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Urban debris flow vulnerability map: an application to the metropolitan cities in Korea

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ABSTRACT

This study is a follow-up study of Park et al. [1] and aims to produce urban debris flow vulnerability maps of metropolitan cities in Korea. While the previous study has limitations that can assess the relative vulnerability of a single city, this study is possible to compare and assess the urban debris flow vulnerability of many metropolises. Target areas are Busan, Daegu, Daejeon, Gwangju, Incheon, Seoul, and Ulsan. The vulnerability of metropolitan cities is evaluated with the same criteria and is represented by using a single index value. The vulnerability is classified into five classes (most vulnerable, more vulnerable, moderate, less vulnerable, and least vulnerable) by using the Jenks optimal algorithm. Finally, urban debris flow vulnerability maps for seven metropolises are produced, and the relative vulnerability assessment is performed between each of metropolises. Also, this study investigated the influences of physical vulnerability and socioeconomic vulnerability through clustering of debris flow disaster vulnerability grades. Its result can be used to decide policy direction for debris flow prevention measures. When the physical vulnerability is relatively high and socioeconomic vulnerability is relatively low such as vulnerability assessment results of Seoul, the disaster prevention project reducing the damage of debris flow disasters should be preferentially carried out for the structural measures. On the other hand, if the physical vulnerability is relatively low and socioeconomic vulnerability is relatively high, non-structural measures should be performed to reduce the damage of debris flow disasters.

Keywords: Debris flow; Metropolis; Physical vulnerability; Socioeconomic vulnerability

1. Introduction

In South Korea, about 70% of the country is made up of mountains. This has led to many studies on landslides for a long time. Studies have been carried out to evaluate the possibility of landslide occurrence using physical characteristics of soil and climate and to prepare measures against it [2–4]. However, in 2011, landslides occurred at Mt. Woomyeon which is located in Seocho-gu, Seoul, resulting in enormous loss of life and property in downtown areas and roads. Mt. Woomyeon landslide changed the research paradigm from studies predominantly predicting the occurrence of landslide disasters and preparing structural countermeasures to studies investigating the effect of urban area resulted from landslide disasters.

The vulnerability is defined as the degree or possibility of human and social structural damage that can be caused by a disaster, and many studies have been conducted with this concept [5–8]. Looking at vulnerability assessments applied to

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domestic or foreign countries, vulnerabilities are evaluated in a single city or nationwide. However, in the case of disasters that occur in a relatively local range, such as a landslide disaster, vulnerability assessments should be performed on a smaller scale [9,10]. Park et al. [1] carried out physical vulnerability and socioeconomic vulnerability estimation for the Seoul metropolitan area and combined them to evaluate the urban vulnerability of debris flow disasters reflecting the social characteristics of the city using the spatial scale of the census-output unit (COU) which is the minimum spatial resolution that can be obtained formally. The COU was created by the Korea National Statistical Office. The spatial size of the COU is determined on the basis of about 500 inhabitants. Socioeconomic homogeneity is also reflected in the COU division.

The results of these vulnerability assessments can be displayed on maps through various visualization techniques and can be used as a basis for decision making for the mitigation of debris flow disasters. This study considered several features in order to construct a map of debris flow vulnerability which reflects the geographical and socioeconomic characteristics of Korea. First, seven metropolitan cities of Korea were used as the study area for debris flow vulnerability assessment. This is because the cities where the vulnerabilities are to be applied must be of similar size and characteristics in order to have a logical basis for comparison. For reference, about 45% of the total population of Korea lives in these seven major cities in Korea. Second, in order to produce a quantitatively comparable vulnerability assessment map, this study graded vulnerabilities such as landslide susceptibility maps provided by Korea Forest Service. The debris flows vulnerability estimated from the proposed method is evaluated by taking into account the physical aspect of assessing the impact of debris flow on the structure destruction and the socioeconomic viewpoint of assessing the impact on the complex social structure that constitutes the urban area. The final debris flow vulnerability is estimated to be a combination of physical and socioeconomic perspectives, which may help to determine appropriate mitigation measures for debris flow.

2. Materials and methods

2.1. Target areas

This study covers seven metropolitan cities with a population of about 45% of the total population in Korea. The spatial resolution of the vulnerability assessment is based on COUs. COUs are the minimum units for publishing statistical information, and the average size of a COU is equal to 1/23 of the minimum administrative unit. Fig. 1 shows autonomous districts (boroughs) of Busan metropolitan city and COUs of Nam-gu, one of its boroughs. The COUs of other metropolitan cities have a similar pattern, and Table 1 shows the number of autonomous districts and specifications of COUs for each metropolitan city.

2.2. Urban debris flow disaster vulnerability assessment

2.2.1. Identification of debris flow spreading areas

For urban vulnerability assessment of debris flow, information on the area affected by debris flow and the intensity of the debris flow is needed. Horton et al. [11] developed the Flow-R to analyze the flow path for gravity-related disasters. Flow-R can estimate the propagation of natural disasters such as debris flow using relatively little data. In this study, the first grade (Rank 1) of landslide susceptibility maps was set as a pre-defined disaster source, and the propagation extent and the corresponding kinetic energy of debris flow were calculated based on digital elevation map using Flow-R (Fig. 2).

