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Flood Risk Analysis by Building Use in Urban Planning for Disaster Risk Reduction and Climate Change Adaptation

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Abstract: In this study, focusing on buildings as the smallest unit of urban space, the distribution characteristics of risk factors were examined by building use as an adaptable measure for urban flooding disasters. Flood risk is calculated as a function of hazard, exposure, and vulnerability. The flood risk for a building was classified into five classes, and the distribution characteristics of buildings were examined according to England's flood risk vulnerability classification system, known as Planning Policy Statement 25 (PPS25). After analyzing the risk of flooding in Ulsan Metropolitan City, one of Korea's representative urban areas, it was found that while Dong-gu District can be considered relatively safe, districts of Jung-gu and Nam-gu, as well as Ulju-gun, have highly vulnerable buildings with red and orange ratings, which include motor vehicles-related facilities, education and welfare facilities, and residential facilities. There has been evidence to prove that urban flood disaster affects topography and the environment, in addition to having a significant effect on adaptability depending on the facility groups that resulted from urbanization. This study is expected to serve as a scientific database for disaster risk reduction and climate change adaptation to floods during land-use planning, which would eventually allow for systematic management of high-risk buildings through verification of location suitability of buildings by facility group.

Keywords: urban planning; flood risk; climate change adaptation; disaster risk reduction; building use; land use

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1. Introduction

Climatological, meteorological, and hydrological hazards have been increasing in magnitude and frequency due to climate change (i.e., temperature, precipitation, and humidity) [1]. The frequency of climate-induced disasters (CIDs) has tripled in the last three decades, driving the World Economic Forum to identify them as the most likely and most impactful risks worldwide [2]. Recently, global research shows that flood hazard has become the most common disaster that may bring more harmful effects than other disasters such as earthquakes and typhoons [3]. In the United States, flooding had devastating impacts on communities in terms of social and economic aspects over the last couple of decades [4]. Flooding has the greatest proportion of the presidential disaster declarations [5]. One-third of the economic losses due to natural hazards in Europe are related to flooding, one of the most frequent hazards with windstorms [6].

"Understanding disaster risk" is the first priority for the action of the Sendai Framework for Disaster Risk Reduction 2015–2030 [7], endorsed by the Member States of the United Nations in 2015, with the aim of "preventing new and reduce existing disaster risk". Disaster risk reduction and management need to be based on understanding disaster risk in all its dimensions of hazard characteristics, exposure, vulnerability, the capacity of people and assets, and the environment [8]. As the world further acknowledges the importance of adaptive capacity, the Paris Agreement and Sendai Framework have been adopted, and the significance of disaster risk reduction strategies is becoming increasingly important [7]. With more than 70% of the world population expected to be living in cities by 2050, ensuring the resilience of urban infrastructure systems under climate-induced disasters is crucial [2].

Land development usually results in increased impervious surfaces, known as the main cause of increased urban surface runoff [9], discharge of higher peak [10], faster runoff reaction [11], and alteration of the hydrological regimes and the water balance in general [12]. Particularly, Hu et al. [13] revealed that change in surface runoff is most strongly related to changes on impervious surfaces when compared with the changes in runoff related to other types of land use [14]. The change in runoff coefficients after urban development due to the increase in impervious areas is shown in Figure 1. The pre-development line expresses the change in the runoff coefficient before urban development, and the post-development line expresses the change in the runoff coefficient after urban development. Prior to development, the change rate of runoff coefficient increased slightly. The runoff rate declined as the rainfall increased, but the change rate of the runoff coefficient was larger due to the increase in impervious areas due to development. In short, in impermeable areas of the development area, the runoff coefficient increases during short-term heavy rains, which puts a heavy burden on the stormwater drainage pipes [15].

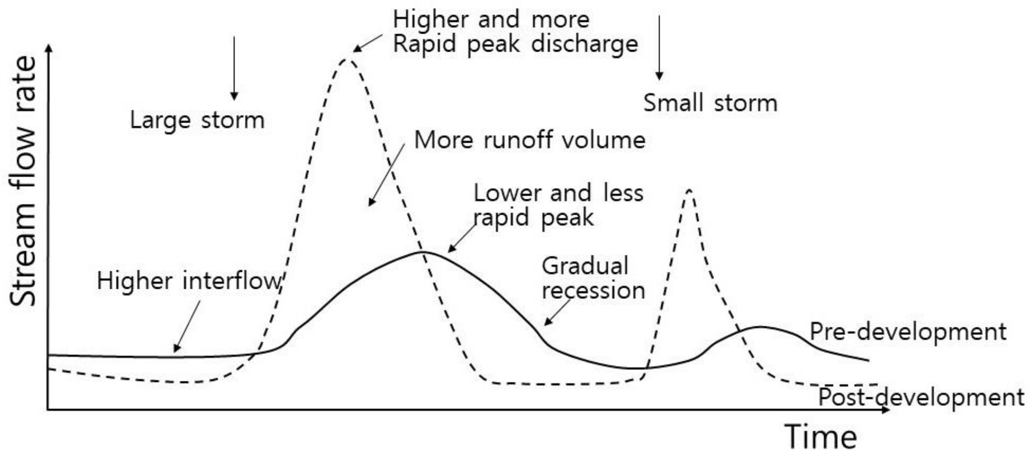

Figure 1. Change in runoff coefficients due to urban development [16].

With the population becoming concentrated in urban spaces due to urbanization, land and buildings have been intensively used. As a result, in urban development, designers and planners have focused on convenience and efficiency, leading to a natural increase in impervious surfaces. Consequently, the damage from urban flooding is becoming increasingly complex and diversified. Moreover, traditional disaster prevention measures have limitations. Therefore, the need for planning measures that can be adapted to the urban has been emphasized.

Adaptation and mitigation have generally been treated as two separate issues, both in public politics and in practice; mitigation is considered the attenuation of the cause, and studies of adaption deal with the consequences of climate change [17]. Based on the 2015 Paris Agreement, the international community is demanding preventive policies to adapt to climate change and minimize losses and damages, so we are aligning our direction with climate change. Accordingly, disaster risk reduction (DRR) and climate change adaptation (CCA) strategies through flood risk assessment are required to protect land and buildings.

The purpose of improving the adaptability of cities is to restore and maintain the functions of the natural circulation system disturbed by urbanization. Since cities are growing rapidly, disasters occur frequently and can easily become social problems when combined with complex social structures. The primary purpose of this study is to support decision making for urban planning and climate change adaptation measures by classifying flood risk according to the use of buildings and determining the priority of risky buildings. In other words, it strives to accurately identify urban areas with high flood risk and classify high and low-vulnerability facilities in these areas so that flood risk could be minimized through systematic management and adaptation, along with formulating effective measures.

2. Materials and Methods

2.1. Adaptation to Cope with Urban Flood Disaster

The response to climate change refers to the implementation of preventive measures to stop or minimize climate change and reduce disaster risk from its negative effects. To combat climate change, the international community has proposed two response strategies in the "United Nations Framework Convention on Climate Change": mitigation and adaptation. While the former aims to mitigate the progress of climate change by limiting greenhouse gas emissions and increasing sinks, the latter seeks to alleviate the adverse effects of climate change and enhance resilience. Mitigation is an approach focused on measures to control and block the causes of climate change in advance, such as curtailing carbon emissions or securing carbon absorption capabilities that existing low-carbon cities are aiming for. In contrast, adaptation is a more comprehensive approach in that it focuses on measures to cope with abnormal weather conditions caused by greenhouse gases and the resulting natural disasters, taking into account mitigation as well as adaptation aspects, such as ways to respond to heavy rains, heat waves, and droughts caused by climate change [18].

