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Development of a Risk Assessment Model of Rainfall for Small Area in Declining Urban Areas

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ABSTRACT

Purpose: Declining cities are vulnerable due to their aging populations and decreasing economic activity. The risk assessment framework developed by IPCC is a representative method of analyzing hazardous impacts in urban spaces. However, most previous research on declining cities and risk assessments are based on macro-scale evaluations. As risk assessment must be included in the urban planning process, development of a risk assessment model for smaller areas is necessary. Thus, this study aims to develop a rainfall disaster risk assessment model for a small area in a declining city. **Method:** This study selected the appropriate indicators for a small area based on the IPCC disaster risk assessment framework. As suggested by IPCC, multidimensional data are used as indicators of the physical, social, and climate-related health of a city. The indicators include not only computational data based on GIS but practical data obtained through a field study involving a site-specific evaluation. In the developed model, the risk of a rainfall disaster at the study site is quantified with a numerical score. **Result:** The numerated assessment result is allocated into the grid of the case study site in Daegu, South Korea. The rasterized image visually represents the risk impact score of a rainfall disaster in a small area. Consequently, this study proposes a high-resolution risk impact assessment model that can be applied to urban design and provides the results of realistic and practical rainfall disaster analysis.

KEYWORD

쇠퇴도시
위험성 분석
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1. Introduction

Declining cities are vulnerable to numerous hazards, including climate change, natural disasters and decreases in economic activity[1]. Such cities suffer from population loss, lack of social activity, and a reduction in infrastructure. Declining cities are generally incapable of adapting to various hazards. Thus, a declining city is vulnerable to disaster-related hazards.

The Intergovernmental Panel on Climate Change (IPCC) suggested a vulnerability assessment model in 2007 and a risk assessment model in 2014 that assess the sustainability of urban spaces[2][3]. The IPCC framework applies to a macro-scale urban space. The framework must be revised to apply to a micro-scale urban area. As the demand for disaster risk assessment increases among experts in the urban design field, an appropriate model for a micro-scale urban area is urgently needed.

This paper aims to develop a rainfall disaster risk assessment model for a small area in a declining city. Revised indicators and assessment models are suggested based on the IPCC disaster assessment framework. This paper uses rainfall disaster to test the developed model at the case study site. The case study site is a district in Indongchon, Daegu, South Korea, which is classified as a declining region[4]. The risk assessment of the case study site is expressed in the form of numerical scores calculated using the developed model. Subsequently, the scores are allocated onto a grid representing the target area. Finally, the rainfall disaster risk scores are visualized with a rasterized image.

2. Literature Review

A region that suffers from decreases in population and economic activity is called a declining city[5]. Such cities face severe problems due to weakened economic activity, reductions in public services, and shrinking urban spaces[6][7]. The problems are primarily caused by social and human factors, for instance, an aging population and decreasing working-age population, along with shrinking fiscal investment[8][9]. As economic and demographic features are weakened, the physical

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environment of a declining city becomes vulnerable due to a lack of additional investment and a dearth of inspections[10].

Therefore, a declining city is potentially at greater risk in a disaster situation. Previous research evaluated urban space with a focus on urban regeneration projects[11][12] or assessed the risk of rainfall disaster in macro-scale cities[13][14]. Thus, there is a need for studies that specifically assess the risk of rainfall in declining areas in cities that are physically, socially, and economically weakened and particularly vulnerable to disasters.

IPCC has presented frameworks for the assessment of urban space, for vulnerability in 2007 and for risk in 2014[2][3]. Specifically, the risk assessment framework suggested in 2014 includes appropriate examples of social indicators, for instance, an aging population and a high proportion of low-paying jobs. As the trend in disaster risk assessment research has shifted from a hazard-centric approach to an approach that centers human and social factors, the framework suggested by IPCC has been broadened in recent disaster risk assessment studies[15]. As the framework suggested a general approach, previous studies used diverse indicators[16][17]. However, social indicators and physical environments have rarely been considered together in previous studies[17].

The Ministry of Land, Infrastructure, and Transport (MLIT) encourages consideration of disaster risk assessment in the regional urban planning process. This is reflected in the MLIT document entitled “Guidelines on the analysis and utilization of urban climate change disaster vulnerabilities.” The guidelines include a suggestion of risk assessment analysis using recommended indicators based on the IPCC framework[18]. MLIT proposes indicators related to global climate change, for instance, the annual number of rainy days, the presence of water supply facilities, and the rate of sea temperature rise. However, the suggested indicators cannot plausibly be applied in a small district or area.

