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Environmental impact assessment of structural flood mitigation measures in Metro Manila, Philippines using an analytical evidential reasoning approach

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Abstract

The practice of environmental impact assessment (EIA) in the planning processes of infrastructure projects has created significant awareness in many parts of the world on the benefits of environmentally sound and sustainable urban development. In the Philippines, the construction of structural flood mitigation measures (SFMMs) gets high priority from the national government to immediately address the destructive effects of flash floods and inundations in highly urbanized areas, especially in Metro Manila. EIA thus, should be carefully and effectively carried out to maximize the potential benefits that can be derived from SFMMs. An environmental assessment that can be reduced to standardized comparable quantitative values may aid flood managers and decision-makers in planning for effective and environmentally sound structural flood mitigation projects. This study proposes a semi-quantitative approach to EIA using the rapid impact assessment matrix (RIAM) technique, coupled with evidential reasoning approach, to rationally and systematically aggregate the ecological and socio-economic impacts of 4 planned SFMM projects (2 river channel improvements and 2 new open channels) in Metro Manila. Based on the results, the environmental benefits from the river channel improvements and new open channels generally outweigh the likely negative impacts. The utility values also imply that the river channel improvements will yield higher environmental benefits over the 2 new open channels. The results of this study thus, provide valuable insights for the development of environmental impact assessment process for SFMMs in the Philippines.

1. Introduction

Environmental impact assessment is a process undertaken to identify the benefits and harmful impacts of projects, plans, programs or policies on the physical, biological and socio-economic components of the environment (Petts 1999; Wang et al. 2006). The use of appropriate EIA techniques can aid planners and decision-makers in formulating appropriate actions based on informed decisions in light of project urgency and limited

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resources, which are common constraints in many developing countries (Shah et al. 2010).

In the Philippines, particularly in Metro Manila, the EIA techniques used for SFMMs are generally descriptive and qualitative in nature (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 address some of the weaknesses of these methods, such as multicriteria/ multiattribute decision analysis (McDaniels, 1996; Kim et al., 1998), weighting-scaling checklists (Canter and Sadler, 1997), input-output analysis (Lenzen et al., 2003), life cycle assessment (Tukker, 2000), analytic hierarchical process (Ramanathan, 2001), fuzzy sets approaches (Parashar et al., 1997), and the Rapid Impact Assessment Matrix (RIAM) technique (Pastakia, 1998; Mondal et al., 2009; Al Malek and Mohamed, 2005).

For the SFMM projects in Metro Manila, the authors proposed the use of a modified RIAM technique to reduce the subjectivity and improve the transparency of the EIA process (Gilbuena et al., 2013). This method, however, does not provide the means to measure the overall impact of each project alternative. If an overall impact can be estimated through a quantifiable value, planners and decision-makers may be able to maximize the potential benefits of each project alternative.

