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FUZZY-BASED M&E OF THE IFRM PERFORMANCE IN METRO MANILA

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This study attempts to conduct a monitoring & evaluation (M&E) of the integrated flood risk management (IFRM) in Metro Manila. In this study, we monitored the performance level at each city in Metro Manila by carrying out a series of interviews and surveys. The performance for IFRM based on the 15 indicators we utilized in this study was appraised qualitatively by the practitioners from each city in Metro Manila. Then, the monitored qualitative appraisals were evaluated using the fuzzy set theory, which was a suitable method for handling imprecise or qualitative data. The indicators and qualitative appraisals were given fuzzy weights, and these were aggregated to evaluate the overall performance for IFRM for each city. The results show that majority of the cities in Metro Manila are performing above the Good level, but this level still suggests that more work and attention are needed to attain substantial achievements for IFRM. The approach in this study is suitable for M&E activities that heavily depended on qualitative data or information.

Key Words : *fuzzy, integrated flood risk management, Metro Manila, monitoring & evaluation*

1. INTRODUCTION

M&E (Monitoring & Evaluation) is used to measure and assess the performance of projects or programs so that sufficient data and information are captured to review the progress and impact[1)]. M&E is an essential task for newly developed projects or programs to ensure that work is in the right direction for progress and success, and to identify how future efforts can be improved. Despite the necessity of conducting M&E, this has not been carried out yet for the integrated flood risk management (IFRM) in Metro Manila.

The IFRM was one of the actions devised by the Philippine government in 2012 to proactively manage flood risks after the devastation in Metro Manila brought by Typhoon Ondoy (internationally known as Typhoon Ketsana) in September 2009. The IFRM was formulated by the Department of Public Works and Highways (DPWH), and it was the first comprehensive flood management in Metro Manila[2)]. The IFRM has four components: prevention, preparedness, response, and recovery/rehabilitation, which are adopted from the disaster risk reduction management (DRRM) activities. Within these four components, DPWH also proposed 15 measures as shown in **Fig.1**, in which 4, 7, 3, and 1 measure are under the prevention, preparedness, response, and recovery/rehabilitation, respectively. At present, the effectiveness of these measures has not been determined in Metro Manila due to the lack of M&E activities for the IFRM. The main cause for the lack of M&E for IFRM is due to the absence of an agency-in-charge of the regional implementation of the IFRM[3)].

In view of this background, this study aims to conduct a city-based M&E of the IFRM performance in Metro Manila. We utilized the 15 measures proposed by the DPWH as the indicators for the M&E, because there is no measurable indicators for IFRM. To monitor these indicators, we carried out a series of interviews and surveys at each city in Metro Manila to obtain qualitative appraisals on each indicator from the practitioners. The interviews and surveys are tedious tasks because the selection of the expert or practitioner who can appraise all indicators is very challenging, and a special connection/ endorsement with the government agencies is needed to conduct these activities. Then, the collected qualitative appraisals are to be evaluated using the fuzzy set theory.

The fuzzy set theory introduces fuzzy numbers to help qualitative data or linguistic terms to be expressed appropriately[4]. This method has a renowned application in multi-criteria decision making (MDCM) problems that required qualitative judgments or preferences from the users[4]. It is extensively applied to MCDM problems related to science, management and business, engineering, and technology[5]. For DRRM-related problems, fuzzy has been applied for risk assessments and evaluations[6),7)], selection of risk management strategies[8], and decision support frameworks[9]. In our previous study[10], we have also applied fuzzy to conduct a quantitative gap assessment[11] of the flood DRRM in Metro Manila, which can be used as baseline information for this study. On the other hand, fuzzy has not yet been applied as a tool for M&E of DRRM or IFRM frameworks, as far as the authors know. Thus, we propose to apply this concept for the first time for the M&E of the IFRM in Metro Manila.

For this study, a fuzzy-based M&E of the IFRM performance was attempted, and this approach is meant to provide a rapid comparison assessment method which identifies the areas and components that needed improvement for the IFRM. The 15 measures in the IFRM are treated as the IFRM indicators, and these are given fuzzy weights based on priority ranking methodology[10),11)]. Likewise, the qualitative appraisals on the indicators are given fuzzy weights, and the results are aggregated using fuzzy arithmetic operations. Then, the aggregated values are to be transformed into crisp values, which represent the overall performance for IFRM in each city.