A literature review identified three major limitations in previous studies. 1) There is no method of rainfall disaster risk assessment specifically for declining cities. 2) Social influence and physical environment are rarely considered together. 3) Risk assessment studies tend to focus on macro-scale urban spaces. Therefore, this study proposes a method that supplements previous studies on rainfall disaster risk assessment.

3. Methods

3.1. Site

The study site is the small district of Indongchon, Daegu, South Korea (Fig. 1.). Indongchon is a representative declining area in Daegu; it has been officially designated a regeneration project site [4]. The micro-scale analysis is restricted to one block in the district to develop a risk assessment model with a fine scale for a small, severely declining area. Not only did the local government designate the site as a declining area on the basis of social and economic phenomena, but the physical environment of the site is also very old and deteriorating, as shown in Fig. 2.

The deteriorating physical environment and demographic structure of the study site are sufficient to evaluate the risk of rainfall disaster. The site is restricted to a 150 m by 100 m area to obtain a fine-resolution result.

3.2. Indicator

In this study, the following indicators (shown in Table 1.) were selected for rainfall disaster risk assessment based on the IPCC risk assessment framework.

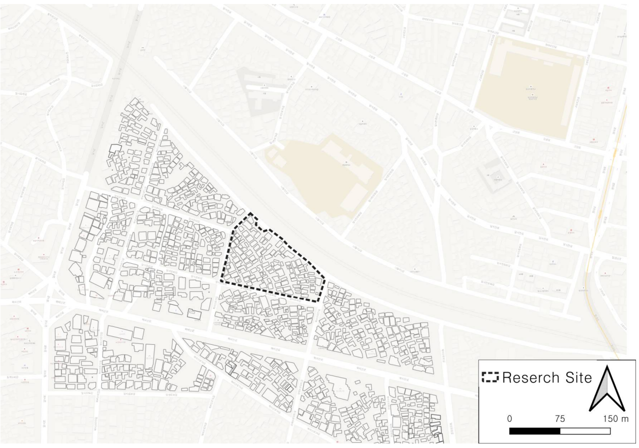

Fig. 1. Research site in Indongchon

Fig. 2. Deterioration of the physical environment at the research site

Table 1. Indicators for Rainfall Disaster Risk Assessment

Component	Indicator
Hazard	H_1: Daily precipitation[19] H_2: Number of heavy rainfall warning[19] H_3: Hourly maximum precipitation[19]
Exposure	E_1: Population of vulnerable class[20] E_2: Number of semi-underground residence[20] E_3: Number of old buildings[20]
Vulnerability	V_1: Impermeability of urban space[21] V_2: Road inclination[20] V_3: Elevation[22]
Management	M_1: Drainage pump capacity[23] M_2: Water storage capacity[24][25] M_3: Distance to trench

The primary indicators were selected based on the IPCC framework and the MLIT guidelines[2, 3, 18]. Subsequently, additional indicators were added to achieve higher resolution and a more targeted analysis. The additional indicators were selected based on the following criteria: 1) can plausibly be used to evaluate the risk of heavy rainfall disaster 2) include both social influence and physical environment 3) optimized to the study site, and 4) applicable to a small area. The physical and social indicators were evaluated in consideration of the specificity of the small, deteriorating area[15]. For instance, "distance to trench" data was calculated according to the locations of trench gathered through a field study to obtain a customized result for the research site.

3.3. Risk Assessment

This study applied the IPCC 2014 risk assessment framework [3] to evaluate risk at the research site. Eq. 1 expresses the risk assessment model.

$$Risk = \frac{\Sigma H_i \times \Sigma E_i \times \Sigma V_i}{\Sigma M_i} \quad \text{(Eq. 1)}$$

Eq. 1 is an improved model for the evaluation of disaster risk in urban spaces that is based on previous research[26]. The selected indicators in Table 1. are given one of 10 possible grades, which are subsequently translated into a score between 0 and 1. The final risk impact result is quantified by Eq. 1, and the index is reallocated into a 1 m grid according to location. Finally, Eq. 1 shows the numerically quantified risk assessment for rainfall disaster according to fine-grained location.

