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Analysis of Urban Heat Island Intensity Among Administrative Districts Using GIS and MODIS Imagery*

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GIS 및 MODIS 영상을 활용한 행정구역별 도시열섬강도 분석*

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ABSTRACT

This study was conducted to analyze the urban heat island(UHI) intensity of South Korea by using Moderate Resolution Imaging Spectroradiometer(MODIS) satellite imagery. For this purpose, the metropolitan area was spatially divided according to land cover classification into urban and non-urban land. From the analysis of land surface temperature(LST) in South Korea in the summer of 2009 which was calculated from MODIS satellite imagery it was determined that the highest temperature recorded nationwide was 36.0℃, lowest 16.2℃, and that the mean was 24.3℃, with a standard deviation of 2.4℃. In order to analyze UHI by cities and counties, UHI intensity was defined as the difference in average temperature between urban and non-urban land, and was calculated through RST1 and RST2. The RST1 calculation showed scattered distribution in areas of high UHI intensity, whereas the RST2 calculation showed that areas of high UHI intensity were concentrated around major cities. In order to find an effective method for analyzing UHI by cities and counties, analysis was conducted of the correlation between the urbanization ratio, number of tropical heat nights, and number of heat-wave days. Although UHI intensity derived through RST1 showed barely any correlation, that derived through RST2 showed significant correlation. The RST2 method is deemed as a more suitable analytical method for measuring the UHI of urban land in cities and counties across the country. In cities and counties with an urbanization ratio of < 20%, the rate of increase for UHI intensity in proportion to increases in urbanization ratio, was very high; whereas this rate gradually declined when the urbanization ratio was > 20%. With an increase of 1℃ in RST2 UHI intensity, the number of tropical heat nights and heat wave days was predicted to increase by approximately five and 0.5, respectively.

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These results can be used for reference when predicting the effects of increased urbanization on UHI intensity.

KEYWORDS : MODIS Satellite Imagery, Urban Heat Island, Land Surface Temperature, Tropical Night, Urbanization Ratio

요 약

본 연구는 MODIS 위성영상을 활용하여 우리나라 전역의 열섬강도를 분석하기 위하여 연구를 수행하였다. 이를 위해 도시지역을 토지피복별 분류에 따라 시가화지역, 비시가화지역으로 공간적 구분하였다. MODIS 위성영상을 활용하여 산출된 2009년 여름철 전국의 표면온도 분석 결과 전국 최고온도는 36.0℃, 최저온도 16.2℃, 평균 24.3℃, 표준편차 2.4℃로 분석되었다. 시군별 열섬현상을 분석하기 위하여 시가화지역과 비시가화지역의 평균온도의 차이를 열섬강도로 정의하였고 RST1, RST2 2가지 방법으로 산출하였다. 그 결과 RST1의 경우 열섬강도가 높은 지역이 산포되어 분포하고 있는 것으로 나타났으며, RST2의 경우 대도시지역을 주변으로 열섬강도가 높은 지역이 집중되어 있는 것으로 분석되었다. 시군별 열섬현상 분석에 효율적 방법을 보기 위하여 시가화율, 열대야일수, 폭염일수와의 상관분석을 하였다. 그 결과 RST1 방식에 의한 열섬강도는 상관성이 거의 없는 것으로 나타났으며, RST2의 경우 유의한 상관성을 나타났다. 전국 시군별 도시지역을 대상으로 열섬현상에 대해 분석하기 위한 방법으로는 RST2 방식이 더 적합할 것으로 판단되며, 시군별 시가화율이 약 20% 이하일 경우 시가화율 증가에 따른 도시지역의 열섬강도의 증가율이 매우 높았으며, 약 20% 이상부터 열섬강도의 증가율이 점차 낮아지는 것을 확인할 수 있다. RST2 열섬강도가 1℃ 증가할 경우 열대야일수와 폭염일수는 약 5일과 0.5일 증가하는 것으로 예측하였다. 이러한 분석결과는 추후 도시화율 증가에 따른 열섬강도 변화를 예측 할 수 있는 자료로서 활용될 수 있을 것으로 판단된다.

주요어 : MODIS 위성영상, 도시열섬현상, 지표면온도, 열대야, 시가화율

INTRODUCTION

Rapid industrialization in modern society has led to the acceleration of indiscreet development and expansion, which has in turn resulted in a gradual increase in urban land. Overpopulation, increases in man-made structures, and changes in terrain brought forth by urbanization along with deterioration of the urban environment have been reported, as the primary causes of urban heat island(UHI) an effect in which the change in urban climate leads to a temperature difference of more than 2℃ between urban and non-urban land (Oke, 1987; Ministry of Agriculture and Forestry, 2007; Takebayashi and Moriyama, 2009; Song and Park, 2012). UHI has a negative influence on the pleasant living environment and high life satisfaction of city residents, because it worsens the heat problems on tropical nights and the heat waves in summer(Kovats and Hajat, 2008; Song and Park, 2013; Song, 2014). Accordingly, recognizing the current state and problems of, and preparing countermeasures against, UHI can be regarded as pressing issues that need to be considered in order to alleviate these problems in urban environments, particularly in relation to climate change(Ymashita, 1995).

