Desalination and Water Treatment
www.deswater.com

doi: 10.5004/dwt.2018.22154

119 (2018) 27–35
July

Vulnerability analysis of urban district on the urban flood damage: a case study—Changwon

Ki-Yong Park*, Man-Hyung Lee

Department of Urban Engineering, Chungbuk National University, Chungdaero 1, Seowon-Gu, Cheongju, Chungbuk 28644, Korea, email: pky3489@gmail.com (K.-Y. Park)

Received 19 December 2017; Accepted 23 February 2018

ABSTRACT

Influenced by recent climate change, urban disasters have increased in scales and diversified in types. Such trend has urged the importance of urban prevention schemes. In this study, risk against urban flood damage in case of local downpour in highly concentrated urban areas is classified based on each use district to effectively cope with such disaster events. For city of Changwon, Korea, risk against economic and social damage of urban flood is classified for each use district by applying a fuzzy model using relevant district data that provide institutional bases of land use, data of land price and land areas that estimate the property values, data of underground space that is expected to have the greatest flood damage, and the data of model year of buildings that influence the vulnerability to flood damage. Analysis result for the districts of Changwon city shows that the highest flood damage was in central commercial areas, followed by general commercial, semiresidential, distribution commercial, neighborhood commercial, private residential, general residential, industrial, and green areas, because commercial areas have the highest density of buildings and the highest land values per unit area. This study has a unique research value because not only could it be used as data designing future land-use and urban planning, but also it proposed a mitigation plan against urban flood under climate change by variating land uses.

Keywords: Climate change; Flood damage; Land use; Urban flood; Use district

1. Introduction

There exists near unanimous scientific consensus that the rising atmospheric concentration of greenhouse gases due to human actions will cause warming (and other climatic changes) at Mother Earth's surface. The Intergovernmental Panel on Climate Change, drawing on the published results of leading modeling groups around the world, forecasts an increase in world average temperature by 2100 within the range 1.4°C–5.8°C [1].

The increase would be even greater at higher latitudes and over land. Global average annual rainfall will increase, although many mid latitude and lower latitude land regions would become drier, whereas elsewhere precipitation events (and flooding) could become more severe. Climate variability is expected to escalate in a warmer world.

Climatological research over the past two decades makes clear that Mother Earth's climate will vary in response to atmospheric greenhouse gas accumulation. The unusually rapid temperature rise (0°C–5°C) since the mid-1970s is substantially attributable to this anthropogenic increase in greenhouse gases [2].

In view of greenhouse gas longevity and the climate system's inertia, climate change would continue for at least several decades even if radical international preemptive action were taken very soon [3].

In the first decade of the 21st century, adaptation to climate change has risen sharply as a topic of scientific inquiry,

* Corresponding author.

Presented at the 10th International Desalination Workshop (IDW 2017), November 22–25, 2017, Busan, Korea.

in local to international policy and planning, in the media, and in public awareness [4].

Trends in natural disasters show they are continuously increasing in most regions of the world. Among all observed natural and anthropogenic adversities, water-related disasters are undoubtedly the most recurrent and pose major impediments to the achievement of human security and sustainable socioeconomic development.

During the period of 2000 to 2006, a total of 2,163 water-related disasters were reported globally in the Emergency Disasters Database [5], killing more than 290,000 people, affecting more than 1.5 billion, and inflicting more than US$422 billion of damage.

The frequency of natural disasters between 1990 and 2006, particularly water-related disasters, has increased markedly as has the estimated economic damage they cause. Extreme events have also become more frequent. Between March 1900 and March 2007, 16,301 disaster events were recorded throughout the world and 6.27 billion people were affected; fatalities were more than 37.58 million, and the estimated economic damage was more than US$1,790 billion. Disasters triggered by hydrometeorological events outnumbered all other disasters combined. Floods, droughts, and windstorms have been the most frequently occurring disaster events since 1900. They account for 88.5% of the thousand most disastrous events. More than 83% of flood-related disasters occurred in Asia. The number of fatalities per decade has shown a continuous decrease from nearly 2 million people in the 1960s to half a million in the 1990s [6].

These facts simply mean that more must be done to mitigate natural disasters—particularly future water-related disasters, given the catalyzing effect of climate change [7].

Land-use law (*Derecho urbanístico*, in Spanish, or *Droit de l´urbanisme*, in French) deals with the regulation of land use. There is a clear relationship between the use of land and disasters. On one hand, the regulation of land can allow urban expansion by means of several instruments (plans, zoning), and urban expansion can bring intensive use of land, industrial development, and construction of infrastructures which can be a factor in future disasters. A good example of this is urban pressure on rivers and flood risks. But, on the other hand, the proper regulation of land can be a preventive tool of disasters, by preventing disasters from happening and by minimizing their impacts when disasters are unavoidable. That point of view has not been traditionally explored in depth by European jurisprudence [8]. That is the perspective the authors want to study in this work.