Cities with high adaptability can be considered less risky to disasters caused by climate change and have relatively safe systems. Improving such adaptability requires identifying potential risk factors, understanding a society's ability to respond to those risks, and setting policy directions based on that information. In order to improve adaptability to climate change and build a disaster-safe city, urban planning strategies should be systematically established, as shown in Figure 2. Urban planning for climate change adaptation and disaster risk reduction minimizes flood risk by preparing urban planning measures, along with structural measures for disaster-prone areas, which are identified by risk analysis.

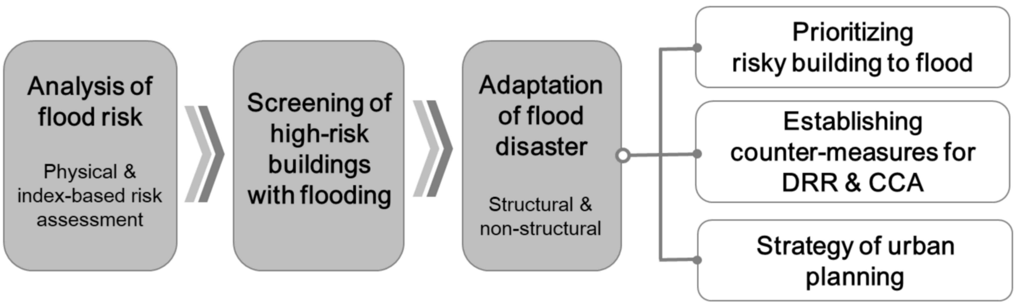

Figure 2. Flood risk analysis for disaster risk reduction (DRR) and climate change adaptation (CCA).

Urban planning for climate change adaptation offers ways to establish a city that is safe from disasters, through the application of urban planning techniques such as land use, infrastructure, and buildings. Land use measures refer to measures for the spatial arrangement, the layout of uses, and the creation of buffer zones in consideration of the characteristics and risks associated with disasters. Infrastructure measures aim at reducing disaster effects by reviewing location and disaster prevention performance (penetration, undercurrent, etc.) necessary for installing existing infrastructure. Building measures aim to strengthen the disaster prevention function of buildings by utilizing construction sites, structures, and facilities.

The urban planning for climate change adaptation as a long-term measure involves making efforts to change natural and human systems to suit the changing environment. In other words, its goal is to reduce or minimize adverse impacts by predicting damage and risks from climate change and to actively increase adaptability to urban components such as space, land, and facilities to a higher level. Since climate change occurs over a long time and is accompanied by uncertainty, efforts to mitigate climate change through greenhouse gas reduction are not enough. Without a proper adaptation plan and action, it is practically impossible to avoid the adverse effects of climate change that are already occurring and affecting the world. Therefore, appropriate adaptation and planning are crucial to reduce risk and increase resilience by predicting changes that will occur in the future based on the current situation. In light of this, the adaptation elements of climate change, along with mitigation elements, are essential for climate change response. This study identified high-risk buildings, determined by building use whether buildings with high vulnerability were clustered, and analyzed buildings that require facility reinforcement, urban planning strategies, and adaptation systems.

2.2. Study Area

Typhoon Chaba caused the deaths of 3 people and approximately 61 million USD of property damage in October 2016 in Ulsan Metropolitan City, Republic of Korea [19]. Recently, Ulsan Metropolitan City has experienced widespread flood damage in areas such as farming, urban, national streams, local streams, and coastal areas, and has hydrological and geographical conditions that are vulnerable to flood disaster [15]. Therefore, as shown in Figure 3, Ulsan Metropolitan City was decided as the target location of this paper. Ulsan Metropolitan City is divided into five administrative districts namely, Buk-gu, Nam-gu, Jung-gu, Dong-gu, and Ulju-gun [20]. It experiences a considerable amount of rain and has climatic conditions vulnerable to floods.

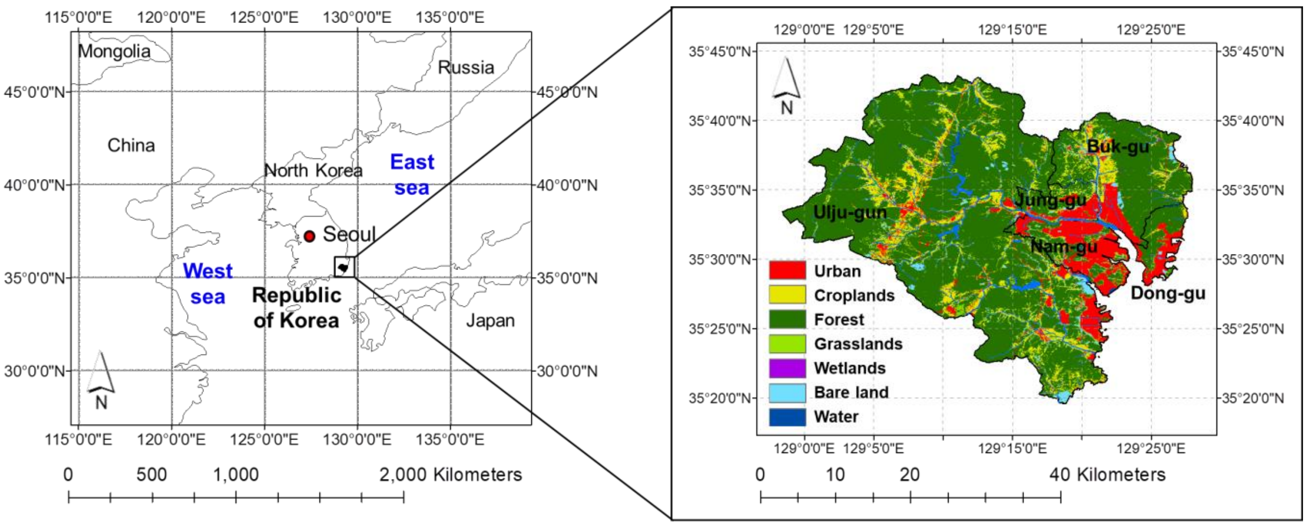

Figure 3. Land cover map of Ulsan Metropolitan City in the Republic of Korea.