In addition to urbanization, the focus on development around metropolitan areas can be regarded as an important factor that exacerbates UHI. Concentration of the urban population further increases the demand for developing residential and commercial buildings; thus, traffic facilities, and cities have become covered with artificial land cover rather than forests. Among such surface materials, asphalt and concrete in particular, can negatively affect the urban climate by increasing the heat on tropical nights, because they absorb and retain heat during the day and release it at night (Park, 2001; Lee *et al.,* 2007; Song and Park, 2015).

Another factor that causes UHI is the prioritization of function, efficiency, and convenience above climate and environment in the existing processes of urban development. Notably, greater emphasis has been placed on improving indoor comfort as opposed to the outdoor environment of a city, which has resulted in the installation of air conditioning systems in most buildings in order to maintain indoor temperatures. However, recent climate change has increased heat stress and the occurrence of abnormal weather(e.g., heat waves and cold waves) has led to excessive use of interior cooling and heating systems. This has resulted in the exacerbation of UHI because artificial heat in cities has sharply increased, particularly in summer(Suh *et al.,* 2009; Park *et al.,* 2011).

It is important to understand the UHI characteristics in addition to various physical environmental factors existing in cities if a mitigation strategy is to be planned for reduction of UHI(Kim and Yeom, 2012); therefore, current studies on the causes of and solutions to UHI widely underway. Previous research on these issues has focused on the need for changing urban land cover materials and urban afforestation as solutions to UHI. This is reasonable, given that UHI is induced by increases in the numbers of roads and buildings in urban areas, which in turn cause tropical heat nights, increased environmental pollution, and severe health problems for urban residents(Kim *et al.,* 2001). Furthermore, because the temperature data obtained from imagery are arranged in a space lattice form, they enable direct comparison with physical environmental factors in cities such as land cover(Song, 2014). This has led to studies for determining methods of lowering UHI by constructing a GIS-integrated database that incorporates remote sensing and the factors causing UHI, the results of which are used to map the decrease in forestation and changes in urban land usage (Ministry of Agriculture and Forestry, 2007). To this end, Song(2014) determined the Land surface temperature(LST) of Changwon City by using satellite imagery, and analyzed the effect of various LST due to urban land usage, on the UHI effect. Ahn(2007) investigated changes from past land use and evaluated the effect of various land uses on the thermal environment, the results formed basis for eco-friendly urban planning.

Although several previous studies have been conducted on UHI by using satellite imagery, those that engage in comparative research between regions or discuss climate change on a large scale are insufficient because most existing studies have approached the topic from a regional perspective. The purpose of this study is to analyze the causes and effects of UHI in South Korea at the national level by using applicable Moderate Resolution Imaging Spectroradiometer (MODIS) satellite imagery. For this purpose, a method for evaluating UHI intensity through regional comparison is proposed. Moreover, this study was conducted to identify the current state and causes of UHI in a practical sense by examining the relationship between controversial topics such as the expansion of urban lands and UHI intensity and by analyzing the correlation between factors such as the numbers of tropical heat nights and heat wave days.

METHODS

1. Research Process

The process of this research is shown in Figure 1. Initially, 2009 spatial and climate information including MODIS imagery data, land cover maps, and the numbers of tropical heat nights and heat wave days was collected. For the land cover map, the 2009 level 2 classification of land cover of the Ministry of Environment was adopted to categorize urban and non-urban land, from which the urbanization ratio was calculated. For the MODIS data, coordinate calibration and unitary transformation were applied to determine LST, and UHI intensity was calculated from the difference in LST between urban and non-urban land. Finally, a correlation between the urbanization ratio

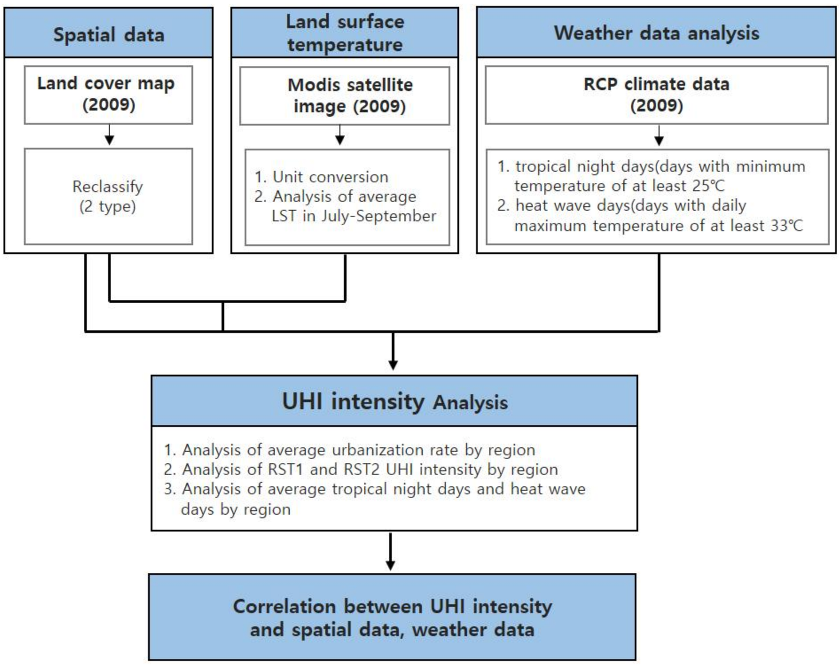


FIGURE 1. Research method

and the consequences of abnormally high urban temperatures in tropical heat nights and heat wave days was performed to select a reliable method for analyzing the UHI phenomenon.

