Development of priority setting process for the small stream restoration projects using multi criteria decision analysis

Jung Pyo Seo, Woncheol Cho and Tae Sung Cheong

ABSTRACT

This study performed a flood risk assessment using one of the multi criteria decision-making methods to identify the small stream basins with high risk of flooding and to determine the optimal small stream restoration measures by priority ranking for flood risk. The 12 representative factors for the flood risk assessment were carefully selected and constructed for the three main aspects, such as pressure factors, state factors and response factors including the government capacities under the pressure-state-response classification system for identifying the 212 small stream watersheds. The entropy weight coefficient method helps to reduce subjective judgments as well as calculate effective weighting coefficients. To evaluate the practical applications of the proposed method, the results from the preference ranking organization method for enrichment evaluation (PROMETHEE) with six preference functions are compared with the official priority ranking of flood risk assessment for the Small Stream Watershed Restoration Projects which is determined by the weighted method. Also, guidelines for the community-based restoration projects such as prevention or preparedness, sustainable development and resilient recovering have been suggested based on the three predicted priority ranking groups. It is expected that the flood risk assessment ranking ensured by full verification can help to establish optimal regional restoration plans against flooding disasters with respect to causes and characteristics of past flash flood.

Key words | flood risk assessment, multi criteria decision-making method, priority ranking, small stream watershed restoration project

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INTRODUCTION

Now, high intensity localized heavy rainfall is increasing in the pacific region which can cause massive flash floods causing enormous damage, especially in small stream watersheds and even in urban areas. Floods depend on precipitation intensity, volume, timing, antecedent conditions of streams and their drainage basins (Collins & Simpson 2007). Human encroachment into flood plains and lack of flood response plans increase the damage potential. Development activity, particularly deforestation and intensive crop production, as well as increasing impervious cover, may drastically change runoff conditions, thereby increasing stream flow during normal rainfall cycles and thus increasing the risk of flooding and soil degradation (Klein 1979; Bannerman *et al.* 1993; Coles *et al.* 2012). Intensive use of the floodplain, even under strict management, usually results in increased runoff rates. Small streams have a high risk for flash floods due to the presence of slopes thus, the rate of down cutting are high and the valley walls are often exposed to bedrock. Those in the mountains and steep narrow valleys generate rapid flowing waters which quickly raises water depths and thus resulting in a reduced evacuation time for residents in affected areas and an increase in damage. In addition, streams such as those in low water crossings, mountains and urban areas rampant with pavement and roof covers have a high risk for flash floods. Flood-related disasters in Korea are classified

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according to several considerations such as location, however, urbanized cities situated within the vicinity of small streams have become more susceptible and vulnerable to flash floods.

Among total streams of 26,595 (62,040 km) in Korea, 84 (3,258 km) are national streams whereas 3,847 streams (26,967 km) are local streams, both covered by the River Law (Han River Flood Control Office 2008). The small streams managed by the Small River Maintenance Act are 22,664 streams (35,815 km) which is 51.2% of the total number of streams. Table 1 shows the number of small streams and restoration ratio performed in each province over 16 years from 1995 to 2010. The mega cities such as Seoul, Jeju, Busan, Ulsan, Gwangju, Incheon, Daejeon and Daegu have a relatively small number of small streams, and provinces such as Jeonra-Buk-do, Gwangwon-do, Jeonra-Nam-do, Chungcheong-Nam-do, Gyunggi-do, Gyeongsang-Nam-do, Chungcheong-Buk-do and Gyeongsang-Buk-do have small streams evenly. The restoration lengths of small streams tasked to the national and metropolitan city government were 3,199 km (98.2%) and 18,417 km (68.3%) respectively while the restoration lengths of small streams tasked to the local government managed was 4,769 km (41.2%). The restoration ratio of small streams managed by local government is not high because the length of these small streams is long. The 14,769 km small streams out of the total length of 35,815 km were restored over 16 years from 1995 to 2012 and the total allocated budget for these projects was almost 310 billion US dollars. The comparative results of damage and expenses of the Small Stream Watershed Restoration Projects (SSWRPs) from 2001 to 2010 demonstrated convincingly that the SSWRPs can help to reduce the flood-related damage in the small stream watersheds (Cheong 2011). Despite its success, existing small streams restoration projects were facing significant resource allocation challenges as well as problems for selecting optimum measures for flood risk reduction considering community needs and available resources. Thus, the priority setting based on the flood risk assessment is needed for decision-making to allocate resources and select optimum community based restoration measures.

Table 1 | The status of the SSWRPs during 16 years from 1995 to 2010

City and province	Stream number	Total length	Restoration ratio
Seoul	13	14.800	10.8
Busan	37	46.600	47.9
Daegu	135	208.60	89.0
Daejeon	78	119.20	67.1
Incheon	118	178.30	61.4
Gwangju	25	49.100	58.4
Ulsan	140	160.70	57.0
Jeju	83	222.90	17.4
Gyeongsang-Buk-do	3821	6851.0	55.8
Chungcheong-Buk-do	2188	3569.8	47.1
Gyeongsang-Nam-do	2949	3463.0	43.9
Gyunggi-do	2224	3245.8	42.0
Chungcheong-Nam-do	2455	3409.3	38.3
Jeonra-Nam-do	3496	5324.8	36.0
Gangwon-do	2427	5652.8	30.2

