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The spatial analysis of the relationship between cooling centers and vulnerable areas to heat waves in Seoul

Sora Han[1] and Hyekyung Lee[2*]

[1]Student, School of Urban Planning and Real Estate Studies, Dankook University, Gyeonggi, Yongin, South Korea

[2]Assistant Professor, School of Urban Planning and Real Estate Studies, Dankook University, Gyeonggi, Yongin, South Korea

***Corresponding author:** hklee@dankook.ac.kr

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ABSTRACT

As heat waves are becoming more frequent and extreme due to global warming, the Seoul metropolitan government has implemented policies to plan and operate cooling centers to prevent heat-related diseases. However, there is a lack of research that finds the relationship between the spatial distribution of cooling centers and vulnerability to heat waves. Therefore, this study aims to analyze whether the distribution of cooling centers throughout 425 administrative dongs in Seoul significantly relates to regional heat wave vulnerability. For this research, variables of climate exposure, sensitivity, and adaptability of 425 administrative dongs in Seoul were considered, and vulnerable areas to heat waves were identified by analyzing the Vulnerable-Resilience Index (VRI). Also, Hotspot analysis and ANOVA were conducted to find the relationship between the distribution of heat wave vulnerable areas and cooling centers. As a result, it showed that the existing distribution of cooling centers in Seoul needs to be improved by considering spatial vulnerability to heat waves for better accessibility. Based on the spatial analysis, additional cooling centers should be installed in some administrative dongs in Jung-gu, Yongsan-gu, Seongbuk-gu, and Gwanak-gu, Seoul. The results of this study would help provide guidelines for planning cooling centers with great accessibility to a vulnerable population.

Keywords: heat wave; cooling center; vulnerable-resilience index (VRI); S-DoT; vulnerability; hotspot analysis

Introduction

Heat waves are becoming more frequent and extreme due to global warming. High density development and population aging at an unprecedently rapid pace are worsening the impacts of heat waves in many cities. Heat waves are one of natural disasters that negatively affect people's health, and heat exposure leads to increased incidences of heat related illness such as heatstroke, sunstroke, heat exhaustion, and heat cramps. According to the Emergency Room Monitoring System Operation Results Report prepared by the Korea Centers for Disease Control and Prevention in 2021, the number of heat wave days from June to August 2021 averaged 11.8 days, an increase of 53.2% compared to the previous year [1]. The number of patients with heat related illnesses reported to the emergency room monitoring system was 1,376, an increase of 27.6% from 1,078 people in 2020. A total of 20

deaths was reported in 2021, and this record marked the second largest death cases since 2011.

It is noteworthy that the levels of vulnerability to the effects of heat waves vary by people's social, physical, and economic characteristics. To prevent heat related illnesses, it is important for people to get access to cooling centers with air conditioning. However, not every person does have good accessibility to cooling shelters due to the absence of the facilities nearby. In other words, the lack of the facilities that can lower body temperature in the event of a heat wave leads to an increase in the incidence of heat-related diseases by lowering the individual's ability to adapt to the heat wave. Previous research explained that the negative health impacts caused by heat waves were high among the socially vulnerable population. In the 2020 Heat Wave Impact Report by Korea Environment Institute defined low-income, 65-year-old or older, outdoor workers, and single-person households as vulnerable population to heat waves [2]. Ahn et al. defined vulnerable groups as the elderly, children, outdoor workers, single-person households, vulnerable housing, pet owners, low-income households, and chronically ill people, considering physical, environmental, and social factors [3].

To reduce adverse impacts of extreme heat event, the Seoul metropolitan government has planned and operated cooling centers since 2018. A cooling center is a facility designated to allow people exposed to extreme heat events to get relief in air. As heat waves were designated as a natural disaster by the Framework Act on the Management of Disasters and Safety in 2018 [4], Korean government started to propose heat response plans of opening cooling shelters and extending its operating hours. However, the current cooling centers are designated by local governments without sufficient consideration of the degree of vulnerability in the region, such as the distribution of vulnerable groups to extreme heat events [5]. According to the 2021 Senior Cooling Center Designation and Support Standards released by Seoul Welfare Policy Office, a cooling center should be designated at a place that is available to use and easily accessible to the people exposed to heat wave [6]. Also, the area at risk of landslides, tsunamis, and flooding should be avoided. Such standards for designating cooling centers do not closely consider the degree of vulnerability to heat waves and the distribution of vulnerable groups in the target area. Particularly, there is a lack of consideration of accessibility to the facilities for the disabled and the elderly. Designation of cooling centers without considering vulnerable areas and vulnerable groups to heat waves would result in not providing enough accessibilities to cooling centers. Also, previous studies emphasized that the accessibility of vulnerable groups should be considered when designating cooling centers [7-10].

To play a significant role in reducing adverse impacts of heat wave in many cities, more spatial analyses for installing a cooling center are needed to consider the vulnerable population to heat waves and spatial vulnerability in cities. Therefore, this study aims to analyze whether the current cooling centers have been planned by significantly considering the vulnerability to heat waves in each administrative dong in Seoul. In addition, the results of this study would contribute to improve existing guidelines for installing cooling shelters with better accessibility especially for vulnerable populations to heat waves.

Literature Review

Identification of the heat vulnerability areas

Cho et al. derived vulnerable areas to thermal environment in Seoul and analyzed the region's physical environment, population, social, and economic characteristics [11]. Variables were collected by dividing them into climate, population, socio-economic, and land use characteristics. Heat island areas were identified through hotspot analysis, variance analysis, and logistic regression analysis, and further physical and social characteristics of the region were studied. As a result of the study, vulnerable areas of the thermal environment were mainly clustered around the old city center and the sub-city center. The areas had higher air temperatures than the surrounding areas, and the vulnerable socio-economic groups were concentrated.

Another study considering the socio-economic characteristics of the population is a study by Bae et al. that analyzed the spatial relationship between vulnerable areas and the risk of heat waves in Cheongju-si [12]. This study evaluated heat wave vulnerable areas by conducting spatial autocorrelation analysis with the average radiant temperature, a temperature variable, and the possibility of residence of the vulnerable class. In addition, nine variables classified as vulnerable factors in physical, economic, and living conditions were selected to analyze the possibility of residence of the vulnerable. As a result of the analysis, the vulnerable group was also likely to live in areas with a high risk of exposure to heat waves, and the vulnerability to heat waves was exceptionally high in the old city center.

