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Interrelationships of the barriers to integrated flood risk management adaptation in Metro Manila, Philippines

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ABSTRACT

Many countries encountered “barriers” or obstacles that hampered the process of adapting to the integrated flood risk management (IFRM) from the traditional hard structural solutions in managing urban flooding. One of the crucial tasks to overcome the barriers is to understand their interrelationships. However, analysis of the interrelationships between the barriers to IFRM adaptation has not been carried out yet. This study attempts to analyze the interrelationships between the barriers to IFRM adaptation using the Interpretive Structural Modeling (ISM) method. The barriers in Metro Manila, a megacity in a developing country, were identified first in this study. Then, the ISM method was slightly modified and applied to analyze the interrelationships of the identified barriers. As a result, we identified 12 barriers which are relatively numerous compared with the developed countries, and so we categorized them into the governance, social, and technological resources aspects. Through the application of the ISM method, the interrelationships of the barriers to IFRM adaptation were systematically analyzed for the first time while also showing their hierarchical diagram. The results of the ISM reveal that barriers in the governance aspect are the most influential in which the lack of a sole organizing body is the most influential barrier. The barriers in the technological resources aspect are the second most influential, while barriers in the social aspect are the least influential and most dependent barriers. The approach presented in this study can be useful for decision makers and practitioners in understanding the interrelationships between the barriers.

1. Introduction

Urban megacities, especially in developing countries, are facing challenges in sustainable development due to occurrences of massive flooding. These flood occurrences are expected to become more frequent and damaging in the future because of climate change [1,2] and non-climatic changes such as alteration of land and river [3]. Among the megacities in Asia, Metro Manila, the Philippines’ center of political and economic activities, is considered to be the most at risk to climate impacts mainly due to its exposure to tropical cyclones [4]. Flooding has been the most frequent natural disaster and a major cause of destruction in Metro Manila. The most disastrous flooding in the last decades was brought by Typhoon Ondoy (internationally known as Typhoon Ketsana) in September 2009. Typhoon Ondoy affected 4,901,234 people with 464 fatalities, 529 injuries and 37 missings, and caused 7-m flood depths in some parts of Metro Manila that resulted in damages amounting to almost Php 4.2 Billion [5] (Php 1.00: USD 0.0216 in 2009). Despite numerous structural mitigation measures established since the early part of the 20th century, the onslaught of this typhoon distressed Metro Manila economically, socially, and environmentally. This disaster and numerous accounts of urban flood disasters indicate that sole reliance on traditional “hard” engineering or structural measures is now insufficient for flood hazard control [6].

In recent years, flood disasters catalyzed policy changes in flood risk management in urban areas, and this led to the global shift towards the adaptation of the integrated flood risk management (IFRM) approach [7]. Likewise, the disaster from Typhoon Ondoy prompted the government of the Philippines to start taking a proactive approach in the flood disaster and risk reduction, and this led to the inception of an IFRM plan for Metro Manila in 2013. The IFRM is a relatively modern approach that combines structural and non-structural measures [1]. Non-structural measures, however, are more critical than structural measures in this approach because IFRM goes beyond flood protection as it includes measures for prevention and preparedness [8]. By principle, IFRM

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mainly adopts the concept of “keeping people away” rather than “keeping water away” [9]. The transition to IFRM from the traditional flood protection, however, had been difficult due to the critical issues or obstacles, identified as “barriers” that hindered the smooth adaptation of this approach. For instance, European countries experienced barriers to IFRM adaptation such as cultural and economic tensions; technical lock-in in prevailing structural measures [6]; political oppositions [7]; weak enforcement and low compliance of building restrictions [10]; and fragmented governance structure for flood management [3]. Meanwhile, the IFRM implementation near the Yangtze River in Asia required more time due to the “not-yet-ready” decision making on the provincial level [11]. Based on these experiences, identifying the barriers to IFRM adaptation is an essential task so that decision makers and practitioners can devise an appropriate, realistic course of action and propose required policy changes to overcome them.

To the authors’ knowledge, research on explicitly identifying barriers to IFRM adaptation for developing countries remains limited to almost no study even though there are some studies carried out for developed countries. Barriers between developed and developing countries profoundly differ from each other because developed countries inherently have good infrastructure, a better environment, and efficient utilization of resources that are generally absent in many developing countries. Developing countries are generally weak in maintaining flood management capabilities [12], so barriers in developing countries are presumed to be more severe and alarming. Ishiwatari [13] suggested two barriers to IFRM adaptation for developing countries such as the Philippines, Vietnam, and Indonesia by only comparing these countries to Japan’s flood management and practices. The current authors have also conducted studies on flood management in Metro Manila, and we have identified several gaps in flood disaster and risk reduction management during the Typhoon Ondoy event [14,15]. Thus, we hypothesize that Metro Manila may have various barriers that can hamper the IFRM adaptation. This study, therefore, identifies the barriers to IFRM adaptation in Metro Manila, a megacity in a developing country.

After identifying the barriers to IFRM adaptation, understanding their interrelationships is also crucial, since barriers are often interrelated to each other as they can alleviate, augment, reinforce, or trigger another [16]. A systematic analysis of barrier interrelationships is imperative so that decision makers can make a rational assessment rather than an intuitive judgment when devising a plan in overcoming the barriers. However, the interrelationships between the barriers to IFRM adaptation have not been analyzed yet, and there is no universally accepted framework where barriers are analyzed, as far as the authors know. In the last decades, there is a growing literature on the application of the Interpretive Structural Modeling (ISM) method in analyzing the barriers in various field such as supply chains management [17–19], knowledge management [20], and landfill development [21], among others. ISM is a method that analyzes the interrelationship of unclear and poorly articulated variables that define a problem or issue. This method produces a diagram to illustrate straightforward relations among a set of variables while also showing the hierarchical structure [22,23]. The ISM method has not yet been applied to the barriers related to natural hazards and disaster risk reduction management such as the IFRM. Hence, this study attempts to apply the ISM method to make an inceptive analysis on the barriers to IFRM adaptation.

The objective of this study is two-pronged: 1) to identify and assess the barriers to IFRM adaptation in the setting of a developing country, and 2) to analyze the interrelationships of the identified barriers. These objectives are crucial tasks in a sustainable flood risk management as these are one of the lessons learned from developed countries when they encountered barriers during their transition to IFRM. In order to accomplish the first objective, a review of the literature is conducted to identify the barriers. The identification of the barriers needs to be case-specific to allow in-depth investigations so that various facets of problems in flood control and management can be examined. For this reason, we focus on Metro Manila, the capital region of the Philippines. In order to accomplish the second objective, the ISM method is applied to analyze the interrelationships between the barriers, and it is also complemented by the MICMAC analysis for added interpretation of the results. In this process, we also made slight modifications to the ISM method. These modifications are intended to improve the results for the barriers to IFRM adaptation in Metro Manila. The following sections introduce the flood condition and management in Metro Manila; elaborate and demonstrate the application of the ISM method; analyze and discuss the results on the barrier interrelationships; and offer insights on how to overcome the barriers to IFRM adaptation in Metro Manila.

