Development of urban debris flow vulnerability assessment model

Développement de glissements de terrain urbains modèle d'évaluation de la vulnérabilité

Hyun-Ki Kim
Department of Civil and Environmental Engineering, Kookmin University, Republic of Korea, geotech@kookmin.ac.kr
Yoonkyung Park, Sangdan Kim
Division of Earth Environmental System Science, Pukyong National University, Republic of Korea

ABSTRACT: This study proposes a model to quantitatively evalute the urban debris flow vulnerability which is obtained by multiplying the computed physical susceptiblity and the estimated socio-economic impact of the local area. Seoul and Busan, the two representative metropolitan cities in South Korea, are selected for example analyses using the proposed model. The local vulnerability of each COU in those cities is evaluated and classified into five categories using the Jenks optimal algorithm. The urban debris flow vulnerability maps for them are also provided. The results show that Busan is much more vulnerable to the debris flow disaster than Seoul, thus recommending that preventive measures also be more urgent there.

RÉSUMÉ: Cette étude propose un modèle permettant d'évaluer quantitativement la vulnérabilité du flux urbain de débris qui est obtenue en multipliant la susceptibilité physique calculée et l'impact socio-économique estimé de la region. Séoul et Busan, qui sont les deux villes métropolitaines représentatives en Corée du Sud, sont sélectionnés pour l'analyse par exemple en utilisant le modèle proposé. La vulnérabilité locale de chaque COU dans ces villes est évaluée et classée en cinq catégories en utilisant l'algorithme optimal de Jenks. Les cartes de vulnérabilité des débris urbains sont fournies. Les résultats montrent que Busan est beaucoup plus vulnérable à la catastrophe du flux de débris que Séoul, recommandant en conséquence que les mesures de prévention soient également plus urgentes là-bas.

KEYWORDS: debris flow, vulnerability, risk assessment, disaster prevention

1 INTRODUCTION.

On 27 July 2011, there was a rainfall with a peak intensity of 113mm per an hour around Umyeonsan area in the Southern part of Seoul and a total of 33 debris flows occurred around there which caused 16 casualties and extensive property damages to the near communities.

Occurrences of the Similar landslide disasters are getting more frequent in South Korea because about 70% of this country is covered by mountains and the unexpected intensive local rainfalls are taking place more often due to the global climite changes and also the infrastructures against such natural disasters gets more deteriorated, which encourages Korean government to develop the domestic model to assess the urban debris flow vulnerability, the quantitatively defined degree or possibility of socio-economic damages caused by a disaster (Carreño et al. 2007, Cutter et al. 2003, Dwyer et al. 2004, Siagan et al. 2014).

This study proposes an assessment model to the urban debris flow vulnerabliity which are evaluated quantitatively considering the physical susceptiblity and the socio-economic impact of the local area. Seoul and Busan, which are the two representative metropolitan cities in South Korea, are selected for case analyses using the proposed model.

The spatial unit in this analysis is the census-output unit (herein after COU) which is the officially minimum spatial resolution used by the Korea national statistical office. A COU is determined on the basis of the area with about 500 inhabitants. COUs are the minimum units for publishing statistical information, and the average size of a COU in South Korea is about 5% of Korea administrative unit, Gu which is a borough. Figure 1 represents the boroughs of Busan and COUs of Nam-Gu which is one of boroughs in Busan.

(a) Broughs in Busan (b) Brough: Nam-Gu (c) COUs in Nam-Gu

Figure 1. Spatial scales of the study: Busan, South Korea

This vulnerability evaluation results can be displayed on the maps through various visualization techniques to be used as a basis for administrative and engineering decision making for the mitigation of debris flow disasters. The urban debris flow vulnerability estimated by the proposed method is evaluated by taking into account the physical susceptibility to the impact of debris flow on the structure destruction and the socio-economic impact on the social communities in the near urban area.

