The Relationship among Land Use, Vegetation and Surface Temperature in Urban Areas
-The Case of Deagu City-

Jae Ik KIM[1][※] · Chang-Hwan YEO[2]

도시지역 지표온도와 토지이용 및 식생상태와의 상관관계에 관한 연구
: 대구광역시의 경우

김재익[1][※] · 여창환[2]

ABSTRACT

The primary purpose of this paper is to prove a clear relationship among land use type, vegetation level and surface temperature. For this purpose, this paper presents series of spatial distribution maps of the three features obtained through the visual interpretation of digital images. The result of study tells us that the spatial distribution of the vegetation level is very similar with that of surface temperature. By analyzing the relationship between surface temperature and land use types, this study categorizes the eighteen urban land uses into 7-8 groups according to their average surface temperature. The Duncan test was conducted to categorize the land uses. The surface temperature of manufacturing related land use is the highest, semi-residential use is the next, non-residential land use is the next to the lowest, and the agricultural and forest land use is the lowest. This paper provides another strong evidence of the relationship by showing the regression result.

KEYWORDS: Land Use, Surface Temperature, Vegetation Index, Land Cover, Duncan Test

요 약

본 연구는 도시지역에서 지표온도를 결정하는 요인으로서 토지이용과 식생분포를 설정하고 이

들의 상호관계를 규명하는 것을 목적으로 한다. 이를 위하여 대구광역시를 사례지역으로 위성영상을 판독하고 그 결과를 수치지도와 중첩하여 분석을 실시하였다. 지표온도와 식생지수(표준식생지수)는 위성영상분석을 통하여 도출하였고 토지이용자료는 통계청이 지난 2001년 제작한 기초단위구 자료를 통하여 획득하였다.

분석결과 예상한 바와 같이 지표온도는 식생분포와 토지이용분포와 깊은 상관관계가 있는 가운데 식생상태보다는 토지이용에 의해 더욱 많은 영향을 받는 것으로 나타났다. 이에 따라 본 연구는 토지이용과 지표온도와의 관계규명에 초점을 두었다. 이를 위하여 본 연구는 18개로 구분된 토지이용을 표면온도에 따라 Duncan 검증방법으로 7-8개의 그룹으로 분류하였다. 이에 의하면 지표온도는 제조업과 관련된 토지이용이 많은 지역에서 가장 높았고, 그 뒤를 이어 도심상업지역이 높았다. 반면 농업 및 임야지역의 지표온도가 가장 낮게 나타났다.

주제어: 토지이용, 표면온도, 식생지수, 토지피복, Duncan 검정

1. BACKGROUND

There are many studies to identify the surface temperature differences in an urban area by using remote sensing data(Nicole, 1994; Jo and Lee, 2000; Kwon and Yamada, 2003). In urban areas, lands are used in various ways, such as residential, commercial, industrial, public, and so on. The difference in the land use makes the surface temperature different. Also, the surface temperature in urban areas can also be varied by vegetation levels. Therefore, it is fair to say that there exists a close relationship among land use, vegetation and surface temperature in urban areas.

The majority of urban land is covered by man-made structures, such as buildings, roads, manufacturing facilities. These structures are, of course, placed according to the land use regulations. Therefore, the land cover has deep relationship with land use. However, the term land cover and land use are distinct. Land cover refers to the physical materials on the surface of a given parcel of land(e.g. grass, concrete, tarmac, water), while land use refers to the human activity that takes place on, or makes use of, that land(e.g. residential, commercial, industrial)(Barnsley et al, 2001,).

