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Urban thermal fringes detection and environmental quality assessment: A case study of Tsukuba City

Ko Ko LWIN* and Yuji MURAYAMA*

Abstract

Remote sensing data mining is the process of extracting the spatial patterns from the images or finding the relationship between spatial features. In this paper, we describe the extraction of urban thermal fringes using remote sensing data and Focal Statistical Analysis method. Urban thermal fringe is one of the results from UHI (Urban Heat Island) effect where the city has low vegetation or less evaporation than surrounding areas. Discovery of urban thermal fringes is an important consideration factor for sustainable urban planning process in order to reduce the UHI effect inside the city. We use Landsat TM/ETM+ thermal images to identify the thermal fringes spatial distribution patterns between 1987 and 2001 in Tsukuba city which is a planned city for research and scientific discovery purposes. The main objective of this study is to extract the urban thermal fringes and analyze the changing patterns for 14 years in Tsukuba City. According to this study, UHI effect was reducing between 1987 and 2001 in Tsukuba City.

Key words: Urban thermal fringes, Focal Statistical Analysis, UHI (Urban Heat Island), environmental quality assessment, Tsukuba City

1. Introduction

The UHI (Urban Heat Island) is one of the clearest impacts of human activity on the climatic environment. It is well known that the intensity of the UHI effect is strongly associated with the urban size, urban surface characteristics, Anthropogenic Heat (AH) release, topography, and meteorological conditions (Oke, 1982; Chen et al., 1997; Atkinson, 2003; Kusaka et al., 2001; Chen and Dudhia, 2001; Kim and Baik, 2004). There are several causes of an urban heat island (UHI). The principal reason for the nighttime warming is that buildings block surface heat from radiating into the relatively cold night sky. Two other reasons are changes in the thermal properties of surface materials and lack of evapotranspiration in urban areas.

Materials commonly used in urban areas, such as concrete and asphalt, have significantly different thermal bulk properties (including heat capacity and thermal conductivity) and surface radiative properties (albedo and emissivity) than the surrounding rural areas. This causes a change in the energy balance of the urban area, often leading to higher temperatures than surrounding rural areas. The energy balance is also affected by the lack of vegetation in urban areas, which inhibits cooling by evapotranspiration. Other causes of a UHI are due to geometric effects. The tall buildings within many urban areas provide multiple surfaces for the reflection and absorption of sunlight, increasing the efficiency with which urban areas are heated. This is called the "urban canyon effect". Another effect of buildings is the blocking of wind, which also inhibits cooling by convection. Waste heat from automobiles, air conditioning, industry, and other sources also contributes to the UHI. High levels of pollution in urban areas can also increase the UHI, as many forms of pollution change the radiative properties of the atmosphere. (Oke, 1982)

UHIs have the potential to directly influence the health and welfare of urban residents. Within the United States alone, an average of 1,000 people die each year due to extreme heat (Changnon et al., 1996). As UHIs are characterized by increased temperature, they can potentially increase the magnitude and duration of heat waves within cities. Research has found that the mortality rate during a heat wave increases exponentially with the maximum temperature (Buechley et al., 1972) an effect that is exacerbated by the UHI. The nighttime effect of UHIs can be particularly harmful during a heat wave, as it deprives urban residents of the cool relief found in rural areas during the night (Clarke, 1972). Research in the United States suggests that the relationship between extreme temperature and mortality varies by location. Heat is more likely to increase the risk of mortality in cities at mid-latitudes and high latitudes with significant annual temperature variation. For example, when Chicago and New York experience unusually hot summertime temperatures, elevated levels of illness and death are predicted. In contrast, parts of the country that are mild to hot year-round have a lower public health risk from excessive heat. Research shows that residents of southern cities, such as Miami, tend to be acclimated to hot weather conditions and therefore less vulnerable to heat related deaths (Davis et al., 2003).

