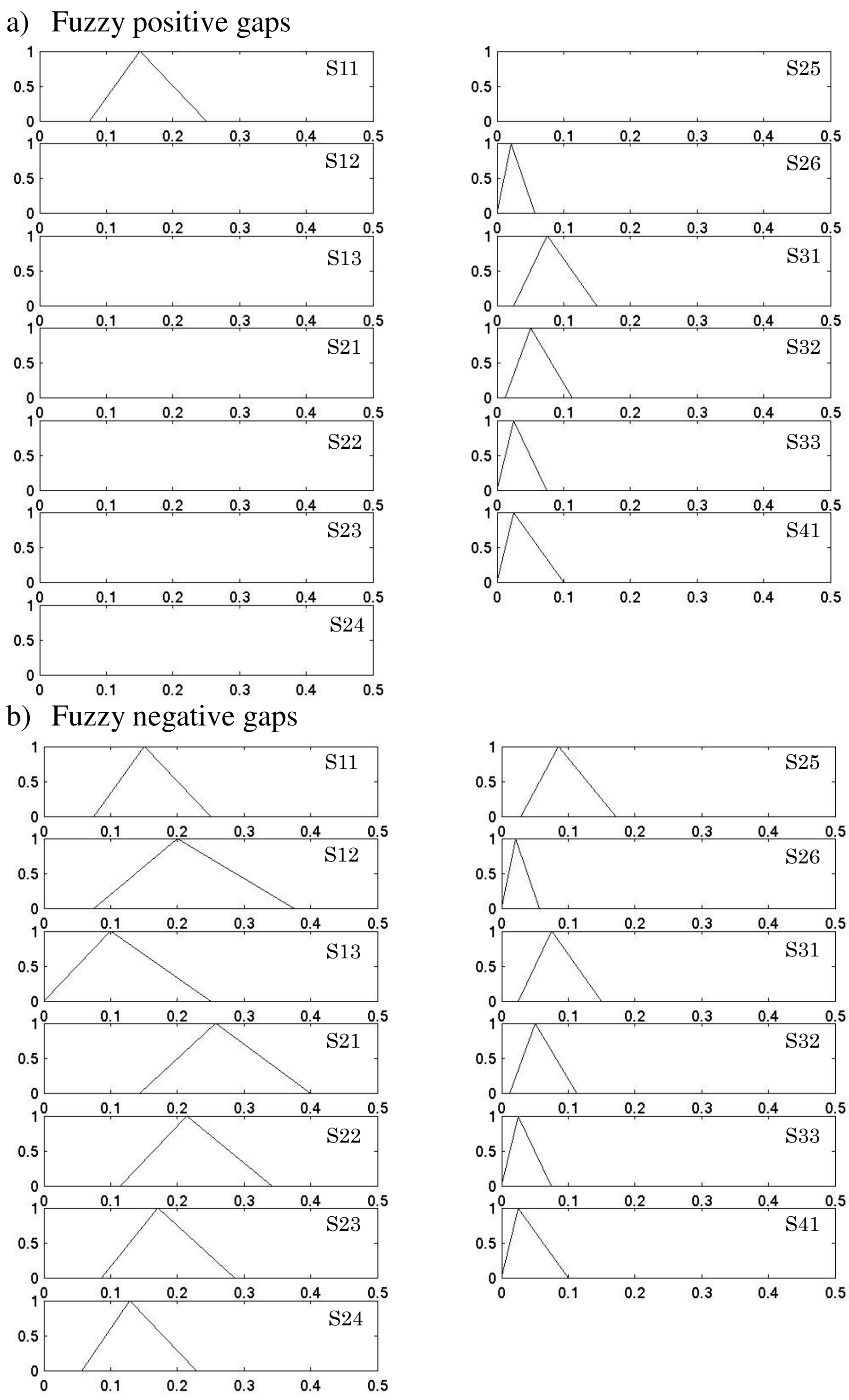
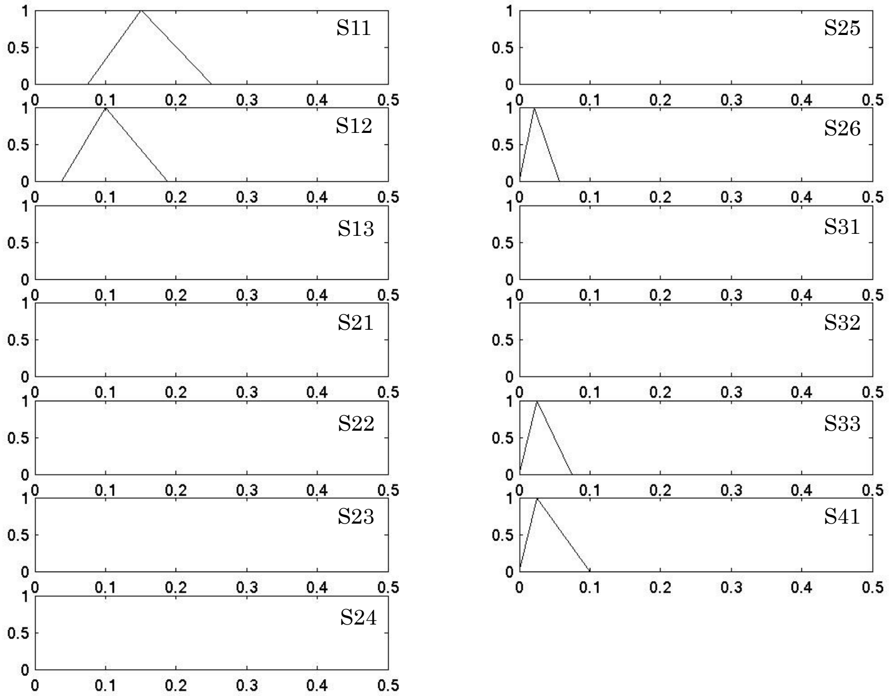


