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The Spatial Topographic Analysis of Urban Surface Temperature using Remotely Sensed Data and GIS

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ABSTRACT

The purpose of this study is to analyze and verify the spatial distribution property of the surface temperature with urban spatial information, related with land-cover, NDVI, and characteristics of topography in Daegu metropolitan area, Korea, using remotely sensed data and GIS. In this study, the surface temperature, land-cover patterns and NDVI were extracted from multi-temporal Landsat TM images, In addition topographic factors, such as elevation, slope, and aspect were analyzed through GIS spatial analysis.

The result showed that the average correlation degree of 0.77 between extracted surface temperature and AWS observed data and the negative(-) correlation more than 80% was identified by the results from the correlation and regression analysis of the extracted surface temperature from Landsat TM images with NDVI. Also this research verified the distribution of the urban surface temperature was very different depends on various land-cover types of surrounding areas. These results will be worked as one of the major factors for environmentally sustainable urban planning considering the characteristics of weather environments in the near future.

? . INTRODUCTION

The development of the social environment from the agricultural society to the industrial one has caused the changes of topography and weather as well as the inner and outer landscapes of the urban areas. These changes of regional weather are analyzed by the correlations with the topographic factors or the land-use rather than merely analyzed as the changes of natural weather patterns. The earlier studies have identified the changes of urban weather patterns on the basis of the ground weather observatory data. However the problem of the confidence level of the regional representation of the observed temperature on the given spot have been enhanced, and so the studies using more various spatial information techniques such as remote sensing and GIS(Geographic Information System), nowadays, have been actively applying.

Park. I. H and others(1999) estimated the urban heat island phenomena of three cities in Kyungpook Province with the vegetation indexes after extracting the surface temperature by regression analysis between Landsat TM band 6 and AWS data. Chae. H. S and others(1999) analyzed the changes of the surface hydrological conditions by extracting vegetation indexes, Albedo, and surface temperatures using Landsat TM images. Prakash A and others(1999) estimated the surface temperatures and figured out their distributions by using Landsat TM data in the study of the surface fire of the coalfield area in India. Meanwhile Yuzo Suga and others(2000) carried out the study on extracting the surface temperatures of the coastal area in Hiroshima by using Lansat 7/ETM+.

The aim of this study is to comprehensively identify the spatial distribution characteristics of the urban surface temperature environments by analyzing the surface temperature distribution patterns in terms of the present land-cover states and NDVI as well as the topographic factors in the urban area with Landsat TM images and GIS spatial analysis. For new urban planning considering the characteristics of the urban weather environments, the results of this study are significantly efficient.

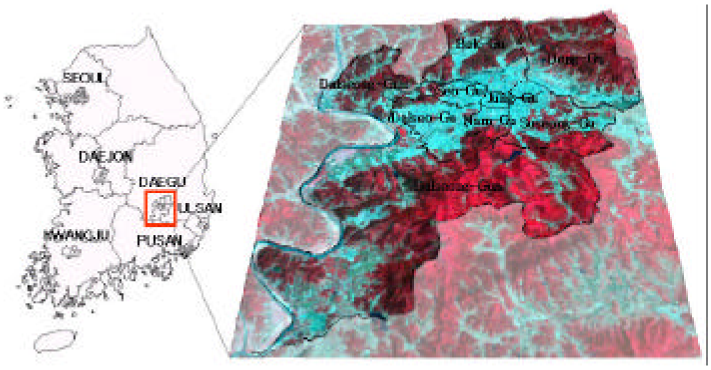

Figure 1. The study area(Daegu city, May. 07. 1999)

? . MATERIALS AND METHODS USED

Multi-temporal Landsat TM images, AWS periodical temperature data of 8 surrounding areas of Daegu city under the weather observatory(Hwa-yang, Ka-san, Wae-gwan, Sin-ryung, Hyun-poong, Kyung-san, Ha-yang, Keum-chon), 1:5,000 digital map, 1:25,000 topographic map and Daegu statistical yearbook were used in order to effectively identify the spatial distribution characteristics of the surface temperature in Daegu area. This research was carried out in the following process in Figure 2.