Table 2. Example of Grading and Scoring of Exposure Indicators

	Exposure Indicators		
Score	Population of vulnerable class (Age under 6 and over 65)	Area of semi-underground residence (m^2)	Building age (year)
1	91.8~	479.97~	~1947
0.9	91.8	479.97	1954
0.8	81.6	426.64	1961
0.7	71.4	373.31	1968
0.6	61.2	319.98	1975
0.5	51	266.65	1982
0.4	40.8	213.32	1989
0.3	30.6	159.99	2003
0.2	20.4	106.66	2010
0.1	~10.2	~53.33	2010~

Table 2. shows examples of stratification and scoring of the exposure indicators. The building and demographic data are stratified into 10 classes between the maximum and minimum values observed over the last 7 years in Indongchon, and the scores for the last 5 years are averaged. Therefore, the grade and score include cumulative data and are updated annually to improve the model for further research. A higher hazard impact score is allocated to a higher risk grade. By aggregating three indicators from grid to grid, the exposure impact score is obtained in the same grid format.

Figs. 3., 4., 5. present examples of the scoring of each exposure indicator by location. A larger unit of data, for instance, E_1, is separated into smaller units (1 m) for data aggregation. Data based on building units (E_2, E_3) is converted into a projection above the 1 m grid for the aggregation. The data on vulnerability and management indicators are processed using a similar method.

The available data on hazard indicators, i.e., precipitation data, cannot be processed by location due to its geographical

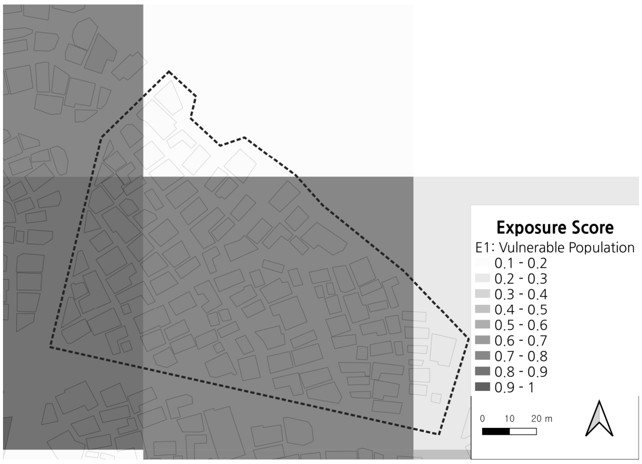

Fig. 3. Example of risk impact score by location of E_1 Vulnerable population

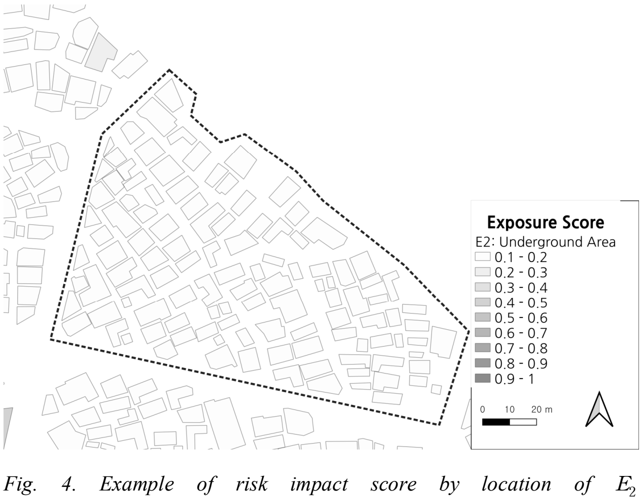

Fig. 4. Example of risk impact score by location of E_2 Underground area

homogeneity. As revealed by Table 3., it is impossible to differentiate precipitation data by location. Thus, this study differentiated precipitation data by time rather than space, as the hazard impact of rainfall varies by season rather than location. Consequently, the hazard indicator scores are separated by month, rather than being applied to a 1 m spatial grid.