Recent years, research into micro-spatial analysis (i.e., Urban Scale) has increased due to remote sensing data

* Graduate School of Life and Environmental Sciences, University of Tsukuba

available at finer spatial resolution with more diverse geo-information sources (IKONOS, QuickBird, LIDAR, etc.) and the availability of fine-scale GIS data with enhanced attribute information (e.g. building footprints with the number of floors, building use type and building name) (Lwin and Murayama, 2009). Integration of remote sensing data with Geographical Information System (GIS) which is a set of tools to analyze, visualize and perform spatial analysis and spatial statistics empowers the researchers to better understanding of earth and eco systems underlying a spatial perspective.

2. Methodology

2.1. Study area and land development history

The study area is Tsukuba City with total area of 284.07km . The city has an estimated population of 207,394 (as of 2008) and a population density of 730 persons per km . Tsukuba is sometimes considered as a part of the Greater Tokyo Metropolitan Area and about 50 km North-East of Tokyo. Figure 1 shows the Tsukuba City land use map in 1994 acquired from Geospatial Information Authority of Japan.

TSUKUBA CITY LAND USE MAP (1994)

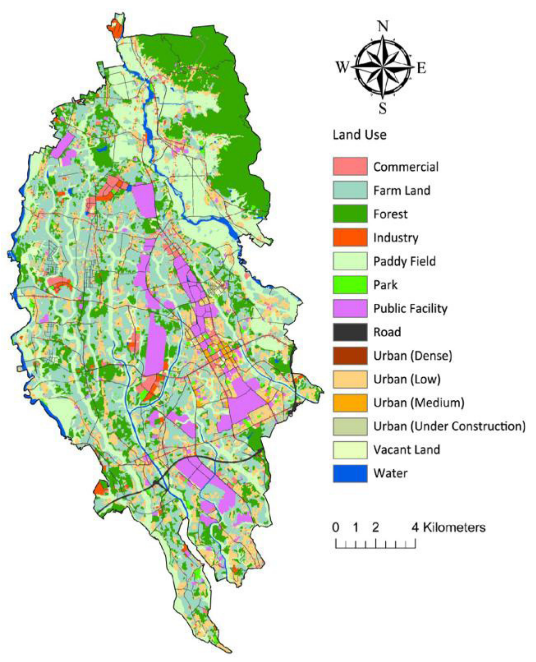

Fig.1 Tsukuba Land Use Map in 1994
(Source: Geospatial Information Authority of Japan)

Tsukuba Science City was planned in order to relieve Tokyo's overpopulation problem and to establish itself as the nation's largest research and education center. In 1963, the new city's construction plan was approved and by 1980 more than 40 research and higher education facilities had been built. Roads, water and sewerage systems, parks and other facilities had also been constructed by then. In Tsukuba there are 88 parks and green areas with a total area of about 100 ha. Each of them has been designed individually according to its location and function. These areas serve as places for the residents to rest, do recreational activities, and participate in sports. Many of these parks, as well as other public, commercial, and educational facilities and residential buildings are connected by a path of 48 km (31 miles) for pedestrians and cyclists. As one of the typical features of the city planning in Tsukuba Science City, this path has brought visitors as well as the local residents' convenience, comfort and enjoyment.

2.2. Data

Following is the list of data used in this study.

(1) Tsukuba City land use data acquired in 1994 from Geospatial Information Authority of Japan
(2) Three Landsat TM/ETM+ images (Path 107 and Row 035): two Landsat TM5 Band 6 (acquired on 19-04-1987 and 22-04-1994) and one Landsat ETM+ Band 6 Low Gain (acquired on 16-03-2001) were used to calculate Ts (Surface Temperature).
(3) Tsukuba City administration boundary in ESRI Shape file format.