A priority setting approach based on flood risk assessment can be used for defining the relative importance of the SSWRPs which can be used to protect sensitive watershed resources or restore small stream watersheds for reducing flood risk (Cheong *et al.* 2011; Lee *et al.* 2011). Lim *et al.* (2010) suggested representative factors for the disaster risk assessment constructed by the P-S-R (pressure-state-response) classification system for identifying the watershed. UNISDR (2004) reported that hazards, vulnerabilities and capacity of local communities should be considered for flood-related disaster risk assessment. Substantial progress has been made in the last decade regarding the development of theoretical frameworks and practical strategies to guide and evaluate priority setting on various areas including flood control projects, water and sanitation improvement (Kang & Kim 2006; Choi *et al.* 2013), multi-object dam construction and small stream watershed restoration (Beechie *et al.* 2000; Beechie 2001; Roni *et al.* 2002; Mitton & Donaldson 2003; Gibson *et al.* 2004; Pess *et al.* 2005). Ridgley (1992) used an analytic hierarchy process method to define the ripple effects of drought on the water demand and supply and also presented analytic hierarchy process based on optimal water allocation method for reducing drought damage (Ridgley 1993). Bruen (2002) validates both methods of analytic hierarchy process and multi-attribute utility theory to develop the watershed management decision support system and Jandric & Srdjevic (2000) used an analytic hierarchy process and multi-attribute utility theory to find the optimal location for groundwater storage at NoviSad city in Yugoslavia. Jaber & Mohsen (2001) applied an analytic hierarchy process to find optimal solution on the water supply system. Udías *et al.* (2011) used a multi-objective evolutionary algorithm to identify efficient trade-offs between program of measures cost and water quality for selecting the most effective combinations of sewage treatment technologies.

Various water allocation management problems were analyzed at operational level (Horboe 1992) which are also related to reservoir management (Ko *et al.* 1992, 1994) and in ground water management (Shafike *et al.* 1992; Woldt & Bogardi 1992). For flood disaster management, Akter & Simonovic (2002) used analytic hierarchy process and multi-attribute utility theory to analyze alternatives and make a group decision. Cetinkaya *et al.* (2007) used a dynamic simulation model with its associated databases and a water resources planning and optimization system for water management in a test basin within the scope of the EU-sponsored SMART and OPTIMA projects. Jason *et al.* (2007) used an analytic hierarchy process to establish flood hazard mitigation and emergency preparedness plan in the urban area. The outranking method is also applied for various cases in Europe. Raju *et al.* (2000) used the preference ranking organization method for enrichment evaluation (PROMETHEE) and elimination et choix traduisant la realité (elimination and choice expressing reality) (ELECTRE) to evaluate the possibility of developing irrigation areas on Flumen Monegros in Spain. Also, the PROMETHEE was used for water resources management, optimal flood mitigation plan and priority setting of river restoration (Hyde *et al.* 2004; Maragoudaki & Tsakiris 2005; Hermans *et al.* 2007). Khelifi *et al.* (2006) developed a decision support tool of Credence Clearwater Revival using the PROMETHEE II algorithm to assess the available technologies and select the preferred groundwater remedial options.

In Korea, most of the multi-criteria decision-making methods including PROMETHEE are limitedly applied in operation level but actively used for research purposes. Within these methods, analytic hierarchy process method is widely used in integrated water resources management (Kim *et al.* 2012). Park (2002) applied an analytic hierarchy process method to set the priority of current streams for adjustment of stream grade and enhancement of the efficiency of managing the river. For making decisions on the drought management, a decision tree method was developed (Kim 2001; Kang & Yoon 2002). Korea Water Resources Corporation (2002) and Lee & Shim (2002) used an analytic hierarchy process to determine the weight and priority of water allocation. Kim *et al.* (2009) performed priority setting research to determine the optimal location for development of small hydropower using the analytic hierarchy process method. Recently, Hong *et al.* (2006) performed risk assessment for the water distribution network using both the PROMETHEE and the analytic hierarchy process method. Kim (2006) proposed the new multi-criteria decision-making methods for priority setting of dam construction projects by using an analytic hierarchy process to determine the weights and added ELECTRE as a rank preferred technique. The PROMETHEE method was used for flood inundation risk assessment (Choi 2009) for increasing flood control capacities of the multi-objective reservoirs (Nam 2007) and for priority setting of non-point pollutants management methods (Min 2009). Park *et al.* (2005) and Kim *et al.* (2012) applied a multi-attribute utility theory for priority setting of government-funded research and development projects. However, despite current efforts to create a comprehensive approach for priority setting, there are no single or easy tools that can help government officials to evaluate SSWRPs and therefore guide them to select optimal measures for flood-related disaster risk reduction.

In this study, the 12 representative factors for flood risk assessment are carefully selected and constructed for the three main aspects under the pressure-state-response (P-S-R) classification system for identifying 212 small stream watersheds. The entropy weight coefficient method is used to determine unbiased weight of criteria. The official priority ranking on the SSWRPs is predicted by the weighted method. The priority ranking of the flood risk assessment estimated by the PROMETHEE with six alternative preference functions are compared with the official values to select best preference function. The priority ranking estimated by the proposed method are divided into three groups such as low priority group for prevention or preparedness projects, middle priority group for sustainable development project and high priority group for resilient recovering projects which can be used for decision-making to find local adapted SSWRPs for protecting sensitive watershed resources or restoring small streams. Also, this will serve as guidelines to establish measures for reducing flood-related damage due to localized heavy rainfall and massive flash flooding.

FEATURES AND CURRENT ISSUES ON THE SSWRPS

In Korea, the main goal of the SSWRPs is to recover stream channels to its natural states by means of sustaining hydraulic stability in the banks and streambeds as well as securing that the channels have enough capacity to transport and utilize its sediment and debris effectively. However, an extensive understanding of how ecosystems have changed according to possible alternates of restoration projects (Parker 1997; Beechie *et al.* 2000; Ehrenfeld 2000) and deep consideration of the major needs of the local communities (Ebersole & Liss 1997) are important for successful SSWRPs. Furthermore, changing of geographical features and channel shapes due to frequent local damage caused by flooding, sediment transport or urban development should be considered in the small stream restoration plans.