Fig. B-9 Fuzzy FDRR gap indices for Marikina City

a) Fuzzy positive gaps



b) Fuzzy negative gaps

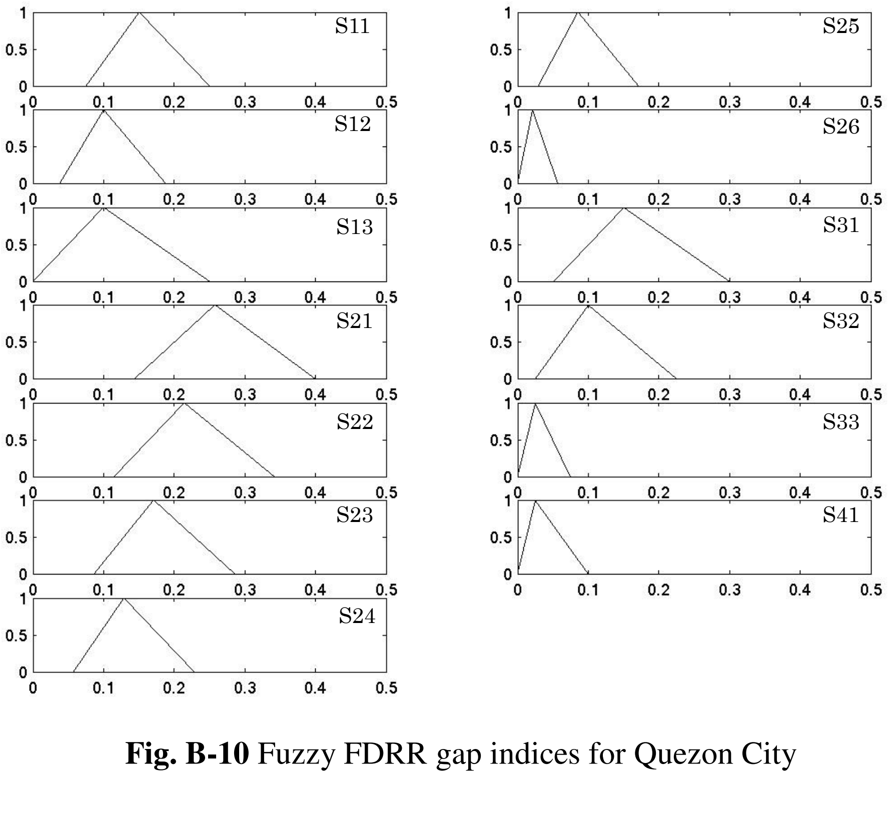
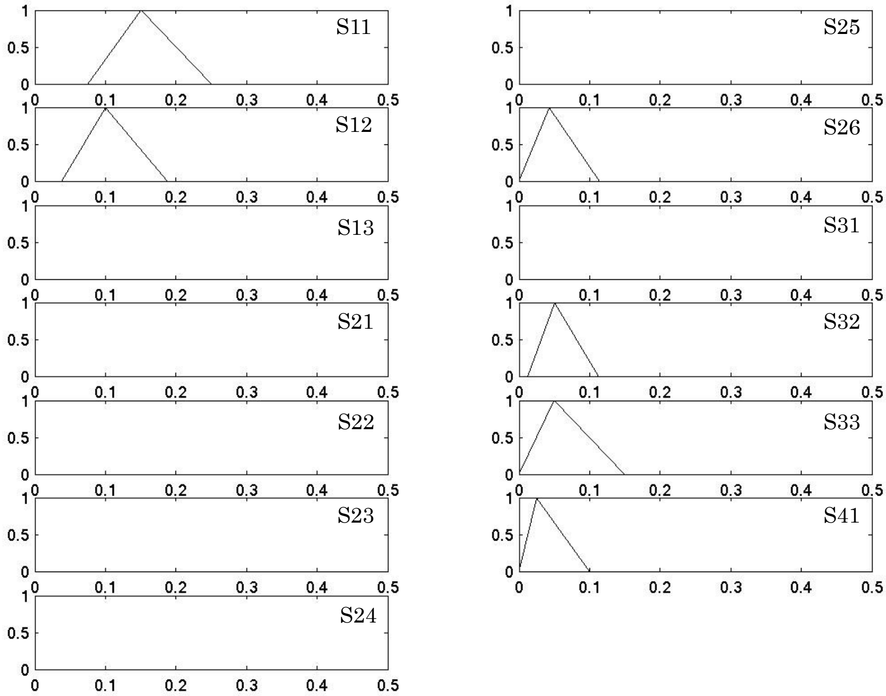