All Landsat images are at a level of 1G (Systematic) product with radiometric and geometrical corrections including systematic geometric correction based on spacecraft telemetry and data from the Level 0R input product and calibration. Landsat-5 (Landsat TM) was developed by the National Aeronautics and Space Administration (NASA) and initially operated by the National Oceanic and Atmospheric Administration (NOAA). The Landsat-7 program is operated entirely by the government, a joint effort between the USGS and NASA. The program added two features to the Landsat-7 (Landsat ETM+) processing system to ensure the quality of calibrated data and less of a "blackbox" approach to data products.

The calibration parameter file (CPF) contains all information relevant to the radiometric and geometric calibration of ETM+ data. This file is issued with every data product and is used in processing it from raw data to calibrated data. CPFs are issued on a quarterly basis, for individual quarters, for all quarters since launch. Each scene is processed with a CPF issued for the specific quarter in which the scene was acquired. This allows for time-dependent calibration coefficients. Of importance here are the band 6 gains, offsets, and view coefficients, all calibration parameters contained in the CPF.

The second improvement to the ETM+ processing system is the advent of the image analysis system (IAS).

The IAS monitors the performance and calibration of ETM+ data on a daily basis by fully processing, through to geometric correction, a sampling of acquired scenes and storing individual scene results to a database (Storey et al., 1999). Although there are some time differences between the satellite images due to the nature of remote sensing data acquisition conditions and availability of data, this will not impact on analysis result, because of this study measures the degree of surface temperature smoothness based on statistical properties of each pixel with neighboring pixels by individual scene rather than comparing time series images.

2.3. Research flow

Figure 2 shows the research flow and data processing steps for this study.

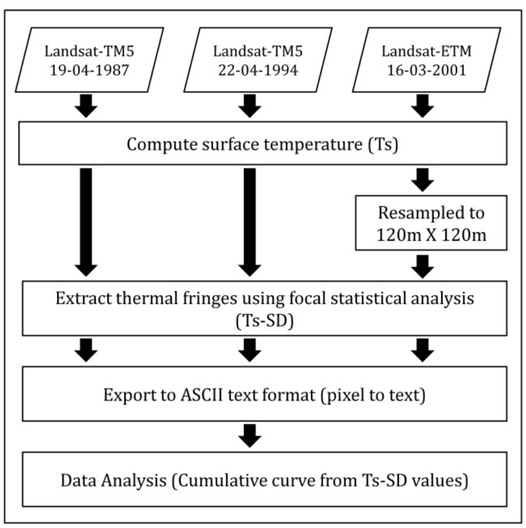

Fig.2 Research flow

2.4. Landsat TM / ETM surface temperature generation

The Landsat Thematic Mapper (TM) and Enhanced Thematic Mapper Plus (ETM+) sensors measure surface temperature and store as a digital number (DN) with a range between 0 and 255. It is possible to convert these DNs to Celsius by performing following three steps.

Step1. Conversion of the Digital Number (DN) to Spectral Radiance (L)

L = LMIN + (LMAX - LMIN) * DN / 255

Where

L = Spectral radiance

LMIN = 1.238 (Spectral radiance of DN value 1)

LMAX = 15.600 (Spectral radiance of DN value 255)

DN = Digital Number

Step2. Conversion of Spectral Radiance to Temperature in Kelvin

$$T_B = \frac{K_2}{h\left(\frac{K_1}{L} + 1\right)}$$

Where

K_1 = Calibration Constant 1 (607.76)

K_2 = Calibration Constant 2 (1260.56)

T_B = Surface Temperature

Step3. Conversion of Kelvin to Celsius

T_B = TB -273

2.5. Focal Statistical Analysis and thermal fringes detection

Focal Statistical Analysis is one of the techniques in spatial data mining process in order to find the spatial distribution patterns by measuring the statistical properties of focused pixel with neighboring pixels. Focal statistical Analysis includes calculation of statistical properties such as mean, standard deviation and mode for each pixel within the specified distance (Figure 3). This is commonly used in spatial analysis to measure a homogeneity or heterogeneity of a surface such as identification of surface roughness based on Digital Elevation Model DEM. Here we applied Focal Statistical Analysis to measure a standard deviation (SD) of each surface temperature (Ts) pixel with neighboring two pixels (radius 300m).