To reduce flood damage in the small stream watersheds, the Korean government legislated the Small Stream Development Act and has performed SSWRPs since 1995. The National Emergency Management Agency, Korea, established the master plan for the SSWRPs every year for the flood-related disaster risk reduction and resilient recovery. The main goals of watershed restoration projects includes rebuilding the channel banks or buying the land in the damaged areas along the stream. Since 2005, small stream restoration project types have been changing in order to cope with environmental changes as presented in Table 2. Despite the government efforts on watershed restorations, numerous stream and watershed restoration projects have failed to accomplish all their objectives, except for reducing flood damage (Cheong *et al.* 2011). However, the small stream restoration plans do not represent recent extreme disasters caused by localized heavy rainfall, massive flash flooding and current social and environment changes. Each failure has various causes such as: (i) damage of the natural environment due to channel maintenance, aggregate extraction, floodplain development; (ii) lack of animal and flora survey; (iii) adverse effect on ecosystems caused by sediment outflow during restoration; (iv) inconsistent small stream restoration between downstream and upstream areas; (v) disconnection of ecosystem by submerged weir and drop structures; (vi) simplification habitat for aquatic organisms and increased erosion due to the river straightening and riverbed flattening; (vii) lack of monitoring data such as water surface elevation and flow discharge for stream runoff analysis; (viii) insufficiency of water pollution reduction measures; (ix) lack of guidelines for more appropriate budget allocation for the SSWRPs; and (x) impaired flood control functions in downstream areas by basin or watershed units of a comprehensive disaster prevention restoration rather than prevention-oriented upstream restoration.

Table 2 | Brief description of three general strategies for prioritizing small stream restoration actions

Strategy	Periods	General description
Embankment Facility Restoration	1995–1999	• Focus on structural changes to prevent river bank • Lost original characteristics of natural streams by concrete embankment • Increase flood risk in downstream by changes in straight channel shape • Disconnect ecosystem by high cutting bank slope or retaining wall • Disharmonize with surrounding landscape by excessive changing channel pattern and geography
Landscape Facility Restoration	2000–2004	• Focus on development of environmental friendly natural stream • Prevent pool-riffle structures in the channel • Use eco-friendly material such as wood, grass, stone, clay and other natural materials • Water as nature-friendly appearance, while very limited habitat features
Eco-river Facility Restoration	2000–2004	• Use natural materials and prevent natural river sinuosity • Provide only part of the ecosystem as habitat • Lack of considering ecological characteristics of upper, middle and down parts in the small stream

Flood risk assessment results defined by priority ranking can support decision-making to allocate limited resources and select optimum small stream restoration projects fulfilling goals of SSWRPs and solve problems caused by many of the reasons listed above. The priority setting based on the flood risk assessment provides a useful tool to reduce indiscriminate projects and lead effective watershed restoration projects for protecting sensitive watershed resources and reducing flood-related damage due to localized heavy rainfall and massive flash flooding. For example, if a small stream in a mountainous or rural area has a low priority ranking on the flood risk assessment, building embankments to prevent high water from flooding the bordering land is sublated and diversity such as buying the agricultural lands along the stream to storage flood water is preferred for flood control on the small streams. The adaptable guideline is also needed for selecting more urgent or optimum restoration projects among various alternates of SSWRPs submitted by local governments. It is also expected that priority ranking can support the local government to establish optimal regional rehabilitation plans against flooding disasters with respect to the causes and characteristics of past floods and major needs of the local communities. Now, there is no flood related damage in small streams of urban areas because the restoration ratio of the small streams managed by the metropolitan city government is almost 70%. Thus guidelines are needed to provide a more appropriate budget allocation for SSWRPs to reduce flood related damage in small streams managed by local government and to increase the flood related disaster management capacity of local government.

MULTI CRITERIA DECISION ANALYSIS (MCDA) MODELLING ON THE SSWRPS

MCDA is aimed at supporting decision makers faced with evaluating alternatives taking into account multiple, and often conflictive, criteria. The MCDA process consists of the following phases: problem identification and structuring, model building and use; and the development of action plans. MCDA modelling consists of four key elements: (1) the alternatives to be appraised; (2) the criteria (or attributes) against which the alternatives are appraised; (3) scores that reflect the value of an alternative's expected performance on the criteria; and (4) criteria weights that measure the relative values of each criterion as compared to others. For the priority setting of the SSWRPs based on flood risk assessment, a set of criteria was established to evaluate the needs of community, environmental effects and benefit of each small stream region. Evaluation criteria were determined by qualitative method to represent small stream characteristics such as: (i) reviewing existing river restoration plans developed by Ministry of Land, Transport and Marin Affairs (MLTM); (ii) discussion with government experts; (iii) deep consideration; and (iv) data availability. To minimize redundancy, some attributes such as two criteria should provide the same or very similar concepts or measures excluding the objectives. MLTM (1999) selected criteria such as: (i) the characteristics of the prone areas; (ii) the frequency of the flood-related damage; (iii) causes of damage; and (iv) the benefit to set the priority of the river restoration project on improving the flood prone area. MLTM (2005) also developed additional guidelines in selected criteria such as regional characteristics, frequency of past flooding, flood risk analysis and economic dimensions (benefit-cost ratio). The evaluation criterion shown in Table 3 was used to determine the priorities of the river restoration projects according to the river master plans.

To solve the multi criteria problem on the SSWRPs priority setting based on flood risk assessment, the 12 representative factors were carefully selected and constructed. Detailed hierarchical structure for priority setting for the flood risk assessment were categorized such as: (i) number of poor facilities; (ii) number of disasters during past five years; (iii) total damage during past five years; (iv) type of damage; (v) watershed area; (vi) ratio of residential area to total watershed area; (vii) channel slope; (viii) restoration ratio of the restoration channel length to total channel length; (ix) number of residents; (x) waterfront revitalization area; (xi) number of public facilities; and (xii) establishment of master plan. For criteria evaluation analysis, 212 small streams data were collected from all stream watersheds of Korea, specifically 38 streams data from Gangwon-do, 65 streams data from Gyeongsang-Buk-do including three of Daegu, 41 streams data from Gyeongsang-Nam-do, 37 streams from Jeonra-Buk-do and 30 streams from Chungcheong-Buk-do. These small streams have a length

Table 3 | The priority of the river restoration project on improving the flood prone area

Evaluation criteria	Generalized criterion 1	2	3	4	5	Weighting factor (%)
Location	Mountainous	Agricultural	Rural	Small urban	Urban	10
Completeness of restoration	Complete	Almost	Half	A little	Incomplete	15
Existing facilities condition	Very good	Good	Fair	Poor	Very poor	15
Future planned facilities	Nothing	A few	Small	Many	So many	10
Flooding damage during past 10 years	0	1–2	3–4	5–6	>7	20
Civil complaint during past 10 years	Nothing	A few	Occasionally	Sometime	Frequent	20
Years after the river master plan	10 years	12 years	13 years	14 years	15 years	10

distribution between 65,011,080 m with an average length of 3,851 m. The statistical values, such as the minimum, mean and maximum values of each criteria indicator collected in provinces, are listed in Table 4. The 12 evaluation criteria were constructed for the three main aspects, such as PF (pressure factors), SF (state factors), and RF (response factors including the capacities of local government) under the P-S-R classification system for identifying the SSWRPs.

