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Simplified Methodology for Urban Flood Damage Assessment at Building Scale using Open Data

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ABSTRACT

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Flooding is a hazardous natural disaster that causes extensive damage to people and infrastructure, especially in cities. Since the content and scope of public data disclosed by each country and city differs, general flood damage assessment methods have not yet been developed. In other words, flood damage assessment methods need to be tailored to each city's public data. This study developed a methodology to easily estimate flood damage based on public data. The method can be applied to various situations and locations. The proposed urban flood damage assessment method uses a geographic information system (GIS) and open data at building scale to provide detailed damage information. Flooded areas are established using GIS, and building inundation heights are obtained from the flood map. Economical losses are derived from inundation data by calculating numbers of loss for residential buildings, industrial buildings, and human life. To validate the proposed method, a simulation using probabilistic flood map in the Masan Bay area, Republic of Korea, was conducted. In the simulation, recently published building and census data were used. The urban flood damage assessment was performed using a 200-year return period coastal flood scenario. The simulation results show that the proposed assessment method provides more detailed information on damage at the building level than regional scale damage assessment results. The results confirm the potential to improve policy decision-making and to reduce the detrimental impacts of urban flooding by adopting the proposed assessment method.

ADDITIONAL INDEX WORDS: *Flood, damage assessment, Risk, Open data, GIS.*

INTRODUCTION

Floods can cause severe damage to urban environments, both socially and economically (Brody *et al.*, 2008; Motevalli and Vafakhah, 2016). Urban flood damage assessment involves estimating the damage associated with floods that have occurred or might occur in the future. This information plays a pivotal role in supporting decision-making and policy development in the field of natural disaster management and adaptation (Merz *et al.*, 2010). Moreover, flood damage assessment is used to estimate the cost of reducing damage caused by inundation (Smith, 1994). The details of its application differ, but damage assessment can be utilized in all aspects of disaster management, such as preparedness, mitigation, response, and recovery. In particular, the evaluation of the economic damage caused by a flood provides information for flood risk management, which is used in flood control policies.

Methodologies for predicting and evaluating flood damage using public data have been studied by a number of researchers (Choi and Ahn, 2008; Shimokawa *et al.,* 2016), such as Japan's disaster information system (DIS) and Taiwan's Hazard Assessment. The United States Federal Emergency Management Agency (FEMA) performs flood damage assessment using Hazus-MH (multi-hazard) based on GIS. Hazus-MH supports prevention, response, and recovery plans for disasters, and produces regional scale outputs (Scawthorn *et al.*, 2006). In Korea, flood damage assessment utilizes Multi-Dimensional Flood Damage Analysis (MD-FDA), which was proposed by the Minister of Land, Infrastructure, and Transport in 2004 (Ministry of Construction and Transportation, 2004). However, these evaluations are performed at a local scale and systematic and scientific damage assessment is still lacking (Choi *et al.*, 2013).

The important parameters of urban flood damage assessment are spatial information and public data. Public data are those collected by public institutions, as prescribed by legislation, for public purpose. In this study, open public data is defined as open data. In a democratic society, access to public data is needed in order to retrieve information on government policies and progress. Efforts to open public data are being made across the world, as monitored by the Open Data Barometer (Davies *et al.*, 2015). By using open data, more universal flood damage assessment methods can be developed.

An urban flood damage assessment methodology that provides outputs at the building scale by utilizing open data was developed in this study. The method provides more detailed information than regional scale analyses by converting property and human losses into building scales. For detailed analyzation, building damages and human losses are calculated with the inundation height of buildings. Providing an urban flood damage assessment at the building scales helps to determine more about flood conditions

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and provides information for disaster policy decisions. The applicability and effectiveness of the proposed urban flood damage assessment method was evaluated using a case study from the Masan Bay area, South Korea, where Typhoon Maemi caused significant damage on 12 September 2003. It was found that the proposed assessment method can provide detailed information on damage at the building level from the simulation results. The approach shows potential to improve policy decision-making and reduce the detrimental impacts of urban flooding in comparison with regional scale damage assessment results.