2. Flood condition and management in Metro Manila

Metro Manila, the capital region of the Philippines, is located on an isthmus between Manila Bay and Laguna Lake shown in Fig. 1. Metro Manila is composed of 16 cities and 1 municipality, and encompasses an area of 619.57 km^2. Flooding is a perennial problem in Metro Manila because it is situated in one of the widest floodplains in the country. Flood occurrences are intense and frequent during the typhoon season, from June to October, when the Philippines typically receives 80% of its annual rainfall. There are about three to four incidences of significant flooding in Metro Manila annually, and these are usually caused by typhoons, monsoon rains, and even torrential rains [24]. The flood depths in the region can range from a gutter-height inundation, usually due to torrential rains that can cause traffic congestion, to more than 5-m inundation due to storms or typhoons that can cause extensive property damages and numerous fatalities. In the last decades, there were at least three disastrous flood events that devastated Metro Manila, and this was brought by Typhoon Ondoy in 2009 and two monsoon rains, locally known as “Habagat”, in 2012 and 2016. These flood occurrences are expected to increase due to climatic and anthropogenic factors.

At present, the nationwide flood control and management in the Philippines is solely under the mandate and function of the Department of Public Works and Highways (DPWH) except in Metro Manila. Initially, the flood control functions for Metro Manila was solely under DPWH until 2002, when it was transferred to the Metro Manila Development Authority (MMDA). MMDA is locally known to be responsible for traffic management and solid waste management in Metro Manila. The incumbent President in 2002 brought this transfer of role to MMDA in order to improve flood control and efficiency within the capital region. However, many officials were critical of this action because MMDA did not have the capacity and expertise to fulfill the newly given directive since flood control has been under DPWH since the 1980s. Currently, DPWH continuously supports MMDA in the flood control and management in Metro Manila.

3. Methods

3.1. Identifying the barriers to IFRM adaptation in Metro Manila

There is no standard method for identifying barriers in general. Reviewing the literature is the most common method for identifying the barriers in past studies on ISM [23]. Thus, we have conducted a literature review to identify the barriers to IFRM adaptation in Metro Manila. There is vast literature regarding flooding in Metro Manila which includes various empirical studies and applications of hydrological and hydraulic models, among others. For this study, we examined journal articles published in the last two decades that discussed issues in flood management to draw out the barriers to IFRM adaptation in Metro Manila. These journal articles include 15 internationally published papers and 2 locally published papers in the Philippines. The number of locally published papers is relatively low due to strict access to scientific records in the Philippines. In addition to these, we have also included 3 project reports from DPWH completed in 2000, 2004 and 2013, and 2 books that feature a case study in Metro Manila. The barriers to IFRM

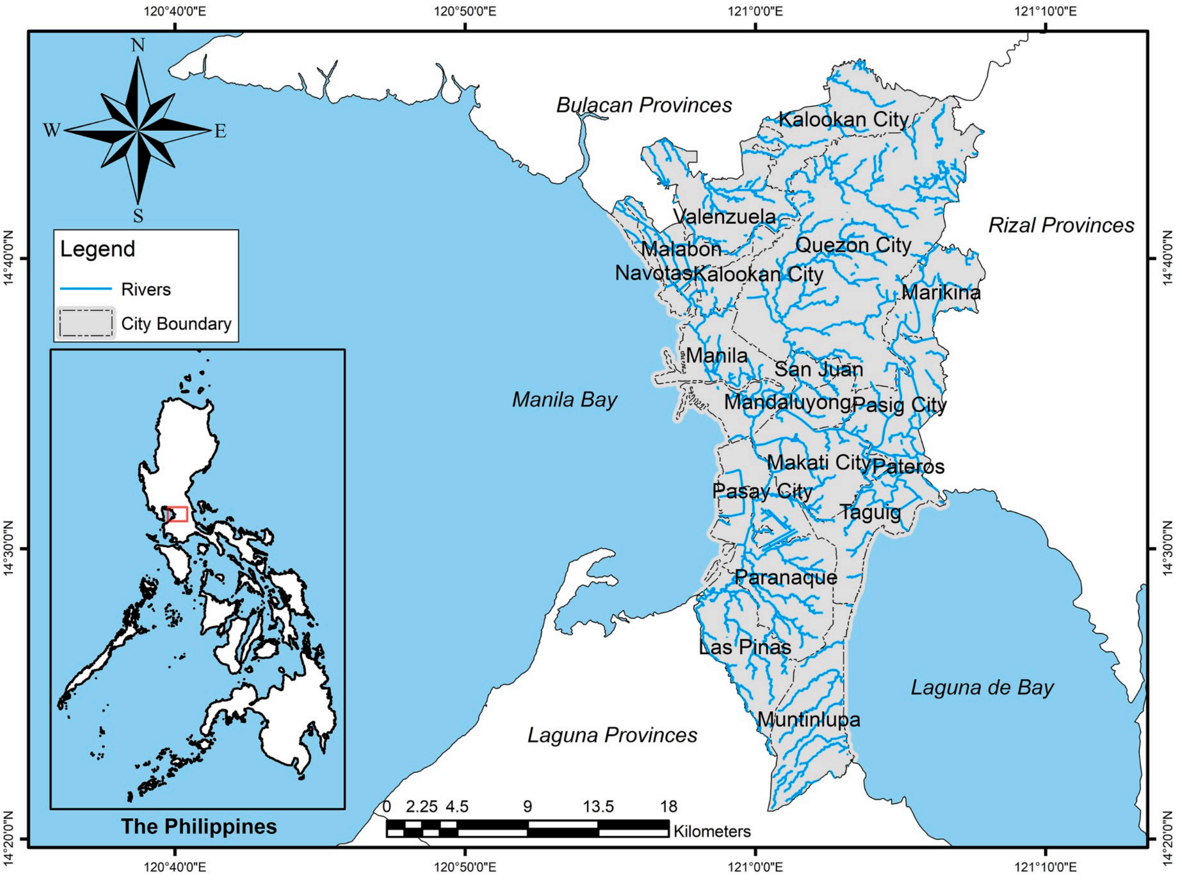

Fig. 1. Location map of Metro Manila, Philippines.

adaptation in Metro Manila are noted if these are recurring issues concerning flood management or cited at least once in the literature. The identified barriers are described in Section 4 and Supplementary Material in Appendix A.

