URBAN ENVIRONMENTAL QUALITY ANALYSIS USING LANDSAT IMAGES OVER SEOUL, KOREA

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ABSTRACT:
The Urban Environmental Quality (UEQ) indicates a complex and various parameters resulting from both human and natural factors in an urban area. Vegetation, climate, air quality, and the urban infrastructure may interact to produce effects in an urban area. There are relationships among air pollution, vegetation, and degrading environmental the urban heat island (UHI) effect. This study investigates the application of multi-spectral remote sensing data from the Landsat ETM and TM sensors for the mapping of air quality and UHI intensity in Seoul from 2000 to 2006 in fine resolution (30m) using the emissivity-fusion method. The Haze Optimized Transform (HOT) correction approach has been adopted for atmospheric correction on all bands except thermal band. The general UHI values ($\Delta(T_{urban}-T_{rural})$) are 8.45 (2000), 9.14 (2001), 8.61(2002), and 8.41°C (2006), respectively. Although the UHI values are similar during these years, the spatial coverage of "hot" surface temperature (>24°C) significantly increased from 2000 to 2006 due to the rapid urban development. Furthermore, high correlations between vegetation index and land surface temperature were achieved with a correlation coefficients of 0.85 (2000), 0.81 (2001), 0.84(2002), and 0.89 (2006), respectively. Air quality is shown to be an important factor in the spatial variation of UEQ. Based on the quantifiable fine resolution satellite image parameters, UEQ can promote the understanding of the complex and dynamic factors controlling urban environment.

KEY WORDS: LANDSAT, urban environmental quality, air pollution, urban heat island

1. INTRODUCTION

The urban environmental quality (UEQ) is an important part of efficient urban environment planning and management. It is determined by reliable information based on bio-geophysical and geomorphologic, dynamics processes, and climatic change effects. The urban heat island (UHI), the distribution of greenery, building density and geometry, and air quality are affecting factors on UEQ (Nichol et al., 2006). As is difficult to quantify the environmental impacts of human and industrial activities in urban areas, often many different indicators can conflict with each other. For examples, the positive relationship between the air quality and the UHI (Dwyer et al., 1992; Klaus et al., 1999), and its inverse relationship with biomass (Gallo et al., 1993; Weng, 2001), surface temperature with UHI (Roth et al., 1989; Nichol, 1994) are well documented. Especially, surface and atmospheric temperatures increase with anthropogenic heat discharge and by land surface coverage.

Integrated measurement data acquired from satellite and ground based measurement allows estimating the change detection and environmental impact classification and assessment in urban area. Seoul (37°35′N, 127°0′E), the capital of Korea, is one of largest mega cities in Northeast Asia. Its emissions of air pollutants can also affect the UEQ, and in turn it is also affected by regional emissions. This study uses the satellite-derived temperature, biomass, and atmospheric aerosols as independent indicators of UEQ and their application to urban structures.

2. METHODOLOGY

2.1 Study area

A study area of approximately 3318 km^2 (37°46′~37°20′N, 126°33′~127°22′E) which includes Seoul metropolitan area was chosen as shown in Fig. 1. Seoul is the largest city in Korea that covers an area of 607 km^2 and had a population of 9.747 millions. The city is surrounded by mountains and the Han River flows through the central part of the city. Due to the high population density, the environmental quality related to air and pollution is a problem.

Seoul is divided into 25 *gu* (urban districts), where an automatic weather station (AWS) and an air quality station are installed. Since this study requires the knowledge of the physical parameters of the meteorological and air quality conditions, ground meteorological data and air quality data were collected. The spatially detailed nature of the imagery enables assessment of temperature and biomass at the satellite pixel level.

2.2 Satellite remote sensing data

Figure 1 illustrates the data processing for UEQ evaluation adopted in this study. The satellite sensors used in the present study were the Landsat-5 TM and Landsat-7 ETM+, for which the spatial resolutions of visible and thermal infrared (TIR) bands are 30 m and 60 m, respectively. The following data were used to estimate the surface temperature and aerosols: ETM data observed at 0201 UTC on September 4, 2000, 0159 UTC on September 23, 2001, 0159 UTC on September 10, 2002, and TM data 0204 UTC on September 13, 2006. These data were obtained under clear sky conditions. The ETM+ TIR data were resampled with a resolution of 30 m.