This study used rating the relative priority of the criteria divided by five scale sections from 1 (equal importance) to 5 (extreme importance) to determine the priority ranking of the flood risk assessment for the SSWRPs. Each scale section was divided due to the normal distribution of each criteria for all the attributes of each alternate shown in Table 5. The weight was determined by an entropy weight coefficient method followed by the procedure presented in Figure 1 to determine the unbiased weight of the criteria. The entropy weight coefficient method, in which weights are determined by attributes information only to avoid distorted assessment by subjective opinion of decision-makers, can be used for multi-criteria decision-making cases including various attributes and many alternates. This method sets the attribute matrix of alternates to calculate entropy from normalized attributes and then determine the weight of criteria. The results of the comparison of weights of all four categories were determined to be 0.401, 0.299, 0.195 and 0.105 for the disaster risk as a pressure factor, watershed characteristics as a state factor, restoration project benefits and establishment of master plan as a response factor, respectively. Based on the comparative results of the weights, factors regarding disaster risk were highly prioritized by SSWRPs rather than environmental or ecological factors. The responses were checked with a consistency index to obtain the weight for each criterion. The response on the consistency index was returned to the respondents for cross-checking answer the questions reasonably. Evaluation criteria was classified to give high weight on the flood-prone areas or the areas with an urgent need for restoration and low weight on the small stream watershed areas located in the mountainous and rural regions. If the SSWRP was planned for buying farmland to use for the floodplain, connected to the national river, and is established for the flood risk reduction plan and, flood damage recovery, a high priority will be given.

The objective of the multi criteria decision is as follows:

$$\text{maximize } \{f_1(a), f_2(a), \ldots, f_j(a), \ldots, f_k(a) | a \in A\} \quad (1)$$

where A is a finite set of n alternates and f_1 to f_k are k criteria, $f_j(a)$ is the evaluation of alternate a on criterion f_j. In order to achieve this objective, it is essential to have some information about the preferences and the priorities of the decision-maker. The two different MCDA approaches of the weighted method and the PROMETHEE approach are applied to demonstrate the potential advantages and pitfalls of using the different MCDA modelling approaches. A very common way to solve multi-criteria decision-making is to compute a weighted sum of the evaluations as $V(a) = \sum_{j=1}^{k} w_j f_j(a)$ where $w_j > 0$ is the weight allocated to criterion f_j, $V(a)$ is the resulting score of alternate a. This weighted method has several limits for the following reasons: (i) bad evaluation on one criterion can always be compensated by better values on other criteria; (ii) the weights of the criteria are linked to the scales of

Table 4 | Statistical chart of criteria collected from small steam watersheds in Korea

						C6									
Region	**Statistics**	**C1**	**C2**	**C3**	**C5**	**Paddy**	**Farm**	**Forest**	**Site**	**Residential**	**C7**	**C8**	**C9**	**C10**	**C11**
Gang won-do	Mean	15	2	0.1940	6.99	9.46	7.82	78.8	1.64	4.60	0.0571	56.5	68	22.82	3
	Max.	39	5	0.6880	30.9	25.2	14.1	90.0	5.20	8.90	0.2865	100	482	171.5	8
	Min.	1	1	0.0010	0.70	0.04	0.07	57.1	0.10	0.18	0.0084	14.5	2	0.200	1
Gyeong sang-Buk-do	Mean	17	3	3.7200	7.28	15.9	6.85	71.0	3.25	4.85	0.0609	32.5	84	16.97	6
	Max.	64	8	25.790	41.1	58.9	16.9	96.3	15.1	15.6	0.3300	80.0	570	66.25	17
	Min.	1	1	0.0280	0.76	0.62	0.31	16.2	0.50	0.94	0.0055	0.80	2	1.000	1
Gyeong sang-Nam-do	Mean	12	4	108.28	28.6	18.9	7.41	68.1	4.38	3.65	0.0384	59.6	137	17.27	3
	Max.	38	9	106.72	1028	42.5	18.3	89.1	12.6	7.80	0.1429	100	1141	104.0	6
	Min.	2	1	0.0023	0.39	3.70	0.60	33.7	0.52	0.10	0.0019	0.7	17	0.210	1
Jeonra-Buk-do	Mean	11	3	106.32	3.24	19.0	8.19	62.3	4.79	8.09	0.0568	67.2	121	52.57	9
	Max.	29	7	655.29	9.95	50.0	27.7	86.2	19.9	26.4	0.2282	100	795	211.0	47
	Min.	1	2	0.1642	0.44	5.47	2.99	16.0	0.38	1.02	0.0058	35.5	17	0.260	2
Chungcheong-Buk-do	Mean	16	4	0.1236	4.50	16.5	13.3	64.2	4.44	8.35	0.1871	53.8	89	52.41	2
	Max.	41	15	0.3583	11.3	43.0	39.6	82.0	8.76	40.0	0.8839	100	292	296.0	6
	Min.	3	1	0.0075	0.98	3.00	2.90	13.6	0.04	1.68	0.0110	14.5	10	1.570	1
Total	Mean	19	4	10.416	66.2	22.5	11.8	58.9	6.01	8.81	0.1358	54.4	255	67.61	8
	Max.	64	15	106.72	1028	58.9	39.6	96.3	19.9	40.0	0.8839	100	1141	296.0	47
	Min.	1	1	0.0013	0.39	0.04	0.07	13.6	0.04	0.10	0.0019	0.7	2	0.200	1

Table 5 | The indicators, subindicators and criteria to set the priority of the SSWRPs