Choi et al. evaluated the vulnerability to the heat wave in the administrative dong in Seoul, and compared relatively safe and vulnerable areas by focusing on adaptability [13]. This study collected variables by dividing into climate exposure, sensitivity, and adaptability, and the vulnerability to heat wave was analyzed by using the Vulnerability-Resilience Index (VRI). As a result of the study, it was found that the old downtown areas of Seoul were vulnerable to heat waves, and the vulnerable areas generally had high levels of climate exposure and sensitivity, but the level of adaptability was low. The study had a meaningful implementation, because it provided empirical evidence for heat wave adaptation plans by considering adaptability in administrative dong level. However, there is a limitation in that detailed temperature analysis for each administrative dong was not considered, because only 28 sensor data provided by the Korea Meteorological Administration were used as an indicator of heat wave measurement. Therefore, our study utilized temperature information of S-DoT (Smart Seoul Data of Things) data collected from 1,100 sensor data installed across Seoul for better analysis.

Designation of cooling centers

Kim et al. analyzed the degrees of exposure to heat wave and responsive behaviors of the heat wave vulnerable groups [9]. As a heat wave response system, they tried to suggest ways to improve the cooling center implementation plans by reflecting the vulnerable characteristics. An indoor and outdoor temperature observations and site survey were conducted in areas with a high incidence rate of heat related diseases. The analysis showed that the vulnerable

were likely to be exposed to high temperatures, and their ability to cope with heat waves was remarkably low. In particular, it was concluded that the effect of the policy might be limited because the actual usage of cooling centers and accessbility to the facilities were limited especially for the disabled and population without transportation modes.

Yoon studied whether the spatial equity of public services was considered for the disaster-prone class by overlapping the distribution of the disaster-prone class and the service area of the cooling centers in Busan Metropolitan City [14]. As a result, it was confirmed that vulnerable people to disaster were clustered particularly in 24 administrative dongs in Busan. However, these areas were not coverd by service areas of existing cooling centers. This study was meaningful in that it emphasized the urgent need to designate these facilities and prepare operating guidelines in the most vulnerable areas. Also, the spatial distribution of the vulnerable should be applied for improving equity in public services. However, since the aging index data in this research was analyzed based on the resident registration population, only the static census population was considered. Therefore, the actual needs for floating population in these districts to use the cooling centers during the extreme heat wave were not fuly considered. The living population refers the de facto population that consisted of all persons who are presented in a given areas at a specific time using open-source spatial big data and the mobile phone signal-based data. It includes the census population and the floating population from outside of Seoul metropolitan area for short-term and mid-to-long-term stays. Using this data, it is possible to accurately analyze the sensitivity to the heat wave by considering both the census population and the floating population in the target area during the heat wave. Our study considered the spatio-temporal pattern changes of the vulnerable class by using living population dataset.

Gaps in literature review

Our study filled the gaps in literature review in two main aspects. First, S-DoT data was used to utilize the temperature data across in Seoul. S-DoT data is environmental information data measured by 1,100 sensors installed throughout Seoul. It collects information such as fine dust, temperature, noise, and wind speed. Previous studies on heat waves generally used the average temperature, maximum temperature, and minimum temperature data released by the Korea Meteorological Administration. However, since the data of the Korea Meteorological Administration is measured at an observatory installed for each administrative Gu level, it is not possible to closely measure the temperature differences in each administrative dong. On the other hand, S-DoT data can grasp a more specific temperature of each administrative dong because the sensors are distributed across administrative dongs. Recently, some studies have emerged that analyzed the environmental characteristics between areas utilizing the S-DoT data [15-17]. Therefore, our study used S-DoT data as climate exposure data to reflect the region's more detailed temperature for the time frame of study.

Second, vulnerable areas to heat waves were analyzed considering the floating population. Many previous research used the number of resident registered populations as a population variable to analyze the vulnerability to

heat waves in the study areas. However, this can lead to results far from existing characteristics because the population living in the area during the heat wave time cannot be considered. For example, outdoor workers in different workplaces are likely to have heat related diseases in other places where the workers have not registered, because they usually work outdoors during the day. However, considering only the resident registration population, living population data may not be sufficiently reflected. Therefore, our study analyzed the characteristics of the floating population that were not included in previous studies by using the living population data provided by Seoul metropolitan government.

Material and Methodology

Data and Variables

To analyze the degrees of vulnerability to heat waves in Seoul, South Korea, 425 administrative dongs in Seoul were considered for this research. As of May 2022, the total designated number of cooling centers in Seoul was 33,161. Heat waves have occurred during summer daytime in South Korea, and heat-related diseases have been reported mostly during the corresponding time [18]. Therefore, the data between PM 12:00 and 17:00 from July to August in 2020, was analyzed for this study.

The empirical analyses for this study were conducted as follows. Based on literature review, the variables for this research were carefully identified. These variables were standardized using the Vulnerability-Resilience Index (VRI) to find spatial distribution of the vulnerability to heat waves in each administrative dong using ArcGIS. Further, ANOVA (Analysis of Variance) test and LISA (Local Indicators of Spatial Association) cluster analysis were conducted to identify the spatial relationship between vulnerable areas to heat waves and locations of cooling centers.

To investigate the vulnerability to heat waves in 425 administrative dongs in Seoul, the variables explained in Table 1 were used. Also, variables were categorized into climate exposure, sensitivity, and adaptability based on the concept of climate change vulnerability index [19]. Climate exposure refers to the degree to which the system is exposed to significant climatic variations caused by climate change, and S-DoT (Smart Seoul Data of Things) data was used to measure climate exposure. As mentioned above, S-DoT data collects temperature data for every hour, enabling detailed temperature measurement by the administrative dong level. Only the data between PM 12:00 and 17:00 from July to August in 2020, was analyzed for this study. Figure 1 shows the result of average temperature in each administrative dong utilizing S-DoT data. Sensitivity refers to the degree to which system is affected by or responsive to climate stimuli. Variables representing sensitivity for this research were hourly average floating population under the age of 10, hourly average floating population over the age of 65, the number of people living alone, the number of basic livelihood recipients, the number of low-income seniors, the number of disabled, childhood support expenses, and elderly support expenses. Floating population under the age of 10 and over 65 were calculated utilizing the population data from PM 12:00 to 17:00 between July 1 to August 31. Each of the total

number of floating population under the age of 10 and over 65 was divided by the total number of floating population for each administrative dong. Finally, adaptability means the ability of the system to respond to damage caused by climate change. Many previous studies analyzed vulnerability to heat waves by using financial ability (household income), social infrastructure (healthcare, education, public facilities), physical environment (green area, etc.) as variables for measuring adaptability. This study considered household income variables, the number of leisure welfare facilities for the elderly, medical institutions, medical personnel, and the green areas for measuring adptabilty to extreme heat exposure.