The spatial and temporal distributions of land cover are fundamental data for urban ecology. Based on the maximum likelihood classification method, land cover classification was performed. Seven bands and the normalized difference vegetation index (NDVI) are involved for classification. The training areas were selected on those invariant-pseduo targets and five classifiers were determined, which are water, urban, grass, tree, and soil. The classified images are then used to make an emissivity image using the emissivity (ε) of water (0.99), forest (0.974), grassland (0.91), urban (0.92) and soil (0.95) (Artis and Carnahan, 1982).

At the same time the surface temperature from the thermal image is corrected using the Planck's constant for differences in emissivity among each land cover. A algorithm for emissivity correction was applied as;

$$T_S = \frac{T_b}{1 + (\lambda T / \alpha) \cdot \ln \varepsilon} \qquad (1)$$

Where : λ = wavelength of emitted radiance,
T_b = Brightness temperature (°K),
$\alpha = hc/K$ (1.438×10^{-2} mK),
h = Planck's constant (6.62×10^{-34} J.sec),
c = velocity of light (2.998×10^{8} m/sec),
K = Stefan Bolzmann's Constant (1.38×10^{-23} J/K)

A complete set of criteria has widely used to evaluate and examine the UEQ, which includes the air pollution condition indicators, water pollution indicators, solid waste treated indicators, noise pollution indicators, urban green space. In this study, the aerosol reflectance derived from the haze optimized transform (HOT) method (Zhang et al., 2002) was retrieved to estimate the spatial distribution of atmospheric aerosol pattern. The results in very fine resolution and in discrete pattern show a lot of