METHODS

Overall procedure of flood damage assessment

Damage from flooding is controlled by factors such as inundation height, duration, velocity, and debris flow, among which the effect of inundation height is the greatest (Kreibich *et al.*, 2009). To evaluate economical losses from urban flood damage in building units, the following indicators should be considered: damage ratio of buildings, building damage costs, flood victims, damage costs of industry, and costs of casualties. In other words, the economic loss caused by floods is calculated by summation of property damage costs and human loss costs. The property damage costs include damage of the building itself, building contents, industries, and infrastructures. Human loss costs incorporate personal losses and the economic losses of flood victims. Figure 1 is a schematic illustration that shows how the census data is converted to building scale information. The information for buildings such as location, area, number of floor, and usability; and the population have been used to calculate economical losses due to the flood damage.

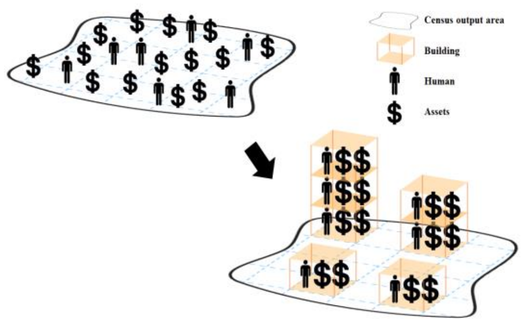

Figure 1. Conversion of census data to building units

The severity of building damage (*i.e.*, the damage rate) plays an important role in urban flood damage assessment. This study utilized with a relationship between inundation height and building damage from Lee *et al.* (2013), which combined insurance records and the flood damage curve. The cost of flood damage to buildings (D_{BI}) is calculated based on the cost of rebuilding, construction costs per unit area in square meter, and the cost ratio for different building construction methods or materials.

Since building contents are damaged as well as the building itself, the economic value of building contents should be also considered in urban flood damage assessment. Consumer durables data information includes furniture and furnishings, household appliances, personal transport equipment, and video-audio and communication apparatus. The consumer durables asset per capita was calculated by dividing the total value of consumer durable assets by the national population. Building contents damage (D_{BC}) was calculated as shown in Equation (1).

$$D_{BC} = \text{Building damage rate} \times \text{Consumer durables asset amount per person} \times \text{Building population} \quad (1)$$

In (1), the building population is calculated from building and census information as shown in (2)

$$\text{Building population} = (\text{Total area of a building} \times \text{Population of census output area})/(\sum \text{Gross floor area of each building}) \quad (2)$$

The area used to calculate the density of the building population, which was assumed to cover the same area as the census output area, is converted based on the area of the building.

Industry can also be damaged when flooding occurs. The industrial assets per building unit can be calculated as follows:

$$\text{Industrial assets per building} = (\text{Total area of a building} \times \text{Productive asset of census output area})/(\sum \text{ the total floor area of buildings in census output area}) \quad (3)$$

where, the total productive assets per unit area can be calculated as the sum of the number of businesses in the census output area and the productive assets of each industry. After calculation, industrial assets per building and the cost of inundation damage on the industry (D_{ID}) can be calculated by (4).

$$D_{ID} = \text{Building damage rate} \times \text{Industrial assets per building} \quad (4)$$

Flood victims were assumed to occur when damage was caused to buildings. The population at each floor, including the basement, was calculated and considered as the flood victims. For calculation of damage due to infrastructure (D_{IS}), rate of public facilities per building in nationwide or metropolitan city has been used. The economic losses of the flood victims (D_V) is calculated by (5).

$$D_V = \text{Victims} \times \text{Evacuation Days} \times \text{Average Daily Income} \quad (5)$$

Human loss (D_H) due to mortality and missing persons is calculated by considering the rate of number of deaths per victims as shown in (6).

