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Analyzing Cooling Effects of Urban Forests on the Surrounding Areas Using Geospatial Analysis Techniques

지리공간분석기법을 이용한 도시 숲이 주변지역에 미치는 냉각효과 분석

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ABSTRACT

The primary purpose of this study was to measure the cooling effect of forests on the surrounding areas using GIS analysis techniques. To achieve the research purpose, I selected the area surrounding Cheongju Industrial Complex in Cheongju city and downloaded Landsat 8 data for this area. First, the LST (Land Surface Temperature) value and the UCI (Urban Cool Island) value were obtained using Landsat 8 images. Also, several geospatial analysis techniques were used to measure the cooling effect of forests on the surrounding areas. 3D visualization, profile analysis, and Valley Depth techniques have been found to be very useful in vividly expressing the cooling effect of forests on the surrounding areas. As a result of the analysis, the size of the wood, the distance to the forest, the vegetation density of the woods, and the distance between forests were proved to be the factors that greatly influenced the cooling effect of the wood on the surrounding areas. In particular, the distance between forests can be used as an essential indicator for understanding the synergistic cooling impact of neighboring forests on the surrounding areas. The result of this study can be used as valuable reference material for managing forests and green spaces in the future.

Keywords : Forest, cooling Effect, LST, UCI, Geospatial analysis technique, Profile analysis

요 약

본 연구의 주된 목적은 GIS분석기법을 이용하여 숲이 주변지역에 미치는 냉각효과를 측정하는 것이었다. 이러한 연구목적을 달성하기 위해 본 연구는 청주시의 청주산업단지 주변지역을 연구지역으로 선정하고 이 지역에 대한 Landsat 8 데이터를 다운로드하였다. 우선 본 연구는 Landsat 8 데이터를 이용하여 LST값과 UCI값을 구하였다. 또한 숲이 주변지역에 미치는 냉각효과를 측정하기 위해 여러 가지 지리공간적 분석기법들을 이용하였다. 3D 시각화, 프로필분석, Valley Depth 기법들은 숲이 주변지역에 미치는 냉각효과를 공간상에 생생하게 표현하는데 있어서 아주 효과적인 것으로 확인되었다. 분석의 결과 숲의 크기, 숲까지의 거리, 숲의 식생밀도, 그리고 숲 간의 거리가 숲이 주변지역에 미치는 냉각효과에 큰 영향을 미치는 요인들로 확인되었다. 특히 숲 간의 거리는 인접한 숲들이 주변지역에 미치는 냉각효과의 시너

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지효과를 파악하는데 있어서 중요한 지표로 이용될 수 있다. 이러한 본 연구의 결과는 앞으로 숲과 녹지를 관리하는데 있어서 중요한 참고자료로 이용될 수 있을 것이다.

주요어 : 숲, 냉각효과, LST, UCI, 지리공간적 분석기법, 프로필분석

1. Introduction

As we enter the 21st century, we are witnessing urbanization on a global scale (Wu et al., 2014). The concentration of population into cities has promoted rapid urban development, resulting in a drastic reduction in the area of land covered by urban forests and green spaces (Chibuike et al., 2018). Also, since most of the roads are paved with asphalt or concrete and urban spaces are filled with high-rise buildings, the temperature of urban areas has risen sharply compared to the surrounding regions (Yu et al., 2018). This phenomenon becomes apparent when impervious structures are slowly releasing stored heat (Cao et al., 2010; Yu et al., 2017). Notably, as green spaces and forests decrease, the urban heat island (UHI) phenomenon becomes clearer (Qiao et al., 2013).

Over the last two decades, quite a few attempts have been made to mitigate urban heat island phenomena. In particular, many scholars have focused on the cooling effect of forests on the surrounding areas (Buyadi et al., 2014). Also, along with the efforts of these scholars, many city governments have worked hard to increase the area and density of forest (Onishi et al., 2010). Woods not only provide cool shades for urban dwellers exhausted from heat but also serve to lower land surface temperature (LST) by evapotranspiration. Thus, forests create urban cool islands (UCI) in the surrounding areas, affecting the microclimate ecosystem of the city (Yang et al., 2017).

To investigate the cooling effect of forests, scholars have used various methods. Early researchers used direct observation methods to estimate the impacts of woods on the microclimate of surrounding areas (Mildrexler et al., 2011). In particular, Chang et al. (2007) attempted to analyze the difference of cool island intensities among 61 urban parks using direct observation method in Taipei, Taiwan and indicated that urban parks are much cooler than their surrounding areas. Fahmy et al. (2010) also investigated how the shape and size of forests affect the cooling effect of forests. They confirmed that the size and shape of wood plays a vital role in mitigating the urban heat island in the surrounding area. Some scholars have also shown that the type of vegetation that grows in the forests also contributes significantly to the magnitude of the cooling effect (Rosenfeld et al., 1998). In other words, they proved that trees have a much larger cooling impact on the surrounding area than bushes. However, measuring the cooling effect of forests using direct observation techniques has several disadvantages. First, it takes a lot of time and effort to install observation equipment and measure the cooling impact of woods. Due to these constraints, direct observation methods tend to reduce the spatial extent of the study area significantly. Besides, to collect data using this method, researchers have to pay a lot of money for the installation and management of measuring equipment in the study process. To measure temperature using direct observation methods, we need a large number of skilled human resources as well. Therefore, the research carried out under these constraints is bound to have various limitations. In particular, it is difficult to generalize the results derived from individual studies to a whole region (Kong et al., 2014).

To overcome these problems and perform research projects more efficiently, many urban cold island researchers today are using thermal infrared (TIR) technology. Using Landsat's thermal band, we can easily derive LST. Landsat Program is a satellite system operated by the United States Geological Survey (USGS), and its image data is open to researchers all over the world for free (USGS, 2016). Recently, some scholars have attempted to measure the cooling effect of forests on the surrounding areas using LST derived from satellite images (Weng et al., 2004; Lu et al., 2006). Early studies on the cooling effect of forests focused attention on the correlation between LST and LULC (Voogt et al., 2003). These studies attempted to measure the difference in LST between land covers rather than the cooling effect of forests on the surrounding areas using qualitative methods.