3.2. Analysis of barriers by ISM with some modifications

The ISM, developed by Warfield [25], is an effective method for analyzing complex and interrelated issues. ISM utilizes some application of elementary graph theory such that theoretical, conceptual, and computational leverage are efficiently exploited to construct a structural diagram [17]. The output of the ISM guides decision makers and practitioners in understanding the complexity of the interrelated issues, and this aids them in devising solutions to the problem [26,27]. Fundamentally, the ISM method has five steps [23] shown in Fig. 2. The succeeding paragraphs discuss in detail the methodology and the modifications in this study.

Step 1: Developing the Structural Self-Interaction Matrix (SSIM).

A pairwise comparison between the identified barriers is first conducted to develop the SSIM. The pairwise comparison can be made individually [28], but we asked five experts for this task. The five experts belong to DPWH, the primary organization that handles flood concerns in the Philippines. These experts have more than 20 years of experience, and they are the foremost authority in the Unified Project Management Office–Flood Control Management Cluster (UPMO-FCMC), the division specializing in flood management in DPWH. To elicit the pairwise comparison from the experts, we conducted interviews by asking them if “one barrier influences the other”, and they selected one relation out of the four predetermined relations described below. In ISM, there are three types of SSIM: original, refined, and final SSIMs. Based on the interview, we tallied their responses to develop the original SSIM. The four types of relations are represented by four symbols wherein the conventional symbolism is modified to provide meaningful representations. The following shows the conventional and modified symbolism:

a. Letter “V” is changed to the symbol “+” which denotes that barrier *i* influences barrier *j*

b. Letter “A” is changed to the symbol “-” which denotes barrier *i* is influenced by barrier *j*

c. Letter “X” is changed to the symbol “±” or “∓” which means barrier *i* and barrier *j* influence each other

d. Letter “O” is changed to symbol “0” which means barrier *i* and barrier *j* are independent of each other.

In the modified approach, all cells of the matrix (except the diagonal which is kept blank) are filled with the modified symbols, whereas only half of the matrix is filled in the conventional approach. Then, the original SSIM is checked for consistency, wherein a consistency is considered as a tally that has a majority (three of more common response in this study). For any inconsistent tally in the original SSIM, we asked the experts to reconsider the relation in the pairwise comparison. The resulting SSIM after checking the consistency is referred to as the refined SSIM. The refined SSIM is further summarized to a final SSIM by considering the majority response.

Step 2: Developing the Reachability Matrix (RM).

There are two types of RM in this step: the initial reachability matrix (RM_{init}) and the final reachability matrix (RM_{fin}). The RM_{init} is derived by transforming the final SSIM into a binary matrix. The rules for this step are also modified into simpler rules which do not affect the values of the expected outcome for the RM_{init} by the conventional approach. The modified rules are as follows:

a. If the final SSIM(i, j) is “+“, then $RM_{init}(i, j)$ is 1.

b. If the final SSIM(i, j) is “-“, then $RM_{init}(i, j)$ is 0.

c. If the final SSIM(i, j) is “±” or “∓“, then $RM_{init}(i, j)$ is 1.

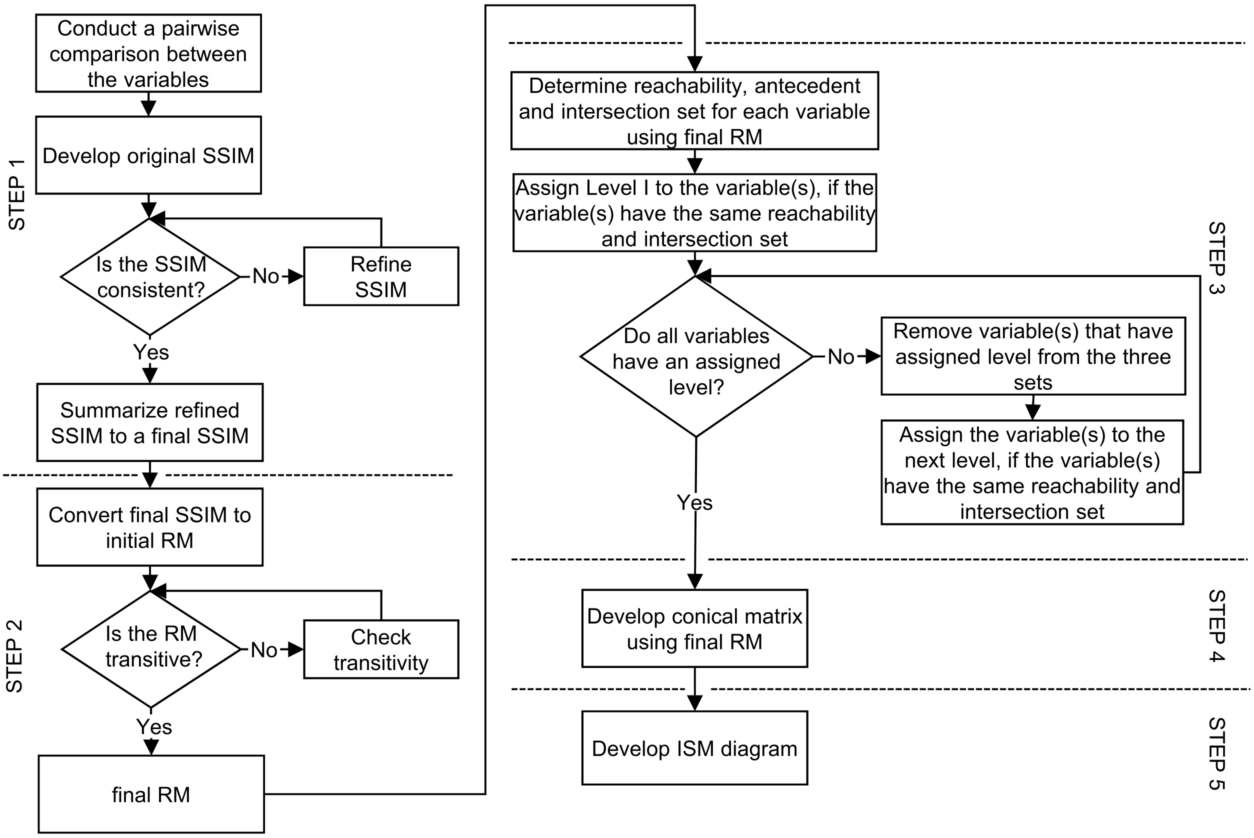

Fig. 2. Flowchart of the ISM method.

d. If the final SSIM(i, j) is “0”, then $RM_{init}(i, j)$ is 0.

e. For the final SSIM(i, i) that is blank, the value 1 is added in $RM_{init}(i, i)$.

Then, the RM_{init} is checked for transitivity to derive the RM_{fin}. The transitivity for both conventional and modified approach is as follows: if the input in $RM_{init}(i, j)$ is equal to 1 and $RM_{init}(j, k)$ is equal to 1, then $RM_{init}(i, k)$ should also be equal to 1. The transitivity in RM_{init} is checked iteratively until all variables are transitive [23].

