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Article

Gap Analysis Between the Level of Heat Wave Adaptation Policy and Heat Wave Effects in South Korean Municipalities

Tae Ho Kim [1], Chang Sug Park [2], Sang-hyeok Lee [3,*], and Jung Eun Kang [4]

[1] Urban Architecture Program Division, Korea Agency for Infrastructure Technology Advancement, Republic of Korea
[2] Division for Environmental Planning, Korea Environment Institute, Republic of Korea
[3] Marine Policy Research Division, Korea Maritime Institute, Republic of Korea
[4] Department of Urban Planning and Engineering, Pusan National University, Republic of Korea

* Corresponding author (shlee@kmi.re.kr)

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Abstract
This study aims to analyze the gap between the level of heat wave adaptation policies and heat wave effects in South Korean municipalities. First, the types of industries in municipalities were classified using factor analysis and cluster analysis. Second, the level of heat wave adaptation policy in the municipalities was assessed using a fuzzy analytic hierarchy process analysis. Third, the gap between the level of heat wave adaptation policy and the heat wave effect was analyzed. The results show that the heat wave adaptation policies were established in accordance with the heat wave effects to at least some degree. However, closer to the long-term future (2095), the policies have not sufficiently matched the level of heat wave effects. The proportion of municipalities with insufficient levels of heat wave adaptation policies against the heat wave effects was higher among urban-type municipalities. The analysis results suggest two policy implications. First, the heat wave adaptation policies of municipalities should be established through continuous feedback on the predictions of future heat wave effects. Second, urban-type municipalities should strengthen their planning authority and competence by securing a professional workforce and budgets for the establishment of heat wave adaptation policies.

Keywords
adaptation policy; climate change; gap analysis; heat wave; local government; municipal policies; South Korea

Issue
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1. Introduction

The fifth report of the Intergovernmental Panel on Climate Change confirms that climate change due to the rising average global temperature is clear (Intergovernmental Panel on Climate Change, 2014, 2021). In fact, numerous studies have demonstrated the various effects of climate change, such as heat waves, heavy rains, and typhoons. Among the effects of climate change, the damage caused by heat waves is especially detrimental to South Korea (Korea Environment Institute, 2014).

During the past 100 years (ca. 1911–2010), the annual average temperature of Korea has increased by 1.8 °C, which is much higher than the global average of 0.75 °C. Moreover, the average temperature of the Korean Peninsula is predicted to increase by 2.6–4.8 °C by the end of the 21st century (ca. 2071–2100) compared to the average temperature of the past few decades (ca. 1971–2000), and the number of heat wave days is predicted to increase from 9.2 days per year on average to approximately 18.9–56.7 days by the end of the 21st century (National Institute of Meteorological Sciences, 2012).

Climate change impacts such as heat waves that threaten human survival are critical environmental problems. Some studies have emphasized that urban sustainability through smart cities is necessary to manage climate-related problems (Angelidou et al., 2018; Choi & Song, 2023).

In an attempt to respond to the effects of climate change—including heat waves—the United Nations Framework Convention on Climate Change has emphasized the importance of adaptation as well as mitigation; since then, the UK, Australia, the US, and other countries have begun to enact laws related to climate change adaptation and have implemented adaptation plans. These legal institutional frameworks play a crucial role in responding to global climate change (Wilson, 2006).

To strategically prepare for the effects of climate change, South Korea established the Framework Act on Low Carbon Green Growth, in which Article 48 of this act and Article 38 of the enforcement decree of this act prescribe the establishment and enforcement of adaptation measures for climate change. At the national level, the South Korean government established the First National Climate Change Adaptation Plan (ca. 2011–2015) in 2010, the Second National Climate Change Adaptation Plan (ca. 2016–2020) in 2015, and the Third National Climate Change Adaptation Plan (ca. 2021–2025) in 2020.

To efficiently and effectively respond to the impacts of climate change, it is essential to strengthen adaptive capacity. In addition, climate change adaptation measures, which are being repeatedly established, must be developed into effective and long-term relevant policies. Therefore, to move toward a city with effective and efficient policies, decision-making support through more scientific and diverse methods is needed. Climate change impacts occur on an international scale, but damages occur on a regional and city level, so it should be possible to reflect various conditions in cities that directly and closely affect citizens. Therefore, it is essential to analyze regional capabilities for climate change from the perspective of securing urban sustainability and preparing smart countermeasures. The derived evaluation results can improve the citizens' awareness of climate change, which is actually affected, and enhance the capacity of residents, such as increased participation in countermeasures.

The existing studies on climate change adaptation at the municipality scale are mainly focused on the assessment of vulnerabilities for the establishment of adaptation policies (Evariste et al., 2018; Prudent et al., 2016), awareness surveys (Cobbinah & Anane, 2016; Shameem et al., 2015), and policy prioritization (Lee et al., 2014; Ndamani & Watanabe, 2017). They are all about preliminary planning for policy formulation and studies on post-assessment of already-formulated adaptation policies are insufficient.

In general, policy assessments are classified into content, implementation, and impact assessment (Brownson et al., 2009). For systematic policy assessment, step-by-step assessments of each component are necessary, but adaptation policies are characterized by the difficulty of monitoring in the implementation stage as well as uncertain policy effects and the long-term manifestation of effects in the impact stage (Füssel & Klein, 2006). Furthermore, since the initial municipality climate change adaptation policies are not scheduled to be implemented until 2020, there are limited ways to carry out implementation and impact assessments at this time.