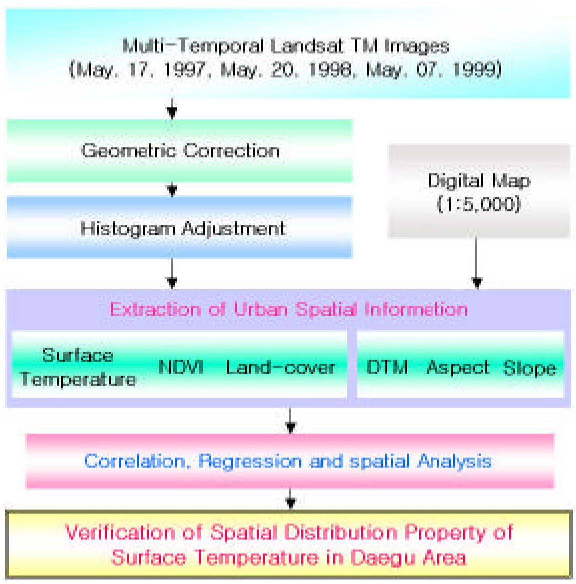

Figure 2. Flow chart of data processing with remote sensing and GIS

This study used Histogram adjustment and matching for minimizing atmospheric effects. This simple method is based primarily on the fact that infrared data(>0.7 ?) are largely free of atmospheric scattering effects, whereas the visible region(0.4-0.7 ?) are strongly influenced by them. Normally, the data collected in the visible wavelengths have a higher minimum value because of the increased atmospheric scattering taking place in these wavelengths. So if the histograms are shifted to the left so that zero values appear in the data, the effects of atmospheric scattering will be somewhat minimized. This simple algorithm models the first-order effects of atmospheric scattering, or haze(John R. Jensen, 2000). Also the atmospheric effects were reduced by Histogram matching the basic image of 1999, the best image among the multi-temporal ones, with the images of 1998 and 1997 by ERDAS Imagine8.4. For spatial topographic analysis, this study created TIN model using 1:5,000 digital map, and then analyzed grid, slope and aspect by Arc/Info8.0, Arcview3.2.

? . ANALYSIS OF THE URBAN SPATIAL INFORMATION

1. Extraction of the surface temperature using Landsat TM images

For the surface temperature estimation, the radiation emitted from the target on the surface is measured by using the remote sensor such as Landsat 5 TM, Landsat 7 ETM+, and Spot 4 HRVIR etc(Yuzo Suga, 2000). Thermal infrared region(10.4-12.5 ?) of Landsat TM image can extract the surface temperature of wide areas under the assumption that satellite sensors should have proximity to the black body. This study estimated the surface temperature using NASA model, the spectral radiance value is converted from DN(digital numbers) in each pixel by using equation(1) and then it can be converted spectral radiance to temperature by equation(2)(Markham and Becker, 1986).

$$L_{?} = L_{min} + (L_{max} - L_{min}) \times QCAL \ / \ 255 \quad (1)$$

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

T = temperature in degrees Kelvin

$L_{?}$ = spectral radiance in $W \cdot m^{-2} \cdot ster^{-1} \cdot mm^{-1}$)

K_2 = calibration constant 2 in degree Kelvin

K_1 = calibration constant 1 in $W \cdot m^{-2} \cdot ster^{-1} \cdot mm^{-1}$

L_{min} = minimum spectral radiance at QCAL = 0 DN in $W \cdot m^{-2} \cdot ster^{-1} \cdot mm^{-1}$

L_{max} = maximum spectral radiance at QCAL = 255 DN in $W \cdot m^{-2} \cdot ster^{-1} \cdot mm^{-1}$