However, with the recent rapid development of remote sensing technology and GIS analysis techniques, it has become possible for us to quantitatively measure the cooling effect of forests on the surrounding area. In particular, Cao et al. (2010) analyzed the relationship between park size and LST in Nagoya, Japan. Their results showed that the cooling effects of urban forests are closely related to the sizes of urban forests. However, the correlation between them proved to be not a linear relationship but a nonlinear relationshipp.Li et al. (2012) examined the relationship between LST and the patterns of greenspaces in Beijing, China. The researchers derived LST using the Landsat TM thermal band. The results of their study showed that a 10% increase in the percentage of green area reduced LST by 0.86 degrees Celsius. Kong et al. (2014) identified UCI and greenspace in Nanjing, China using satellite data, and analyzed the correlation between them. Their findings revealed that forests with higher vegetation density have a more significant cooling impact on surrounding regions than those with less dense vegetation density.

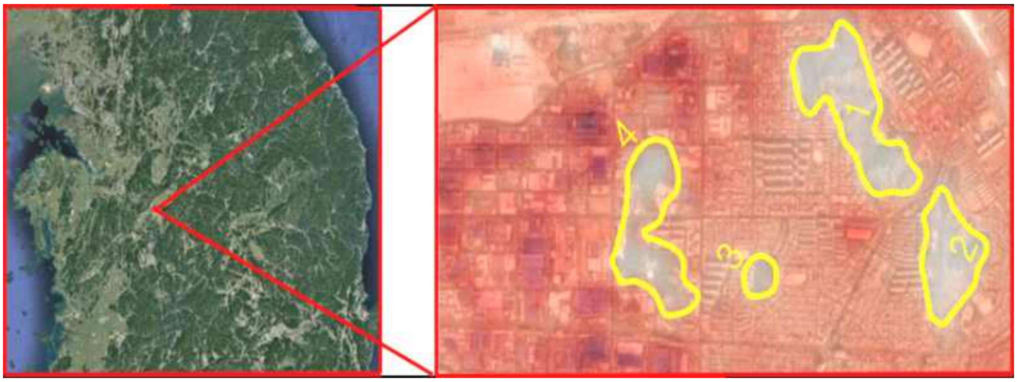
However, this quantitative approach used mainly correlation analysis or simple regression analysis to measure the effect of forests on the surrounding areas. These analytical techniques fail to properly analyze how the cooling effect of woods on the surrounding regions changes as the distance from the forest increases. To accurately measure the cooling impact of forests on the surrounding area, we must use geospatial techniques developed in the GIS field. However, there are not many studies using geospatial techniques to examine the cooling effect of forests on the surrounding regions. Nonetheless, the research works done by some scholars are noteworthy. In particular, Buyadi et al. (2014) analyzed how the LST changes around the urban green space using remote sensing and GIS techniques. In other words, they used buffer analysis and profile analysis to gauge the cooling effect of the urban green areas on the surrounding region. And Chibuike et al. (2018) used the buffer analysis method to measure how the cooling effect of forests varies with intervals. The researchers set 10 buffers around the woods at intervals of 50m and analyzed how the mean LST changes for each buffer. Also, some scholars have used the profile analysis to estimate the cooling impact of the river on the surrounding areas. Their findings provide many implications for measuring the cooling effect of forests on the surrounding region (Chen et al., 2014).

However, only buffer analysis and profile analysis cannot adequately measure the spatial variation pattern of the cooling effect of forests. To accurately measure the cooling impact on the surrounding areas, buffer analysis, contour line analysis, profile graph, valley depth analysis, and 3D visualization technique should be used. Therefore, this study aims to measure the cooling effect of forests on the surrounding areas using geospatial analysis techniques.

2. Study Area and Data

2.1 Study Area

The study area is located in the western part of Cheongju City, the provincial capital of Chungcheongbuk-do in the Republic of Korea. Geographically, the area ranges from 127.4410° E to 127.4786 ° E in longitude, and from 36.6389 ° N to 36.6612 ° N in latitude. Also, as shown in [Figure 1], the study area has a rectangular shape with a width of 3,810m and a height of 2,730m, with a total area of 10.4013 square kilometers. The mean elevation of the study area is 62.40 m, the maximum altitude is 122 m, and the minimum elevation is 33 m. Overall, the altitude of this region is not high. The mean slope of the study area is 4.397 degrees, the maximum slope is 34.44 degrees, and the lowest slope is 0.00 degrees. After analyzing the data, we can conclude that the whole study area is a flat or low hilly area. From the viewpoint of land use, we can see that this region is mainly used for forests, low-density residential areas, high-density residential areas, and industrial areas. In particular, the four forests within the study area not only provide comfortable resting



〔Figure 1〕 Study Area

places for the citizens, but they also act as refrigerants to cool the hot air in the surrounding regions. Besides, the region has the mean annual temperature of 12.7 degrees Celsius and the average yearly precipitation of 1,388 mm, which is characteristic of a typical inland regional climate. Reviewing these regional characteristics, I considered this site to be the most suitable place to measure the cooling effects of forests on the surrounding areas and selected this place as the study area.

2.2 Data

To measure the cooling effects of forests on the surrounding areas, we must first obtain the LST value using satellite images. To estimate the LST value, We need Landsat 8 OLI (Operational Land Image) and TIRS (Thermal Infrared Sensor) images for the study area. I connected to the GloVis site operated by USGS and downloaded Landsat 8 OLI and TIRS images for the study site. However, since the downloaded image files are too large and have a wide range of space, I clipped out parts of these images that correspond to the study area using the 'Clip by mask layer' function of QGIS. And I used QGIS 'Fill sinks' function to pre-process the data. Using these pre-processed images, I obtained the LST value for the study area. The Landsat 8 image consists of 11 bands. Band 1 to Band 7 and Band 9 have a spatial resolution of 30 m. However, the thermal bands, Band 10 and Band 11 were resampled at a spatial resolution of 30 m, although the spatial resolution was originally 100 m (USGS, 2016). These images were acquired on June 16, 2017, and were generated on June 29, 2017. These images use WGS84 Datum and WGS84 Ellipsoid.