It is known that the structures or land cover materials make surface temperature higher in urban areas than in rural areas. There are also significant temperature differences among urban land uses mainly because different land uses make the land cover different. Many other studies also point out that the surface temperature can be determined mainly by the vegetation level. The vegetation level can also be considered as a proxy of land use because main determinant of vegetation level is land use type. However, there is a strong tendency that researches of different origin focus only their concern. For example, natural science-oriented study focuses on vegetation conditions while social science-oriented study focuses on land use type. If the temperature on urbanized area matters for some reasons (environmental and/or health problem), then policy attention should be paid. In this case, the information on the level, change, factors and distributional characteristics of the surface temperature is essential for effective policy establishment. However, unfortunately, studies on the clear relationship

among land use, vegetation level and surface temperature are scanty. This paper is designed to show the surface temperature differences by land use type and vegetation index and to verify which factor affect more on the surface temperature.

2. STUDY AREA

This paper employs Daegu city, the fourth largest city in Korea with population 2.8 millions in 2000 as a study area. Daegu is located in the southeastern part of Korea. Geographical feature of Daegu city can be summarized as a basin — a flat plain surrounded by mountains. Figure 1 shows the boundaries of the study area that includes eight local government boundaries. Daegu area is selected as study area because researchers have information and knowledge about the city in depth and thus easy to check and confirm any uncertain data and information.

3. DATA AND APPROACH

This paper utilizes Landsat TM 5 imagery of 2000(October 16) of Daegu city to derive vegetation index and to measure average surface temperature. The land use data was not available in primary administration unit until 2000. Even worse, the existing land use maps need more detailed ground survey. Under these circumstances, digital images acquired by satellite sensors can be a reasonable substitute for conventional land use maps. Fortunately, however, Korea National Statistical Office established "the basic survey unit" which is similar with the census block in year 2001, and thus, the land use data is available by the basic survey unit. It provides 18 land use types along with primary information on population and housing(see Table 1 and Figure 4 for the land use classification and spatial distribution by land use).
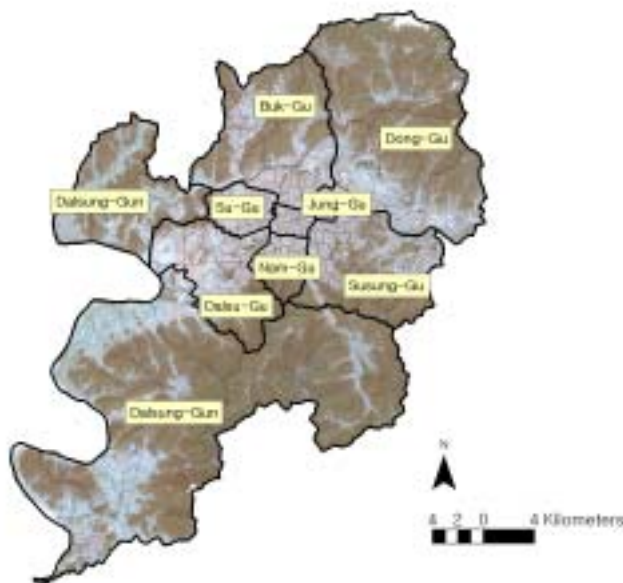

FIGURE 1. Study area

The satellite data were examined using standard image processing software, ERDAS (v.8.6) and ERDAS IMAGINE, and the results of the digital processing were presented with ARCVIEW(v.3.3). The statistical analyses were performed by using SAS package. The satellite image was transformed into Transverse Mercator(TM) coordinate system by using 1/25000-scale standard topographic maps. Geometric correction was based on the first order polynomial equations. The pixel size was maintained at 30m.

4. SURFACE TEMPERATURE, VEGETATION AND LAND USE TYPES

4-1 Surface temperature distribution

The surface temperature was calculated by the following conversion formula.

$$T = \frac{K2}{\ln(\frac{K1}{L_\lambda} + 1)}$$

where

T: effective at-satellite temperature in kelvin;
K2: calibration constant 2 in kelvin;
K1: calibration constant 1 in $W/(m^2 \cdot sr \cdot \mu m)$;
L: spectral radiance at the sensor's aperture;

and

$$L_\lambda = (\frac{LMAX_\lambda - LMIN_\lambda}{Q_{cal\ max}})\ Q_{cal\ max} + LMIN_\lambda$$

where

L_λ: spectral radiance at the sensor's aperture in $W/(m^2 \cdot sr \cdot \mu m)$;