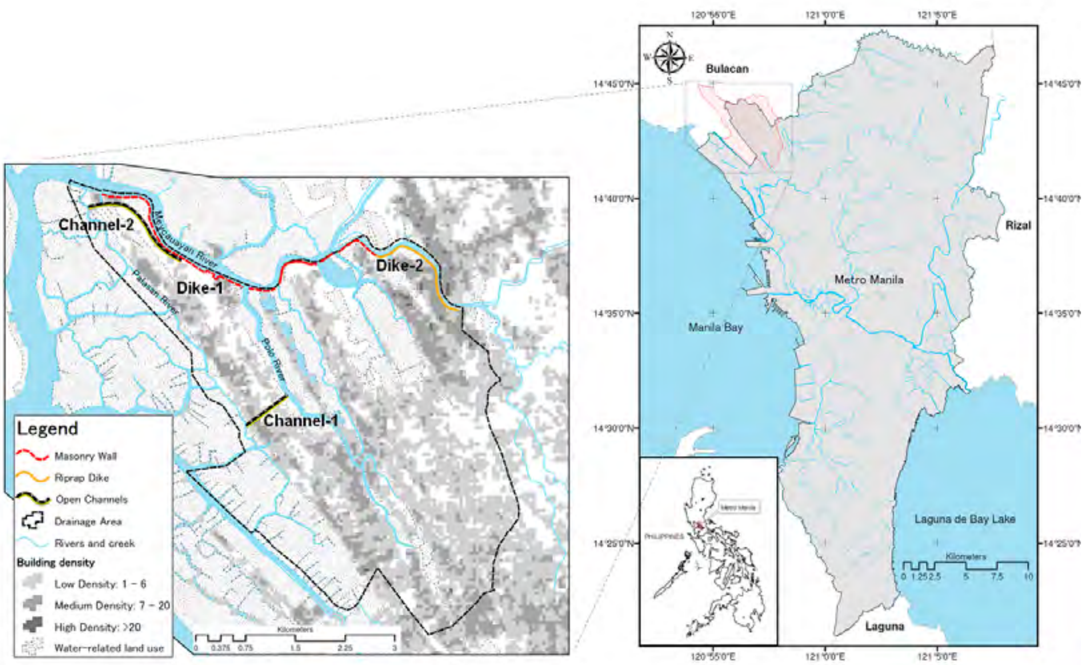

Figure 1 *Maps showing the geographical location of Metro manila, the study area and the planned structural flood mitigation measures indicated by Dike-1, Dike-2, Channel-1 and Channel-2 (Gilbuena et. al, 2013).*

DOI: 10.5675/ICWRER_2013

Yang and Sen (1994) developed an evidential reasoning approach that uses a belief structure to model qualitative assessments on the basis of decision theory and the Dempster-Shafer theory of evidence. This method focuses primarily on the uncertainties that are inherent in subjective assessment processes. The evidential reasoning approach, since then, has been used in many multiattribute decision analysis problems in engineering and management (e.g. Yang and Sen, 1994; Sen and Yang, 1995; Wang et al., 1995; Wang, 1997;Yang and Xu, 1998; Yang, 2001; Wang et al., 2006).

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 new evidential reasoning approach has been coupled with the RIAM technique to obtain a unified EIA result in the form of utility values (Wang et al., 2006), which opens a systematic and effective way to compare and rank alternatives. The potential of this approach however, has not been fully explored, especially for its application in the EIA of planned SFMM projects.

This study explores the use of a utility-based recursive evidential reasoning approach, coupled with the RIAM technique, in the EIA of planned SFMM projects. The utility function has been slightly modified to cope with the modified RIAM technique and to estimate the utility values in terms of the utility range [-1 1] to distinctly represent the effects of the aggregated positive and negative impacts. These modifications are intended to improve the outcome of the EIA, but may also find application in other types of projects. The succeeding sections describes the EIA of the 4 SFMMs using the modified RIAM technique; elaborate the recursive evidential reasoning approach; 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 the 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 comprising of 2 dike and 2 new open channels (Gilbuena et al., 2013). The following sub-sections describe the environmental conditions of the study area and the EIA method used.

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

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)	4,900	4.0	-
Dike-2	Raising of riprap dike, installation of new ripraps, and alteration of river bank configuration at the upper section of the Meycauayan River	2,340	4.0	-
Channel-1	Construction of diversion canal between the Polo River and the Palasan River by excavation	850	9.6	3
Channel-2	Construction of drainage channel in the lower reaches of the Meycauayan River by excavation	1,650	5.6	2.1

2.1. Environmental Setting

Metro Manila serves as a focal point for the major political and economic activities in the Philippines. **Figure 1** shows the geographic location of Metro Manila. At present, the metropolis is comprised of 17 highly urbanized municipalities that has a total population of about 11.76 million (National Statistics Office, 2007). According to the study of the National Statistical Coordination Board (2009), about 30% of the country's gross domestic product is contributed by Metro Manila. Despite the high economic activities in this region, economic growth and urban development is persistently slow, which according to Page (2000), is partly due to the frequently occurring disasters caused by immense and violent floods that take place during the monsoon and storm periods (from May to October). Recent flood events (Rabonza, 2009) are increasingly devastating, resulting in the loss of many lives and immense damages to agriculture and properties.