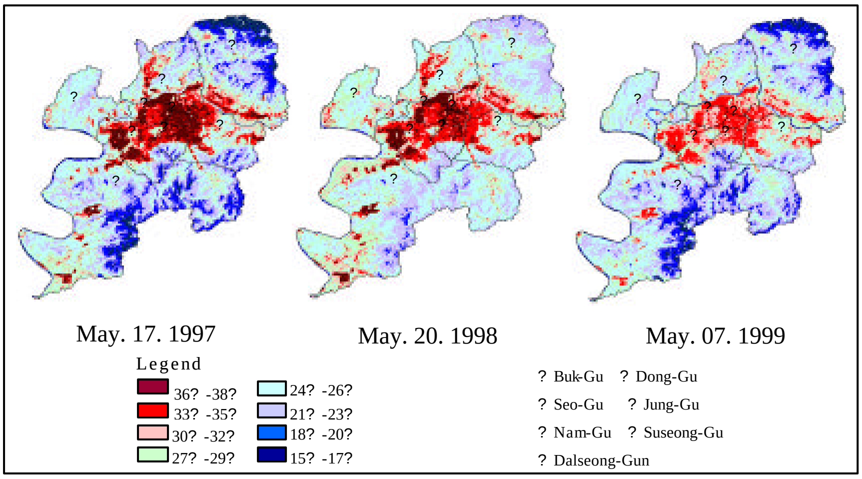

Figure 3. Distribution of the surface temperature by Landst TM images

After extracting surface temperature from Landsat TM band 6, this study achieved Pearson correlation coefficient(R) by using AWS data of the 8 surrounding areas of Deagu to compared and analyzed correlations between AWS observed data and the extracted surface temperature. According to the result in Table 1, the correlation was identified as the average level of about 77%, but in fact the extracted surface temperature of Landsat TM were proved to be generally higher than those of AWS observed data. The difference between them was identified as ±0.2-2.0? .

Table 1. Correlation analysis between extracted surface temperature and AWS data(unit:?)

NO	May. 17. 1997		May. 20. 1998		May. 07. 1999	
	AWS data	TM band 6	AWS data	TM band 6	AWS data	TM band 6
1	20.1	21.6	24.9	22.5	20.9	21.2
2	20.9	20.7	23.2	23.4	22.6	22.0
3	20.8	20.3	23.2	22.0	21.2	20.3
4	21.7	22.9	24.9	24.3	23.0	22.9
5	23.1	23.4	23.9	24.3	23.7	22.9
6	23.3	24.7	24.0	26.0	21.9	23.3
7	21.6	22.9	22.4	22.0	22.7	23.4
8	22.1	23.4	24.2	24.7	22.6	22.5
R	0.85		0.75		0.72	

According to the results in Figure 3, the range of 21-23? each year are the most widely distributed over the suburban crop lands and the low elevation forests(1997:346.07? , 1998:415.09? , 1999:404.99?). Meanwhile the major industrial district along the watershed of Kumho river, the commercial area in the center of the city, the residential area of high density and the area near the airport maintain the level of high temperature above average 30? . These areas obviously present the different distributions of surface temperature from those of low temperature of the other suburban areas.

Table 2. The average surface temperature per an administration district(unit:?)

District / Date	Buk-Gu	Seo-Gu	Nam-Gu	Dalseong-Gun	Dalseo-Gu	Dong-Gu	Jung-Gu	Suseong-Gu
May.17.1997	25.13	29.42	26.65	22.49	27.19	22.84	31.84	24.81
May.20.1998	25.67	29.30	26.30	23.73	27.03	23.75	30.07	24.84
May.07.1999	24.42	27.95	25.31	22.09	26.01	22.66	29.02	24.55

Table 2 is the results that surface temperature were extracted per an administration district by spatial analysis. In this results, the highest surface temperature district were Jung-Gu and Seo-Gu, the lowest surface temperature district was Dalseong-Gun and Dong-Gu. Also these results will be explained with correlation analysis among land-cover patterns, NDVI and topographic factors.

2. Land-cover classification

After selecting training areas on 1:5,000 digital map and 1:25,000 topographic map, the study area was classified into total 9 classes(residential area, commercial area, industrial area, road, forest, water, paddy field, barley field, barren land) with Maximum Likelihood Classification method among Supervised Classification techniques. Then the results were used as basic data for the analysis of the surface temperature by the land-cover patterns.

Table 3. The result of land-cover classification in Daegu area(unit:?)

