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Environmental impact assessment using a utility-based recursive evidential reasoning approach for structural flood mitigation measures in Metro Manila, Philippines

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A B S T R A C T

In recent years, the practice of environmental impact assessment (EIA) has created significant awareness on the role of environmentally sound projects in sustainable development. In view of the recent studies on the effects of climate change, the Philippine government has given high priority to the construction of flood control structures to alleviate the destructive effects of unmitigated floods, especially in highly urbanized areas like Metro Manila. EIA thus, should be carefully and effectively carried out to maximize or optimize the potential benefits that can be derived from structural flood mitigation measures (SFMMs). A utility-based environmental assessment approach may significantly aid flood managers and decision-makers in planning for effective and environmentally sound SFMM projects. This study proposes a utility-based assessment approach using the rapid impact assessment matrix (RIAM) technique, coupled with the evidential reasoning approach, to rationally and systematically evaluate the ecological and socio-economic impacts of 4 planned SFMM projects (i.e. 2 river channel improvements and 2 new open channels) in Metro Manila. Results show that the overall environmental effects of each of the planned SFMM projects are positive, which indicate that the utility of the positive impacts would generally outweigh the negative impacts. The results also imply that the planned river channel improvements will yield higher environmental benefits over the planned open channels. This study was able to present a clear and rational approach in the examination of overall environmental effects of SFMMs, which provides valuable insights that can be used by decision-makers and policy makers to improve the EIA practice and evaluation of projects in the Philippines.

1. Introduction

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

In principle, EIA is a process undertaken to identify the beneficial and harmful effects of projects, plans, programs or policies on

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the physical, biological and socio-economic components of the environment (Petts, 1999; Wang et al., 2006). The use of appropriate EIA techniques can aid planners and decision-makers in formulating appropriate action plans based on informed decisions in light of project urgency and limited resources, which are common constraints in many developing countries (Shah et al., 2010).

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

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

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

This study explores the application of a utility-based recursive evidential reasoning approach (as an extension in the RIAM technique) in the EIA of planned SFMM projects. As a novel approach, the modified RIAM technique (Gilbuena et al., 2013a) was coupled with the utility-based evidential reasoning approach to evaluate the environmental impacts of SFMMs. A new utility function based on the mean environmental score of each range bands in the modified RIAM technique (Gilbuena et al., 2013a), standardized to a range [−1 to 1], was proposed to estimate the overall utility values of the SFMMs in terms of the negative and positive utility ranges. The concept of “gains” and “losses” (Kahneman and Tversky, 1979) was used to interpret the results to create a distinction between the effects of different decision preferences on the aggregated positive and negative impacts. As far as the authors know, no other similar approach that utilizes the RIAM technique and takes into account decision preferences in the environmental assessment of SFMMs, is available in the literature. In addition, the algorithm of the utility-based assessment is presented in a simple “step-by-step” approach to provide a clear and comprehensive procedure for the EIA of SFMM projects.

The proposed modifications in the utility-based evidential reasoning approach are intended to advance the EIA process for SFMM projects in the Philippines, but may also find application in other forms of EIA studies. The succeeding sections describe the EIA of the 4 SFMMs using the modified RIAM technique and the analysis previously carried out by the authors (Gilbuena et al., 2013a); elaborate the recursive evidential reasoning approach, including the development of a new utility function that is compatible with the modified RIAM technique; analyze and discuss the results of the impact assessment; and offer some recommendations and conclusions with the aim of improving the practice of EIA for SFMMs in the Philippines.

2. EIA by RIAM technique

The authors carried out a study that investigated the use of a modified RIAM technique to assess the environmental impacts of 4 planned SFMM projects in Metro Manila consisting of 2 river improvement works (dikes) and 2 new open channels (Gilbuena et al., 2013a). The following sub-sections describe the environmental conditions of the study area and the EIA method used.

2.1. Environmental and socio-economic conditions of the study area

Fig. 1 shows the geographic location of Metro Manila (right figure) and its administrative boundary (center figure). Metro Manila is a megacity situated in a semi-alluvial fan that opens to Manila Bay on the west and Laguna de Bay Lake on the southeast. It is composed of 17 highly urbanized municipalities that collectively have a total population of around 11.76 million (National Statistics Office, 2007). Its total land area is about 638 km^2, which makes it the most densely populated administrative region in the country. Metro Manila is also the focal point for major political and economic activities in the Philippines. A study by the National Statistical Coordination Board (2009) revealed that around 30% of the country’s gross domestic product comes from Metro Manila. Despite the high economic activities in this region, economic growth and urban development is persistently slow, which, according to Page (2000), is largely due to the frequently occurring floods during the monsoon and storm periods (from May to October).