3. Methodology

To achieve the research purpose, I used the following methods. First, the LST value was calculated using Landsat 8 images. I also derive the UCI value using the LST value at a certain point and the mean LST value of the study area. Besides, this study used geospatial analysis techniques such as buffer analysis, contour lines, profile graph, 3D visualization, valley depth to visualize the cooling effects of forests on the surrounding areas vividly.

3.1 LST and the Urban Cool Island

3.1.1 LST

LST means land surface temperature. LST, measured using satellite imagery, is being used today to solve problems in a variety of areas such as urban planning, forestry, and agriculture. This study used the mono-window algorithm to generate the LST value. The mono-window algorithm requires three parameters: emissivity, transmittance, and effective mean atmospheric temperature (Sobrino et al., 2004). This study derived LST through the following steps (Jiménez-Muñoz et al., 2014).

3.1.1.1 Conversion of the DN(Digital Number) to the Spectral Radiance

The first step in generating LST is to convert the DN to the spectral radiance (L_λ). The formula for obtaining the spectral radiance (L_λ)

is as follows (USGS, 2016; Pal et al., 2017).

$$L_\lambda = M_L * Q_{cal} + A_L \quad (1)$$

Where, L_λ is the spectral radiance, M_L is the multiplicative scaling factor of the band, A_L is the radiance additive scaling factor of the band and Q_{cal} is the DN value of pixel (USGS, 2016; Pal et al., 2017).

3.1.1.2 Conversion from the Spectral Radiance to the Top of the Atmospheric Brightness Temperature (TB)

The second step in LST estimation is to convert the spectral radiance to top of the atmospheric brightness temperature (TB). The equation for deriving TB is as follows (Bhatti et al., 2014; USGS, 2016).

$$TB = \frac{K_2}{\ln\left(\frac{K_1}{L_\lambda} + 1\right)} \quad (2)$$

Where, TB is top of the atmospheric brightness temperature in Kelvin, L_λ is the spectral radiance, K_1 is the thermal conversion constant of the band and K_2 is the thermal conversion constant of the band (Bhatti et al., 2014; USGS, 2016; Reddy et al., 2017).

To estimate the top of the atmospheric brightness temperature in degrees Celsius, we should subtract -273.15 degrees from equation 2.

$$TB = \frac{K_2}{\ln\left(\frac{K_1}{L_\lambda} + 1\right)} - 273.15 \quad (3)$$

3.1.1.3 Generation of NDVI and the Proportion of Vegetation (PV)

The third step in calculating LST is to obtain NDVI (normalized difference vegetation index) using Landsat 8 images and extract the proportion of vegetation (PV) again based on the NDVI value. The formula for deriving NDVI is as follows (Townshend et al., 1986; Pepin et al., 2016; USGS, 2016).

$$NDVI = (NIR-R)/(NIR+R) \quad (4)$$

Where, NIR is the reflectance values of the infrared band, and R is the reflectance values of the red band (Townshend et al., 1986; Pepin et al., 2016).

The formula for deriving the proportion of vegetation (PV) is as follows (Mwangi et al., 2018).

$$PV = \left(\frac{NDVI - NDVI_{\min}}{NDVI_{\max} - NDVI_{\min}}\right)^2 \quad (5)$$

Where, PV is the proportion of vegetation, NDVI is the normalized difference vegetation index, $NDVI_{\min}$ is the minimum NDVI and $NDVI_{\max}$ is the maximum NDVI (Mwangi et al., 2018).

3.1.1.4 Calculation of the Land Surface Emissivity (e)

The fourth step of deriving LST is to calculate the land surface emissivity (e) using the PV value. The e value can be obtained using the following equation (Mahato et al., 2018).

$$e = 0.004 * PV + 0.986 \quad (6)$$

Where, e is the land surface emissivity value, and PV is the proportion of vegetation.

3.1.1.5 Estimation of the LST Values

The last step of retrieving LST is to generate the LST value using the TB value and the e value. The LST value can be obtained using the following equation (Orhan et al., 2016; Pal et al., 2017; Mwangi et al., 2018; Mahato et al., 2018).

$$LST = \frac{TB}{\left[1 + \left\{\left(\frac{\lambda \times TB}{\rho}\right) \times \ln(e)\right\}\right]} \quad \cdots\cdots\cdots\cdots\ (7)$$

Where, LST is land surface temperature in degrees Celsius, TB is the top of the atmospheric brightness temperature in degrees Celsius, λ is the wavelength of emitted radiance in meters (10.895 μm for Landsat 8 band 10), e is the land surface emissivity value and ρ is h * c/σ(1.4328 * 10^{-2}mK) in which, σ is the Boltzmann constant (1.38 * 10^{-23} J/K), h is the Planck's constant (6.626 * 10^{-34} Js), and c is the velocity of light (2.9998*10^{8} m/s) (Orhan et al., 2016; Pal et al., 2017; Mwangi et al., 2018; Mahato et al., 2018).

3.1.2 the Urban Cool Island(UCI)

Scholars have developed various indices to measure the cooling effect of the forests on the surrounding areas. Among them, UCI which can easily measure the cooling impact on the surrounding regions based on LST is remarkable. UCI means the area where the LST value is lower than the average LST value. UCI can be obtained by using the following equation (Zhang et al., 2018).

$$UCI = \triangle T = T_i - \overline{T} < 0 \quad \cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\ (8)$$

Where, T_i is the LST value of a given pixel and $\overline{T}$ is the mean LST value of the study area, respectively.

3.2 Geospatial Analysis Techniques

3.2.1 Buffer Analysis

3.2.1.1 Buffer analysis on the LST layer

This study first set 100m buffers around four forests using the 'buffer' function of QGIS to measure the cooling effect of forests on the surrounding areas. To calculate mean LST in each buffer, I clipped the LST grid using 'Clip raster with polygon' function of SAGA GIS. Also, this study used the 'Raster layer statistics' function of QGIS to obtain basic statistics for each clipped grid. Finally, I compared the mean LST value of each forest with that of each clipped grid to measure the cooling impacts of woods on the surrounding regions.

