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Analysis of Flood-Vulnerable Areas for Disaster Planning Considering Demographic Changes in South Korea

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Abstract: Regional demographic changes are important regional characteristics that need to be considered for the establishment of disaster prevention policies against climate change worldwide. In this study, we propose urban disaster prevention plans based on the classification and characterization of flood vulnerable areas reflecting demographic changes. Data on the property damage, casualties, and flooded area between 2009 and 2018 in 229 municipalities in South Korea were collected and analyzed, and 74 flood vulnerable areas were selected. The demographic change in the selected areas from 2000 to 2018 was examined through comparative analyses of the population size, rate of population change, and population change proportion by age group and gender. Flood vulnerable areas were categorized into three types through K-mean cluster analysis. Based on the analysis results, a strategic plan was proposed to provide information necessary for establishing regional flood-countermeasure policies.

Keywords: urban disaster prevention plan; flood vulnerability; climate change; demographic change; cluster analysis

1. Introduction

Floods are one of the most dangerous and destructive natural hazards that can cause human loss and economic damages [1–3]. Climate change is expected to increase the frequency of flooding and the extent of damage caused by it [4–6].

To minimize the damage caused by natural hazards, policies, treaties, and conventions, including the Nations Framework Convention on Climate Change (1992), Kyoto Protocol (1997), Hyogo Framework (2005), Sendai Framework (2015) and Paris Agreement (2015), have been established. There is increasing awareness of the important role of policies that consider regional characteristics on the mitigation of damages, adaptation to climate change, and sustainable development in response to climate change [7–11].

Although there are several studies on regional flood risk management globally, policies, practices, and approaches relevant to and effective in some countries may not be applicable to the rest. Indeed, differences in governance structures and processes, topography, weather patterns, and vulnerabilities will lead to difficulties in developing effective community flood risk management strategies [12,13].

Various approaches for establishing a flood disaster prevention plan considering regional characteristics have been proposed, including the development of flood vulnerability assessment indicators and their application for the selection of vulnerable regions.

Cardona et al. [14] calculated the local disaster index using flood damage indicators, such as the number of casualties and victims and the monetary value of the flood damage. Kubal et al. [15]

proposed three types of area vulnerability indicators: Social indicators, e.g., transport, housing, and commerce; economic indicators, e.g., schools, hospitals, children, and elderly people; and ecological indicators, e.g., forest, biodiversity, and potential pollution. They used these indicators to evaluate the flood vulnerability of a city in Germany by a multicriteria approach. Balica et al. [16] proposed the flood vulnerability index (FVI) with four types of vulnerability indicators: Social, economic, environmental, and physical. Planners and policymakers can use the FVI as a tool to prioritize flood risk hotspots. Balica et al. [17] developed the coastal city FVI using hydro-geological, socio-economical, and politico-administration indicators and applied it to nine coastal cities around the world to evaluate the most vulnerable ones.

In South Korea, various studies on flood damage mitigation have been carried out. The potential flood damage indicator was proposed to evaluate the flood potential by evaluating the possibility of flooding and the flood control capability considering potential damage factors, such as the population, types of property, urbanization rate, and infrastructures, and risk factors, such as flood damage extent, rainfall probability, river improvement rate, and flood control capacity [18]. Regional safety assessment techniques have been proposed to identify the risk of disaster related to natural hazards in specific regions [19]. The flood damage index was developed considering the main causes of flood damage subdivided into natural, social, policy, and facility factors. This index considers 11 causes representing each factor [20]. In areas were divided into risk and vulnerability groups through the excess flood vulnerability index (EFVI) [21].

The results of the flood vulnerability analyses depend on the type, characteristics, and duration of analysis of the selected evaluation indicators, as well as the region under investigation [22–24]. Several studies on flood vulnerability analyses considered flood damage indicators (e.g., casualties and amount of damage), socio-environmental indicators (e.g., urbanization rate, traffic, and residential ratio), regional indicators (coastal area, urban area, and rural area), and population indicators (e.g., the number of people living in the disaster-prone areas, such as coastal areas and areas with a history of multiple floods, disaster-vulnerable population, such as children and the elderly, and the population affected by the disaster).

Demographic change is one of the most important topics discussed globally, along with the issue of climate change [25,26]. Demographic change is an important criterion for policymaking because it cannot be reversed in a short time, and it is necessary to analyze its characteristics to use them for policymaking in a pre-emptive manner [27,28]. In its Fifth Assessment Report, the Intergovernmental Panel on Climate Change (IPCC, 2015) highlighted demographic characteristics such as age, gender, income, and health status as parameters to shape the resilience capacities of urban areas [29].

South Korea is the country with the fastest decrease in the birth rate and the fastest growth in an aging population in the world [30,31]. Therefore, research has been conducted in various fields on problems and prevention based on demographic changes, and many related national policies have been established. When establishing a disaster prevention policy that prevents human losses and property damage during disasters, it is essential to reflect demographic changes. However, studies discussing and investigating demographic change are scarce in the flood disaster prevention plan. In this study, we propose a strategy for establishing flood disaster preventive urban policies by classifying flood vulnerable areas based on flood characteristics and demographic changes in each region in South Korea.

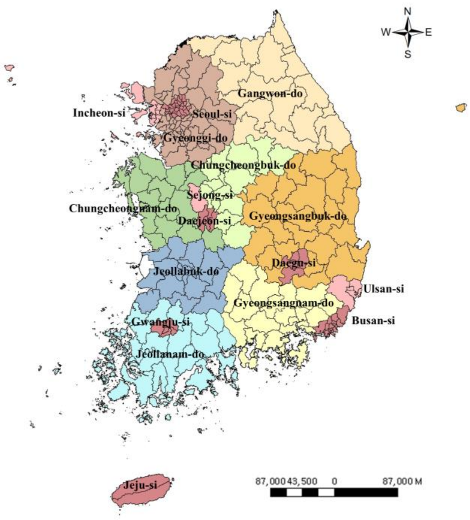
2. Materials and Methods

2.1. Study Area: Spatial Division and Regional Characteristics of Floods

South Korea is characterized by its meteorological features: Rainfall during the rainy season between June and September—when air masses from the northern Pacific and tropical cyclones head north—accounts for 55% of the annual precipitation [32]. In addition, more than two-thirds of the entire land consists of mountainous terrain with weathered rocks, and most of the heavy rainfall is concentrated in the west and south river basin because of the tilted landform (high altitudes in the east and low altitudes in the west). Therefore, streams occur frequently in the western region. Further, coastal floods occur repeatedly every year because the three sides of the peninsula are in contact with the sea [33]. However, the recent industrialization and urbanization have resulted in a larger population concentration in metropolitan city areas and increased land use. This has led to an increase in impervious surfaces. Therefore, the frequency and scale of damage caused by urban floods are increasing.