Therefore, this study intends to derive measures to reduce flood damage in land use and building parts reflecting urban planning characteristics. Main purpose of this study is not only post-disaster treatment but also protection of vulnerable areas by analyzing the causes of urban flooding using use district as an evaluation unit and classifying urban flood risks to generate priorities in flood response. To create a city that is safe from disaster, a city planning system should be developed from the stage of establishing urban planning to the area vulnerable to flooding in heavy rainfall. For this purpose, we need to analyze the risk of flooding due to climate change and build a disaster prevention urban planning system. The purpose of research is shown in Fig. 1.

2. Methods

This study will focus on the following contents.

First, to overcome the limit of short-term structural measures in urban flooding issues, a long-term nonstructural mitigation measures in urban planning perspectives especially in terms of use district[1] which is an institutional base for land use and building characteristics are focused. Second, urban damage from storm and flood among various urban disasters is focused. As shown in the research need and background, damage from storm and flood that have been intensified and frequently occurred is focused in this study. Third, the scope of the study is limited to the urban area, and the micro space in the usage area is emphasized in the urban area. Although urban disaster prevention was targeted for the whole city and the "administrative plan and use law" was enacted to cover the entire administrative districts in urban planning, this study is to investigate highly populated urban areas to formulate urban planning countermeasures to urban disasters. In the meantime, as the importance of urban planning reflecting both regional and entire urban characteristics is highlighted, land-use planning can be appropriately adjusted to prevent such urban disasters in advance. Therefore, this study aims to evaluate and analyze the risk of flooding in urban areas using use district as a spatial unit.

The basic concept of this study is to allocate less vulnerable areas to areas with higher flood risks, more vulnerable areas to lower flood risks, simultaneously considering local characteristics. The principle of this concept is shown in Fig. 2.

2.1. Causes of flood damage

The cause of flood damage and the influence factors can be classified as in Fig. 3. According to analysis perspectives and precision, it can be classified into natural factors such as rainfall and terrain conditions and social factors such as land use (use district) conditions, and facility factors such as disaster prevention facility conditions and drainage facility conditions. Interaction of these factors affects hydrological and hydraulic characteristics to cause flooding damage. Hydrological and hydrological factors include flood depth, flood duration, flow velocity, flood wave, and soil entrainment [9].

2.2. Analysis area

The distribution of flood damage in Korea analyzed by Korean Ministry of Land, Infrastructure, and Transport is shown in Fig. 4 [10], and Changwon city is selected as the target area for its advantages of data construction because it includes areas with both high and low flood damage.

Changwon city is has become one of the first successful administrative integration models in the nation as it integrated Changwon, Masan, and Jinhae cities in July 2010, and it is becoming the first growth base of the southeastern greater economic zone in Korea. The administrative district consists of five districts of Masanhappo-gu, Masan

---

1 By restricting land and building use, floor area ratio, building coverage ratio, height, etc., land could be economically and efficiently used, and area that prevents ineffective overlapping by urban planning and management schemes in order to promote public welfare.

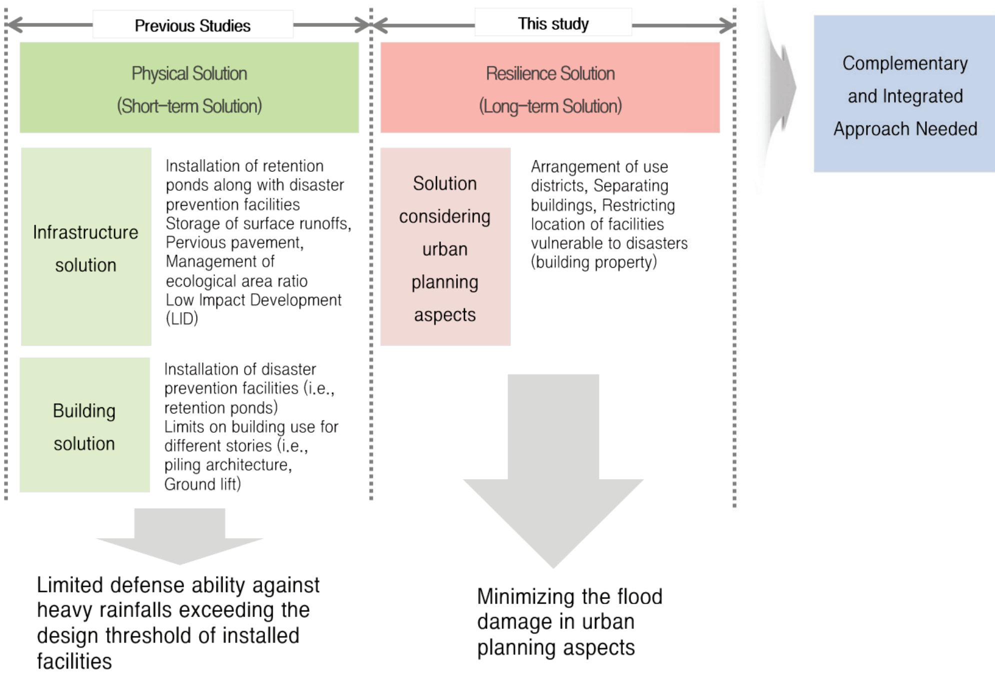

Fig. 1. Research purpose.

