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Fuzzy-based gaps assessment of flood disaster risk reduction management systems in Metro Manila, Philippines

Romeo Gilbuena Jr [1,2], Akira Kawamura[1], Reynaldo Medina[2] & Hideo Amaguchi[1]

[1]Department of Civil and Environmental Engineering, Tokyo Metropolitan University, Tokyo, Hachioji, Japan and [2]Woodfields Consultants, Inc, Quezon City, Philippines

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Correspondence
Romeo Gilbuena, Jr., Department of Civil and Environmental Engineering, Tokyo Metropolitan University, Tokyo Japan, 1-1 Minami-Ohsawa, Hachioji 192-0397, Japan.
Email: romeogilbuena@gmail.com

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Abstract

Planning and prioritization in flood disaster risk reduction (FDRR) is critical and often tedious to both planners and decision-makers. In Metro Manila, Philippines, flooding is a perennial problem that requires regular assessments and updating of its municipal-based FDRR management systems. A simple, but practical approach may prove useful in the identification of priority schemes, especially when the need for improvement is urgent and resources are limited. This study provides a simple quantitative approach to gaps assessment for FDRR management systems using a fuzzy multiattribute decision-making technique. This is demonstrated by utilizing the stakeholders' perceptions and field information obtained during the aftermath of the tropical storm Ketsana in 2009. Study results show that the gaps can be quantified and ranked to establish the priority schemes for the improvement of the FDRR management systems in Metro Manila, focusing mainly on the following FDRR management systems: prevention, preparedness, response and disaster recovery.

Introduction

On 26 September 2009, Metro Manila, the Philippines' capital and centre for political and economic activities (see description in the following section), has been placed under critical condition when a rare meteorological event, the tropical storm *Ketsana*, occurred. Tropical storm Ketsana brought in the highest 12-h rainfall ever recorded in Metro Manila (Gilbuena *et al.*, 2013) that resulted in the flooding 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 (2013), this picture of disaster is becoming more and more frequent in many cities around the world (e.g. Hurricane Katrina in 2005, Cyclone Nargis in 2008, and Typhoon Morakot in 2009, and Hurricane Patricia in 2015), 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 Ketsana 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 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 readopted 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 a protected area system can meet 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 (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 utilized in the evaluation of FDRR management systems. In Metro Manila, the framework for a FDRR management system is typically composed of various measures encapsulated in four phases: prevention, preparedness, response and recovery (Department of National Defense, 2011). The evaluation of the FDRR management system entails the appraisal of each measure (as performance indicators) in each phase, thus, taking the form of a multiattribute decision-making problem. Multiattribute decision making is widely regarded for its robust application in various fields (Rebai *et al*., 2006; Yoe 2007; Zhai *et al*., 2007; Corsair *et al*., 2009; Calizaya *et al*., 2010; Wu *et al*., 2010), particularly those that require comparison of benefits and importance. Each multiattribute decision-making problem is associated with multiple attributes that often are 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 that can be used to deal with multiattribute decision-making problems (Jiang *et al*., 2011; Uyun and Riadi, 2011; Behzadian *et al*., 2012; Babaei *et al*., 2013). 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 judgement into quantitative-based assessment. Qualitative judgements, however, often operate within a fuzzy environment because of its imprecision and vagueness (Mechefske and Wang, 2001). Bellman and Zadeh (1970) first introduced the theory of fuzzy sets in multicriteria 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 judgements, a fuzzy approach to TOPSIS using fuzzy sets is necessary (e.g. Chen, 2000; Wang and Elhag, 2006; Chen and Tsao, 2008; Krohling and Campanharo, 2011; Momeni *et al*., 2011; 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 subsystems 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*. Further description of this relationship is explained in the following section, Gaps Assessment.

Metro Manila

Metro Manila, Philippines is a megacity (population of more than 10 million) that is 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). Figure 1 shows the administrative boundary of Metro Manila including