2.3. Methods of Assessing Flood Risk

Researchers from various scientific backgrounds have different understandings of the definition of risk [21,22]. Definitions and methodologies for risk are not general and vary depending on the researcher and the research purpose [23,24]. Methods of calculating risk and spatial resolution are determined according to the subject who establishes countermeasures for disaster risk reduction and climate change adaptation and the spatial scope of risk assessment. Since the central government provides financial support to local governments, risk assessment at the resolution of administrative districts is required for the entire country. Index-based risk assessment using proxy variables of administrative districts is useful for the central government since there are time and economic limitations in performing high-resolution risk assessment for the entire country [25–28]. In contrast, since local governments plan and implement structural and non-structural measures, high-resolution risk assessment methods for administrative districts are suitable [29–32]. In particular, it is necessary to utilize the results of physical flood simulation that reflects rainfall in addition to high-resolution regional characteristics. The concept of climate change risk was formulated through the IPCC Climate Change Assessment Report [33]. The risk is defined as a function of hazard, exposure, and vulnerability in the report. This study applied the IPCC risk concept, and the study area has a local government, so high-resolution risk assessment results were required. A combination of methods on physical risk and index-based risk assessment was developed for high-resolution flood risk assessment of a building, as shown in Figure 4. Hazard was calculated by using the flood map developed through numerical analysis, and exposure was calculated by estimating whether flooding would occur by overlapping the building location and the flood map. Vulnerability was calculated by converting five individual indexes of buildings related to flooding into a composite index. Since the correlation between building use and flooding was not physically identified, a qualitative method was applied to estimate vulnerability. The significance of the method lies in enabling high-resolution flood risk assessment for local governments by combining physical and index-based risk assessment techniques proposed in previous studies.

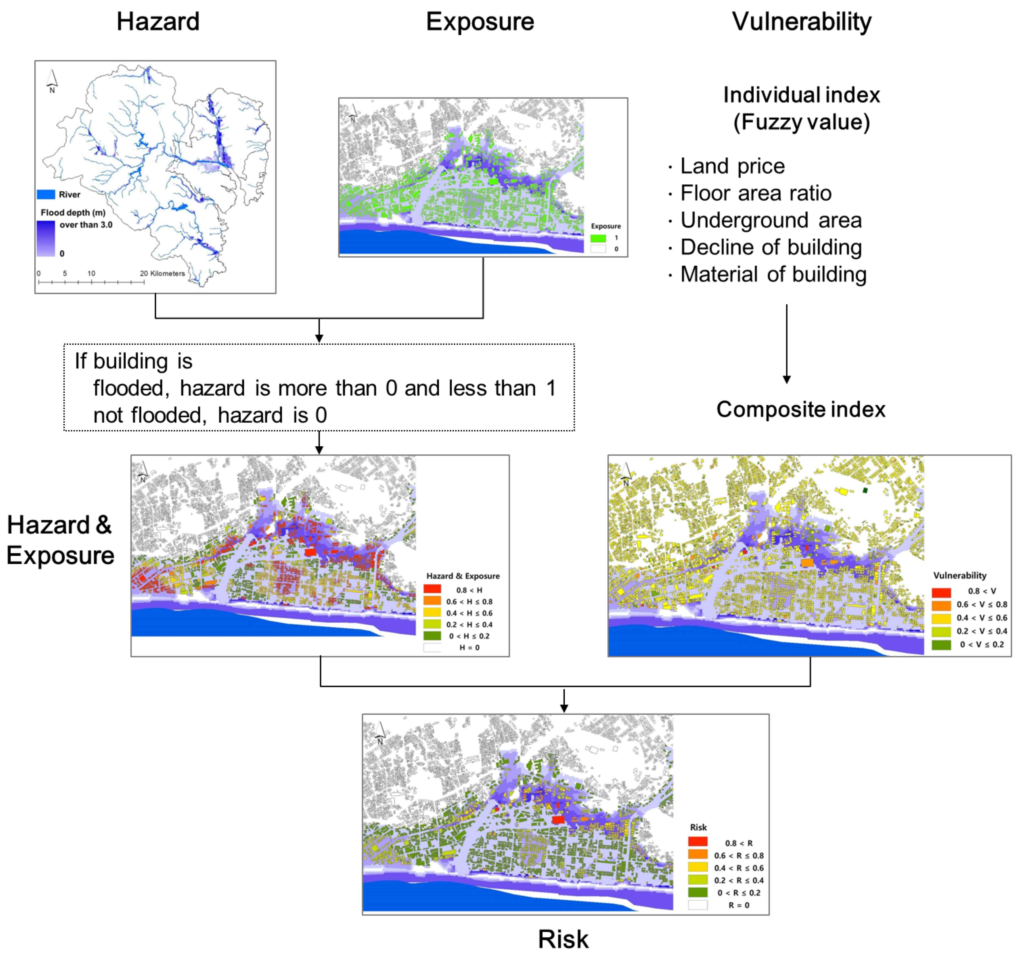

Figure 4. Procedure of calculating flood risk by combing methods of physical and index-based risk assessment.

The flood risk calculation method is expressed as Equations (1) and (2), with reference to the risk estimation guideline suggested by *Risk Supplement to the Vulnerability Sourcebook* of GIZ; EURAC research. The risk is the damage ratio of buildings due to flooding and is calculated through the flood depth–damage ratio curve developed based on empirical data on flood damage, as shown in Figure 5. The flood damage ratio can be expressed as follows: It has a value of 0–1, as in Equation (3), as a function of the flood depth in the area where the building is located. If the damage ratio is 0, the flood depth is 0, and if the damage ratio is 1, it means that the flooding depth is 3 m or more, and damage to the entire building has occurred. Exposure is determined by the presence or absence of flooding in the area where the building is located. If the building is flooded, the exposure is 1; otherwise, the exposure is 0, as shown in Equation (4). The vulnerability is a fuzzy value calculated using five building-related indicators, as shown in Equation (5), and has a value of 0–1 using the results.

$$R_{i,\,0\ to\ 1} = \frac{R'_i - R'_{\min\ of\ i}}{R'_{\max\ of\ i} - R'_{\min\ of\ i}} \tag{1}$$

$$R'_i = \mathrm{H} + \mathrm{E} + \mathrm{V} \tag{2}$$

$$H_{i,\,0\ to\ 1} = -0.0238x^3 + 0.048x^2 + 0.3988x + 0.0173, \quad if\ x = 0,\ H = 0 \tag{3}$$

$$E_{i,\,0\ or\ 1} = 0 \text{ or } 1, \text{ if a building is flooded, } \mathrm{E} = 1, \text{ not flooded, } \mathrm{E} = 0 \tag{4}$$

$$V_{i,\,0\ to\ 1} = \text{Fuzzy value using building characteristics} - \text{related indicators} \tag{5}$$

where R_i is the risk of building i, R'_i is the risk of building i before normalized using min-max methods, $R'_{\max\ of\ i}$ is the highest value for R'_i, $R'_{\min\ of\ i}$ is the lowest value for R'_i, H_i, E_i, V_i are the hazard, exposure, and vulnerability of building i, respectively. x is flood depth.