2 ASSESSMENT MODEL OF URBAN DEBRIS FLOW VULNERABILITY

2.1 *Physical vulnerability assessment*

The urban regions which are affected by the possible debris flow disaster are defined using the digital elevation map (DEM) and the computer simulation program, Flow-R (Horton et al. 2013) in this study. The first grade areas in the landslide susceptibility maps by Korea Forest Services are selected as

pre-defined debris-flow disaster sources as shown in Figure 2 and the flow propagation and the corresponding kinetic energy of debris flow, i.e. the impact pressure, are computed using Flow-R. The calculated local impact pressures are spatially averaged for each COU and the results on Seoul are represented in Figure 3.

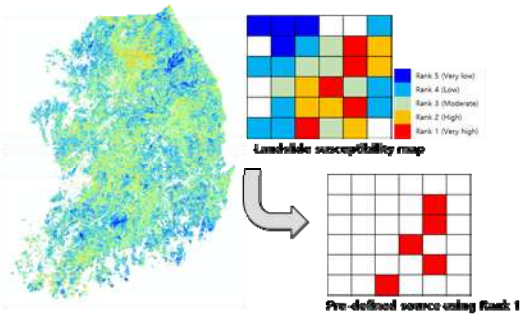

Figure 2. Selection of the pre-defined debris-flow disaster sources

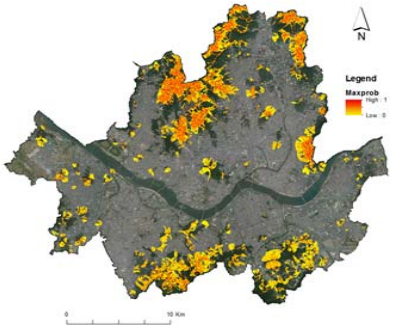

Figure 3. Spatial distribution of flow propagation and the corresponding impact pressure of the simulated debris flows in Seoul

Kang and Kim (2016) suggest the physical vulnerability assessment method for debris flow disaster considering the affected structure types: Reinforced concrete frame structures and non-concrete frame structures. They propose the two different physical vulnerability curves with respect to the structure types to estimate physical damages with the computed impact pressure. Physical vulnerability is evaluated between zero (no physical damage) and one (total physical damage) based on those curves.

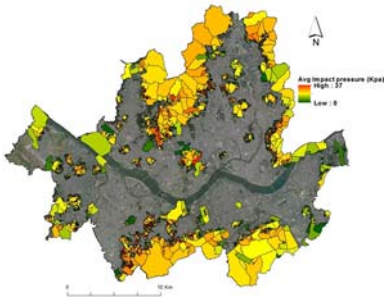

Figure 4. Spatially averaged impact pressure distribution in Seoul

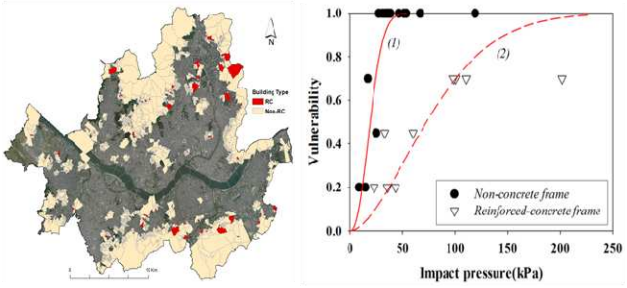

Figure 5. Classification of structure types in COUs, Seoul and the corresponding physical vulnerability curves

2.2 *Socioeconomic vulnerability assessment*

For the assessment of socio-economic vulnerability, the indicator-based model by Park et al. (2016) is applied. This model consists of three evaluation indicators: Demographic and social indicator, trigger secondary-damage indicator and preparatory and response indicator. Each indicator is composed of five or six variables.