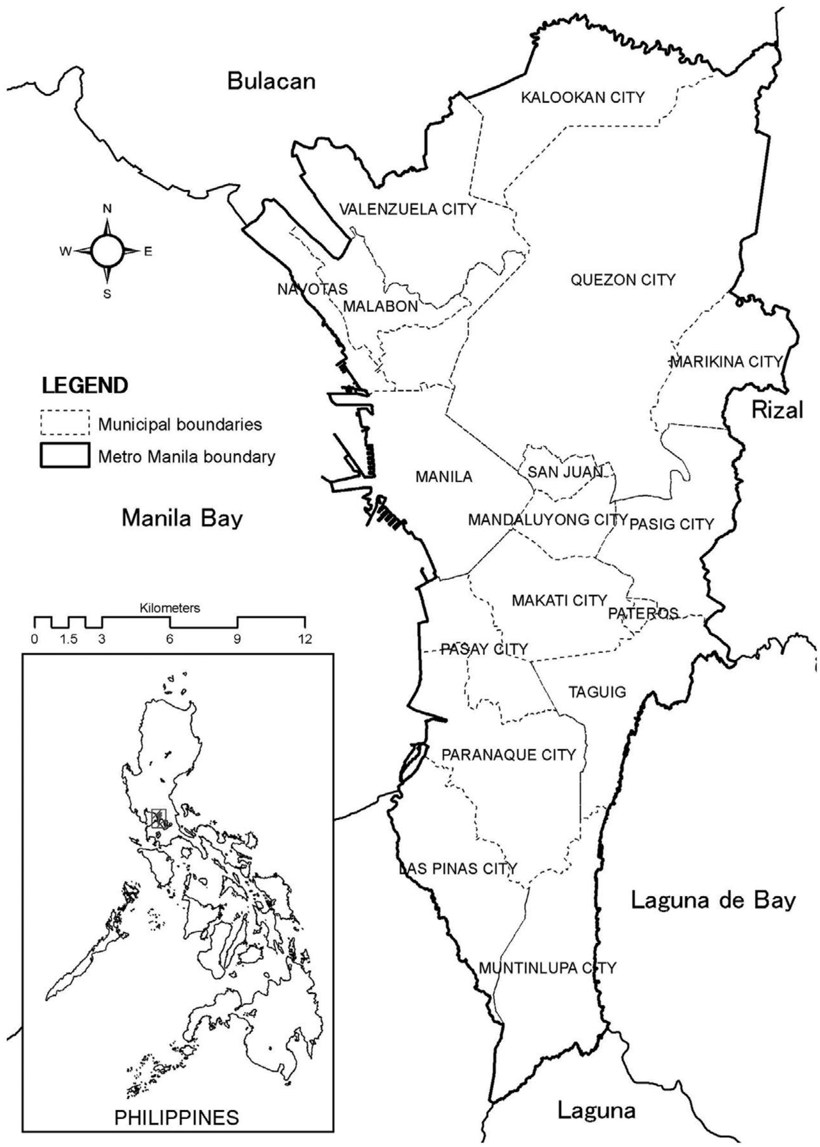

Fig. 1. Geographical location of Metro Manila and its 17 Municipalities.

its 17 municipal local government units. It is the country's political and economic capital with annual contribution of around 33% to the country's gross domestic product. Based on the 2007 population census, there were a total of approximately 11.54 million residents in Metro Manila. The population density then was around 18,600 people/km^2. In 2009, the gross regional domestic product of Metro Manila was around PhP 247,000 (National Statistics Coordination Board 2009). Despite its progress, floods have persistently slowed down Metro Manila's economic growth. Parts of Metro Manila would easily succumb to flood, even at moderate precipitation, because of the poor drainage system and unmitigated runoffs, which are primarily caused by poor solid waste management (near the open channels), improper land use and the high rate of urbanization. The negative impacts of flooding in Metro Manila range from minor inconveniences, such as heavy traffic and suspension of office work and school activities, to catastrophic levels, such as loss of lives and damage to public infrastructure and property (Page 2000; Gilbuena *et al*., 2013).

In 1952, the national government completed its first comprehensive drainage improvement plan covering most of the present day Metro Manila (Bureau 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

Table 1 Damage profile of the14 assessed municipalities in Metro Manila during the tropical storm Ketsana

Code	Municipalities	Area, km^2	Flooded area (%)	Estimated population ($\times 10^3$)	Affected population (%)	Direct damage ($\times 10^6$ 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

several of the national government offices. The tasks typically include the operation of structural measures; implementation of non-structural measures (e.g. flood hazard zoning); preparedness operations; response operations; and rehabilitation/recovery operations. At present, the Philippine government is pursuing the implementation of structural and non-structural flood control projects recommended in the report, 'Flood Management Master Plan for Metro Manila and Surrounding Areas' prepared in 2012.

Tropical Storm Ketsana

On 26 September 2009, the tropical depression Ondoy (local name) developed into the tropical storm Ketsana (international name), and raged across Metro Manila with a rainfall far exceeding all the precipitation levels recorded in this area since 1961. The highest 12-h 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 1 shows a summary of the inundated areas and number of people (by municipality) affected by the tropical storm Ketsana, based on an unpublished work for the flood management master plan in Metro Manila.

During the first few weeks after the storm, the authors carried out 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 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 Ketsana, during Ketsana and after Ketsana (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 National 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.

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. Figure 2 shows the conceptual framework used in the assessment of gaps in the FDRR management system in Metro Manila.