2. Scope of Research

In this study, the temporal scope focused on the hottest time of the year, July to September, but excluded the monsoon season. In order to utilize the Ministry of Environment' s 2009 level 2 classification land cover map, MODIS satellite imagery and the numbers of heat wave days and tropical nights were set to the temporal scope of 2009. UHI intensity was analyzed for the entire South Korean country. South Korea has 1 metropolitan government, 1 special autonomous city, 6 metropolitan cities, 77 cities, and 77 counties. Its topographical characteristics are a low west and high east layout in which mountains can be found in the latter. As the capital of South Korea, most of Seoul Metropolitan Government has been developed into urban land; this pattern can also be seen in the other six metropolitan cities. From a thermal environmental perspective, these cities can be considered as regions with severe negative effects including the phenomenon of UHI. For cities and counties, significant differences appear among localities regarding the extent of their development and land use. Because such characteristics lead to differences in the thermal environments of various cities, a comparative study on the UHI phenomenon in each region is necessary

3. Research Method

1) Land cover classification by region

The increase in artificial land cover owing to urban development transforms the thermal environment of land surfaces, which causes an alteration in LST. This ultimately results in UHI by creating a discrepancy between the urban and suburban temperatures. Because UHI intensity rises when this discrepancy is greater, urban and suburban areas were categorized and their LST were calculated to compare their differences. The 2009 level 2 land cover map provided by the Ministry of Environment was used to categorize urban and non-urban land. Such maps are produced at 5m resolution by using Arirang-2 satellite imagery, aerial photographs, and digital topographic maps (Ministry of Environment, 2009).

The system of land cover classification from the Ministry of Environment' s Spatial Data Service was adopted as the standard for classification. By using the "dissolve" tool of ArcGIS, six out of the twenty-three level 2 classification categories including residential, industrial, commercial, recreational, transportation, and public facilities regions were reclassified as urban surfaces; the remaining regions were reclassified as non-urban surfaces (Table 1). The areas were calculated after classifying the urban and non-urban surfaces according to region by conducting overlap analysis of the government administrative district map, which employed the land cover map that had been reclassified into urban and non-urban lands. Regions with high percentages of artificial land cover indicate a high level of urbanization, which enabled the effects

TABLE 1. Classification according to land cover material

Land cover reclassification	Sub-categories(23Items)	
Urban surface	Residential area	110
	Industrial area	120
	Commercial area	130
	Cultual facilities	140
	Transportation facility	150
	Public facility	160
Non-urban surface	Rice paddy	210
	Farm	220
	Cultivation	230
	Orchard	240
	Others	250
	Deciduous forest	310
	Coniferous forest	320
	Mixed forest	330
	Natural grassland	410
	Artificial grassland	420
	Others	430
	Inland wetland	510
	Coastal wetland	520
	Natural bare land	610
	Others	620
	Inland water	710
	Marine water	720

(Source : Ministry of Environment, 2009)

of the urbanization ratio on LST to be examined accordingly.

2) Construction of MODIS land surface temperature data

The LST data derived from MODIS satellite imagery was used to analyze the differences between the LST of urban and non-urban lands. MODIS is a sensor onboard the Terra satellite, which is a United States (NASA) Earth Observing System satellite in a Sun synchronous orbit at an altitude of 705km(Ahn and Kim 2007).

The LST data used for the heat island intensity analysis in this study were products of MOD11A2, a MODIS satellite. The MOD11A2 images were observed by the Terra MODIS satellite, which uses bands 31 and 32 with a spatial resolution of 1km and includes 46 composite LST datasets collected at eight-day intervals over one year. MODIS LST data were used without calibration because they were produced by satellite imagery processing. For the MODIS LST data, coordinate calibration and unitary conversion were performed by using ArcGIS for each image(Ahn, 2007)(Figure 2). The LST data for the summer weeks of 2009 were constructed by calculating the mean values from the LST imagery for the summer months of July through September, when temperatures are highest.

In order to utilize the constructed LST data for the analysis of heat island intensity, the zonal statics tool of ArcGIS was used to input the land cover maps of the previously classified urban and non-urban surfaces by region as spatial data for calculating the average LST of the urban and non-urban surfaces by region.

3) Numbers of heat wave days and tropical nights

The construction of data on the numbers of tropical nights and heat wave days utilized the climate change scenario specific to South Korea(1km) based on the Representative Concentration Pathway (RCP), one of the climate change scenarios for the Korean Peninsula provided by the Climate Information Portal of the Korea Meteorological Administration. This climate change scenario was produced by using a statistical refinement process based on the 12.5 km Korean Peninsula climate change scenario produced by regional climate models. Observation data of 2000-2010