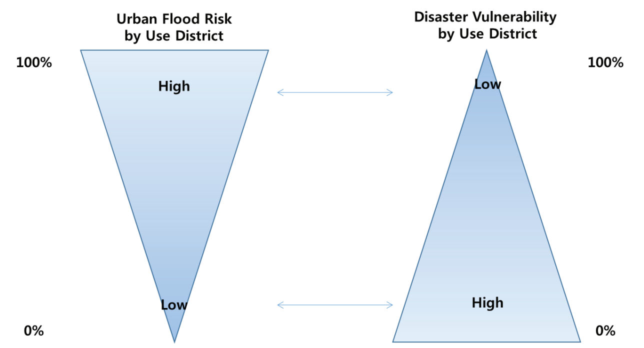

Fig. 2. Basic concept of space allocation considering urban flood risk and disaster vulnerability for each use district.

Hwewon-gu, Seongsan-gu, Euchang-gu, and Jinhae-gu, 351 legal smaller districts, and 62 administrative smaller districts. The administrative area of Changwon City is 746.58 km^2.

As a result of examining the land use situation from 1975 to 2007, using the land cover map of Changwon city, urbanization rate greatly increased from 3.95% in the 1990s to 13.61% in recent years. Especially, as Changwon City Hall is located in Seongsan-gu, development of commercial and residential areas has increased the flood risk by increasing impermeable land areas. In addition, countermeasure to flood damage in Changwon city is needed because urbanization rate is planned to increase from 14.13% in 2020 to 15.72% in 2025 [11] according to the step-by-step development plan of Changwon City Basic Plan 2025. In response, the risk grading according to flood damage was analyzed in Seongsan-gu of Changwon city.

The use district in Changwon city basic plan is shown in Table 1. The urban area is 466,228 × 10^3 m^{-2}, 54.5% of the total, administrative area 83,111 thousand/m^2 (9.7%), agricultural area 181,683 × 10^3 m^{-2} (21.3%), and natural environment preservation area is 105,408 × 10^3 m^{-2} (12.3%).

2.3. Evaluation item

Objective indicators and values were calculated to analyze the risk of flooding. Each indicator is selected based on the following standards.

Land price for each use district provided by Korea Appraisal Board is considered an important indicator of flood damage because property damage is the major loss in case of flood [12]. As Ministry of Construction and Transportation established a long-term water resource use planning in 2001, local characteristics of water resource were carefully examined to identify investment priority in watershed planning and development. As a result, potential flood damage was estimated, which property value plays an important role [13]. In the research of Han [14], correlation between various indicators of flood vulnerability and the damage costs for flooding from 1971 and 2000 in different watersheds was analyzed. As a result, property density had a significant correlation with the damage cost of flooding, a result attributed to the estimation method of flood damage cost largely reflecting the land price [14].

The underground space index is directly related to the flood reference system to prevent building submergence within the flood-water disaster prevention criterion for buildings [15]. In a study of Jang [16], the vulnerability of buildings due to flooding was found to be closely related to the presence and size of underground space. The top 10 items with the greatest damage were the place where there are significant portions of underground space while the bottom 10 items had no underground space. Therefore, the size of underground space was important for determining the vulnerability of buildings. Also, it is considered that rainwater

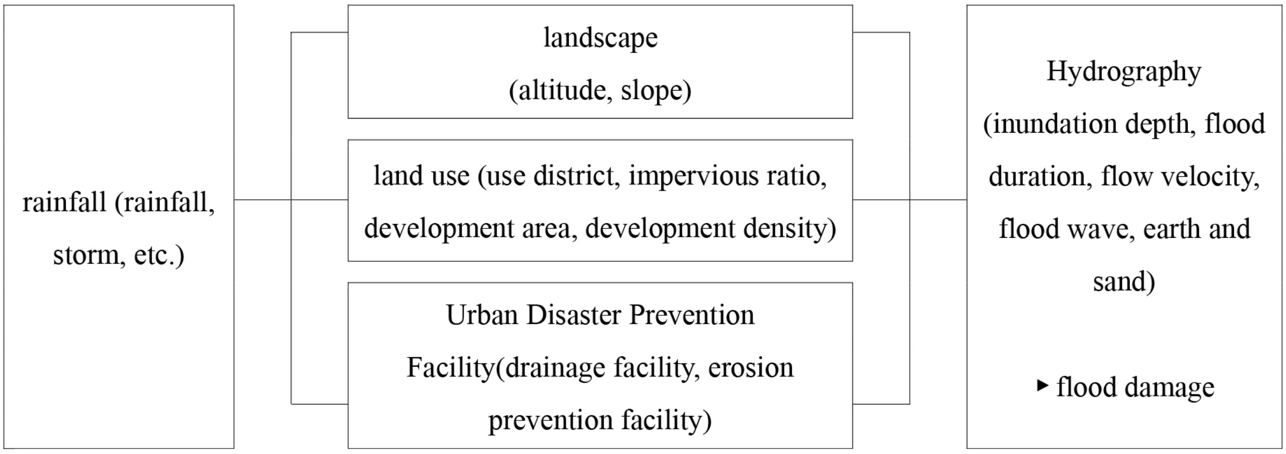

Fig. 3. Influence factors of flood damage.