Step 3: Assigning levels for each barrier.

The three sets (reachability, antecedent, and intersection set) for each barrier are defined first using the RM_{fin}. The reachability set for barrier i consists of those barriers that it influences and itself (when barrier $j = 1$ within its row i), while the antecedent set for barrier j consists of those barriers that influence it and itself (when barriers $i = 1$ within its column j). Meanwhile, intersection set for barrier i consists of the intersection between its reachability set and antecedent set.

The barriers assigned to level I are those barriers that have the same reachability and intersection set. Then to determine the barriers assigned to level II, barriers in level I are eliminated first from the three sets, thereby resulting in new sets of reachability, antecedent, and intersection. Using these new sets, the barriers that have the same reachability and intersection set are assigned to level II. Likewise, to assign the barriers in level III, the barriers in level II are eliminated from the three sets, and new sets of reachability, antecedent, and intersection sets are produced. This process is recursively done until all barriers are assigned to a corresponding level [23].

Step 4: Developing the conical matrix (CM).

After assigning a level for each barrier, the RM_{fin} is transformed to a CM by simply rearranging barriers i and j (including their values) in descending order from the highest to the lowest level across the rows and columns. The rearrangement of these barriers is also modified from the conventional ascending order so that the ISM diagram can be constructed according to the modified schematic described in the next step.

Step 5: Developing the ISM diagram.

The ISM diagram is a kind of directed graph (or digraph), which shows the interconnections among a set of variables while also showing the hierarchy. The CM is used to develop the ISM diagram. In the CM, if $CM(i, j) = 1$ (except those with “1*”), an arrow is drawn from barrier i to barrier j. The barriers are arranged in descending levels from the top towards the bottom when constructing the diagram. The ISM diagram is modified to a pyramid schematic, in which the highest level is placed at the top while the lowest level is placed at the bottom. This modification illustrates that the variable at the top of the diagram implies to be the most influential, whereas the conventional schematic shows the opposite (the barrier at the top is the least influential).

3.3. Classifying the barriers to IFRM adaptation using MICMAC analysis

Previous studies typically integrate ISM with MICMAC analysis (cross-impact matrix multiplication applied to classification translated from *Matrice d'Impacts croises-multiplication appliqúe the classment*) to complement the results of the ISM [29]. MICMAC analysis, developed by Duperrin and Godet [30], is a useful tool that identifies the most influential, highly dependent, and very unstable variables through an influence map [17]. To plot the influence map, the influence power and dependence power is obtained first using the RM_{fin}. The influence power of barrier i is the quantity of the barriers that barrier i influences, including itself, which is calculated as the summation of row i for barrier i in the RM_{fin}. On the other hand, the dependence power of barrier j is the quantity of the barriers that influence barrier j, including itself, which is calculated as the summation of column j for barrier j in the RM_{fin}. Then, the influence map is prepared by plotting the barrier's influence power against its dependence power. The influence map is divided into four equal regions to represent the four classifications: Influential, Relay, Dependent, and Autonomous.

4. Results

4.1. Barriers to IFRM adaptation in Metro Manila

The barriers to IFRM adaptation were identified for a megacity in a developing country by conducting a literature review, as mentioned in the Methods section. Based on the literature review, we have identified 12 barriers in Metro Manila which are relatively numerous than those found in developed countries. Thus, we categorized these barriers into three aspects: governance, social, and technological resources. Each category contains 4, 3, and 5 barriers shown in Table 1. The barriers are discussed briefly in the succeeding paragraphs, and the detailed discussion is found in Appendix A as Supplementary Material.

The governance aspect is related to how the Philippine government develops policies and implements projects for flood control. There are four barriers in this aspect: G1~G4. The barrier G1 describes the fragmented governance in flood management in Metro Manila because the current institutional framework does not have a clear demarcation of tasks among government agencies [13,31–34]. The barrier G2, on the other hand, describes the lack of inter-agency communication and the lack of information exchange and communication on the local level [13,33,35]. Meanwhile, G3 describes the lack of funding for flood mitigation and control projects. This barrier emanates from the lack of national focus on flooding and the influence of lingering nepotism in funding for government projects [33,36,37]. Thus, one of the outcomes of G3 is barrier G4 which describes that the existing flood control infrastructures are inadequate, while non-structural measures are almost non-existent in Metro Manila [15,33,35,38,39].

The barriers classified to the social aspect are associated with urban growth, social security, and society's standard of living. There are three barriers in this aspect: S1~S3. The barrier S1 is a very distinct phenomenon in many developing countries, in which urban poor populations encroach at marginal and flood-prone areas where they can live cheaply on the interim [32,33,35,36,39–42]. Meanwhile, the barrier S2 describes prevailing problems in solid waste management in Metro Manila that is exacerbated by the indiscriminate waste disposal by the majority of the households, ordinary citizens, and informal settler families (identified as S1) [31,33,42–44]. Problems underlying S1 and S2 are emanated from barrier S3. The services provided by the government of the Philippines are inadequate to address issues on both S1 and S2 that are likely to worsen because of continuous population growth and migration of people from rural areas to Metro Manila [31,33,34,37,40,42,43,45,46].

The barriers categorized under the technological resources aspect are related to the systems that support decision making based on scientific evidence and the current technologies used to alleviate flooding in Metro Manila. There are five barriers in this aspect: T1~T5. The barrier T1 depicts the absence of real-time flood forecasts, water level, and rainfall depth updates in Metro Manila [14,33,47,48]. Similar to T1 is barrier T2 which describes that available hydro-meteorological information is thinly distributed, not automated, and measured on a daily time interval [14,24,38,47,48]. On the other hand, the barrier T3 describes the lack of experts from government agencies and local government units in Metro Manila [24,33,35,47]. The barrier T4 depicts the lack of data processing systems, and this resulted in just storing of hydro-meteorological information and not used for analysis [14]. Lastly, the barrier T5 describes the deterioration of existing flood control structures (e.g., pumping stations, drainage systems, hydraulic control structures) due to poor maintenance [14,24,32,33,48].

Table 1
Barriers to IFRM adaptation in Metro Manila, Philippines.