Therefore, this study focuses on content assessment for the municipalities' climate change adaptation policies. First of all, among the event representing various climate changes, the heat wave, which has recently become stronger in frequency and intensity in Korea, was targeted in this study. The analysis used a gap analysis methodology that can examine the difference between impact and policy. For detailed analysis, the types of local governments were classified according to regional characteristics and used for evaluation. To evaluate the impact of heat waves, future impacts according to climate change scenarios were used, and for policies, regional gaps were analyzed using the policies of the local government. The analysis of the gap was intended to derive many implications, such as presenting the current and future status and direction for a response.

2. Materials and Methods

The gap analysis was carried out broadly in three stages. The analysis flow and method of each analysis stage are shown in Figure 1.

First, the types of industries in municipalities were classified based on the industrial characteristics using factor and cluster analysis.

Second, the heat wave adaptation policy level was assessed. To do this, a list of sectors and response areas were derived by building an inventory of heat wave adaptation policies, and the importance weights of the sectors and response areas by municipality type were derived through a fuzzy analytic hierarchy process (AHP) analysis. The policy level was then assessed using the number of projects, project budgets, and importance weights.

Third, the gap between the policy level and heat wave effects was analyzed. The gap analysis was conducted in two ways: a gap analysis by municipality type using Kendall's concordance coefficient and a gap analysis by municipality.

2.1. Classification of Municipalities

Before the classification of administrative district types, basic local governments, which are the spatial scope of this study, mean *si*/*gun*/*gu*, which are the basic administrative units of Korea and can be said to be similar to counties in the US. There are no exact equivalent administrative units to the Korean *si*/*gun*/*gu* system in the US.

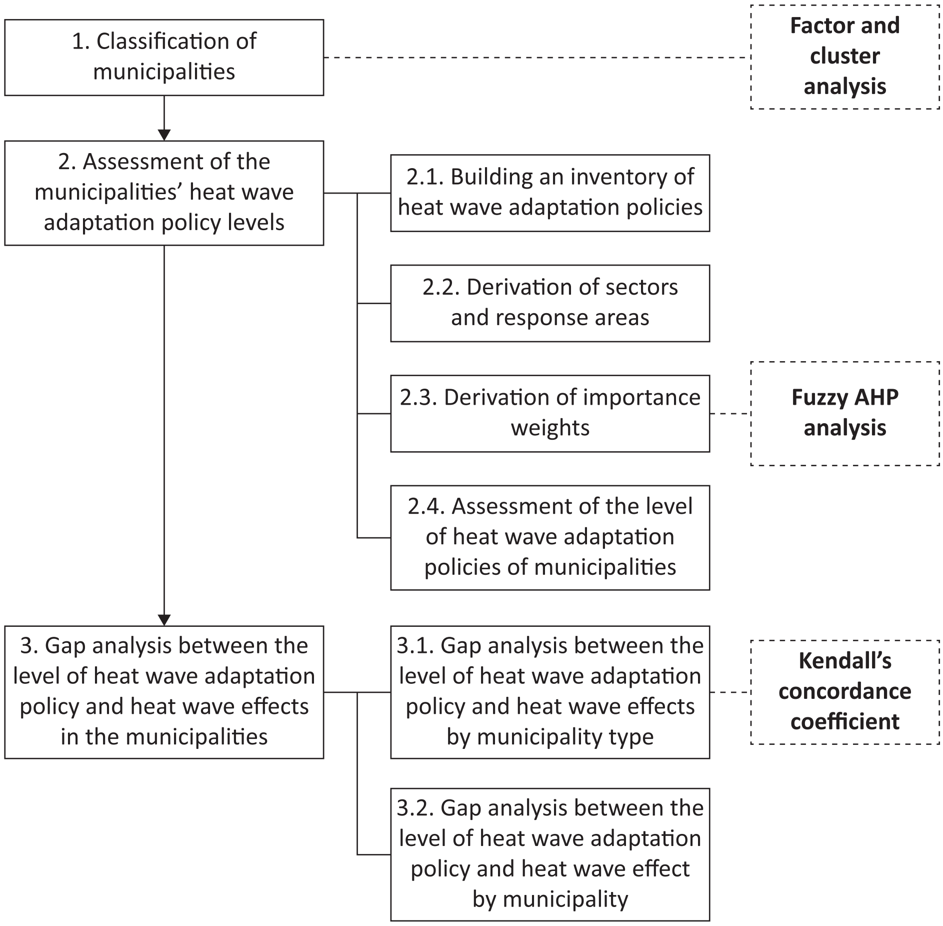

Figure 1. The flow of this study.

However, counties in the US are similar to Korean *si* in that they are the primary unit of local government, responsible for providing many essential services to residents, including law enforcement and education.

The administrative unit is the basic unit for decision-making such as finance, administration, and policy in each region, and is the subject of the detailed implementation plan for climate change adaptation measures used in this study. Therefore, in this study, the spatial scope of the study, such as the impact of heat waves and the level of policies, is based on the local government.

The social ripple effects of heat waves mainly affect the agriculture, livestock, fishery, and forestry industries, leading to economic damages such as coastal aquaculture animal mortalities, the spread of alien species, and livestock mortalities (Korea Environment Institute, 2014). In order to cope with these damages, municipalities are establishing detailed implementation plans for climate change adaptation measures around the components that require the prevention and management of properties or personal injuries. In particular, they are establishing adaptation plans for the primary industry, which is in the public goods sector and the main adaptation plans differ depending on the industrial characteristics of each region. Therefore, in order to assess the level of heat wave adaptation policies by reflecting the characteristics of municipalities, the municipalities need to be classified in accordance with their primary industries.