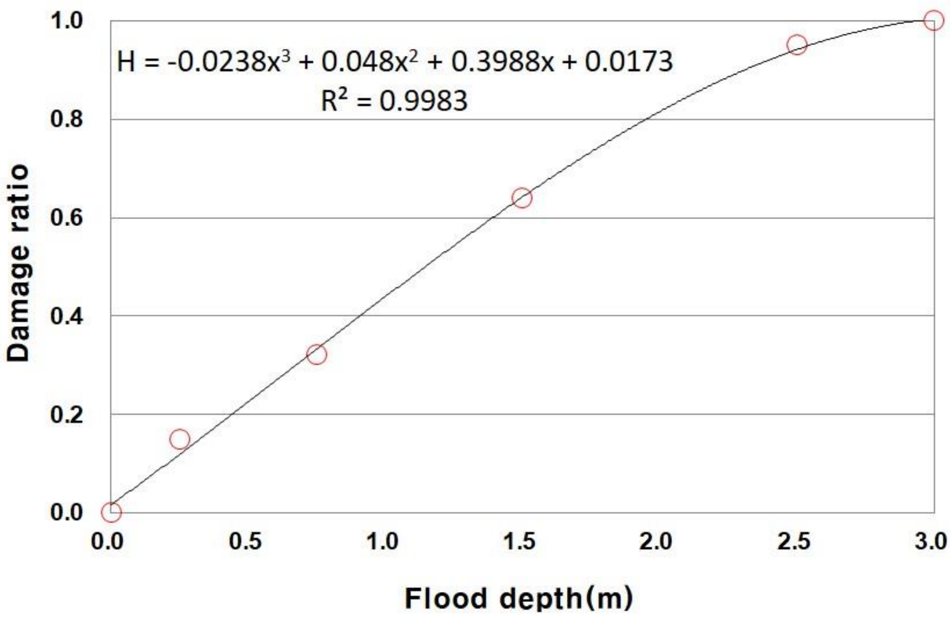

Figure 5. Flood depth–damage ratio curve of building for hazard calculations.

The urban flood risk classification by facility and use group, introduced in England's Guidance about Planning Policy Statement 25 (PPS25), is used as a standard to examine buildings in Korea. The flood risk was analyzed to find which facility groups are included in the high-risk category, according to the resultant analysis of flood risk by each building use and suggest ways to reduce the level of flood disaster to buildings.

2.4. Characteristics of Building by Use

A building is a structural foundation for people in modern society. Members of society choose buildings that are suitable and affordable to ensure the stability of life. However, establishing a new building cannot be the only alternative for enhancing their lives. As improvements made to buildings already constructed or the strengthening of functions of new buildings are linked to increased adaptability, re-establishment of abandoned buildings by demolishing them must also be treated under the concept of building adaptability. Moreover, since the spatial expansion of buildings occurs vertically, buildings should be approached differently from cities in terms of adaptability.

In England, it is deemed that vulnerability to flood risk varies depending on the use and facility in the course of performing the flood risk assessment. The Planning Policy Guidance (PPS25; Planning Policy Statement 25: Development and Flood Risk) established a flood risk vulnerability classification system by use and facility and made decisions on whether the location was feasible (development permitted or development prohibited) or required exceptional verifications by reviewing the compatibility between use and facility and flood area during sequential verification [24].

The actual damage, as well as the potential impacts and hazards resulting from flooding, may vary by the building use and facility groups. In urban planning and land use policy in England, vulnerability is classified by uses and facilities groups, as demonstrated in Figure 6, and the sequential test is operated according to urban flood risk for flood disaster risk reduction in advance by regulating the location of development and land use. The classification revealed that "essential infrastructure" includes essential transport infrastructure, strategic utility infrastructure, and electricity-generating power stations, while the "highly vulnerable" category enumerates facilities that must be operated in the event of a flooding, such as police stations, rescue teams, fire stations, command centers, and communication facilities. As such, this classification system strives to ensure effective disaster management.

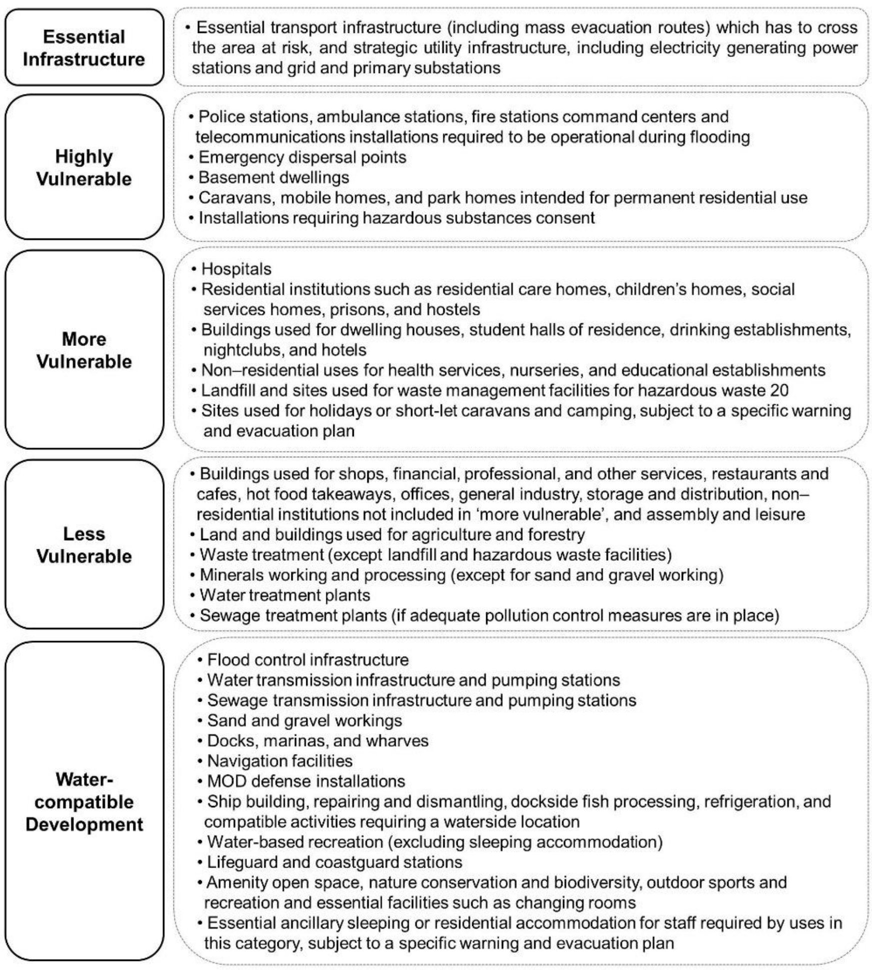

Figure 6. Classification of flood risk vulnerability [34].

Republic of Korea classified buildings by use (Figure 7) in the Enforcement Decree of the Building Act to define matters required in applying elements for the design and construction of buildings [35]. Therefore, based on the vulnerability classification by uses and facility groups offered by the Planning Policy Statement 25, the groups of facilities classified in Korea by their uses were matched to the same categories in Planning Policy Statement 25, and the distribution of building uses was analyzed with respect to the urban flood risk rating.

Group of facilities	Uses of buildings
Facilities for relating to motor vehicles	Facilities for motor vehicles.
Facilities for industrial purposes	Transportation facilities, warehouses, factories, facilities for storage and disposal of hazardous substances, resource recycling-related facilities, facilities related to cemeteries.
Facilities for telecommunications	Broadcasting and telecommunications facilities, power generation facilities.
Facilities for cultural activities and assembly	Facilities for cultural activities and assembly, religious facilities, amusement facilities, tourism and leisure facilities.
Facilities for commerce	Sales facilities, sports facilities, lodging facilities, Class 2 neighborhood living facilities (communal living facilities).
Facilities for education and welfare	Medical facilities, education and research facilities, facilities for older persons and children, training facilities, campground facilities.
neighborhood living Facilities	Class 1 neighborhood living facilities, Class 2 neighborhood living facilities (excluding communal living facilities).
Facilities for residential and business purposes	Detached houses, multi-family housing, business facilities, correctional facilities and military installations.
Miscellaneous	Facilities for animals and plants.