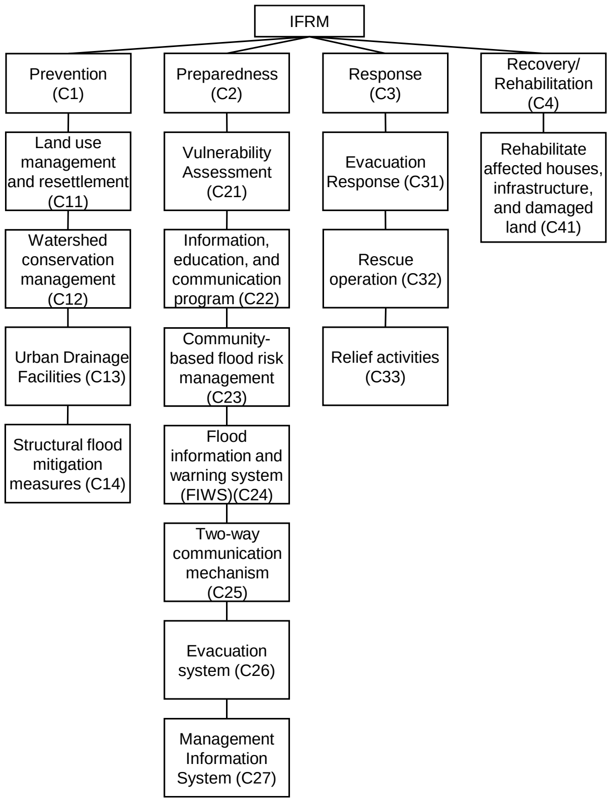

Fig. 1 Components and indicators of the IFRM[2] arranged according to priority ranking methodology.

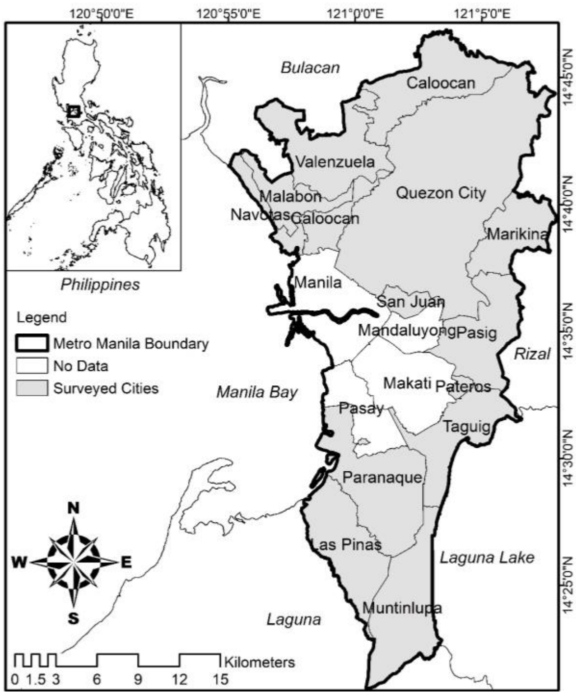

Fig.2 Location map of Metro Manila, Philippines.

2. METHODOLOGY

(1) Study Area

Metro Manila is the capital region of the Philippines. This region is situated on a semi-alluvial fan that opens to Manila Bay on the east and Laguna Lake to the southeast as shown in **Fig.2**. Metro Manila is composed of 17 cities and encompasses an area of 619.57 km^2. It is the center of political, education, and economic activities in the Philippines. However, economic activities are perennially disrupted by flood occurrences, as this region is situated in one of the widest floodplains in the country. Flood occurrences are frequent and intense during the typhoon season, from June to October, which are usually caused by typhoons, monsoon rains, and even torrential rains[2]. The flood depths in this region can range from a gutter-height inundation caused by torrential rains to more than 5-meter inundation caused by typhoons.

(2) Monitoring scheme for the IFRM

To carry out the monitoring of the indicators for each city in Metro Manila, a team of researchers organized by the authors carried out a series of interviews and surveys from December 2019 to February 2020 in Metro Manila to monitor the current performance for IFRM. Out of the 17 cities in Metro Manila, 13 cities had completed the interviews and surveys during the period of investigation, and these 13 cities are shaded in **Fig.2**. The target respondents were the officers-in-charge of the City Disaster Risk Reduction Management Office, Engineering Office, and City Environment and Natural Resources Office, because they are specifically mandated to be responsible for DRRM-activities at their respective local government unit.