Fig. B-10 Fuzzy FDRR gap indices for Quezon City

a) Fuzzy positive gaps



b) Fuzzy negative gaps

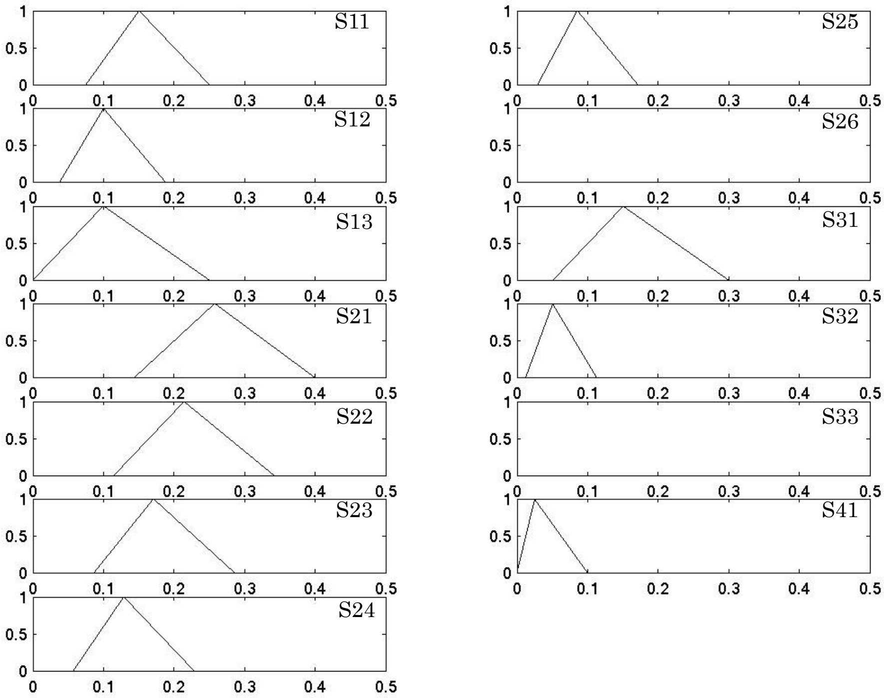
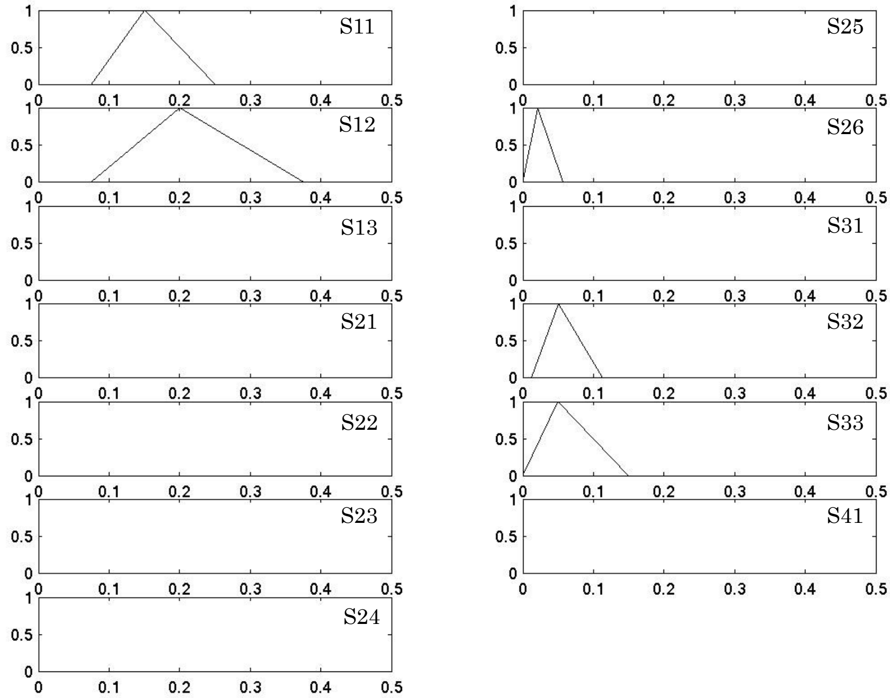