Large floods have been documented in Metro Manila as early as 1898 (Fano, 2000). The first comprehensive flood study and flood control plan were carried out in 1943, but was only completed in 1952 (Bureau of Public Works, 1952). The flood control plan consisted mainly of drainage improvement works covering most parts of the present day Metro Manila. In 2009, Recent flood events are increasingly devastating, which often results in the loss of many lives and widespread damages to agriculture and properties. Based

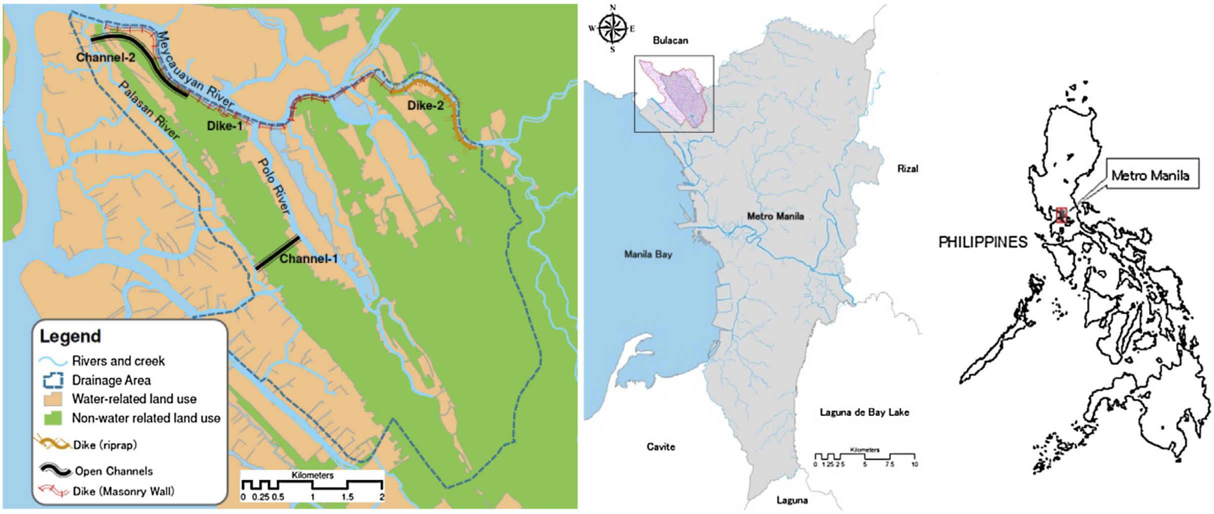

Fig. 1. Maps showing the geographical location of Metro manila (right), the study area (middle) and the planned structural flood mitigation measures (left) (i.e. Dike-1, Dike-2, Channel-1 and Channel-2).

on a study by the authors regarding Metro Manila's flood management systems (Gilbuena et al., 2013b), more than 30% of the metropolis was flooded due to the heavy rainfall caused by the tropical storm Ondoy in 2009, which overwhelmed most of Metro Manila's major SFMMs. This resulted in heavy losses to life, property and public infrastructures, making it the worst climate-related disaster in Metro Manila's recorded history. It is thus clear that there is still a need to further strengthen and improve the flood mitigation management systems in Metro Manila.

This paper focuses on the flood-prone sub-drainage area (approximately 20 km^2) located at the north-northwest part of Metro Manila (as shown in Fig. 1) that has a population of approximately 160,000 people. Its topography is generally characterized by flat and low-lying coastal plains with ground elevation ranging from 0 to 1.5 m above mean sea level. It has a mixed land-use system comprised of commercial districts, industrial districts, residential areas and fishponds. The study area, as shown in the left figure of Fig. 1, is bordered by two rivers and three creeks with 3 minor river systems traversing the drainage area from southeast to northwest. The average annual rainfall in Metro Manila is less than 3000 mm (Department of Public Works and Highways, 2001). Based on the on-site investigations carried out by the authors, the river system has limited aquatic biota due to the poor water quality conditions. Garbage, especially commercial plastics, was observed deposited along the riverbanks and floating along the river mid-streams. Migratory birds that feed on insects, fishes and invertebrates were observed wandering and nesting close to the Meycauayan River, while few patches of mangroves exist at the lower river section. Most mangrove areas have been converted to fishponds and settlement areas. Water hyacinths are commonly observed at the approaching upstream of the Meycauayan River. High density of settlers is found surrounding the left bank of the upper section of the Meycauayan River and along narrow natural waterways. Due to the very poor discharge capacity in this drainage area, floods can easily manifest during the rainy seasons, contributing to the slow economic growth rate of the affected municipalities.

