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Identifying Major Components of Extreme Heatwave Risk Assessment Indexes in Urban Areas

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ABSTRACT

Purpose: The risk of urban heatwaves is increasing due to climate change. High temperatures which last for a long periods affects people, society and the environment. The risk assessment herein can play a crucial role in establishing a response plan for urban heatwaves. The factors affecting heatwaves include; size, shape and duration of the heatwaves. The aim of this study is to establish the indicators to be considered for the risk assessment of urban heatwaves and suggest a direction for creation of a basis for risk assessment. **Method:** In this study, the indicators were assessed through review of previous case studies. **Result:** Consequently, the evaluation index with the urban scale was created afresh by listing the indicators that could be considered in the heatwaves risk assessment. The indicators are divided into three categories: risk factors, vulnerability factors, and exposure factors. The results of this study enhance the understanding of the heatwaves in different cities and improve the heatwaves risk assessment. Additionally, it suggests a direction for urban planners to develop counter-measures strategy in regards to heatwaves.

KEYWORD

폭염
극한기후
기후변화
위험도 평가

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Extreme weather
Climate Change
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1. Introduction

1.1. Research background and purpose

The frequency of summer heatwaves is increasing as extreme weather events increase due to the rapid climate change in the 21st century, resulting in an increase in casualties[1],[2]. In this study, the effects of heatwaves on the temperature was investigated by using the simulation results[2]. Particularly, the intensity of heatwaves varies depending on the climate characteristics and the level of infrastructure development in the city[3], and the extent of the damage caused by such extreme events is on an increase[4],[5].

Various infrastructures in the city are directly or indirectly affected by climate, as the risk of heatwaves from climate change within the city can be changed by the urban infrastructure. Particularly, human health problems are closely associated to the risk assessment indexes. In addition, the risk can be vary based on the distribution of buildings and forests in the city, and the change of spatial temperature. Therefore, this study seeks to identify risk assessment indexes and elements of extreme heatwave in urban areas. Different types of risk assessment indices based on the characteristics of the urban space is crucial in urban planning in regards to improving the resilience and reducing the impact of the city's future heatwaves[4].

1.2. Method and scope of research

The methods considered for the risk assessment of recent heatwaves are limited to assessing the characteristics of urban climate change. Therefore, studies on the impacts of climate change and risk assessment based on the urban characteristics have been done mainly to reduce the causes of heatwaves[6].

Spatial evaluation is limited due to lack of consideration of social and environmental indicators. Using statistical data as a risk index because the indicators were cited in previous literature, limited the accuracy of the study. Moreover, the suitable components of the city could not be considered. Consequently, it is necessary to enhance the accuracy of risk assessment and the policy usability by considering both physical and social factors such as urban infrastructure and environment.

This study suggests that the risk assessment can be enhanced by considering physical and social indicators in the assessment of urban risk for heatwaves. This study seeks to identify the types of damage caused by urban heatwaves, the vulnerable areas in the city, and identify the areas that need improvement. First, we

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analyze various methods of heatwaves analysis, and compare the detailed indicators and variables from previous studies. Various methods includes analyses of urban heat island areas, and vulnerable areas and demographic groups since those analyese are helpful to analyze heatwave in urban areas to develop a plan to reducing heatwave effects on urban areas[7]. Accordingly, we seek to find relevant indicators for the heatwaves risk assessment in a city through the addition of indicators that can be included for the risk assessment of heatwaves in urban areas.

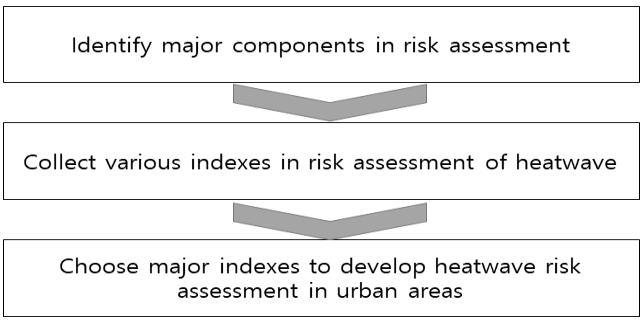

Fig. 1. Research steps

2. Concepts and Theories of Heatwaves Risk Assessment

Previous studies on the risk of heatwaves occasioned by climate change in urban areas did not include urban characteristics. As urbanization continues to increase, the need for detailed thermal risk assessment becomes increasingly important. Moreover, existing studies on heatwaves have been tackled from the following viewpoints; medical field, disaster, and heat island phenomenon. However, the risk assessment of urban heatwaves considering the local environment and characteristics is required.