Metro Manila FDRR management system

Figure 3 shows the hierarchical structure for the evaluation of the performance of the FDRR management systems in Metro Manila. From this figure, the FDRR management system is composed of four sub-systems (i.e. Prevention (S1), Preparedness (S2), Response (S3) and

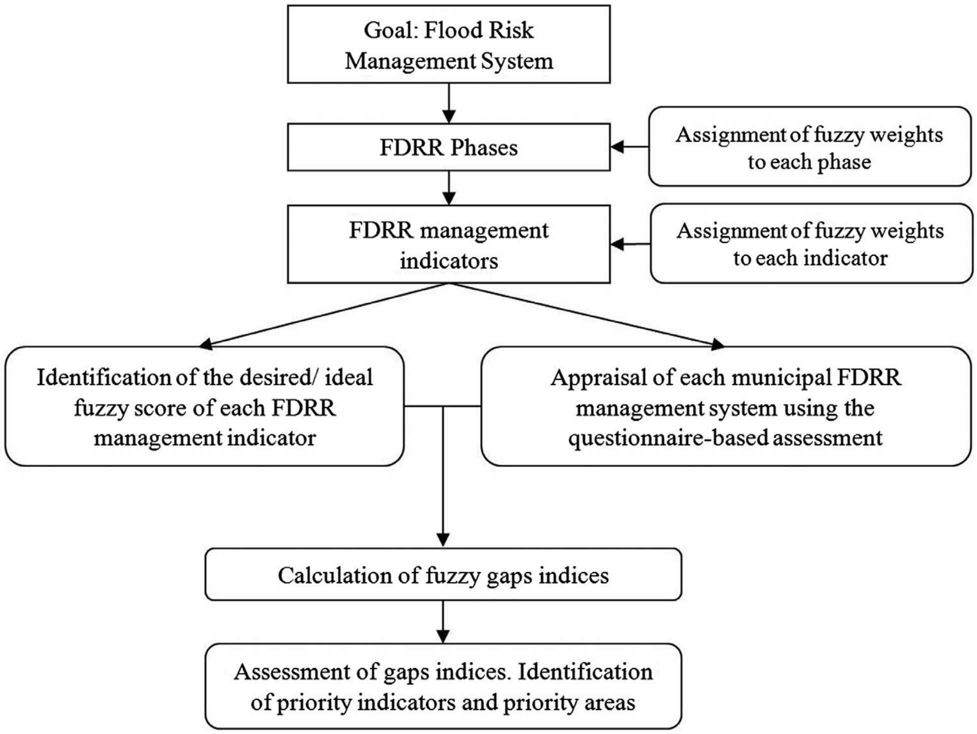

Fig. 2. Gaps assessment framework of the FDRR management systems in Metro Manila.

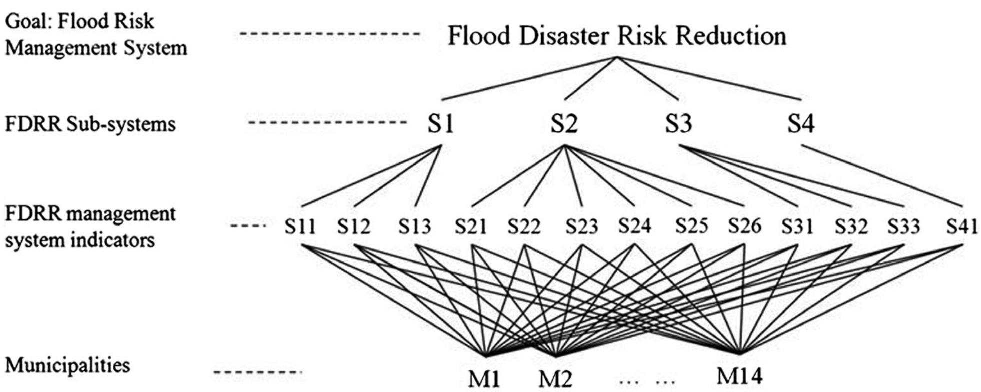

Fig. 3. The decision hierarchy for the performance appraisal of FDRR management systems in Metro Manila.

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 aggregating the performance ratings of each FDRR indicator. In this study, 14 out of 17 municipalities of Metro Manila were assessed for FDRR management gaps. Table 2 shows the description of each FDRR performance indicators in each FDRR subsystem. As shown in this table, each of the subsystems and FDRR indicators is ranked by the authors according to 'relative importance'. All the authors have years of knowledge and experience in both planning and implementation of urban flood management systems. The rank of 1 indicates *highest priority*. The relative importance of a FDRR sub-system/ FDRR indicator is subjectively determined based on (1) order of need prior to the occurrence of disaster (i.e. Prevention sub-system is expected to provide higher risk reduction compared to the Recovery sub-system) and (2)

Table 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)

the subsystem/indicator is most likely a prerequisite of another sub-system/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 sub-system) is given the rank of 1, while the rest of the FDRR indicators are ranked accordingly.

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 multiattribute decision making with uncertain data, resulting in a fuzzy TOPSIS (Triantaphyllou and Lin, 1996; Chen, 2000; Krohling and Campanharo, 2011).