Table 1. Variables

Categories	Variables and data descriptions	Functional relationships	Data sources
Climate exposure	S-DoT Temperature Data: Average Temperature by Administrative Dong	Average temperature by administrative dongs ↓, Climate Exposure ↓	Seoul Open Data Plaza (2020)
Sensitivity	Hourly Average floating population under ten years old: (Population under ten years old / Total population by dong) / 6 hours	Population under the age of 10 ↓, Sensitivity ↓	Seoul Open Data Plaza (2020)
	Hourly Average floating population aged 65 or older: (Population aged 65 or older / Total population by dong) / 6 hours	Population aged 65 or older ↓, Sensitivity ↓	Seoul Open Data Plaza (2020)
	Number of senior citizens living alone: Number of older people living alone by administrative dong	The elderly living alone ↓, Sensitivity ↓	Seoul Open Data Plaza (2020)
	Number of basic livelihood recipients: Number of basic livelihood recipients by administrative dong	Basic Livelihood Recipient ↓, Sensitivity ↓	Seoul Open Data Plaza (2020)
	Number of low-income senior citizens: Number of low-income senior citizens by administrative dong	Low-income elderly ↓, Sensitivity ↓	Seoul Open Data Plaza (2020)
	Number of persons with disabilities: Number of persons with disabilities by administrative dong	Disabled ↓, Sensitivity ↓	Seoul Open Data Plaza (2020)
	Childhood Support Expenses: Childhood Support Expenses by Administrative dong	Child support cost ↓, sensitivity ↓	Seoul Open Data Plaza (2020)
	Elderly Support Expenses: Elderly Support Expenses by Administrative dong	Elderly support cost ↓, sensitivity ↓	Seoul Open Data Plaza (2020)
Adaptability	Income by household: Household Income by administrative dong	Household income ↑, Adaptability ↑	Environmental Big Data Platform (2020)
	Number of leisure welfare facilities for the elderly: Number of leisure welfare facilities for the elderly by administrative dong (elderly welfare center, senior citizen center, senior citizens' classes)	Number of leisure welfare facilities for the elderly ↑, Adaptability ↑	Seoul Open Data Plaza (2020)
	Number of medical centers: Number of hospitals and public health centers by administrative dong	Number of hospitals ↑ ,Adaptability ↑	Health and Medical Big Data Opening System (2020)
	Number of medical personnel: Number of medical personnel by administrative dong	Number of medical personnel ↑, Adaptability ↑	Health and Medical Big Data Opening System (2020)
	Green area: Green area by the administrative dong	Green area ↑, Adaptability ↑	Statistical Geographic Information Services (2020)
Cooling center	Number of cooling center by the administrative dong	-	Seoul Open Data Plaza (2020)

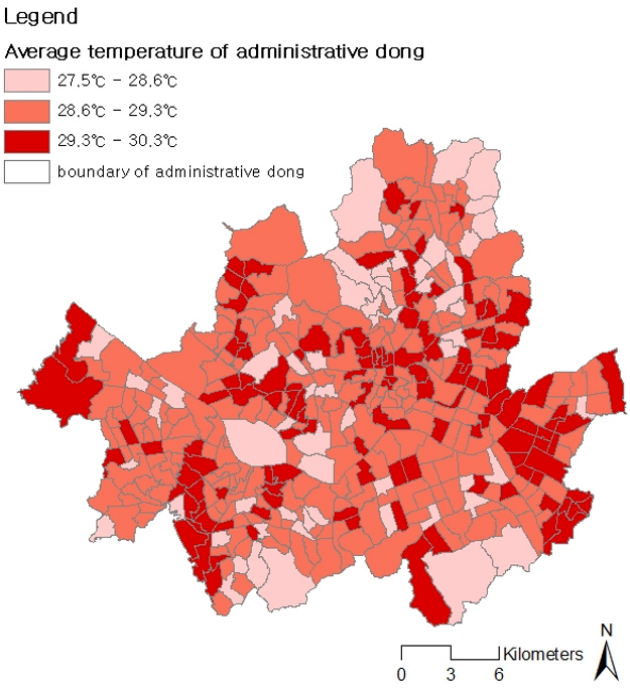

Figure 1. The average temperature of the administrative dongs in Seoul.

For this study, Vulnerability-Resilience Index (VRI) was measured to standardize different variables of climate exposure, senstivity, and adaptability in each dong to put these variables on an identical scale. Considering the concept of climate change vulnerability assessment proposed in previous studies, researchers have developed and applied various vulnerability assessment indicators especially for built environment in South Korea [20-24]. Yoo and Kim developed a Vulnerability-Resilience Index (VRI) to evaluate climate change vulnerability by modifying the vulnerability concept proposed by Moss et al. [25, 26]. Our study evaluated the vulnerability-resilience to heat waves by administrative dong based on the modified vulnerability indicators for further empirical analyses. To standardize various variables into one scale, each variable was derived as a Z-value using mean and standard deviation, which was arithmetically averaged by category (climate exposure, sensitivity, adaptability). Vulnerability-Resilience Index (VRI) to heat waves was then calculated for each administrative dong.

$$VRI = \frac{\frac{exposure + sensitivity}{2} + adaptability}{2} \quad (1)$$

Equation (1) calculates the VRI index by reflecting each of the three concepts explained by IPCC. Climate exposure and sensitivity are combined to represent the potential risk of a disaster. These potential risks are combined with the adaptability index to offset the disaster risk. Therefore, the VRI index derived through Equation (1) represents the overall vulnerability-resilience of the region. Since the VRI value contains both a negative aspect of the concept of vulnerability, and a positive attribute of the concept of resilience, it should be interpreted carefully

by considering conceptual signs to standardized variables [24]. Climate exposure and sensitivity variables are interpreted as negative (-) aspects, and variables of adaptability are interpreted as positive (+) signs. In other words, the larger the Z-value of the climate exposure and sensitivity variables means more vulnerability. Therefore, the vulnerability increases and the total VRI value decreases. On the other hand, the larger the Z-value of the adaptability means more resilience, so the vulnerability decreases and the overall VRI value increases.