South Korea is divided into 17 administrative regions: Three special cities, six metropolitan cities, and eight provinces (Table 1). There are a total of 69 autonomous districts in nine special cities and metropolitan cities, 78 autonomous cities and 82 counties in nine special cities and metropolitan cities, and eight provinces, making up a total of 229 municipalities, hereinafter referred to as city (si)/county (gun)/district (gu). In this study, we analyzed the flood damage characteristics and the demographic change in the 229 municipalities of si/gun/gu in South Korea.

Table 1. Seventeen administrative regions of South Korea.



	Regions	Area (km^2)	Si	Gun	Gu
1	Seoul-si	605.24	-	-	25
2	Busan-si	769.94	-	1	15
3	Deagu-si	883.52	-	1	
4	Incheon-si	1063.27	-	2	8
5	Gwanju-si	501.18	-	-	5
6	Deajeon-si	539.53	-	-	5
7	Ulsan-si	1061.54	-	1	4
8	Sejong-si	464.91	1	-	-
9	Gyeonggi-do	10,187.79	28	3	-
10	Gangwon-do	16,827.91	7	11	-
11	Chungcheongbuk-do	7407.85	3	8	-
12	Chungcheongnam-do	8229.20	8	7	-
13	Jeollabuk-do	8069.07	6	8	-
14	Jeollanam-do	12,343.58	5	17	-
15	Gyeongsangbuk-do	19,032.87	10	13	-
16	Gyeongsangnam-do	10,540.12	8	10	-
17	Jeju-si	1850.16	2	-	-
Total		100,377.68	78	82	69

2.2. Methods

The purpose of this study is to provide the basis and implications for the establishment of urban disaster preventive policies in response to climate change. To this end, we considered two aspects that were not considered in previous studies. First, in relation to the establishment of a flood disaster prevention policy considering regional characteristics, we conducted regional flood disaster vulnerability assessments of the 229 municipalities in South Korea. In this study, the term "regional flood disaster vulnerability" represents the degree to which flood disaster will occur again based on past flood damage. Second, we categorized the flood vulnerable areas in South Korea by considering the demographic change indicators. In this study, the "Demographic change" implies any change in the population, for example, a change in population size, the rate of population change, and the population proportion change by age groups and gender. The research flow chart applying the two aspects considered is explained below (Figure 1).

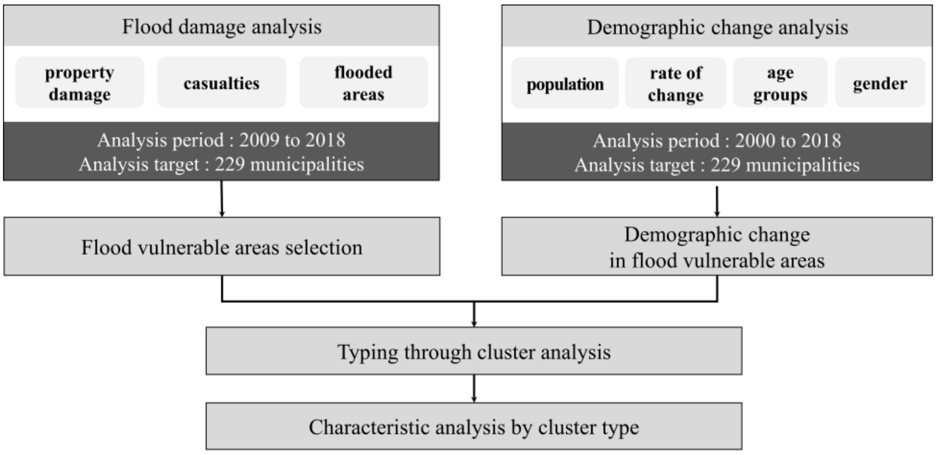


Figure 1. Flow chart of the procedure followed in this study.

First, we analyzed the three types of flood damage characteristics, i.e., the property damage, casualties, and flooded area between 2009 and 2018. We rated the extent of flood damage among the 229 municipalities of si/gun/gu and selected the 30 most flooded areas for each category as the flood vulnerable areas. Second, for the selected flood vulnerable areas, we compared the population size, rate of population change, and population proportion change between 2000 and 2018 and analyzed them by age groups and gender. Third, to generalize the demographic changes in the flood vulnerable areas for comparison, we performed typing through cluster analysis.

In addition, through a comparison of the characteristics by flood vulnerable area type derived from cluster analysis and spatial distribution analysis, this study aims to provide the information necessary to establish flood countermeasure policies for each type of region in the future.

2.3. Flood Vulnerable Area Selection Data

Past flood damage data have been widely used for the selection of flood vulnerable areas because they reflect the characteristics and status of the flood damage in each region [34–36]. In particular, flood damage data comprehensively reflect socio-economic and topographical factors. In this study, property damage (one million South Korean won), casualties (persons), and flooded area (km^2) data were selected as the flood vulnerable area characterization variables.

The South Korean Ministry of the Interior and Safety publishes major statistics on natural hazard damage and recovery status in the annual disasters related to the natural hazard report in Statistics Korea [37]. Statistical data on annual disaster related to the natural hazard report provide statistics for each natural hazard period by facility (public or private facility) and cause (e.g., typhoon, heavy rain, heavy snow, storm, and earthquake). In terms of spatial distribution, they provide the statistics for each major city and province in the 17 administrative regions up to the level of gun/gu. However, the statistics by province are provided according to each natural cause (e.g., heavy rain, typhoon, heavy snow, strong wind, and earthquake), while the statistics in the unit of gun/gu provide only the total of the natural hazard and no classification according to the causes.