First of all, municipalities can be broadly classified into urban and rural municipalities. Urban municipalities are centered on secondary and tertiary industries, whereas rural municipalities are centered on primary industries. Thus, these two types of municipalities have significant differences in their industrial characteristics. In order to distinguish between them, the population size of the municipalities was used as the classification criterion. For urban municipalities, the criterion for large cities prescribed by Article 198 ("recognition of exceptions for large cities") of the Local Autonomy Act was referenced. Thus, every autonomous district that belongs to a metropolitan city or a special city, or every city with a population of at least 500,000 people was classified as "urban," while the other municipalities were classified as "rural" (Table 1).

The rural municipalities can be classified further by their primary industry characteristics: mountain types (centered on forestry and livestock industries) or farming and fishing types (centered on agriculture and fisheries). For this classification process, the growing stock volume and livestock count were selected to represent the characteristics of the forestry and livestock industries in the mountain-type municipalities, and the rice

Table 1. Selection of variables for the classification of municipalities.

Type		Variables
Urban		Every autonomous district that belongs to a metropolitan city or a special city, or every city with a population of at least 500,000 people
Rural	Mountain	The livestock count The growing stock volume
	Farming and fishing	The rice field area The field area The fish farm area

field, field, and fishery farm areas were selected to represent the agriculture and fishery industries in the farming-and-fishing-type municipalities. In addition, factor analysis and cluster analysis were performed to characterize municipalities with similar industrial characteristics.

The livestock count, growing stock volume, rice field area, field area, and fish farm area data were constructed for the South Korean municipalities nationwide based on the Korean Statistical Information Service. The reference year was set as 2015 for data acquisition.

2.2. Assessment of the Municipalities' Heat Wave Adaptation Policy Levels

In this study, the assessment goal was whether municipalities actively acquired budgets and explored projects to meet the heat wave adaptation policy goal to evaluate the policy level. Accordingly, the policy project budget and the number of policy projects were selected to assess the level of the heat wave adaptation policies. In addition, considering that the importance of the sector and response areas of the heat wave adaptation policies may vary by the industrial characteristics of the municipalities, the importance weights of sectors and response areas were reflected by municipality type (Table 2).

The data on the project budget, number of projects, and importance of each sector and response area were constructed largely in three steps.

Firstly, an inventory of climate change adaptation policies was built by collecting reports about the detailed implementation plans from municipalities around the country, which they are required to submit to the Korea Adaptation Center for Climate Change. The establishment and maintenance of detailed implementation plans for climate change adaptation measures by the local government are established every five years, and each local government has a different period. This study used the inventory made based on the plan submitted and established in 2018.

An inventory of climate change adaptation policies was constructed for all projects from the 156 municipalities that were confirmed to have established detailed implementation plans. In these plans, a total of 10 sectors were identified: health, disasters/accidents, agriculture, forestry, marine/fisheries, water management, ecosystem, climate change monitoring and forecasting, adaptive industry/energy, and education promotion and international cooperation. Thus, the inventory of climate change adaptation policies was divided into 10 sectors, and the budget amount of each detailed project was included.

Secondly, from this inventory, the sectors and response areas of heat wave-related adaptation policies were derived. Before doing this, the heat wave-related adaptation projects were separated from the total climate change inventory. Next, sectors and response areas were derived by grouping similarly detailed projects and reviewing them through three expert meetings. Through this process, 24 response areas in six sectors were finally derived, as shown in Figure 2.

Thirdly, data about project budgets and the number of projects were constructed for the sectors and response areas. The sums of the detailed project budgets and the number of projects were calculated for each sector and response area of municipalities' heat wave adaptation policies that had been previously determined and converted into variables. To derive the importance weight of each sector and response area, a fuzzy AHP analysis was carried out.

The AHP analysis method, which was developed by Saaty (1980), is mainly used for prioritization in complex decision-making problems, but it involves the ambiguity or uncertainty inherent in the evaluator's language or thoughts. Recently, to overcome this problem, the fuzzy AHP analysis method, which was developed

Table 2. Selection of variables for assessing the level of the heat wave adaptation policies.

Variables	Description
Project budget	Assessment criterion for efforts to acquire project budgets
Number of budgets	Assessment criterion for efforts to explore projects
Importance of each sector and response area	Importance weight for the sector and response area by type of municipality