For this study, based on the VRI index of each administrative dong, further spatial and statistical analyses were conducted as follows. Clustering analysis of administrrative dongs based on the VRI, an analysis of variance to test the difference of distribution of cooling centers among the clustered groups , and hot spot analysis to find spatially clusterd vulnerable areas were empirically analyzed.

Results and Discussions

Vulnerability-Resilience Index (VRI)

This study attempted to analyze spatial patterns of vulnerable areas to heat waves by grouping administrative dongs based on the degrees of VRI values in Seoul. Choi et al. showed the spatial distribution of heat wave vulnerability by dividing the VRI index of administrative dongs into quartiles [13]. This study applied the quartile method and organized the VRI values in ascending order and then classified administrative dongs by vulnerable stages from G1 to G4. G1 group consists of the administrative dongs that are relatively vulnerable to heat waves, G2 is for the administrative dongs that belongs to 25 to 50%. The administrative dongs that correspond to 50 to 75% belong to G3, and G4 is for the group of administrative dongs that are relatively less vulnerable to heat waves. Figure 2 shows the results of classifying the Vulnerability-Resilience index of administrative dongs in Seoul.

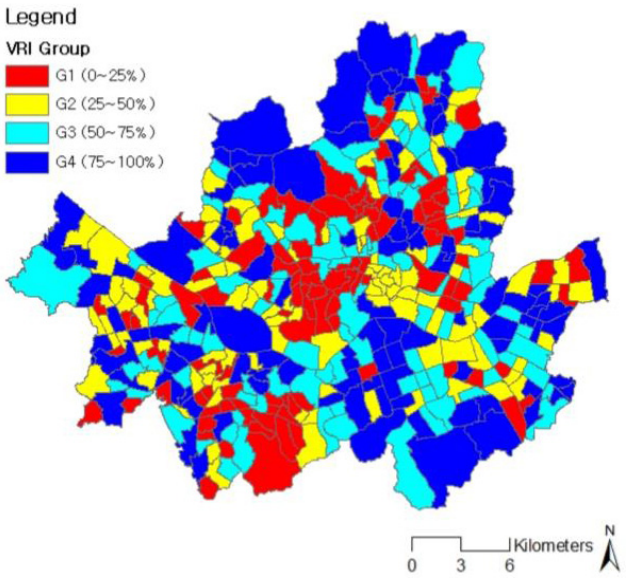

Figure 2. Classified Vulnerability-Resilience Index (VRI) of administrative dongs in Seoul.

As a result of this analysis, 106 of the 425 administrative dongs were classified as G1. In particular, administrative dongs in G1 group the most vulnerable to heat waves are listed below. Yongsan-gu (Huam-dong, Yongsan 2-ga-dong, Namyeong-dong, Yongmun-dong, Itaewon 1-dong, Itaewon 2-dong, Cheongpa-dong, Hangang-ro dong), Jung-gu (Sogong-dong, Hoehyeon-dong, Pil-dong, Jangchung-dong, Gwanghui-dong, Jungnim-dong, Sindang-dong, Dasan-dong, Cheonggu-dong), Seongbuk-gu (Donam 1-dong, Donam 2-dong, Jeongneung 1-dong, Jeongneung 2-dong, Jeongneung 3-dong, Seongbuk-dong, Dongseon-dong, Anam-dong, Bomun-dong, Jangwi 1-dong, Jangwi 3-dong, Seokwan-dong), and Gwanak-gu (Cheongnim-dong, Haengun-dong, Nakseongdae-dong, Jungang-dong, Seowon-ding, Inheon-dong, Seorim-dong, Sillim-dong, Nanhyang-dong, Jowon-dong, Daehak-dong, Seonghyeon-dong, Sinsa-dong, Cheongryong-dong). On the other hand, 106 of the 425 administrative dongs were classified as G4. In particular, some parts of southern districts and northern districts in Seoul were relatively less vulnerable to heat waves. These administrative dongs in Southern districts are Gangdong-gu (Cheonho 1-dong, Cheonho 3-dong, Seongnae 2-dong, Seongnae 3-dong, Dunchon 2-dong, Gangil-dong, Amasa 1-dong, Gil-dong, Cheonho 2-dong), Songpa-gu (Pungnap 1-dong, Geoyeo 1-dong, Macheon-1dong, Macheon-2dong, Garak 2-dong, Jamsilbon-dong, Jamsil 4-dong, Jangji-dong), Gangnam-gu (Sinsa-dong, Nonhyeon 1-dong, Nonhyeon 2-dong, Yeoksam 1-dong, Dogok 1-dong, Gaepo 4-dong, Ilwonbon-dong, Suseo-dong, Segok-dong, Cheongdam-dong, Apgujeong-dong), and Seocho-gu (Seocho 2-dong, Seocho 3-dong, Seocho 4-dong, Banpo 3-dong, Banpo 4-dong, Bangbae 4-dong, Naegok-dong, Yangjae 1-dong). Also, administrative dongs in Northern district are Eunpyeong-gu (Galhyeon 1-dong, Bulgwang 1-dong, Daejo-dong, Jingwan-dong, Bulgwang 2-dong, Eungam 3-dong, Yeokchon-dong), Dongdaemun-gu (Cheongnyangni-dong, Yongshin-dong, Jegi-dong, Jeonnong 1-dong, Jangan 1-dong, Jangan 2-dong), Dobong-gu (Ssangmun 2-dong, Banghak 1-dong, Banghak 2-dong, Banghak 3-dong, Dobong 1-dong), and Nowon-gu (Gongneung 2-dong, Sanggye 1-dong, Sanggye 2-dong, Sanggye 5-dong, Sanggye 6•7-dong, Junggye 2•3-dong, Gongneung 1-dong). Using the result of the spatial disparities in vulnerability based on VRI values, this study further analyzed the spatial relationship between cooling centers and vulnerable areas to extreme heat exposure.

Analysis of Variance

An Analysis of Variance to test the difference among the four groups classified based on VRI values was conducted. This statistical model was used to find the relationship between the number of cooling centers and vulnerability groups in Seoul. A total of 33,161 cooling shelters were assigned to the four groups from the most vulnerable dongs to heat waves (G1) to the relatively less vulnerable areas (G4). ANOVA was conducted based on the assumtion that the average value of the spatial distribution of cooling centers among four different groups classified by the VRI index would be different.