In this study, statistical damage data from the flooding of 229 municipalities are extracted by comparing the total number of the natural hazards in the 229 municipalities with the flood damage in the 17 administrative regions and the natural hazard for each period.

The damage status derived for comparative analysis by si/gun/gu was divided into the total area by si/gun/gu to determine the amount of damage per km^2, and through comparison, the 30 most damaged regions in each category, i.e., property damage (one million South Korean won/km^2), casualties (persons/$km^{2)}$, and flooded area (km^2/km^2) were selected as the flood vulnerable areas.

2.4. Demographic Change Analysis Data

Characteristics, such as the population size, distribution, and structure, provide the basic data for policymaking, planning, research, and evaluation. Statistics Korea periodically conducts a population census for all persons in the country. Statistical data for the population census are prepared up to the eup-myeon-dong unit (the sub-district unit of si/gun/gu) and published every five years. However, from 2015, the survey method changed to a registered census method using national administrative data from the total number of surveys, and the data are now published every year [38].

For the analysis of the demographic change in flood vulnerable areas, the total population, population by age, and gender between 2000 and 2018 of the 229 municipalities were extracted from Statistics Korea's population census data. Unlike most demographic analysis studies and the data provided by the National Statistical Office, which categorizes demographic age groups into youth (0–14 years old), working-age (15–64 years old), and aged (+65 years old) [27,39,40], this study further divided the youth group and aged group because they are more vulnerable to the flood damage. In total, five age groups were categorized: Infants (0–9 years old), school-age (10–19 years old), working-age (20–64 years old), aged (65–74 years old), and super-aged (+75). Then, a comparative analysis by si/gun/gu was performed on the population size, rate of population change, population proportion, and proportion change by age group and gender in the last 18 years.

2.5. Cluster Analysis

Cluster analysis is a statistical analysis whereby data values are converted into distances based on the similarity between variables, and nearby variables are classified into clusters. This method can be broadly divided into hierarchical clustering and non-hierarchical clustering [41,42]. For the analysis by typing of flood vulnerable areas corresponding to demographic change, this study utilized the K-mean method, which is a non-hierarchical method.

We selected the flood damage characteristics as indicators, i.e., the property damage (million South Korean won/km^2), casualties (person/km^2), and flooded area (km^2/km^2), and the demographic change characteristics, i.e., the population by age group and gender (population in 2018), population change (population in 2018–population in 2000), rate of population change ((population in 2018–population in 2000)/population in 2018 × 100), proportion (population by age group or gender/total population in 2018 × 100) and proportion change (proportion in 2018–proportion in 2000) (Table 2).

Table 2. Variables considered for the cluster analysis.

Variable			Calculation Method
Vulnerable area characteristics			
Property damage (million South Korean won/km^2)			Flood property damage between 2009 and 2018
Casualties (person/km^2)			Flood casualties 2009 and 2018
Flooded areas (km^2/km^2)			Flooded areas between 2009 and 2018
Demographic characteristics			
Population (person)	0–9 years old	Male	Population in 2018
Population change (person)	10–19 years old	Female	Population in 2018–Population in 2000
Rate of population change (%)	20–64 years old		(Population in 2018–Population in 2000)/Population in 2018 × 100
Population proportion (%)	65–74 years old		Population by age group or gender/population in 2018 × 100
Rate of population proportion change (%)	+75 years old		Population proportion in 2018–Population proportion in 2000

3. Results

3.1. Flood Vulnerable Area Selection

3.1.1. Selection and Characteristics of Vulnerable Areas by Major Administrative Region

Prior to the selection of the detailed flood vulnerable areas among the 229 municipalities of si/gun/gu, based on the annual disaster report of the Ministry of the Interior and Safety, the flood damage of 17 administrative regions nationwide in the last 10 years was recalculated as the ratio of the area, and the results were compared and analyzed (Figure 2).

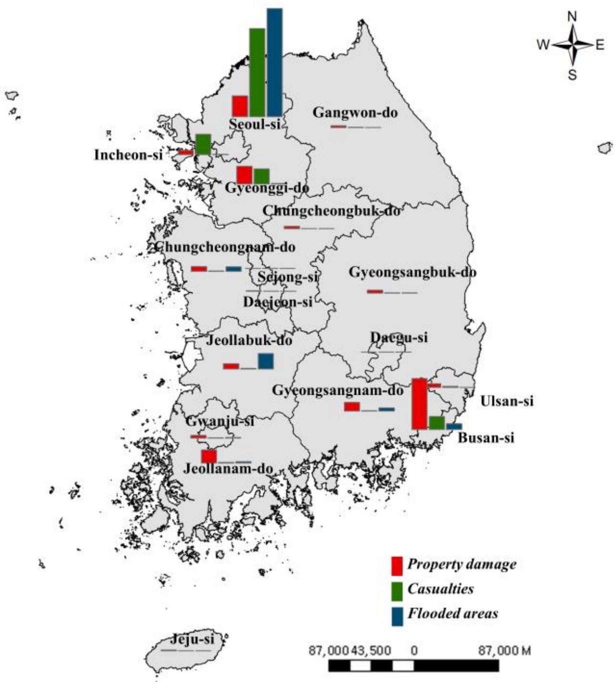


Figure 2. Comparison of flood damage for the 17 administrative regions (2009 to 2018).

As shown in Figure 2, Busan-si was the most damaged with the amount of damage reaching 5077 million won/km^2 (36.45%), followed by Seoul-si with 2085 million won/km^2 (14.97%), and Gyeonggi-do with 1767 million won/km^2 (12.68%). The casualties were 4632 persons/km^2 (63.12%), 1061 persons/km^2 (14.46%), and 801 persons/km^2 (10.91%) in Seoul-si, Incheon-si, and Gyeonggi-do, respectively. Seoul-si, Jeollabuk-do, and Busan-si had flooded areas of 23.68 km^2/km^2 (77.60%), 0.38 km^2/km^2 (11.07%), and 0.14 km^2/km^2 (4.13%), respectively. Overall, the flood damage in the western provinces was greater than that in the eastern provinces because of the topographical features of the tilted landform (higher altitudes in the east and low altitudes in the west) of South Korea.