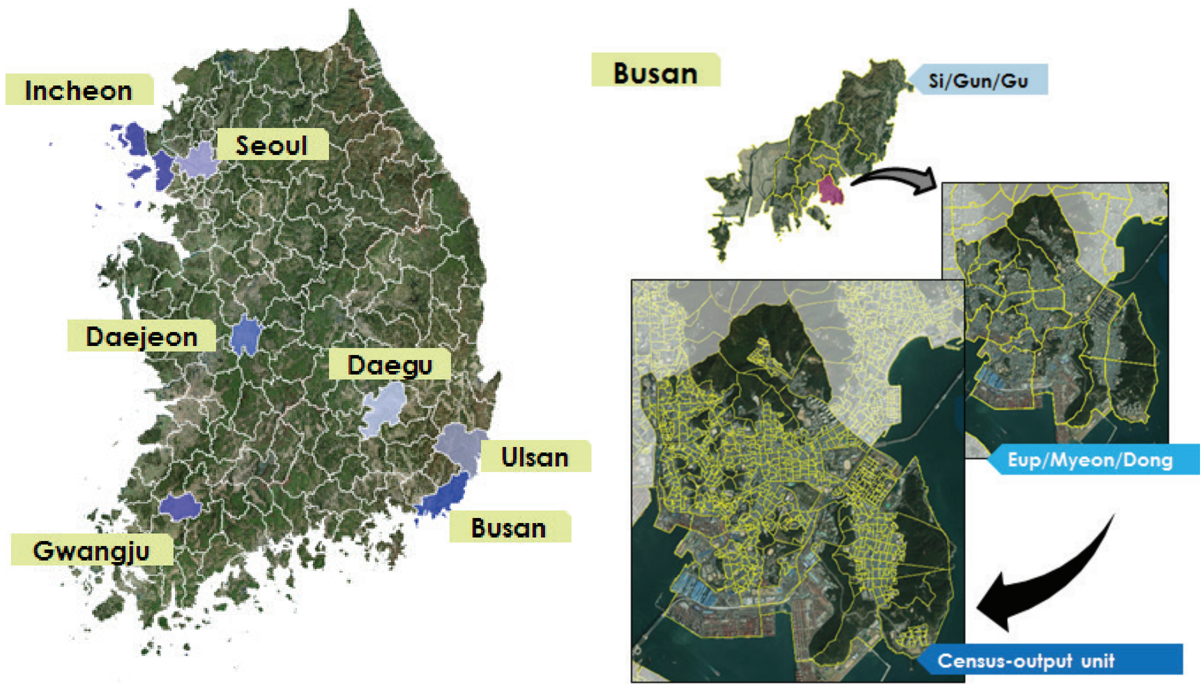

Fig. 1. Target area and spatial resolution.

Table 1
Census-output unit information of the seven metropolitan cities

Metropolitan city	Seoul	Busan	Daegu	Incheon	Gwangju	Daejeon	Ulsan
Number of boroughs	25	16	8	10	5	5	5
Number of COUs	16,230	5,921	4,320	4,588	2,522	2,542	1,896
Average size (km^2) of COUs	0.0374	0.1319	0.204	0.2543	0.1979	0.2124	0.5636
[Minimum–Maximum]	[0.00012–10.10]	[0.00032–21.93]	[0.000517–42.57]	[0.00082–47.10]	[0.0012–23.52]	[0.00017–24.38]	[0.0014–47.62]

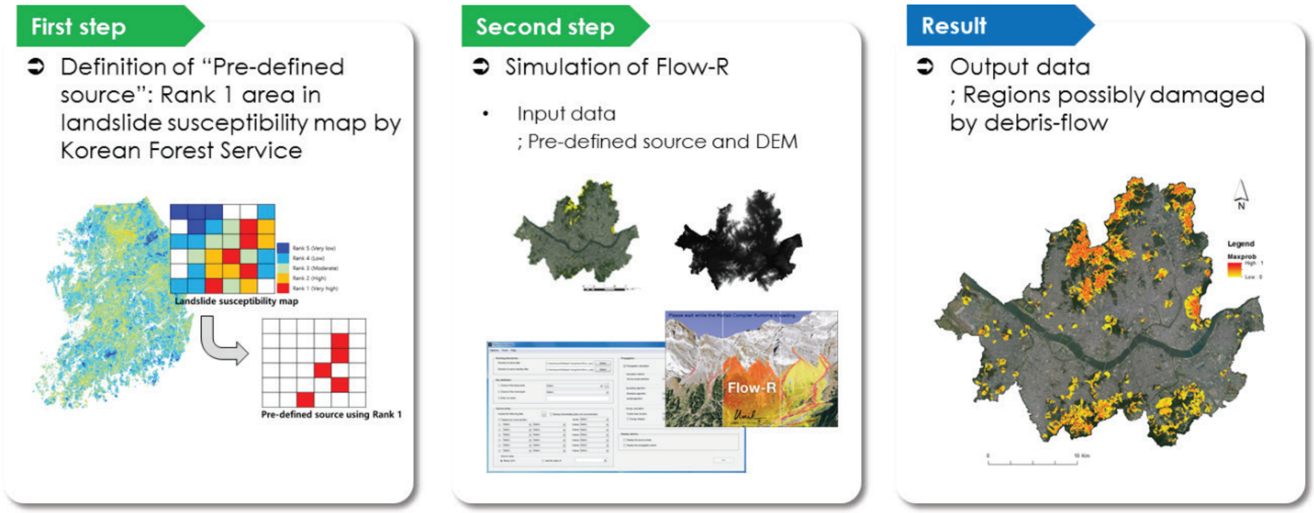

Fig. 2. Procedure for the identification of urban areas that are vulnerable to landslide.

2.2.2. Physical vulnerability assessment

The physical vulnerability was estimated using the vulnerability curves developed by Kang and Kim [3]. For physical vulnerability assessment, the COUs affected by debris flow disasters are extracted using Flow-R analysis results. The mean impact pressure is calculated in the extracted COU. The next step is to classify the COUs into a concrete structure COU and a non-concrete structure COU in order to apply vulnerable curves. If there is a single house in a particular COU, the COU is defined as a COU with a non-concrete structure. Most of the detached houses in South Korea are made with brick structures, which are easily damaged when landslides occur than concrete structures such as apartments. Finally, the mean impact pressure estimated at the COU is used to calculate the physical vulnerability by substituting into vulnerability curves. The vulnerable curves are divided into two building structures as described in Eqs. (1) and (2). Physical vulnerabilities are calculated from 0 to 1 using vulnerable curves. The higher the vulnerability value, the greater the loss of the building. A physical vulnerability value equal to 1 implies that the building is completely destroyed (Fig. 3).