$$D_H = \text{Cost of loss (won/person)} \times \text{Casualties (person)} \quad (6)$$

Flood Damage Assessment Utilizing Open Data

Open data is one of the most important parameters in flood damage assessment. For calculations of urban inundation damage, sum of property damage and human loss, building and census data have been used. Table 1 describes the correlation between inundation height and damage rate applied in this study. The calculation of damage rate is modified from the methodology which is suggested by Lee *et al.* 2013 (Lee *et al.* 2013). It can be seen that the damage rates of houses and other buildings are different. And also, as the inundation height of the building increases, the damage increases. When the inundation height is less than 0.15 m, it is assumed that no building damage is caused. If the building has a basement, it is assumed that 100 % damage is caused to the basement when flood depth was over than 0.15 m. The cost of flood damage to buildings is calculated based on the cost of rebuilding, with reference to MOLIT Notice No. 2015-633 (Ministry of land and Transportation, 2015).

Table 1. *Relationship between inundation height and building damage rate (n=No. of floor)*

Inundation Height (m)	Housing	Other Building	Inundation Height (m)	Housing	Other Building
0-0.15	0/*n*	0/*n*	1.25-1.55	0.53/n	0.40/n
0.15-0.35	0.22/*n*	0.22/*n*	1.55-1.85	0.59/n	0.43/n
0.35-0.65	0.32/*n*	0.30/*n*	1.85-2.15	0.63/n	0.52/n
0.65-0.95	0.40/*n*	0.31/*n*	2.15-2.4	0.71/n	0.53/n
0.95-1.25	0.47/*n*	0.32/*n*	>2.4	0.73/n	0.54/n

The economic value of building contents is expressed by reference to consumer durables data from the National Wealth Statistics report produced by Statistics Korea (KOSTAT, 2011). The consumer durables asset amount per person was calculated as 3,867,863.96 won (KOSTAT, 2011). Data from the National Wealth Statistics report on the productive assets of different industries in Korea, along with census data on the number of industries in census output areas (KOSTAT, 2011), are used to calculate the productive assets per industry. The industrial assets per building unit are calculated using the data in Table 2. The cost of damage to infrastructure is calculated as the rate of building damage, and the death toll is calculated as the victim occurrence rate, which is shown in Table 3. Losses due to death and casualties per missing persons are estimated at 250 million by reference to the MD-FDA (Ministry of Construction and Transportation, 2004).

Table 2. *Productive assets per industry. Original data from Statistics Korea (KOSTAT, 2011)* *units: Million won*

Industry	Productive Assets/Number of Industrial Units
Agriculture, Forestry and Fisheries	57,539
Mine	2,445
Manufacturing	2,528
Electricity, Gas, and Water supply	100,926
Construction	1,547
Wholesale and Retail Food Hospitality	193
Transportation and Storage	419
Publishing Video Broadcast Communications and Information Services	5,175
Finance and Insurance	1,474
Real Estate and Leasing	6,275
Business Services	573
Public Administration and Social Security	39,607
Education Service	695
Health and Social Services	513
Arts, Sports and Leisure Related Services	409
Other Services	218

Table 3. *Rate of building damage and victim occurrence rate, based on data from 2005 to 2014*

	No.Deaths/No.Victims	Public Facilities/Buildings
Nationwide	0.002429	32.1697
Metropolitan	0.000369	7.7661

RESULTS

Application of Urban Flood Damage Assessment Method

The proposed urban flood damage assessment method was validated using a case study from Masan Bay, South Korea, which was subject to severe storm surge inundation caused by Typhoon Maemi in September 2003 (Shim *et al.*, 2013). Masan experienced much damage due to the flooding, and many previous studies have focused on the event (Kang *et al.*, 2009; Shim *et al.*, 2013).