To improve the drainage conditions, 2 river improvement works and 2 open channels were proposed by the Department of Public Works and Highways (2001), under the Metro Manila flagship program on flood management. Each of the proposed drainage improvements (or SFMMs) are expected to independently yield benefits for the sub-drainage area, thus in this study, each of these SFMMs was treated as a project alternative. Table 1 shows salient information of the 4 planned SFMM projects investigated in this study. The locations of these structures are shown in Fig. 1. The river improvement works as described in Table 1 involves the construction of masonry walls (Dike-1) and riprap dikes (Dike-2) at the left bank of the lower and upper sections of the Meycauayan River, respectively. These structures will serve as protection measures from bank overflow, and scouring effects from turbulent flows against the river's critical bends and bridge abutments. The planned open channels consist of a diversion canal (Channel-1) that will discharge excess water from the Polo River to the Palasan River; and a small drainage channel (Channel-2) that will aid in the draining of surface water near the lower section of the Meycauayan River (Fig. 1). Settlements can be found along the alignment of the planned open channels. Each of the planned SFMM was evaluated by means of a utility-based environmental assessment. The results of which can be used to compare and assess the suitability of each of the planned SFMMs for implementation.

Table 1
Salient features of the planned structural flood mitigation measures in Metro Manila (Gilbuena et al., 2013a).

Structural flood mitigation measures	Description of activities	Length (m)	Width (m)	Depth (m)
Dike-1	Raising of masonry wall, installation of ripraps and alteration of river bank configuration at the lower section of the Meycauayan River)	4900	4.0	–
Dike-2	Raising of riprap dike, installation of new ripraps, and alteration of river bank configuration at the upper section of the Meycauayan River	2340	4.0	–
Channel-1	Construction of diversion canal between the Polo River and the Palasan River by excavation	850	9.6	3
Channel-2	Construction of drainage channel in the lower reaches of the Meycauayan River by excavation	1650	5.6	2.1

2.2. The RIAM technique

The EIA of the 4 SFMM projects was carried out by the authors using a modified RIAM technique (Gilbuena et al., 2013a). This EIA technique provides a semi-quantitative approach for the evaluation of environmental factors using a set of standardized assessment criteria. Unlike the simple checklist method mentioned in Section 1, the evaluation of the assessment criteria in RIAM is clearly explained by a standard scaling procedure (Pastakia and Jensen, 1998). Table 2 shows the scope of the EIA as indicated by the list of 32 environmental components, and the summary of the RIAM analysis carried out for Dike-1, Dike-2, Channel-1 and Channel-2. Each of the environmental components fall under one of the 4 environmental categories (Pastakia and Jensen, 1998): Physical/Chemical (PC), Biological/Ecological (BE), Social/Cultural (SC) and Economics/Operational (EO). Each environmental category is divided in terms of project phases (pre-construction, construction and operation), and then further divided into specific environmental components (Gilbuena et al., 2013a). In this study, the abandonment phase was not considered since open channels and river improvements are taken as permanent structures that are only subject to either maintenance or further enhancement due to their long term (or perpetual) use in Metro Manila (Gilbuena et al., 2013a). Details of this method are described as follows:

- Assessment criteria are categorized into 2 groups, *A* and *B*. The *A* group consists of the Importance Criterion ($A1$) and Magnitude Criterion ($A2$), while the *B* group consists of the Permanence Criterion ($B1$), Reversibility Criterion ($B2$) and Cumulative Criterion ($B3$). The scale values of $A1$ and $A2$ and the impact description of each scale are described by Gilbuena et al. (2013a)
- Given the scales determined in each of the assessment criteria, the environmental score (ES) was calculated using the formula (Pastakia and Jensen, 1998):

$$ES = [A1 \times A2] \times [B1 + B2 + B3] \quad (1)$$

- The environmental score, which ranges from −108 to 108, represents the degree of change that may occur in an environmental component due to the implementation of a project. To define the *levels of impact* according to the environmental

Table 2
Results of the RIAM analysis of the selected planned structural flood mitigation measures in Metro Manila (Gilbuena et al., 2013a), and relative weights of the environmental category and environmental components.