- Frame type: nonreinforced-concrete frame

$$V = 1 - e^{\left(-0.0010 \times p^{2.227}\right)} \quad (1)$$

- Frame type: reinforced-concrete frame

$$V = 1 - e^{\left(-0.0005 \times p^{1.690}\right)} \quad (2)$$

2.2.3. Socioeconomic vulnerability assessment

For the assessment of socioeconomic vulnerability to natural disasters, the indicator-based model applied in a study by Park et al. [1] is applied. To assess socioeconomic vulnerability, the model consists of three groups, each group consisting of 6, 5, and 6 proxy variables. Unlike previous studies, in order to assess disaster vulnerability from a more conservative point of view, actual values, not ratios, have been applied to the surrogate variables of the demographic and social indicator which can assess the degree of life and social vulnerability in the event of natural disasters. In other words, the population vulnerable to disaster refers to the number of age (4 or less and 65 or older) who are more likely to suffer damage when a disaster occurs. The higher the value, the higher the vulnerability to natural disasters. Trigger secondary-damage indicator is a component to evaluate indirect damage such as destruction of service distribution line and an increase of disaster vulnerability due to continuous disaster in addition to direct damage caused by the disaster. The preparatory and response indicator is composed of indicators for assessing the degree of coping of a local government in case of a disaster. The data for evaluating the preparatory

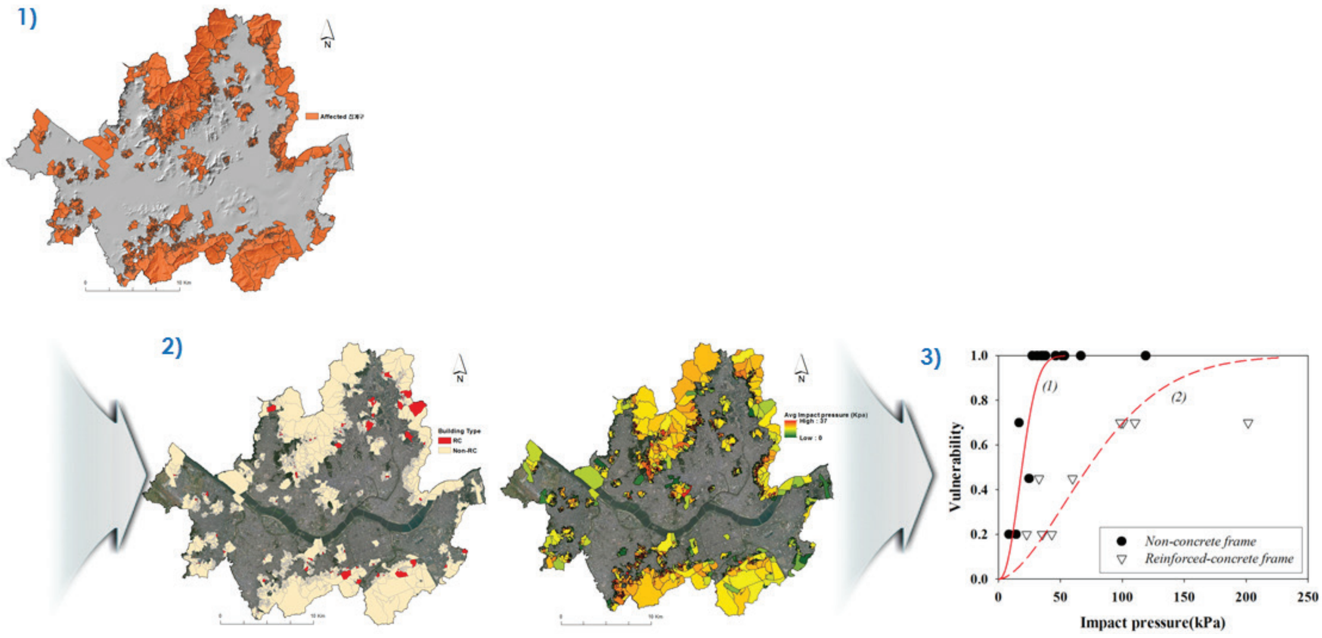

Fig. 3. Procedure for physical vulnerability assessment.

and response indicator are borough data, it differs from the scale of used data for evaluating other indicators. The data scale of demographic and social indicator and trigger secondary-damage indicator is COU. In South Korea, disaster management is performed in city, county or province rather than COU. So that it is impossible to gather available COU data for calculating the preparatory and response indicator. This is the reason why data scale of preparatory and response indicator is different from other indicators. Therefore, this study used the borough data in preparatory and response indicator. More detailed information on each proxy variable can be found in Park et al. [1].