GIS and Flood Map of Masan Bay

Masan Bay is located in Changwon southeast South Korea (see Figure 2). A GIS was established in the surrounding area using a digital elevation model (DEM) with resolution of 90 m as a basis. Building and road information from MOLIT, and census information from KOSTAT, were input into the GIS. The GIS and satellite image of the Masan Bay area are shown in Figure 2 and census data on building population and industry properties are shown in Figure 3, respectively.

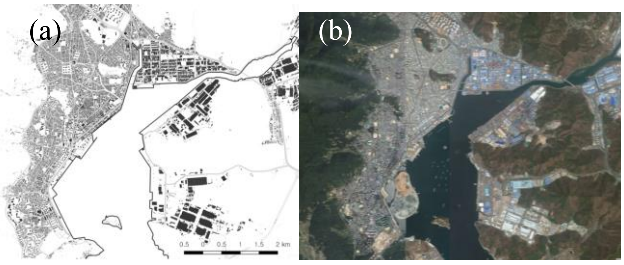

Figure 2. Masan Bay area. (a) GIS of the Masan Bay, (b) Google satellite image of Masan Bay

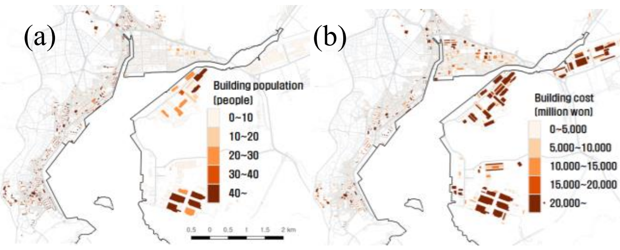

Figure 3. Building population and cost per building unit. (a) Building population, (b) building cost

The building information from MOLIT contains information on location, building area, gross floor area, and number of floors; however, it does not include census information. The building population and industry properties are shown as building units in Figure 3, using the methodology outlined in the previous section.

Flood maps, including past, future and probability maps, are required in order to perform urban flood damage assessment. This research utilized the coastal inundation prediction map produced by the Korea Hydrographic and Oceanographic Agency (KHOA, 2015). The coastal inundation map is designed to predict potential inundated regions and flooding depth in response to flooding by typhoons, heavy rainfall, and surge and hydrological factors including dam failure, and reservoir and dike overflow (KHOA, 2015). Figure 4 shows a 200-year return period coastal inundation map for Masan Bay (KHOA, 2015).

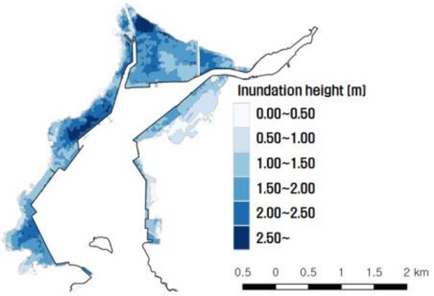

Figure 4. Two hundred-year return period coastal inundation map of Masan Bay, based on data from the Korea Hydrographic and Oceanographic Agency (KHOA, 2015)

Results of Masan Bay Flood Damage Assessment

Based on the aforementioned data, results of the urban flood damage assessment for Masan Bay, based on the 200-year return period coastal inundation event, are shown in Figure 5.

DISCUSSION

A total of 7,173 buildings were flooded when the 200-year return period event scenario was applied to Masan Bay. Building damages were greater in areas with greater inundation height, and taller buildings experienced less damage for the same inundation height. The total number of victims was estimated as 12,327, and the dead and missing estimated as 30. Economic losses associated with the event are summarized in Table 4. Figure 5 shows that the proposed urban flood damage assessment methodology provides more detailed information on the extent of flood damage than a regional scale approach, including building damage, inundation of roads, and location of victims. The urban flood damage assessment methodology provides valuable information for mitigating flood damage in a city, and it is more appropriate for identifying vulnerable areas or buildings.