3.2.1.2 Buffer analysis and NDVI

In this study, I used the NDVI value, which is the vegetation index indicating the vegetation density in the area, to measure the cooling effect of the vegetation density on the surrounding areas. First, the NDVI grid was clipped using the 'Clip raster with polygon' function of SAGA GIS to calculate the mean NDVI value of four forests in the study area. Besides, I used 'Raster layer statistics' function of QGIS to obtain basic statistics for each clip of NDVI grid. Lastly, this study performed a correlation analysis between the mean LST of the 100m buffers derived from the LST grid and the mean NDVI of each forest.

3.2.1.3 Buffer analysis on the UCI layer

To measure the cooling effect of forests on the surrounding areas, I set up 200m buffers around four forests in the study area. This buffered layer was then overlaid onto the UCI layer. In this way, we can investigate how many UCIs are located within the 200m buffers around the forests.

3.2.2 Contour Lines Analysis

To visualize the impacts of woods on the surrounding regions more vividly, I derived contour lines from the LST grid. Generally, contour lines can be obtained from a DEM grid with altitude values but using a GIS program, we can obtain contour lines from all raster data with z values. In this study, the contour lines were derived by setting the interval between the contour lines to 1, and then the contour lines layer was overlaid on the LST layer. By looking at how the contour lines change around forests, we can deduce the cooling impacts of woods on the surrounding regions.

3.2.3 Profile Graph

When we have a grid with a z value, we can create a profile graph along a line connecting two points on the grid. By creating a profile graph along the line joining one point of a forest and the other point of the surrounding area on the LST grid, we can more accurately measure the cooling effect of woods on the surrounding region in three dimensions. This study derives the LST Profile Graph between two points on the LST grid using the 'Profile Tool' of QGIS.

3.2.4 3D Visualization

Using the 3D visualization of the GIS program, we can easily visualize the grid with z values in three dimensions. In particular, by visualizing the LST grid in three dimensions, we can more easily identify the cooling effects of forests on the surrounding area than using other techniques. Also, we can make the effect of 3D visualization bigger by overlaying contour lines on the 3D mapp.This study visualizes the LST grid in three dimensions using 'Qgis2threejs' plugin of QGIS.

3.2.5 Valley Depth

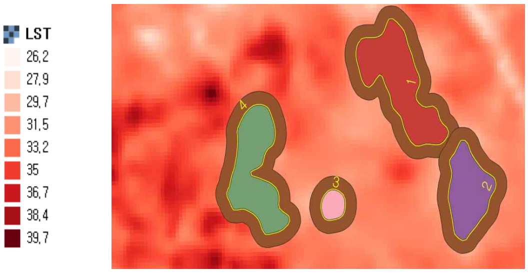
Valley depth means the vertical distance from a point to a channel network base level, i.e., a ridge or top on a DEM grid. To obtain the valley depth at any point, we should calculate the elevation of a channel network base level and subtract this value from the altitude at any location. The larger the valley depth of a place, the higher the probability of the deep valley, and the lower the valley depth of a point, the higher the probability that the site is a ridge or topp.Therefore, using valley depth grids, we can clearly distinguish forests with high valley depth value from urban heat islands with low valley depth value. This study used Valley Depth module of SAGA GIS to calculate valley depth value of LST grid.

4. Results

4.1 Buffer Analysis

4.1.1 Buffer analysis on the LST layer

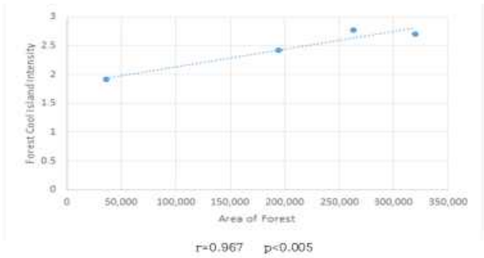
[Figure 2] shows the 100m buffers set around four forests in our study area. To measure the cooling impacts of woods on the surrounding regions, I obtained the mean LST value in each forest and the mean LST value in each buffer and compared with each other.



〔Figure 2〕 the 100m buffers set around four forests in the study area

As can be seen in Table 1, the mean LST inside forests is nearly 2 degrees Celsius lower than the mean LST in 100 buffers. The results of this study are consistent with those of previous studies. The findings of this study also show that forests faithfully perform the role of urban cooling islands which mitigate the temperature of surrounding areas in the urban region.

This study also investigated how the size of forests affects the cooling effect of the woods on the surrounding areas. To analyze the relationship between the size of the forest and the cooling impact of woods on the surrounding regions, I conducted a correlation analysis between two variables. The results of the study show that there is a very significant positive correlation between the size of the forest and the cooling effect on the surrounding areas.



〔Figure 3〕 Relations between forest cool island intensity and area of forest

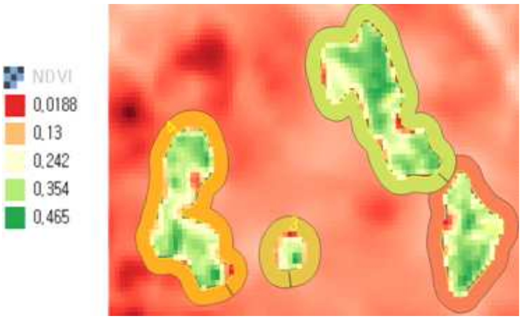
4.1.2 Buffer Analysis and NDVI

[Figure 4] shows the 100m buffer set around each forest in the study area. To investigate the relationship between vegetation density and LST, I calculated the mean LST and the mean NDVI value of each forest in each buffer and

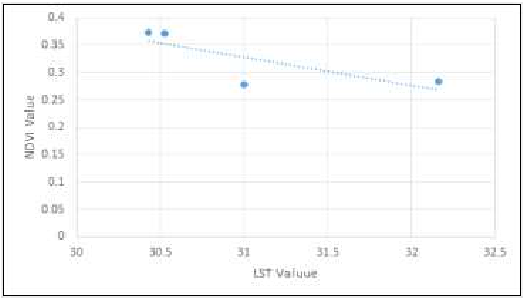
〈Table 1〉 Forest Cool Island Intensity

ID	Name	100m Buffer Mean LST (A) (degrees Celsius)	Forest Mean LST (B) (degrees Celsius)	Forest Cool Island Intensity (A-B)	Area (square meters)
1	Myeongshim Park	30.4310	27.7252	2.7058	319,500
2	Uncheon Park	30.1269	27.7056	2.4213	194,400
3	The 2nd Bongmyeong Park	31.0028	29.0843	1.9185	36,000
4	Bongmyeong Park	32.1633	29.3946	2.7687	262,800

then analyzed the correlation between them. As a result of the analysis, it was confirmed that there is a strong negative correlation between LST and NDVI [Figure 5]. Therefore, we can infer that the higher the density of forest vegetation, the stronger the cooling effect on the surrounding area.