The socioeconomic vulnerability index of a metropolitan city can be calculated as follows: (1) the quantification process is performed according to the socioeconomic vulnerability quantification standard for each proxy variable, and (2) the quantified value for each proxy variable is calculated by weighted average. In this case, since the proxy variables have different units and sizes, the qualitative characteristics of proxy variables are evaluated through relative comparison. In this study, the data of seven metropolitan cities are divided into five grades from 1 point to 5 points, and the number of grades is assigned to 20% of the total number of data. The higher the rating, the more vulnerable the proxy variable is to disasters. For weighted averages, weights for each proxy variable are estimated by analytic hierarchy process (AHP). The AHP is a theory through pairwise comparisons and relies on decisions of an expert to derive priority scales such as weights of variables [12]. The decisions of expert are gained by questionnaire. The weights of each proxy variables are determined based on the results of the expert survey participated by 312 professionals. The estimated weights for detailed indicators were 0.31 for demographic and social indicator, 0.25 for trigger secondary-damage indicator and 0.44 for preparatory and response indicator, respectively. Grading criteria and weights for each proxy variable are shown in Tables 2–4. As shown in Tables 2–4, when the rating is calculated for each surrogate variable, Eq. (3) can be used to estimate socioeconomic vulnerability:

$$\mathrm{SVI} = \frac{\sum \mathrm{weight}_i \times \mathrm{score}_i}{\sum \mathrm{weight}_i} \tag{3}$$

where SVI is the socioeconomic vulnerability index, weight_i is the weight of the proxy variable *i*, and score_i is the rating of the proxy variable *i*. Finally, just like the physical vulnerability, only the COUs that are affected by debris flow disasters were extracted and the socioeconomic vulnerability was expressed by normalizing the vulnerability of the extracted aggregate from 0 to 1.

2.3. Metropolitan vulnerability assessment and grading

The debris flow disaster vulnerability is assessed by combining physical vulnerability and socioeconomic vulnerability. This is done by multiplying the physical vulnerability and socioeconomic vulnerability and then normalizing their product between 0 and 1. The combined vulnerability obtained can be expressed as a vulnerability map. It is more effective to classify vulnerability results by map rather than quantitative numbers when conducting disaster prevention projects to mitigate the destructive damage. There are simple ways to grade spatial data, such as equidistant method and quantile method as well as the Jenks Natural Break method [13] which is more subjective than the methods described above but can be used to effectively grade data. The vulnerability of urban debris flow disasters is classified into five classes (most vulnerable,

Table 2
Classification criteria and its weight about surrogate variables of demographic and social indicator

surrogate variable	Weight	Classification	Class
Number of vulnerable employee under disaster (agriculture, forestry, mining, transportation, and construction)	0.24	Less than 10 people	1
		More than 10 people, less than 19 people	2
		More than 19 people, less than 41 people	3
		More than 41 people, less than 112 people	4
		More than 112 people	5
Population intensity	0.23	Less than 15,874 people/km^2	1
		More than 15,874 people/km^2, less than 26,950 people/km^2	2
		More than 26,950 people/km^2, less than 46,773 people/km^2	3
		More than 46,773 people/km^2, less than 69,465 people/km^2	4
		More than 69,465 people/km^2	5
Housing type (ratio of people who live in apartment)	0.18	More than 85%	1
		More than 60%, less than 85%	2
		More than 30%, less than 60%	3
		More than 10%, less than 30%	4
		Less than 10%	5
Number of vulnerable population under disaster	0.16	Less than 43 people	1
		More than 43 people, less than 60 people	2
		More than 60 people, less than 79 people	3
		More than 79 people, less than 106 people	4
		More than 106 people	5
Education level (ratio of eligible people who have attended, or are attending, a post-secondary education)	0.11	More than 39.41%	1
		More than 28.09%, less than 39.41%	2
		More than 20.47%, less than 28.09%	3
		More than 14.39%, less than 20.47%	4
		Less than 14.39%	5
Number of foreigner	0.08	Less than 761 people	1
		More than 761 people, less than 1,839 people	2
		More than 1,839 people, less than 3,077 people	3
		More than 3,077 people, less than 5,443 people	4
		More than 5,443 people	5

more vulnerable, moderate, less vulnerable, and least vulnerable) and Jenks Natural Break algorithm is used to classify the data. This algorithm is one of the most effective ways to visualize spatial data while maximizing the variance between classes while reducing the variance of the data within the grade.

3. Results and discussion

Urban debris flow disaster vulnerability can be developed by assessing physical and socioeconomic vulnerability and then integrating these two vulnerabilities. Before assessing the integrated vulnerability of debris flow disasters, the results of physical and socioeconomic vulnerability assessments must be investigated.

3.1. Result of physical vulnerability

Table 5 shows the number and percentage of COUs affected by the debris flow for each classification which were developed following Jenks Natural Break algorithm.

In Busan, Incheon, and Seoul, more than one-third of COUs affected by debris flow disasters is physically the most vulnerable. On the other hand, in Daegu, Daejeon, and Gwangju, the number of COUs classified as 'least vulnerable' is the largest among five vulnerable classes. In case of Gwangju, the number of damaged COUs is 319 and the number of COUs included in the 'least vulnerable' is 164. The number is equivalent to 51.4% of the number of affected COUs by debris flow. This means that Daegu, Daejeon, and Gwangju are safer in terms of physical vulnerability as compared with other metropolises.

3.2. Result of socioeconomic vulnerability

The socioeconomic vulnerability is calculated by three indicators: (1) demographic and social indicator, (2) trigger secondary-damage indicator, and (3) preparatory and response indicator. The ternary diagram was used to evaluate the relative influence of these three indicators on the socioeconomic vulnerability of metropolitan cities. By applying the three indicators of socioeconomic vulnerability, it is possible to identify

Table 3
Classification criteria and its weight about surrogate variables of trigger secondary-damage indicator