This paper focuses on the flood-prone sub-drainage area (approximately 20 km^2) that is located at the north-northwest part of Metro Manila (as shown in **Figure 1**), which is home to approximately 160,000 residents. Its topography is generally characterized by flat and low-lying coastal plains with ground elevation ranging from 0 to 1.5 m above mean sea level. It has a mixed land-use comprised of commercial districts, industrial districts, residential areas and fishponds. The river system has limited aquatic biota due to the poor water quality conditions. Migratory birds that feed on insects, fishes and invertebrates were observed wandering and nesting near the Meycauayan River, while few patches of mangroves exist at the river's lower section. Most mangrove areas have already been converted to fishponds and settlement areas. Water hyacinths were observed at the approaching upstream of the Meycauayan River. High volume of settlers

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is found at and near the left bank of the upper section of the Meycauayan River and along narrow natural waterways. Due to the very poor discharge capacity in this drainage area, floods easily manifest during the rainy seasons, which contributes to the slow economic growth rate of the affected municipalities.

To improve the drainage conditions, 2 river improvement works and 2 open channels were planned by the Department of Public Works and Highways (2001) under the Metro Manila flagship program on flood management. **Table 1** shows salient information of the 4 planned SFMM investigated in this study. The locations of these structures are shown in **Figure 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 preventive measures from bank overflow, and protection from the scouring effects of turbulent flow against the river's critical bends and bridge abutments. The open channels consist of a diversion canal (Channel-1) that will discharge excess water from the Polo River to the Palasan River; and a small drainage channel (Channel-2) that will aid in the draining of surface water near the lower section of the Meycauayan River (**Figure 1**).

2.2. The RIAM technique

The EIA of the 4 SFMMs was carried out by the authors using a modified RIAM technique (Gilbuena et al., 2013). The RIAM technique provides the means for a semi-quantitative evaluation of the environmental factors using a set of standardized assessment criteria. **Table 2** shows assessment of Dike-1, Dike-2, Channel-1 and Channel-2 in terms of the 32 environmental components. **Figure 2** shows the summary of the RIAM analysis in **Table 2**. Each of the environmental component falls 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 (i.e. Preconstruction, Construction and Operation phases), and then further divided into specific environmental components. Details of the RIAM technique are described briefly 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 is composed 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 used in this study are described in Gilbuena et al. (2013)

DOI: 10.5675/ICWRER_2013

- 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 based on the environmental scores, impact bands (or range bands) are assigned to each range of environmental scores denoted by the symbols [-E], [-D], [-C], [-B], [-A], [NC], [NI], [+A], [+B], [+C], [+D] and [+E] as described in Gilbuena et al., 2013.