Aspect	Code	Barrier
Governance	G1	Lack of a sole organizing body
	G2	Lack of communication
	G3	Lack of funding
	G4	Lack of flood control measures
Social	S1	Informal settlers
	S2	Poor solid waste management
	S3	Poor social planning
Technological Resources	T1	Lack of technological capabilities
	T2	Sparse data and limited access
	T3	Lack of experts
	T4	Lack of data processing systems
	T5	Deterioration of flood control structures

4.2. ISM results

The interrelationships of the identified barriers to IFRM adaptation in Metro Manila were analyzed by applying the slightly modified ISM method. The ISM method has five fundamental steps as mentioned in the Methods section. In Step 1, there were three kinds of SSIM derived: original, refined, and final SSIMs. The original SSIM is the initial result of the pairwise comparison from the experts. The original SSIM is presented in Mercado et al. [49], where we carefully discussed the differences and similarities of the experts' pairwise assessment. Then, this original SSIM was checked for consistency so that the refined SSIM can be derived. During the consistency check of the original SSIM, we encountered 12 inconsistencies out of the 66 pairwise combinations (total combination from the 12 identified barriers). In order to address these inconsistencies, we asked the experts again to reassess all inconsistent pairwise comparisons, and this task took only one iteration to obtain consistent results. The resulting refined SSIM is presented in Table B.1 of Appendix B. Then, this refined SSIM was summarized by considering the majority response to each pairwise assessment so that we can derive the final SSIM. The final SSIM is presented Table 2 in which this matrix have symbols that represent the relations between the barriers. For example, the final SSIM$(i, j) = (1, 2)$ is "+" which indicates that G1 influences G2, while the other symbols "-", "$\pm/\mp$" and "0" shows a relationship described in the Methods section.

In Step 2, a final RM (RM_{fin}) was derived. Firstly, the final SSIM was transformed into a binary matrix called the initial RM (RM_{init}) by following the procedures in the Methods section. The RM_{init} is presented in Table B.2 of Appendix B. After obtaining the RM_{init}, this matrix was checked iteratively for transitivity to obtain the RM_{fin}, and this task took four iterations. The RM_{fin} is shown in Table 3 in which this matrix has 0, 1, and 1* values. The "0" value signifies no influence relation between barrier i and j, while "1" value signifies a direct influence relation between barrier i and j. For "1*" value, this signifies an indirect influence relation between barrier i and j as these are initially "0" in the RM_{init} (Table B.2 of Appendix B). Using these relations, we can interpret in Table 3, for example, G1 directly influences all the barriers in the governance and technological resources aspect, and it indirectly influences all the barriers in the social aspect.

In Step 3, the barriers were assigned to a corresponding level. By following the procedures to assign the level in the Methods section using the RM_{fin}, we determined the summary of the reachability, antecedent, and intersection sets, and the levels for each barrier shown in Table 4. The 12 barriers were assigned to seven levels which indicated that the process of assigning the level took seven iterations. The levels assigned to the barrier determines its hierarchical standing wherein the barrier assigned to level VII is considered the highest level, while barrier assigned to level I is considered the lowest level.

Then, in Step 4, a conical matrix (CM) was derived. The RM_{fin} and levels for each barrier were used to derive the CM by rearranging the RM_{fin} in descending order of the levels. The resulting CM is presented in Table 5.

In the last step, Step 5, an ISM diagram was constructed, and this visually shows the interrelations between the barriers. The CM was used

Table 2
Final Structural Self-Interaction Matrix (final SSIM).

	j		1	2	3	4	5	6	7	8	9	10	11	12
i	Aspect		Governance				Social			Technological Res.				
		Barrier	G1	G2	G3	G4	S1	S2	S3	T1	T2	T3	T4	T5
1	Governance	G1		+	+	+	0	0	0	+	+	+	+	+
2		G2	-		+	0	+	+	+	0	+	0	0	0
3		G3	-	-		+	0	0	0	+	+	+	+	+
4		G4	-	0	-		0	0	+	+	+	±	±	+
5	Social	S1	0	-	0	0		+	-	0	0	0	0	0
6		S2	0	-	0	0	-		-	0	0	0	0	0
7		S3	0	-	0	-	+	+		0	0	-	0	0
8	Technologial Resources	T1	-	0	-	-	0	0	0		+	-	±	+
9		T2	-	-	-	-	0	0	0	-		-	-	0
10		T3	-	0	-	∓	0	0	+	+	+		+	+
11		T4	-	0	-	∓	0	0	0	∓	+	-		+
12		T5	-	0	-	-	0	0	0	-	0	-	-	

"+" means barrier *i* influences barrier *j*; "-" means barrier *i* is influenced by barrier *j*; "±" or "∓" denotes barrier *i* and barrier *j* influence each other; "0" means barrier *i* and barrier *j* are independent of each other.

Table 3
Final Reachability Matrix (RM_{fin}).

i	*j*		1	2	3	4	5	6	7	8	9	10	11	12	Influence Power**
	Aspect		Governance				Social			Technological Resources					
		Barrier	G1	G2	G3	G4	S1	S2	S3	T1	T2	T3	T4	T5	
1	Governance	G1	1	1	1	1	1*	1*	1*	1	1	1	1	1	12
2		G2	0	1	1	1*	1	1	1	1*	1	1*	1*	1*	11
3		G3	0	0	1	1	1*	1*	1*	1	1	1	1	1	10
4		G4	0	0	0	1	1*	1*	1	1	1	1	1	1	9
5	Social	S1	0	0	0	0	1	1	0	0	0	0	0	0	2
6		S2	0	0	0	0	0	1	0	0	0	0	0	0	1
7		S3	0	0	0	0	1	1	1	0	0	0	0	0	3
8	Technological Resources	T1	0	0	0	1*	1*	1*	1*	1	1	1*	1	1	9
9		T2	0	0	0	0	0	0	0	0	1	0	0	0	1
10		T3	0	0	0	1	1*	1*	1	1	1	1	1	1	9
11		T4	0	0	0	1	1*	1*	1*	1	1	1*	1	1	9
12		T5	0	0	0	0	0	0	0	0	0	0	0	1	1
Dependence Power**			1	2	3	7	9	10	8	7	8	7	7	8	77/77

[*] Originally zero in the RM_{init}.
[**] Used for MICMAC analysis.

to construct the ISM diagram, and this was accomplished by following the procedures discussed in the Methods section. The resulting ISM diagram is shown in Fig. 3. This diagram illustrates the interrelationships of the barriers using the arrows, and these arrows indicate a direct influence relation between barrier *i* and *j*. For example, the arrow drawn from G1 to G2 implies that G1 directly influences G2. In addition to the influence relations, the hierarchy is also depicted in the ISM diagram through a pyramid schematic, i.e., the barrier(s) positioned at the top have the most influence and the degree of influence decreases towards the bottom of the diagram.

The ISM diagram in Fig. 3 reveals that the most influential barrier is G1, followed by G2, then G3 as these barriers are assigned to level VII, VI, and V, respectively. G1 directly influences all other barriers except the barriers in the social aspect. G2, on the other hand, influences G3, T2, and all barriers in the social aspect. Meanwhile, G3 influences all barriers assigned in level IV (G4, T1, T3, T4) and the level I technological resources barriers, T2 and T5. The barriers positioned in the middle of the hierarchy are found to be the level IV barriers, and these barriers directly influence T2 and T5. Among these level IV barriers, G4 and T3 are determined to have more influence than T1 and T4, because these two barriers also influence T1, T4, and the social aspect barrier S3 assigned in level III. On the other hand, T4 has more influence than T1, because of the former influences G4 and T1 while the latter influences T4 only. After the level IV barriers, the ISM diagram shows that S3 has the strongest influence among the barriers in the social aspect, and S1 follows this. The ISM diagram reveals that there are three least influential barriers, S2, T2, and T5, as these barriers are positioned at the bottom of the hierarchy, and they have no influence on any other barrier.