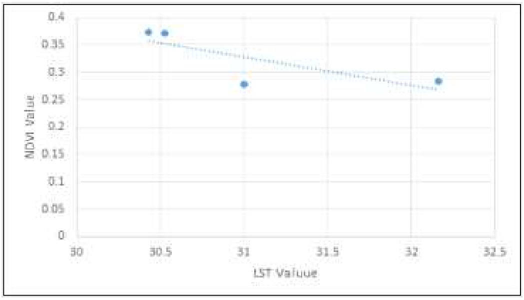


〔Figure 4〕 Buffer analysis and NDVI



r=-0.814 p<0.10

〔Figure 5〕 Relations between LST and NDVI

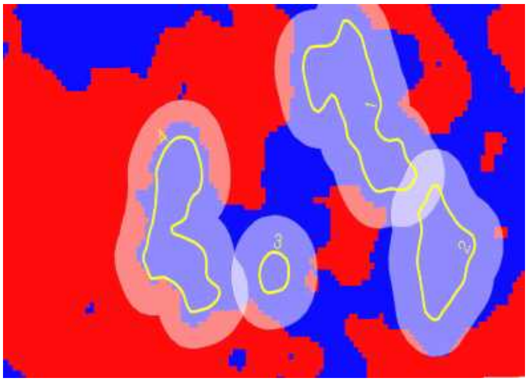


r=-0.814 p<0.10

〔Figure 5〕 Relations between LST and NDVI

4.1.3 Buffer analysis on the UCI layer

In this study, 200m buffers were set around four forests in our study area, and then this buffered layer was overlaid on the UCI grid again. In [figure 6], the zone in blue indicates Urban Cool Islands where the LST of the place is lower than the mean LST of the entire study area, and the area in red means the area where LST is higher than the mean LST of the whole study area. Yellow polygons mean forests, and polygons around woods indicate 200m buffers set around the forests. As can be seen in this figure, the forests have a considerably large cooling impact on the surrounding regions. UCI means the area where LST is lower than the mean LST of the surrounding areas. It seems that most of the areas within a radius of 200m from forests belong to UCI. Particularly, Forest 1 and Forest 2 are adjacent to each other, and as a matter of fact, they function as a forest, so that they have an enormous cooling impact on the surrounding regions. Also, Forest 3 and Forest 4 are so close to each other that they have a considerable cooling effect on the surrounding areas.

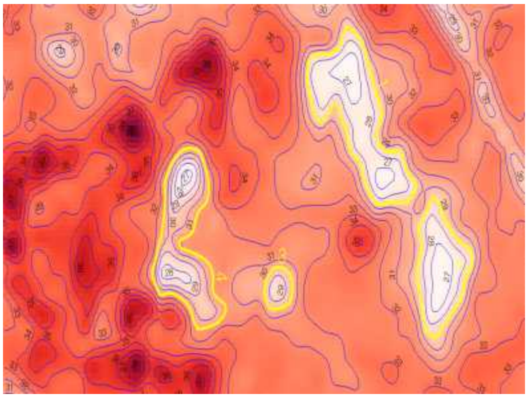


〔Figure 6〕 Buffer analysis on the UCI layer

4.2 Contour Lines Analysis and 3D Visualization

4.2.1 Contour Lines Analysis

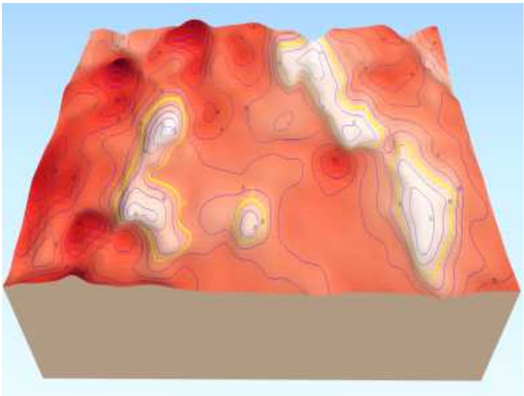
[Figure 7] shows the contour lines extracted from the LST grid. The contour lines analysis shows that forests have a significant cooling effect on the surrounding areas. Mainly, I can see through the contour lines pattern analysis that Forest 1 and Forest 2 are adjacent to each other and have a very powerful cooling impact on the surrounding regions. In the vicinity of Forest 1 and Forest 2, contour lines are very sparsely located, which indicates that there is no rapid temperature change around these forests. It is because the cooling effects of these two forests are synergistic, pushing hot air out. Also, the regions between Forest 3 and Forest 4 were proved to have much lower LST value than other surrounding areas. I can confirm that although areas around Forests 3 and Forest 4 are the regions with the highest LST in the study area, the hot air in these areas is significantly cooled down due to the synergistic effect of the adjacent forests.



〔Figure 7〕 Contour lines extracted from the LST grid

4.2.2 3D Visualization

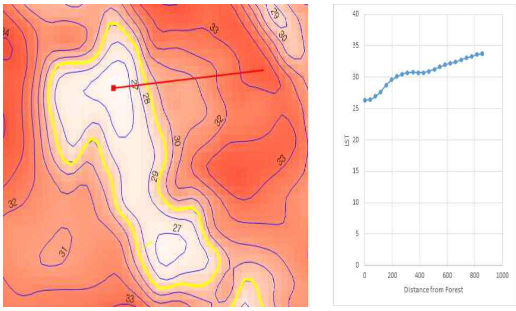
[Figure 8] is a three-dimensional visualization of the LST grid. Through this picture, I can more accurately measure the cooling effect of the forest on the surrounding areas. The areas around the four forests form deep valleys, which demonstrate the strong cooling impacts of the woods on the surrounding regions. In particular, I can confirm that the valleys formed around the forest 4 are deeper than those created in the other areas, indicating that the Forest 4 has a more significant cooling effect on the surrounding areas.