In the interviews and surveys, we asked the respondents to make qualitative appraisals on the 15 IFRM indicators listed in **Fig.1**. The respondents are requested to select one out of the six linguistic performance appraisals, shown in **Table 1**, that best describe the performance for each IFRM indicator. The six linguistic performance appraisals are explicitly described in **Table 1**, and these descriptions aims to aid the respondents in making the appraisals for each indicator. In addition to the appraisal, we also asked queries to justify their appraisal for each indicator.

(3) Fuzzy-based evaluation

The idea of the fuzzy set theory was developed by Zadeh[12] to describe modes of reasoning as approximate, rather than exact. This method is effective for decision-making problems where available data is imprecise because such data can be represented using a linguistic variable. The values of these linguistic variables can be generated from a possibility distribution through the use of attributed grammar techniques[12], i.e., the use of “Bad”, “Poor”, “Fair”, “Good”, “Very Good”, and “Excellent” to describe the performance for IFRM.

In this study, we utilized a fuzzy set having a triangular membership function for the linguistic variables, and this is defined as follows[13]:

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 real number in the

Table 1 Appraisal for the IFRM component indicators.

Linguistic Performance Appraisal	Description
Bad (B)	No improvement
Poor (P)	Minor improvement with few signs of forward action in plans or policy
Fair (F)	Some progress, but without systematic policy and or institutional commitment
Good (G)	Institutional commitment attained, but achievements are neither comprehensive nor substantial
Very Good (VG)	Substantial achievement but with recognized limitations in capacities and resources
Excellent (E)	Comprehensive achievement with sustained commitment in capacities

interval [0, 1]. The numerical value of $\mu_A(x)$ stands for a grade membership function of x in A.

Definition 2: The fuzzy elements of A having a triangular membership function is parameterized by a triplet (a, b, c):

$$\mu_A(x)=\begin{cases}\dfrac{(x-a)}{(b-a)}, & a \le x \le b\\ \dfrac{c-x}{(c-b)}, & b \le x \le c\\ 0, & otherwise\end{cases} \quad (1)$$

Definition 3: For triangular fuzzy numbers, the fuzzy addition operations and fuzzy multiplication operations are expressed as follows[11]:

$$\mathrm{A}\oplus\mathrm{B} = (a_1,b_1,c_1)\oplus(a_2,b_2,c_2) = (a_1+a_2,\, b_1+b_2, c_1+c_2) \quad (2)$$

$$\mathrm{A}\otimes\mathrm{B} = (a_1,b_1,c_1)\otimes(a_2,b_2,c_2) = (a_1 \times a_2,\, b_1 \times b_2,\, c_1 \times c_2) \quad (3)$$

The operators ⊕ and ⊗ denotes fuzzy addition and fuzzy multiplication operations. Triangular fuzzy numbers can also be expressed to a singular value or crisp number, Υ, as follows[13]:

$$\Upsilon =(a+2b+c)/4 \quad (4)$$

In this study, there are three stages in the fuzzy-based M&E for the IFRM. The first stage is to assign fuzzy weights to the four components and 15 indicators of the IFRM. In this stage, the components and indicators are first ranked by following the priority ranking methodology[10),11)]. The ranks are positive values from 1 to p, where p is the number of components and indicators within the same group. Rank 1 has the highest importance within the group, while p is the lowest. To conduct the priority ranking methodology subjectively, we adopted the two main criteria based from our previous study on gap analysis of flood DRRM[10),11)]: 1) order of need prior to the occurrence of a disaster, and 2) prerequisite activities, i.e., when an indicator is a prerequisite activity of succeeding indicator. According to these criteria, the prevention component (C1) ranks highest since measures for prevention lessens the adverse impact of flooding. C1 is followed by preparedness (C2), then the response (C3), and finally, recovery/rehabilitation (C4) components, as shown in **Fig.1**. The indicators within the same component are also ranked according to these two criteria, and they are arranged from the highest to lowest ranking from top to bottom within the same group in **Fig.1.**