			Generalized criterion					
Evaluation criteria			**1**	**2**	**3**	**4**	**5**	**Weight**
Pressure factors	Number of poor facilities	C1	– 1	2–10	11–20	20–30	31	0.10
	Number of disasters during past 5 years	C2	0	1	2 ~ 3	4–5	6	0.10
	Total damage during past 5yrs (M$)	C3	0	0.1–0.5	0.6–5	6–50	51	0.10
	Type of damage	C4	Agricultural land inundation (AI)	Agricultural land lost (AL)	House inundation (HI)	House lost (HL)	Public facilities damage	0.10
State factors	Watershed area (km^2)	C5	0–1.0	1.1–2.0	2.1–5.0	5.1–8.0	8.1	0.05
	Residential area Ratio[a]	C6	0–20%	21–40%	41–60%	61–80%	81–100%	0.15
	Channel slope	C7	– 0.100	0.101–0.070	0.071–0.040	0.041–0.010	0.011–0.000	0.05
	Restoration ratio[b]	C8	0–20%	21–40%	41–60%	61–80%	81–100%	0.05
Response factors	Number of residents	C9	0–10	11–40	41–80	81–160	161	0.05
	Waterfront revitalization area (ha)	C10	0–1.0	1.1–5.0	5.1–10.0	10.1–50.0	50.1	0.10
	Number of public facilities	C11	0	1–2	3–4	5–7	8	0.05
Others	Establishment of master plan	C12	–	Unfinished master plan (U)	Finished master plan (P)	Ongoing project (O)	Last year project (L)	0.10
Total								1.00

[a] Residential area : residential area/total watershed area

[b] Restoration ratio : restoration length/total channel length.

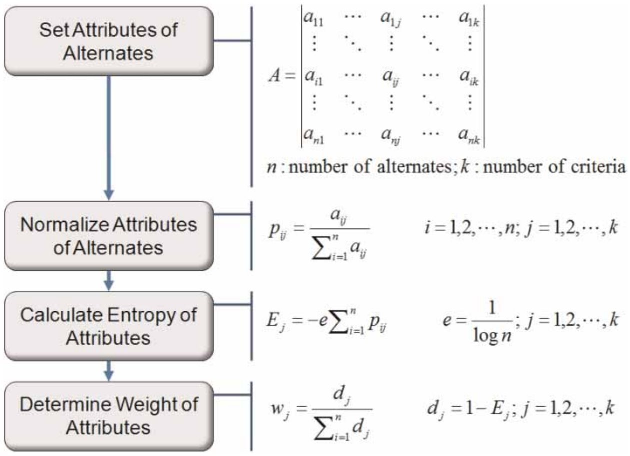


Figure 1 | Concept diagram of the entropy weight calculation procedure.

measurement of the criteria in a way that is difficult to manage; and (iii) for reducing an alternate to a single score, a lot of information should be lost about the conflicts among the criteria. For this reason, Roy (1991) proposed to build outranking relations including only realistic enrichments of the dominance relation.

The PROMETHEE method is an outranking method based on the principle of pairwise comparison of the attributes. In this model, the weighting vector W represents the relative importance of k criteria for the problem. The decision matrix X represents the performance ratings a_{ij} of alternates A_i with respect to criteria f_j. Given the weighting vector W and decision matrix X, the objective is to rank or select the alternatives by giving each of them an overall preference value with respect to all criteria shown in Figure 2. The decision maker perceives the measurement scale of the criterion in order to make a model, the PROMETHEE method, however, requires associating a preference function to each criterion as $P_j(a, b) = F_j\left[d_j(a, b)\right] \forall a, b \in A$ in which $d_j(a, b) = f_j(a) - f_j(b)$ and for which $0 \le P_j(a, b) \le 1$. To maximize a criterion, this function is giving the preference of a over b for observed deviations between their evaluations on criterion $f_j(\cdot)$. The six types of preference functions presented in Table 6 (Brans & Mareschal 2005; Podvezko & Podviezko 2009) can be used to predict priority ranking.

For pairwise comparison of more than two criteria with a given weight, preference indices are as follows:

$$\pi(a, b) = \sum\nolimits_{j=1}^{k} w_j P_j(a, b) \tag{2}$$

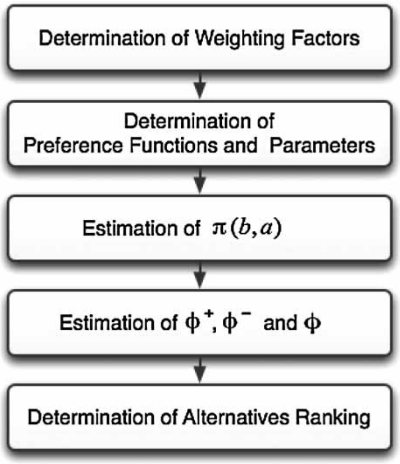
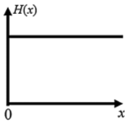
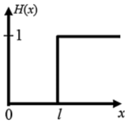
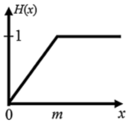
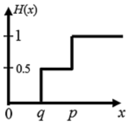
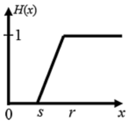
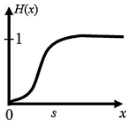


Figure 2 | Concept diagram of the PROMETHEE procedure.