In addition, more than half of the property damages, casualties, and flooded areas were observed in two to three administrative regions. A large variation in flood damage was obtained in different regions. These results indicate that flood disaster prevention plans need to be established such that the most damaged regions are prioritized in terms of the implementation of plans. Further, the most damaged areas need to be analyzed with more precise units such as si/gun/gu.

3.1.2. Selection and Characteristics of Vulnerable Areas (si/gun/gu)

Considering the last 10 years, the regions were ranked according to the property, casualty, and flood area damages caused by floods in 229 municipalities of si/gun/gu, and the 30 most damaged towns and districts for each category were selected as flood vulnerable areas (Figure 3 and Table 3).

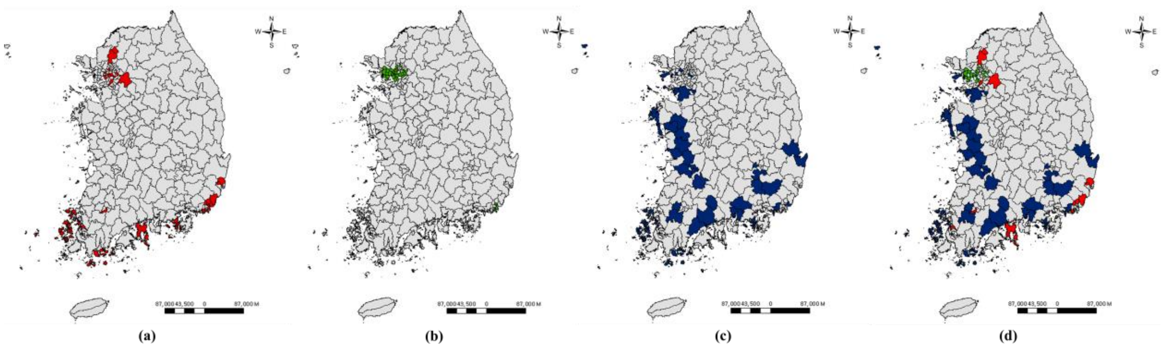


Figure 3. Spatial analysis of flood vulnerable regions (**a**) property damage, (**b**) casualty losses, (**c**) flooded areas, (**d**) overlap.

Table 3. Characteristics of regions most vulnerable to floods.; Regions in the two categories of property and casualty(yellow), property and flood area(red), casualty and flood area(green).regions in the three categories of property, casualty, and flood area(gray).

Property Damage				Casualties				Flooded Areas			
Municipalities Si/Do/Gun/Gu		Million won/km^2	%	Municipalities Si/Do/Gun/Gu		Person/km^2	%	Municipalities Si/Do/Gun/Gu		km^2/km^2	%
Total		1,392,9.54	100.00	Total		7337.55	100.00	Total		3.46	100.00
Sub-Total: Top 30		796,5.27	57.18	Sub-Total: Top 30		6440.45	87.77	Sub-Total: Top 30		3.46	99.94
Busan	Suyeong	843.49	6.06	Seoul	Yangcheon	658.19	8.97	Seoul	Gangseo	2.683	77.59
Busan	Seo	763.30	5.48	Seoul	Dongjak	497.73	6.78	Chungcheongbuk	Jeonju	0.368	10.36
Busan	Yeongdo	702.68	5.04	Seoul	Gwanak	496.70	6.77	Chungcheongnam	Seocheon	0.080	2.31
Busan	Saha	555.82	3.99	Incheon	Michuhol	441.16	6.01	Busan	Yeonje	0.076	2.20
Busan	Nam	438.00	3.14	Seoul	Gangdong	364.00	4.96	Busan	Haeundea	0.066	1.91
Seoul	Seocho	436.77	3.14	Seoul	Guro	352.38	4.80	Gyeongsangnam	Sacheon	0.028	0.82
Busan	Yeonje	332.96	2.39	Seoul	Geumcheon	339.93	4.63	Gyeongsangnam	Changnyeong	0.028	0.81
Busan	Gijang	316.96	2.28	Seoul	Gwangjin	314.18	4.28	Jeollanam	Suncheon	0.024	0.68
Seoul	Yangcheon	299.54	2.15	Incheon	Bupyeong	313.88	4.28	Gyeonggi	Hwaseong	0.017	0.50
Busan	Buk	235.70	1.69	Seoul	Seocho	267.71	3.65	Chungcheongbuk	Gimje	0.017	0.49
Jeollanam	Wando	228.65	1.64	Seoul	Gangseo	240.85	3.28	Gyeongsangnam	Miryang	0.011	0.31
Seoul	Gwanak	228.59	1.64	Gyeonggi	Bucheon	239.78	3.27	Chungcheongnam	Taean	0.010	0.29
Busan	Dongnae	227.67	1.63	Gyeonggi	Gwangmyeong	178.56	2.43	Gwanju	Gwangsan	0.009	0.29
Busan	Haeundea	226.73	1.63	Busan	Dongnae	167.68	2.29	Gyeongsangbuk	Pohang	0.007	0.20
Gyeonggi	Dongducheon	213.61	1.53	Seoul	Gangnam	162.22	2.21	Chungcheongbuk	Iksan	0.007	0.19
Jeollanam	Mokpo	191.51	1.37	Seoul	Yeongdeungpo	145.02	1.98	Chungcheongnam	Cheongyang	0.006	0.18
Busan	Geumjeong	176.15	1.26	Seoul	Songpa	119.21	1.62	Gyeongsangnam	Jinju	0.006	0.18
Gwanju	Nam	149.98	1.08	Seoul	Mapo	115.68	1.58	Chungcheongnam	Buyeo	0.005	0.16
Seoul	Seodaemun	145.63	1.05	Busan	Yeonje	112.49	1.53	Jeollanam	Naju	0.005	0.14
Ulsan	Buk	138.71	1.00	Seoul	Eunpyeong	106.54	1.45	Jeollanam	Boseong	0.002	0.06
Gyeonggi	Gwangmyeong	137.73	0.99	Incheon	Namdong	102.09	1.39	Chungcheongnam	Yesan	0.002	0.06
Gyeonggi	Gwangju	125.54	0.90	Busan	Nam	89.21	1.22	Incheon	Jung	0.002	0.06
Gyeonggi	Yangju	119.23	0.86	Busan	Dong	87.41	1.19	Jeollanam	Gurye	0.002	0.05
Seoul	Dongjak	114.73	0.82	Incheon	Gyeyang	87.37	1.19	Incheon	Bupyeong	0.001	0.04
Ulsan	Jung	114.17	0.82	Seoul	Dongdaemun	82.94	1.13	Chungcheongbuk	Imsil	0.001	0.02
Gyeonggi	Uiwang	111.31	0.80	Seoul	Seodaemun	80.57	1.10	Incheon	Ongjin	0.001	0.02
Gyeongsangnam	Tongyeong	99.70	0.72	Seoul	Gangbuk	72.96	0.99	Deagu	Dalseong	0.001	0.01
Jeollanam	Yeosu	98.03	0.70	Gyeonggi	Anyang	70.73	0.96	Busan	Gangseo	0.000	0.01
Seoul	Songpa	97.71	0.70	Busan	Yeongdo	68.80	0.94	Chungcheongnam	Hongseong	0.000	0.01
Jeollanam	Shinan	94.65	0.68	Incheon	Seo	64.47	0.88	Seoul	Seocho	0.000	0.01