As a result of ANOVA, it was found that there was a statistically significant difference in the average number of cooling centers across the four groups in Seoul (see Figure 3 and Table 2). The average number of cooling shelters was the least in G1 , the group most vulnerable areas to heat waves at 58.53, while the average number of the

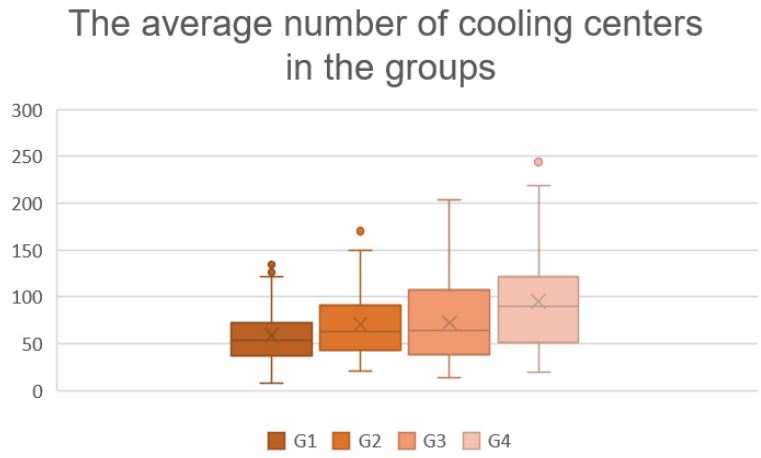

Figure 3. ANOVA test of the average number of cooling centers in the groups.

Table 2. Descriptive statistics and results of ANOVA test 1

Groups	Number of observations	Sum of Cooling Shelters	Average	Dispersion
G1	106	6,204	58.53	857.26
G2	106	7,492	70.68	1,090.20
G3	107	7,780	72.71	1,614.02
G4	106	10,094	95.23	2,628.16

Variable factor	Sum of squares	Degree of freedom	Square average	F ratio	P-value	F reject	Variable factor	Sum of squares
Processing		74,446.02		3	24,815.34	16.04	6.8871E-10	2.6261
Residual		651,526.1		421	1,547.57			
System		725,972.1		424				

facilities was the most in G4, the group relatively less susceptible to extreme heat exposure at 95.23. This result can be interpreted that cooling centers are more distributed in relatively less vulnerable areas than the most vulnerable area to heat wave. Since cooling centers have been designated to increase adaptability to heat waves, more cooling shleters should be installed to the administrative dongs grouped as G1, the most vulnerable to heat waves in Seoul. However, the result of the ANOVA analysis showed that the current cooling centers are distributed more in relatively less vulnerable areas than in administrative dongs vulnerable to heat waves. Therefore, it is necessary to provide additional cooling centers to administrative dongs vulnerable to heat waves which were grouped as G1 and G2.

For further analysis of ANOVA test, a variance analysis was conducted on the distribution of cooling shelters per square kilometer to find whether the cooling shelters are properly distributed considering the area of each administrative dong in Seoul. The number of cooling shelters per square kilomiter was calculated by dividing the number of cooling centers by the area of each administrative dong.

As a result of the AVONA test to check whether there was statistical differences between groups considering the number of cooling centers per square kilometer, it was found that the average differences in the spatial distribution

of cooling shelters per unit area (1 km^2) from G1 to G4 were statistically significant. The average number of shelters per unit area for each group was derived as follows; G1 was 73.94, G2 was 91.90, G3 was 72.84, and G4 was 71.48 (see Figure 4 and Table 3). Except for the G2 group, there were not big significant differences of the average number of cooling shelters among the three groups. To provide people better accessibilities to cooling centers, more facilities should be distributed in the most vulnerable area (G1). However, as the differences among the groups were not significant, it can be interpreted that the cooling centers in Seoul have been supplied focusing on the number of cooling centers without considering the spatial disparaties of vulnerability of each administrative dongs.

Cooling shleters as one of adpatation strategies to extreme heat exposure should be provided in consideration of the spatial disparities in vulnerability of the administrative dongs to increase its effectiveness as a policy implementation. However, the results of this study showed that only a quantitative supply of cooling centers have been implemented without careful consideration of vulnerability in various aspects. It showed that there were many cooling centers distributed in relatively less vulnerable areas than in the most vulnerable administravie dongs to heat wave. Therefore, cooling shelters should be supplied considering the vulnerability to heat waves, especially in areas analyzed as G1 and G2 groups relatively vulnerable to heat waves.

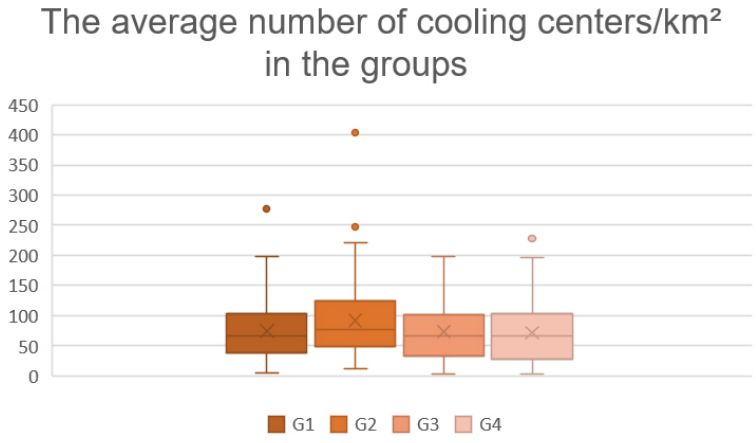

Figure 4. ANOVA test of the average number of cooling centers/km^2 in the groups.

Table 3. Descriptive statistics and results of ANOVA test 2

Groups	Number of observations	Sum of Cooling Shelters	Average	Dispersion		
G1	106	7,838	73.94	2,344.19		
G2	106	9,741	91.90	3,812.80		
G3	107	7,793	72.84	2,134.59		
G4	106	7,577	71.48	2,604.66		
Variable factor	Sum of squares	Degree of freedom	Square average	F ratio	P-value	F reject
Processing	29,492.09	3	9,830.69	3.6106	0.0134	2.6260
Residual	1,146,240	421	2,722.66			
System	1,175,732	424				

Hotspot analysis

Based on the results of heat wave vulnerability analysis, this study conducted an LISA analysis to find areas in which supply of cooling centers is needed most. LISA analysis is a local spatial autocorrelation analysis method that compares a specific region's index value with a neighboring region's index value to derive spatially clustered regions. The spatial association derived through LISA analysis is largely divided into four categories: HH type (high-high) adjacent to regions with high index values, LL type (low-low) adjacent to regions with low values, HL type (high-low), and LH type (low-high) adjacent to regions with high values. Also, HL type and LH type are considered unusual areas [27]. Therefore, this study conducted a LISA analysis especially to find spatial clusters of HH and LL types. LISA analysis results were described in Figure 5. Since this study conducted LISA analysis using the VRI, careful interpretation of VRI is necessary. As the VRI is an indicator that includes both vulnerability and resilience conepts, it means that the higher the VRI, the lower the vulnerability, while the lower the VRI index, the higher the vulnerability. Therefore, compared to the typical interpretation of result from LISA analysis, the administrative dongs belonging to HH (high-high) should be interpreted as the least vulnerable areas to heat waves, and the administrative dongs corresponding to LL (low-low) were the most vulnerable areas to heat waves. This is summarized as follows.