Q_{cal} : quantized calibrated pixel value in DNs;
$Q_{cal\ min}$: minimum quantized calibrated pixel value (DN) corresponding to $LMIN_\lambda$
$Q_{cal\ max}$: maximum quantized calibrated pixel value (DN) corresponding to $LMAX_\lambda$
$LMIN_\lambda$: spectral radiance that is scaled to $Q_{cal\ min}$ in $W/(m^2 \cdot sr \cdot \mu m)$;
$LMAX_\lambda$: spectral radiance that is scaled to $Q_{cal\ max}$ in $W/(m^2 \cdot sr \cdot \mu m)$.

Authors recommend to read Chander and Markham(2003) for more information on these formula and related calculations.

Figure 2 illustrates the surface temperature distribution of the study area. The figure tells us that the surface temperature of urbanized areas with over 17℃ is higher than that of non-urban areas with below 14℃ in general. The surface temperature is the lowest in mountainous areas and the highest in urban centers and traditional manufacturing areas. In addition, high temperature areas are observed along east-west axis of the city.
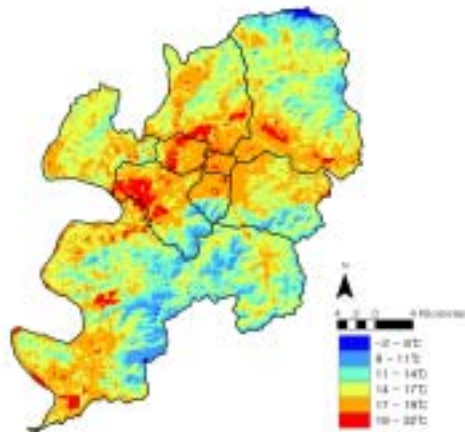

FIGURE 2. The Surface Temperature: Daegu City

4-2. Spatial distribution of vegetation index

Vegetation level refers the density of green vegetation across the Earth′s landscapes. It can be measured by using satellite sensors that observe the distinct wavelengths of visible and near-infrared sunlight that is absorbed and reflected by the plants. The vegetation index(VI) ranges from 0 to 255(0=a pure black pixel, 255=a pure white pixel, and all the numbers between=gray). By subtracting the red light images from the near-infrared image, everything that has about the same brightness level in the two wavelengths becomes dark, and everything that is brighter in the near-infrared becomes light. The VI range of study area begins from 15 and up to 255. The low value of VI in certain area implies that the area is close to the natural condition. One shortcomings of the VI in this study is that the VI of water is considered the lowest vegetation index with 15-100 which is almost the same as urbanized area. But this cannot ruin the confidence of analysis results, because the portion is small.

The vegetation level is frequently converted into NDVI(Normalized Difference Vegetation Index) range from -1 to +1 by calculating the following equation.

$$NDVI = \frac{Band4 - Band3}{Band4 + Band3}$$

where ″Band4″ is near-infrared light, and ″Band3″ is red light. NDVI can be interpreted as the difference in reflectance is divided by the sum of the two reflectances. An NDVI value of -1 means no green vegetation and close to +1 (usually 0.8-0.9) indicates the highest possible density of green leaves. This study utilizes the NDVI since it is most commonly used index for satellite imagery.