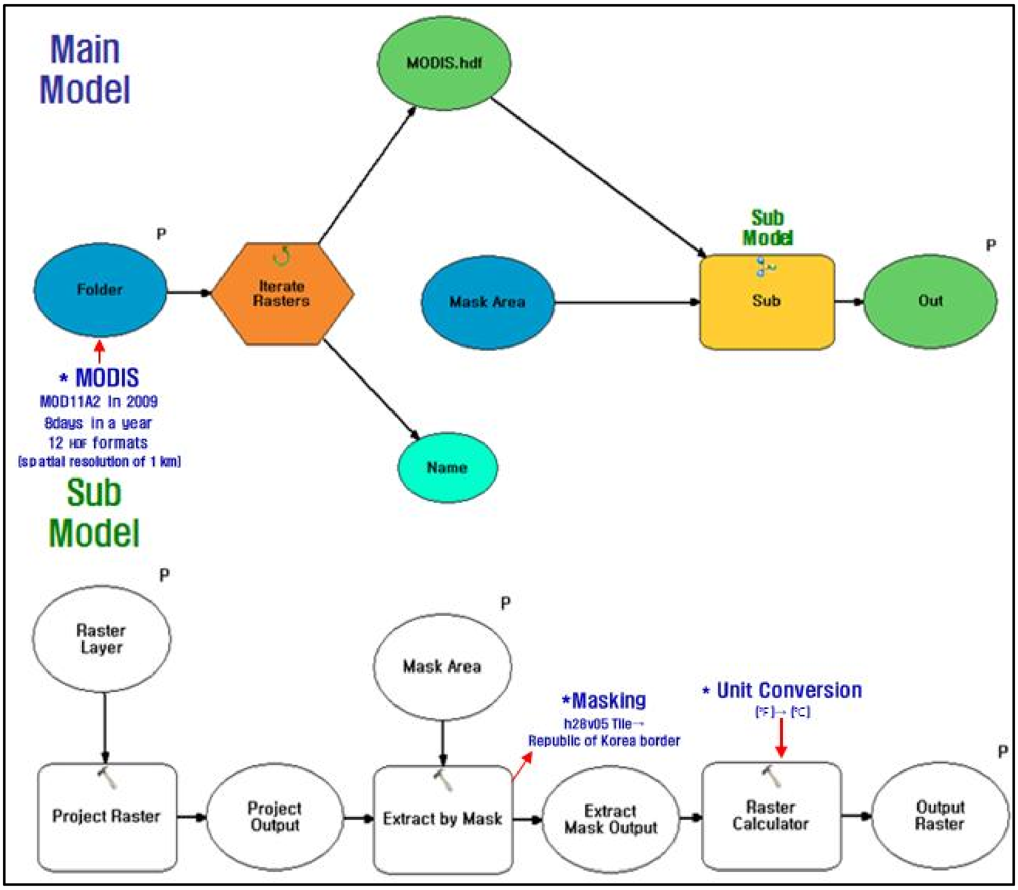


FIGURE 2. MODIS LST processing using modelbuilder, ArcGIS

were applied to the Policy and Regulatory Instruments in a Decentralized Economy (PRIDE) climate model to produce observational grid data of 1km resolution and were used as climate values. In addition, anomaly data were extracted after removing the effects of seasonal cycles from each grid point in the Korean Peninsula scenario data. Adding the regional climate model anomalies to the climate values obtained from the observations produced a new 1km grid scenario data without systematic model error (Climate Information Portal, 2009)

In this study, we obtained daily temperature data of 2009 from the climate change data specific to South Korea, which was constructed by using the same process as that described previously. We then calculated the number of days in which the daily maximum temperature was 33℃ or higher to calculate the number of heat wave days. To calculate the average number of tropical nights for each region, the heat wave day data, which include the number of days in which the daily minimum temperature was 25℃ or more, were used to construct the climate data for each administrative district.

4. Evaluation of Urban Heat Island Effects

The differences in LST between urban and non-urban lands were calculated to compare the intensity of UHI by region, and this is referred to as UHI intensity in this study. Two methods were applied when analyzing UHI intensity. Equation-1 uses an analysis method often used in previous studies, which determines UHI intensity by calculating the LST difference between urban and non-urban lands in each region(Jin, 2012). Equation-2 is an analysis method in which UHI intensity is calculated by applying the national mean value for the LST of non-urban land, by analyzing the difference between a region's LST of urban land and the average LST of non-urban lands across the country. The two methods differ in their consideration of non-urban land temperature, as one approaches it regionally and the other nationally. In terms of analyzing UHI intensity, the method used to consider non-urban land regionally was labeled RST1, and the one used to consider it nationally, RST2. The analysis results of the heat island intensity according to each method were analyzed by correlation analysis and regression analysis among urbanization ratios, number of tropical nights and the number of heat wave days by region throughout the country, to analyze the impacts of actual abnormally high urban temperature and the urban heat island intensity calculation method based on the land cover.

$$UHI_{citys\ \mathrm{and}\ counties} = Tu_{average\ urban\ LST\ of\ cities\ \mathrm{and}\ counties} - Tr_{average\ non-urban\ LST\ of\ cities\ \mathrm{and}\ counties}(RST1) \quad (1)$$

$$UHI_{citys\ \mathrm{and}\ counties} = Tu_{average\ urban\ LST\ of\ cities\ \mathrm{and}\ counties} - Tr_{average\ nationwide\ non-urban\ LST}(RST2) \quad (2)$$

RESULTS AND DISCUSSION

1. Analysis of Urban Environmental Characteristics by Region

1) Analysis of Urbanization ratio by region

The average urbanization ratio of all regions across the country was 9.2%. The highest, 61.2%, was reached in Bucheon City(Gyeonggi Province), and the lowest, 1.2%, was recorded in Yeongyang County (North Gyeongsang Province). The Seoul Metropolitan Government, Busan Metropolitan City, Incheon Metropolitan City, Gwangju Metropolitan City, and major cities in Gyeonggi Province had urbanization ratios of >10%, which are higher than the national average. For the Seoul Metropolitan Government and Bucheon City, urban land constituted more than half of the city, with urbanization ratios >60%. These regions clearly lack significant amounts of low-temperature areas such as forests or streams that generally decrease urban heat. Figure 3(a) shows that urban land is concentrated around major cities, and that the urbanization ratio for Gyeonggi-do is especially high in the region near the capital. Conversely, the percentage of urban land in Gangwon Province was found to be <2.3%, which can be attributed to the mountains and forests that cover most of the region.