Fig. 5. Example of risk impact score by location of E_3 Building age

Table 3. Example of Grading and Scoring of Hazard Indicators

	Hazard Indicators		
Score	Avg. daily precipitation (mm)	Number of Heavy rainfall warnings	Hourly maximum precipitation (mm)
1	25.065~	2.7~	58.95~
0.9	25.065	2.7	58.95
0.8	22.28	2.4	52.4
0.7	19.495	2.1	45.85
0.6	16.71	1.8	39.9
0.5	13.925	1.5	32.75
0.4	11.14	1.2	26.2
0.3	8.355	0.9	19.65
0.2	5.57	0.6	13.1
0.1	~2.785	~0.3	~6.55

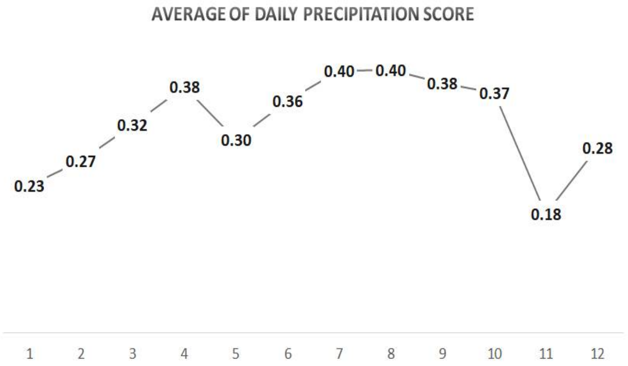

Fig. 6. Average daily precipitation by month

Fig. 6. shows H_1 score by month. The scores were obtained by averaging the precipitation data of the last 5 years. As empirically known, the hazard impact score of the summer is significant compared to that of the winter. The monthly hazard impact scores are homogeneously allocated to entire cells of the grid, and the risk assessment model calculates the time-differentiated result of the risk impact score for rainfall disaster.

3.4. Evaluation

Fig. 7. shows the risk analysis calculation process. The score of each grid of the indicator is calculated linearly using Eq. 1. How the hazard indicator is differentiated depends on seasons, so the final result is differentiated based on the month of the hazard indicator. Finally, the calculated score, which quantifies the risk assessment for each area, is allocated to the grid corresponding to the research site.

The final result is a risk impact score for every 1 m by 1 m grid cell of the case study site. The result can be used to obtain a risk impact score for a finely segregated district in a small area.

4. Result

Fig. 8. shows the result of rainfall disaster risk assessment calculated using Eq. 1. Cells with higher scores are darker. The figure shows rudimentary findings. 1) The cells containing older buildings, where a more vulnerable population resides, have the highest risk scores. 2) Risk impact is mitigated by the presence of trenches. 3) Depending on the residents and the buildings, the risk impact differs even between adjacent cells. Given the above findings, the results of the model are sufficient to visualize the risk impact score of a small area in a declining city with fine resolution.

Fig. 9. shows the results of the hazard impact model for the month of January. Overall, the risk impact scores are lower than those presented in Fig. 8. As empirically known, the risk derived from rainfall differs by month, which considered different precipitation and seasonal characters.

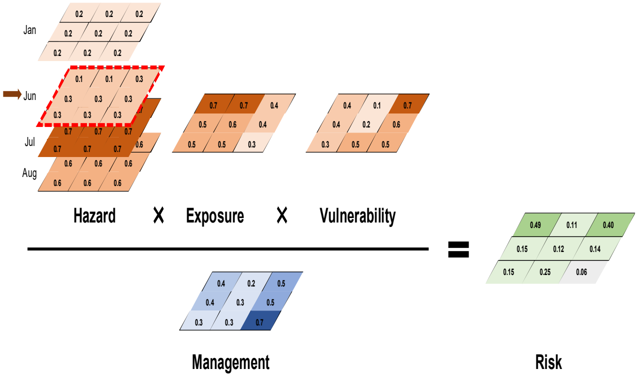

Fig. 7. Geographical evaluation process

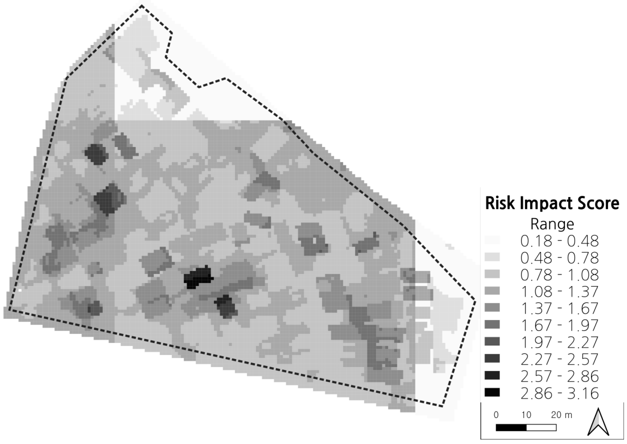

Fig. 8. Risk impact score in August

Fig. 9. Risk impact score in January.