Surrogate variable	Weight	Classification	Class
Number of electronic supply facility	0.31	Less than 1 unit	1
		More than 1 unit, less than 2 units	2
		More than 2 units, less than 3 units	3
		More than 3 units, less than 8 units	4
		More than 8 units	5
Area ratio of road	0.25	Less than 7.98%	1
		More than 7.98%, less than 16.39%	2
		More than 16.39%, less than 22.10%	3
		More than 22.10%, less than 28.83%	4
		More than 28.83%	5
Area ratio of commercial and industry regions	0.18	Less than 0.28%	1
		More than 0.28%, less than 0.57%	2
		More than 0.57%, less than 0.99%	3
		More than 0.99%, less than 2.37%	4
		More than 2.37%	5
Number of public office	0.15	Less than 2 units	1
		More than 2 units, less than 4 units	2
		More than 4 units, less than 6 units	3
		More than 6, less than 10 units	4
		More than 10 units	5
Area ratio of education region	0.11	Less than 0.59%	1
		Mora than 0.59%, less than 3.08%	2
		More than 3.08%, less than 6.04%	3
		More than 6.04%, less than 9.60%	4
		More than 9.60%	5

which sub-indicators have more influence among socioeconomic vulnerabilities. Fig. 4 shows the template of the ternary diagram used to express the results of this study. If the location information calculated from the three detailed indicators is located above the triangle, it means that the proportion of trigger secondary-damage indicator in socioeconomic vulnerability is relatively large. The lower left corner of the triangle represents the relative increase in preparatory and response indicator, while the lower right corner of the triangle represents the relative increase in demographic and social indicator.

Fig. 5 shows the ternary diagrams of the seven metropolitan cities using detailed indicators of socioeconomic vulnerability. The relative importance of preparatory and response indicator to a socioeconomic vulnerability in all cities is significant. In particular, the average impact of preparatory and response indicator on a socioeconomic vulnerability in Busan and Daegu is more than 50% but the average impact of preparatory and response indicator on a socioeconomic vulnerability in other metropolises is less than 50%. Therefore, in order to improve the socioeconomic vulnerability of Busan and Daegu, it seems that the most effective method is to strengthen the disaster management capability of the local government. In Seoul and Incheon, the relative ratio of demographic and social indicator is over 0.3. In case of other metropolitan cities, the relative ratio of demographic and social indicator is under 0.3. In the case of Daejeon, Gwangju, and Ulsan, the relative weightings of the three indicators are similar.

3.3. Result of integrated urban debris flow disaster vulnerability

Urban debris flow disaster vulnerability is estimated as the product of physical vulnerability and socioeconomic vulnerability. The calculated vulnerability scores are then normalized between 0 and 1. The normalized data were classified into five classes using the Jenks Natural Break algorithm. The lowest vulnerability range was between 0 and 0.147, marked 'least vulnerable'. Conversely, the highest vulnerability range (most vulnerable) was estimated to be between 0.602 and 1.

Fig. 6 shows integrated maps of debris flow disaster vulnerabilities for the seven cities. In Seoul (Fig. 6(a)), 2,249 COUs out of a total of 16,230 COUs are affected by debris flow disasters. Of the total COUs, 0.12% was classified as the most vulnerable. In Busan (Fig. 6(b)), 2,221 COUs out of 5,921 COUs are affected by debris flow disasters. The number of COUs determined to be 'most vulnerable' is about 12% of the total number of COUs. Compared with Seoul, the number of COUs affected by landslides is similar, but the ratio of the most vulnerable classes is higher than that of Seoul, so Busan is more vulnerable to debris flow disasters than Seoul. Fig. 6(c) is the result of the vulnerability assessment of Daegu, 2.78% of the 468 COUs affected by debris flow disasters were identified as 'most vulnerable'. In the case of Incheon (Fig. 6(d)), landslide susceptibility map is not completely constructed for the whole city. Therefore, at present, the city cannot perform the vulnerability assessment perfectly. As a result of the vulnerability

Table 4
Classification criteria and its weight about surrogate variables of preparatory and response indicator

Surrogate variable	Weight	Classification	Class
Awareness ratio of safety under disaster (ratio of people who think that they are very safe or safe under natural disaster)	0.24	More than 20.8%	1
		More than 19.1%, less than 20.8%	2
		More than 17.2%, less than 19.1%	3
		More than 15.1%, less than 17.2%	4
		Less than 15.1%	5
Number of disaster prevention facility	0.23	More than 475 units	1
		More than 185 units, less than 475 units	2
		More than 113 units, less than 185 units	3
		More than 81 units, less than 113 units	4
		Less than 81 units	5
Frequency of disaster occurrence	0.16	More than 2,267 cases	1
		More than 1,779 cases, less than 2,267 cases	2
		More than 1,137 cases, less than 1,779 cases	3
		More than 477 cases, less than 1,137 cases	4
		Less than 477 cases	5
Number of doctor per thousand people	0.16	More than 4.03 people	1
		More than 2.47 people, less than 4.03 people	2
		More than 1.82 people, less than 2.47 people	3
		More than 1.56 people, less than 1.82 people	4
		Less than 1.56 people	5
Financial independence ratio at local government	0.12	More than 44.5	1
		More than 33.9, less than 44.5	2
		More than 23.0, less than 33.9	3
		More than 18.8, less than 23.0	4
		Less than 18.8	5
Internet penetration rate	0.09	More than 81.0%	1
		More than 75.9%, less than 81.0%	2
		More than 72.5%, less than 75.9%	3
		More than 71.2%, less than 72.5%	4
		Less than 71.2%	5