2) Analysis of Land surface temperature

MODIS LST indicated that the highest nationwide temperature recorded for summer

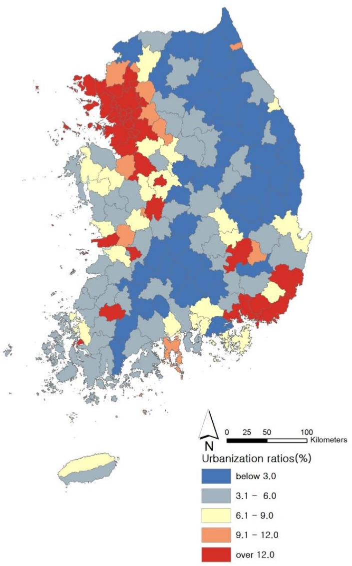
2009 was 36.0℃, the lowest temperature was 16.2℃, and the mean temperature was 24.3℃ with a standard deviation of 2.4℃ (Figure 3(b), Table 2). The results from analyzing the average LST for the categories of urban and non-urban land by region are shown in Figures 3(c) and 3(d). Bucheon City in Gyeonggi Province had the highest average surface temperature among urban areas in summer 2009 with a temperature of 31.9℃ followed by Suwon City in Gyeonggi Province at 31.7℃, the Seoul Metropolitan Government at 31.5℃, Ansan City in Gyeonggi Province at 31.3℃, Incheon Metropolitan City at 30.7℃, Gwangmyeong City in Gyeonggi Province at 30.6℃, Hanam City in Gyeonggi Province at 30.4℃, and Daegu at 30.3℃. The LST for urban land was found to be high in major cities and urban regions with high urbanization ratios and in cities within the capital area of Gyeonggi Province. More areas with higher LST were found in South Gyeongsang Province than in other regions(Figure 3(c)). On the contrary, the average LST for urban land in the counties of Yeongyang, Uljin, Cheongsong Inje, and Jeongseon and in Taebaek City was less than 23℃. This result shows an 8℃ difference from that in Bucheon City in Gyeonggi Province. The LST for urban land was revealed to be higher mostly in major cities, which can be attributed to the accumulation of radiant heat as urban land expands and increases in the numbers of concrete structures and water-impervious covering. Furthermore, the availability of forests and streams within the urban lands of each region is regarded to have been a major contributing factor. The LST of non-urban land(Figure 3(d)) was also considerably similar to the LST spread of urban land(Figure 3(c)). This occurred because regions with a high urbanization ratio have a relatively low proportion of non-urban land, and urban lands are spread widely across the region; therefore, the temperatures of non-urban lands are significantly influenced by those of urban lands.

3) Analysis of abnormally high urban temperature

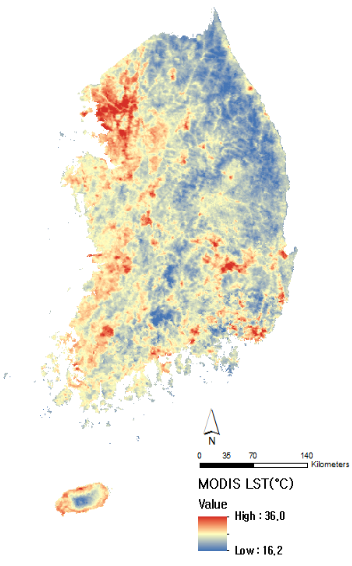
In order to analyze the numbers of tropical heat nights and heat wave days occurring in cities, the 2009 Extreme Climate Indices Data of the Korea Meteorological Administration were used in calculating the average numbers of such days by region(Figure 3(e)). The regions with the highest and lowest numbers of tropical heat nights were Bucheon City in Gyeonggi Province and Pyeongchang County in Gangwon Province at 57.3 days and 0.7

TABLE 2. Analysis of urban environment characteristic

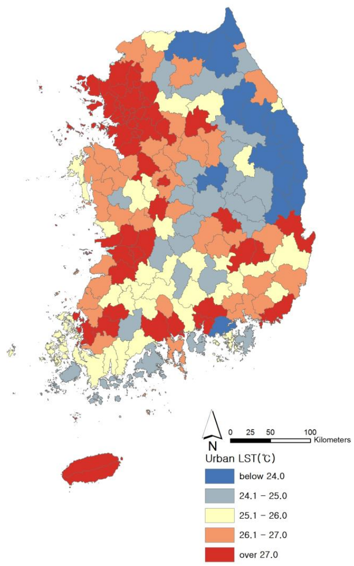
	Maximum	Minimum	Average	Standard deviation
Urbanization ratio(%)	61.2	1.2	9.2	10.5
Land surface temperature(LST)(℃)	36.0	16.2	24.3	2.4
LST of urban land(℃)	31.9	21.3	26.4	2.0
LST of non-urban land(℃)	30.5	20.5	24.8	1.8
Number of tropical heat nights(day)	98	0.0	27.1	18.2
Number of heat wave days(day)	35.0	0.0	3.0	3.5