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 gap 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 gap 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. Triantaphyllou and Lin, 1996; Chen, 2000; Krohling and Campanharo, 2011). 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 *et al*. (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:

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

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:

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

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

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

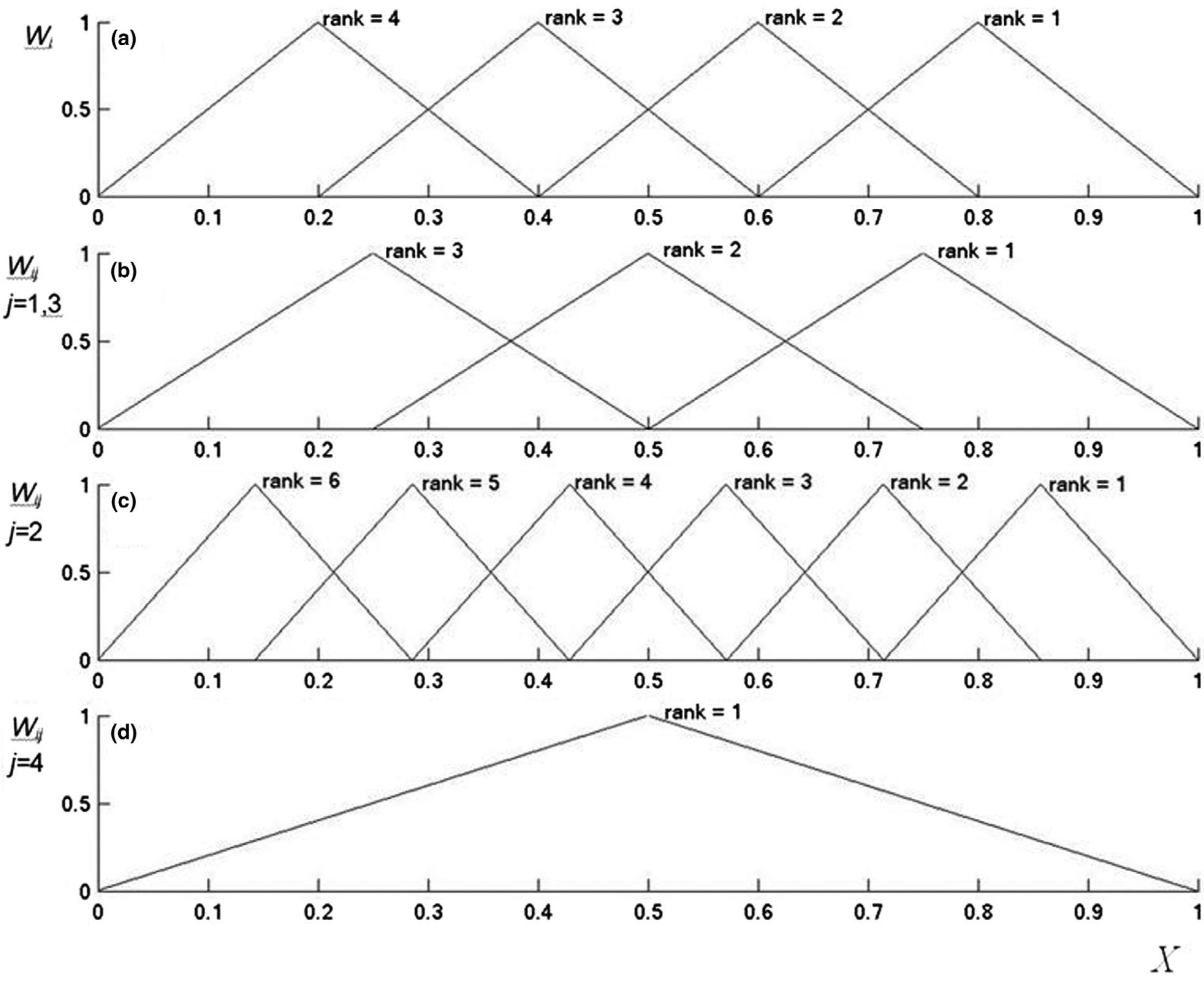

Fig. 4. Membership functions used in the assignment of fuzzy weights for the sub-systems (*i*) and FDRR indicators (*ij*). The numbers at the top of the plots represent the corresponding priority of each fuzzy weight. (a) Four attributes, (b) Three attributes, (c) Six attributes, (d) One attribute.

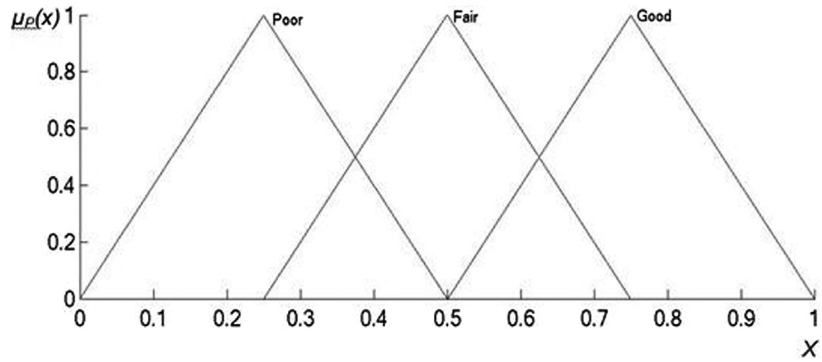

Fig. 5. Membership functions of the performance ratings for the evaluation of FDRR management systems in Metro Manila.