The study of heatwaves is based on the statistical estimation through mortality or the setting of the heat generation standard and basic analysis of the urban heat island phenomenon. Lee et al. [8] investigated the relationship between heat and work-related mortality and climate adaptation based on the regional vulnerability. According to the results of six large cities in Korea [8], we acknowledged the characteristics of mortality due to heat waves in Busan. Steeneveld et al.[9] studied the criteria setting for combining the quality and quantity of urban air heat. They simulated heatwave by using the weather research and forecasting model to quantify heat islands in urban areas, and accordingly highlighted the relationship between heat waves and urban heat islands. In particular, the relative risk of high temperature exposure was an significant element to determine the excess risk of urban heat island phenomenon. Ward et al.[10] highlighted the relationship between European heatwaves and urban heat island. To analyze the vulnerability of the heatwaves, Lemonsu et al.[11] evaluate the urban diffusion scenarios for the Paris urban heat island and the study on the improvement of the urban heat island mitigation system. Existing studies on heatwaves have been conducted from the following point of views; medical care, disaster, and heat island phenomenon. However, recent interest in climate change has led to the analysis of extreme events and the need for vulnerability assessments in view of the local environment and characteristics.

In the IPCC climate change 2014 Synthesis Report, the determinants of risk are classified into physical and social factors and include; Hazard, Exposure, and Vulnerability[12]. Urban disaster can consist of the elements of the natural environment, and the influence of the interaction between the social and urban environment. Therefore, it is essential to consider the hazards of meteorological phenomena and their exposure and vulnerability [12]. The factors which are considered for the risk index are divided into three categories, and the detailed attributes are separated based on the characteristics of the variables included in the element. Fig. 2. illustrates the schematic of the relationship between disaster risk core concepts developed by IPCC (Intergovernmental Panel on Climate Change) in 2014[13]. The three components that are weather and climate events, exposure, and vulnerability are significant components to assess disaster risk.

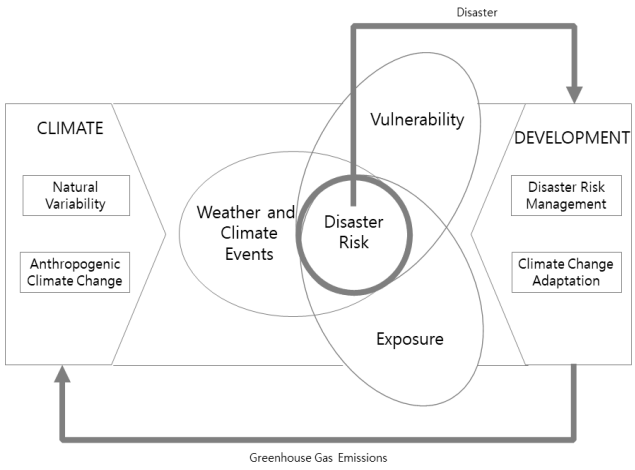

Fig. 2. Schematic relationship between disaster risk core concepts[13]

3. Review and Selection of Risk Assessment Index

3.1. Selection of index through analysis of previous research

This study re-classified the risk assessment factors in regards to the urban environment based on the existing studies associated with heatwaves risk assessment. The risk determinants are classified into the following factors; environmental, social, and

physical. Environmental aspects refer to vulnerable nature such as geographical factors and climate. Social factors consist of population density, population of the elderly and children, population, health and welfare status. In particular, the indicators of population of the elderly and children explain the amount of people who are relatively vulnerable to climate change and whose ages are over 65 and under 5 years old. Physical factors include urban structures, building density, urban materials, and green spaces.