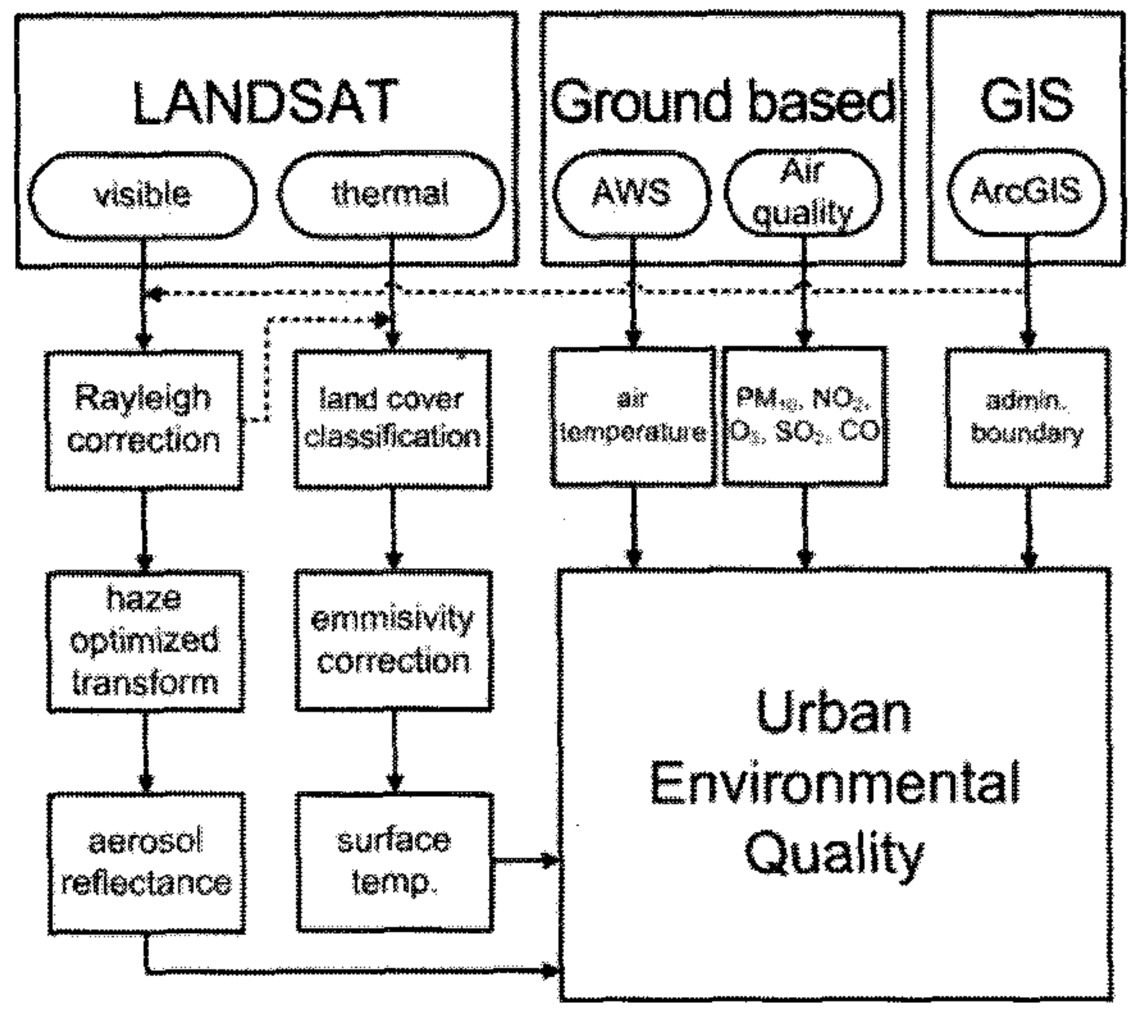


Figure 1.Illustrative flow chart for the UEQ used in this study.

pixels with missing values. Thus, the missing values were filled with neighbouring pixels and then applied a Gaussian Kernel convolution on the images. The size of Gaussian filter was selected to be 150m x 150m (5 x 5) pixel.

3. RESULTS

3.1 Urban heat island

Figure 2 shows the Landsat surface temperature distribution for all cases. Although the range of temperatures is narrow for each image except for the case of year 2000, the surface temperatures of the urbanized areas are always higher than those of the rural areas. The general UHI values ($\Delta(T_{urban}-T_{rural})$) are 8.45 (2000), 9.14 (2001), 8.61 (2002), and 8.41°C (2006), respectively. Although the UHI values are similar during these years, the spatial coverage of "hot" surface temperature (>24°C) significantly increased from year 2001 to 2006 due to the rapid urban development.