$$\text{Division: } A\,(/)\,B = (a_1, a_2, a_3) \,/\, (b_1, b_2, b_3) = \left(\frac{a_1}{b_1}, \frac{a_2}{b_2}, \frac{a_3}{b_3}\right) \tag{5}$$

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

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. 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. 4(b). Similarly, the fuzzy weights of the FDRR indicators of S2 and S4 subsystems are based on the membership functions in Fig. 4(c) and 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:

$$W_{eq,ij} = W_i \times W_{ij} \tag{7}$$

The performance of each FDRR indicator is then rated using the appraisal carried out 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 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

Table 3 Performance appraisal of the flood disaster risk reduction management systems of 14 municipalities

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

are shown in Table 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. 5, which is expressed by:

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

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

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

The fuzzy TOPSIS approach to gap analysis 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* that corresponds to the performance appraisal 'Good', while the negative ideal rating, P^-, is defined as the *worst performance* that 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:

$$F^+_{m,ij} = \left(W_{eq,ij} \times P^+\right) \quad (10)$$

$$F^-_{m,ij} = \left(W_{eq,ij} \times P^-\right) \quad (11)$$

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

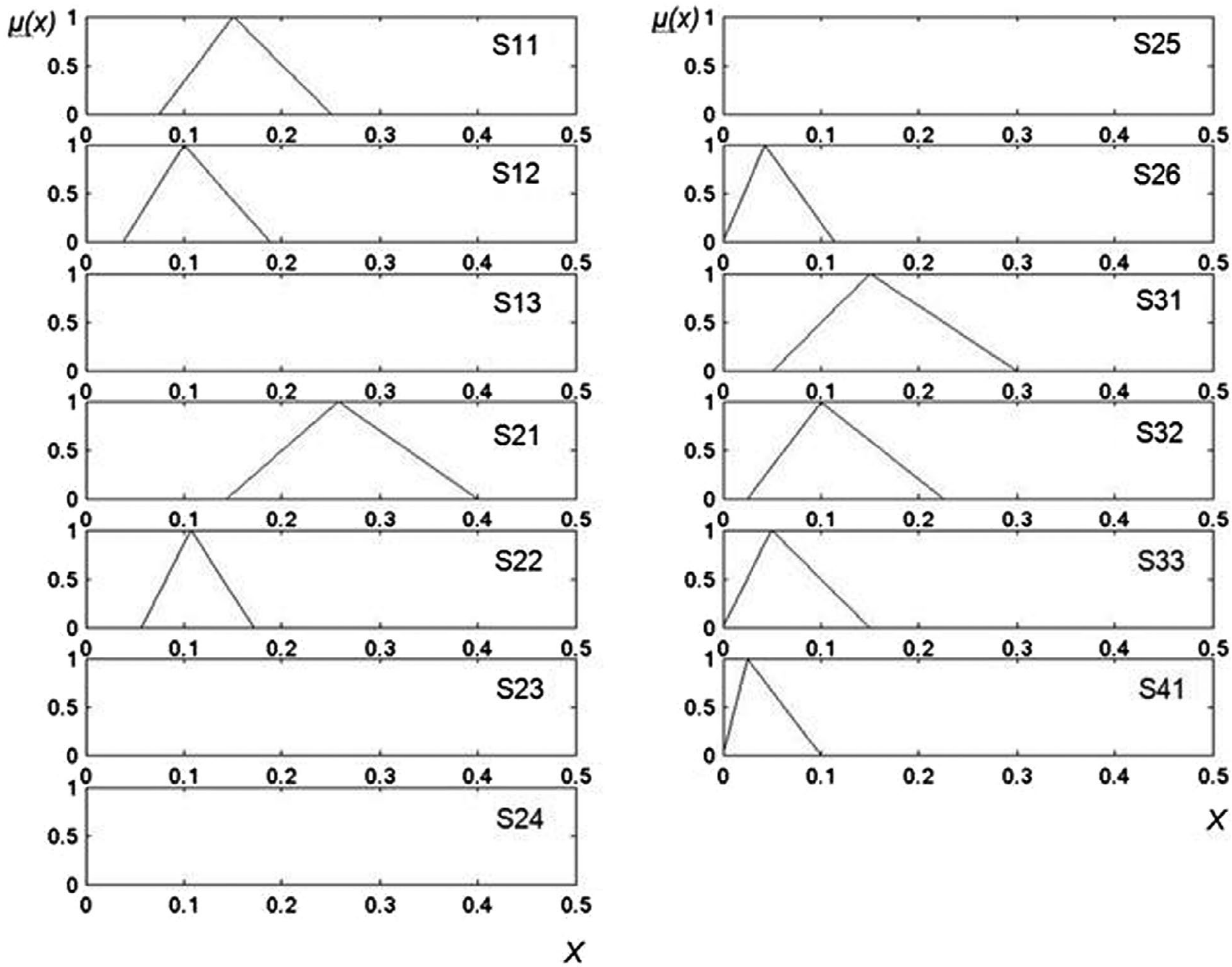

Fig. 6. Fuzzy positive gaps in the FDRR management of Pateros based on the FDRR indicators in Table 2.