Figure 7. Group classification of facilities according to Republic of Korea's Building Act.

3. Results and Discussion

3.1. Vulnerability Analysis for Building

Vulnerability is defined as a function of the nature, scale, and ratio of climate change, as well as the sensitivity and adaptability to which a system is exposed, referring to the extent to which such a system is susceptible or unable to respond to the adverse effects (climate variability, extreme weather, etc.) of climate change [36]. The IPCC considers vulnerability as a function of sensitivity, and adaptability to climate change and identifies a system as highly vulnerable if a system shows low adaptability under a strong impact of climate change.

The impact of disaster risk is local, discontinuous, and uncertain. The way to mitigate flood risk is to reduce the vulnerabilities in a system. Vulnerability to natural disasters can be reduced through changes in social infrastructure and systems [37]. In other words, the vulnerability in the field of climate change implies that the external stress of climate change is caused by certain components of human systems—namely, urbanization. Further, given that such external stresses can be large or small depending on human efforts, vulnerability can be reduced by the external stress strengthening the ability of the internal parts of the system to respond to a disaster.

Five building-related indicators were selected to assess vulnerability to urban flood hazards. To yield indices, the fuzzy analysis method was utilized. The fuzzy inference process analyzed vulnerability by replacing indices with the appropriate fuzzy value via fuzzification and converting them to a defuzzification value. For analyzing the characteristics of buildings, they were treated as the most basic unit of urban space. To evaluate the vulnerability of each building in Ulsan Metropolitan City, the information on the official land price announced by the Korea Real Estate Board was obtained, and the data on underground area, floor area ratio, building materials, and building decline were collected using the building registry established by Ulsan Metropolitan city, as shown in Table 1. The results of fuzzy inference analysis conducted across five districts in Ulsan Metropolitan City led to an examination of vulnerabilities from urban flooding for each building category. As each building category has different economic and social vulnerabilities, the degree of damage was found to vary even under the same risk factor. At this point, each indicator had its own characteristics and thus was standardized. Vulnerability was ranked in five levels by applying the standardized values of up to 1.0 and at least 0.1 to all buildings, as shown in Table 2.

Table 1. Fuzzy analysis for vulnerability.

Districts		Land Price (KRW/m^2)	Floor Area Ratio (%)	Underground Area (m^2)	Building Decline	Building Materials	Fuzzy Score
Jung-gu	Maximum	6,463,180	696	26,416	149	4	0.92
	Minimum	959,470	0	14	2	1	0.10
	Mean	1167	124	263	30	3	0.49
Nam-gu	Maximum	12,200,000	2194	1,512,911	136	4	0.94
	Minimum	1153	0	2	2	1	0.10
	Mean	1,101,654	140	443	26	2	0.49
Dong-gu	Maximum	3,133,527	2548	13,736	108	4	0.92
	Minimum	155	0	19	2	1	0.15
	Mean	930,410	135	384	25	2	0.92
Buk-gu	Maximum	4,151,378	551	56,506	153	4	0.78
	Minimum	104	0	3	2	1	0.10
	Mean	614,318	81	907	24	2	0.49
Ulju-gun	Maximum	3,339,000	827	37,660	229	4	0.50
	Minimum	188	0	4	1	1	0.10
	Mean	308,655	57	813	27	2	0.50

Table 2. Classification of administrative districts by buildings on flood vulnerability [15].

Districts		Total # of Buildings	Green		Yellowish Green		Yellow		Orange		Red	
			# of Buildings	%	# of Buildings	%	# of Buildings	%	# of Buildings	%	# of Buildings	%
Ulsan Metropolitan City	Jung-gu	24,059	1297	5.4	835	3.5	20,842	86.6	234	1.0	851	3.5
	Nam-gu	24,302	2567	10.6	821	3.4	19,221	79.1	578	2.4	1115	4.6
	Dong-gu	10,343	808	7.8	216	2.1	9073	87.7	89	0.9	157	1.5
	Buk-gu	11,909	543	4.6	209	1.8	11,098	93.2	26	0.2	33	0.3
	Ulju-gun	37,643	570	1.5	11	0.0	37,062	98.5	-	-	-	-

3.2. Hazard and Exposure Analysis for Urban Flood

Hazard refers to the nature and extent of climate stress on the system, including long-term changes in climate conditions and changes in climate variability, and can be combined with the particular vulnerability of factors exposed to certain risks [36]. The analysis applying FLUMEN and HEC-Ras are normal flood depth analysis models that carry out a simulation by constructing the centerline of the river, the river bank line, the river crossing data, using the flood level and the flood amount as the boundary conditions. In this analysis, a flood depth map was prepared by applying the numerical analysis model based on environmental factors such as topographical and rainfall data developed by the Ministry of Interior and Safety [37]. As a result of the hazards analysis (Figure 8), the meeting points of Jung-gu, Nam-gu, and Buk-gu, as well as the low-lying districts centered on the Taehwa River, were found to be particularly flood prone.

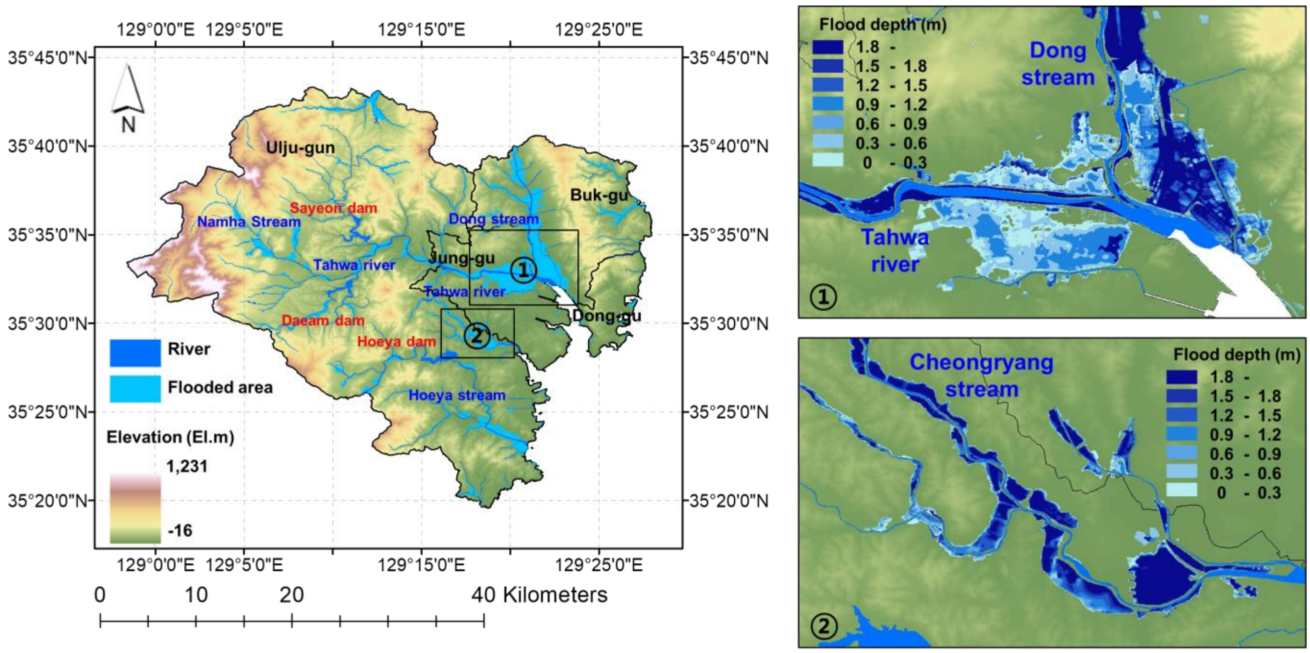

Figure 8. Hazard analysis for urban flood.