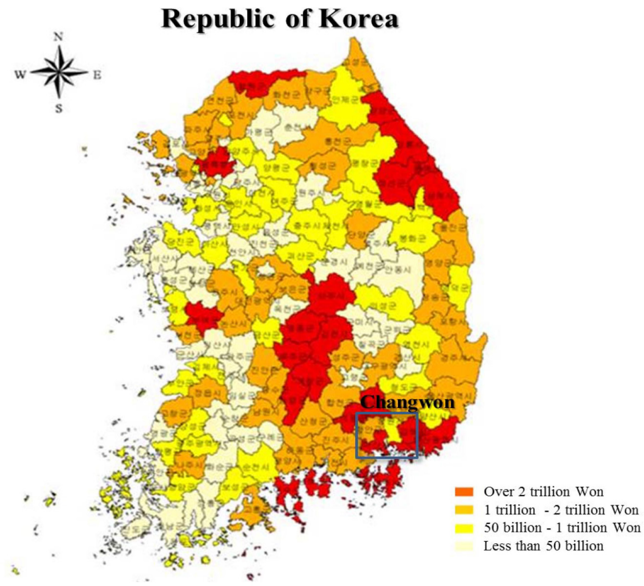

Fig. 4. Distribution of national flood damage in Korea.

adversely affects the building structures by moisture, warping, cracks, and corrosion when rainwater fills the underground space or penetrates through the wall [16].

Floor area ratio is a concept of disaster that collectively refers to the case where urban spaces lose their function and damages are multiplied due to high density. Because of the high utilization of urban space, complex factors such as underground space and human instigate unpredictable large-scaled disasters. In the United States, Community Rating System, which was established in 1990 to operate the flood insurance system, must evaluate the building height issued by Federal Emergency Management Agency among 19 items. Because the damage is expected to vary depending on the area and density of the building, the indicators are selected by considering urban functional damage [12].

Mode year of the building shows that the incidence of accidents is frequent as the durability reaches to the limit. Also, development-centered paradigm of urban planning has escalated an event to a series of failures, resulting in a disaster. Therefore, urban disasters have a high potential to result in collective paralysis of urban functions [13].

Table 1
Current status of Changwon use district

	Area (×10^3 m^{-2})	Proportion (%)
Total sum	854,768	100.0
Sum of urban areas	466,228	54.5
Urban areas		
Residential	57,644	12.4
Commercial	9,383	2.1
Industrial	38,285	8.2
Green	360,461	77.3
Management	83,111	9.7
Agriculture	181,683	21.3
Conservation	105,408	12.3
Undefined	18,338	2.2

Flood depth in relation to land area is the most fundamental indicator in hydrological and hydraulic factors representing the flood damage. As shown in Table 2 [17], the actual flood damage is on underground and up to 50 cm above the ground whereas over 50 cm above the ground is affected by small indirect damages.

2.4. Fuzzy classification

Fuzzy classification is beside neural networks [18] and probabilistic approaches [19] a very powerful soft classifier. As an expert system for classification [20] it takes into account the following:

- uncertainty in sensor measurements,
- parameter variations due to limited sensor calibration,
- vague (linguistic) class descriptions, and
- class mixtures due to limited resolution.

Fuzzy classification consists of an n-dimensional tuple of membership degrees, which describes the degree of class assignment μ of the considered object obj to the n considered classes.

Table 2
Flood damage for a typical residential property

Depth of floodwater	Damage to the building	Damage to services and fittings	Personal property damage
Below ground floor level	Minimal damage to the main building Floodwater may enter basements, cellars, and voids under floors Possible erosion beneath foundations	Damage to electrical equipment and other services in basements and cellars Fittings in basements and cellars may need to be replaced	Possessions and furniture in basements and cellars damaged
Up to half a meter above ground level	Damage to internal finishes, such as wall coverings and plaster linings. Wall coverings and linings may need to be stripped to allow walls to dry out Floors and walls will become saturated and will require cleaning and drying out. Damp problems may result Chipboard flooring likely to require replacement Damage to internal and external doors and skirting boards	Damage to electricity meter and consumer unit Damage to gas meters, low-level boilers, and telephone services Carpets and floor coverings may need to be replaced Chipboard kitchen units are likely to require replacement Washing machines, free standing cookers, fridges, and freezers may need to be replaced	Damage to sofas, other furniture, and electrical goods Damage to small personal possessions Food in lower kitchen cupboards may be contaminated
More than half a meter above ground level	Increased damage to walls, possible structural damage	Damage to higher units, electrical services, and appliances	Damage to possessions on higher shelves

$$f_{\text{class,obj}} = [\mu_{\text{class\_1}}(\text{obj}), \mu_{\text{class\_2}}(\text{obj}), \ldots \mu_{\text{class\_}n}(\text{obj})] \quad (1)$$

Crisp classification would only give the information, which membership degree is the highest, whereas this tuple contains all information about the overall reliability, stability, and class mixture.

Fuzzy classification requires a complete fuzzy system, consisting of fuzzification of input variables resulting in fuzzy sets, fuzzy logic combinations of these fuzzy sets and defuzzification of the fuzzy classification result to get the common crisp classification for map production.