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

scores, impact bands (or range bands) are assigned to each range of environmental scores, which is denoted by the symbols [−E], [−D], [−C], [−B], [−A], [N], [+A], [+B], [+C], [+D] and [+E] as shown in Table 3. The range band [−E] corresponds to the most severe negative change, [N] represents *no change*, and [+E] corresponds to the most beneficial positive change (Pastakia and Jensen, 1998). The authors later proposed the split of [N] into [NC] and [NI] (Gilbuena et al., 2013a) to cope with the modifications made on the assessment criteria, where both [NC] and [NI] carry an environmental score of zero. The range band [NI] refers to assessments that have no identifiable impacts (i.e. all assessment criteria are zero). The range band [NC] (or negligible change), on the other hand, refers to assessments that have scores in some of the assessment criteria, however the environmental score still calculates to zero.

- To illustrate the identification of range bands, take for example the assessment of Dike-1 on PC-C-2 (Gilbuena et al., 2013a): $A1 = 1$ (Important only to the local condition), $A2 = -2$ (Significant negative disbenefit or change), $B1 = 2$ (Temporary), $B2 = 2$ (Reversible) and $B3 = 3$ (Cumulative/synergistic), then $\mathrm{ES} = -14$ shown in Table 2. Thus, the corresponding range band according to Table 3 is [−B].

Table 2 shows the summary of the RIAM analysis carried out for Dike-1, Dike-2, Channel-1 and Channel-2, while Fig. 2 shows the distribution profile of the assessment results (range bands) in Table 2 according to environmental categories and project phases. The RIAM analysis in Table 2 is based on the EIA study (Gilbuena et al., 2013a) by the authors for the 4 planned SFMMs. The ES values were calculated and the range bands were assigned in accordance to the RIAM method described in Section 2.1. The environmental categories are based on the original categories proposed by Pastakia and Jensen (1998), while the environmental components (and their corresponding Codes) are based on the evaluation attributes proposed by the authors (Gilbuena et al., 2013a) for the RIAM analysis of planned SFMMs. The environmental components were carefully selected by the authors based on the actual observation and environmental investigation of the study area in Metro Manila, which deemed these environmental components necessary and sufficient for the RIAM analysis of SFMMs. The following general observations are obtained based on the summary of the RIAM analysis in Table 2 and Fig. 2 (Gilbuena et al., 2013a):

- For all 4 SFMM projects, the worst situation may take place in the Social/Cultural environment during the pre-construction phase. The levels of impacts will be equivalent to [−C] for Dike-1 and Channel 2, and [−D] for Dike-2 and Channel-1 due to involuntary resettlement (SC-P-1).
- Dike-1 and Dike-2 will significantly contribute to the Physical/Chemical environment with impact equivalent to range band [+D] due to the improvement of the hydraulic conditions (PC-O-2) during the operation phase.
- The significant contributions of Channel-1 and Channel-2 will mostly be on the Economic/Operational environment during the operational phase. The local revenue (EO-O-3), in particular, can generate an impact equivalent to [+C].
- Most of the negative impacts are within the range band [−A]. On the other hand, most of the positive impacts are found within the range of [+A] for Dike-1 and Dike 2, and both [+A] and [+B] for Channel-1 and Channel-2.

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

Table 3
Equivalent range bands based on the environmental scores according to Gilbuena et al. (2013a).

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

3. EIA of SFMM using the evidential reasoning approach

The recursive evidential reasoning approach provides an effective way to synthesize the information of assessed environmental factors. The process is based on the belief decision matrix and the combination rule of the Dempster–Shafer theory (Yang, 2001). The Dempster–Shafer Theory is a mathematical theory of evidence that was first developed by Dempster (1967), and later extended by Shafer (1976), that deals with the weights of evidence and numerical degrees of support based upon the available evidences (Barnett, 1981). This theory also allows the aggregation of the measures of evidence (known as probability mass) from different sources using the Dempster's rule of combination (Beynon et al., 2000; Wang et al., 2006), resulting in a new measure of evidence that represents how strongly the evidence supports the hypothesis (Wang et al., 2006). In this study, the evidences are based on the results of the RIAM analysis of 4 planned SFMM projects in Metro Manila (Gilbuena et al., 2013a).