Property damage to the 30 most damaged si/gun/gu accounted for 57.18% of the total damage. Busan-si Suyeong-gu was the most damaged, accounting for 6.06% of the total damage. Among the administrative regions analyzed, 12 gu/gun in Busan-si, 6 gu in Seoul-si, 5 si in Gyeonggi-do, and 4 si/gun in Jeollanam-do were the 30 most damaged. Among the administrative regions not categorized into flood vulnerable areas in the analysis, Gwangju-si Nam-gu, Ulsan-si Buk-gu, Ulsan-si Jung-gu, and Gyeongsangnam-do Tongyeong-si were among the 30 most damaged.

The 30 most damaged municipalities accounted for 87.77% of the total casualties. Yangcheon-gu in Seoul-si had the largest number of casualties, accounting for 8.97% of the total. The si/gun/gu distribution showed that these 30 areas were in Seoul-si (17 gu), Incheon-si (5 gu/gun), Gyeonggi-do (3 cities), and Busan-si (4 districts).

Gangseo-gu in Seoul-si had the largest damaged area, accounting for 77.59% of the total damaged area. The flooded areas of the 30 most damaged municipalities accounted for 99.94% of the total damage. This result indicates that all the regions with flooded areas were ranked in the top 30. With the analysis of the overlap between the 30 most damaged regions in the three categories of property, casualty, and flood area, two si/gun/gu (i.e., Seocho-gu in Seoul-si and Yeonje-gu in Busan-si) overlapped across all three categories of damage, whereas 12 si/gun/gu (i.e., Seodaemun-gu, Yangcheon-gu, Gangseo-gu, Dongja-gu, Gwanak-gu and Songpa-gu in Seoul-si; Yeongdo-gu, Dongrae-gu, Nam-gu and Haeundae-gu in Busan-si; Bupyeong-gu in Incheon-si; and Gwangmyeong-si in Gyeonggi-do) overlapped across two categories. Considering these, 74 si/gun/gu were selected as the final flood vulnerable areas.

3.2. Demographic Change Analysis

3.2.1. Demographic Change across South Korea

As of 2018, Korea's total population was 51,630,000, which is an increase of 12% (5,644,000) from that in 2000.). However, the population decreased in 136 out of 229 municipalities (59.39%) and increased in only 93 regions (40.61%) (Figure 4). This indicates that, like flood damage, population change has large variations among regions, and this must be considered in disaster preventive urban planning.

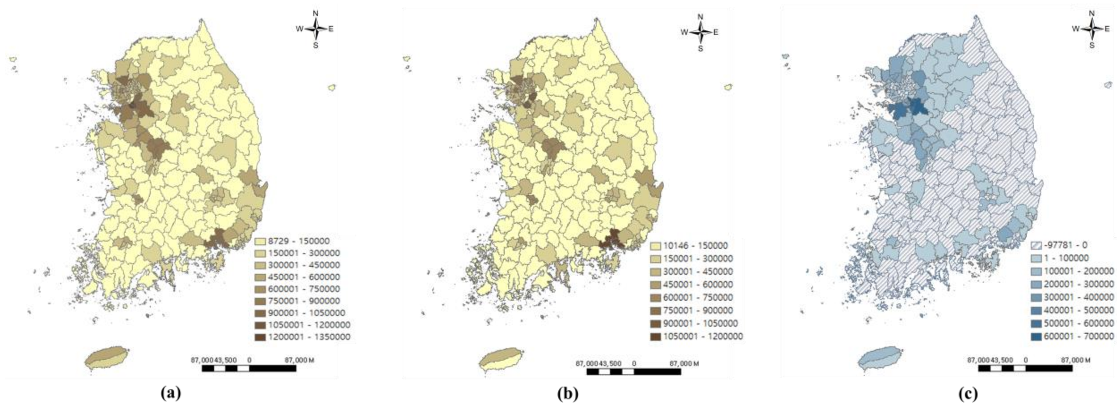


Figure 4. Spatial analysis of Korea's population change (2000–2018). (**a**) 2018 population, (**b**) 2000 population, (**c**) population change (2018–2000).

Table 4a shows the demographic change for all age groups in South Korea between 2000 and 2018. The super-aged (+75) and infants (0–9) were the age group with the highest increase (3.96%) and decrease (−6.01%), respectively. The proportion of infants, school-age (10–19), and working-age (20–64) decreased, while that of aged (65–74) and super-aged (+75) increased. Similar to the results of many previous studies, the above findings show that South Korea is the country with the fastest decrease in the birth rate and the fastest aging population in the world. In addition, the low birth rate and fast population aging are expected to accelerate the demographic change in the long run, and the most flood vulnerable group is also changing from the younger groups to the older ones. Based on several analyses, this change is expected to be more severe in the future.

Examining the demographic change by age group and by gender, the proportion of women in the super-aged group (+75) showed the highest increase of 3.97% in 2018, which represents an increase of 2.38% compared to the 1.59% increase in 2000. The proportion of men in the infants (0–9) group showed the largest decrease to 4.26% in 2018, which represents a decrease of 3.30% over to the 7.55% increase in 2000. These results indicated that the proportion of women in the flood vulnerability group increased.