Fuzzy logic is a multivalued logic quantifying uncertain statements. The basic idea is to replace the two boolean logical statements "true" and "false" by the continuous range of [0,...,1], where 0 means "false" and 1 means "true" and all values between 0 and 1 represent a transition between true and false. Avoiding arbitrary sharp thresholds, fuzzy logic is able to approximate real world in its complexity much better than the simplifying Boolean systems do. Fuzzy logic can model imprecise human thinking and can represent linguistic rules.

Hence, fuzzy classification systems are well suited to handle most sources of vagueness in remote-sensing information extraction. The mentioned parameter and model uncertainties are considered by fuzzy sets, which are defined by membership functions. Fuzzy systems consist of three main steps, fuzzification, the combination of fuzzy sets.

In the flood damage risk classification analysis, it is very difficult to quantify and compare the flood damage in commercial and residential areas when the same area is submerged. In other words, it is ambiguous to express the level of flood damage as numerical values. Therefore, to overcome the linguistic ambiguity for decision-makings in previous studies and to analyze complex relationships between different indicators and indices, fuzzy logic method is adopted to perform more objective analysis of flood risk by deriving quantitative and accurate indicators.

3. Results and discussion

3.1. Analysis of land price, land area, and underground space by use district in Changwon city

Changwon is a city where commercial and residential areas have been developed centered on public institutions including Changwon City Hall. Recently, major commercial areas and residential areas have been additionally developed. The reason why the commercial area has higher land price than the industrial area and the green area is the difference in building coverage ratio and the floor area ratio. In general, residential and commercial areas have higher coverage ratio and floor area ratio than green areas. The higher the building coverage and floor area ratio, the higher are the economic benefits from taller buildings.

Data are constructed using individual official land price for each use district proposed by Korea Appraisal Board. Total of 177,193 land price data for each use district for Changwon city are collected. The average land price is the highest in central commercial areas, followed by general commercial, semiresidential, private residential, neighborhood commercial, general residential, distribution commercial, industrial areas, and green areas. Details of the data are shown in Table 3.

Data are constructed using the building register of Changwon city to understand the floor area ratio and underground area for each use district.

Floor area ratio of each parcel of Changwon city was constructed by obtaining 66,269 data. Land use and land ratio are restricted due to characteristics of use district. In general, the average value of the floor area ratio by use district was the highest in commercial areas, followed by residential areas, industrial areas, and green areas.

Among the commercial areas, central commercial area has the highest average floor area ratio, and the distribution commercial area was relatively low. This is because the central business district and the general commercial district, which perform the core functions of the city, are constructed with high-rise buildings to improve the economic efficiency and efficiency of the land, and sales facilities, transportation facilities, and warehouse facilities are the main building components in the distribution commercial areas. Unlike private residential areas and general residential areas, residential areas have relatively high floor area ratio due to facilities that complement the commercial functions such as amenity.

Table 4 shows the details of the maximum, minimum, and average values of the floor area ratio.

The underground space of each parcel of Changwon city was constructed by using 15,021 data. The average value of underground space by use district was the highest in commercial areas, followed by residential areas, industrial areas, and green areas. Industrial area seems to need more underground space to effectively store products, and commercial area many times utilizes underground spaces as parking lots. Table 5 shows the maximum, minimum, and average values of the underground space.

The building decline of each parcel of Changwon city was constructed by using 97,346 data.

The older the model year of the building, the lower is the durability of building. As previously mentioned, Changwon has recently developed central and distribution commercial areas by constructing a large number of new buildings, so the average model year of the buildings is relatively low. However, general residential and general commercial areas include many aged buildings as they have a long history and tradition. The average value of building decline by use district was the highest in commercial areas, followed by residential areas, industrial areas, and green areas. Table 6 shows the maximum, minimum, and average values of the building decline.

3.2. Flood risk classification by use district

Risk classification for the use district is evaluated based on four groups: residential areas (exclusive residential area, general residential area, and semiresidential area), commercial areas (central commercial area, general commercial area, neighborhood commercial area, and commercial area), industrial areas, and green areas. Based on the results, official land price, floor area ratio, and underground space were selected as principal indicators of flood risk. However, considering the difference of the land price, the volume ratio and the importance

Table 3
Land price for each use district

Administrative area (total # of items)	Use district		# of items	Land price (Won/m^2)		
				Minimum	Maximum	Average
Changwon city (177,193)	Residential area	Private residential area	16,766	17,900	1,490,000	766,319
		General residential area	92,094	1,700	3,053,000	416,431
		Semiresidential area	3,891	67,500	3,030,000	898,127
	Commercial area	Central commercial area	172	191,400	1,800,000	1,103,016
		General commercial area	18,049	13,300	5,200,000	940,464
		Neighborhood commercial area	225	127,300	2,331,000	729,673
		Distribution commercial area	195	42,500	1,190,000	294,441
	Industrial area		8,169	1,200	1,320,000	378,731
	Green area		37,632	396	854,700	86,521

Table 4
Floor area ratio for each use district

Administrative area (total # of items)	Use district		# of items	Floor area ratio (%)		
				Minimum	Maximum	Average
Changwon city (66,269)	Residential area	Private residential area	11,552	0.01	383.90	86.95
		General residential area	38,493	0.02	970.92	99.16
		Semiresidential area	2,036	0.56	640.11	146.80
	Commercial area	Central commercial area	80	0.07	908.67	251.47
		General commercial area	7,050	0.04	952.21	211.45
		Neighborhood commercial area	227	3.46	544.76	132.73
		Distribution commercial area	257	0.15	399.75	76.60
	Industrial area		2,344	0.01	439.44	61.16
	Green area		4,230	0.01	522.54	34.31