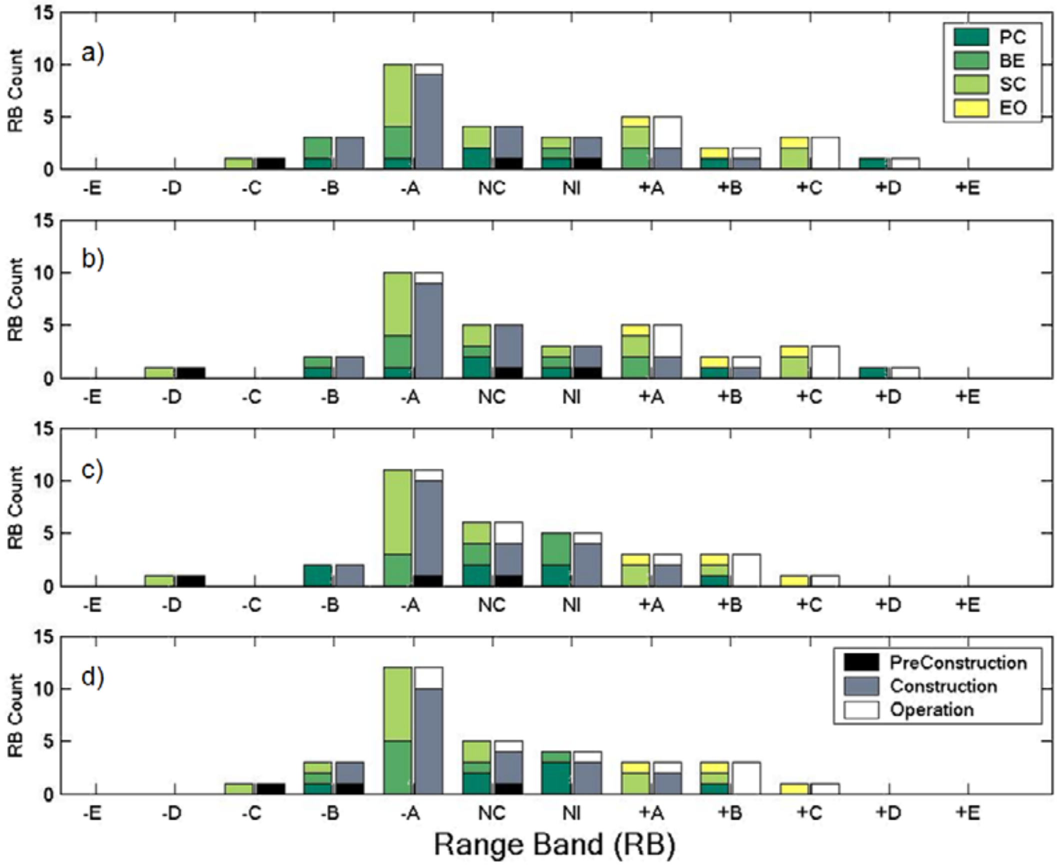

Figure 2 *Histograms for the planned SFMM projects, a) Dike-1, b) Dike-2, c) Channel-1 and d) Channel-2, based on the RIAM analysis in Table 2. The figures show the distribution of the range band counts in terms of environmental categories (PC, BE, SC and EO) and project phases (Pre-construction, Construction and Operation phases).*

DOI: 10.5675/ICWRER_2013

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

Environmental Category, Relative Weight (W_q) -Environmental Components	Code	Item No.	Relative Weight ($W_{q,i}$)	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
-Wildlife and terrestrial impacts	BE-C-2	2	0.125	-7	-A	-7	-A	0	NI	-7	-A
-Riparian and wetlands	BE-C-3	3	0.125	-10	-B	0	NC	0	NI	0	NI
-Waste generation from construction and excavation	BE-C-4	4	0.125	-7	-A	-7	-A	-7	-A	-7	-A
-Aquatic/freshwater biology	BE-C-5	5	0.125	0	NI	0	NI	-6	-A	-6	-A
-Surface water quality	BE-C-6	6	0.125	-6	-A	-6	-A	-6	-A	-6	-A
-Aquatic habitat	BE-O-1	7	0.125	6	+A	6	+A	0	NC	0	NC
-Water quality	BE-O-2	8	0.125	6	+A	6	+A	0	NC	-6	-A
Social/ Cultural (SC),0.25											
-Involuntary Resettlement	SC-P-1	1	0.0714	-28	-C	-42	-D	-42	-D	-28	-C
-Public acceptance	SC-P-2	2	0.0714	0	NI	0	NI	-6	-A	-18	-B
-Air quality	SC-C-1	3	0.0714	-5	-A	-5	-A	-5	-A	-5	-A
-Noise levels	SC-C-2	4	0.0714	-4	-A	-4	-A	-4	-A	-4	-A
-Population dynamics	SC-C-3	5	0.0714	-4	-A	-4	-A	-4	-A	-4	-A
-Dependency burden	SC-C-4	6	0.0714	8	+A	8	+A	8	+A	8	+A
-Housing characteristics and utilities	SC-C-5	7	0.0714	0	NC	0	NC	0	NC	0	NC
-Health and safety of construction workers	SC-C-6	8	0.0714	-4	-A	-4	-A	-4	-A	-4	-A
-Health and safety of general public	SC-C-7	9	0.0714	-4	-A	-4	-A	-4	-A	-4	-A
-Aesthetic and cultural scenic sites	SC-C-8	10	0.0714	0	NC	0	NC	0	NC	0	NC
-Local planning, coordination and economic growth	SC-C-9	11	0.0714	4	+A	4	+A	4	+A	4	+A
-Public utilities and infrastructure	SC-C-10	12	0.0714	-4	-A	-4	-A	-4	-A	-4	-A
-Natural environmental and health hazards	SC-O-1	13	0.0714	30	+C	30	+C	-8	-A	-8	-A
-Urban living conditions	SC-O-2	14	0.0714	30	+C	30	+C	15	+B	15	+B
Economic/ Operational (EO), 0.25											
-Property and infrastructure	EO-O-1	1	0.3333	5	+A	5	+A	5	+A	5	+A
-Development potential	EO-O-2	2	0.3333	15	+B	15	+B	15	+B	15	+B
-Local revenue and economy	EO-O-3	3	0.3333	30	+C	30	+C	30	+C	30	+C

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3. EIA of SFMM by evidential reasoning approach

The 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 of evidence (Yang, 1994).