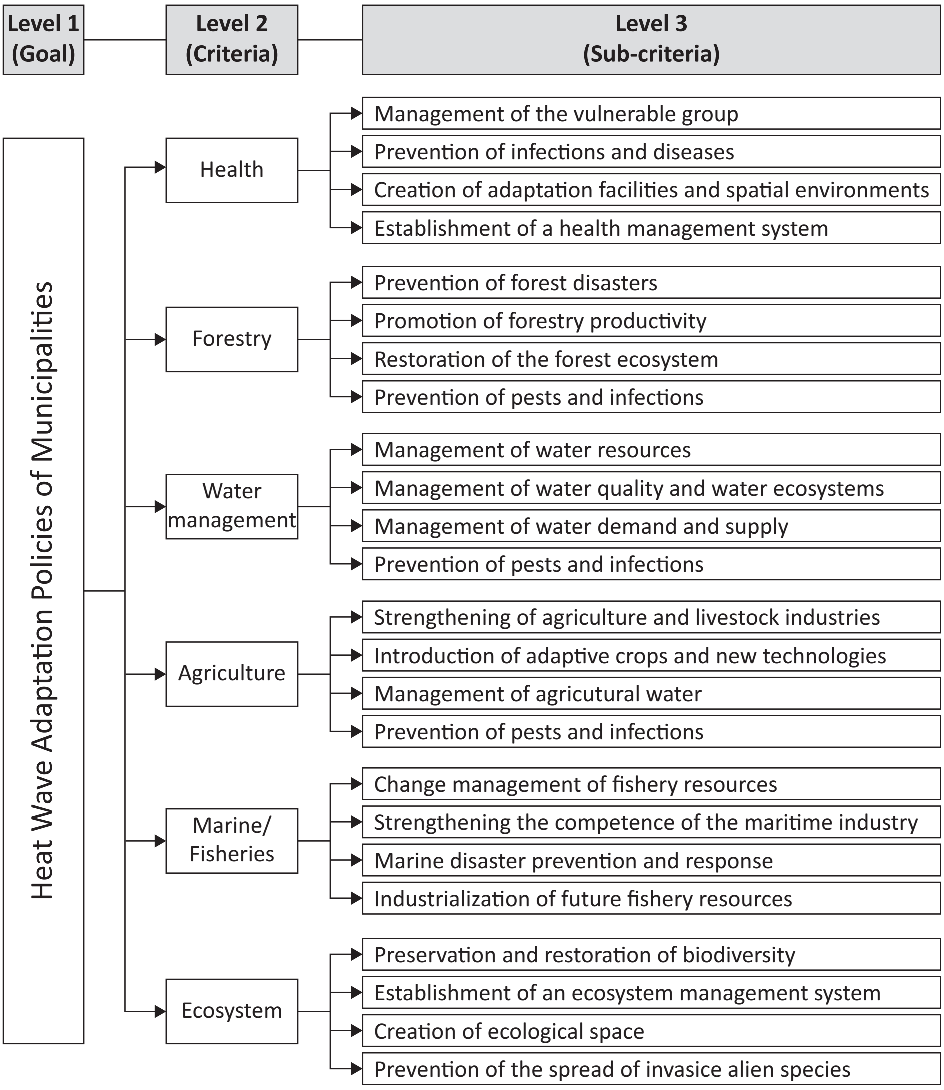

Figure 2. The sectors and response areas of heat wave policy.

by van Laarhoven and Pedrycz (1983), has often been applied. The fuzzy AHP analysis method is different from the conventional AHP method in that the data used in the computation process are not normal numbers but fuzzy numbers. A fuzzy number is a value converted from the result of a pairwise comparison in order to deal with the uncertainty and ambiguity inherent in human judgment. For fuzzy numbers, the triangular fuzzy number is generally used. A triangular fuzzy number is composed of three parameters (a_1, a_2, a_3), and the function is defined as Equation 1, where a_1 and a_3 are the lower and upper limits of the triangular fuzzy number, respectively:

$$\mu_A(x) = \begin{bmatrix} y_a^L(x) = \dfrac{x - a_1}{a_2 - a_1},\ a_1 \leq x \leq a_2 \\ y_a^R(x) = \dfrac{x - a_3}{a_2 - a_3},\ a_2 \leq x \leq a_3 \\ 0,\ \text{otherwise} \end{bmatrix} \quad (1)$$

To calculate the level of heat wave adaptation policies of the municipalities, the assessment model was established as in Equation 2 below using the project budget, number of projects, and importance of the sector and response area, which were selected as the quantitative variables. The sum of the unit project budgets and the sum of the number of unit projects for each response area were normalized to values of 0 and 1, respectively:

$$\text{Assessment score of the level of heat wave adaptation policies of municipalities} = \sum_{j=1}^{m}\left(\sum_{i=1}^{n} B_i \times N_i \times W_i\right) \times K_j, \quad (2)$$

where m is the number of sectors, n is the number of response areas, K is the importance weight for each sector, B is the sum of the unit project budgets for each response area, N is the sum of the number of unit projects for each response area, and W is the importance weight for each response area.

2.3. Gap Analysis Between the Level of Heat Wave Adaptation Policy and Heat Wave Effects in the Municipalities

The gap analysis between the heat wave adaptation policy level and heat wave effects was divided into gap analysis by municipality type using Kendall's concordance coefficient and gap analysis by the municipality. In addition, the number of heat wave days for each local government was used as an impact indicator for the heat wave effect in the analysis.

First, to analyze the gap between the level of heat wave adaptation policy and heat wave effects by the type of municipality, the correlation between the analysis results for the level of municipalities' heat wave adaptation policies and the heat wave effect level was analyzed using Kendall's concordance coefficient. Kendall's concordance coefficient indicates the correlation of assessments when multiple assessors evaluate the same sample. In this study, the level of heat wave adaptation policies and the heat wave effects are not the same, but, assuming that the ideal heat wave adaptation policy is established when these two levels are identical, the correlation between the assessment results of the two samples was analyzed. The equation for calculating Kendall's concordance coefficient for this purpose is as follows:

$$\text{Kendall's concordance coefficient} = \frac{S}{12K^2\,(N^3 - N)}, \quad (3)$$

where S is the mean deviation for each ordinal scale, K is the number of assessors, and N is the number of assessment subjects.

For the gap analysis between the level of heat wave adaptation policy and heat wave effect by municipality, the difference in the scores between the previously derived level of heat wave adaptation policy and the number of heat wave days for each municipality was analyzed.

The heat wave effect variable, the number of heat wave days based on the number of days in which the daily maximum temperature is 33 °C or higher was selected. These data were established based on the RCP (representative concentration pathways) 8.5 scenario provided by the Korea Meteorological Administration. The reference years were set as 2015, 2035, 2055, 2075, and 2095. Since long-term future predictions involve large variability, the cumulative mean value of 10 years was estimated in order to consider this variability. For example, the mean value for the period from 2011 to 2020 was selected as the representative value for 2015.