Table 5
Underground space for each use district

Administrative area (total # of items)	Use district		# of items	Underground area (m^2)		
				Minimum	Maximum	Average
Changwon city (15,021)	Residential area	Private residential area	6,242	2.00	4,677.99	156.41
		General residential area	5,138	1.62	90,831.99	1,028.85
		Semiresidential area	529	30.00	14,969.04	618.39
	Commercial area	Central commercial area	97	233.47	37,965.85	4,130.13
		General commercial area	1,785	7.00	68,438.48	700.16
		Neighborhood commercial area	53	50.56	2,920.28	1,563.74
		Distribution commercial area	78	55.00	9,312.00	1,600.65
	Industrial area		673	6.50	371,071.85	12,177.76
	Green area		426	3.50	38,015.55	1,403.87

Table 6
Decline of building for each use district

Administrative area (total # of items)	Use district		# of items	Underground area (m^2)		
				Minimum	Maximum	Average
Changwon city (97,346)	Residential area	Private residential area	15,925	1	157	21
		General residential area	55,129	1	217	29
		Semiresidential area	3,110	1	107	28
	Commercial area	Central commercial area	135	1	37	22
		General commercial area	9,127	1	167	29
		Neighborhood commercial area	330	1	102	27
		Distribution commercial area	346	1	110	17
	Industrial area		7,059	1	133	16
	Green area		6,185	1	217	27

of the underground space under flooding events, the questionnaire was conducted to group of professionals on the correlations among each factor and their effects on flood risk.

According to Anderson, a small group of 10–15 experts or panels can obtain useful results [21]. To investigate the risk of flooding in urban areas, a group of 15 experts who have more than 10 years of professional experience in various fields such as environment, construction, civil engineering, urban policy, and construction management are surveyed to collect relevant data through direct visit and e-mail.

Determining the importance of the evaluation items is to derive a reasonable and efficient measure of importance and apply it to the site. For this purpose, the survey results from the selected experts are schematized as membership function and analyzed using fuzzy logic as shown in Fig. 5. The analysis result shows that land price is more important than floor area ratio and underground space, and the importance of the underground space is higher than the floor area ratio. Model year of the building has relatively low importance. Implication of the result is that the land price and the underground space are direct indicators of property damage and physical damage in the case of flooding whereas the floor area ratio is directly related to the only corresponding floor and indirectly related to other floors for its inconvenience in urban functional aspects.

This means that urban flood damage is hinged on how much it directly impacts the socioeconomic or physical loss along with how much it indirectly affects the urban functions or convenience of living.

The higher the fuzzy score, the higher is the flood risk level (flood damage is greater), while the lower the fuzzy score, the lower is the flood risk level (no damage). As a result of the fuzzy analysis, the order of flood damage by use district was analyzed as shown in Table 7. The flood damages were prioritized based on the fuzzy analysis. When the same area was submerged, the area with the highest economic and social damage by flood was central commercial area, followed by the general commercial area, semiresidential area, distribution commercial area, neighborhood commercial areas, private residential areas, general residential areas, industrial areas, and green areas.

Changwon city is a new city where commercial and residential areas have been developed centered on Changwon City Hall. In general, fuzzy score was high due to high density of commercial areas, and also the residential areas served with commercial facilities had high fuzzy scores. The reason that the green area has a low fuzzy value is interpreted that the asset value is low and development activity is also unlikely to occur.

In conclusion, it was found that the precautionary measures against flooded areas should be focused on the commercial areas in the urban region and the disaster prevention measures should be prepared. It was also confirmed that the risk of flooding could be reduced by appropriate allocation of green areas.

Based on the results of the final analysis, internal flooding risk classification by use districts in Changwon can be