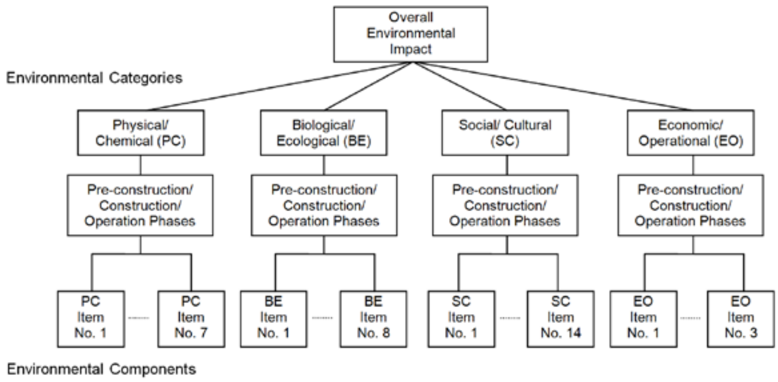

Figure 3 *The hierarchical diagram for the environmental impact assessment of the structural flood mitigation measures in Metro Manila.*

An evidential reasoning algorithm was developed by Wang et al., 2006, which can be used to aggregate the assessment results of the basic environmental components in the EIA of planned SFMM project p. The assessment follows a hierarchical process as shown in **Figure 3**. Based on this figure, the environmental components are first aggregated in each environmental category using the evidential reasoning approach. The assessment results of the environmental categories are then aggregated to determine the overall assessment for each SFMM project. The recursive evidential reasoning algorithm used in this study is briefly described in the following steps:

Step 1: Construct the decision matrix $D_{p,q}(i,n)$, composed of decision elements $\beta_{p,q,i,n}$, for each q^{th} environmental category of each p^{th} SFMM project according to the results of the RIAM analysis, where row i is the item number of each environmental component of q^{th} environmental category, and column n is the identifier of the range band variable H_n, where $p=1$ to 4, $i=1$ to $I_{p,q}$ (where $I_{p,q}= 7$, 8, 14 and 3 for $q= 1$, 2, 3 and 4, respectively), and H_n {[-E], [-D], [-C], [-B], [-A], [-NC], [-NI], [+A], [+B], [+C], [+D], [+E]} that sequentially corresponds to $n=1,2,3, \ldots ,N$ (where). Based on the RIAM analysis in **Table 2**, $\beta_{p,q,i,n}$ were determined using the following conditions:

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

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

DOI: 10.5675/ICWRER_2013

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

Step 2: Relative weights and are assigned to the q^{th} environmental category and i^{th} environmental component, respectively (as shown 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 have the relative weights: and $w_{p,4,i} = 1/3$

Step 3: Transform the degrees of belief $\beta_{p,q,i,n}$ into basic probability mass $m_{p,q,i,n}$ and calculate the "unassigned" probability mass $\hat{m}_{p,q,i}$ (Wang et al., 2006). The probability mass $\hat{m}_{p,q,i}$ is split into two parts: $\bar{m}_{p,q,i}$ and $\tilde{m}_{p,q,i}$. The probability mass $\bar{m}_{p,q,i}$ 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

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

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

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

$$\hat{m}_{p,q,i} = \tilde{m}_{p,q,i} + \bar{m}_{p,q,i} \tag{7}$$

When the RIAM analysis of a SFMM project is complete (i.e. all environmental components are individually assessed), the value $\tilde{m}_{p,q,i}$ for is zero, thus making $\hat{m}_{p,q,i} = \bar{m}_{p,q,i}$.

Step 4: Construct the decision matrix $D_p^i(q,n)$, whose elements consist of $\beta^i_{p,q,n}$ (aggregated in terms of i environmental components). The aggregated decision elements $\beta^i_{p,q,n}$ 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 j^{th} the aggregation ($j = 1$) of the environmental components i using **Equation 8**:

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

And then calculate the probability masses, $\mu_{p,q,j,n}$, $\tilde{\mu}_{p,q,j}$, $\bar{\mu}_{p,q,j}$, $\hat{\mu}_{p,q,j}$ at $j = 1$ using **Equations 9 - 12**.