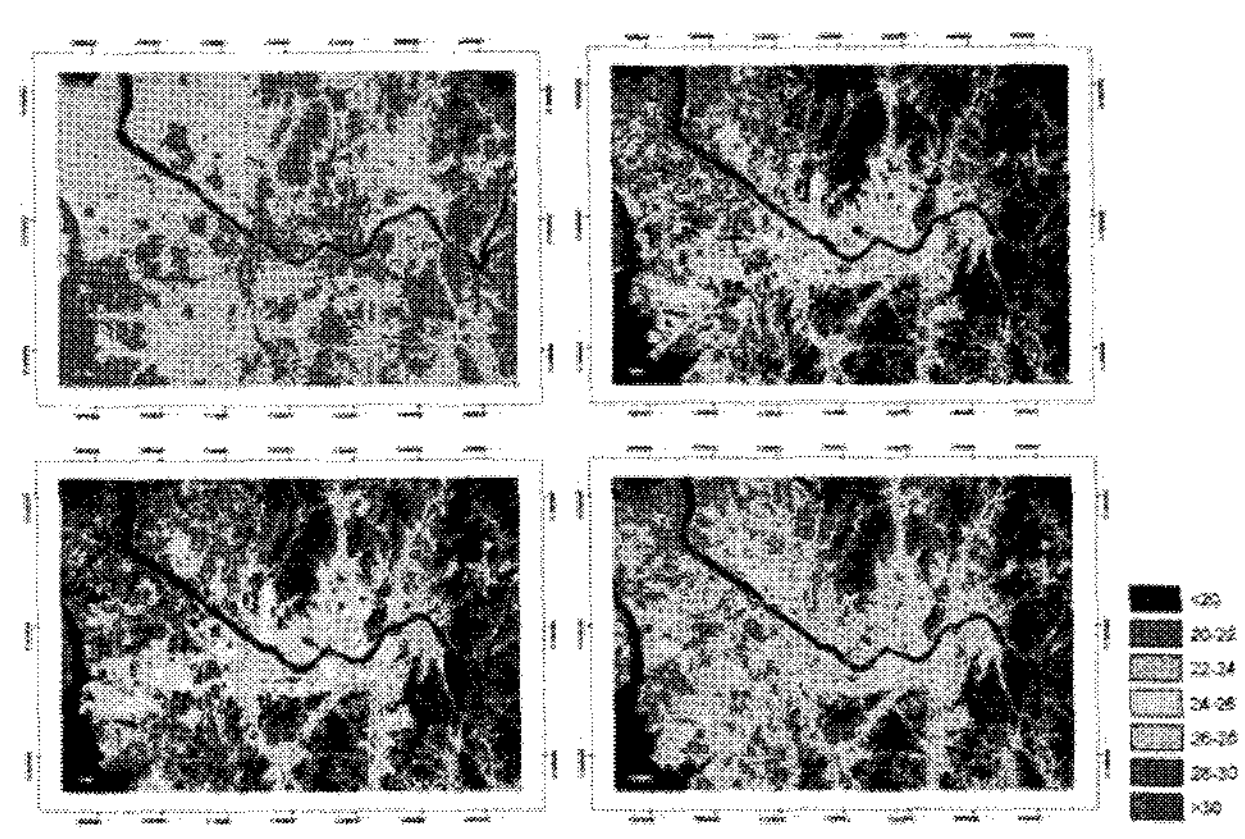


Figure 2. Surface temperature distribution in Seoul metropolitan area, Korea on (a) September 4, 2000, (b) September 23, 2001, (c) September 10, 2002, and (d) September 13, 2006.

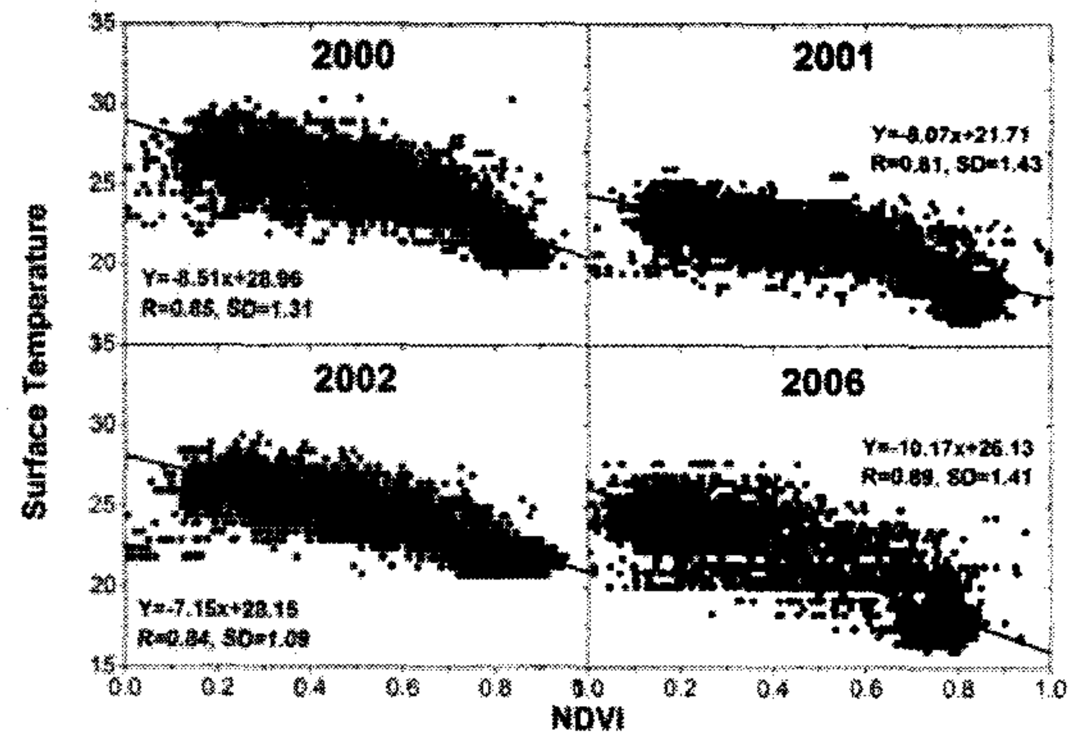


Figure 3. correlation between NDVI with surface temperature (*Ts*)

The linear regression analysis results between the surface temperature and NDVI are shown in Figure 3. High correlations between NDVI and land surface temperature were observed as 0.85 (2000), 0.81 (2001), 0.84 (2002), and 0.89 (2006), respectively. This suggests that the dense vegetation can cool down the surface temperature and planting inside the metropolitan areas is important for reducing the effect of Urban Heat Island.