The concept defined in the IPCC report and the study of the heatwaves was analyzed and the risk assessment defined for each constituent element to differentiate the constitutional factors. Factors of risk assessment based on the commonness of existing studies include; Hazard, Exposure, and Vulnerability (Table 1.), and the concept of factors are similar[14]. The three factors that are hazard, exposure, and vulnerability follow the schematic relationship between disaster risk core concepts in Fig. 2.. In particular, since this study focuses on a severe weather event, i.e. heatwave, hazard in the component represents a severe weather event and environmental element that is a climatic factor that directly affect a disaster.

Table 1. Risk-related definitions and comparisons

Component		Definition
Hazard	Environmental element	· Risk factors that directly affect disaster (climatic factors)
Exposure	Social element	· Factors that can be exposed to hazardous areas in the event of a disaster (property, population, social and economic factors in disaster areas)
Vulnerability	Physical element	· Vulnerable factors that can be easily damaged in the event of a disaster (topographical factors)

Based on similar researches, the index system of the urban heatwaves risk assessment of this study is distinguished from the previous studies through classification of the risk factors into Hazard, Exposure, and Vulnerability based on the characteristics that emphasize actual risks in cities. It is possible to use factors given for other climate change related disaster types (floods, typhoons) other than heatwaves by dividing the consideration factors in the city, Vulnerability).

3.2. Derivation of the heatwaves risk assessment factor

Based on the similar studies, the disaster risk assessment system for this study is based on the change of existing research method emphasizing disaster management risk from macro perspective, which is different from the previous studies as the heatwaves risk assessment methods are presented separately. It can be utilized to assess climate change related disasters by focusing on types (floods, hurricanes, heavy snow, heatwaves, landslides).

This study partially revised and enhanced the methodology of the previous studies for analyzing th!e risk, exposure, and vulnerability of the heatwaves. First, analysis of the elements of Hazard, Exposure, and Vulnerability was conducted based on the disaster to be measured, the factors causing these results, and the effects of these phenomena, respectively. Second, identification of the suitability of the indicators derived primarily through the review of existing data and the ease of data acquisition and construction was done, and the indicators were upgraded and alternative indicators selected. Third, the disaster risk assessment index was derived from the preliminary study on the heatwaves.

In Table 2., the criteria was used to select the indicators of risk, vulnerability, and vulnerability constituting the risk assessment:

- Hazard index :
  Dominant climatic factors by disaster
- Exposure index :
  Factors such as population, infrastructure, and buildings that may be damaged in the event of a disaster in a hazardous area
- Vulnerability index:
  Factors such as topographical, social, and economic vulnerabilities

Table 2. Risk Assessment Indexes

Index	Description	References
Population density	Number of people per certain area	[6], [10], [11], [12], [14], [17]
Percentage (or number) of people over 65 years old	Ratio of people over 65 years old per population	[14], [15], [16]
Percentage of infants and young children (under 5)	Ratio of people under 5 years old per population	[14]
Deaths due to heat stroke / sunstroke	Number of deaths due to heat	[16]
Industrial Complex Area	Area of industry and industrial complex	[10]
Building volume	Volume of buildings in a certain area	[11], [15]
Heat island area	Area of heat island in a certain area	[10]
Road area	Area of road in a certain area	[15]
Impervious packing rate (area)	Area of impervious parking	[14]

Index	Description	References
Tropical nights (minimum temperature above 25 ℃)	Number of nights over 25 ℃	[11], [14]
Maximum temperature	Number of maximum temperature in a certain period	[11], [14]
Highest daily temperature	Number of highest temperature in a day	[11]
Ground temperature	Number of ground temperature	[7], [10], [11]
Daily average temperature	Number of daily average temperation within a period in a certain area	[7]
Heatwave persistence index	Number of calculation of heatwave persistence	[10], [16], [17]
Number of low-income family	Number of low-income family in a certain area	[14]
Number of shelters	Number of shelters in a certain area	[6]
Green Area	Area of green space in a certain area	[6]

4. Result of Risk Assessment Index Selection

The risk assessment indicators of the heatwaves were summarized and the relevant indicators derived through the examination of the influence of each factor. The most influential climatic factors affecting heatwaves include; temperature, radiation, and humidity. High temperature is one of the most significant impacts of climate change phenomenon due to the rising temperature. As the high temperature phenomenon endures, the risk of damage due to heatwaves increases. Hence, the maximum temperature and the number of days of tropical nights are considered. The criteria for determining the maximum temperature and the number of days of tropical nights is based on the number of days at night, which experience a high of 33 ℃ and a temperature of 25 ℃ or higher from 6 pm to 9 am the following day. Relative humidity which increases the solar irradiance and discomfort index, is viewed as a risk influence index for the heatwaves.