A recursive evidential reasoning algorithm (Yang and Singh, 1994; Yang and Sen, 1994; Yang, 2001) was used to aggregate the assessment results of the basic environmental components in the EIA of planned SFMM project p. Fig. 3 shows the hierarchical process used in the EIA of the 4 planned SFMM projects. Based on this figure, the environmental components are first aggregated in terms of the environmental category using the evidential reasoning approach. The assessment results of the environmental categories are then further aggregated to obtain an overall assessment of each SFMM project. The recursive evidential reasoning algorithm used in this study is described in detail in the following steps:

Step 1: Construct the decision matrix $D_{p,q}(i, n)$ for each qth environmental category of each pth SFMM project according to the results of the RIAM analysis, where row i is the item number of each environmental component of qth environmental category, and column n is the identifier of the range band variable H_n, where $p = 1$

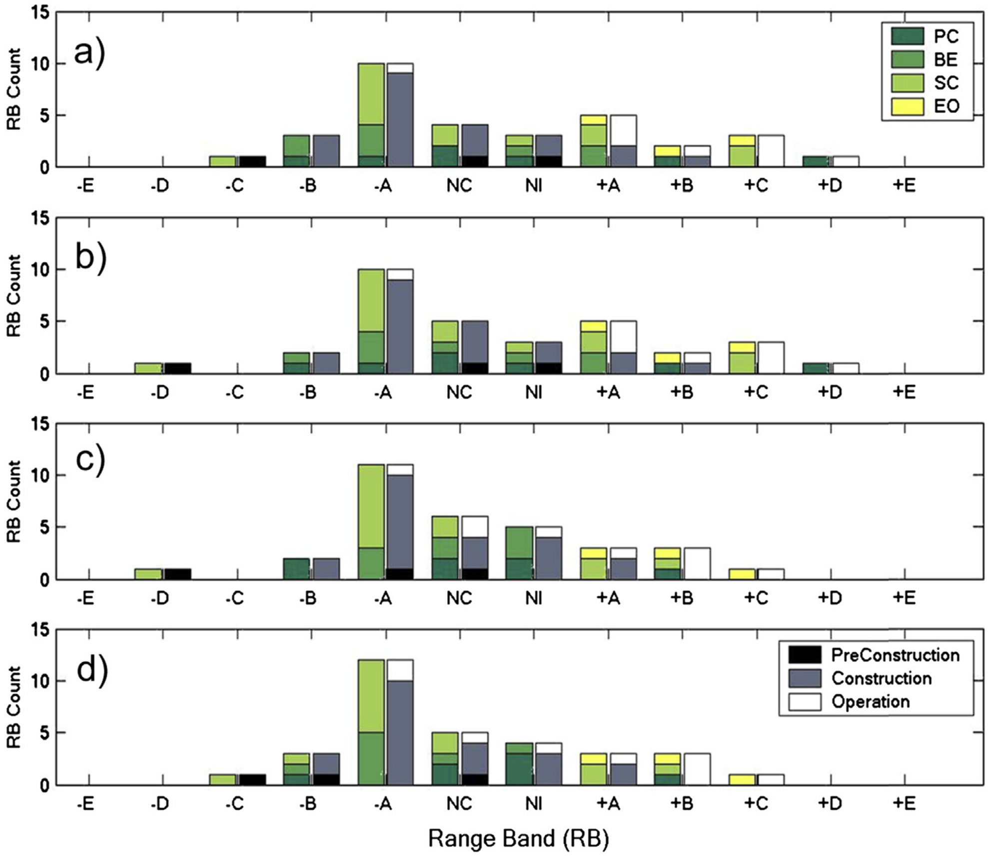

Fig. 2. Histograms of the 4 structural flood mitigation measures, which shows the summary of the assessment carried out by RIAM. a) Dike-1, b) Dike-2, c) Channel-1 and d) Channel-2.

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

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

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

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

Step 2: Relative weights $w_{p,q}$ and $w_{p,q,i}$ are assigned to the qth environmental category and ith environmental component, respectively (as shown independent of project p in Table 2), with conditions $\sum_{q=1}^{4} w_{p,q} = 1$ and $\sum_{i=1}^{I_q} w_{p,q,i} = 1$ (Wang et al., 2006). In this study, each environmental category is assumed to be of equal relative importance, thus $w_{p,1} = w_{p,2} = w_{p,3} = w_{p,4} = 1/4$. Similar to Wang et al. (2006), the environmental components of the qth environmental category are assumed to have the same relative weights, thus $w_{p,1,i} = 1/7$, $w_{p,2,i} = 1/8$, $w_{p,3,i} = 1/14$ and $w_{p,4,i} = 1/3$.