Table 6 | Six types of preference functions for the PROMETHEE method

Types	**Function**	**Shape**
Type I (Usual)	$H(x_j) = \begin{cases} 0, & x_j \le 0 \\ 1, & x_j \ge 0 \end{cases}$	
Type II (U-shape)	$H(x_j) = \begin{cases} 0, & x_j \le l \\ 1, & x_j \ge l \end{cases}$	
Type III (V-shape)	$H(x_j) = \begin{cases} \frac{x}{m}, & x_j \le m \\ 1, & x_j \ge m \end{cases}$	
Type IV (Discrete)	$H(x_j) = \begin{cases} 0, & x_j \le q \\ 1/2, & q < x_j \le p \\ 1, & x_j > p \end{cases}$	
Type V (Linear)	$H(x_j) = \begin{cases} 0, & x_j \le s \\ (x - s)/r, & s < x_j \le r \\ 1, & x_j > r \end{cases}$	
Type VI (Gaussian)	$H(x_j) = \begin{cases} 0, & x_j \le 0 \\ 1 - e^{-\frac{x_j^2}{2\sigma^2}} & x_j \ge 0 \end{cases}$	

$$\pi(b, a) = \sum\nolimits_{j=1}^{k} w_j P_j(b, a) \tag{3}$$

where in the expression $\pi(a, b)$ degree a is preferred to b over all the criteria and in $\pi(b, a)$ b is preferred over a. In most cases, there are criteria for which a is better than b, and criteria for which b is better than a. Consequently, $\pi(a, b)$ and $\pi(b, a)$ are usually positive. If $\pi(a, b) \approx 0$, a weak global preference of a over b is implied, and if $\pi(a, b) \approx 1$, a strong global preference of a over b is implied. As each alternate a is facing $n - 1$ alternates in A, the positive outranking flow, φ^+ and the negative outranking flow, φ^-, can be calculated by using the following equations

$$\varphi^+(a) = \frac{1}{n-1}\sum_{x\in A}\pi(a, x) \tag{4}$$

$$\varphi^-(a) = \frac{1}{n-1}\sum_{x\in A}\pi(x, a) \tag{5}$$

The positive outranking flow expresses how an alternate is outranking the others. The PROMETHEE I use partial ranking (P^I, I^I, R^I) obtained from the positive and the negative outranking flows. P^I, I^I, R^I are variables for preference, indifference and incomparability, respectively

$$aP^I b \text{iff} \begin{cases} \varphi^+(a) > \varphi^+(b) \quad \text{and} \quad \varphi^-(a) < \varphi^-(b) \quad \text{or} \\ \varphi^+(a) = \varphi^+(b) \quad \text{and} \quad \varphi^-(a) < \varphi^-(b) \quad \text{or} \\ \varphi^+(a) > \varphi^+(b) \quad \text{and} \quad \varphi^-(a) = \varphi^-(b) \end{cases} \tag{6}$$

$$aI^I b \text{iff} \ \ \varphi^+(a) = \varphi^+(b) \quad \text{and} \quad \varphi^-(a) = \varphi^-(b) \tag{7}$$

$$aR^I b \text{iff} \begin{cases} \varphi^+(a) > \varphi^+(b) \quad \text{and} \quad \varphi^-(a) > \varphi^-(b) \quad \text{or} \\ \varphi^+(a) < \varphi^+(b) \quad \text{and} \quad \varphi^-(a) > \varphi^-(b) \end{cases} \tag{8}$$

For complete ranking, the PROMETHEE II uses the net outranking flow as $\varphi(a) = \varphi^+(a) - \varphi^-(a)$. It is the balance between the positive and the negative outranking flows. The higher the net flow, the better the alternate, such as $aP^{II} b\text{iff}\varphi(a) > \varphi(b)$ and $aI^{II} b\text{iff}\varphi(a) = \varphi(b)$. $\varphi(a) > 0$ indicates that a is outranking all the alternates on all the criteria, however, if $\varphi(a) < 0$, others are more outranking than a. The complete ranking is easy to use, but the analysis of the incomparability often helps to finalize a proper decision. As the net flow $\varphi(\cdot)$ provides a complete ranking, it may be compared with a utility function. One advantage of $\varphi(\cdot)$ is that it is built on clear and simple preference information and that it relies on comparative statements rather than absolute ones.

RESULTS

Official priority ranking predicted by the value measurement model

The priority of alternatives for selecting optimum SSWRPs was determined by a weighted method in which the priority ranking was calculated by multiplying the weight and scale section values determined from attributes of alternates. For the analysis, attribute information of 93 SSWRPs applied from local government in 2012 were collected which were specifically composed of 16 from Gangwon-do, 26 from Gyeongsang-Buk-do including three of Daegu, 25 from Gyeongsang-Nam-do, 11 from Jeonra-Buk-do and 15 from Chungcheong-Buk-do. The predicted results of priority ranking officially determined by the weighted method showed that A01 has the highest priority with net outranking flow of 0.4712 which mean that this stream is urgently needed for small stream watershed restoration followed by A13, A24 and A52, while A54 was the lowest priority with a net outranking flow of – 0.4296. Among the alternates, 42 small streams have positive net outranking flow and 51 small streams have negative net outranking flow. For comparison between the evaluation criteria and the net outranking flow values predicted by the weighted method, the alternates were divided into three groups: the upper rank group with the net outranking flow values from 0.2503 to 0.4712, the middle rank group with the net outranking flow values from 0.0108 to 0.2467 and the lower rank group with the net outranking flow values from – 0.4296 to – 0.0032 as shown in Table 7. To define the main criteria affecting the priority setting of the SSWRPs, correlation coefficients of each criteria to the net outranking flow values were calculated and listed in Table 8. The results show that the number of poor facilities (C1), type of damage (C4) and establishment of master plan (C12) were significantly correlated with the priority setting in the upper and middle rank groups. In the lower group, the number of disasters during the past five

Table 7 | Categorization of alternates for comparison between the evaluation criteria and the net outranking flow values

Group	Net outranking flow	Alternatives
Upper rank	Positive (+)	A01, A13, A24, A52, A50, A30, A33, A22, A21, A18, A23, A35, A62, A55, A31
Middle rank	Positive (+)	A49, A87, A76, A93, A32, A70, A43, A26, A51, A46, A27, A28, A07, A08, A11, A69, A68, A59, A75, A72, A42, A80, A84, A64, A67, A65, A57
Lower rank	Negative (−)	A74, A88, A53, A73, A90, A82, A03, A47, A34, A02, A10, A16, A05, A81, A77, A78, A61, A85, A36, A25, A15, A45, A37, A17, A19, A40, A38, A04, A09, A39, A41, A89, A86, A92, A44, A48, A20, A29, A66, A56, A79, A06, A91, A58, A83, A71, A60, A63, A14, A12, A54

years (C2), total damage during the past five years (C3), watershed area (C4) and restoration ratio (C8) were correlated with priority setting of SSWRPs.