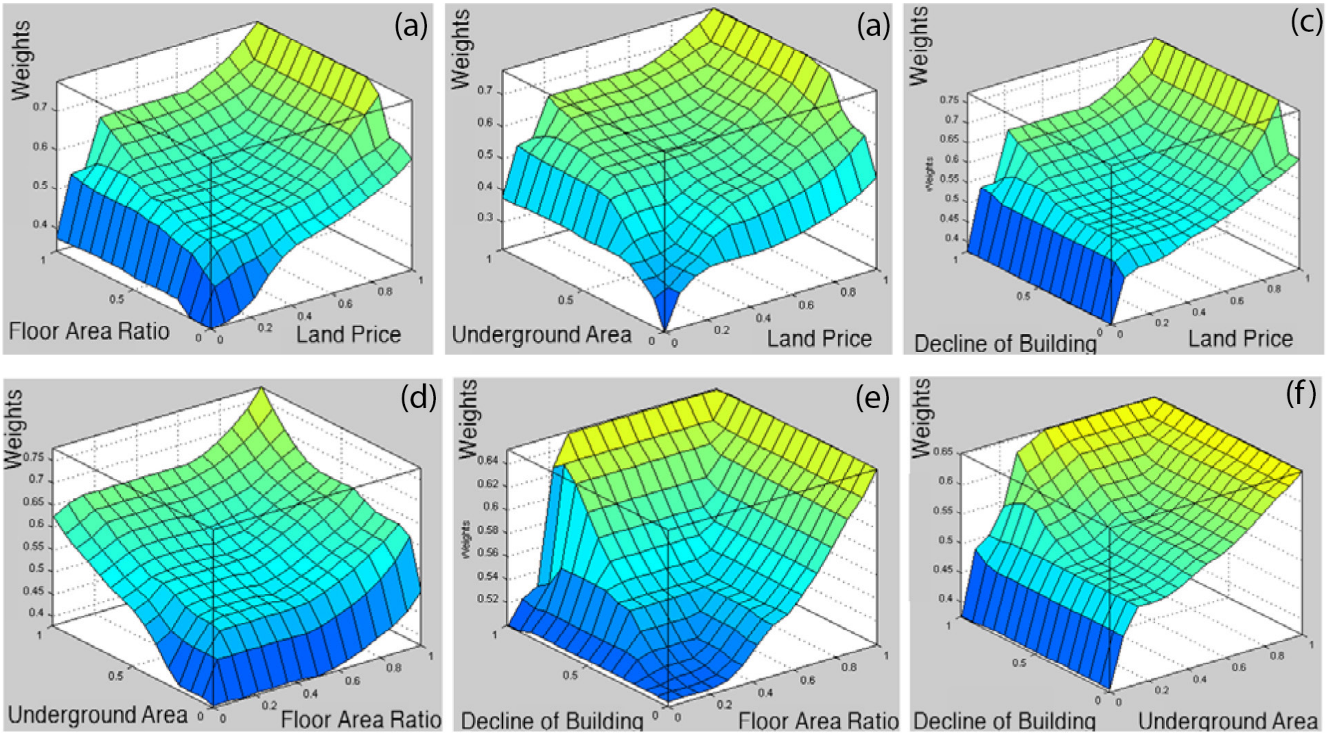

Fig. 5. Flood damage scheme: (a) land price—floor area ratio, (b) land price—underground area, (c) land price—decline of building, (d) floor area ratio—underground area, (e) floor area ratio—decline of building, and(f) underground area—decline of building.

Table 7
Fuzzy priority for each use district

Administrative district	Use district		Land price	Floor area ratio	Underground area	Decline of building	Fuzzy	Priority
Changwon city	Residential area	Private residential area	0.259	0.093	0.002	0.096	0.236	6
		General residential area	0.120	0.106	0.017	0.195	0.219	7
		Semiresidential area	0.258	0.157	0.017	0.193	0.257	3
	Commercial area	Central commercial area	0.354	0.273	0.055	0.101	0.367	1
		General commercial area	0.259	0.226	0.013	0.196	0.282	2
		Neighborhood commercial area	0.236	0.142	0.018	0.167	0.251	5
		Distribution commercial area	0.146	0.138	0.022	0.099	0.253	4
	Industrial area		0.101	0.065	0.062	0.103	0.213	8
	Green area		0.026	0.037	0.028	0.166	0.156	9

mapped as in Fig. 6. Area with the highest flood risk was indicated by red zone, followed by orange, and yellow zone. The area with the lowest flood risk is indicated by green zone.

Fuzzy analysis based on actual land price distribution, underground space, floor area ratio, and model year of buildings shows that red zone is formed centering on a central commercial area where various infrastructures are centered on the public institutions. Such development result can be attributed to economy, convenience, and efficiency. The orange zone has a fan-shaped distribution centering on the red zone. In other words, the orange zone is centered on functional and socioeconomic center of the city including general and distribution commercial areas and semiresidential areas. The yellow zone is distributed around the residential area that was constructed a long time ago, a factor closely related to deterioration of buildings. It is analyzed that the green zone is mainly distributed in the areas where environmental value or conservation is needed rather than land development.

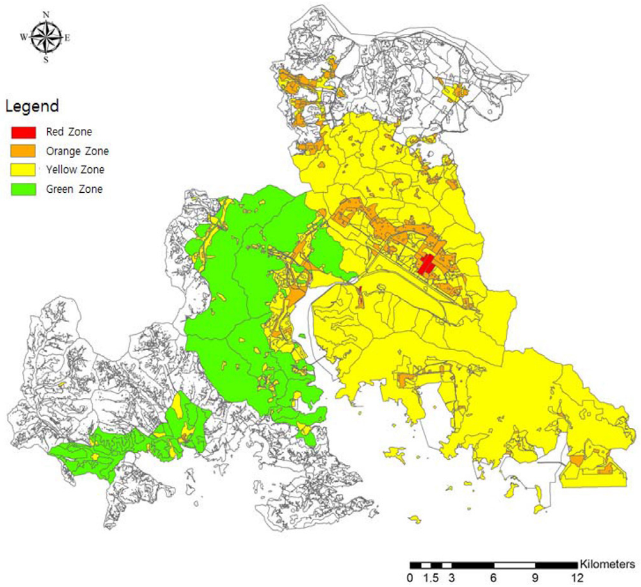

Fig. 6. Risk mapping of vulnerability analysis.