Then, the components and indicators are given fuzzy weights based on the decided ranking in **Fig. 3**, in which the horizontal axis represents the weight scores. There is no objective way to determine the weights of the components and indicators, and so we followed the priority ranking methodology's[10)] standard approach, in which the weight is equally distributed, between 0 to 1, depending on the number of components or indicators. Thus, The fuzzy weights of the four components, W_i, have membership functions with respect to the decided ranking shown in **Fig.3(a).** Likewise, indicators were assigned with fuzzy weights, W_{ij} of the j^{th} indicator (j=1,2,3,4 if i=1; j=1,2,…7 if i=2; j=1,2,3 if i=3; and j=1 if i=4), according to the decided rank**,** such that, the fuzzy weights of the indicators within the same group have membership functions shown in **Fig.3(a)~Fig.3(d)**. The equivalent fuzzy weight for each indicator, $W_{eq,ij}$, is then calculated using the following equation:

$$W_{eq,ij} = W_i \otimes W_{ij} \qquad (5)$$

The second stage is the calculation of the fuzzy weighted performance appraisal ($WP_{m,ij}$) for city m. First, the six linguistic performance appraisal ($P_{m,ij}$) are given triangular membership functions shown in **Fig.4**. Then, the $P_{m,ij}$ appraised by the practitioner of the m city for j^{th} indicator in i^{th} component is multiplied to the $W_{eq,ij}$ of the same indicator to determine $WP_{m,ij}$, as expressed by the following equation:

$$WP_{m,ij} = W_{eq,ij} \otimes P_{m,ij} \qquad (6)$$

The third stage is the calculation of the fuzzy performance for city m, F_m. The F_m is the aggregation according to Eq. 2 of the $WP_{m,ij}$ in which the $WP_{m,ij}$ can also be aggregated according to the four components, $F_{m,i}$, as expressed by the equations below:

$$F_{m,i} = \left(\sum_{j=1}^{n_i}\right) WP_{m,ij} \quad , \quad F_m = \left(\sum_{i=1}^{n}\right) F_{m,i} \qquad (7)$$

where, n is the number of components and n_i is the number of indicators within the same group. The crisp values for F_m and all other fuzzy numbers can also be calculated using Eq. 4.

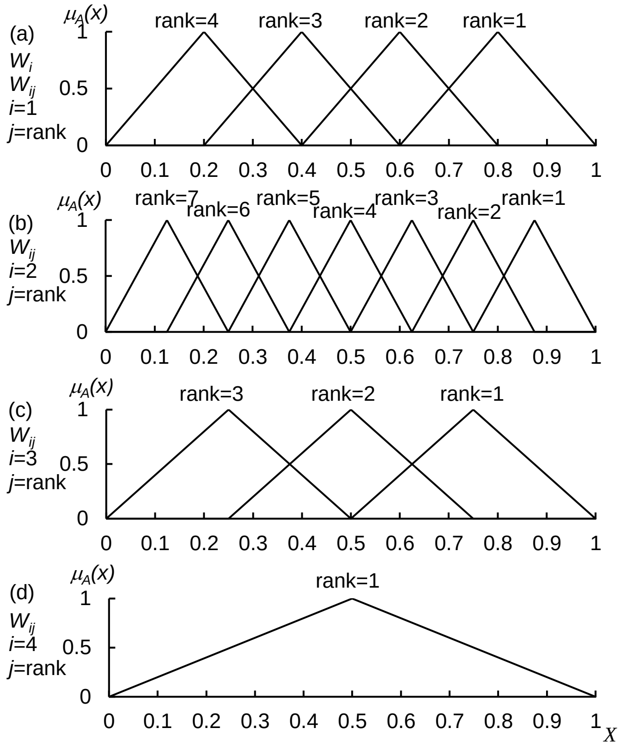

Fig.3 Membership functions used for the fuzzy weights of (a) components (i) and indicators (ij) that have (a) 4 attributes, (b) 7 attributes, (c) 3 attributes, (d) 1 attribute.

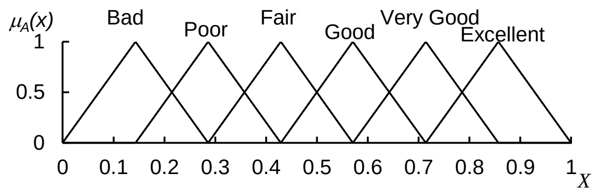

Fig.4 Membership functions of the linguistic performance appraisals

3. RESULTS AND DISCUSSION

The summary of the qualitative assessments, which are the linguistic performance appraisal for the 15 indicators of the IFRM is shown in **Table 2**. These linguistic performance appraisals were evaluated using fuzzy set theory, as explained in Section **2.(3)**. **Table 3** shows the $W_{eq,ij}$ for the 15 indicators at the $W_{eq,ij}$ column. In the same table, the $WP_{m,ij}$ values for Muntinlupa City (m=5) is also shown as an example. Furthermore, the component fuzzy performance, $F_{m,i}$, and fuzzy performance , F_m, for Muntinlupa City is also shown in **Table 3** in the fourth column and last row, respectively as an example.