3. Results

3.1. Classification of Municipalities

There were 229 classified municipalities across the country. First, for Level 1, they were classified into urban and rural types based on the population size. Every district that belongs to a metropolitan city or special city or every city with a population of at least 500,000 people was classified as urban, and the others were classified as rural. Next, for Level 2, in order to reflect the characteristics of the primary industries, the rural municipalities were classified into mountain type or farming and fishing type through factor analysis and cluster analysis using the variables for classification. The factor analysis was performed first using the characteristic variables of the primary rural industries after standardizing the variables so that variables with different units could be compared. For the rotation method, the varimax method was used, which is an orthogonal rotation of the factor axes.

As a result of the factor analysis, as shown in Table 3, the KMO value was determined to be 0.622, which is greater than 0.5, and Bartlett's sphericity test was also significant ($p < 0.001$). Thus, the variables used in the factor analysis are appropriate for our purposes.

From the result of the rotated component matrix, as shown in Table 4, the field area, fishery farm area, and rice field area are classified as Component 1 (*farming and*

Table 3. Results of KMO and Bartlett's test for the characteristic variables of the primary rural industry.

KMO measure of sampling adequacy		0.622
Bartlett's sphericity test	Approximate chi-square	82.123
	Degree of freedom	10
	Probability of significance	0.000

Table 4. Result of the rotated component matrix for the characteristic variables of the primary rural industry.

	Components	
	1	2
Standardizing score (the field area)	0.822	−0.013
Standardizing score (the fish farm area)	0.715	0.099
Standardizing score (the rice field area)	0.614	−0.381
Standardizing score (the livestock count)	0.213	0.796
Standardizing score (the growing stock volume)	−0.437	0.649

Notes: Factor extraction method—primary component analysis; rotation method—varimax with Kaiser normalization.

fishing type), while the livestock count and growing stock volume are classified as Component 2 (*mountain type*).

The municipalities were classified into the farming and fishing type or the mountain type by performing a cluster analysis using the components derived from the factor analysis. For the cluster analysis, the *K*-mean cluster analysis method was used.

As a result of the cluster analysis, as shown in Table 5, Cluster 1 was classified as the farming and fishing type, and Cluster 2 was classified as the mountain type. Thus, 229 municipalities were classified into 84 urban, 58 mountain, and 87 farming and fishing municipalities.

Among them, 156 municipalities, which were confirmed to have established detailed implementation plans for climate change adaptation measures, were reclassified. Finally, as shown in Figure 3, they were classified into 58 urban, 42 mountain, and 56 farming and fishing municipalities.

3.2. Assessment of the Level of Heat Wave Adaptation Policies of Municipalities

The importance of each sector and response area of the heat wave adaptation policies is expected to appear differently depending on the industrial characteristics of the municipalities. Thus, the weights were derived for each type of municipality classified above. To derive the weights of the sector and response area by municipality type, the fuzzy AHP analysis was performed through a survey of experts related to climate change adaptation. The relative importance of the sectors and response areas for the fuzzy AHP analysis was evaluated using the pairwise comparison scale based on the nine-point Likert scale, which is described in Table 6.

The expert survey was conducted through an e-mail request between 10 November and 30 November 2017. The survey request was sent to 234 persons in total,

Table 5. Cluster analysis results for the characteristic variables of the primary rural industries.

	Clusters	
	1	2
Component 1	**0.31828**	−0.47742
Component 2	−0.52919	**0.79378**

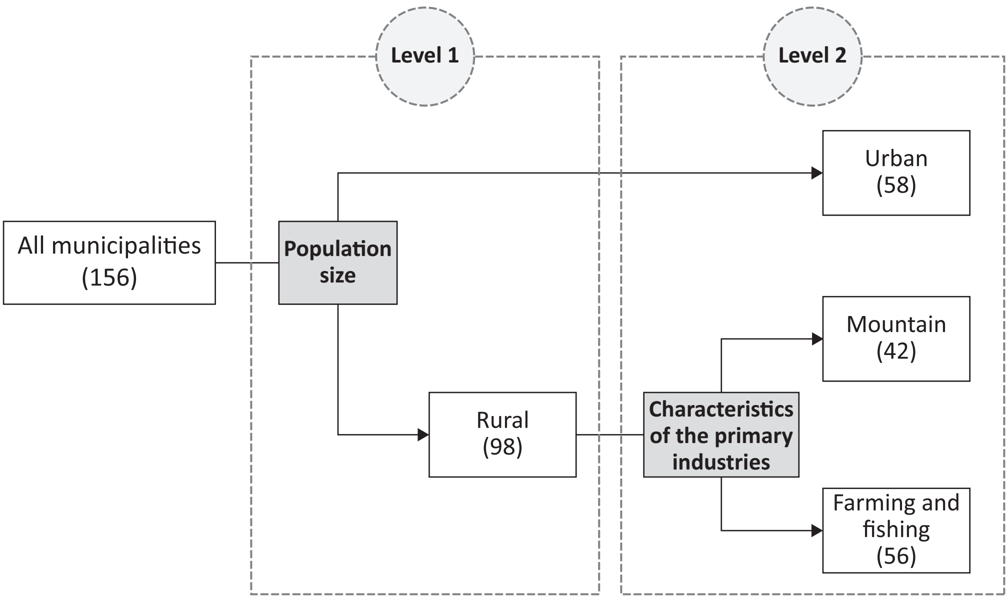

Figure 3. Result of classification of municipalities.

Table 6. Description of the scale of pairwise comparison.