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

$$m_{p,q,i,n} = w_{p,q,i}\beta_{p,q,i,n} \tag{4}$$

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

$$\overline{m}_{p,q,i} = 1 - w_{p,q,i} \tag{6}$$

$$\widehat{m}_{p,q,i} = \tilde{m}_{p,q,i} + \overline{m}_{p,q,i} \tag{7}$$

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

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

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

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

And then calculate the aggregated probability masses $\mu_{p,q,j,n}$, $\tilde{\mu}_{p,q,j}$, $\overline{\mu}_{p,q,j}$, $\widehat{\mu}_{p,q,j}$, at $j = 1$ using eqs. (9)–(12).

$$\mu_{p,q,1,n} = K_{p,q,1}\left[m_{p,q,1,n} m_{p,q,2,n} + m_{p,q,1,n}\widehat{m}_{p,q,2} + \widehat{m}_{p,q,1} m_{p,q,2,n}\right] \tag{9}$$

$$\tilde{\mu}_{p,q,1} = K_{p,q,1}\left[\tilde{m}_{p,q,1}\tilde{m}_{p,q,2} + \tilde{m}_{p,q,1}\overline{m}_{p,q,2} + \overline{m}_{p,q,1}\tilde{m}_{p,q,2}\right] \tag{10}$$

$$\overline{\mu}_{p,q,1} = K_{p,q,1}\left[\overline{m}_{p,q,1}\overline{m}_{p,q,2}\right] \tag{11}$$

$$\widehat{\mu}_{p,q,1} = \tilde{\mu}_{p,q,1} + \overline{\mu}_{p,q,1} \tag{12}$$

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

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

$$\mu_{p,q,j,n} = K_{p,q,j}\Big[\mu_{p,q,j-1,n} m_{p,q,j+1,n} + \mu_{p,q,j-1,n}\widehat{m}_{p,q,j+1} + \widehat{\mu}_{p,q,j-1} m_{p,q,j+1,n}\Big] \tag{14}$$

$$\tilde{\mu}_{p,q,j} = K_{p,q,j}\left[\tilde{\mu}_{p,q,j-1}\tilde{m}_{p,q,j+1} + \tilde{\mu}_{p,q,j-1}\overline{m}_{p,q,j+1} + \overline{\mu}_{p,q,j-1}\tilde{m}_{p,q,j+1}\right] \tag{15}$$

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

$$\widehat{\mu}_{p,q,j} = \tilde{\mu}_{p,q,j} + \overline{\mu}_{p,q,j} \tag{17}$$

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

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

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

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

4. Utility-based environmental assessment

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

$$U_p = \sum_{n=1}^{N} \beta^{q,i}_{p,n} u(H_n) \tag{20}$$

In the estimation of the environmental utility index U_p, it is more desirable if the utility values can be explicitly estimated, which may provide a standard basis for all succeeding environmental assessment using the RIAM technique. The overall utility value (or environmental utility index) can then be calculated and used to estimate the overall environmental benefit of the SFMMs for evaluation and comparison purposes. Therefore it is important to establish a clear basis for the values of $u(H_n)$ to further reduce subjectivity in the outcome of the EIA for decision analysis.

Wang et al. (2006) adopted a set of linear utility functions, which is similar to the curves shown in Fig. 4, to carry out a utility-