The purpose of this analysis is to measure the homogeneity of surface temperature (Ts) and extract the thermal fringe patterns which directly control by land use land cover. Mapping the spatial distribution patterns of thermal fringes and measuring the Ts-SD are useful for city and urban planners to balancing and reducing the UHI (Urban Heat Island) effect inside the city. If the city has less UHI effect, the Ts-SD becomes low value.

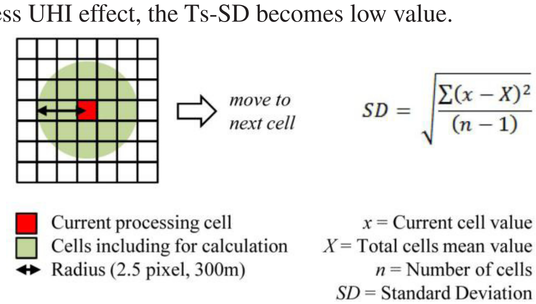

Fig.3 Focal Statistical Analysis of surface temperature data and urban thermal fringe patterns extraction.

3. Result and Discussion

Figure 4 shows the extraction of urban thermal fringe patterns from three surface temperature images and comparison of their statistical properties within a period of

14 years. According to Figure 4, thermal fringe patterns are reducing in year 2001 (i.e., smoothing surface temperature with lower standard deviation pixels). These urban thermal fringe patterns are potentially controlled by vegetation or green spaces. This can be improved by proper urban planning and management. Moreover, trees contribute to a better quality of living environments in cities by means of improving air quality. Figure 5 shows the whole Tsukuba City cumulative curves of Ts-SD for 1987, 1994 and 2001. Y-axis shows the Ts Standard Deviation and X-axis shows the number of pixels (frequency) and 2001 Ts-SD curve is lower than previous two years. Mapping the thermal fringes and measuring the Ts-SD is useful for urban and city planners to balancing the surface temperature and reducing the UHI effects inside the city. According to Figure 5, Tsukuba city surface temperature is becoming homogeneity and reducing the UHI effect compares to previous years.

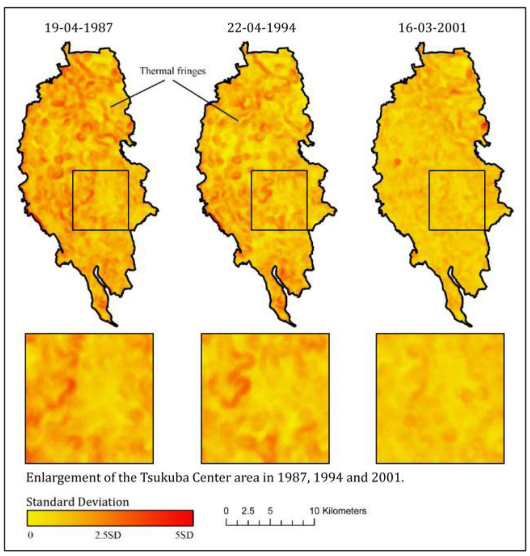

Fig.4 Maps of Ts-SD (Surface Temperature Standard Deviation) for the whole Tsukuba City and enlargement of Tsukuba Center area in 1987, 1994 and 2001

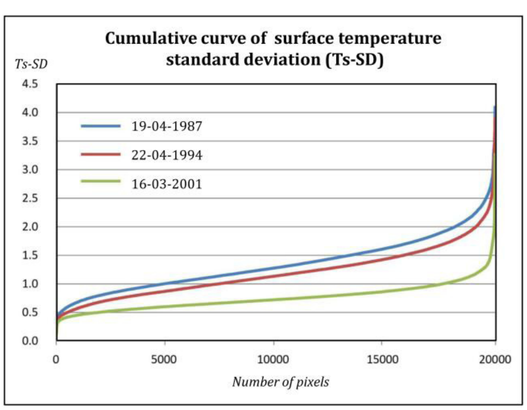

Fig.5 Cumulative Curves of Ts-SD for 1987, 1994 and 2001.