Visualized result such as risk mapping enables to identify potential flooding areas, therefore, providing intuitive understanding of urban flooding impact. Ultimately, classification of use districts based on flooding risk can formulate selective preventive measures against flood by focusing on areas with higher risks.

Finally, to create a city safe from disasters, urban planning should reflect vulnerability to flood for different areas. Based on the analysis of flood vulnerability, land use or use district should be used as evaluation unit to establish a long-term defense measure against urban flood.

4. Conclusion

This study tried to analyze the flood risk classification for Changwon, a metropolis in Korea, with a purpose to minimize the flood damage in the future by prioritizing urban areas in terms of flood risk by district as to deal with climate change issues in urban environments.

Fuzzy analysis is performed for Changwon on land price which can roughly estimates the economic scales of flood damage, floor area ratio which can identify building area and density, model year of buildings which is related to vulnerability to flood by aging, and underground space which is expected to have the greatest physical damage.

Analysis result shows that the risk of flooding is the highest in the order of 0.367 in the central commercial area, 0.282 in the general commercial area, 0.257 in the semiresidential area, 0.253 in the distribution commercial area, 0.251 in the neighborhood commercial area, 0.236 in the private residential area, 0.219 in the general residential area, 0.213 in the industrial area, and 0.156 in the green area.

The overall result shows that the area of Changwon is generally analyzed as having a high flood risk due to its high value of property and high density of construction in commercial areas. If the land use plan is appropriately distributed, it will be possible to cope with flood damage and systematically manage it.

If flood risk classification of urban use districts is applied in one of the nonstructural measures, the land use planning, it will be useful and effective for the long-term urban development. In this context, future studies would be more reliable if flood areas or flood maps containing actual weather and topographical factors are overlapped with risk classification considering current disaster prevention facilities.

References

[1] IPCC, Climate Change 2001: the Scientific Basis. Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge, 2001.

[2] K.E. Trenberth, Climate variability and global warming, Science, 293 (2001) 48–49.

[3] J. Houghton, Global Warming: the Complete Briefing, 3rd ed., Cambridge University Press, Cambridge, 2004.

[4] J.B. Smith, J.M. Vogel, J.E. Cromwell III, An architecture for government action on adaptation to climate change, an editorial comment, Clim. Change, 95 (2009) 53–61.

[5] EM-DAT, The OFDA/CRED International Disaster Database, Brussels, Universite Catholique de Louvain, 2005. Available at: www.EMDAT.be.

[6] UN-WWAP, The United Nations World Water Assessment Programme, The United Nations World Water Development Report 2: Water, a Shared Responsibility, World Water Assessment Programme (WWAP), Paris, UNESCO Publishing and New York, Berghahn Books, 2006.

[7] UNESCO, Global Trends in Water-Related Disasters: and Insight for Policymakers, 2009.

[8] J. Ponce, Land Use Planning and Disaster: A European Perspective from Spain Oñati Socio-Legal Series, Vol. 3, 2013, pp. 196–220.

[9] S.Y. Shin, H.R. Kim, Analyzing Relationships between Land Use Characteristics and Flood Damage Areas, Seoul Development Institute, 2011, pp. 1–67.

[10] Ministry of Land, Infrastructure and Transport, A Study on the Effective Reducing for Prevention the Urban Flood Damage, 2008, pp. 1–346.

[11] Changwon City, 2025 Urban Masterplan for Changwon, 2014, pp. 99–124.

[12] K.Y. Park, J.H. Jeong, W.S. Jeon, Analysis of Risk Classification on the Urban Flood Damage in Changwon City, Vol. 18, 2017, pp. 685–693.

[13] C.H. Lee, Development of the Regional Safety Assessment Model in Seoul-Focusing on Flood, Seoul Development Institute, 2006, pp. 1–130.

[14] H. Han, Climate Change Impact Assessment and Development of Adaptation Strategies in Korea, Korea Environment Institute, 2007, pp. 1–417.

[15] H. Park, Disaster Site Investigation and Disaster Prevention Planning Standard Establishment for Urban Space and Facilities, National Disaster Management Research Institute, 2010, pp. 1–371.

[16] M.S. Jang, Vulnerability Analysis of Building Inundation Caused by Storm Surge in Masan Bay, Master's Degree Dissertation, Sungkyunkwan University, 2015, pp. 1–55.

[17] CIRIA, Designing for Exceedance in Urban Drainage, Good Practice, London, 2006, pp. 115–121.

[18] S. Gopal, C. Woodcock, Remote sensing of forest change using artificial neural networks, IEEE Trans. Geosci. Remote Sens., 34 (1996) 398–404.

[19] J. Curlander, W. Kober, Rule Based System for Thematic Classification in SAR Imagery, Proc. IGARSS, IEEE Press, New York, 1992, pp. 854–856.

[20] C. Tsatsoulis, Expert Systems in Remote Sensing Applications, IEEE Geoscience and Remote Sensing Society Newsletter June, 1993, pp. 7–15.

[21] D. Anderson, Strando System: The Philosophy of Charles Peirce, Purdue University Press Series in the History of Philosophy, West Lafayette, 1995.