3.2.2. Demographic Change in Flood Vulnerable Areas

The 74 flood vulnerable areas selected in Section 3.1 account for 17.18% (17,247 km^2) of the total land area in Korea and include 40.29% (20,799 thousand people) of the total population in 2018. Therefore, most of the vulnerable areas are densely populated.

Table 4. Demographic changes between 2000 and 2018 in South Korea and in flood vulnerable areas in South Korea.

	(a) South Korea						(b) Flood Vulnerable Areas in South Korea					
	Population ($\times 10^3$)			Proportion (%)			Population ($\times 10^3$)			Proportion (%)		
	2000	2018	2018–2000	2000	2018	2018–2000	2000	2018	2018–2000	2000	2018	2018–2000
Total	45,985	51,630	+5644	100.00	100.00	-	19,255	20,799	+1544	100.00	100.00	-
Male	23,068	25,877	+2809	50.16	50.12	−0.04	9660	10,340	+681	50.17	49.72	−0.45
Female	22,917	25,752	+2835	49.84	49.88	+0.04	9595	10,459	+864	49.83	50.28	+0.45
Infants	6574	4280	−2294	14.30	8.29	−6.01	2621	1683	−938	13.61	8.09	−5.52
Male	3473	2198	−1275	7.55	4.26	−3.30	1383	864	−519	7.18	4.15	−3.03
Female	3102	2083	−1019	6.74	4.03	−2.71	1238	819	−419	6.43	3.94	−2.49
School-age	6756	5036	−1720	14.69	9.75	−4.94	2853	1943	−910	14.82	9.34	−5.48
Male	3529	2614	−915	7.67	5.06	−2.61	1494	1005	−489	7.76	4.83	−2.93
Female	3227	2421	−806	7.02	4.69	−2.33	1360	939	−421	7.06	4.51	−2.55
Working-age	29,281	34,859	+5577	63.68	67.52	+3.84	12,536	14,215	+1678	65.11	68.34	+3.23
Male	14,778	17,877	+3099	32.14	34.63	+2.49	6311	7190	+879	32.78	34.57	+1.79
Female	14,503	16,982	+2478	31.54	32.89	+1.35	6226	7025	+799	32.33	33.77	+1.44
Aged	2294	4202	+1907	4.99	8.14	+3.15	853	1735	+883	4.43	8.34	+3.92
Male	942	1984	+1041	2.05	3.84	+1.79	352	821	+470	1.83	3.95	+2.12
Female	1352	2218	+866	2.94	4.30	+1.36	501	914	+413	2.60	4.40	+1.79
Super-aged	1078	3254	+2176	2.34	6.30	+3.96	391	1222	+831	2.03	5.88	+3.85
Male	345	1205	+860	0.75	2.33	+1.58	120	460	+340	0.63	2.21	+1.59
Female	735	2049	+1316	1.59	3.97	+2.38	270	762	+492	1.40	3.66	+2.26

Table 4b also shows the demographic change for all age groups in flood vulnerable areas between 2000 and 2018. Similar to the overall pattern in South Korea, the proportion of aged (65–74) and super-aged (+75) people increased, and the proportion of infants (0–9) and school-age (10–19) people decreased in flood vulnerable areas, indicating a low birth rate and fast population aging. The demographic change according to gender in flood vulnerable areas also showed the largest increase in the proportion of women in the super-aged (+75) groups (+2.26%) and the largest decrease in the proportion of men in the infants (0–9) groups (−3.03%), similar to the overall pattern in South Korea. Furthermore, the population decreased in 42 regions and increased in 32 regions. The demographic changes by region according to age group are as follows. For infants (0–9) and school-age children (10–19), the population decreased in 67 and 63 regions, respectively, and increased in 7 and 11 regions, respectively, which indicates many regions witnessed a decrease in the population of these age groups. For the working (20–64) and aged (65–74) groups, the population increased in 43 and 63 regions, respectively, and decreased in 31 and 11 regions, respectively. This indicates that many regions demonstrated an increase in the population of these age groups. The super-aged (+75) group demonstrated a population increase in all 74 vulnerable areas.

3.3. Characteristics of Flood Vulnerable Area Type Reflecting Demographic Change

3.3.1. Type Classification through Cluster Analysis

For the analysis of flood vulnerable area type reflecting demographic changes, a K-mean cluster analysis was conducted by selecting flood vulnerability and demographic change characteristics as variables. Unlike hierarchical cluster analyses, the K-mean cluster analysis requires the number of clusters to be specified in advance. To select the appropriate number of clusters, the number of clusters was varied, and the number of cases for each cluster was determined through ten iterations (Table 5). In this process, it was confirmed that each case (18, 25, 30, 1) showed relatively uniform distribution when classified into four clusters, and, excluding one region with exceptional characteristics, 73 si/gun/gu were categorized into three types.

Table 5. Comparison of the number of cases by clusters.

Cluster	Number of Cases in Each Cluster					
	1	2	3	4	5	6
2	30	44				
3	35	38	1			
4	18	25	30	1		
5	11	12	21	29	1	
6	18	2	18	21	22	1

3.3.2. Analysis of Characteristics by Type

The characteristics of three types of flood vulnerable areas derived through cluster analysis were examined by comparing the mean values of the flood vulnerable area characteristic variables and demographic change characteristic variables (Table 6).

Regions in Cluster 1 (Type 1) have the smallest property damage due to floods but the largest casualties and flooded areas, and includes 18 si/gun/gu, with Yangcheon-gu, Seoul-si, which has the largest number of casualties, and Dongjak-gu, Gwanak-gu in Seoul-si, Haeundae-gu in Busan-si, Anyang-si in Gyeonggi-do, and Pohang-si in Gyeongsangbuk-do (Table 7). In addition, Type 1 regions have the largest mean population and relatively large population growth (smaller than that of Type 3 regions). Although the male population in Type 1 regions increased by 4273 thousand people on average, the female population increased by 13,851 thousand people, indicating a significant increase in the female population. The decrease in the infants (0–9) and school-age (10–19) population and the increase in the working-age (20–64), aged (65–74), super-aged (+75) population is characteristic of the pattern of South Korea, i.e., low birth rate and fast population aging.

Table 6. Characteristics of clusters and comparison of the variables' mean values.