4. Conclusion

This study detects the urban thermal fringes by utilizing remote sensing and GIS in order to assess the urban quality and take an action for future urban development planning. In this study, we used focal statistical analysis to extract the urban fringes patterns and analyze the statistical properties to measure the surface temperature smoothness. Measurement of thermal fringes is important for future sustainable urban development in order to allocate the green spaces and to construct other eco-friendly landscapes. To achieve sustainable urban development, cities must be planned and managed to form a balance between human being and natural environment by using resources carefully and transferring them to the next generations. In order to protect and enhance environmental conditions of future generations, it is essential to provide the sustainability of urban ecosystems (Dizdaroglu et al., 2009). Moreover, city and urban planners need to monitor UHI effect frequently because cities are always changing based on government policy and socio-economic situation.

References

Atkinson, B.W. 2003. Numerical modeling of urban heat island intensity. *Boundary layer Meteorology* **109**, 285-310.

Buechley, R.W., Van Bruggen, J., Truppi, L.E. 1972. Heat island = Death island?. *Environmental Research* **5**, 82-92.

Changnon, S.A., Kunkel, K.E. and Reinke, B.C. 1996. Impacts and responses to the 1995 heat wave: A call to action. *Bulletin of the American Meteorological Society* **77**, 1497-1506.

Chen, F., Janjic, Z. and Mitchell, K. 1997. Impact of atmospheric surface layer parameterization in the new land-surface scheme of the NCEP mesoscale Eta numerical model. *Boundary-Layer Meteorology* **85**, 391-421.

Chen, F. and Dudhia, J. 2001. Coupling an advanced land surface hydrology model with the Penn State–NCAR MM5 modeling system, Part I: Model implementation and sensitivity. *Monthly Weather Review* **129**, 569-585.

Clarke, J. F. 1972. Some effects of the urban structure on heat mortality. *Environmental Research* **5**, 93-104.

Davis, R.E., Knappenberger, P.C., Michaels, P.J. and Novicoff, W.M. 2003. Changing heat-related mortality in the United States. *Environmental Health Perspectives* **111**, 1712-1718.

Dizdaroglu, D., Yigitcanlar, T. and Dawes, L.A. 2009. Sustainable urban futures: an ecological approach to sustainable urban development. In *Proceedings of the Second Infrastructure Theme Postgraduate*

Conference 2009: Rethinking Sustainable Development - Planning, Infrastructure Engineering, Design and Managing Urban Infrastructure, 26 March 2009, Queensland University of Technology, Brisbane.

Kim, Y.H. and Baik, J.J. 2004. Daily maximum urban heat island intensity in large cities of Korea. *Theoretical and Applied Climatology* **79**, 151-164.

Kusaka, H., Kondo, H., Kikegawa, Y. and Kimura, F. 2001. A simple Single-Layer Urban Canopy Model for Atmospheric Models: Comparison with Multi-Layer and Slab Models. *Boundary Layer Meteorology* **101**, 329-358.

Lwin, K. K. and Murayama, Y. 2009. A GIS approach to estimation of building population for micro-spatial analysis. *Transactions in GIS* **13**, 401-414.

Oke, T.R. 1982. The energetic basis of the urban heat island. *Quarterly Journal of the Royal Meteorological Society* **108**, 1-24.

Storey, J., Morfitt, R. and Thorson, P. 1999. Image processing on the Landsat 7 image assessment system. In *Proceedings of the 1999 ASPRS Annual Conference, From Image to Information, 17-21 May 1999, Portland, Oreg*. CD-ROM. American Society for Photogrammetry and Remote Sensing, Bethesda, Md.

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