Table 5
Result of physical vulnerability assessment

Class	Vulnerability range	Number of damaged COUs						
		Seoul	Busan	Daegu	Incheon	Gwangju	Daejeon	Ulsan
Least vulnerable	0.000–0.228	319 (14.2%)	200 (9.0%)	198 (42.3%)	361 (29.6%)	164 (51.4%)	138 (42.6%)	141 (28.7%)
Less vulnerable	0.229–0.456	269 (12.0%)	181 (8.1%)	69 (14.7%)	253 (20.7%)	31 (9.7%)	22 (6.8%)	10 (2.0%)
Moderate	0.457–0.658	291 (12.9%)	307 (13.8%)	113 (24.1%)	83 (6.8%)	23 (7.2%)	31 (9.6%)	62 (12.6%)
Vulnerable	0.659–0.838	527 (23.4%)	699 (31.5%)	88 (18.8%)	87 (7.1%)	77 (24.1%)	108 (33.3%)	244 (49.7%)
Very vulnerable	0.839–1.000	843 (37.5%)	834 (37.6%)	0 (0.0%)	437 (35.8%)	24 (7.5%)	25 (7.7%)	34 (6.9%)
Sum damaged COUs (All COUs)		2,249 (16,230)	2,221 (5,921)	468 (4,320)	1,221 (4,588)	319 (2,522)	324 (2,542)	491 (1,896)

assessment, the 1,221 COUs were affected by debris flow disasters, and 2.62% of the total COUs were judged to be 'most vulnerable' to debris flow disasters. In Gwangju (Fig. 6(e)), about 0.63% of the 319 COUs affected by debris flow disasters were identified as 'most vulnerable'. In Daejeon (Fig. 6(f)), 324 COUs out of 2,542 COUs are affected by debris flow disasters. The number of COUs determined to be 'most vulnerable' is about 0.43% of the total number of COUs. Finally, in Ulsan (Fig. 6(g)), 491 COUs out of 1,896 COUs were affected by debris flow disasters and about 0.26% of all COUs were identified as 'most vulnerable'.

Fig. 7 is a diagram that distinguishes the vulnerability grade for each city in order to examine the relative influence of physical vulnerability and socioeconomic vulnerability in

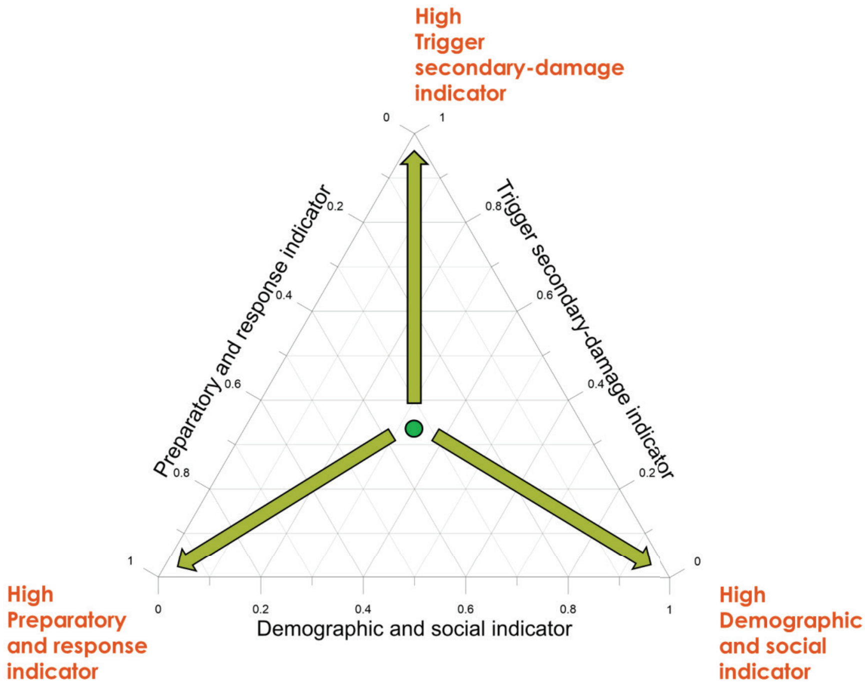

Fig. 4. Schematic of ternary diagram.

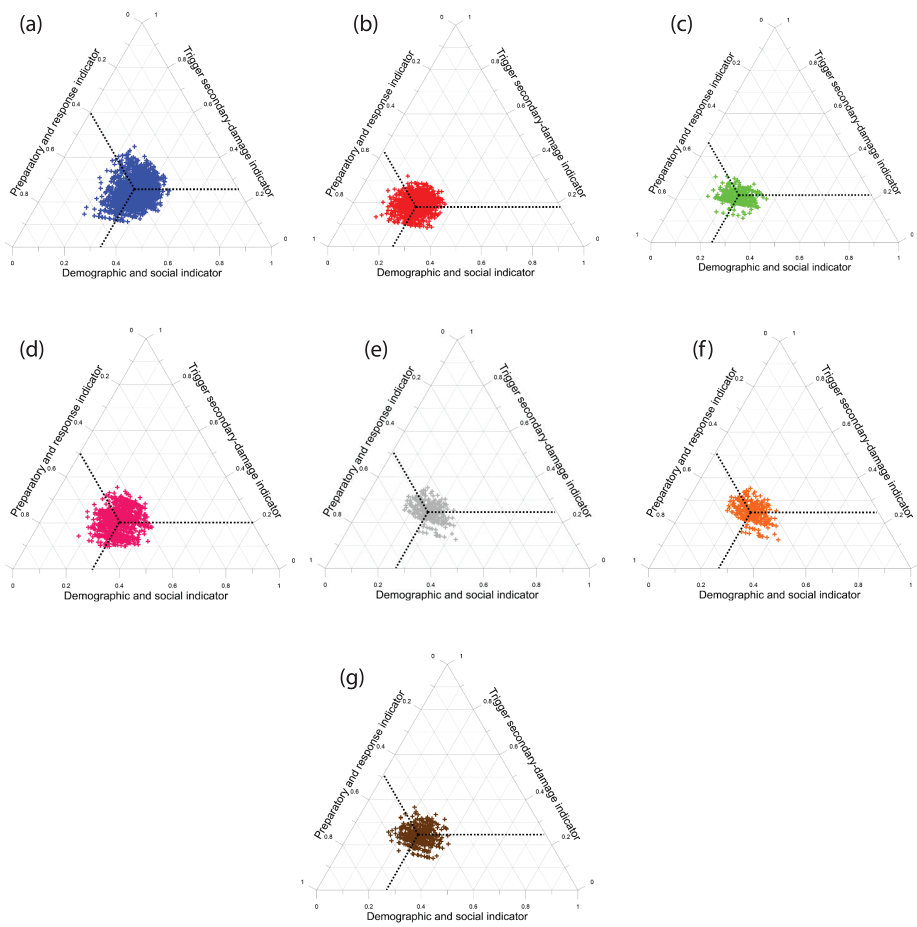

Fig. 5. Ternary diagram of sub-indicators: (a) Seoul, (b) Busan, (c) Daegu, (d) Incheon, (e) Gwangju, (f) Daejeon, and (g) Ulsan.