Importance intensity	Description
9	Absolute importance of one element over another
7	Demonstrated importance of one element over another
5	Strong importance of one element over another
3	Weak importance of one element over another
1	Equal importance of both elements
2, 4, 6, and 8	Intermediate values between two adjacent judgments

and 50 of them responded, with a return rate of 23.4%. The fuzzy AHP analysis was performed using 37 of the 50 returned survey questionnaires, excluding 13 questionnaires that did not answer some questions or were inconsistent. The general criterion for consistency is a consistency ratio (CR) of less than 0.1, but, in this survey, the criterion for CR was lowered to 0.2 to consider the relatively high number of questions. This is also consistent with the assertion of Saaty and Kearns (1985) that consistency be maintained even when the CR is less than 0.2.

Based on the results of the fuzzy AHP analysis, the importance weights of sectors and response areas by municipality type were derived as shown in Table 7.

3.3. Gap Analysis Between the Level of Heat Wave Adaptation Policy and Heat Wave Effects in the Municipalities

To analyze the gap between the level of heat wave adaptation policy and heat wave effect by the municipality type, an analysis of Kendall's concordance coefficient was performed, which requires ordered data. Thus, the scores for the level of heat wave adaptation policies and the number of heat wave days derived above were graded to convert them from continuous data to ordered data. For this grading, the uniform interval method was used based on the corresponding year. However, although it is easy to find the distribution of a group with the uniform interval method, there is a concern that it may be distorted by the ideal and extreme values. Thus, the ideal and extreme values were removed before grading and the grades were divided into seven steps in total. After removing the ideal and extreme values, Kendall's concordance coefficient was analyzed for a total of 143 municipalities (Table 8).

The analysis results show that the concordance coefficient between the level of heat wave adaptation policy and the heat wave effect for all municipalities and each municipality type tends to decrease as the heat effect time moves further into the future. For all municipalities, the concordance coefficient was significant at every heat wave effect time ($p < 0.05$), and the concordance coefficient tends to decrease as the heat wave effect time moves further into the future. For the urban municipalities, the concordance coefficient was significant at every heat wave effect time except for 2095 ($p < 0.05$), and the concordance coefficient tended to decrease as the heat wave effect time moved further into the future. For the mountain municipalities, the concordance coefficient was significant at every heat wave effect time ($p < 0.05$), and the concordance coefficient tended to decrease in general as the heat wave effect time moved further into the future, although it increased in 2055. For the farming and fishing municipalities, the concordance coefficient was significant at every heat wave effect time except for 2095 ($p < 0.05$), and the

Table 7. Importance of the sector and response areas of heat wave adaptation policies by municipality type.

Type	Sector	Importance	Response areas	Importance
Urban	Health	0.371	Management of the vulnerable group	0.350
			Prevention of infections and diseases	0.248
			Creation of adaptation facilities and spatial environments	0.209
			Establishment of a health management system	0.242
	Forestry	0.127	Prevention of forest disasters	0.363
			Promotion of forestry productivity	0.161
			Restoration of the forest ecosystem	0.237
			Prevention of pests and infections	0.279
	Water management	0.240	Management of water resources	0.198
			Management of water quality and water ecosystems	0.210
			Management of water demand and supply	0.365
			Maintenance of water and sewage	0.262
	Agriculture	0.102	Strengthening of agriculture and livestock industries	0.203
			Introduction of adaptive crops and new technologies	0.297
			Management of agricultural water	0.227
			Prevention of pests and infections	0.315
	Marine/fisheries	0.083	Change management of fishery resources	0.275
			Strengthening the competence of the maritime industry	0.202
			Marine disaster prevention and response	0.297
			Industrialization of future fishery resources	0.259
	Ecosystem	0.127	Preservation and restoration of biodiversity	0.250
			Establishment of an ecosystem management system	0.249
			Creation of ecological space	0.305
			Prevention of the spread of invasive alien species	0.237

Table 7. (Cont.) Importance of the sector and response areas of heat wave adaptation policies by municipality type.

Type	Sector	Importance	Response areas	Importance
Mountain	Health	0.221	Management of the vulnerable group	0.313
			Prevention of infections and diseases	0.360
			Creation of adaptation facilities and spatial environments	0.162
			Establishment of a health management system	0.210
	Forestry	0.284	Prevention of forest disasters	0.380
			Promotion of forestry productivity	0.203
			Restoration of the forest ecosystem	0.182
			Prevention of pests and infections	0.270
	Water management	0.190	Management of water resources	0.413
			Management of water quality and water ecosystems	0.222
			Management of water demand and supply	0.238
			Maintenance of water and sewage	0.182
	Agriculture	0.132	Strengthening of agriculture and livestock industries	0.227
			Introduction of adaptive crops and new technologies	0.271
			Management of agricultural water	0.221
			Prevention of pests and infections	0.324
	Marine/fisheries	0.061	Change management of fishery resources	0.288
			Strengthening the competence of the maritime industry	0.223
			Marine disaster prevention and response	0.271
			Industrialization of future fishery resources	0.244
	Ecosystem	0.165	Preservation and restoration of biodiversity	0.392
			Establishment of an ecosystem management system	0.224
			Creation of ecological space	0.128
			Prevention of the spread of invasive alien species	0.296
Farming and Fishing	Health	0.249	Management of the vulnerable group	0.321
			Prevention of infections and diseases	0.321
			Creation of adaptation facilities and spatial environments	0.173
			Establishment of a health management system	0.228
	Forestry	0.099	Prevention of forest disasters	0.336
			Promotion of forestry productivity	0.176
			Restoration of the forest ecosystem	0.217
			Prevention of pests and infections	0.312
	Water management	0.179	Management of water resources	0.409
			Management of water quality and water ecosystems	0.184
			Management of water demand and supply	0.269
			Maintenance of water and sewage	0.187
	Agriculture	0.238	Strengthening of agriculture and livestock industries	0.240
			Introduction of adaptive crops and new technologies	0.187
			Management of agricultural water	0.305
			Prevention of pests and infections	0.303
	Marine/fisheries	0.141	Change management of fishery resources	0.208
			Strengthening the competence of the maritime industry	0.268
			Marine disaster prevention and response	0.361
			Industrialization of future fishery resources	0.205
	Ecosystem	0.152	Preservation and restoration of biodiversity	0.329
			Establishment of an ecosystem management system	0.216
			Creation of ecological space	0.158
			Prevention of the spread of invasive alien species	0.338

Table 8. Analysis results of Kendall's concordance coefficient between the level of heat wave adaptation policy and the heat wave effect by municipality type.