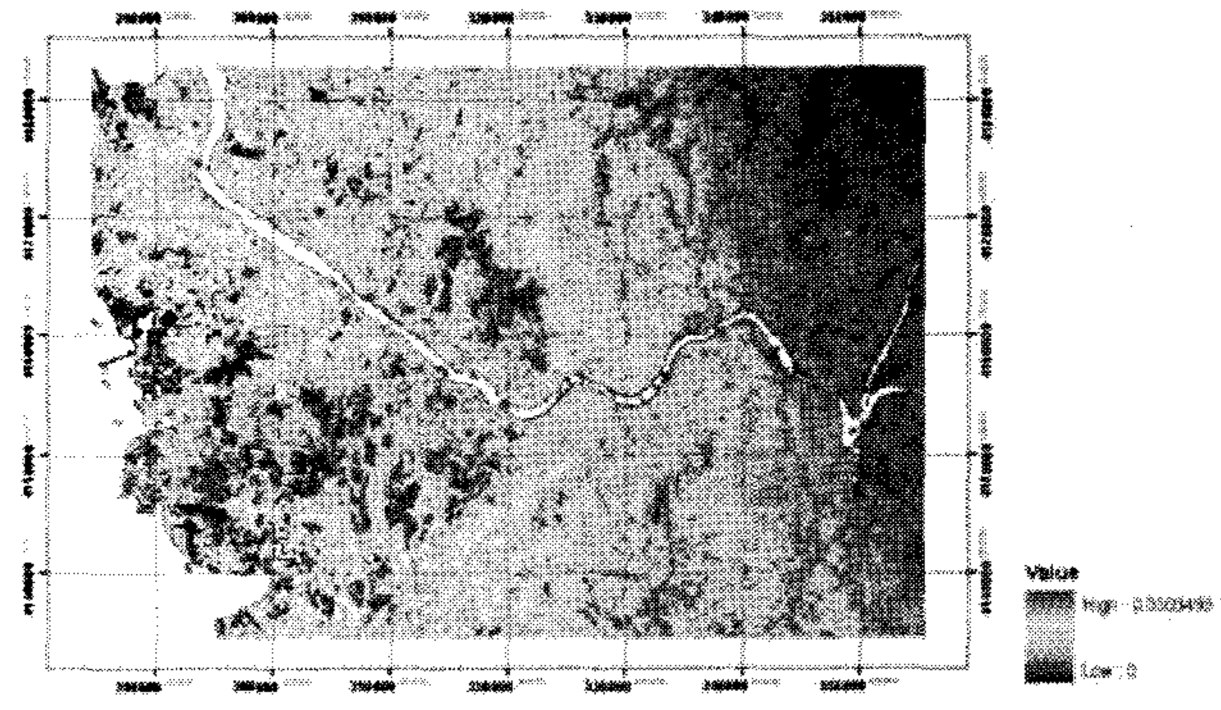
Table 1 summarizes the mean and standard deviations of *Ts* for each land cover type for the five classes. In general, the tree (forest) has the lowest surface temperature where urban and soil have the highest. It was true in most part of the mega cities the highest surface temperature due to high albedo object such as concrete and soil appears around the year. Thus, suggestions like more vegetation planting and more streams and rivers passing through the cities were adopted for reducing the UHI effect.

Table 1. Surface temperature (*Ts*) for different land cover types.