Demographic and social indicator reflects the degree of life and social vulnerability in the event of natural disasters considering number of vulnerable population (0.24), population of intensity (0.23), housing type (0.18), number of vulnerable employees (0.16), education level (0.11) and number of foreigners (0.08). The numbers in parentheses mean the weight factor of each variable determined by the intensive expert surveys and Analytic Hierarchy Process (AHP) (Park et al. 2016). The AHP is a theory through pairwise comparisons and relies on decisions of experts to derive priority (Saaty 2008).

Trigger secondary-damage indicator is a component to estimate the possible indirect damages due to continuous disaster in addition to direct damages caused by disaster itself considering number of electronic supply facilities (0.31), areal ratios of road (0.25), commercial and industry regions (0.18), education regions (0.12) and number of public offices (0.15).

Preparatory and response indicator responses the capability for disaster mitigation of the local community/government considering safety awareness about disasters (0.24), number of disaster prevention facilities (0.23), number of doctors per thousand persons (0.16), frequency of disaster occurrence (0.16), financial independence of local government (0.12) and internet supply rate (0.09)

According to the analytic hierarchy process, the relative weighting for each indicator is 0.31 for Demographic and social indicator, 0.25 for Trigger secondary-damage indicator and 0.44 for Preparatory and response indicator. The computed socio-economic impact for Seoul is shown in Figure 6.

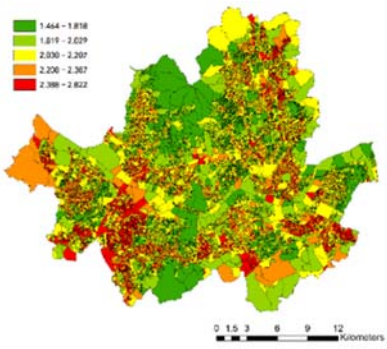

Figure 6. Computed socio-economic impact for COUs in Seoul

2.3 *Metropolitan vulnerability assessment and grading*

The debris flow disaster vulnerability is assessed by combining physical vulnerability and socioeconomic vulnerability. The combined vulnerability is quantified between 0 and 1 multiplying physical vulnerability value and socioeconomic vulnerability value assigned at each COU. The vulnerability evaluated for the COUs in Seoul and Busan are displayed as shown in the following Figures 7 and 8.

Jenks natural break method (Jenks 1967) is applied to classify the level of vulnerability into five categories: Least vulnerable, less vulnerable, moderate, more vulnerable and most vulnerable. This algorithm is one of the most effective ways to visualize spatial data by maximizing the variance between classes and reducing the variance of the data within the grade.

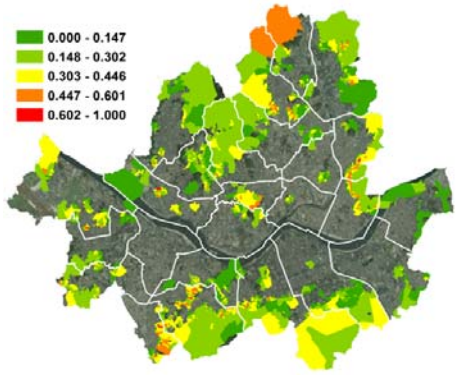

Figure 7. Computed debris flow disaster vulnerability for COUs in Seoul

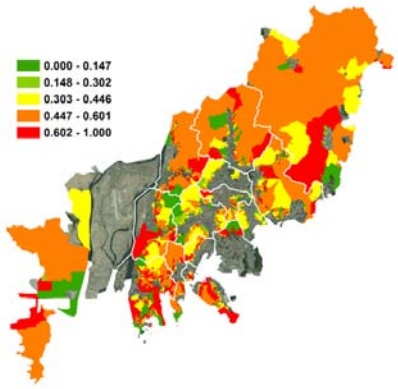

Figure 8. Computed debris flow disaster vulnerability for COUs in Busan

2.4 *Exemplary results and discussions*

Metropolitan debris flow disaster vulnerability can be assessed by assessing physical and socioeconomic vulnerability, and then integrating two vulnerabilities. Before assessing the integrated vulnerability of debris flow disasters, the results of physical and socioeconomic vulnerability assessments will be investigated.