By comparing Figure 3 with Figure 2, it is easy to find out that the spatial distribution of the vegetation level is very similar with that of surface temperature.
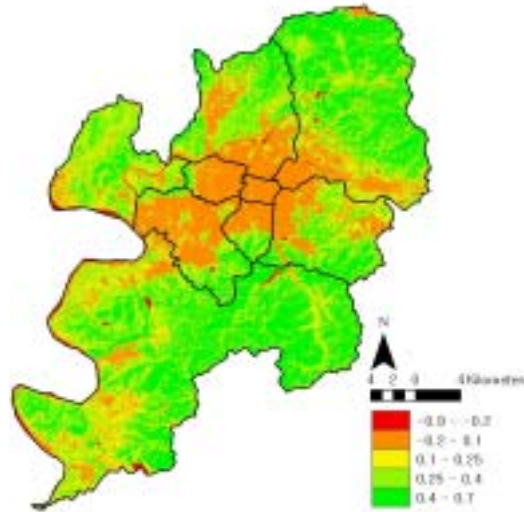

FIGURE 3. NDVI: Daegu City

4-3. Spatial distribution of land use

Figure 4 shows the land use distribution map constructed based on the basic survey unit information. Land Use Classification by the Basic Survey Unit is presented in Table 1. As shown in Figure 4, the urbanized areas(residential, semi-residential, and non-residential use) are surrounded by rural uses. In the case of urbanized areas, non-residential use, especially commercial use, is surrounded by the residential use in general. The manufacturing activity is located northwestern part of the city and outer southwestern edge of the urbanized area.
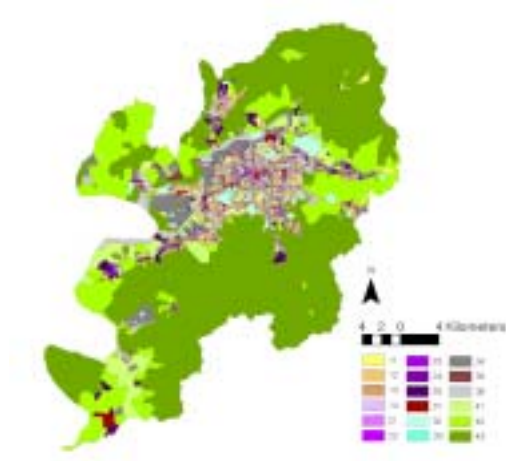
FIGURE 4. The land use distribution: Daegu City

4-4. The relationship among land use types, vegetation and surface temperature

The surface temperature and vegetation index are quantitative variables. Their relationship can easily be measured by many ways. But the land use number is not a variable. Therefore, one can compare the surface temperature with vegetation index quantitatively, but cannot compare the surface temperature with land use directly. By combining the three figures, however, the difference of the surface temperature by land use type and by vegetation index can be derived clearly.

First of all, by combining surface temperature information with land use information, the highest temperature is found at manufacturing and commercial areas, with surface temperature higher than 19℃.

Before test the strong relationships between land uses and surface temperature, this study checks if there exists surface temperature differences by land use type. The ANOVA test

TABLE 1. Land use classification by the basic survey unit

Land Use Classification	Two-digit Land Use Classification
1. Residential Use	11. single-detached housings
	12. apartment housings
	13. other multi-family housings
	14. Mixed housing types
2. Semi-residential Use	21. mixed use of single-detached housings and commercial buildings
	22. mixed use of multi-family housings and commercial buildings
	23. mixed use of single-detached housings and manufacturing facilities
	24. mixed use of multi-family housings and manufacturing facilities
	25. other mixed uses
3. Non-residential Use	31. commercial use
	32. public facilities
	33. cultural facilities
	34. manufacturing use
	35. commercial and manufacturing use
	36. other mixed uses
4. Rural Areas	41. plain field
	42. semi-plain field
	43. mountainous area
	44. seashore