Variable	Cluster 1		Cluster 2		Cluster 3	
Property damage	94.50 million won/ km^2		112.43 million won/km^2		173.53 million won/km^2	
Casualties	241.09 person/km^2		10.24 person/km^2		71.83 person/km^2	
Flooded area	0.17 km^2/km^2		0.01 km^2/km^2		0.00 km^2/km^2	
	Male	Female	Male	Female	Male	Female
Population ($\times10^3$)	253,366	259,782	40,145	39,388	145,500	147,723
Infants	20,284	19,209	2998	2847	12,420	11,775
School-age	24,313	22,593	3454	3166	14,590	13,706
Working-age	178,617	179,774	26,298	22,947	100,926	99,145
Aged	19,866	21,822	4305	4849	11,280	12,717
Super-aged	10,285	16,385	3088	5578	6283	10,380
Population change ($\times10^3$)	4273	13,851	−478	−2088	10,025	13,011
Infants	−15,278	−12,679	−1924	−1571	−7734	−6231
School-age	−14,940	−12,943	−2447	−2173	−6325	−5457
Working-age	14,109	17,266	693	−1974	12,670	11,683
Aged	12,584	11,532	1,250	402	6643	6139
Super-aged	7803	10,680	1953	3230	4773	6879
Rate of population change						
Infants	−77.55%	−67.95%	−101.40%	−91.73%	−71.65%	−61.23%
School-age	−65.15%	−60.77%	−86.37%	−88.36%	−50.66%	−46.68%
Working-age	+6.71%	+8.63%	−3.44%	−18.70%	+11.29%	+11.24%
Aged	+63.06%	+52.87%	+25.03%	+2.80%	+59.51%	+48.62%
Super-aged	+75.79%	+64.71%	+62.93%	+57.80%	+76.28%	+66.91%
Population proportion	49.37%	50.63%	50.48%	49.52%	49.62%	50.38%
Infants	3.95%	3.74%	3.77%	3.58%	4.24%	4.02%
School-age	4.74%	4.40%	4.34%	3.98%	4.98%	4.67%
Working-age	34.81%	35.03%	33.07%	28.85%	34.42%	33.81%
Aged	3.87%	4.25%	5.41%	6.10%	3.85%	4.34%
Super-aged	2.00%	3.19%	3.88%	7.01%	2.14%	3.54%
Rate of population proportion change						
Infants	−3.23%	−2.70%	−2.23%	−1.80%	−3.22%	−2.65%
School-age	−3.19%	−2.78%	−2.84%	−2.52%	−2.77%	−2.42%
Working-age	+1.58%	+2.21%	+1.88%	−1.50%	+1.75%	+1.44%
Aged	+2.40%	+2.17%	+1.69%	+0.68%	+2.13%	+1.90%
Super-aged	+1.50%	+2.04%	+2.50%	+4.15%	+1.58%	+2.24%

Type 2 regions cover 25 si/gun/gu, including Seo-gu and Dong-gu in Busan-si, Jung-gu and Ongjin-gun in Incheon-si, Dongducheon-si, and Uiwang-si in Gyeonggi-do, Buyeo-gun and Seocheon-si in Chungcheongnam-do Kim Jae-gun, Insil-gun in Chungcheongbuk-do, Naju-si, and Gurye-gun in Jeollanam-do and Tongyeong-si and Sacheon-si in Gyeongsangnam-do (Table 7). Excluding four gu in Busan-si and two gu/gun in Incheon-si, the majority of the Type 2 regions are regional small- or medium-sized cities with the smallest population sizes and are the only ones where the populations decreased. In the Type 2 regions, the population decreased across a wide range of ages from infants (0–9) to working-age (20–64), and the rate of decrease was greater than that in Type 1 and three regions. The working-age (20–64) female population (−18.70%) and the infants (0–9) male population (−101.40%) decreased sharply. The proportion of infants and school-age people was the smallest, and that of aged and super-aged was the highest, which had the greatest contribution to the low birth rate and fast population aging. In addition, the casualties due to floods were the fewest among the three types, and the property damages and flooded areas were the second largest, which is attributed to the larger average land area of Type 2 flooded areas.

Type 3 regions have the largest property damage owing to floods and include 30 si/gun/gu. Among these, Suyeong-gu in Busan-si, Gwangjin-gu, and Dongdaemun-gu in Seoul-si, Dalseong-gun in Daegu-si, Gyeyang-gu in Incheon-si, Nam-gu in Gwangju-si, and Jung-gu in Ulsan-si have the greatest property damage (Table 7). The population size in Type 3 regions is smaller than that in Type 1 regions, but the population growth is the largest. The number of men and women increased uniformly, and the growth rate of working-age (20–64) (male: 11.29%, female: 11.24%) is large. In addition, the reduction rate of infants (0–9) is the smallest, and the population proportion is the largest.

Table 7. Regional classification by type.

Cluster (number)	Characteristics	Regions (Si/Do/Gun/Gu)
1 (18)	Large number of casualties; large flooded areas; low population growth	Seoul: Eunpyeong, Yangcheon, Gangseo, Guro, Yeongdeungpo, Dongjak, Gwanak, Gangnam, Songpa, and Gangdong; Busan: Haeundea; Incheon: Michuhol, Namdong, and Bupyeong; Gyeonggi: Anyang and Bucheon; Chungcheongbuk: Jeonju; Gyeongsangbuk: Pohang
2 (25)	Small and medium cities; population reduction; low birth rate; fast population aging	Busan: Seo, Dong, Yeongdo, and Gangseo; Incheon: Jung and Ongjin; Gyeonggi: Dongducheon and Uiwang; Chungcheongnam: Buyeo, Seocheon, Cheongyang, Hongseong, Yesan, and Taean; Chungcheongbuk: Gimje and Imsil; Jeollanam: Naju, Gurye, Boseong, Wando, and Shinan; Gyeongsangnam: Tongyeong, Sacheon, Miryang, and Changnyeong
3 (30)	Large property damage; high population growth; high proportion of young people	Seoul: Gwangjin, Dongdaemun, Gangbuk, Seodaemun, Mapo, Geumcheon, and Seocho; Busan: Dongnae, Nam, Buk, Saha, Geumjeong, Yeonje, Suyeong, and Gijang; Deagu: Dalseong;, Incheon: Gyeyang and Seo; Gwanju: Nam and Gwangsan; Ulsan: Jung and Buk; Gyeonggi: Gwangmyeong, Gwangju, and Yangju; Chungcheongbuk: Iksan; Jeollanam: Mokpo, Yeosu, and Suncheon; Gyeongsangnam: Jinju