Type	Sample size	Result	2015	2035	2055	2075	2095
All	143	Kendall's *W*	0.515	0.488	0.404	0.134	0.028
		Approximate probability of significance	0.000	0.000	0.000	0.000	0.045
Urban	56	Kendall's *W*	0.137	0.137	0.126	0.080	0.010
		Approximate probability of significance	0.006	0.006	0.008	0.035	0.446
Mountain	35	Kendall's *W*	0.488	0.488	0.541	0.357	0.333
		Approximate probability of significance	0.000	0.000	0.000	0.000	0.001
Farming and fishing	52	Kendall's *W*	0.501	0.428	0.448	0.124	0.057
		Approximate probability of significance	0.000	0.000	0.000	0.011	0.086

concordance coefficient tended to decrease in general as the heat wave effect time moved further into the future, although it also increased in 2055.

To analyze the gap between the level of heat wave adaptation policy and heat wave effect by the municipality, the difference in the scores derived above between the level of heat wave adaptation policy and the number of heat wave days (score of heat wave adaptation policy–heat wave effect score) was analyzed. To do this, each score was normalized to a value of 0–1.

The analysis results are outlined in Figure 4. The dashed part indicates municipalities whose heat wave effect scores are higher than the score of the heat wave adaptation policy, and the light-colored part indicates the municipalities whose heat wave adaptation policy scores are higher than the heat wave effect scores. The former can be regarded as those whose current heat wave adaptation policies are insufficient relative to the heat wave effects. These municipalities are summarized by municipality type in Table 9. The municipalities

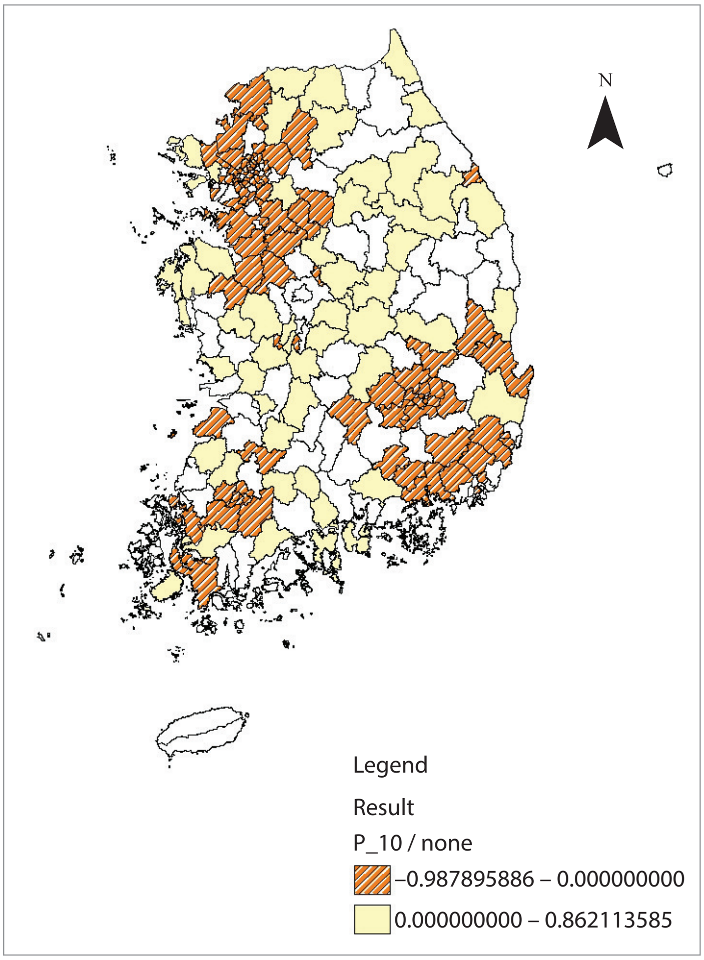

Figure 4. Result of the gap analysis between the level of heat wave adaptation policy and heat wave effects by municipality.

Table 9. Ratios of municipalities with insufficient levels of heat wave adaptation policies compared to the heat wave effects by municipality type.

Type of municipality	Total number	Number of insufficient municipalities	Ratio of insufficient municipalities (%)
Urban	56	51	91.07
Mountain	35	11	31.42
Farming and fishing	52	28	53.84
All	143	90	62.93

with insufficient heat wave adaptation policies consist of 51 urban types, 11 mountain types, and 29 farming and fishing types. Proportionally, urban municipalities had the highest ratio of insufficient heat wave adaptation policy levels (91.07%), followed by farming and fishing municipalities (53.84%) and mountain municipalities (31.42%).

4. Discussion

The gap analysis results between the level of heat wave adaptation policy and heat wave effect by municipality type showed that Kendall's concordance coefficient was significant and tended to decrease as the heat wave effect time advanced further into the future. Significant concordance means securing the validity of the evaluation model of the municipality's heat wave adaptation policy. At the same time, it means that the municipalities acquired the project budget and discovered the proper project in accordance with the effect of the heat wave at the decision-making and policy establishment step. Furthermore, the fact that the concordance coefficient decreases as the heat wave effect time moves further into the future means that the degree of concordance between the level of heat wave adaptation policy and the future heat wave effect decreases.