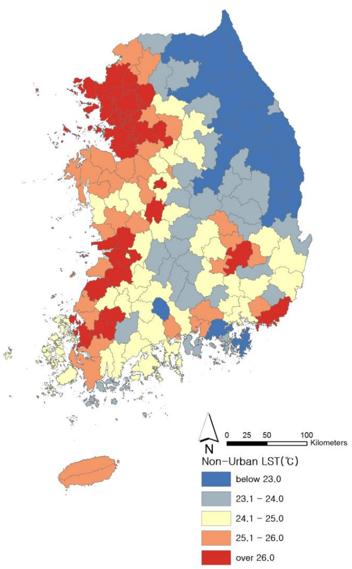
(a) Urbanization ratios



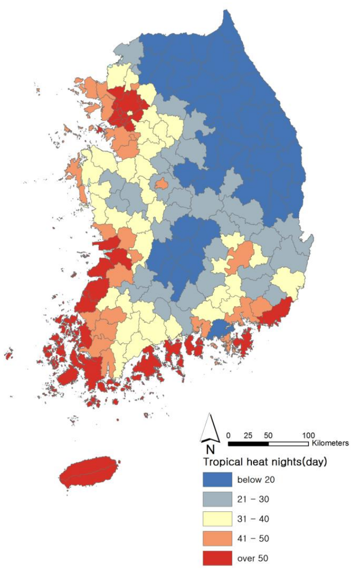
(b) MODIS land surface temperature



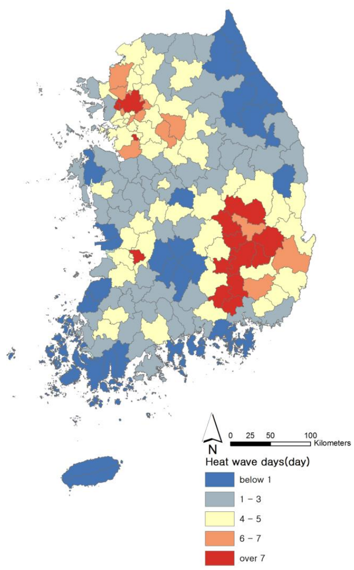
(c) Urban land surface temperature



(d) Non-Urban land surface temperature



(e) Number of tropical heat nights



(f) Number of heat wave days

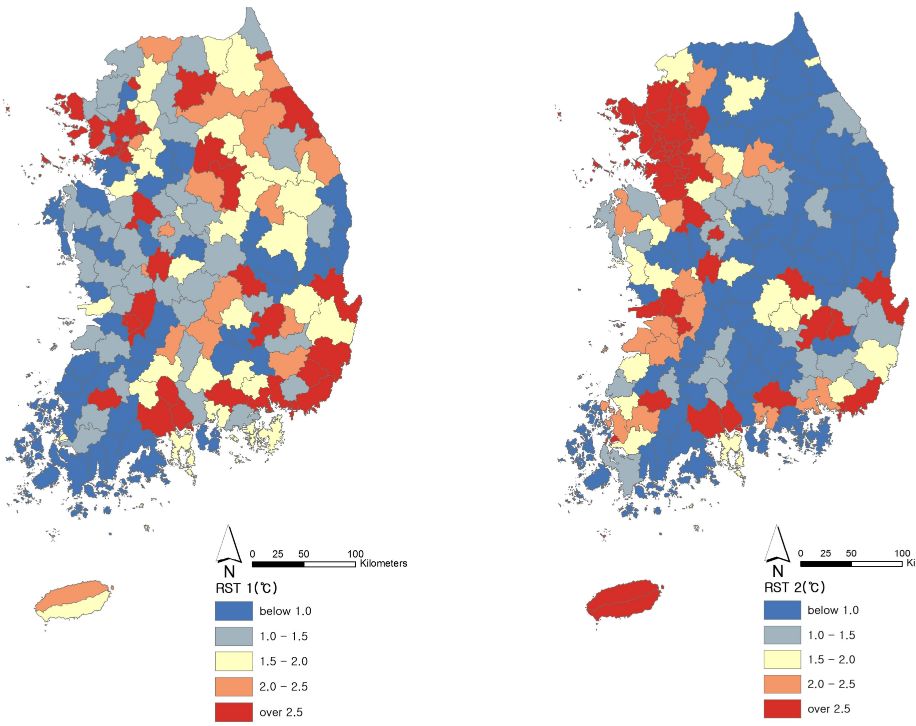
FIGURE 3. Analysis of urban heat island factor according to administrative boundaries

days, respectively(Table 2). Regarding the number of heat wave days, the region of Gyeongsang Province showed generally high values, the highest of which was 12.4 days in Gyeongsan City, North Gyeongsang Province. The regions with an average of >10 days include Changnyeong County, South Gyeongsang Province, at 11.9 days and Daegu Metropolitan City at 11.5 days (Figure 3(f)).