3.3. Building Risk Analysis

The likelihood that the loss may be greater than ordinarily expected is referred to as a risk. Risk is a probability concept, but it can also cover the gap between the currently expected amount of loss and future probability [38].

The urban flood risk analysis is based on the following equation: Risk = Hazard (Exposure) + Vulnerability [39]. The analysis results are shown in Table 3. The risk analysis also classified the buildings according to their vulnerability level using different color codes (very high risk—red, high risk—orange, medium risk—yellow, low risk—yellowish green, and very low risk—green). According to the analysis of urban flood risk, there was a high risk of flooding in areas where urban development has been carried out, which are low-lying areas centered on the Taehwa River. With regard to the buildings with red and orange ratings, indicating high flood risk, the distribution rate varied by district, with Nam-gu having the highest number of buildings (6545; 26.9%), followed by Buk-gu (2576; 21.6%), Jung-gu (4856; 20.2%), Ulju-gun (3205; 8.5%), and Dong-gu (0; 0%).

3.4. Distribution Characteristics by Building Use

While it is important to analyze the risk of urban floods in buildings, it is also extremely important to analyze which groups of facilities are classified as dangerous buildings and whether facilities with similar use are concentrated in high-risk flood areas. Hence, based on the flood risk analysis derived from the study of hazard, exposure, and vulnerability, the distribution characteristics of the facility groups by building use were organized, as shown in Table 4 and Figure 9.

Table 3. Classification of administrative districts by each building on flood risk.

Districts		Total # of Buildings	Green		Yellowish Green		Yellow		Orange		Red	
			# of Buildings	%	# of Buildings	%	# of Buildings	%	# of Buildings	%	# of Buildings	%
Ulsan Metropolitan City	Jung-gu	24,059	17,131	71.2	192	0.8	1880	7.8	4433	18.4	423	1.8
	Nam-gu	24,302	15,419	63.4	414	1.7	1924	7.9	6388	26.3	157	0.6
	Dong-gu	10,343	10,187	98.5	116	1.1	40	0.4	-	-	-	-
	Buk-gu	11,909	8936	75.0	11	0.1	386	3.2	1564	13.1	1012	8.5
	Ulju-gun	37,643	33,515	89.0	0	0.0	923	2.5	2387	6.3	818	2.2

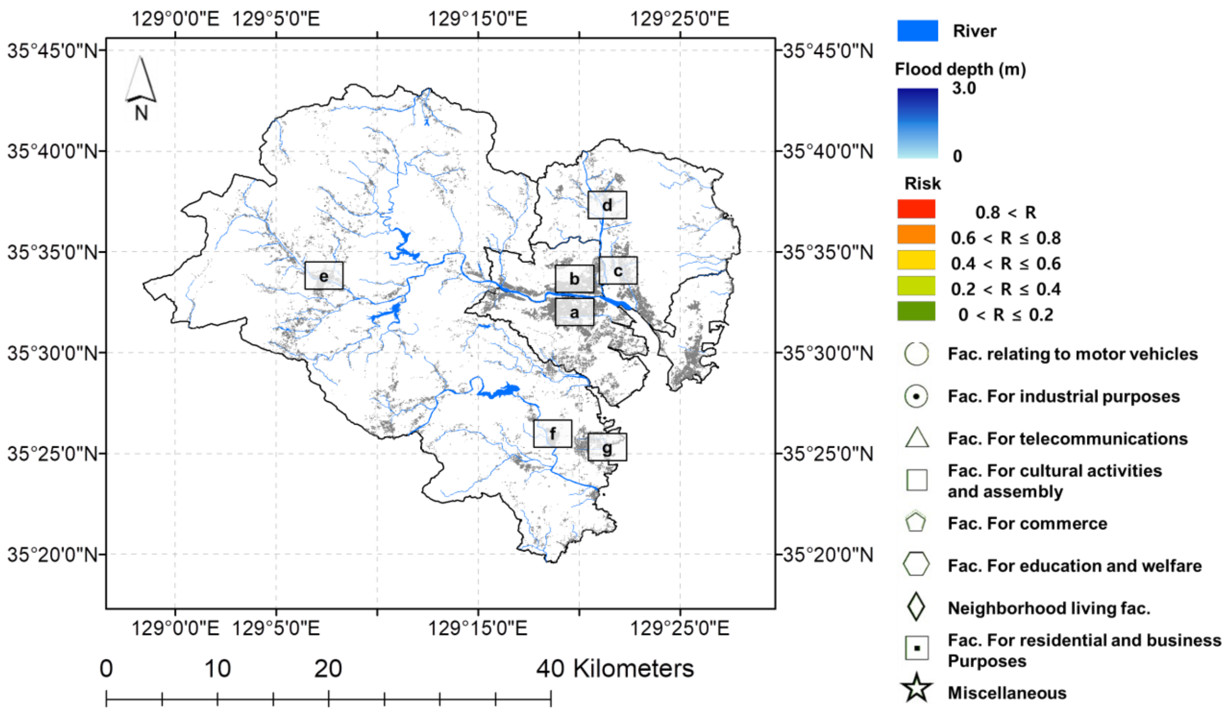

Figure 9. Key distribution map of administrative districts by building use on flood risk.

The vulnerability classification by building use in England's land and urban planning system was compared and matched to the Korean classification by building use, resulting in the following classification in Korean context: "essential infrastructure" category includes facilities for telecommunications; "highly vulnerable" category includes education and welfare facilities; "more vulnerable" category includes commercial facilities; "less vulnerable" category includes facilities relating to motor vehicles, industrial purposes, cultural assembly, and neighborhood living facilities.

The distribution analysis of facilities groups by each building use (Figure 10) revealed that residential facilities were constructed with the largest numbers, amounting to 66,133 buildings. Next in rank were 21,203 neighborhood living facilities, followed by 12,262 industrial facilities, 2189 education and welfare facilities, 972 facilities for commerce, 959 cultural groups, 675 motor vehicles-related facilities, and lastly, 54 telecommunications facilities.