3.4. Recommendations

Flood disaster risk reduction management is a continuous process that involves identifying issues, defining objectives, assessing risks, appraising strategies, implementation, monitoring, and review [43]. Flood damage and demographic characteristics are constantly changing, and there is a need to monitor the changing trends and re-evaluate flood vulnerable areas. Further, the effectiveness of the proposed strategy for each region needs to be monitored based on type, and the goals and strategies need to be adjusted according to the monitoring results. Within this monitoring system, evaluating flood vulnerable areas is considered a cyclical process involving the design and evaluation of alternative strategies. The proposed monitoring system is illustrated in Figure 5 and explained below:

1. Data monitoring: Identify trends of change through flood damage and population census data monitoring.
2. Flood vulnerable area monitoring: The flood vulnerable areas are re-selected and re-categorized according to the changing trend.
3. Strategic planning monitoring: The regional type is divided into “existing” and “new” to monitor the strategic plan by region type.
4. Strategic effectiveness monitoring: The strategy is adjusted by monitoring the effectiveness of the strategy in a region, or by reviewing the application of other strategies in other regions where they worked well.

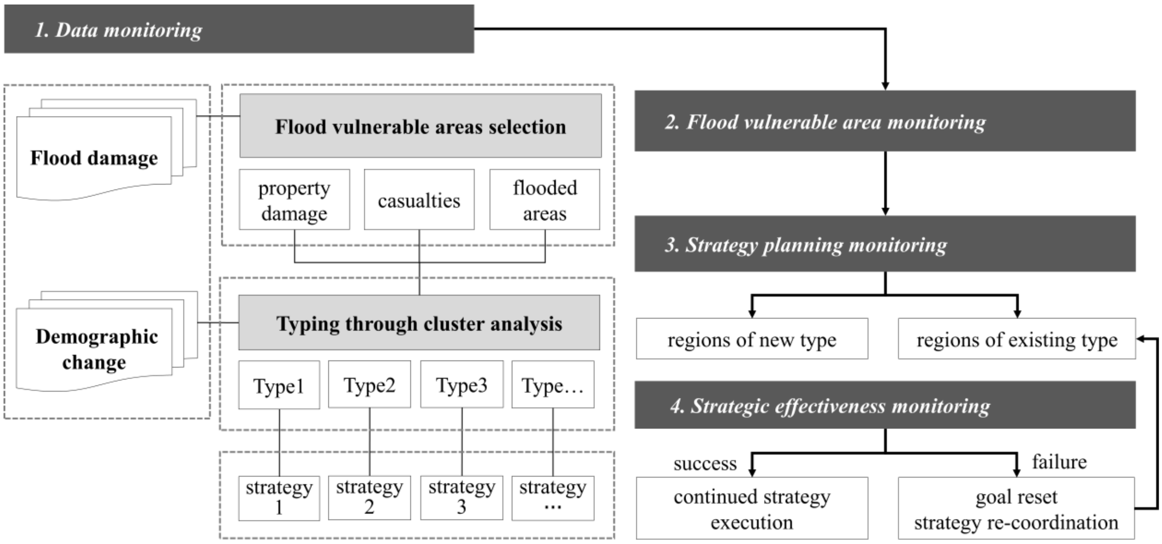


Figure 5. Monitoring flood risk prevention strategies.

4. Discussions and Conclusions

In this study, we designed a methodology for categorizing flood-vulnerable areas through cross and cluster analyses of flood damage and demographic changes. The methodology was applied to 229 local governments in South Korea to derive three types of flood-vulnerable areas.

Type 1 regions comprise of 18 municipalities (si/gun/gu) with metropolitan cities having a large average population (4865 people/km^2). The total population has increased since 2000. In particular, the female population in these areas has increased significantly compared to the male population, and floods have caused substantial human casualties.

Type 2 areas typically include small- and medium-sized regional cities with a small population over a large area (209 people/km^2). Korea has 25 Type 2 municipalities (si/gun/gu). The flood damage in these regions is not as extensive as that in other areas, however, they are the only regions characterized by population decrease, low birth rate, and aging population.

Type 3 areas include 30 Korean municipalities (si/gun/gu) with a population size (1716 people/km^2) larger than the overall average population size of Korea (514 people/km^2), but smaller than the metropolitan Type 1. This is a new city type with large population growth and the largest increase in the youth population.

The vulnerable areas of categorized floods should be handled at the community level through various strategies, such as installing structures that increase height (e.g., levees and sandbags [44,45]), acquiring open spaces and conserving wetlands [46–49], land use planning for further development and densification regulation in flood-prone areas [50], flood-proofing buildings [51], insurance programs and tax incentives for flood risk [52–54], flood risk response strategy communication (e.g., flood information, early disaster warning, risk mapping and distribution, and evacuation training [50,55]), involvement of local community members in the flood planning and recovery processes [49,50], minimization of the constraints of the disaster vulnerable population [49,56] and mitigation efforts for flood risk factors through continuous monitoring of the local community [49,50]. The strategy presented in this paper can be additionally considered when establishing flood prevention measures on the local community level. Therefore, the proposed strategy cannot encompass all elements of community flood disaster prevention planning. A flood risk prevention strategy appropriate to the area type can be developed through additional research. Moreover, the suitability of the proposed strategy should be verified through continuous monitoring.

This study differs from previous studies in that it categorized flood-vulnerable areas into three types considering the demographic change factors and improved the accuracy of the regional differences by subdividing Korea into 229 municipalities and performing a detailed analysis. However, as suggested in Section 3.4, flood damage and demographic factors are constantly changing variables. Therefore, flood-vulnerable areas must be re-evaluated through monitoring and continuous improvement and update of response measures and planning. In addition, in terms of demographic change, the quality of research is expected to be further improved if various disaster vulnerable group variables, such as foreigners, the disabled, and the poor, can be additionally considered and if long-term demographic data are supplemented.

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