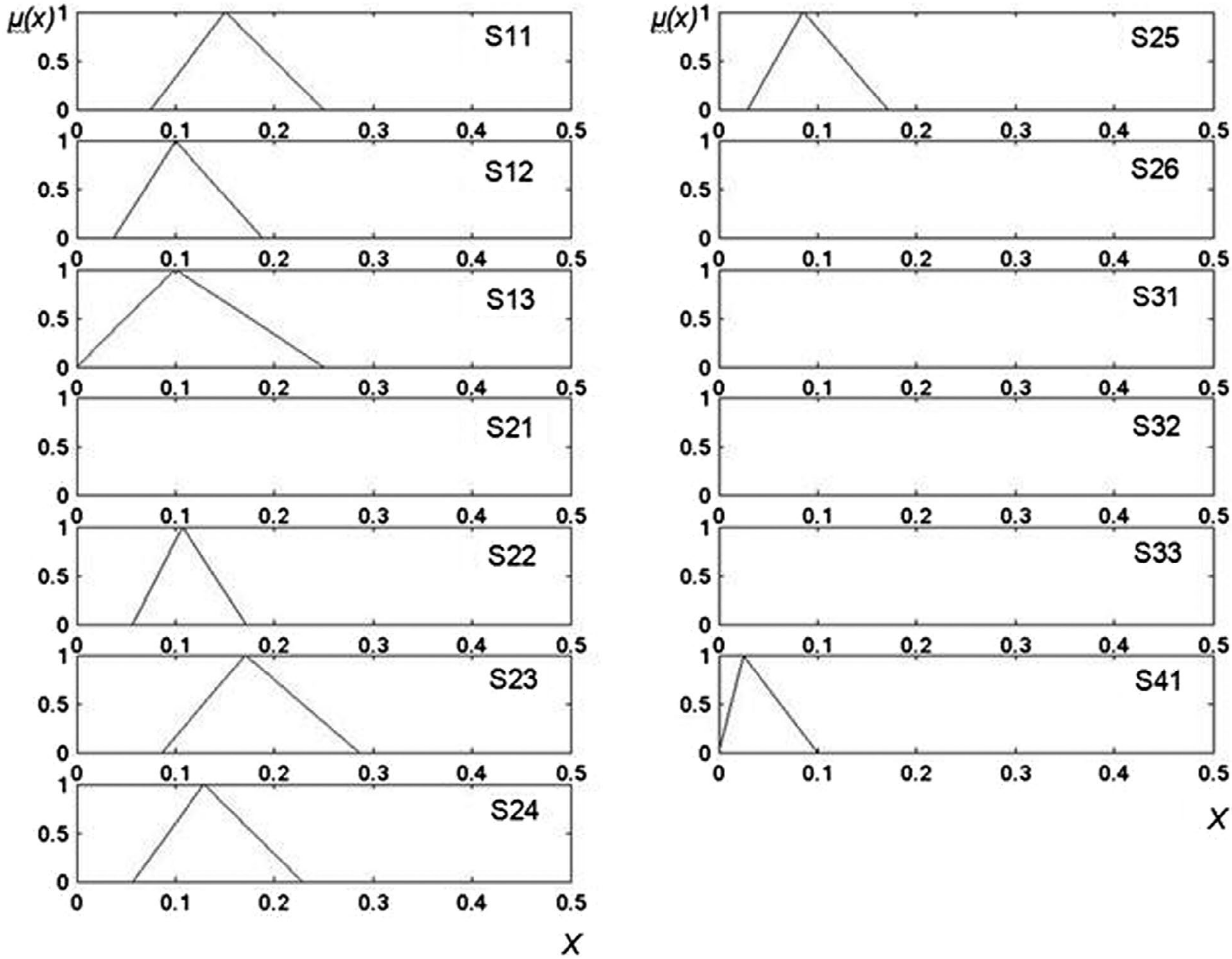

Fig. 7. Fuzzy negative gaps in the FDRR management of Pateros based on the FDRR indicators in Table 2.

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

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

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:

$$D^{+}_{m} = \sqrt{\sum_{ij} \left(D^{+}_{m,ij}\right)^2} \quad (14)$$

$$D^{-}_{m} = \sqrt{\sum_{ij} \left(D^{-}_{m,ij}\right)^2} \quad (15)$$

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:

$$\Delta_m = \frac{D^{+}_{m}}{D^{+}_{m} + D^{-}_{m}} \quad (16)$$

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; Szmidt and Kacprzyk 2000; Chen and Tsao 2008):

$$d^{+}_{m} = \sqrt{\frac{1}{3}\left[\left(d^{+}_{m1}\right)^2 + \left(d^{+}_{m2}\right)^2 + \left(d^{+}_{m3}\right)^2\right]} \quad (17)$$