Table 4. *Costs of damage due to buildings and human losses*

Property Damage Costs (won)	Building Damage	2,167,283
	Contents Damage	47,671
	Industrial Damage	3,042,492
	Infrastructure Damage	69,719,352
	Sum	74,976,798
Human Loss Costs (won)	Economic Loss of Victims	8,140
	Losses Due to Deaths and Casualties	7,489
	Sum	15,629

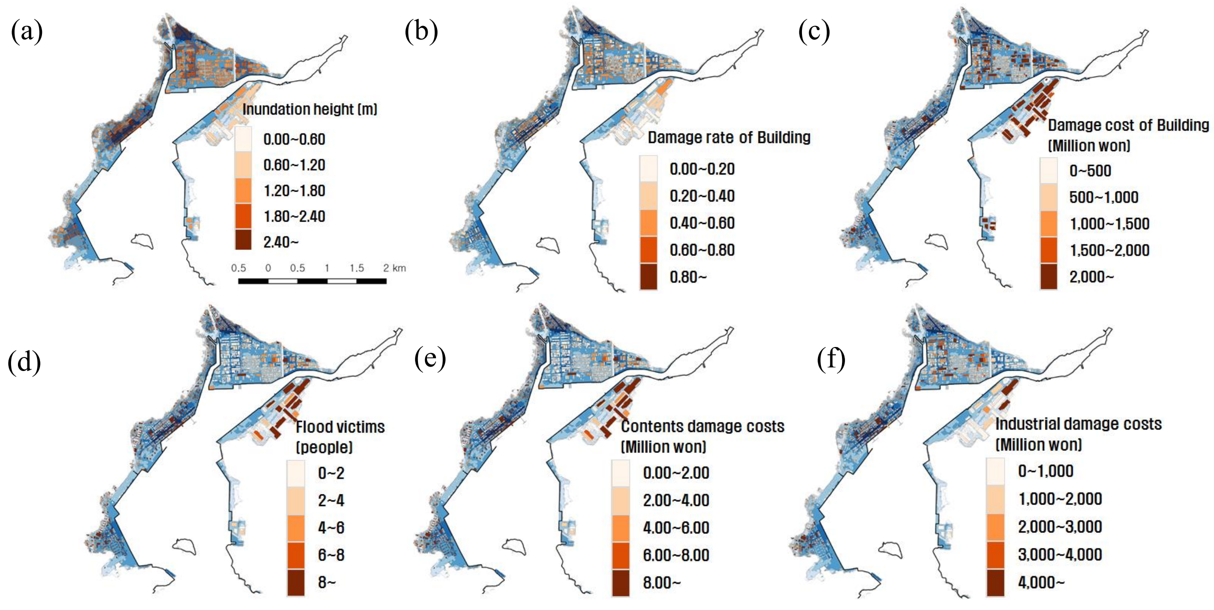

Figure 5. Results of urban flood damage assessment for Masan Bay based on a 200-year return period coastal flooding event. (a) Inundation height; (b) building damage rate; (c) building damage cost; (d) number of flood victims; (e) cost of damage to building contents; (f) industrial damage costs

As shown in the results, the proposed urban flood damage assessment methodology successfully calculated the damage caused by coastal flooding in Masan Bay. The urban flood damage assessment is expressed at the building scale, but it is also possible to aggregate the results at a regional scale. The detailed information relevant to all steps in disaster management has a potential to improve decision-making in natural disaster management and adaptation planning.

CONCLUSIONS

This study developed an urban flood damage assessment methodology that gives results at the building scale, which can be used to mitigate flood damage and improve decision-making. The proposed method evaluates the damage rate of buildings, building damage cost, industrial damage cost, and flood victims using open data. The methodology was verified using an assessment of urban flood damage in the Masan Bay area using a 200-year return period coastal inundation map, provided by KHOA. The results demonstrated that the proposed urban flood damage assessment methodology is able to simultaneously deliver information about flood damage at the building scale and the regional scale. It also confirmed that the building scale used in the proposed methodology delivers more detailed information on flood damage than a regional scale approach; therefore, it has great potential to provide sufficiently detailed information to improve disaster management and policy decisions for mitigating urban flood damage.

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