Priority ranking predicted by the outranking approach

This study used PROMETHEE to evaluate the given criteria in the process of determining the investment priorities, the positive outranking flow, φ^+, the negative outranking flow, φ^- and the net outranking flow as φ were calculated. The PROMETHEE uses preference indices for pairwise comparison of more than two criteria with given weight. Preference indices determined by Equations (2) and (3) with predetermined weights, preference functions and criteria were all calculated. For predicting priority ranking by the PROMETHEE, entropy weight coefficient method was also used to determine unbiased weight of the criteria. The estimation results of weights for the application of the PROMETHEE show that the residential area ratio (C6) had the highest value of 0.167 and the total damage during the past five years (C3) had 0.108 and both of the waterfront revitalization area (C10) and the establishment of master plan (C12) had 0.105. To determine the preference function of PROMETHEE, the characteristics of each attributes should be considered. The specific property of indicator consists of attributes represented by six types of distribution: Usual, U-shape, V-shape, Discrete, Linear and Gaussian distributions as shown in Table 2. To verify the present approach, the official priority ranking on the flood risk assessment for the SSWRPs from the weighted method are also compared with the values simulated with the PROMETHEE with six preference functions as shown in Figure 3. The predicted ranking of the PROMETHEE with Gaussian preference function (Type VI) clearly predicts the official priority ranking. This is in contrast to the usual preference function (Type I) which seems to overestimate the official priority ranking. The PROMETHEE predictions with four types of preference functions (Types II–V) are also in good agreement with the priority ranking obtained by the weighted method. For comparison between the evaluation criteria and the net outranking flow values estimated by the PROMETHEE with Gaussian preference function, the net outranking flow values of 93 alternates were plotted as shown in Figure 4. The results of priority ranking predicted by the PROMETHEE with Gaussian preference function show that A02 have the highest priority which mean that this stream is urgently needed for small stream watershed restoration followed by A11, A22 and A68, while A59 was the lowest priority as shown in Figure 4.

Table 8 | The correlation coefficient of each criteria to the net outranking flow values

	Correlation coefficient											
Group	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12
Upper rank	0.632	0.284	0.363	0.483	0.054	0.325	0.019	0.270	0.291	0.408	0.239	0.615
Middle rank	0.314	0.396	0.254	0.695	0.147	0.102	0.033	0.007	0.041	0.198	0.236	0.024
Lower rank	0.145	0.443	0.435	0.420	0.096	0.008	0.150	0.495	0.003	0.398	0.181	0.162

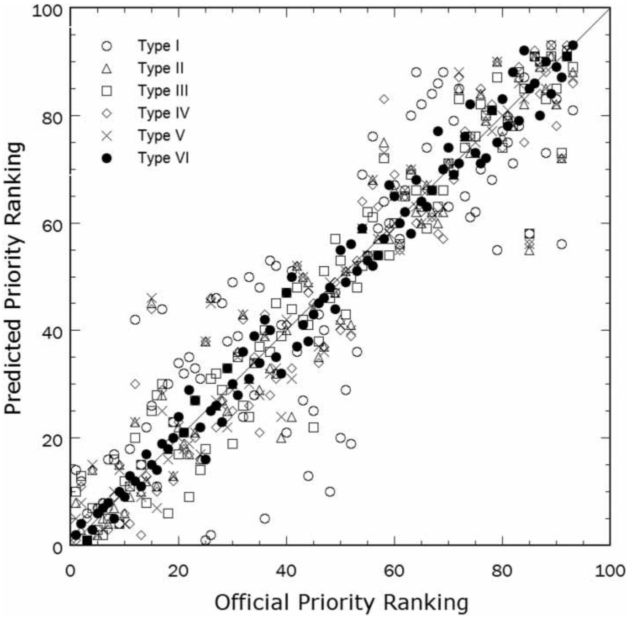


Figure 3 | Comparisons of determined priority ranking based on flood risk assessment with official ranking data used in verification.

Evaluations of multi criteria decision approaches on the SSWRPs

To evaluate the difference between the official and the predicted values of the flood risk assessment priority ranking more quantitatively, the discrepancy ratio defined by Cheong & Seo (2003) was used as a measure of error

$$Dr = \log \frac{R_P}{R_O} \tag{9}$$

in which Dr is the discrepancy ratio, R_P is the predicted value and R_O is the official value. If the discrepancy ratio is 0, the predicted value is identical to the official values. If the discrepancy ratio is larger than 0, the predicted value is overestimated and if the discrepancy ratio is smaller than 0, the predicted value is underestimated Accuracy is defined as the proportion of numbers for which the discrepancy ratio is between -0.05 and 0.05 for the total number of data. Figure 5 shows the histogram of discrepancy ratios for the proposed method used in the analysis of the 93 official priority ranking set. The discrepancy ratio distributions for the proposed method with Gaussian function presented a range of values between -0.3 and 0.3. The accuracy of the proposed method with the usual preference function was 35%, with the u-shape preference function as 60%, v-shape preference function as 57%, discrete preference function as 53%, and linear preference function as 61%, while that of the proposed method with the Gaussian preference function at 73%. Overall, the accuracy of the proposed method with the Gaussian preference function was the highest amongst all preference functions tested.