By municipality type, the urban type showed a relatively low concordance coefficient. This seems to be because factors other than the heat wave effect are reflected when the heat wave adaptation policies are established in urban-type municipalities. Residents in cities have more diverse ages and economic levels than do those in farming and fishing villages and mountain areas. Therefore, in the event of a heat wave, the damages appear differently depending on the social, economic, and demographic characteristics of the city. The concordance coefficient may be low because this vulnerability of cities affected the establishment of heat wave adaptation policies.

When the difference between the score of the heat wave adaptation policies and the heat wave effect score was analyzed for the gap analysis by municipality, 90 of 143 municipalities showed an insufficient level of heat wave adaptation policy compared to the heat wave effect.

By municipality type, the urban type showed a relatively high ratio of municipalities with insufficient heat wave adaptation policies. Of the 51 urban-type municipalities with insufficient heat wave adaptation policies, 40 were autonomous districts in administrative units. A *gu* district is an autonomous district that belongs to a metropolitan city or a special city. Under the current laws of South Korea, these autonomous units have the same status as cities (*si*) and counties (*gun*) that belong to a province (*do*), but they have considerable limitations in planning authority, manpower, and budget (Yang et al., 2015). Consequently, there is a tendency for the metropolitan city and special city to take the lead in planning, and the autonomous districts only take charge of simple projects. This tendency appears to be related to the number and budget of projects for heat wave adaptation policies, resulting in a low level of heat wave adaptation policy compared to the heat wave effect. Another possible reason is that cities do not need to establish adaptation policies related to costly infrastructure because the proportion of primary industries is low.

5. Conclusions

This study aimed to analyze the gap between the level of heat wave adaptation policy and the heat wave effect in South Korean municipalities. For this purpose, this study was conducted largely in three steps. First, the types of industries in the municipalities were classified considering their industrial characteristics using factor analysis and cluster analysis. Second, the level of heat wave adaptation policy in the municipalities was assessed. To do this, a list of sectors and response areas were derived by building an inventory of heat wave adaptation policies, and the importance weights of the sectors and response areas by municipality type were derived through a fuzzy AHP analysis. Then, the level of heat wave adaptation policies by municipality type was assessed using the number of projects, project budgets, and importance weights. Third, the gap between the level of heat wave adaptation policy and the heat wave effect was analyzed. The gap analysis was conducted in two ways: a gap analysis by municipality type using Kendall's concordance coefficient and a gap analysis by municipality.

The analysis results can be largely summarized in two parts. First, the heat wave adaptation policies were established in accordance with the heat wave effects to some degree, and the extent of concordance decreased as the time of the heat wave effect was moved further into the future. Second, the number of municipalities that have insufficient heat wave adaptation policies against heat wave effects was 90 out of 143. The proportion of municipalities with insufficient levels of heat wave adaptation policy against heat wave effects was higher among urban-type municipalities.

The analysis results suggest policy implications. First, the heat wave adaptation policies of municipalities should be established through continuous feedback on the predictions of future heat wave effects. Second, urban-type municipalities should strengthen their planning authority and competence by securing a professional workforce and budgets for the establishment of heat wave adaptation policies.

On the other hand, this study has limitations in that the assessment of heat wave adaptation policies reflected only quantitative variables, such as the number of projects and project budgets, and did not reflect the competence and perception of the civil servants carrying out the projects. Furthermore, a total policy assessment was not carried out because the implementation process, which is critical in adaptation policies, was not assessed. Therefore, comprehensive policy assessments need to be carried out that include the policy implementation process and results once the implementation of existing heat wave adaptation policies of municipalities is completed. As mentioned in Section 1, heat waves cause negative impacts on human life, especially on the poor. Solving these problems by developing adaptation policies is a critical topic in the smart sustainable city. This research is meant to suggest a good example of a new modality for the smart sustainable city and environmentally-minded smart citizenship. Further research needs to examine a more detailed discussion on citizens' participation in smart climate change planning.

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Conflict of Interests

The authors declare no conflict of interests.

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About the Authors

Tae Ho Kim is a researcher at the Korean Agency for Infrastructure Technology Advancement. He received his MA from Chungbuk National University in the Republic of Korea in 2017. His research focuses on the various urban environmental challenges arising from climate crises, such as heavy rain and heat waves. He is especially interested in the development of spatial information-based decision-making support system that can be used to address various urban environmental issues.

Chang Sug Park is a chief research fellow at the Korea Environment Institute (Sejong, Republic of Korea). His focus of research is on spatial and environmental planning for carbon-neutral and resilient mainstreaming strategies on different scales. He is currently conducting research on megacities and circular cities in terms of carbon neutrality and balanced development, and researching the direction of urban and environmental planning for climate resilience.

Sang-hyeok Lee is a senior researcher at the Marin Policy Research Division at the Korea Maritime Institute. He received his PhD from the Pusan National University, Republic of Korea. His research explores city planning, coastal planning, spatial temporal big-data analysis, and climate change risk analysis. He is currently researching marine climate change impact, digital coast platform, and assessment of the declining coastal city.

Jung Eun Kang is a professor at the Department of Urban Planning and Engineering at Pusan National University, Republic of Korea. She received her PhD from Texas A&M University. She is teaching environmental planning, spatial analysis in urban planning, and disaster management planning. Her research explores city planning, urban form, climate change impacts and responses, and spatiotemporal big data.