〔Figure 8〕 3D Visualization OF the LST grid

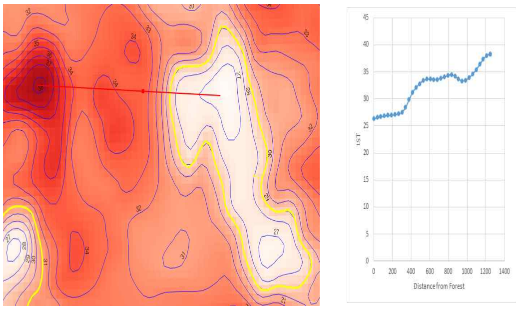
4.3 Profile Graph

In this study, the profile analysis was performed to measure how the LST value changes as the distance from the forest increases. First, this study carried out two profile analysis to estimate the cooling effect of Forest 1 on the surrounding areas.



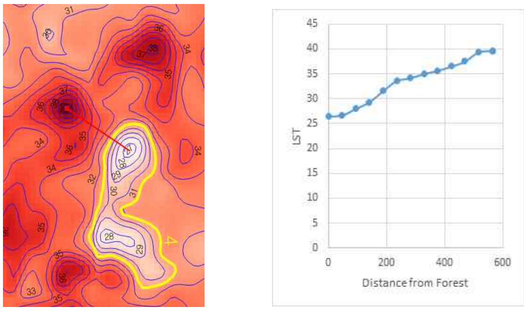
〔Figure 9〕 Profile Analysis for Forest 1 (East direction)

[Figure 9] shows the result of profile analysis in the eastward direction from Forest 1. The profile graph indicates that the LST value is sharply rising as we head east along the red line. Notably, the LST value increases dramatically up to 200m from the forest. However, in the zone between 200m and 400m, the trend of LST increase is considerably slowed. Judging from these results, I can see that Forest 1 has a very powerful cooling impact up to 200m from the forest in the east direction.



〔Figure 10〕 Profile Analysis for Forest 1 (West direction)

[Figure 10] shows the cooling impact of the Forest 1 on the surrounding regions in the west direction. As can be seen in this figure, Forest 1 has a very powerful cooling effect on the surrounding areas in the western direction. In particular, the profile graph of Fig. 10 shows that Forest 1 has a large impact on the LST value of the surrounding areas up to 600m from the forest in the west direction.

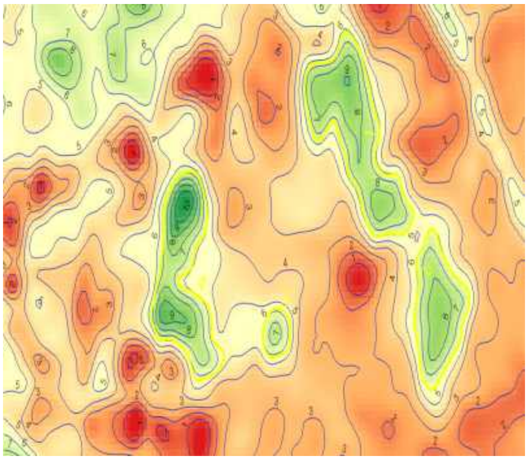


〔Figure 11〕 Profile Analysis for Forest 4 (Northwest direction)

Also, this study conducted a profile analysis to estimate the cooling effect of the Forest 4 on the surrounding areas. [Figure 11] shows the cooling impact of Forest 4 on the surrounding regions in the northwest direction. The northwesterly direction of Forest 4 is the central area of the Cheongju industrial complex, which has a very high LST value compared to other parts of our study area. Therefore, it can be said that the cooling effect of the Forest 4 on surrounding areas is entirely different from that of the other forests on the surrounding areas. As shown in [Figure 11], Forest 4 has a very powerful cooling impact on the surrounding regions. The cooling effect of Forest 4 on the surrounding regions is shown in the profile graph of [Figure 11]. This graph shows that Forest 4 has a very powerful cooling impact up to 600 m from the forest in the northwest direction.

4.4 Valley Depth

[Figure 12] shows the result of valley depth analysis for the LST grid. This study also derived contour lines from the valley depth grid. As can be seen in this figure, all forests within the study area have high valley depth values. For example, the highest valley depth value for Forest 1 is 9, which means that the LST value of Forest 1 is 9 degrees lower than the base level LST value of the channel network to which Forest 1 belongs. The results of this study also show that a considerable part of the vicinity of Forest 1 has a high LST value. The findings of this study confirm that Forest 1 has a significant cooling effect on the surrounding areas. We can find similar spatial distribution patterns of valley depth values around Forest 2. In particular, the region between Forest 1 and Forest 2 was found to have a high valley depth value, though not forest. This phenomenon appears to happen because the two vast forests are adjacent to each other, resulting in more substantial cooling impacts on the surrounding regions.



〔Figure 12〕 Valley depth and contour lines

Regarding valley depth, we also need to pay attention to the area around Forest 4. The valley depth value of the Forest 4 was found to be the largest among the valley depth values of the four forests in the study area. It proves that Forest 4 has the greatest cooling impact on the surrounding regions. Finally, it should be noted that the place between Forest 3 and Forest 4 has a higher valley depth values than other areas. I think this phenomenon occurs because the synergistic action of the cooling effects of Forest 3 and Forest 4 significantly lowers the LST values of this region.

5. Discussion

This study used geospatial analysis technique to measure the cooling impacts of woods on the surrounding regions. As a result of the analysis, forests were found to have a considerable cooling effect on the surrounding areas. However, the magnitude of the cooling impact of woods on the surrounding regions varies greatly depending on the size of the forest, the distance to the forest, the vegetation density of the wood, and the distance between forests. First, the forest size was found to be highly correlated with the cooling effect on the surrounding areas. The findings of this study have implications for urban planners who are trying to plan and develop sustainable cities. In other words, the results of this study can be a good reference when determining whether it is desirable to create a large number of small forests or to create a few vast forests.