In case of Seoul, the number of COUs which can be affected by the possible debris flows is 2249. It is about 14% among the whole COUs in Seoul metropolitan area and only 19 COUs are classified as the most vulnerable ones. It is just 0.12% in Seoul. This means that considerable part of Seoul is physically vulnerable to the debris flow disaster, however most of them have a low socio-economic impact, which corresponds to low risk against that.

On the other hand, analysis results on Busan show that the number of COUs which can be affected by the possible debris flows is 2221. It is about 38% among the whole COUs in Seoul metropolitan area and 764 COUs are classified as the most vulnerable ones. It is about 13% in Busan. This reflects that considerable part of Seoul is very vulnerable to the debris flow disaster, and also most of them have a high socio-economic impact, which corresponds to much higher risk in Busan than Seoul.

3 CONCLUSION

This study proposes the method to evaluate debris flow disaster vulnerability quantitatively. The vulnerability of debris flow disasters is defined as one of the five classes: Least vulnerable, less vulnerable, moderate, more vulnerable and most vulnerable. Seoul and Busan, the two most representative cities in South Korea, are analyzed with this method and mapped. About 13% of COUs in Busan are classified as the most vulnerable one to the debris flow disaster where the urgent measures or the more intensive investigation are required. On the other hand, only 0.1% of COUs in Seoul are classified as the most vulnerable ones, which means that Busan is much more susceptible to the debris flow disasters than Seoul.

As shown above, debris-flow vulnerability map can be used as decision making information to select the priority regions for prevention program against debris flow disasters and it also can help to identify the locally more appropriate physical and/or administrative prevention measures. The proposed methodology is proposed as a pre-study tool to estimate urban debris flow vulnerability of all the cities in South Korea.

4 ACKNOWLEDGEMENTS

This research was supported by a grant(13SCIPS04) from Smart Civil Infrastructure Research Program funded by Ministry of Land, Infrastructure and Transport(MOLIT) of Korea government and Korea Agency for Infrastructure Technology Advancement(KAIA).

5 REFERENCES

Carreño M.L., Cardona O.D. and Barbar A.H. 2007. A disaster risk management performance index. *Natural Hazards* 41 (1), 1-20.

Cutter S.L., Boruff B.J. and Shirley W.L. 2003. Social vulnerability to environmental hazards. *Social Science Quarterly* 84 (2), 242-261.

Dwyer A., Zoppou C., Nielsen O., Day S. and Roberts S. 2004. *Quantifying Social Vulnerability: A methodology for identifying those at risk to natural hazards*, Australian Government.

Horton P., Jaboyedoff M., Budaz B. and Budaz M. 2013. Flow-R, a mode for susceptibility mapping of debris flows and other gravitational hazards at a regional scale. *Natural Hazards and Earth System Sciences* 13, 869-885.

Jenks G.F. 1967. The data model concept in statistical mapping. *International Yearbook of Cartography* 7, 186-190.

Kang H. and Kim Y.-T. 2016. The Physical vulnerability of different types of building structure to debris flow events. *Natural Hazard* 80 (3), 1475-1793.

Park Y., Pradhan A.M.S., Kim U., Kim Y. and Kim S. 2016. Development and application of urban landslide vulnerability assessment methodology reflecting social and economic variables. *Advances in Meteorology* 2016 (2016), 1-13.

Saaty T.L. 2008. Decision making with the analytic hierarchy process. *International Journal of Services Sciences* 1(1), 83-98.

Siagan T.H., Purhadi P., Suhartono S. and Ritonga H. 2014. Social vulnerability to natural hazards in Indonesia: Driving factors and policy implications. *Natural Hazards* 70 (2), 1603-1617.