- High-high (HH): Areas with high VRI for the administarive dong's VRI and the surrounding area's VRI. Relatively less vulnerable administrative dongs.
- Low-low (LL): Areas where both the VRI of the district and the VRI of the surrounding region are low. The most vulnerable administrative dongs.
- High-low (HL): Areas with high VRI but a relatively low VRI.
- Low-high (LH): Areas with low VRI but a relatively high VRI.

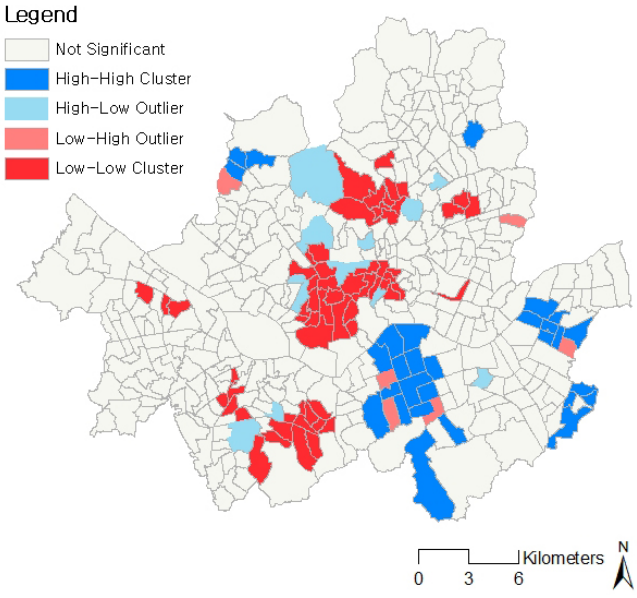

Figure 5. LISA cluster analysis results of each administrative dong in Seoul.

Table 4. Classification of administrative dongs by LISA cluster analysis

Classes	Corresponding Administrative Dongs
High-High	Hagye 1-dong, Galhyeon 1-dong, Galhyeon 2-dong, Bulgwang 2-dong, Seocho 2-dong, Seocho 3-dong, Seocho 4-dong, Jamwon-dong, Yangjae 2-dong, Sinsa-dong, Nonhyeon 1-dong, Nonhyeon 2-dong, Samseong 2-dong, Yeoksam 1-dong, Yeoksam 2-dong , Dogok 1-dong, Gaepo 1-dong, Apgujeong-dong, Pungnap 1-dong, Geocheon-dong, Macheon-dong, Macheon-dong, Cheonho 3-dong, Seongnae 1-dong, Seongnae 2-dong, Seongnae 3-dong, Dunchon 2-dong, Cheonho 2-dong, Geoyeo 1-dong, Wirye-dong.
Low-Low	Sajik-dong, Gyonam-dong, Sogong-dong, Hoehyeon-dong, Pil-dong, Jangchung-dong, Gwanghui-dong, Sindang 5-dong, Jungnim-dong, Sindang-dong, Dasan-dong, Cheonggu-dong, Donghwa-dong, Huam-dong, Yongsan 2-ga-dong, Namyeong-dong, Hyochang-dong, Yongmun-dong, Itaewon 1-dong, Itaewon 2-dong, Cheongpa-dong, Wonhyo-ro 1-dong, Hangang-ro 1-dong, Kumho 1-ga-dong, Songjeong-dong, Kumho 2.3-ga-dong, Imun 1-dong, Imun 2-dong, Junghwa 2-dong, Donam 1-dong, Donam 2-dong, Jeongneung 1-dong, Jeongneung 2-dong, Jeongneung 3-dong, Gileum 1-dong, Gileum 2-dong, Seongbuk-dong, Dongseon-dong, Samyang-dong, Chunghyeon-dong, Mok 2-dong, Mok 3-dong, Hwagok 6-dong, Singil 4-dong, Singil 6-dong, Daelim 1-dong, Sadang 1-dong, Sadang 3-dong, Sadang 4-dong, Sadang 5-dong, Sindaebang 1-dong, Cheongnim-dong, Haengun-dong, Nakseongdae-dong, Jungang-dong, Inheon-dong, Seorim-dong, Sinsa-dong, Cheongryong-dong, and Samseong-dong
High-Low	Pyeongchang-dong, Muak-dong, Ewha-dong, Cheongunhyoja-dong, Myeong-dong, Euljiro-dong, Yaksu-dong, Jangwi 2-dong, Jongam-dong, Bukhyeon-dong, Gongdeok-dong, Sinwon-dong, Euncheon-dong, Nangok-dong, Miseong-dong, Jamsil Bon-dong
Low-High	Mangwoo 3-dong, Gusan-dong, Seocho 1-dong, Banpo 1-dong, Dogok 2-dong, and Dunchon 1-dong