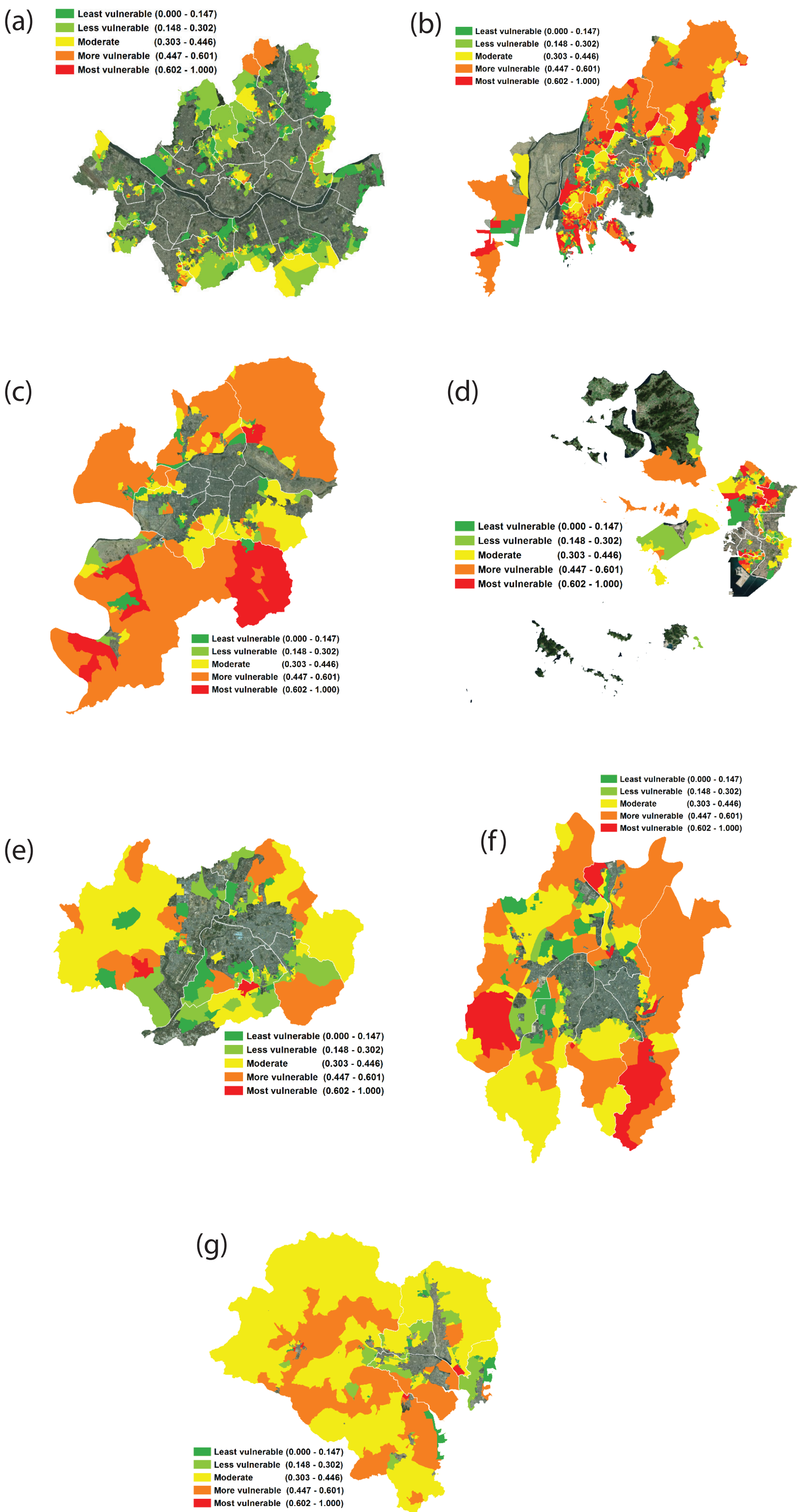

Fig. 6. Urban debris flow vulnerability in seven metropolitan cities: (a) Seoul, (b) Busan, (c) Daegu, (d) Incheon, (e) Gwangju, (f) Daejeon, and (g) Ulsan.