As a result of this study, the distance to the forest is also an essential factor in determining the cooling impact of woods on the surrounding regions. The profile analysis shows that as the distance from the forest increases, the cooling effect of the forests on the surrounding area is greatly reduced. The findings of this study can be an essential reference material in planning the spatial arrangement of woods and green spaces in urban areas. As can be seen from the results of this study, if the forests are adjacent to each other, the cooling effect on the surrounding area becomes greater. The synergistic cooling impact of woods due to adjacency is one of the crucial factors that urban planners should consider in planning the wood and green space layout in the future. Vegetation density was also found to be an essential factor in determining the cooling effect of the forests on the surrounding areas. Forests of small size but a high density of vegetation have cooling impacts on the surrounding regions as much as big forests. We can find this type of case in Forest 2 of our study area. Forest 2 has been found to have a considerable cooling effect on the surrounding areas due to dense vegetation although it is smaller than Forest 1. The findings of this study suggest many implications for urban planners who are planning the future city. It is crucial to increase the amount of forest or green space to mitigate the temperature of the urban region and create a beautiful cityscape, but it is equally important to improve the quality of forests and green areas.

The urban forests perform in the urban space the same role that the lung plays in the human body. To make the city a healthy and sustainable place, urban planners should understand the functions of the forest and take the initiative in creating healthy forests.

6. Conclusion

The primary purpose of this study was to measure the cooling effects of forests on the surrounding areas using GIS analysis techniques. To accomplish the goal of this study, I selected the areas around the Cheongju Industrial Complex located in the western part of Cheongju city, which is the provincial capital of Cheongju city, Chungcheongbuk province, and downloaded the Landsat 8 data for this area. In this study, LST and UCI were obtained using Landsat 8 images. Besides, various geospatial analysis techniques were used to estimate the cooling impact of woods on the surrounding regions. As a result of the analysis, the size of the forest, the distance to forests, the vegetation density of forests, and the distance between forests were found to be factors that greatly influenced the cooling impact of woods on the surrounding regions. In particular, there was a strong positive correlation ($r = 0.967$) between forest size and its cooling effect and a negative relationship ($r = -0.814$) between NDVI and LST.

This study can contribute to the study of the cooling effects of forests in several aspects. First, this study is different from previous studies in that it uses geospatial analysis techniques to measure the cooling impact of woods on the surrounding region. To estimate the cooling effect of the forests on the surrounding area, researchers mainly used regression analysis or correlation analysis. However, it is difficult to explain the cooling impacts of woods on the surrounding regions more vividly by using only these analysis techniques. The contour lines analysis, profile analysis, and 3D visualization techniques used in this study were found to be very useful in measuring the cooling effect of forests on the surrounding areas. Second, this study is different from previous studies in that it uses valley depth analysis to estimate the cooling impact of woods on the surrounding regions. Originally, valley depth means the vertical distance between a base level of a channel network and a certain point in hydrology. Using this concept of valley depth, we can measure the cooling effect of forests on the surrounding areas more precisely in a new dimension. The result of this study can be used as essential reference material for urban planners to create and manage new green spaces and forests in the future.

However, despite this differentiation and usefulness, this study has the following limitations. First, this study only used such variables as the size of the forest, the distance to the forest, the vegetation density, and the distance between the forests to estimate the cooling impact of woods on the surrounding regions. However, the cooling effect of forests on the surrounding areas can also be affected by factors such as elevation and slope. Future studies should take into account those factors in a comprehensive way and measure the cooling effect of forests on the surrounding areas. Second, this study mainly used geospatial analysis techniques to estimate the cooling impact of woods on the surrounding regions. However, geospatial analysis alone can not accurately measure the cooling effect of forests on the surrounding areas. Future research should estimate the cooling impact of woods on the surrounding regions more precisely by using statistical analysis techniques such as regression analysis as well as geospatial analysis techniques.

〈References〉

1. Ahmed, S., “Assessment of urban heat islands and impact of climate change on socioeconomic over Suez Governorate using remote sensing and GIS techniques”, *The Egyptian Journal of Remote Sensing and Space Science*, 21(1), 2018, pp.15-25.
2. Artis, D. A., & Carnahan, W. H., “Survey of emissivity variability in thermography of urban areas”, *Remote Sensinng of Environment*, 12(4), 1982, pp.313-329.
3. Bhatti, S. S., & Tripathi, N. K., “Built-up are extraction using Landsat 8 OLI imagery”, *GIScience & remote sensing*, 51(4), 2014, pp.445-467.
4. Buyadi, S. N. A., Mohd, W. M. N. W., & Misni, A., “Quantifying green space cooling effects on the urban microclimate using remote sensing and gis techniques”, *Proceedings of the XXV International Federation of Surveyors*, 2014, pp.1-16.
5. Cao, X., Onishi, A., Chen, J., & Imura, H., “Quantifying the cool island intensity of urban parks using ASTER and IKONOS data”, *Landscape and urban planning*, 96(4), 2010, pp.224-231.
6. Chang, C. R., Li, M. H., & Chang, S. D., “A preliminary study on the local cool-island intensity of Taipei city parks”, *Landscape and Urban Planning*, 80(4), 2007, pp.386-395.
7. Chen, Y. C., Tan, C. H., Wei, C., & Su, Z. W., (2014). “Cooling effect of rivers on

metropolitan Taipei using remote sensing", *International journal of environmental research and public health*, 11(2), 2014, pp. 1195-1210.