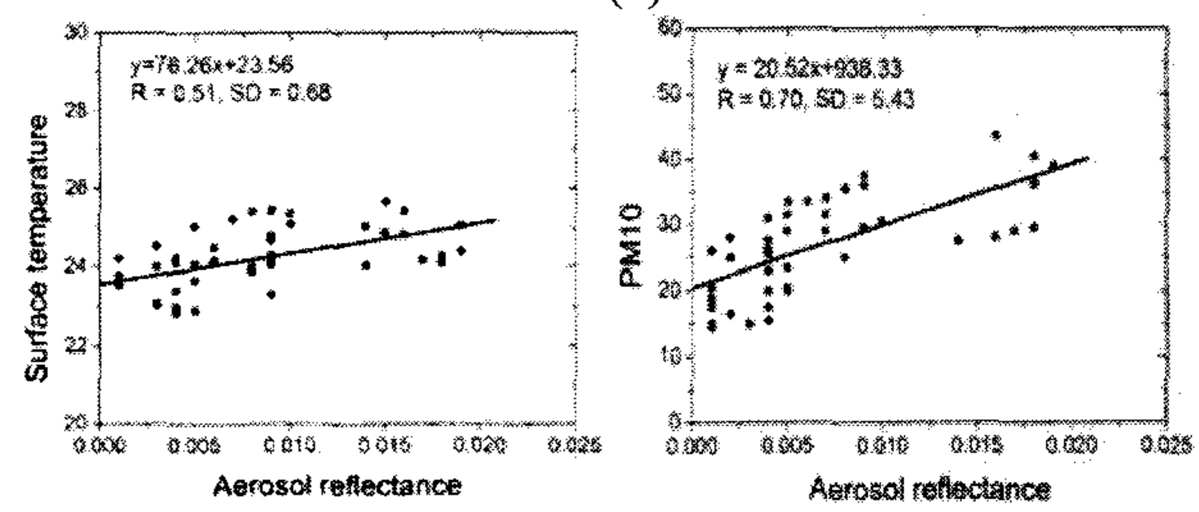
Land cover	Sep. 4, 2000		Sep. 23, 2001		Sep. 10, 2002		Sep. 13, 2006	
	mean	σ	mean	σ	mean	σ	mean	σ
Urban	27.8	0.9	24.4	0.9	24.7	0.9	25.9	1.3
Grass	22.5	0.5	20.6	0.6	19.8	0.3	22.6	1.8
Tree	20.9	0.9	16.6	1.2	19.0	0.8	18.3	1.2
Soil	27.2	2.4	26.1	2.1	24.9	1.4	24.0	3.8
Water	21.1	1.1	18.9	0.7	18.5	0.8	19.6	1.4

3.2 Air quality

Aerosol reflectances data were the by-product of the HOT process. Due to its discrete pattern, Gaussian Kernel convolution was applied over the image. Figure 4(a) shows the aerosol reflectance image of year 2000. The comparison of Landsat aerosol reflectance versus ground PM_{10} and Landsat aerosol reflectance versus *Ts* shows good correlations in Figure 4(b). This means aerosol concentration is higher in non-vegetated high *Ts* area. The other gaseous air quality data (SO_2, O_3, NO_2, CO) has very low correlation with *Ts*.



(a)



(b)

Figure 4. (a) Landsat ETM Aerosol reflectance (ρ_a) map (2002). Note that the range is 0~0.03 (0.55 μm) in this image. Comparison results between (a) *Ts* and aerosol reflectance, (b) aerosol reflectance and PM_{10}.

3.3 Urban environmental quality (UEQ)

By combining the weather, air quality and satellite derived data including surface temperature *Ts*, air temperature *Ta*, vegetation fraction NDVI, air quality (PM_{10}), aerosol reflectances ρ_a in a database, 5 different classes (from 1 to 5) were classified based on all five parameters. Then each parameter is assumed to have equal weighting by adding up to a final UEQ value.

$$UEQ = Ts \cdot w_1 + Ta \cdot w_2 + NDVI \cdot w_3 + PM_{10} \cdot w_4 + \rho_a \cdot w_5$$

where w is the weighting factor for each parameter. Each administrative polygon represents one UEQ value. Figure 5 illustrates the UEQ index map from 2000 to 2006. It is surprising that two districts (*Seongdong gu* and *Yeongdeungpo gu*) are generally high UEQ value over this period. Also, it is indicated that the increases in air pollutant (PM_{10} and aerosol reflectance), reduction of vegetation areas (decreasing of NDVI) and increases in temperature induce the declining of UEQ (*e.q.* high UEQ class) over most of the districts from 2000 to 2006.

4. SUMMARY AND CONCLUSION

The relationships between topography, the UHI, biomass and air pollution within an urban area are complex and dynamic and only superficially understood. Satellite remote sensing data enable to improve this