As a result of the LISA analysis, as shown in Table 4, HIGH-HIGH areas appeared in some administrative dongs of Gangnam-gu, Gangdong-gu, Nowon-gu, Seocho-gu, Songpa-gu, and Eunpyeong-gu. This means that administrative dongs clustered in the HIGH-HIGH areas are relatively less vulnerable to heat waves. On the other hand, some administrative dongs in Jongno-gu, Jung-gu, Yongsan-gu, Gwanak-gu, Dongjak-gu, Dongdaemun-gu, Seongbuk-gu, Yangcheon-gu, and Yeongdeungpo-gu showed LOW-LOW areas. In particular, the largest cluster appeared in the administrative dongs of Jung-gu (Sogong-dong, Hoehyeon-dong, Pil-dong, Jangchung-dong, Gwanghui-dong, Sindang 5-dong, Jungnim-dong, Sindang-dong, Dasan-dong, Cheonggu-dong, Donghwa-dong), Yongsan-gu (Huam-dong, Yongsan 2-ga-dong, Namyeong-dong, Hyochang-dong, Yongmun-dong, Itaewon 1-dong, Itaewon 2-dong, Cheongpa-dong, Wonhyo-ro 1-dong, Hangang-ro 1-dong), Seongbuk-gu (Donam 1-dong, Donam 2-dong, Jeongneung 1-dong, Jeongneung 2-dong, Jeongneung 3-dong, Gileum 1-dong, Gileum 2-dong, Seongbuk-dong, Dongseon-dong), and Gwanak-gu (Cheongnim-dong, Haengun-dong, Nakseongdae-dong, Jungang-dong, Inheon-dong, Seorim-dong, Sinsa-dong, Cheongryong-dong, and Samseong-dong). This means that relatively vulnerable administrative dongs are concentrated in Jung-gu, Yongsan-gu, Seongbuk-gu, and Gwanak-gu. Therefore, the cooling centers that can increase the ability to adapt to the heat wave should be provided to the area first.

Conclusions

This study evaluated the vulnerability-resilience of the heat wave in 425 administrative dongs in Seoul, and analyzed its significant relationships with the existing spatial distribution of cooling shelters in Seoul. A variance

analysis was conducted to confirm whether the vulnerability to heat waves in administrative dongs and the spatial distribution of cooling centers had a significant relationship. As a result of the analysis, the average number of cooling centers was the smallest in the most vulnerable group to heat waves. Results from the analysis of the number of cooling centers per unit area showed similar differences among vulnerable groups. It can be interpreted that only quantitative supply of the cooling centers has been made without considering the spatial disparities in vulnerability of each administrative dong in Seoul.

In addition, LISA cluster analysis revealed areas that require an additional installation of cooling shelters in vulnerable areas to heat waves. As a result of the analysis, it was found that relatively vulnerable administrative dongs are concentrated in Jung-gu, Yongsan-gu, Seongbuk-gu, and Gwanak-gu. Considering the vulnerability to heat waves in the regions when supplying cooling shelters, it is possible to increase the service accessibility of vulnerable population to extreme heat exposure. As these people could have better accessibility to the facility, the effectiveness of the city's mitigation strategy to heat waves will be enhanced. Therefore, to increase the district's ability to adapt to heat wave events, additional cooling centers should be provided in the administrative dongs according to the priority based on vulnerability.

This study has the following contributions. First, it was confirmed that the cooling centers in Seoul currently have been implemented across admistrative distrcits, but these are spatially distributed without considering individual vulnerability to heat wave in each administrative dong. This can lead to ineffective utilization of cooling shelters by lowering accessibility of vulnerable population to extreme heat waves to cooling shelters. Therefore, to increase effectiveness of the the adpatation strategy for extreme heat exposure, it is suggested that additional cooling shelters are necessary for the vulnerable areas to heat waves. Based on the results of this study, the priority administrative dongs for additional cooling centers were suggested as shown in Table 5. The priority areas are the LL cluster and G1 administrative dongs, where the most vulnerable administrative dongs are clustered. Additional cooling centers in the areas can effectively mitigate heat wave vulnerability.

Second, this study utilized floating population and S-DoT spatial big datasets, that were not fully considered in previous studies. Since the previous research was conducted using the static census population data and the data from the Korea Meteorological Administration, there were some barriers to analyze the actual influences of the heat wave to floating population and to consider detailed climate information in administrative dong level. However, utilizing the spatial big datasets allows to find areas vulnerable to heat waves more precisely. Compared to the

Table 5. Priority administrative dongs for cooling centers

	Administrative Dongs
Priority administrative dongs for cooling centers	Sajik-dong, Sogong-dong, Hoehyeon-dong, Pil-dong, Jangchung-dong, Gwanghui-dong, Jungnim-dong, Sindang-dong, Dasan-dong, Cheonggu-dong, Huam-dong, Yongsan 2-ga-dong, Namyeong-dong, Yongmun-dong, Itaewon 1-dong, Itaewon 2-dong, Cheongpa-dong, and Hangang-ro dong, Imun 2-dong, Donam 1-dong, Donam 2-dong, Jeongneung 1-dong, Jeongneung 2-dong, Jeongneung 3-dong, Seongbuk-dong, Dongseon-dong, Chunghyeon-dong, Singil 4-dong, Daelim 1-dong, Sadang 3-dong, Sadang 5-dong, Cheongnim-dong, Haengun-dong, Nakseongdae-dong, Jungang-dong, Inheon-dong, Seorim-dong, Sinsa-dong, Cheongryong-dong

results of a study by Choi et al. who derived vulnerable areas for administrative dongs in Seoul, the results of our study found similar vulnerable districtis of Yongsan-gu, Jung-gu, Eunpyeong-gu, and Seocho-gu [13]. However, unlike previous research, the results of this study showed that Gangnam-gu was a less vulnerable area and Gwanak-gu was a vulnerable area to heat wave. This different results can be interpreted that floating population, household income, and S-DoT data in our study were significant factors to analyze spatial disparities in vulnerability to heat wave.

This study analyzed areas that require additional cooling center implementation considering the spatial distribution of cooling centers and vulnerabilities to heat wave in administrative dong level. However, the actual accessibility to the cooling shelter was not carefully considered because only the number aspects of cooling centers distributed in administrative dong was considered. Also, there is some limitations that there may be some differences from the actual vulnerability caused by heat waves because variables are not weighted in VRI. Therefore, it is necessary to conduct a study in consideration of the service area of the cooling centers in future study. Also, it is necessary to derive an accurate vulnerable areas to heat wave by weighting variables for VRI analysis. Furthermore, this study used only temperature data among the climate information provided from S-DoT. Furthrer research considering the temperature and relative humidity would evalute more accurate vulnerability to extreme heat exposure.

References

[1] Korea Disease Control and Prevention Agency (KCDC), *Results of the 2021 heat-related illness surveillance*. Public Health Weekly Report, 14(46) (2021), pp. 3251-3263.

[2] Korea Environment Institute, *Heat Wave Impact Report*. (2020).

[3] H.C. Ahn, C.W. Shon, I.C. Shin, I.H. Jang, H.C. Pahk, H.M. Cho, J.A. Kim, J.H. Lee, H.R. Lee, and J.W. Choi, *How does the heat wave change the Seoulite's lifestyle*. The Seoul Institute, (2021).