Fig. B-11 Fuzzy FDRR gap indices for Manila City

a) Fuzzy positive gaps



b) Fuzzy negative gaps

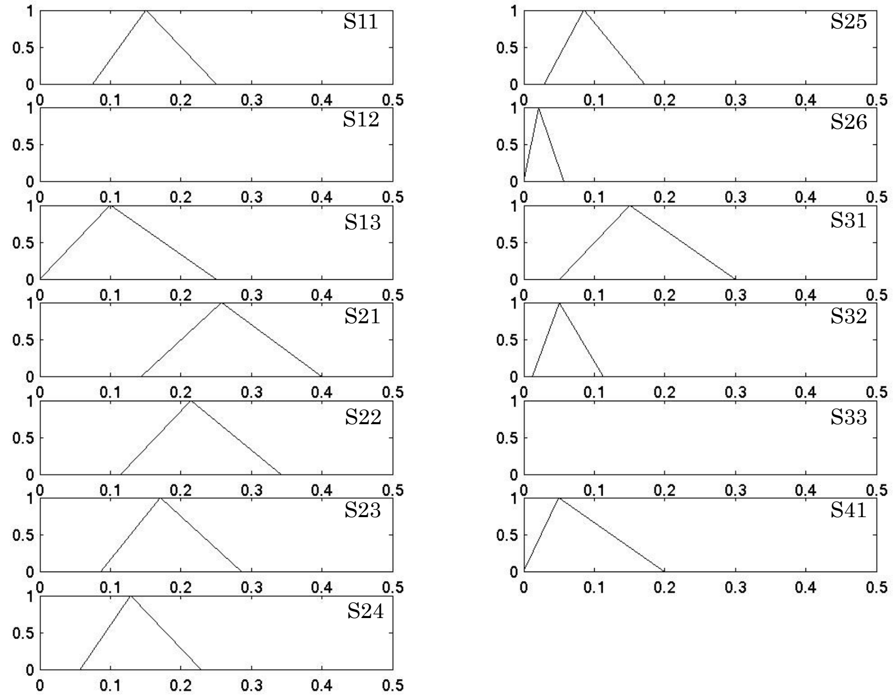
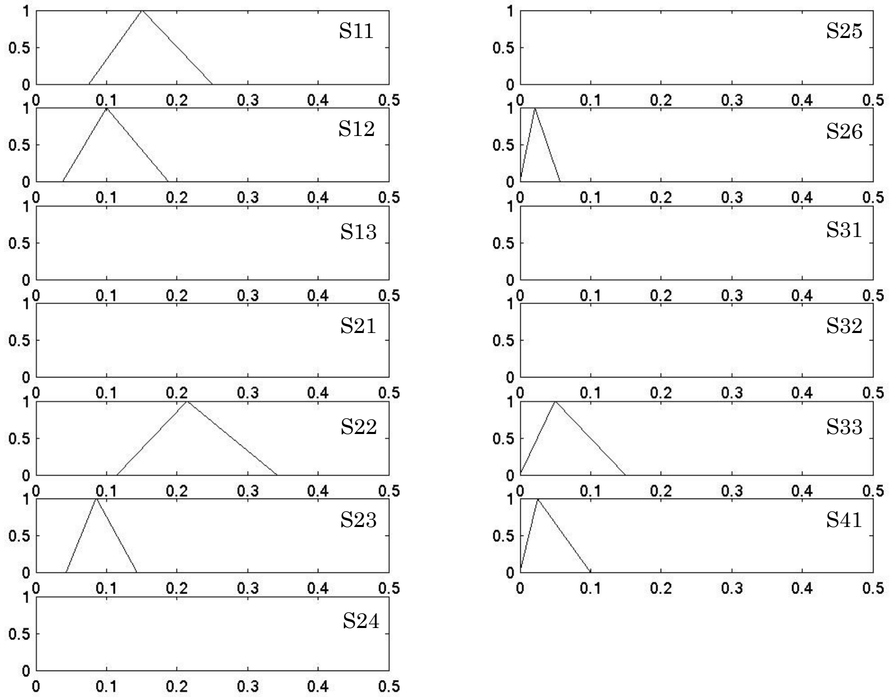