Class / Year	Residential area	Commercial area	Industrial area	Road	Forest	Water	Paddy field	Barley field	Barren land	Total
1997	99.31	27.77	1.55	5.63	702.38	17.18	19.06	9.23	1.84	883.95
1998	98.14	26.53	1.70	6.55	700.33	16.19	23.26	5.90	5.34	883.94
1999	135.05	26.64	4.07	9.41	641.45	16.50	34.67	8.68	7.51	883.98

In the result of land-cover classification, land-cover patterns were not so changeable for three periods. However, in 1999, forest areas were decreased and the other areas were increased because of the development of Dalseong-Gun area. Almost 60? of forest areas were changed to the other areas, especially, residential areas were more increased than 1997 and 1998. Also the other classes were little bit increased than before.

3. Normalized difference vegetation index

The original vegetation activity had the values between -1 and 1 but this study transformed them into images of 8bit(0-255) value. The result showed the fact that NDVI more gradually increases in the suburban areas except the urban park areas. The topographic property of a basin area of Daegu surrounded by mountains causes to obviously distinguish the low NDVI distributions in its center area from the high NDVI distributions in its suburban area.

Table 4. The average NDVI per an administrative district

District / Date	Buk-Gu	Seo-Gu	Nam-Gu	Dalseong-Gun	Dalseo-Gu	Dong-Gu	Jung-Gu	Suseong-Gu
May. 17. 1997	164	118	159	194	149	189	101	180
May. 20. 1998	173	135	168	196	160	197	120	183
May. 07. 1999	176	144	171	198	164	197	134	186

As shown in Table 4, Dalseong-Gun and Dong-Gu had the highest NDVI values but Jung-Gu and Seo-Gu had the lowest NDVI values because these areas are located in the center of Daegu city, therefore, there were just a few green spaces, most of the districts were consisted of residential area, commercial area, and road. However, Dalseong-Gun and Dong-Gu were different from Jung-Gu and Seo-Gu, because Palgongsan Province Park and most of agriculture area belong to these areas.

4. Analysis of topographic characteristics

The thermal distribution patterns by topographic factors were subdivided with the slope and aspect which were analyzed by the same 30m DTM(Digital Terrian Model) as the spatial resolution of Landsat TM image produced with 1:5,000 digital map. In this study, analysis of topographic properties was focused on the urban area, so it was also necessary to be produced 5m DTM. Finally, 35 classes were subdivided for elevation, 24 classes for slope and 9 classes for aspect. It is one of most important analysis to clarify distribution characteristic of urban surface temperature because land-cover and NDVI distribution patterns are different by topographic properties.

? . SPATIAL TOPOGRAPHIC ANALYSIS OF URBAN SURFACE TEMPERATURE

1. Analysis of the surface temperature by land-cover patterns and elevation

According to the result in Table 5 the urban surface temperature were verified to form respectively different distributions in terms of the land-cover patterns of the surrounding areas. Most of land-cover classes belong to 30-60 elevations except forest area because of the property of the basin area, so elevation was not changeable in Deagu city. The industrial area in the urban areas formed the averagely highest surface temperature distribution, and then that of commercial district was the second highest. The residential area formed the same surface temperature distribution as that of the road.

Table 5. Surface temperature per land-cover class with elevation

Date / Land-cover	May. 17. 1997			May. 20. 1998			May. 07. 1999		
	Area(?)	Temp(?)	Elevation(m)	Area(?)	Temp(?)	Elevation(m)	Area(?)	Temp(?)	Elevation(m)
Residential area	99.31	29.1	45	98.14	29.2	42	135.05	27.4	45
Commercial area	27.77	30.2	43	26.53	29.3	42	26.64	28.3	41
Industrial area	1.55	32.0	34	1.70	31.8	31	4.07	27.5	42
Road	5.63	29.6	43	6.55	28.9	45	9.41	27.5	39
Forest	702.38	21.2	306	700.33	22.1	327	641.45	21.0	315
Water	17.18	19.9	49	16.19	20.4	46	16.50	18.1	55
Paddy field	19.06	23.6	49	23.26	24.6	46	34.67	22.4	47
Barley field	9.23	23.7	49	5.90	25.5	29	8.68	22.7	26
Barren land	1.84	27.3	46	5.34	28.2	45	7.51	25.0	54