4.3. *Classification of the barriers to IFRM adaptation*

The MICMAC analysis that shows an influence map was also applied in this study to complement the results of the ISM method. The influence map was plotted by identifying the influence and dependence power of each barrier, as described in the Methods section. The influence map for the barriers to IFRM adaptation in Metro Manila is shown in Fig. 4.

The influence map is typically divided into four equal regions that represent the four classifications: Influential, Relay, Dependent, and Autonomous barriers. The Influential barriers are those that have a high influence power and low dependence on other barriers and are found at the north-west of the influence map. In this study, these are composed mainly of barriers on the governance aspect, except for G4. These barriers are considered as stable, most important, and the strongest drivers among the barriers [29]. Relay barriers, on the other hand, are those that are highly dependent yet influential at the same time and are

Table 4
Summary of the reachability, antecedent, and intersection set and levels for each barrier.

Barrier	Reachability Set	Antecedent Set	Intersection Set	Level
G1	G1,G2,G3,G4,S1,S2,S3,T1,T2,T3,T4,T5	G1	G1	VII
G2	G2,G3,G4,S1,S2,S3,T1,T2,T3,T4,T5	G1,G2	G2	VI
G3	G3,G4,S1,S2,S3,T1,T2,T3,T4,T5	G1,G2,G3	G3	V
G4	G4,S1,S2,S3,T1,T2,T3,T4,T5	G1,G2,G3,G4,T1,T3,T4	G4,T1,T3,T4	IV
S1	S1,S2	G1,G2,G3,G4,S1,S3,T1,T3,T4	S1	II
S2	S2	G1,G2,G3,G4,S1,S2,S3,T1,T3,T4	S2	I
S3	S1,S2,S3	G1,G2,G3,G4, S3,T1,T3,T4	S3	III
T1	G4,S1,S2,S3,T1,T2,T3,T4,T5	G1,G2,G3,G4,T1,T3,T4	G4,T1,T3,T4	IV
T2	T2	G1,G2,G3,G4,T1,T2,T3,T4	T2	I
T3	G4,S1,S2,S3,T1,T2,T3,T4,T5	G1,G2,G3,G4,T1,T3,T4	G4,T1,T3,T4	IV
T4	G4,S1,S2,S3,T1,T2,T3,T4,T5	G1,G2,G3,G4,T1,T3,T4	G4,T1,T3,T4	IV
T5	T5	G1,G2,G3,G4,T1,T3,T4,T5	T5	I

located at the north-east of the influence map. In this study, G4, T1, T3, and T4 are classified as Relay, and these are regarded as the most unstable because any action on these barriers has an effect on other barriers with a feedback effect on themselves [17].

Meanwhile, Dependent barriers are those that have a high dependency and low influence on other barriers that are located on the south-east of the influence map. S1, S2, S3, T2, and T5 are classified as Dependent barriers, and they highly depend on both the Influential and Relay barriers. Lastly, the Autonomous barriers have low dependence and low influence power and are located on the south-west of the influence map. These barriers can neither stop nor make an impact on other barriers as these are entirely disconnected from the system of barriers [29]. The influence map in Fig. 4 revealed that there are no Autonomous barriers, which therefore indicates that all the barriers to IFRM adaptation in Metro Manila are interconnected with each other.

5. Discussion

The identified barriers in Metro Manila are relatively numerous than those found in developed countries. Some of these barriers are similar to those experienced in Europe, such as the fragmented governance structure for flood management [3] and weak enforcement of building restrictions [10]. Nonetheless, some barriers related to the social and technological resources aspects such as S1, S2, T1, T2, T4, and T5, are considered unique because these are mainly dependent on normative behaviors and socioeconomic factors of a developing country. Meanwhile, barriers related to the governance aspect are not unusual, even in developed countries.

The identified 12 barriers to IFRM adaptation can have multiple interpretations, but through the application of the ISM method, we systematically established for the first time the interrelationships between these barriers. Aside from the interrelationships, the hierarchy depicted in the ISM diagram also revealed which aspect had the most influence. From the ISM diagram in Fig. 3, the governance aspect is considered as the most influential aspect, and this is supported by the MICMAC analysis because the majority of the barriers (3 out of 4) in this aspect are classified as Influential barriers. The technological resources aspect can be considered as the second most influential aspect because majority (T1, T3, T4) are assigned to the mid-level (level IV), and these are also classified as Relay (influential and dependent) barriers in MIMAC analysis even though the other two (T2, T5) barriers are assigned to the lowest level. The social aspect is considered as the least influential aspect because the barriers in this aspect are found at the lower half of the hierarchy, and each barrier is assigned to different lower levels (level I ~ level III). The MICMAC analysis also classified the barriers in this aspect as having low influence and high dependence on the other barriers.

The interrelationship and hierarchy of the three aspects generated in the ISM diagram can serve as a roadmap of priority to overcoming the barriers. Thus, we focus the discussion on the barriers in the most influential aspect and its interrelationship with the barriers in the other two aspects. In this study, the governance aspect is regarded as the key to successful IFRM adaptation. Some studies suggest that adaptation should focus first on the promotion and development of good governance, especially when governance is weak, yet vulnerability is high [50,51]. Governance is considered as the key to stimulating adaptation and overcoming reported barriers [52]. The concept of governance has also been increasingly recognized in the water management context [3] and climate change adaptation [52–55]. Therefore, the first step in promoting good governance in Metro Manila is by addressing G1 (lack of a sole organizing body), the most influential among the barriers in the governance aspect. G1 has the most influence on all other barriers which suggests that it is necessary to improve the institutional framework for flood management in Metro Manila. The institutional framework plays the most significant role in the smooth adaptation [52], and so, there must be evidence of clear institutional structures and demarcated mandates among the government agencies [56]. Then, the second step is by addressing G2 (lack of communication), the second most influential among the barriers in the governance aspect. G2's direct influence on all of the barriers in the social aspect may imply that G2 is the key to resolving this aspect. According to Buchecker et al. [8], effective

Table 5
Conical matrix (CM).