8. Chibuike, E. M., Ibukun, A. O., Abbas, A., & Kunda, J. J., "Assessment of green parks cooling effect on Abuja urban microclimate using geospatial techniques", Remote Sensing Applications: *Society and Environment*, 11, 2018, pp.11-21.
9. Dai, Z., Guldmann, J. M., & Hu, Y., "Spatial regression models of park and land-use impacts on the urban heat island in central Beijing", *Science of the Total Environment*, 626, 2018. pp.1136-1147.
10. Deng, Y., Wang, S., Bai, X., Tian, Y., Wu, L., Xiao, J., … & Qian, Q., "Relationship among land surface temperature and LUCC, NDVI in typical karst area", *Scientific reports*, 8(1), 2018, p.641.
11. Fahmy, M., Sharples, S., & Yahiya, M., "LAI based trees selection for mid latitude urban developments: A microclimatic study in Cairo, Egypt", *Building and Environment*, 45(2), 2010, pp.345-357.
12. Guo, G., Wu, Z., Xiao, R., Chen, Y., Liu, X., & Zhang, X., "Impacts of urban biophysical composition on land surface temperature in urban heat island clusters", *Landscape and Urban Planning*, 135, 2015, pp.1-10.
13. Jiménez-Muñoz, J. C., Sobrino, J. A., Skoković, D., Mattar, C., & Cristóbal, J., (2014). "Land surface temperature retrieval methods from Landsat-8 thermal infrared sensor data", IEEE *Geoscience and Remote Sensing Letters*, 11(10), 2014, pp.1840-1843.
14. Kong, F., Yin, H., James, P., Hutyra, L. R., & He, H. S., "Effects of spatial pattern of greenspace on urban cooling in a large metropolitan area of eastern China", *Landscape and Urban Planning*, 128, 2014, pp.35-47.
15. Li, X., Zhou, W., Ouyang, Z., Xu, W., & Zheng, H., "Spatial pattern of greenspace affects land surface temperature: evidence from the heavily urbanized Beijing metropolitan area, China", *Landscape ecology*, 27(6), 2012, pp.887-898.
16. Lu, D., & Weng, Q., "Spectral mixture analysis of ASTER images for examining the relationship between urban thermal features and biophysical descriptors in Indianapolis, Indiana, USA", *Remote Sensing of Environment*, 104(2), 2006, pp.157-167.
17. Mahato, S., & Pal, S., "Changing land surface temperature of a rural Rarh tract river basin of India", Remote Sensing Applications: *Society and Environment*, 10, 2018, pp,209-223.
18. Mildrexler, D. J., Zhao, M., & Running, S. W., "A global comparison between station air temperatures and MODIS land surface temperatures reveals the cooling role of forests", *Journal of Geophysical Research: Biogeosciences*, 116(G3), 2011.
19. Mwangi, pp.W., Karanja, F. N., & Kamau, pp.K., "Analysis of the Relationship between Land Surface Temperature and Vegetation and Built-Up Indices in Upper-Hill, Nairobi", *Journal of Geoscience and Environment Protection*, 6(01), 2018, p.1.
20. Onishi, A., Cao, X., Ito, T., Shi, F., & Imura, H., "Evaluating the potential for urban heat-island mitigation by greening parking lots", *Urban forestry & Urban greening*, 9(4), 2010, pp.323-332.

21. Orhan, O., & Yakar, M., "Investigating Land Surface Temperature Changes Using Landsat Data in Konya, Turkey", *International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences*, 41, B8. 2016.
22. Pal, S., & Ziaul, S., "Detection of land use and land cover change and land surface temperature in English Bazar urban centre", *The Egyptian Journal of Remote Sensing and Space Science*, 20(1), 2017, pp.125-145.
23. Pepin, N. C., Maeda, E. E., & Williams, R., "Use of remotely sensed land surface temperature as a proxy for air temperatures at high elevations: Findings from a 5000 m elevational transect across Kilimanjaro", *Journal of Geophysical Research: Atmospheres*, 121(17), 2016, p.9998.
24. Qiao, Z., Tian, G., & Xiao, L., "Diurnal and seasonal impacts of urbanization on the urban thermal environment: a case study of Beijing using MODIS data", ISPRS *Journal of Photogrammetry and Remote Sensing*, 85, 2013, pp.93-101.
25. Reddy, S. N., & Manikiam, B., "Land surface temperature retrieval from LANDSAT data using emissivity estimation", *International Journal of Applied Engineering Research*, 12(20), 2017, pp.9679-9687.
26. Rosenfeld, A. H., Akbari, H., Romm, J. J., & Pomerantz, M., "Cool communities: strategies for heat island mitigation and smog reduction", *Energy and Buildings*, 28(1), 1988, pp.51-62.
27. Sobrino, J. A., Jimenez-Munoz, J. C., & Paolini, L., "Land surface temperature retrieval from LANDSAT TM 5", *Remote Sensing of environment*, 90(4), 2004, pp.434-440.
28. Townshend, J. R., & Justice, C. O., "Analysis of the dynamics of African vegetation using the normalized difference vegetation index", *International Journal of Remote Sensing*, 7(11), 1986, pp.1435-1445.
29. USGS, Landsat 8 (LS8) *Data Users Handbook*. Sioux Falls : Department of the Interior U.S. Geological Survey, 2016.
30. Voogt, J. A., & Oke, T. R., "Thermal remote sensing of urban climates", *Remote sensing of environment*, 86(3), 2004, pp.370-384.
31. Weng, Q., Lu, D., & Schubring, J., "Estimation of land surface temperature - vegetation abundance relationship for urban heat island studies", *Remote sensing of Environment*, 89(4), 2004, pp.467-483.
32. Wolch, J. R., Byrne, J., & Newell, J. P., "Urban green space, public health, and environmental justice: The challenge of making cities just green enough", *Landscape and urban planning*, 125, 2014, pp.234-244.
33. Wu, H., Ye, L. P., Shi, W. Z., & Clarke, K. C., "Assessing the effects of land use spatial structure on urban heat islands using HJ-1B remote sensing imagery in Wuhan, China", *International Journal of Applied Earth Observation and Geoinformation*, 32, 2014, pp.67-78.
34. Yang, C., He, X., Wang, R., Yan, F., Yu, L., Bu, K., … & Zhang, S., "The effect of urban green spaces on the urban thermal environment and its seasonal variations", *Forests*, 8(5), 2017, p.153.
35. Yu, Z., Guo, X., Jørgensen, G., & Vejre, H., "How can urban green spaces be planned for climate adaptation in subtropical cities?", *Ecological Indicators*, 82, 2018, pp.152-162.

36. Yu, Z., Guo, X., Zeng, Y., Koga, M., & Vejre, H., “Variations in land surface temperature and cooling efficiency of green space in rapid urbanization: The case of Fuzhou city, China”, *Urban Forestry & Urban Greening*, 29, 2018 pp.113-121.

37. Zhang, Y., Zhan, Y., Chen, X., Li, L., & Yu, T., “The impact of thermal image spatial enhancement on the estimation of the urban green cooling effect”, *Infrared Physics & Technology*, 88, 2018, pp.206-211.

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