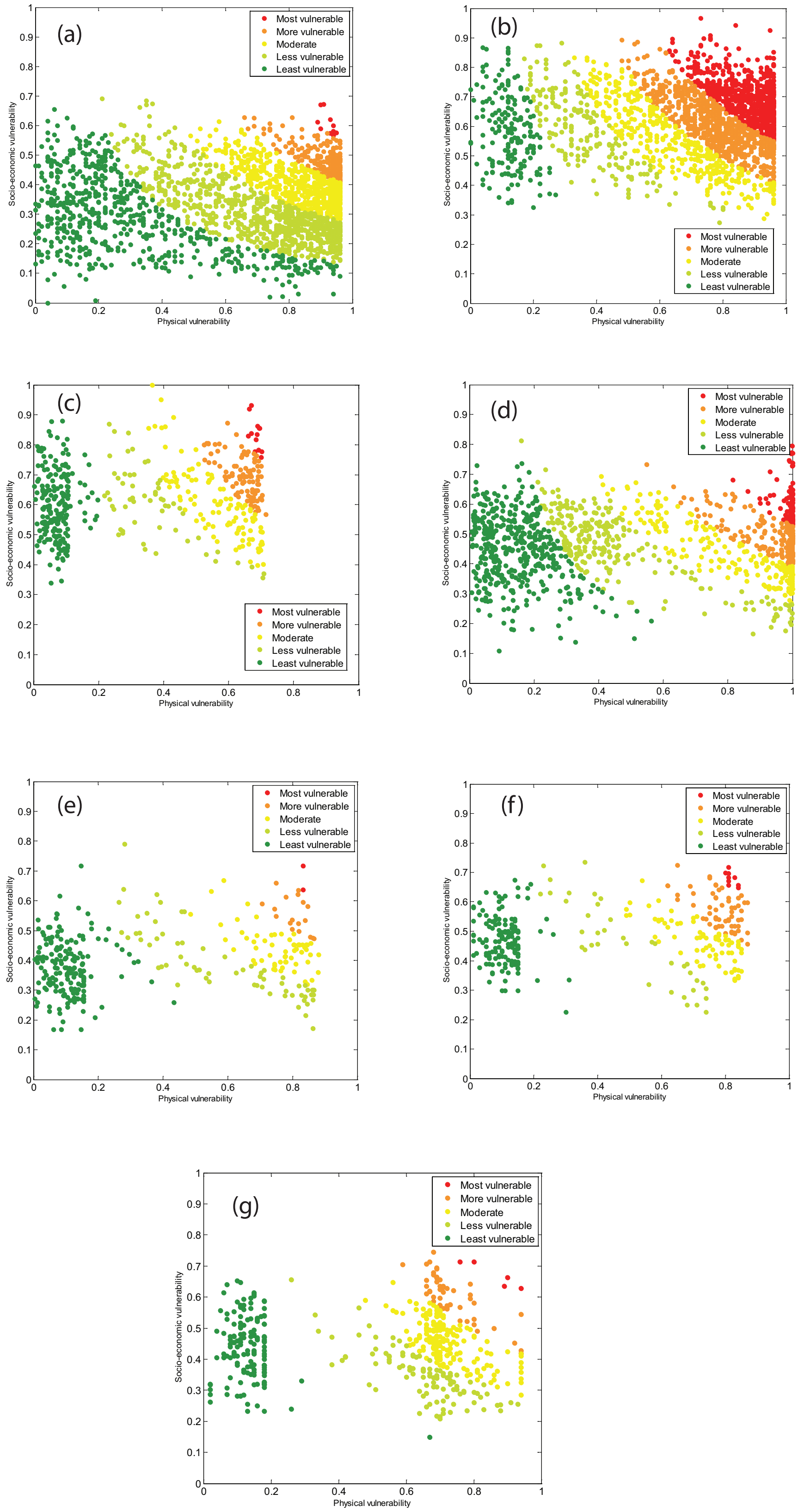

Fig. 7. Clusters of metropolitan debris flow vulnerability: (a) Seoul, (b) Busan, (c) Daegu, (d) Incheon, (e) Gwangju, (f) Daejeon, and (g) Ulsan.

the integrated vulnerability. The horizontal axis of the graph is a physical vulnerability and the vertical axis represents socioeconomic vulnerability. Seoul has a lower socioeconomic vulnerability than other metropolises. The physical vulnerability of Seoul was relatively high, but because of the low socioeconomic vulnerability, the final integrated vulnerability was estimated to be low. Therefore, if a disaster prevention project is to be carried out to reduce the damage of debris flow disasters in Seoul, the structural measures must be prioritized. Busan has a higher socioeconomic vulnerability than Seoul. As a result, if the physical vulnerability is raised a little, the final integrated vulnerability index will also be relatively high. Therefore, compared with Seoul, Busan has a relatively higher proportion of socioeconomic vulnerability in the integrated vulnerability. It can be seen that Daejeon, Gwangju, Incheon, and Ulsan have relatively similar clusters with Seoul, while Daegu has similar clusters with Busan.

4. Conclusions and recommendations

This study tried to evaluate debris flow disaster vulnerability in seven metropolitan cities of South Korea with the same standard. The vulnerability of debris flow disasters has been classified into five classes (least vulnerable, less vulnerable, moderate, more vulnerable, and most vulnerable). In Busan, the percentage of COUs considered to be the most vulnerable to debris flow disasters corresponds to 12.9% of all COUs, the highest among the seven metropolitan cities. This means that Busan is the most vulnerable to debris flow disasters in comparison with other metropolitan cities. In addition, through clustering of debris flow disaster vulnerability rating, the influence of physical vulnerability and socioeconomic vulnerability on metropolitan cities was examined.

The relative impact of physical vulnerability and socioeconomic vulnerability will be an important part to decide policy direction for debris flow prevention measures in specific cities. For instance, while the physical vulnerability of Seoul was found to be higher than that of socioeconomic vulnerability, the influence of physical vulnerability was grater in Busan. This is because the characteristics of the topography and social structure of Seoul and Busan are different. Therefore, if debris flow reduction policy is implemented, Seoul should apply structural disaster prevention measures to improve physical vulnerability, and Busan should apply both non-structural measures to improve socioeconomic vulnerability as well as structural disaster prevention measures.

This study is limited to metropolitan cities, but it will be possible to extend vulnerability assessment map to the whole country by extending its coverage to small and medium cities. The extension of this study can be useful as a necessary data to recognize the damage to debris flow disasters in advance and to carry out the disaster prevention project to reduce the damage caused by debris flow disasters. This study is an initial study to develop a map of debris flow disasters vulnerability for urban areas in the country. It is expected that research methodology and results will be useful in subsequent studies.

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