Level	VII	VI	V	IV	IV	IV	IV	III	II	I	I	I	Level
Barrier	**G1**	**G2**	**G3**	**G4**	**T1**	**T3**	**T4**	**S3**	**S1**	**S2**	**T2**	**T5**	
G1	1	1	1	1	1	1	1	1*	1*	1*	1	1	VII
G2	0	1	1	1*	1*	1*	1*	1	1	1	1	1*	VI
G3	0	0	1	1	1	1	1	1*	1*	1*	1	1	V
G4	0	0	0	1	1	1	1	1	1*	1*	1	1	IV
T1	0	0	0	1*	1	1*	1	1*	1*	1*	1	1	IV
T3	0	0	0	1	1	1	1	1	1*	1*	1	1	IV
T4	0	0	0	1	1	1*	1	1*	1*	1*	1	1	IV
S3	0	0	0	0	0	0	0	1	1	1	0	0	III
S1	0	0	0	0	0	0	0	0	1	1	0	0	II
S2	0	0	0	0	0	0	0	0	0	1	0	0	I
T2	0	0	0	0	0	0	0	0	0	0	1	0	I
T5	0	0	0	0	0	0	0	0	0	0	0	1	I

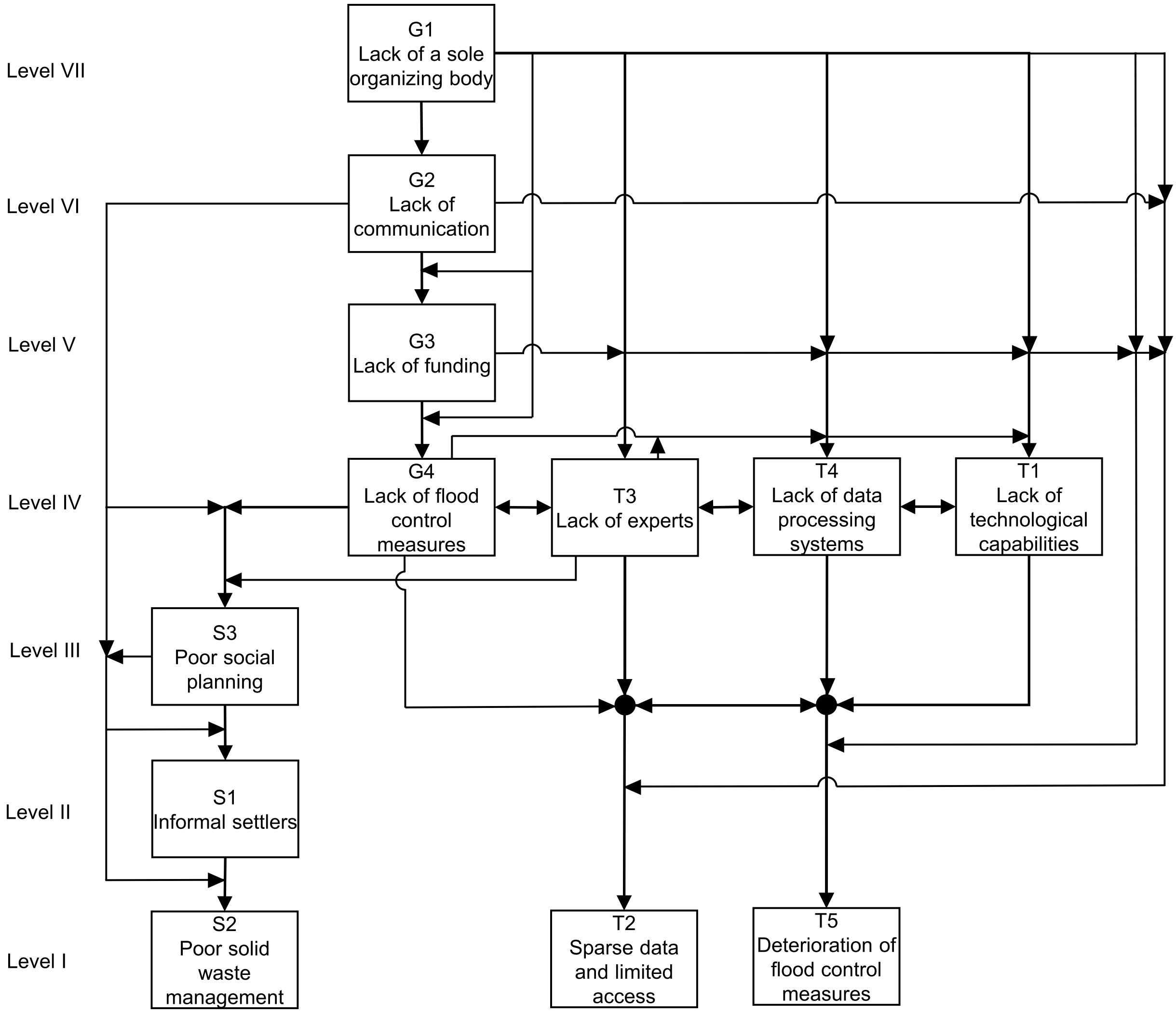

Fig. 3. ISM diagram for the barriers to IFRM adaptation in Metro Manila.

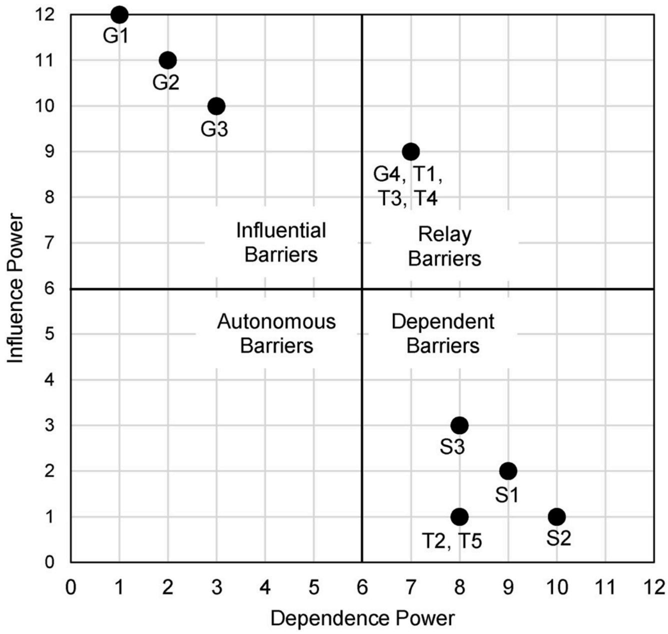

Fig. 4. Influence map by MICMAC analysis.

communication and participation of the community in the implementation processes of non-structural measures can bring about a positive attitude towards the IFRM.