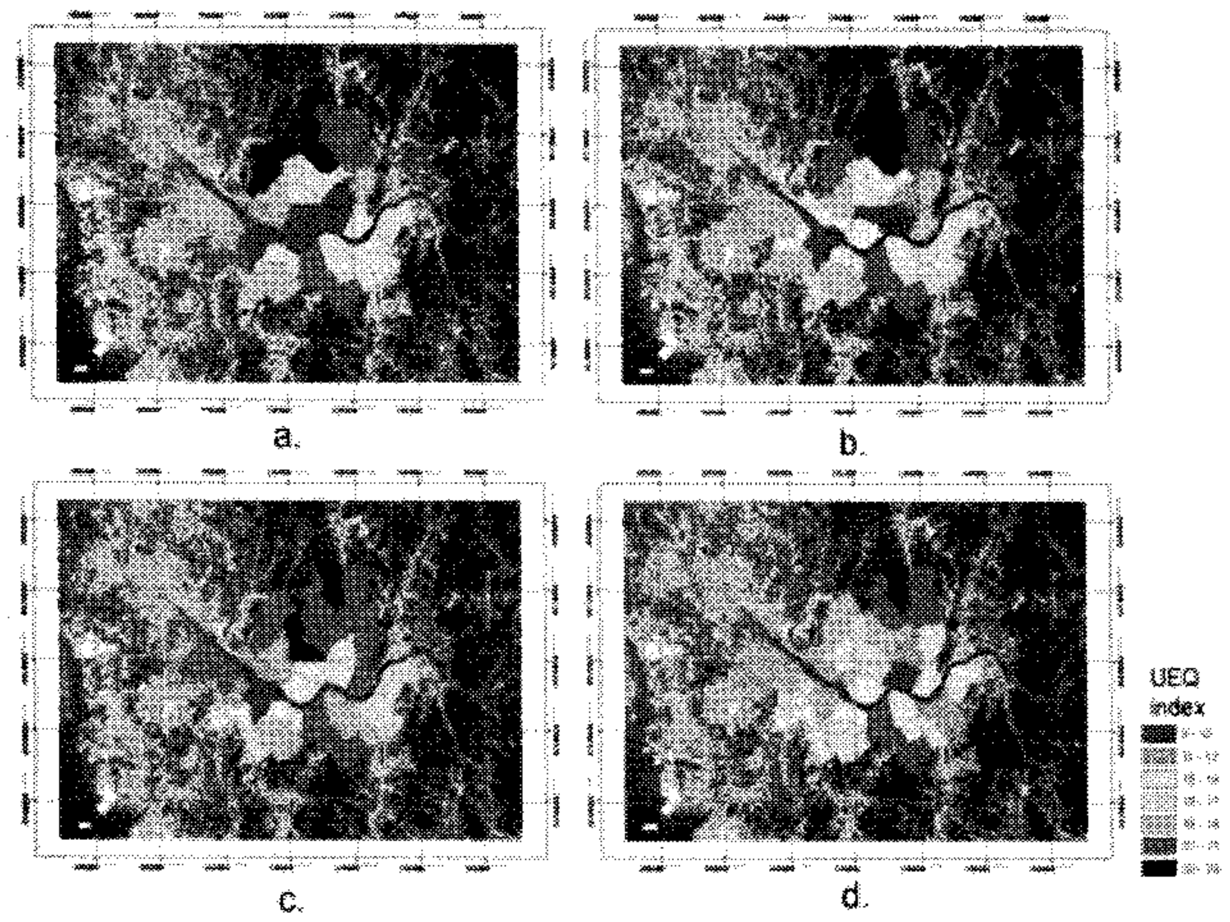


Figure 5. UEQ index maps for Seoul, Korea, in (a) year 2000, (b) 2001, (c) 2002, and (d) 2006, respectively.

understanding. Thus the 30 m spatial resolution of Landsat *Ts* has been analyzed with the other parameters such as land cover, vegetation fraction, air quality to assess the UEQ in an urban area.

The ground based air quality data are also used here to estimate the relationship between image-based parameters and air quality. Landsat derived aerosol reflectance is well matched with ground based PM_{10} concentrations. This suggests that satellite would provide more compatible spatial resolution data for UEQ mapping.

GIS based UEQ was also established for 25 urban districts in Seoul, Korea. The district areas of low UEQ are identified in this study as being low vegetation fraction, high air pollution, high surface and air temperature. Equal weights were assumed between air pollution, vegetation fraction, surface and air temperature for generating UEQ index. In order to increase the UEQ in this area watering to promote cooling by evapo-transpiration, as well as the addition of vegetated sections and road cleaning for controlling of particles are recommended.

Moreover, this work is limited to medium-resolution sensors from Landsat ETM and TM (30 m). However, the use of higher resolution imagery from Korean multi-purpose satellite (KOMPSAT) would give more detail quantification of UEQ.

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