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

$$\tilde{\mu}_{p,q,1} = K_{p,q,1}\left[\tilde{m}_{p,q,1}\tilde{m}_{p,q,2} + \tilde{m}_{p,q,1}\bar{m}_{p,q,2} + \bar{m}_{p,q,1}\tilde{m}_{p,q,2} \right] \quad (10)$$

$$\bar{\mu}_{p,q,1} = K_{p,q,1}\left[\bar{m}_{p,q,1}\bar{m}_{p,q,2} \right] \quad (11)$$

$$\hat{\mu}_{p,q,1} = \tilde{\mu}_{p,q,1} + \bar{\mu}_{p,q,1} \quad (12)$$

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

$$K_{p,q,j} = \left[1 - \sum_{n_1=1}^{N} \sum_{\substack{n_2=1 \\ n_2 \neq n_1}}^{N} \mu_{p,q,j-1,n_{j-1}} m_{p,q,j+1,n_{j+1}} \right]^{-1} \quad (13)$$

$$\mu_{p,q,j,n} = K_{p,q,j}\left[\mu_{p,q,j-1,n} m_{p,q,j+1,n} + \mu_{p,q,j-1,n}\hat{m}_{p,q,j+1} + \hat{\mu}_{p,q,j-1} m_{p,q,j+1,n} \right] \quad (14)$$

$$\tilde{\mu}_{p,q,j} = K_{p,q,j}\left[\tilde{\mu}_{p,q,j-1}\tilde{m}_{p,q,j+1} + \tilde{\mu}_{p,q,j-1}\bar{m}_{p,q,j+1} + \bar{\mu}_{p,q,j-1}\tilde{m}_{p,q,j+1} \right] \quad (15)$$

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

$$\hat{\mu}_{p,q,j} = \tilde{\mu}_{p,q,j} + \bar{\mu}_{p,q,j} \quad (17)$$

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.

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

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

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

Step 6: Calculate the expected utility value U_p of the SFMM project p. **Figure 4** shows the utility functions used in this study. The expected utility is calculated from the decision vector $D_p^{q,i}(n)$ and utility functions $u(H_n)$ (from **Figure 4**) as shown in the following equation.

$$U_p = \sum_{n=1}^{N} \beta_{p,n}^{q,i} u(H_n) \tag{19}$$

where $u(H_n)$ is assumed to be equidistantly distributed in the normalized utility range, such that $u(\text{-}E)$=-1.00,$u(\text{-}D)$=-0.80,$u(\text{-}C)$=-0.60,$u(\text{-}B)$=-0.40,$u(\text{-}A)$=-0.20,$u(NC)$=0.00, $u(NI)$=0.00,$u(+A)$=0.20,$u(+B)$=0.40,$u(+C)$=0.60,u($+D$)=0.800,$u(+E)$=1.00

4. Results and discussion

Table 3 shows the degrees of belief $\beta_{p,n}^{q,i}u$ determined using **Steps 1** to **5** in Section 3 and the expected utility estimated using **Equation 18** for Dike-1, Dike2, Channel-1 and Channel-2. These results are similar to the distribution profile in **Figure 2**, but are not exactly the same. For instance, the range band counts of [-A] in **Figure 2** for Dike-1 and Dike-2 are considered the same, while the degree of belief for Dike-2 in **Table 4** is slightly higher than in Dike-1. The difference in the distribution profile between **Figure 2** and **Table 4** can be attributed to the assignment of relative weights $w_{p,q}$ and $w_{p,q,i}$ in the calculation of the probability masses, which contributes to the flexibility of the evidential reasoning approach in terms of defining the relative importance of each environmental component and environmental category in the decision process.

Based on the results in **Table 3**, the degrees of belief of Dike-1 and Channel-2 are distributed from [-C] to [+C], while Dike-2 and Channel-1 are distributed from [-E] to

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[+E]. The domain of the negative range band is dominated by the range band [-A]. This suggests that slight negative change will generally occur for Dike-1, Dike-2, Channel-1 and Channel-2. The domain of the positive range bands, on the other hand, is dominated by [+A] in Dike-1 and Dike-2, while [+B] dominates in Channel-1 and Channel-2. The dominance of [+A] in the dike projects indicates that most of the positive change will only be slightly beneficial, while the [+B] dominance implies that substantial benefits can be obtained from the channelization projects. The distribution of the degrees of belief provides clear insights on the characteristics of the positive and negative domains of the impacts however it is not sufficient to infer the overall characteristics of each SFMM. The overall characteristic of each SFMM, perhaps, can be estimated by determining the expected utility based on the distribution of the degrees of belief. The expected utilities are calculated using **Equation 20**.