TABLE 2. Duncan grouping by land use type

Duncan Grouping		Mean	N	Land Use
	A	20.81	482	manufacturing use(34)
	B	19.20	72	commercial and manufacturing use(35)
	B	19.11	160	single-detached housings + manufacturing(23)
	B	19.01	4	multi-family housings + manufacturing(24)
	C	18.27	653	commercial use(31)
	C	18.18	2,130	single-detached housings + commercial use(21)
	C	18.17	696	other semi-residential mixed uses(25)
D	C	18.04	5,280	single-detached housing (11)
D	C	18.04	71	multi-family housings + commercial use(22)
D	C	17.93	733	mixed housing types(14)
D	E	17.64	421	public facilities(32)
D	E	17.56	113	other multi-family housings(13)
D	E	17.54	163	other non-residential mixed uses(36)
F	E	17.18	12	cultural facilities(33)
F		17.06	78	plain field(41)
F	G	16.83	4,022	apartment housings(12)
	G	16.42	302	semi-plain field(42)
	H	14.55	298	mountainous area(43)

statistics provide clear evidence of surface temperature differences by land use type with F-value 654.84 and Pr<0.0001.

One step further, the eighteen land use types are grouped based on results of Duncan method, or similarity of the average surface temperatures. Table 2 shows the Duncan grouping by land use type. In Duncan method, means with the same letter are not significantly different.

According to the table, the highest surface temperature is found at manufacturing use with average temperature 20.8℃. The next highest group consists of mixed use of commercial and manufacturing use, mixed use of single-detached housings and manufacturing, and mixed use of multi-family housings and manufacturing - all land uses are related with manufacturing use. This result implies that there is a strong relationship between land use types and surface temperature.

A special attention should be given to the surface temperature of apartment housings, the major housing types of new housing construction. It is extremely low − even lower than the temperature of the single family housing areas. This difference may stem from building material difference−especially roofing materials. Most of apartment structures are covered with concrete and apartment sites have planned open space required by the law. By contrast, the roofing material of most single-family house is a tile and there is no regal requirement for open space for the single-family housing areas.

In addition, the correlation coefficient between surface temperature and vegetation index is − 0.34 at Pr<0.0001. This a clear evidence of close relationship between surface temperature and vegetation index, though not as

strong as expected.

These findings can be further verified by regression analysis. By regressing vegetation index and land use types on surface temperature, this study obtains strong statistical evidence of the relationships among the three variables as shown in Table 3. The effect of land use is measured by using dummy variables. The method of avoiding dummy variable trap is a delete one category method, which measures deviation from deleted variable(mean value of single housing residential area, 18.04℃). In Table 3, the negative relationship between surface temperature and vegetation index is derived as expected. Among dummy variables, negative(positive) values represent lower(higher) temperature than average value of the deleted variable.

5. CONCLUSION

This paper presents series of spatial distribution maps of surface temperature, vegetation and land use through the visual interpretation of multi-spectral images. There is a clear relationship among surface temperature,

TABLE 3. The regression analysis

Variables	Parameter Estimate	Standard Error	t -Value	Pr > |t|
Intercept	20.2837***	0.0817	248.3900	<.0001
VI: vegetation index	−0.0186***	0.0007	−27.9600	<.0001
D2: apartment housings(12)	−1.1616***	0.0222	−52.2400	<.0001
D3: other multi-family housings(13)	−0.2808***	0.1010	−2.7800	0.0055
D4: Mixed housing types(14)	−0.0699 *	0.0418	−1.6700	0.0944
D5: mixed use of single-detached housings and commercial buildings(21)	0.1294***	0.0272	4.7500	<.0001
D6: mixed use of multi-family housings and commercial buildings(22)	−0.0138	0.1266	−0.1100	0.9134
D7: mixed use of single-detached housings and manufacturing facilities(23)	1.1853***	0.0852	13.9200	<.0001
D8: mixed use of multi-family housings and manufacturing facilities(24)	1.0676 **	0.5302	2.0100	0.0441
D9: other mixed uses(25)	0.2396***	0.0429	5.5800	<.0001
D10: commercial use(31)	0.1825***	0.0440	4.1500	<.0001
D11: public facilities(32)	−0.2154***	0.0541	−3.9800	<.0001
D12: cultural facilities(33)	−0.3716	0.3068	−1.2100	0.2259
D13: manufacturing use(34)	2.8765***	0.0506	56.8700	<.0001
D14: commercial and manufacturing use(35)	1.2283***	0.1258	9.7600	<.0001
D15: other mixed uses(36)	−0.2851***	0.0846	−3.3700	0.0008
D16: plain field(41)	−0.2348 *	0.1238	−1.9000	0.0579
D17: semi-plain field(42)	−0.7591***	0.0698	−10.8800	<.0001
D18: mountainous area(43)	−2.1754***	0.0786	−27.6900	<.0001
R^2= 0.4431, Adj R^2= 0.4425 n=15,690				