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

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

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:

$$D_{ij}^+ = \sqrt{\sum_m \left(D_{m,ij}^+\right)^2} \quad (20)$$

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

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

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

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

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

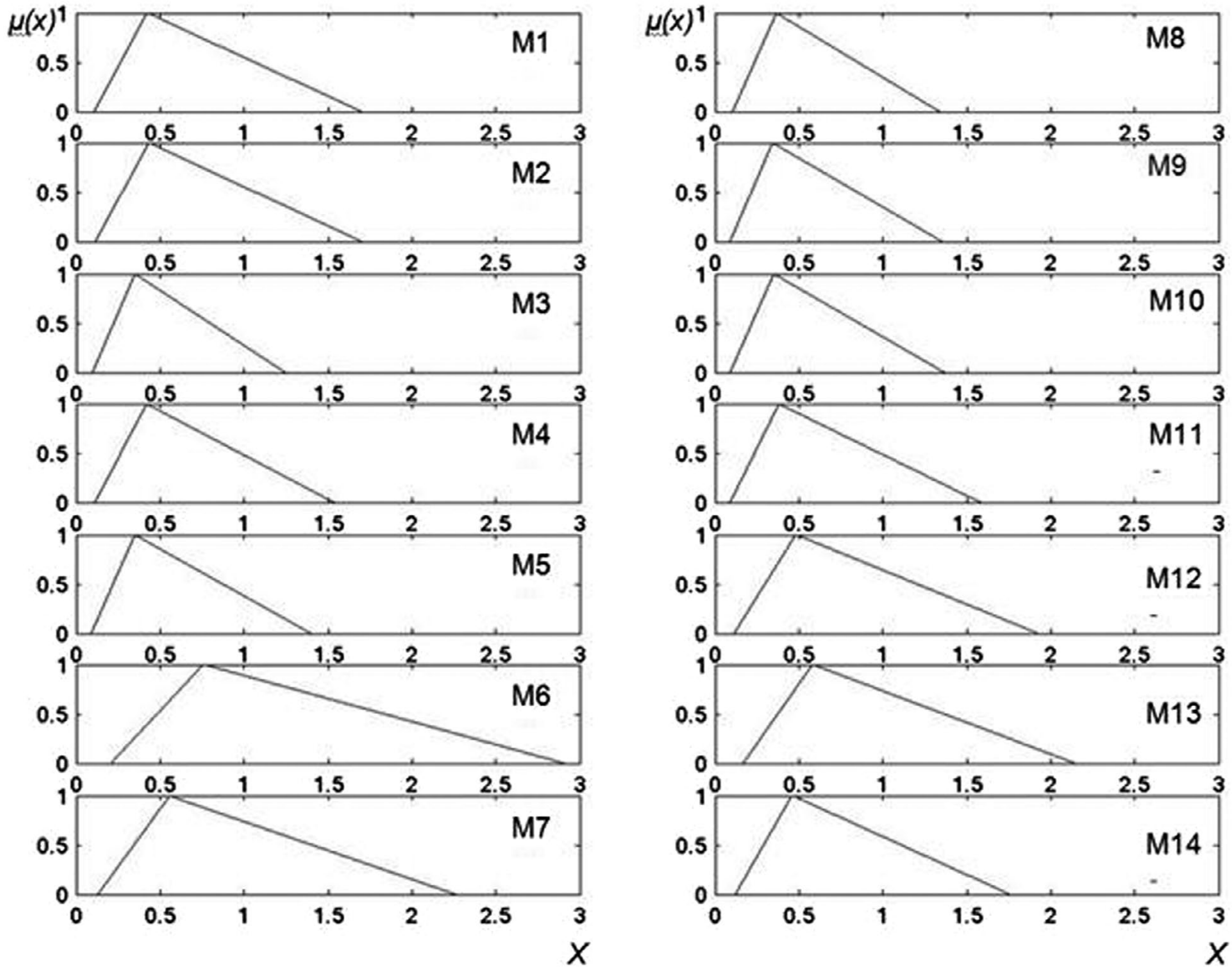

Fig. 8. Fuzzy gap indices of the 14 assessed municipalities (M1 to M14 in Table 1).