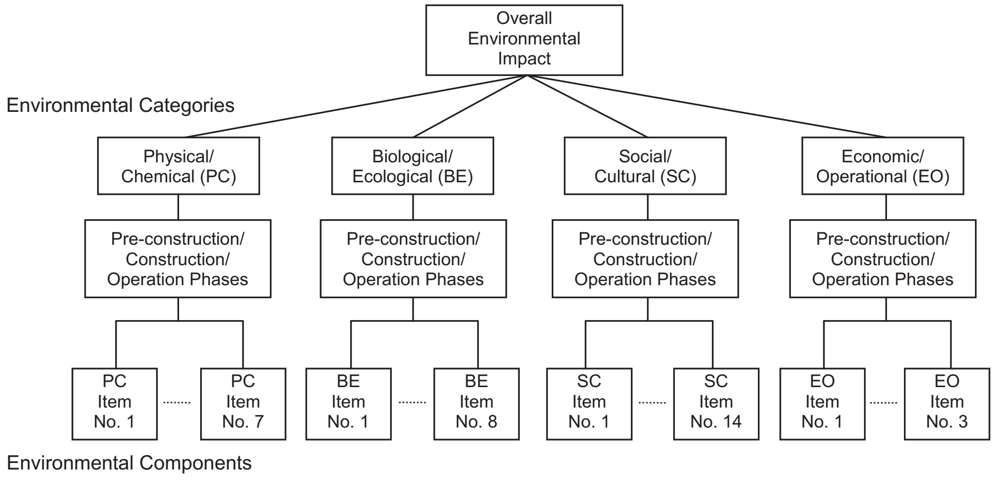

Fig. 3. The hierarchical diagram for the environmental impact assessment of the structural flood mitigation measures in Metro Manila.

based information transformation on the distributed degrees of belief (based on the EIA of alternative methods to conserve Rupa Tal Lake), and to help illustrate how the project options can be compared and ranked according to the results of the environmental assessment. From this figure, the range of the utility values is from 0 to 1, which implies that the expected utility will always be greater than or equal to zero. The preferences of the decision-makers (i.e. *risk neutral*, *risk-aversive* and *risk-seeking*) have also been taken into consideration. The risk neutral decision-maker is represented by curve A (Fig. 4), which assumes that the utility values are equidistantly distributed in the normalized utility range. The other two curves B and C (Fig. 4) represent the decision preferences *risk-aversive* and *risk-seeking* behaviors, respectively. Based on Fig. 4, a risk-aversive decision-maker's marginal utility (curve B) drastically increases as the level of impact (denoted by the range bands) improves up to range band [N], and then gradually increase (reduced slope) as the level of impact improves further towards the range band [+E]. Inversely, the marginal utility of a risk-seeking decision-maker (curve C in Fig. 4) gradually increase from [−E] to [N], then drastically increase (increase in slope) from [N] to [+E].

4.1. Development of utility functions for RIAM-based evaluation of planned SFMMs

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

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

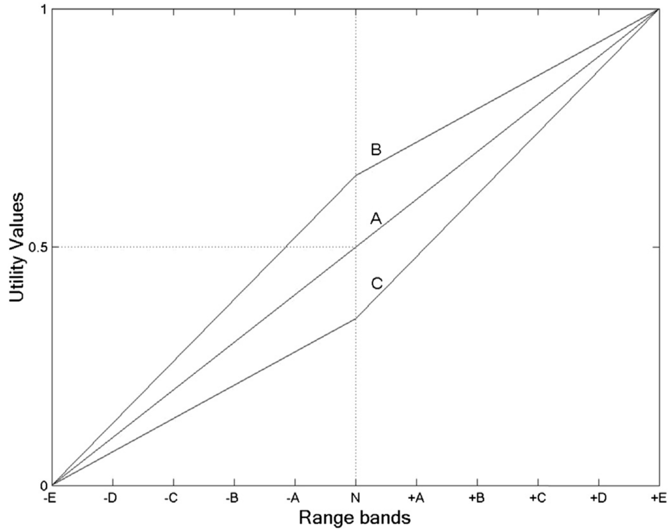

Fig. 4. Utility functions showing 3 types of decision preferences according to Wang et al. (2006): *neutral* (curve A), *risk-aversed* (curve B) and *risk-seeking* (curve C).

$$u_{\text{ave}}(H_n) = \frac{u_{\min}(H_n) + u_{\max}(H_n)}{2} \tag{21}$$

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

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

Curve I represents the average basic attitude of a decision maker towards a planned SFMM project. In some instances however, an *optimistic* (or a *pessimistic*) decision-maker may opt for higher (or lower) utility values. In this case, Curve II represents the basic optimistic attitude, while Curve III may represent the basic pessimistic attitude of a decision-maker for the estimation of the environmental utility index. Note that Curves I, II and III converge at