2. Correlation analysis between the surface temperature and NDVI

Table 6 shows the results of correlation and regression analysis between the surface temperature and NDVI based on 900 sample data. The results identified the apparently negative(-) correlation between the surface temperature and NDVI. However the correlation analysis cannot explain the correlations among variables and their correlative degrees. For these explanations linear regression analysis was carried out to bring out the following regression equation. The suitability analysis for this equation can be explained with the coefficient of determination and in the case of the image on May 1998 it will explain approximately 81% of the surface temperature by NDVI.

Table 6. Correlation analysis between extracted surface temperature and NDVI

YEAR	Regression Equation	R	R^2
1997	Y = -0.0632x + 35.162	-0.8339	0.6954
1998	Y = -0.0624x + 36.613	-0.9038	0.8168
1999	Y = -0.0616x + 35.106	-0.8553	0.7315

3. Analysis of the surface temperature and NDVI distribution patterns by topographic properties

The result of spatial analysis, which were the distribution characteristics of the surface temperature according to topographic properties in Daegu areas presented that topographies with the aspect toward the southeast and plat, 26-60m average elevation, and 1-3 degree of the slope formed the high surface temperature distributions above 26? . According to the analysis of the present land-cover type of these areas, most these area were covered on the urban areas consisted of the residential, commercial, industrial areas, road and the low levels of vegetation cover were presented except the urban park areas. Daegu has the low and plain average elevation of the inner city because of the property of the basin area, but the suburban areas are surrounded on mountains. Thus the surface temperature appears to be greatly different between the inner city areas and the suburban areas.

Table 7. The result of spatial analysis between surface temperature and NDVI based on topographic factors

Topographic Analysis	Surface Temperature	NDVI

Surface Temperature(?)	**36 - 38***	19 - 20
Elevation(m)	29 - 38	Above 500
Slope(degree)	1 - 2	Above 25
Aspect(degree)	150 - 170	180 - 240
NDVI	97 - 125	**241 - 255***

* : the standard of the highest distribution region

? . CONCLUSION

This study analyzed the spatial distribution of urban surface temperature according to land-cover types and NDVI by being related with the topographic properties with remotely sensed data and GIS. The results are summarized as the followings:

1. Approximately 77% of the correlative level was derived from the correlation analysis of the extracted surface temperature from Landsat TM band 6 with AWS observed data. However the difference between the surface temperature and those of AWS data were about ±0.2-2.0? .

2. According to the results of analyzing the surface temperature in terms of land-cover classification patterns, the industrial area, the commercial area, the residential area, and the road in order were verified to form the high surface temperature distributions. Also these classes belong to the range of 30-60m elevations, and elevation was not so changeable in case of Deagu city. The dense industrial area along Kumho River and the commercial district of the central city with the highest surface temperature distribution presented the lowest vegetation cover ratio.

3. The negative(-) correlation more than 80 % was identified by the results from the correlation analysis of the extracted surface temperature from Landsat images with NDVI. The regression analysis presented average 75% of the confidence level among the three periods. Meanwhile the more suburban areas were concerned, the more vegetation activity was increased. Thus those areas formed the low temperature distributions, but the only park areas in the inner city distributed in the form of points presented the low temperature distributions. The result needs to be expand green space in the urban areas.

4. The highest surface temperature range(36-38?) was distributed on the range of 29-38m elevation, the distribution of 97-125 NDVI, 150-170 aspect, and 1-2 degree of the slope. The highest distribution of 241-255 NDVI was located in the range of 19-20 surface temperature, above 500m elevation, above 25 slope, and the region of 180-240 aspect. Meanwhile it is probably predicted that the analysis of surface temperature in terms of the aspect would present the different results depending on seasons and the detecting time by Landsat TM.

These results will be worked as one of the major factors for environmentally sustainable urban planning considering the characteristics of weather environments in the near future.

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