Fig. B-12 Fuzzy FDRR gap indices for Las Piñas City

a) Fuzzy positive gaps



b) Fuzzy negative gaps

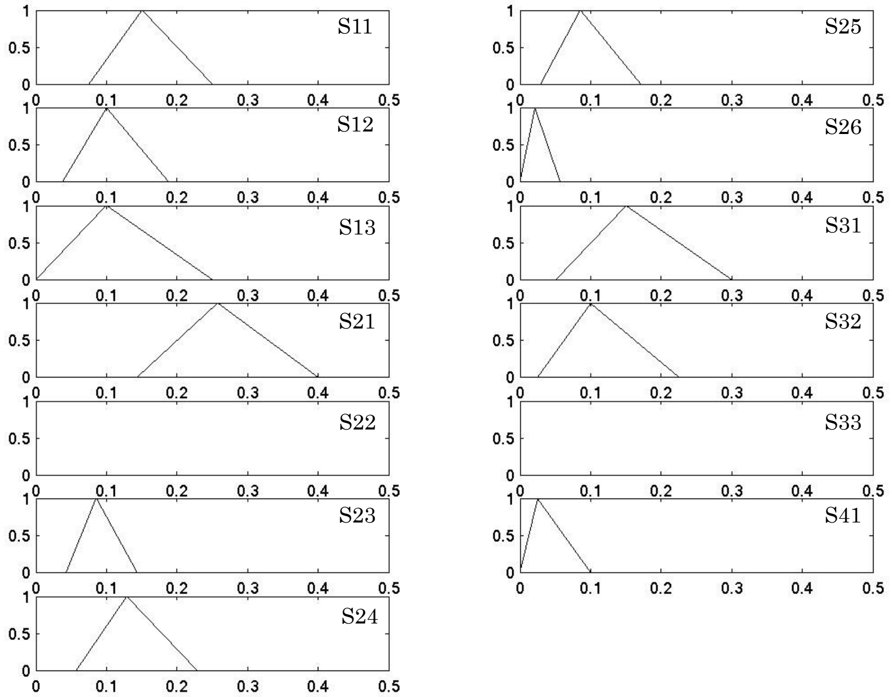
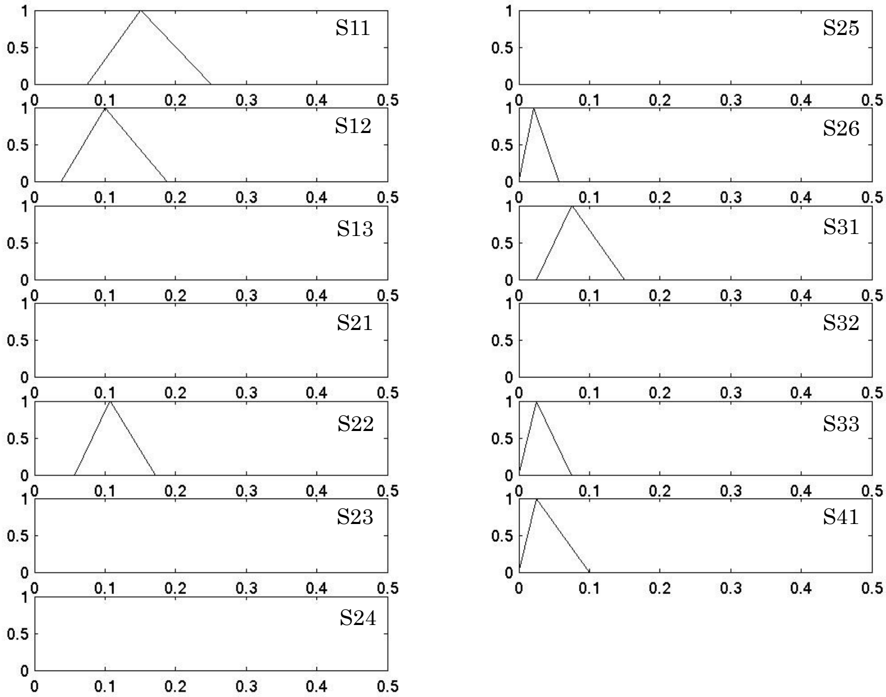