Development of the guideline for selecting the optimum SSWRPs

The small stream restoration projects are facing challenges regarding resources allocation and also selection of optimum measures on how to reduce flooding risk in their watershed areas. Flood risk assessment results defined by priority ranking of the SSWRPs could help decision-makers for planning future disaster risk reduction projects and to design future

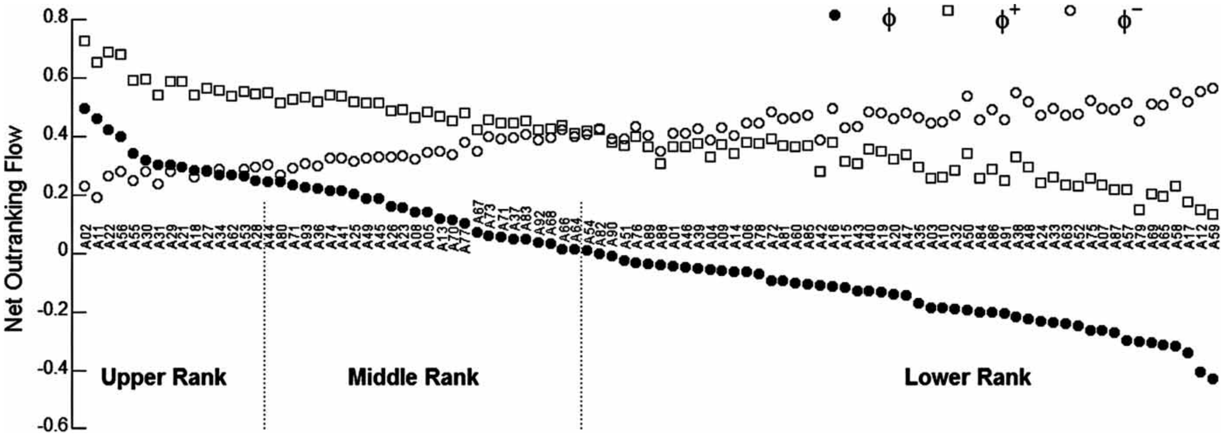


Figure 4 | **The** results of the investment priorities, the positive outranking flow, the negative outranking flow and the net outranking flow.

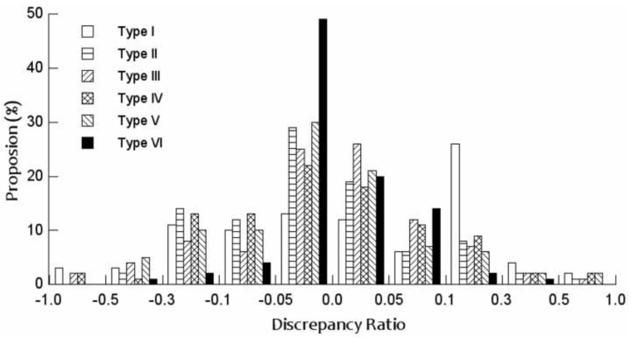


Figure 5 | Comparison of discrepancy ratios of the PROMETHEE with six preference functions for official priority ranking used in verification.

SSWRPs coping with extreme events such as flash floods and localized heavy rainfall. Efficiency of the priority setting of flood risk assessment could be evaluated by considering the following: (i) whether priority setting has an improved capacity for making decision on the cost- and environment-effective small stream restoration measures; and (ii) whether stakeholders and decision-makers felt that the priority setting process provided the needs of the community on resilient recovering and sustainable development. In this study, the optimal restoration project guideline was developed based on the priority ranking predicted by PROMETHEE with Gaussian preference function for decision-making in which alternates were divided into three ranking groups such as the upper rank, the middle rank and the lower rank as shown in Figure 4. To make a decision on the optimal SSWRPs, the decision-maker can select one management option among prevention or preparedness, sustainable development and resilient recovery by predicting the priority ranking and then determine the optimum restoration measure listed in Table 9. The guideline can be used to rebuild the small streams to be in harmony with the natural environment and to prepare the floodplain to minimize future flood damage and to maximize natural stream habitat. This guideline can also help the government and the community in their decision-making regarding the protection of the sensitive watershed by means of floodplain or restoration of small stream watersheds for reducing flood risk. Reducing the embankment facility-oriented restoration project and increasing the landscape facility restoration project as well as the eco-river facility restoration project are some of the expected outcomes of this guideline.

CONCLUSIONS

Flood-related disasters on small streams caused by high intensity localized rainfall and flash floods has been continuously increasing, especially in residential areas. Recent survey results showed that the SSWRPs, as one of the disaster risk reduction measures, could contribute to reduce flood-related damage in small streams. However, the existing restoration plans did not develop good responses in terms of extreme disasters and current social and environment changes due to geographical and physical features of stream channels like flooding, sediment transport or urban development. Furthermore, the SSWRPs were facing significant resource allocation challenges as well as problems for the selection of optimum measures for flood risk reduction considering community needs such as prevention or preparedness, sustainable development, resilient recovery and available resources. Flood risk assessment results defined by priority ranking can be used for decision-making to allocate resources and select optimum community based restoration measures. The 12 representative factors for the flood risk assessment are carefully selected and constructed for the three main aspects under the P-S-R classification system for identifying the 212 small stream watershed. The entropy weight coefficient method is also applied to calculate the weight of flood risk factors in order to reduce subjective judgments on the effects of the weight coefficients. The weighted method was used to predict the official priority ranking based on the flood risk assessment of 93 SSWRPs and the PROMETHEE with six preference functions was used here to validate predicted results with official values. To evaluate the practical application of the PROMETHEE for identifying

Table 9 | Guideline for the restoration measures for the flood related disaster risk management

Group	Upper rank	Middle rank	Lower rank
Management	Resilient recovering	Sustainable development	Prevention/preparedness
Restoration	Ecology, community stream	City, culture and theme stream	Channel and bank restoration
Measures	Purchase of lands for floodplain	Establishment of artificial park area	Bridge reconstruction

the flood prone area, the results with six preference functions are compared with official priority ranking predicted by weighted method. The predicted priority ranking from the PROMETHEE with Gaussian preference function clearly predicts quite well the official priority ranking while the usual preference function overestimates the official values. The accuracy of the proposed method with the Gaussian preference function is the highest amongst all preference functions tested. Also the optimal restoration guideline for decision-making such as prevention or preparedness, sustainable development and resilient recovering has been suggested by the determined three priority ranking groups. The guideline can be used to rebuild the small streams to be in harmony with the natural environment and to establish the floodplain to minimize future flood damage and to maximize natural stream habitat. It is expected that the flood risk assessment ranking ensured by full verification can support the optimal regional rehabilitation plans against flooding disasters with respect to the causes and characteristics of past floods. The procedures in this study can be used to establish evaluation criteria considering the weights in the decision-making process for similar projects using various alternates in small stream watershed restoration.

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