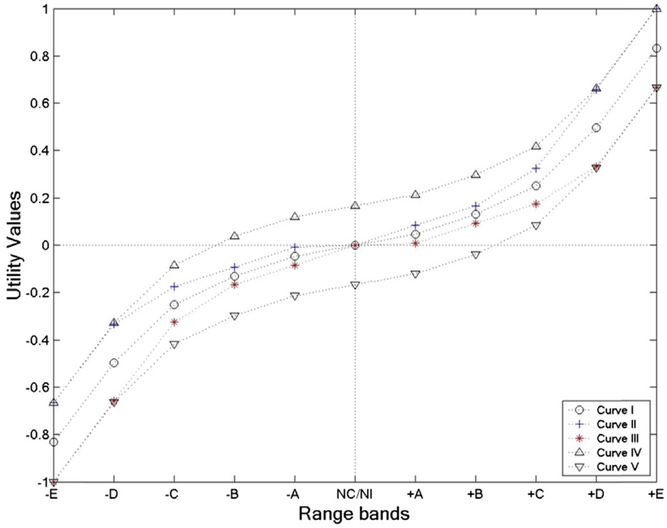

Fig. 5. Expected utility functions indicating the preferences and attitudes of the decision decision-makers. Attitudes: Neutral/average (Curve I), Basic optimistic/basic maximum (Curve II), Basic pessimistic/basic minimum (Curve III), relative optimistic (Curve IV) and relative pessimistic (Curve V).

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

5. Results and discussion

Table 4 shows the distribution of the degree of belief of the aggregated environmental components $\beta^{i}_{p,q,n}$ and aggregated environmental categories $\beta^{q,i}_{p,n}$ of Dike-1, Dike-2, Channel-1 and Channel-2.

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

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

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

With regards to the distribution of $\beta^{q,i}_{p,n}$, it is clear that range band [−A] dominates all other range bands (shown in Table 4), but more importantly, [−A] dominates the domain of the negative range bands, which indicates that most of the negative impacts will likely be equivalent to [−A]. In the domain of the positive range bands, [+A] dominates in Dike-1 and Dike-2, while [+B] dominates in Channel-1 and Channel-2. The desirability of the projects however, cannot be based entirely on the dominant range bands, since these range bands represent only small portions of the overall distribution (for each SFMM) of the degrees of belief. To estimate the overall utility (or environmental utility index) U_p based on the distribution of $\beta^{q,i}_{p,n}$, eq. (19) was used.

Table 5 summarizes the environmental utility indices of the planned SFMM projects according to the different attitudes (or viewpoints) of a decision-maker based on the proposed basic utility

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

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

curves (Curves I, II and III) and relative optimistic and pessimistic utility curves (i.e. Curves IV and V, respectively). For a neutral decision maker (Curve I), the order of rank of the SFMMs, from highest to lowest net benefits, is Dike-2, Dike-1, Channel-1 and Channel-2. For a basic optimistic decision-maker (Curve II), the order of rank is Dike-2, Dike-1, Channel-2 and Channel-1, and for a basic pessimistic decision-maker (Curve III), the order is Dike-2, Dike-1, Channel-1 and Channel-2.

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

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

The result of the EIA of the planned SFMM projects using the evidential reasoning approach thus, provides valuable insights as to how the projects can be further optimized to maximize the environmental benefits, and to minimize the effects of the negative impacts. The preferences and attitudes of a decision-maker must also be given serious consideration, since this could significantly affect the final decision for the SFMM project. The characteristics of the distribution of impacts of the 4 SFMMs have been accurately captured by the environmental utility indices. Other social preferences, such as different shapes of utility functions, can also be explored in future studies in terms of the application of the new utility-based environmental assessment approach.

6. Conclusion

This study explores the application of a utility-based recursive evidential reasoning approach as an extension to the RIAM technique for SFMM projects in Metro Manila. The utility-based recursive evidential reasoning approach was used to determine the distributed assessment of the environmental categories in terms of the degrees of belief on each range band variable H_n, and calculated the environmental utility index U_p of each SFMM. Using the outcome of the recursive evidential reasoning approach, the SFMMs were assessed based on benefits maximization (risk-seeking positive gains) and benefits loss aversion. The evidential reasoning approach shows flexibility by allowing the assignment of relative weights on the environmental components and environmental categories, and by means of the utility functions that can be adjusted according to the decision-maker's preference and attitude (or viewpoint). The basic utility functions, $u_{\min}(H_n)$, $u_{\max}(H_n)$ and $u_{\text{ave}}(H_n)$ provide the basis for decision preferences, which on their own, can generate reasonable results that can be used to analyze the characteristics of the distributed impacts for benefit maximization and/or impact optimization. In terms of the environmental utility index, a positive value is more desirable than a negative value. In essence, the higher the environmental utility index, the more desirable is the outcome.

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

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