To derive the heatwave index, we utilized the indicators applied in the previous research and summarized in Table 2., and the related indexes of the Hazard, Exporsure, and Vunerability of heatwaves risk were summarized in Table 3.. The physical and social indexes of the heatwaves risk assessment were identified as geographical (natural), social, and economic vulnerable items associated with heatwaves. Imperviousness, which is a physically weak element, is an indicator of imperviousness because it absorbs heat well but does not absorb water and is associated with persistent high temperature phenomena. Socially, children and elderly people are the most vulnerable to heatwaves as a result of the rapid increase in the frequency of the earth's heatwaves due to the abnormal temperature. Dilapidated stand-alone buildings are suggested as one of the indicators of heatwave damage. Economically, the low-income group (the basic livelihood recipient) are more vulnerable because the resilience to disaster is low as a result of economically poor local governments.

Table 3. Results of index selection

Component		Index
Hazard	Environmental element	• Tropical nights (minimum temperature above 25 ℃)
		• Maximum temperature
		• Ground temperature
		• Heatwave persistence index
Exposure	Social element	• Population density
		• Impervious packing rate (area)
		• Building density
		• Road area
		• Impervious packing rate (area)
		• Number of Shelters
		• Green Area
		• Industrial Complex Area
Vulnerability	Physical element	• Percentage (or number) of people over 65 years old
		• Percentage of infants and young children (under 13)
		• Number of low-income
		• Number of hyperthermia patients (including deaths)

This result is expected to be proven through practical application of the evaluation index for of the heatwaves' intensity risk assessment index derived from the previous research and data collection.

5. Conclusion

The aim of this study was to identify indicators that have been adopted in previous studies and system to develop risk assessment for urban heatwaves. This study classified the evaluation index as 'social factor' and 'physical factor' and presented the evaluation indicators in combination with 'environmental factor'. Accordingly, by analyzing and comparing relevant studies, this study was sought to provide detailed characteristics of indicator for effective urban disaster management that would be useful in the future.

This study demonstrated the improved strategies to assess potential disaster risks in Korea by comparing relevant studies in different countries. The improved strategies include additional index suggestion and integrating approaches between social, physical and environmental factors. In particular, the proposed strategies included the capability of risk improvement that can response disasters. The aim of disaster risk assessment is to assess the potential disaster risk for local governments and to support the decision making of disaster response using the results of the analysis. An adequate support to the disaster risk assessment is significant to effectively institutionalize the results of disaster risk assessment and utilize them in establishing national and local disaster prevention plans, and formulate national and local planning. Among major disasters including heatwave, flood, storm, typhoon and hurricane, this studies focuses on heatwave. Existing approaches to assess heatwave risk were analyzed and compared.

To improve disaster risk assessments, well-collected statistical data is essential. Re-evaluation and enhancement of currently derived indicators is required when the risk indicators are complete and the available statistics accumulated. According to Tables 1., 2., and 3., this study identified the significance of data and statistic collections to develop risk assessment. Continuous re-evaluation would be helpful to improve existing risk assessment system. Additionally, continuous monitoring of disaster-risk-assessment results is significant in improve the disaster risk assessment. The disaster risk assessment is suggested to analyze vulnerable areas for unexpected disasters in the future. The disaster risk assessment can analyze national and local levels, which would be helpful to develop national, regional, and local plans.

This study is expected to be a starting step to develop a reference to develop an intensity index of heatwave risk for national and local governments. The suggested three elements, i.e. social, physical and environmental factors is expected to help develop an inclusive index for various people to analyze heatwave risks in urban areas. However, this study is necessary to consider weighting effects between factors and indicators for the heatwave risk assessment. Although this study demonstrated significant indexes and component, it is not fully evaluated to develop an advanced index. In the future, investigating weighting effects is plan to conduct for improving the heatwave risk assessment in urban areas.

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