[4] D.W. Kim, C.Y. Kwon, J.E. Kim, and J.S. Lee, *Characteristics of Heat Waves From a Disaster Perspective. Journal of Preventive Medicine and Public Health*. Journal of Preventive Medicine and Public Health. 53(1) (2020), pp. 26-28. DOI: https://doi.org/10.3961/jpmph.19.315.

[5] C.Y. Kwon, J.E. Kim, M.H. Lee, and D.W. Kim, *Development of an Evaluation Methodology for Accessibility of Cooling Centers in Ulsan using Landsat Images*. KCIS a collection of academic papers. 2020(2) (2020), pp. 496-497.

[6] Seoul Welfare Policy Office, 2021 Designation and Support Criteria for Senior Citizens' Hot Shelters [WWW Document], n.d. [Online], 2021. Available at: https://opengov.seoul.go.kr/sanction/22840083 [Accessed 15/07/2022].

[7] S.G. Nayak, S. Shrestha, S.C. Sheridan, W.H. Hsu, N.A. Muscatiello, C.I. Pantea, Z. Ross, P.L. Kinney, M. Zdeb, S.A. Hwang, and S. Lin, *Accessibility of cooling centers to heat-vulnerable populations in New York State*. Journal of Transport & Health. 14 (2019), 100563. DOI: 10.1016/j.jth.2019.05.002.

[8] J.W. Kim, *A Study on the Cooling Center Manual of Facility and Maintenance for Extreme Heat Disaster*. Journal of The Korean Society of Hazard Mitigation. 8(4) (2008), pp. 17-22.

[9] D.S. Kim, J.C. Park, and Y.R. Chae, *The Policy Measures to Reduce Heat-Wave Damage of Vulnerable Groups in Korea*. Journal of Environmental Policy and Administration. 28(2) (2020), pp. 211-230. DOI: 10.15301/jepa.2020.28.2.211.

[10] Y.R. Chae, Y.J. Ahn, and D.S. Kim, *A Study on the Effectiveness of Heat Shelter in preparation for Heat Wave*. KEI Focus. 4(1) (2016), pp. 1-28.

[11] H.M. Cho, J.H. Ha, and S.G. Lee, *Exploring Physical Environments, Demographic and Socioeconomic Characteristics of Urban Heat Island Effect Areas in Seoul*. Journal of the Korean Regional Science Association. 35(4) (2019). DOI: 10.22669/krsa.2019.35.4.061.

[12] M.K. Bae, B.E. Kim, and C.Y. Lee, *Analysis on the Spatial Relationship between the Residential Area of the Vulnerable Groups and the Hazardous Area during the Heat Wave*. Journal of Environmental Policy and Administration. 28(3) (2020). DOI: https://doi.org/10.15301/jepa.2020.28.3.243.

[13] Y.S. Choi, J.W. Kim, and U. Lim, *An Analysis on the Spatial Patterns of Heat Wave Vulnerable Areas and Adaptive Capacity Vulnerable Areas in Seoul*. Journal of Korea Planning Association. 53(7) (2018), pp. 87-107. DOI: https://doi.org/10.17208/jkpa.2018.12.53.7.87.

[14] S.B. Yoon, *The Spatial Distribution Characteristics of Disaster-vulnerable Population and Cooling center*. Master's thesis at the Graduate School of Pusan National University. (2022).

[15] H.S. Ahn, J.W. Lee, and A. Hong, *Urban form and air pollution: Clustering patterns of urban form factors related to particulate matter in Seoul, Korea*. Sustainable Cities and Society. 81 (2022), 103859. DOI: https://doi.org/10.1016/j.scs.2022.103859.

[16] D.Y. Yoo, *Analysis of fine dust exposure mechanisms and estimation of vulnerable walking areas using IoT city big data*. Master's thesis at University of Seoul. (2022).

[17] G.S. Shin, *Assessing the risk of sidewalks due to freezing: a case study in Mia-dong*. Master's thesis at Seoul National University General Graduate School. (2021).

[18] Korea Disease Control and Prevention Agency (KCDC), Annual Report on the Notified Patients with Heat-related illness in Korea, Seoul [WWW Document], [Online], 2020. Available at: https://www.kdca.go.kr/contents.es?mid=a20308040106 [Accessed 18/08/2022].

[19] J.J. McCarthy, O.F. Canziani, N.A. Leary, D.J. Dokken, and K.S. White, *Climate Change 2001: Impacts, Adaptation, and Vulnerability: contribution of working group II to the third assessment report of the Intergovernment Panel on Climate Change*. 2001, Cambridge: Cambridge University Press.

[20] J.K. Koh and H.S. Kim, *A Study on Vulnerability Assessment to Climate Change in Gyeonggi-Do*. Gyeonggi Development Institute. (2009).

[21] H.S. Hwang and B.S. Byun, *Building Vulnerability Index on Climate Change: Focused on Seoul Metropolitan City*. Journal of Environmental Policy and Administration. 19(4) (2011), pp. 93-119.

[22] J.S. Lee and H.I. Choi, *Comparison of Flood Vulnerability Assessment Outcomes by Classification Schemes for Vulnerability Components to Climate Change*. Journal of The Korean Society of Hazard Mitigation. 18(3) (2018). pp. 221-229. DOI: 10.9798/KOSHAM.2018.18.3.221.

[23] K.W. Kim, B.C. Park, J.B. Heo, J.Y. Kang, and I.J. Lee, *Assessment of Heat Wave Vulnerability in Busan Using the IPCC Climate Change Vulnerability Assessment Framework*. The Korea Spatial Planning Review. 104 (2020), pp. 23-38.

[24] D.W. Kim, J.E. Kim, C.R. Jang, and M.Y. Jang, *Assessment of Heatwave Vulnerability in Korea Considering Socio-economic Indices*. Journal of The Korean Society of Hazard Mitigation. 21(5) (2021), pp. 39-47. DOI: https://doi.org/10.9798/KOSHAM.2021.21.5.39.

[25] G.Y. Yoo and I.A. Kim, *Development and application of a climate change vulnerability index*. Korea Environment Institute. (2008).

[26] R.H. Moss, A.L. Brenkert, and E.L. Malone, *Vulnerability to Climate Change: A Quantitative Approach*. Report No. PNNL-SA-33642, Pacific Nortwest National Laboratory, Washington DC. (2001).

[27] H.Y. Lee and J.H. Shim, *GIS Geographic Information: Theory and Practice*. 2011, Seoul, Korea: Beopmunsa.