The rightmost column in **Table 3** summarizes the expected utility values of each SFMM based on the utility function defined in Section 3. The expected utility of Dike-2 is slightly higher than Dike-1, while Channel-1 is higher than Channel-2.These results imply that Dike-2 is more desirable than Dike-1, while Channel-1 is more desirable than Channel-2. In general the results show that the expected utility of all SFMMs are greater than zero, indicating that the projects are most likely to become beneficial. However, the relatively low expected utility values indicate that the net effect will only be slightly positive. A zero expected utility value would imply that the net environmental effect of a project is the balance between the effects of the positive and negative changes.

Table 3: *Aggregated distributed assessment of the 4 planned structural flood mitigation measures in Metro Manila.*

SFMM	Degree of belief, $\beta_{p,n}^{q,i}$												Expected Utility, U_p
	-E	-D	-C	-B	-A	NC	NI	A	B	C	D	E	
Dike-1	0	0	0.015	0.094	0.262	0.106	0.078	0.182	0.116	0.114	0.033	0	0.0777
Dike-2	0	0.015	0	0.061	0.263	0.138	0.078	0.182	0.115	0.114	0.033	0	0.0889
Channel-1	0	0.014	0	0.069	0.260	0.166	0.168	0.112	0.131	0.079	0	0	0.0268
Channel-2	0	0	0.015	0.073	0.325	0.129	0.137	0.113	0.130	0.079	0	0	0.0095

The result of the EIA of the planned SFMM projects using the evidential reasoning approach provides valuable insights with regards to the characteristics of the overall impacts, as well as its distribution in terms of degrees of belief, which can be very useful in the optimization of project environmental benefits. The use of negative utility values in the utility function provided additional insights as to how the negative impacts generally affect the desirability of a SFMM project. It is however recommended to explore other forms of utility functions to further improve the level of environmental assessment and decision analysis. For instance, risk preferences (i.e. risk-aversiveness and risk-seeking) and decision-maker attitudes (i.e. optimistic and pessimistic) can be taken into

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consideration to have a more holistic view of the environmental benefits for decision analysis.

5. Conclusion

This study explores the application of an evidential reasoning approach as an extension in the environmental impact assessment process for SFMMs in Metro Manila. The evidential reasoning approach was used to determine the distributed assessment of the environmental categories in terms of the degrees of belief on each assessment grade (range band), and calculated the expected utility of each SFMM. The results showed that Dike-2 is more desirable than Dike-1, while Channel-1 is more desirable than Channel-2. The dike projects are generally more desirable than the channelization projects. The results also showed that the expected utility of all SFMMs are greater than zero, which indicates that the projects are most likely to become environmentally beneficial. However, the relatively low expected utility values imply that the net environmental effects will only be slightly positive. In general, the evidential reasoning approach provides flexibility to the RIAM technique by allowing the assignment of relative weights. The adjustment made on the utility function allowed for a more meaningful interpretation of the utility values in terms of the degrees of belief. This in turn gave the means to calculate the expected utility values in terms of the basic definition of positive and negative impacts. A SFMM project that has a negative expected utility value ($U_p < 0$) would indicate that the negative impacts of the project will outweigh its positive impacts, thus should be avoided or re-evaluated. A positive expected utility value ($U_p > 0$), similarly, would indicate that the positive impacts will outweigh the negative impacts, thus can be pursued or further enhanced for higher positive utility. The combination of the RIAM technique and the evidential reasoning approach thus provides a useful alternative in project assessment, especially when evaluating under the context of environmental sustainability. One important potential application of this new approach is in the optimization of the environmental management plan. The expected utility value can serve as a measure that would help further minimize the potential negative impacts, as well as maximize the positive impacts, of planned SFMM projects. This new approach opens more windows for the improvement of the EIA procedures for planned SFMM projects in the Philippines, but may also find application on other types of EIA studies.

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