2. UHI Intensity Analysis Results

1) Evaluation of UHI intensity

Figure 4 depicts the analysis results of regional UHI intensity across the nation according to RST1 and RST2. When RST1 was used, Daegu Metropolitan City showed the highest UHI Intensity at 4.6℃ followed by Pohang City at 4.3℃, Sokcho City at 4.2℃, Gangneung City at 4.0℃, Incheon Metropolitan City at 3.7℃, Daejeon Metropolitan City at 3.6℃, and Chuncheon City at 3.5℃. When RST2 was used, the capital regions showed high UHI intensity, with Bucheon City in Gyeonggi Province peaking at 7.1℃, followed by Suwon City in Gyeonggi Province at 6.9℃, Seoul Metropolitan Government at 6.8℃, Ansan City in Gyeonggi Province at 6.5℃, Incheon Metropolitan City at 5.9℃, Gwangmyeong City in Gyeonggi Province at 5.8℃, and Hanam City in Gyeonggi Province at 5.6℃. Therefore, high values were shown for metropolitan areas surrounding the capital of Seoul. Analysis



(a) RST1 UHI intensity (b) RST2 UHI intensity

FIGURE 4. Analysis of UHI Intensity RST1, RST2

using RST1 revealed scattered regions of high UHI intensity(Figure 4(a)), whereas that determined by using RST2 were concentrated around major cities(Figure 4(b)).

RST1 has been employed often in previous studies analyzing UHI in which the temperature difference between urban and non-urban lands were obtained on a regional basis. However, the LST of urban and non-urban lands included in an administrative district can contain a margin of error owing to the urban environmental characteristics related to each region. For example, if mountains and forests around a city are relatively abundant, the temperature of non-urban land would be significantly lower, showing a deceptively high UHI intensity even if the temperature of the urban land is low. On the contrary, the RST2 method circumvents this problem because it calculates UHI intensity by expanding non-urban lands within and around a city and considers them as a single patch. Because the scope of this patch was extended nationwide for this study, further research is necessary to determine the proper scope of non-urban land patches in accordance with the homogeneity of regional thermal environments.

2) Correlation between UHI intensity and abnormally high urban temperature

Table 3 and Figure 5 show the results of the analysis of applying the RST1 and RST2 method for heat island intensity and the number of tropical nights and heat wave days through correlation analysis and regression analysis. Examining (a) and (b) of Figure 5, there appears to be low correlation between RST1 UHI intensity and the number of tropical heat nights and heat wave days. Conversely, UHI intensity derived from RST2 showed high correlation with the number of tropical heat nights and heat wave days, with R^2 values of 0.42 and 0.24, respectively (Figure 5 c and d). From this, it is apparent that the RST2 method of analyzing UHI intensity is more useful than RST1 in explaining abnormally high urban temperatures. Analysis results of the heat island intensity from RST2 and the regression analysis of the days of abnormally high temperature phenomenon predict that the increase of the heat island intensity by 1 ℃ increases the number of tropical nights by about 5 days and the heat wave days by 0.5 days (Table 3).

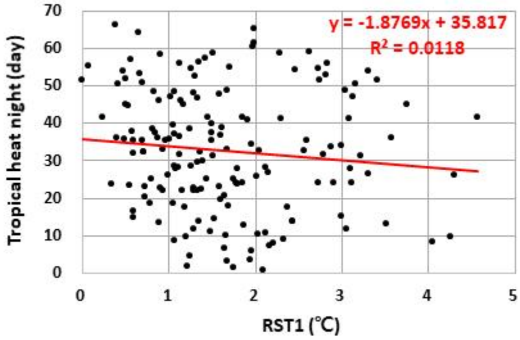
3) Correlation between UHI intensity and urbanization ratio

Figure 6 shows the results of correlation analysis between UHI intensity derived from RST2 and the urbanization ratio. The graph in the figure indicates that an

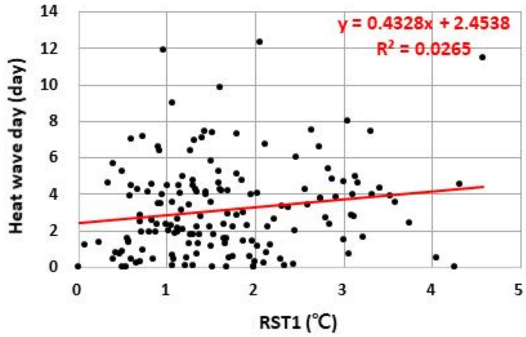
TABLE 3. Correlation analysis between UHI intensity and abnormally high urban temperatures

x	y	Regression equation	R^2	R	P-value*
RST1	Number of tropical heat nights	y = −1.8769x + 35.817	0.01	0.16	0.00
	Number of heat wave days	y = 0.4328x + 2.4538	0.03	0.11	0.00
RST2	Number of tropical heat nights	y = 5.1594x + 24.023	0.42	0.65	0.00
	Number of heat wave days	y = 0.5992x + 2.1629	0.24	0.49	0.00

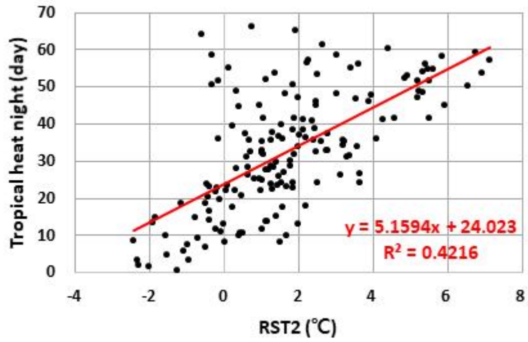
*P-value<0.001



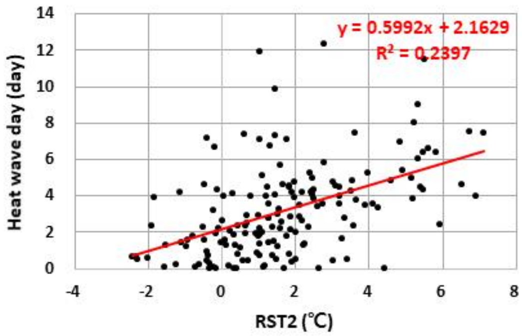
(a) Between the number of tropical heat night and UHI intensity (RST1)