Fig.5 shows the crisp F_m (Υ_m) for all 13 cities which was calculated using Eq. 4. In addition to the Υ_m, the crisp $F_{m,i}$ ($\Upsilon_{m,i}$), performance for the four components of the IFRM for each city and the maximum $\Upsilon_{m,i}$ values, are also depicted in **Fig.5**. This figure also shows the threshold for the overall performance level using

Table 2 Summary of the linguistic performance appraisal on the 15 indicators of the IFRM.

m	City	IFRM indicators (Cij)														
		C11	C12	C13	C14	C21	C22	C23	C24	C25	C26	C27	C31	C32	C33	C41
1	Caloocan City	G	P	F	F	G	VG	G	VG	VG	G	G	G	G	G	P
2	Las Pinas City	E	E	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG
3	Malabon City	VG	B	G	VG	G	G	VG	VG	G	G	G	G	G	VG	G
4	Marikina City	VG	G	G	VG	VG	VG	VG	E	VG	VG	VG	VG	E	VG	VG
5	Muntinlupa City	E	B	G	VG	G	G	G	G	G	G	G	G	VG	E	VG
6	Navotas City	VG	G	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG
7	Paranaque City	VG	B	VG	VG	VG	VG	G	VG	G	VG	VG	VG	VG	VG	VG
8	Pasig City	G	G	G	VG	G	G	G	VG	G	G	G	G	G	G	G
9	Pateros City	G	B	VG	VG	G	VG	B	VG	G	G	G	G	G	G	G
10	Quezon City	VG	G	G	G	VG	G	VG	VG	E	E	E	VG	E	E	VG
11	San Juan City	G	G	VG	VG	VG	E	G	VG	E	F	VG	E	E	E	VG
12	Taguig City	G	G	G	G	G	G	G	G	G	G	VG	G	G	E	G
13	Valenzuela City	G	G	G	G	G	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG

horizontal broken lines, which was derived by assuming that all indicators were given one linguistic appraisal, e.g., all indicators were given “Excellent” to derive the Excellent threshold. The γ_m and $\gamma_{m,i}$ allowed rapid comparison on the performance for the IFRM between the 13 cities of Metro Manila, but the actual performance of each city is still fuzzy in which there is an upper and lower boundary in the performance shown in $F_{m,i}$ and F_m in **Table 3** as an example. These boundaries vary with each city and components, and these values provide a range in the actual performance which copes with uncertainty in the quantification of qualitative information.

From **Fig.5,** it can be seen that majority of the cities have surpassed the Good level in which one city, Las Pinas City (*m*=2), even surpassed the Very Good level. The $\gamma_{m,i}$ for the prevention component in Las Piñas City is highest while the $\gamma_{m,i}$ for its other components are relatively similar to the other cities. The $\gamma_{m,i}$ for prevention is also found to be very close to the maximum value, and so this component attributed to the Very Good level for this city. According to the practitioners of Las Piñas, a comprehensive drainage masterplan was formulated for this city, and it had strengthened the prevention measures. Nevertheless, despite surpassing the Very Good level, the Very Good level suggests that there are still recognized limitations in capacities and resources despite having substantial achievements, as we have explicitly described in **Table 1.**

It is also seen in **Fig. 5** that two cities, Pateros City (*m*=9) and Caloocan City (*m*=1), did not reach the Good level but surpassed the Fair level. Pateros City has the lowest γ_m because the $\gamma_{m,i}$ for all four components are generally low. The practitioners from this city have stressed that the lack of city income attributed to the low IFRM performance. Caloocan

Table 3 Equivalent fuzzy weight of the indicators and fuzzy weighted performance appraisal