***, **, * : significant at (=0.01, 0.05 and 0.10 respectively.

vegetation level and land use as expected. We admit that there are many other factors that affect surface temperature, such as season, year, urban characteristics, and so on. However, land use type is not easily converted within short period. For the data consistency, this study considers only the two factors, holding other factors remain constant.

This study also categorizes the eighteen land use types into 7-8 groups according to their average surface temperature. Among them, the surface temperature of manufacturing related land use is the highest, semi-residential use is the next, and non-residential land use is the lowest, except agricultural and forest land use. The relationship between surface temperature and vegetation index is negative as expected. The regression result supports the findings derived from series of figures and tables.

Environmental scientists tend to concern only about vegetation condition while urban planners and economists may concern only land use type in determining surface temperature in urban areas. The results of this study tell us that the level of surface temperature is affected by both vegetation condition as well as land use type. By this finding, this study suggests that interdisciplinary efforts needed to cure surface temperature-related urban environmental problems, if any.

ACKOWLEDGEMENTS

REFERENCES

Barnsley, M.J., L. Moller-Jensen and S.L. Barr. 2001. Inferring Urban Land Use by Spatial and Structural Pattern Recognition. in Remote Sensing and Urban Analysis, Edited by Jean-Paul Donnay, M.J. Barnsley and P.A.Longley, pp.115-144.

Chander, G. and B. Markham. 2003. Revised Landsat-5 TM Radiometric Calibration Procedures and Postcalibration Dynamic Ranges. IEEE Transactions on Geoscience and Remote Sensing 41(11): 2674-2677.

ERDAS Inc.(2003), ERDAS Field Guide Sixth Edition.

ERDAS Inc.(2003), The ESRI Guide to GIS Analysis.

ERDAS Inc.(2003), Using ARCGIS Spatial Analyst.

Jo, Myung-Hee and Kwang-Jae Lee. 2000. A study on the spatial distribution characteristic of urban surface temperature using remotely sensed data and GIS. Journal of the Korean Association of Geographic Information Studies 4(1): 57-66.

Kwon, Bong-Kyum, Kiyoshi Yamada, T. Niren, Myung-Hee Jo. 2003. A study on the landcover classification using band ratioing data of landsat TM. Journal of the Korean Association of Geographic Information Studies 6(2): 80-91.

Nichol, Janet E. 1994. Modelling the relationship between landsat TM thermal data and urban morphology. ASPRS/ACSM 1: 494-502.

Park, Kyung-Hun, Sung-Gwan Jung, H. Lee, J. Oh, and K. Kim. 2004. An Analysis of Landscape Ecological Pattern of the Geumho River Watershed Forest. Journal

of the Korean Association of Geographic Information Studies 7(3): 22-34.

Park, Min-Ho. 2001. A study on the urban heat island phenomenon using landsat tm thermal infrared data. Korean Society of Civil Engineers. 21(6-D): 861-874.

Prakash, A. and R. P. Gupta. 1999. Surface fires in Jharia coalfield. India - their distribution and estimation of area and temperature from TM data. International Journal of Remote Sensing 20(10): 1935-1946.

Richards, J.A. and X. Jia. 1999. Remote Sensing Digital Image Analysis, Springer, Berlin.

Shin, Sha-Chul and Tae-Young An. 2004. Estimation of Areal Evapotranspiration Using NDVI and Temperature Data. Journal of the Korean Association of Geographic Information Studies 7(3): 79-89.