(b) Between the number of heat wave day and UHI intensity (RST1)



(c) Between the number of tropical heat night and UHI intensity (RST2)



(d) Between the number of heat wave day and UHI intensity (RST2)

FIGURE 5. Correlation analysis between UHI intensity and abnormally high urban temperatures

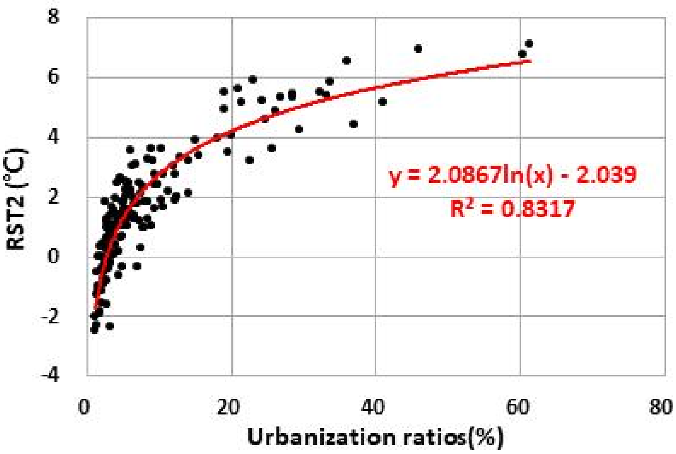


FIGURE 6. Correlation analysis between UHI intensity and urbanization ratio (RST2)

increase in the urbanization ratio resulted in a significantly high rate of increase in UHI intensity when the proportion of urban land in a city or county was below ~20%, whereas this rate of increase began to decline at urbanization ratios of >20%. By using the equation using the relationship between UHI intensity and urbanization ratio to predict the resulting level of UHI intensity from increases in the urbanization ratio, the UHI intensity was be predicted to reach a maximum of 7.6℃ at an urbanization ratio of 100%.

CONCLUSION

This study was conducted to analyze the nationwide UHI intensity of South Korea by using MODIS satellite imagery. Further-more, it attempted to confirm a limitation of RST1, the existing regional analysis method, in calculating the temperature of non-urban land in the context of UHI intensity analysis and to demonstrate the greater effectiveness of RST2, an expan-sive analysis method. For this purpose, UHI intensity was evaluated by region, and its correlation with abnormally high urban temperatures was verified. Furthermore, the relationship between UHI intensity and urbanization ratio by region, which is regarded to have a significant influence on the UHI phenomenon, was identified to phenomenologically determine the effects of future urbanization on UHI intensity and ultimately on abnormally high urban tem-peratures. This work determined the follo-wing research results.

First, the entire region of South Korea was divided into urban and non-urban land by using a 2009 level-2 land cover map. The proportion of urban lands is strongly related to the urbanization ratio of each region. The nationwide average urbanization ratio was found to be about 9.2% with highest and lowest values reached in Bucheon City, Gyeonggi Province, at 61.2% and Yeongyang County, at 1.2%, respectively.

Correlation analysis between UHI inten-sity and the phenomena resulting from abnormally high urban temperatures such as tropical heat nights and heat wave days was conducted to select an effective UHI intensity analysis method for determining the UHI phenomenon on a wide scale. The UHI intensity derived from RST1 showed almost no correlation. In in the case of RST2, however, a correlation was shown with R^2=0.42 for the number of tropical nights and R^2=0.23 for the number of heat wave days. Therefore, the RST2 method appears to be more suitable for the nationwide identification of the heat island phenomena. In 2009, the heat island intensity was the highest, at 7.1℃ in Bucheon City in Gyeonggi Province, followed by 6.9℃ in Suwon City, 6.8℃ in the Seoul Metropolitan Government, and 6.5℃ in Ansan City. Therefore, high values were shown for the metropolitan area surrounding the capital of Seoul.

The results of regression analysis heat island intensity using RST2, the urban-ization ratio, and the numbers of tropical nights and heat wave days revealed that when the heat island intensity increases by 1℃ in urban areas, the numbers of tropical nights and heat wave days increase by about 5 days and 0.5 days, respectively. Moreover, an increase in the urbanization ratio resulted in a significantly high rate of increase for UHI intensity for cities and counties, with an urbanization ratio of <20%, whereas the gradually declined when the urbanization ratio was >20%. These results should be useful as references in the future for predicting changes in UHI intensity based on increases in the urbanization ratio.

The use of MODIS satellite imagery is advantageous because it enables quantitative comparison; the UHI intensity can be derived across a broad area utilizing the same data and method. On the other contrary, its limitation is the difficulty in carrying out a detailed regional analysis when compared with recent high-resolution satellite imagery data because MODIS LST data has a spatial resolution of 1×1km. However, because this study focused on evaluating UHI intensity at the national level, MODIS satellite imagery was considered to be more effective for analyses of this type. Furthermore, an additional advantage of the MODIS data is its high temporal resolution owing to daily observations. This may be useful in the future when conducting a time-series analysis of changes in UHI intensity.

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