Cij	Equivalent fuzzy weight ($W_{eq,ij}$)	*m* = 5	
		Fuzzy weighted performance appraisal ($WP_{m,ij}$)	Fuzzy performance of each component ($F_{m,i}$)
C11	(0.36,0.48,1.00)	(0.26,0.41,1.00)	(0.31,0.77,2.00)
C12	(0.24,0.48,0.80)	(0.00,0.07,0.23)	
C13	(0.12,0.32,0.60)	(0.05,0.18,0.43)	
C14	(0.00,0.16,0.40)	(0.00,0.11,0.34)	
C21	(0.30,0.53,0.80)	(0.13,0.30,0.57)	(0.45, 1.20, 2.50)
C22	(0.25,0.45,0.70)	(0.11,0.26,0.50)	
C23	(0.20,0.38,0.60)	(0.09,0.21,0.43)	
C24	(0.15,0.30,0.50)	(0.06,0.17,0.36)	
C25	(0.10,0.23,0.40)	(0.04,0.13,0.29)	
C26	(0.05,0.15,0.30)	(0.02,0.09,0.21)	
C27	(0.00,0.08,0.20)	(0.00,0.04,0.14)	
C31	(0.10,0.30,0.60)	(0.04,0.17,0.43)	(0.07,0.40,1.12)
C32	(0.05,0.20,0.45)	(0.03,0.14,0.39)	
C33	(0.00,0.10,0.30)	(0.00,0.09,0.30)	
C41	(0.00,0.10,0.40)	(0.00,0.07,0.34)	(0.00,0.07,0.34)
		Fuzzy performance (F_m)	(0.83,2.45,5.96)

City, on the other hand, has the second-lowest γ_m because this city had the lowest $\gamma_{m,i}$ for prevention and recovery/rehabilitation among all cities, but the $\gamma_{m,i}$ for preparedness and response in this city was relatively similar to other cities. Thus, the γ_m of Caloocan City is slightly higher than Pateros City. According to the practitioners in Caloocan City, the lack of political will was the main hindrance for high IFRM performance. The results in these two cities suggest that serious attention and effort for all components of the IFRM is necessary.

When compared to the maximum $\gamma_{m,i}$, almost all cities show relatively low performance for prevent and preparedness component. Thus, efforts for IFRM for all cities need to focus on these components. Overall,

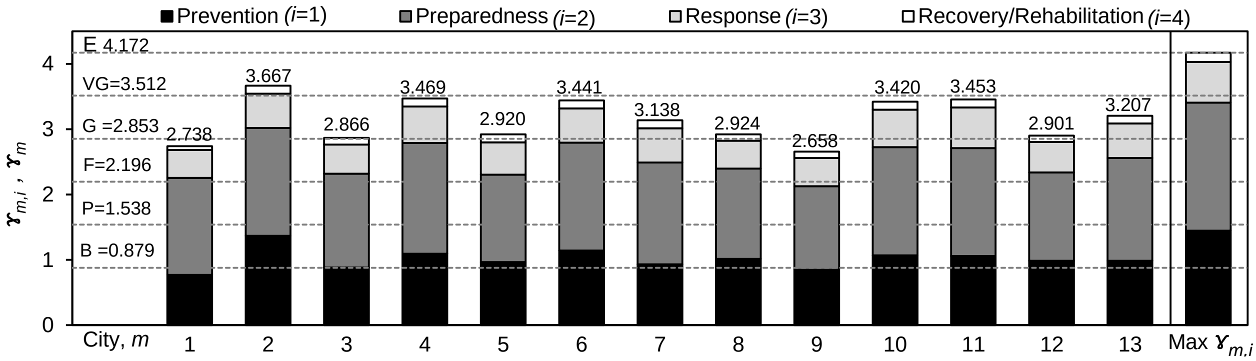

Fig.5 Crisp performance for IFRM (Υ_m) and components ($\Upsilon_{m,i}$) of each city in Metro Manila.

the results of the fuzzy M&E show that almost all cities are performing above the Good level, but the Good level still indicates that achievements for the IFRM are not comprehensive or substantial, as described in **Table 1**. The results suggest that continuous M&E activities is necessary.

4. CONCLUSIONS

This study is a first attempt to conduct a fuzzy-based M&E of the IFRM in Metro Manila since the inception of IFRM. The M&E of the IFRM was heavily dependent on the qualitative appraisals from the respondents. Thus, the fuzzy set theory was the most suitable method to quantify and evaluate the qualitative appraisals.

The results from the fuzzy-based M&E provided a reasonable means to aggregate quantitatively the highly subjective appraisals from the experts. This study reveals that almost all cities have surpassed the threshold for the Good level, but the current performances for IFRM still suggest that serious attention and improvements are needed, especially for the prevention and preparedness components. The fuzzy-based M&E enabled a systematic, rapid, and quantitative comparisons of the components and overall performance for IFRM at each city in Metro Manila. Through this method, the priority (least performing) cities and IFRM components were identified. The approach in this study is simple and useful for the M&E, but inclusion of quantitative indicators can provide comprehensive assessment of the IFRM.

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