Then, the third step is by addressing G3 (lack of funding), the third most influential among the barriers in the governance aspect. The lack of funding appears to have caused G4 and all the barriers in the technological resources aspect (T1∼T5), as illustrated in Fig. 3, since these barriers mainly depend on funding. Hence, technological systems and capabilities can be strengthened by providing more funding because flooding in Metro Manila necessitates technological solutions [32]. Technological solutions come from detailed flood risk assessments, which is considered as a fundamental step in a sustainable flood risk management cycle [57]. The amount of detail in flood risk assessment determines a realistic figure of the expected flood risks [58]. According to past research, 1D/2D hydraulic models combined with mesoscale flood loss models are the best compromise between data requirements, simulation effort, and acceptance of flood loss estimates for flood risk analysis in urban areas [58]. There are also other approaches to conduct a flood risk assessment in urban contexts where information and data are scarce, e.g., the case study in the urban area in Ethiopia [59]. The outcomes from these flood risk assessments can be utilized as a tool for decision making, i.e., screening and ranking of viable mitigation measures, and can be used to provide flood risk maps and illustrative results that can fairly estimate damage prediction [59]. However, persons with expertise are also necessary for carrying out such flood risk assessments to ensure the reliability of the assessments, especially when data is scarce. Hence, scientific-based evidence analyzed by experts should be given importance because effective risk reduction is hindered by the incapacity to provide disaster managers and non-technical persons the mapped information on the risks, hazards, or vulnerabilities [60].

Overall, through the application of the ISM method and the categorization of the barriers into aspects, we systematically identified which facet had the most influence, thus considered as the most crucial. The practical benefit of the ISM diagram is the visualization of the influence interrelationships between barriers which can manifest as triggers for improvement. Moreover, the ISM diagram can enhance the perception of these barriers, and this can aid in knowledge sharing, training, or even risk management communications through visual clarity.

6. Conclusions

The transition to the IFRM approach has been a reactive response from a disastrous flood event. However, the adaptation of this approach is often faced with barriers. Hence, from a research perspective, understanding the interrelationships of these barriers is a crucial task to overcome reported barriers. In this study, we systematically analyzed for the first time the interrelationships of barriers to IFRM adaptation by applying and slightly modifying the ISM method. We first identified the barriers for a megacity in a developing country by conducting a literature review. From the literature review, we identified 12 barriers in Metro Manila, and these were found to be multifaceted and complex. The identified barriers in Metro Manila were also relatively numerous, and some were unique as compared with the barriers in the developed country. Hence, we categorized them into three aspects wherein 4, 3, and 5 barriers were categorized under the governance, social, and technological resources aspects, respectively. Through the ISM method, we were able to establish the influence interrelationships between the 12 identified barriers shown in the ISM diagram. The ISM diagram revealed that the most influential barrier was the lack of a sole organizing body, and this was followed by the lack of communication then lack of funding. In terms of aspect, governance was the most influential aspect, as also supported by the MICMAC analysis. Therefore, it can be inferred that a positive change in the governance aspect can also positively influence all other barriers.

In the application of the ISM, the slight modifications made in this method resulted in meaningful symbolism, a smoother transition of the steps, and a clear representation of the hierarchy in the diagram. The approach in this study is simple and systematic so that it can be useful for decision-makers and practitioners in devising a plan for overcoming the barriers. This study has substantiated insights that barriers to IFRM adaptation are interrelated and dependent on each other to a specific hierarchy.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ijdrr.2020.101683.

Appendix B

Table B.1
Refined Structural Self-Interaction Matrix (refined SSIM)

	j		1	2	3	4	5	6	7	8	9	10	11	12
i	Aspect		Governance				Social			Technological Resources				
		Barrier	G1	G2	G3	G4	S1	S2	S3	T1	T2	T3	T4	T5
1	Governance	G1		+++ +-	+++ ++	+++ +0	+00 00	++0 00	++0 00	+++ 00	+++ ++	+++ +0	+++ +±	+++ +±
2		G2	- - - -∓		+++ +±	++0 00	+++ +0	++0 0+	+++ 0±	+00 0±	+++ ±±	-00 00	-00 00	+00 00
3		G3	- - - - -	--- -∓		+++ -±	-00 0±	000 ±±	+00 0±	+++ -±	+++ 0±	+++ 0±	+++ ± ±	+++ ±±
4		G4	- - - -0	--0 00	--- +∓		+00 0±	+00 00	+++ 00	+++ +±	+++ +±	++± ±±	+0± ±±	+++ ++
5	Social	S1	-00 00	--- -0	+00 0∓	-00 0∓		+++ +±	+-- -±	000 00	000 00	000 00	000 00	000 0±
6		S2	--0 00	--0 0-	000 ∓∓	-00 00	--- -∓		--- 00	-00 00	000 00	-00 00	000 00	000 0±
7		S3	--0 00	--- 0∓	-00 0∓	--- 00	-++ +∓	+++ 00		-00 00	-00 0±	--- 00	000 ±±	000 0±
8	Technological Resources	T1	--- 00	-00 0∓	--- +∓	--- -∓	000 00	+00 00	+00 00		+++ +±	++- --	+±± ±±	+++ 0±
9		T2	--- --	--- ∓∓	--- 0∓	--- -∓	000 00	000 00	+00 0∓	--- -∓		+-- --	+-- -±	+00 0±
10		T3	--- -0	+00 00	--- 0∓	--∓ ∓∓	000 00	+00 00	+++ 00	--+ ++	-++ ++		+++ 00	+++ 00
11		T4	--- -∓	+00 00	--- ∓∓	-0∓ ∓∓	000 00	000 00	000 ∓∓	-∓∓ ∓∓	-++ +∓	--- 00		0+0 ++
12		T5	--- -∓	-00 00	--- ∓∓	--- --	000 0∓	000 0∓	000 0∓	--- 0∓	-00 0∓	--- ∓∓	0-0 --	

"+" means barrier *i* influences barrier *j*; "-" means barrier *i* is influenced by barrier *j*; "±" or " ∓ " denotes barrier *i* and barrier *j* influence each other; "0" means barrier *i* and barrier *j* are independent of each other.

Table B.2
Initial Reachability Matrix (RM_{init})

i	*j*		1	2	3	4	5	6	7	8	9	10	11	12
	Aspect		Governance				Social			Technological Res.				
		Barrier	G1	G2	G3	G4	S1	S2	S3	T1	T2	T3	T4	T5
1	Governance	G1	1	1	1	1	0	0	0	1	1	1	1	1
2		G2	0	1	1	0	1	1	1	0	1	0	0	0
3		G3	0	0	1	1	0	0	0	1	1	1	1	1
4		G4	0	0	0	1	0	0	1	1	1	1	1	1
5	Social	S1	0	0	0	0	1	1	0	0	0	0	0	0
6		S2	0	0	0	0	0	1	0	0	0	0	0	0
7		S3	0	0	0	0	1	1	1	0	0	0	0	0
8	Technological Resources	T1	0	0	0	0	0	0	0	1	1	0	1	1
9		T2	0	0	0	0	0	0	0	0	1	0	0	0
10		T3	0	0	0	1	0	0	1	1	1	1	1	1
11		T4	0	0	0	1	0	0	0	1	1	0	1	1
12		T5	0	0	0	0	0	0	0	0	0	0	0	1

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