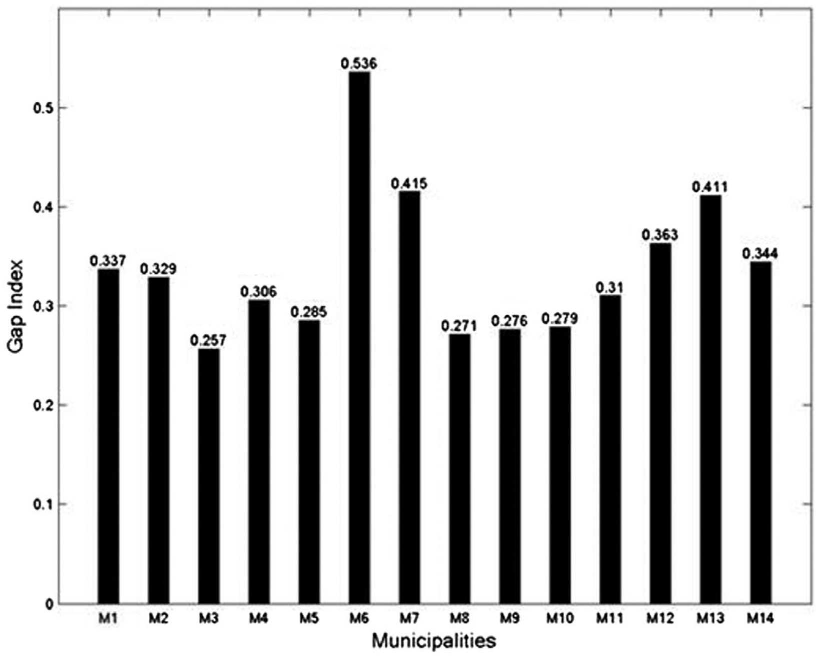

Fig. 9. Histogram of crisp gap indices representing the overall gaps in the FDRR management systems of the 14 assessed municipalities in Metro Manila.

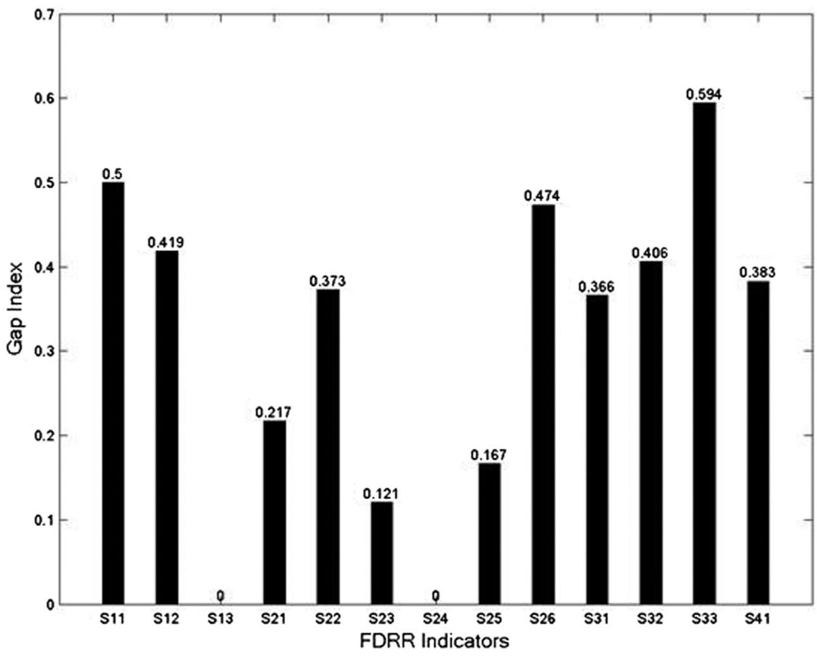

Fig. 10. Histogram of crisp gap indices representing the overall gaps in each of the FDRR indicators of the 14 assessed municipalities in Metro Manila.

Results of fuzzy-based gaps assessment

The fuzzy and crisp gap indices of the FDRR management system of each municipality were calculated 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. Using the definition of the fuzzy performance appraisal ($P_{m,ij}$) in Eq. (8), the fuzzy equivalent performance appraisal ($F_{m,ij}$) was calculated using Eqs. (7)

and (9). By following the procedures Steps 1 to 3 in the previous section, the fuzzy positive and negative gaps ($D^{+}_{m,ij}$, $D^{-}_{m,ij}$) were calculated. The results were plotted as shown Figs 6 and 7, for $D^{+}_{m,ij}$ and $D^{-}_{m,ij}$, respectively. Based on the fuzzy positive gaps in Fig. 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. 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. 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. 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. 9. 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 of the previous section. The results are summarized in a histogram as shown in Fig. 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.

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 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 analysed and discussed. For the purpose of brevity, four municipalities with the highest gaps and four municipalities with the lowest gaps are analysed and discussed.

Based on Fig. 9, the four 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 Ketsana, which indicates that Pateros requires immediate support from governing authorities to improve their FDRR management system. From Table 3, 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 Ketsana, where 92.86% of its total land area was inundated and nearly 100% of its population was affected as shown in Table 1.

Pasig City, on the other hand, is poor in terms of their disaster response (S3) during the tropical storm Ketsana. As seen in Table 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 terms of the highest amount of damage incurred 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, 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 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. 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 reveals that Navotas City is much more similar with Taguig City than with Marikina City and Quezon City. All four 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 as a result of its rapidly increasing urbanization.

Quezon City is the largest and most populated municipality in Metro Manila (as shown in Table 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 because of 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 two municipalities (Navotas City and Taguig City) indicated that the speed of their response and rescue operations during the flooding of the tropical storm Ketsana 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. 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 because of 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.

Conclusion

This study is a first attempt to describe a method for gaps assessment of FDRR management using a fuzzy multiattribute 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 multiattribute gaps assessment method;
2. The use of priority ranking in the multiattribute 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;
4. 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). In addition, we may improve this scheme by creating a database of priority rankings and FDRR performance ratings from other flood management experts and stakeholders.

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