Since telecommunication facilities are essential infrastructures that are closely related to the lifelines of urban residents, it is clear that the impact of flooding would be tremendous, leading to difficulties in daily lives and paralysis of a city's functions. Telecommunication facilities are of great importance when there is flooding because they communicate changing circumstances and also serve as a central operations center in terms of rapid disaster management and response, such as firefighting, first aid, and emergency measures. In addition, various infrastructures such as water and sewage, electricity, gas, and heat supply facilities are located underground, which means potential power outages, electric shock, explosions, and fires pose the risk of secondary damages, exacerbating overall harm. As such, it is imperative to secure the stability of telecommunication facilities. In examining the urban flood risk in telecommunication facilities and building distribution in each district, it was found that the distribution ratios of the buildings with a high-risk rating of red and orange across evaluated districts were 0.02% in Jung-gu, 0.01% in Ulju-gun; the rest of the districts did not reflect a high-risk rating. The ratio to green rating was relatively high, which is considered to be a positive sign in terms of stability.

Table 4. Distribution of administrative districts by building use according to flood risk.

Group of Fac.	Risk	Jung-gu		Nam-gu		Dong-gu		Buk-gu		Ulju-gun		Ulsan Metropolitan City
		# of Fac.	%	# of Fac.	%	# of Fac.	%	# of Fac.	%	# of Fac.	%	# of Fac.
Fac. relating to motor vehicles	Green	26	5.9	123	28.0	45	10.2	73	16.6	173	39.3	440
	Yellowish green	0	0.0	2	66.7	1	33.3	0	0.0	0	0.0	3
	Yellow	10	18.9	31	58.5	0	0.0	9	17.0	3	5.7	53
	Orange	16	14.2	60	53.1	0	0.0	27	23.9	10	8.8	113
	Red	5	7.6	10	15.2	0	0.0	43	65.2	8	12.1	66
Fac. for industrial purposes	Green	231	2.2	3306	30.9	324	3.0	1240	11.6	5603	52.3	10,704
	Yellowish green	0	0.0	1	100.0	0	0.0	0	0.0	0	0.0	1
	Yellow	33	11.0	64	21.3	21	7.0	68	22.6	115	38.2	301
	Orange	61	7.9	134	17.4	0	0.0	280	36.3	297	38.5	772
	Red	6	1.2	25	5.2	0	0.0	287	59.3	166	34.3	484
Fac. for telecommunications	Green	5	11.1	4	8.9	4	8.9	2	4.4	30	66.7	45
	Yellowish green	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0
	Yellow	1	50.0	0	0.0	0	0.0	0	0.0	1	50.0	2
	Orange	4	57.1	0	0.0	0	0.0	0	0.0	3	42.9	7
	Red	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0
Fac. for cultural activities and assembly	Green	132	18.3	100	13.9	106	14.7	73	10.1	311	43.1	722
	Yellowish green	6	28.6	10	47.6	5	23.8	0	0.0	0	0.0	21
	Yellow	11	29.7	19	51.4	0	0.0	2	5.4	5	13.5	37
	Orange	48	30.0	95	59.4	0	0.0	2	1.3	15	9.4	160
	Red	3	15.8	11	57.9	0	0.0	2	10.5	3	15.8	19
Fac. for commerce	Green	40	7.5	196	36.6	102	19.1	29	5.4	168	31.4	535
	Yellowish green	2	8.3	14	58.3	7	29.2	1	4.2	0	0.0	24
	Yellow	35	37.2	38	40.4	0	0.0	1	1.1	20	21.3	94
	Orange	72	26.5	157	57.7	0	0.0	9	3.3	34	12.5	272
	Red	11	23.4	25	53.2	0	0.0	5	10.6	6	12.8	47
Fac. for education and welfare	Green	273	14.7	385	20.8	340	18.3	277	14.9	578	31.2	1853
	Yellowish green	15	27.8	27	50.0	10	18.5	2	3.7	0	0.0	54
	Yellow	19	18.6	52	51.0	7	6.9	8	7.8	16	15.7	102
	Orange	47	32.2	62	42.5	0	0.0	11	7.5	26	17.8	146
	Red	5	14.7	1	2.9	0	0.0	4	11.8	24	70.6	34
Neighborhood living fac.	Green	2096	14.7	2990	21.0	2156	15.2	1303	9.2	5670	39.9	14,215
	Yellowish green	69	18.1	243	63.6	63	16.5	7	1.8	0	0.0	382
	Yellow	489	30.8	773	48.6	3	0.2	94	5.9	231	14.5	1590
	Orange	1160	26.5	2333	53.4	0	0.0	305	7.0	575	13.1	4373
	Red	128	19.9	69	10.7	0	0.0	252	39.2	194	30.2	643
Fac. for residential and business purposes	Green	14,246	26.7	8292	15.5	7101	13.3	5684	10.7	18,028	33.8	53,351
	Yellowish green	100	40.3	117	47.2	30	12.1	1	0.4	0	0.0	248
	Yellow	1281	44.2	946	32.6	9	0.3	194	6.7	468	16.1	2898
	Orange	3025	35.0	3547	41.1	0	0.0	870	10.1	1193	13.8	8635
	Red	265	26.5	16	1.6	0	0.0	391	39.1	329	32.9	1001
Miscellaneous	Green	82	2.5	23	0.7	9	0.3	255	7.7	2954	88.9	3323
	Yellowish green	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0
	Yellow	1	1.3	1	1.3	0	0.0	10	13.2	64	84.2	76
	Orange	0	0.0	0	0.0	0	0.0	60	20.4	234	79.6	294
	Red	0	0.0	0	0.0	0	0.0	28	24.1	88	75.9	116