These findings demonstrate that the model provides risk assessment for rainfall disaster in a small declining area at fine resolution. Moreover, the risk of rainfall disaster is time-differentiated, as shown by a comparison between Figs. 8. and 9. This study shows that the risk of rainfall disasters can differ even in a small area, and a declining city is at greater risk of rainfall disaster due to its vulnerable population and deteriorating physical infrastructure.

5. Discussion

Fig. 10. shows the calculated risk impact scores in a 10 m grid of rainfall for a small area in this declining area. According to this evaulation, three high risk areas are determined within the boundaries. Given the conditions in the area, risk impact scores would be useful to establish redevelopment strategies and hiearachies. Additionally, the risk impact scores are different in months. For example, Figs 8. and 9. shows that the risks in August are much higher than those in January. Thus, this risk impact scores are useful criteria to improve this small declinig area.

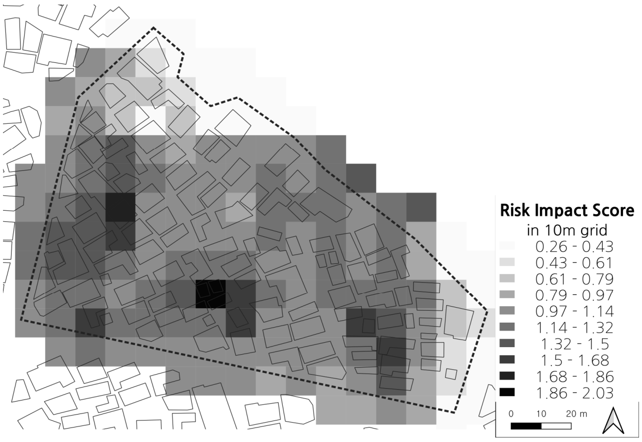

Fig. 10. Risk impact score in a 10m grid in August

However, the developed model addresses the limitations of previous research on disaster risk assessment in urban spaces. 1) The model is specialized for a declining city. Naturally, the model can also be used to inform urban regeneration projects, as it emphasizes the vulnerability of deteriorated physical environments and the social structure in deteriorating areas, specifically for rainfall disaster. 2) The model enables practical assessment of the local context. Unlike previous studies which focused on assessment of macro-scale urban areas, this study calculates risk in finer units. Thus, the developed model is more applicable to a small area. 3) The model includes indicators of the state of the physical environment as well as social impact to evaluate the risk of rainfall disaster. Deteriorating physical infrastructure tends to be ignored in traditional definitions of a declining city that emphasize, for instance, demographic data and economic activity. The appropriate mix of two considerations enables a plausible assessment of a declining city.

6. Conclusion

This paper establishes an evaluation model of risk assessment for rainfall disaster in a small area in a declining city. The model is based on the risk assessment model suggested by IPCC. The indicators used in the model are selected with an emphasis on applicability to a micro-scale targeted area. The indicator data are aligned by GIS and rasterized. The improved model grades the data based on the maximum and minimum observed values; scores were produced that numerically quantify the risk of the area. Consequently, the risk assessment result for a small area is evaluated with a numerical score and visualized on 1 m and 10 m grids using GIS. The conclusions of this paper are applicable to establishment of regeneration projects in declining cities. In particular, the model is useful because it is resident-friendly and suitable for micro-scale evaluation.

This study can be improved for further research. The integrated results of risk impact score in a 10 m grid suggest the direction in which this study, based on locality, could possibly be expanded to a much larger area in future studies. Moreover, a risk assessment model for snow, heat wave, or earthquake can be developed based on the rainfall model presented in this paper. Accordingly, a follow-up study will be conducted on evaluation models for various disasters. On the other hand, the model has some limitations involving the methods used to weight and calculate the results. Further research on the adjustment of indicator weights and scores is necessary to address these limitations.

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