Fig. B-13 Fuzzy FDRR gap indices for Parañaque City

a) Fuzzy positive gaps



b) Fuzzy negative gaps

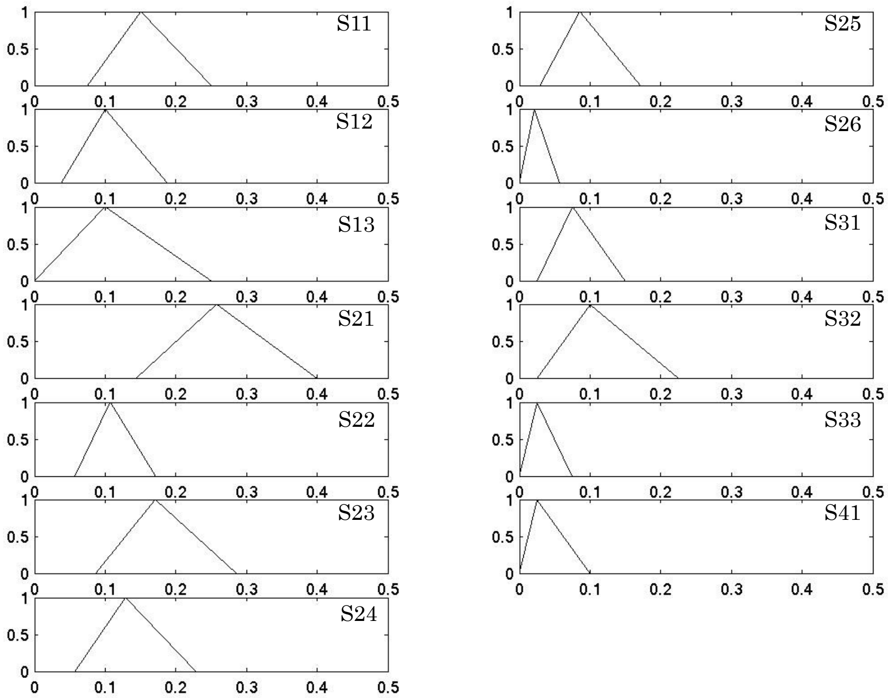


Fig. B-14 Fuzzy FDRR gap indices for Muntinlupa City