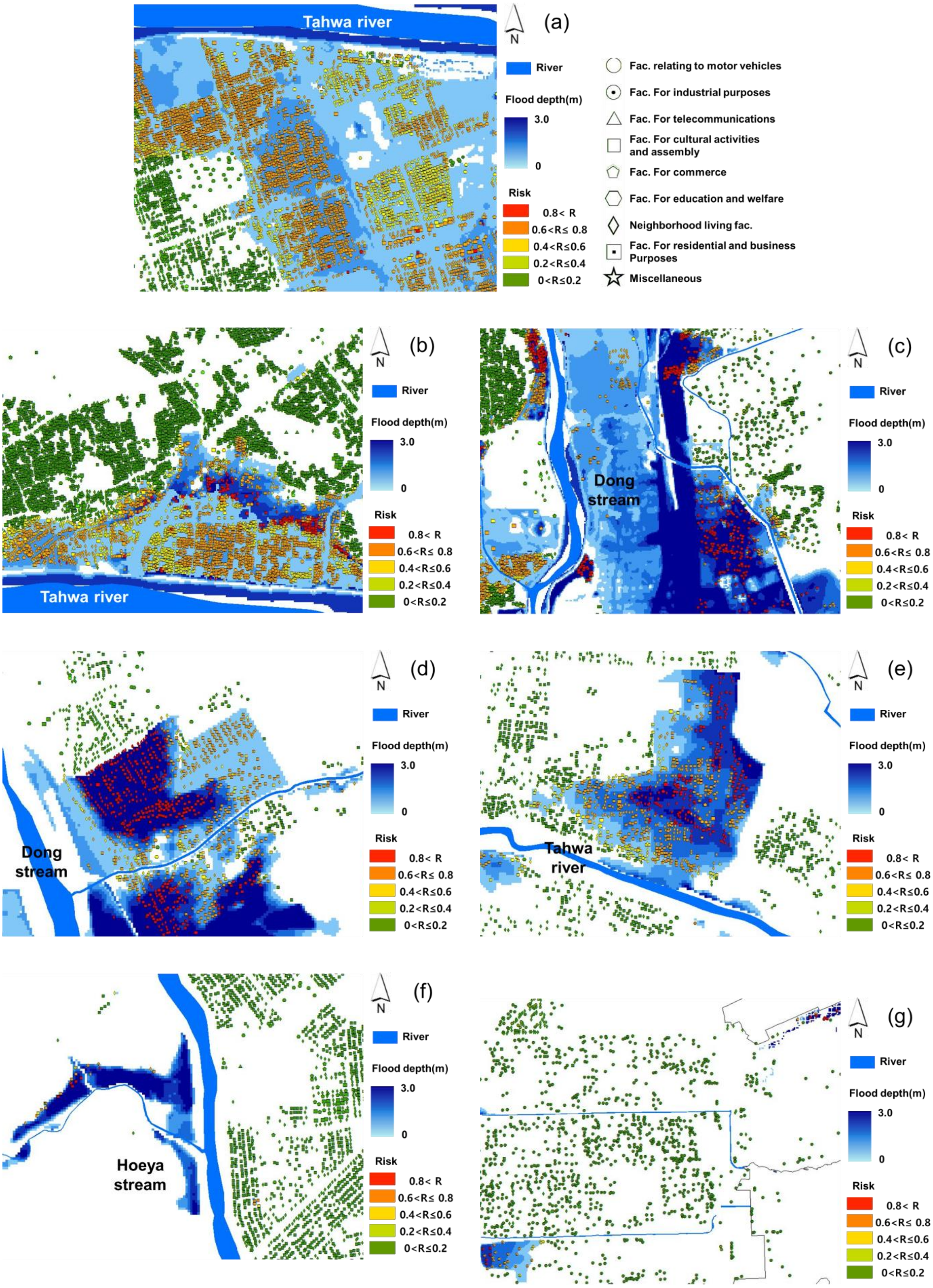

Figure 10. Distribution by each building use on flood risk (Micro view). (**a**–**e**) The Facility for cultural activities and assembly, commerce, residential and business purposes, and neighborhood living facility located near the Tahwa river and Dongstream is exposed to flooding of yellow grade or higher. In particular, (**c**) area, facility for industrial purposes is exposed to red-grade flooding, and a lot of damage is expected, and (**d**,**e**) area, red-grade facilities are located at high density. Conversely, (**f**,**g**) area, there is little risk because flooding is not expected in the facility-dense areas.

Medical facilities that belong to the education and welfare facility group are related to emergency rescue, and police and fire stations are classified as important facilities, as their operation during flooding is critical. The group of facilities for residential and business purposes, which include detached houses, apartment buildings, and multifamily houses, is where city residents live at all times and underground spaces exist for most structures this makes them fall under the highly vulnerable category, along with education and welfare facilities.

Following the urban flood risk assessment for these groups, the distribution status of buildings in each district was examined. For education and welfare facilities, around 0.26% of Nam-gu District, 0.22% of Jung-gu District, 0.13% of Ulju gun, and 0.12% of Buk-gu District were found to be high-risk buildings, graded with red and orange ratings. There are also a number of buildings with a green rating. Distribution ratios for red and orange-rated buildings within the group of facilities for residential and business purposes were 14.67% in Nam-gu, 13.67% in Jung-gu, 10.59% in Buk-gu, and 4.04% in Ulju-gun, with none in Dong-gu District. Yellow-rated buildings were found in a small number of districts, while relatively more green-rated buildings existed.

The group of facilities for commerce includes sales facilities, sports facilities, and lodging facilities, which correspond to the relatively "more vulnerable" category. For commerce-related facilities, the distribution status of buildings in each district was investigated after the urban flood risk analysis was conducted, revealing that they were distributed across the districts at the ratios of 0.75% in Nam-gu, 0.35% in Jung-gu, 0.12% in Buk-gu, 0.11% in Ulju-gun, and none in Dong-gu.

Facilities related to motor vehicles, industrial purposes, cultural activities and assembly, and neighborhood living facilities all fall under the less vulnerable category, as they are considered to have low asset value for not being subject to citizens' permanent residency. According to the analysis of the risk of urban flooding, the distribution status of buildings in each region demonstrated a low distribution ratio of high-risk for red and orange-rated buildings and a significantly high ratio of green-rated buildings in the neighborhood living facilities group. Other groups of facilities showed an even distribution ratio by rating.

Furthermore, the urban flood risk analysis confirmed that topographical aspects, environmental factors, and the progress of urbanization could exert significant influences. Therefore, in order to minimize and reduce flood disasters to high-risk buildings, the location of buildings should be considered in advance in terms of the vulnerability by the buildings' use, importance, and usability; following the construction of buildings, management and disaster preparedness must be designed according to risk level.

4. Conclusions

A recent increase in the frequency of natural disasters has been attributed to environmental factors such as climate change and urbanization. Korean climate change and urbanization rates are significantly higher than the global average, raising concerns that the country will become extremely vulnerable to disasters. As climate change and rapid urbanization are increasing the risk of disasters, developed countries and international organizations have introduced the concept of adaptation into the disaster prevention sector. Moreover, the importance of response measures associated with urban planning for climate change adaptation using various urban planning, land use, and buildings, is gaining recognition, in addition to the traditional disaster prevention measures.

In this study, the scope of the research was limited to the flood hazard in urban areas, as it has been the most destructive damage of natural disasters, and the flood risk was assessed for buildings, which can be considered the smallest unit of urban space. Specifically, the characteristics of risk distribution were analyzed by the uses of buildings in order to come up with feasible countermeasures from an urban planning perspective by increasing the adaptability of buildings by spatial units. According to the risk analysis of urban floods, it was found that low-lying areas around the Taehwa River, where urban development has progressed at a rapid pace, were facing a high risk of flooding, and that a substantial number of highly vulnerable facilities were distributed in the districts of Jung-gu and Nam-gu, and Ulju-gun. No such group of facilities was found in the Dong-gu District, which suggests that it has established a land-use plan that is safe from flood disasters. Based on the overall findings of the urban flood risk assessment by facility group and the distribution characteristic analysis by building use, several meaningful implications can be derived.

First, measures were proposed to reduce flood disasters in urban areas and adapt to heavy rains. This is significant in that it has allowed for efficient and systematic building-based management of urban space and land use as part of urban planning measures that could supplement the limitations of existing traditional measures. Second, the development of a new methodology based on spatial information obtained through statistical synthesis and spatial localization was suggested. By evaluating the locational distribution characteristics by building use, flood damage can be minimized through the improvement of the city's ability to adapt to flood hazards by selecting high-risk buildings that demand primary management and response and determining the level of concentration of a particular facility group in flood-prone zones. Third, the study emphasized that the urban flood risk by facility group can be analyzed by district, and that disaster prevention measures should be established in a large framework by first considering the administrative districts with a relatively high distribution ratio of red-rated facilities. Legislative and policy enforcement in the initial step of urban planning may give rise to or facilitate the implementation of scientific results. It is anticipated that if proper land use planning is established in consideration of the findings of this study, such planning will serve as a short-term measure to minimize flood disaster risk but will also function as an effective long-term measure for urban planning and other spaces.

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